JOURNAL OF TELECOMMUNICATIONS AND INFORMATION TECHNOLOGY

4/2005

E-health: near-term challenges in the European Union

Special issue edited by Pantelis A. Angelidis

ISSN 1509-4553

Circulation: 300 copies

Sowa - Druk na życzenie, www.sowadruk.pl, tel. 022 431-81-40

JOURNAL OF TELECOMMUNICATIONS AND INFORMATION TECHNOLOGY

E-health

Pantelis A. Angelidis
Guest Editor

E-health is a collective term aiming to reflect all modes of electronic healthcare delivery via the electronic communication means. E-health applications bring technology to patient care, ranging from prevention and diagnosis to follow-up, allowing the utilization of modern communication equipment and services capacity to link distant healthcare stations and individuals for the provision of healthcare services in real-time to remote groups of populations. More than that, e-health practices minimize the paperwork involved in the healthcare delivery, optimize the provided services, and ensure seamless communication and access to information independently of geographical limitations.

According to the eEurope2005 action plan "*e-health refers to the use of modern information and communication technologies to meet needs of citizens, patients, healthcare professionals, healthcare providers, as well as policy makers*" [3].

The following factors favor the adoption of e-health programs:

– growing concern regarding medical error;

– advance of patient-centric healthcare systems;

– need to improve cost benefit ratios and to rationalize healthcare;

– citizen mobility across Europe.

Having realized the impact of the information technology era to the healthcare industry, this e-health special issue focuses on the e-health tools and practices, recent R&D efforts and outcome and investigates the current and future trends in the e-health field along with the relevant policy and standardization processes within the EU and worldwide.

Papers have been organized in six key areas.

1. Regional healthcare systems – interoperability issues

Health information networks typically involve the linking of healthcare institutions, via telemedicine and web-based services, to professionals and patients disseminated over a broader geographic area, than could be serviced by the institution without the technology. There is no standard "regional" health information network.

The importance lies on the interoperability of different healthcare networks. An autonomous, self-functioning regional system, may entail a range of automated processes having a positive effect on the organization in local level, but in the event it cannot communicate and exchange data with external systems constitutes a mere office automation application instead of an advanced e-health application. Ad hoc industrial standards, like HL7 and DICOM, have prevailed today, nevertheless interoperability is a hot open issue.

Over the last two decades, European standardization has increasingly and substantially contributed to the implementation of various European policies. In the light of the changing conditions under which European standardization in the enlarged EU needs to operate and taking account of the challenges due to digitalization and globalization, it has become necessary to review the objectives, scope and needs of European standardization policy.

The CEN/ISSS has on the request of the European Commission started a new investigation of standards requirements in the area of "e-health", in connection with the eEurope 2005 action line. The investigation is performed by a focus group comprising all major stakeholders with a mandate to overview the existing achievements and proposed e-health related and relevant standardization activities, in formal standardization and industry consortia and prepare a report, containing proposals and priorities for future standardization work.

A recent initiative of the German government is the e-health interoperability workshop – *The Government and Expert View* – an informal meeting of government representatives together with key standardization experts dealing with interoperability problems with the target to agree upon a draft action plan for collaboration on interoperability aspects.

Papers tackling the interoperability in this issue:

1. M. Mauher *et al.*, "National, regional and international interoperability of Croatian healthcare information system" presents the general architecture of the Croatian healthcare information system and the respective pilot projects and results of pilot implementations as well as national ICT environmental accelerators for health ICT implementations.

2. A. Berler *et al.*, "The use of HL7 as an interoperability framework in a regional healthcare system in Greece" discusses the impact of health level 7 (HL7) message-based communication systems in achieving interoperability in a regional healthcare information system.

3. M. Tsiknakis *et al.*, "An architecture for regional health information networks addressing issues of modularity and interoperability" describes the regional health information network of Crete in Greece, HYGEIAnet, and introduces its framework for the reuse of standardized common components and public interfaces, thus enabling integrated and personalized delivery of healthcare.

2. M-health: independent living exploiting mobile technologies

Telemonitoring systems for the mobile citizen allow for healthcare provision away from the traditional nursing areas (i.e., at the home environment, work setting, while traveling, etc.). They address the mobile citizen wishing to undertake an active role in monitoring his/her health status. M-health applications enable ambiguous healthcare monitoring, seamless to the patient and contribute to the elevation of the quality of life, enhance independence, while tackling social exclusion, as the patient is now able to participate in social activities. Bringing smart handheld devices to the fore would strive healthcare to intensive remote diagnosis, prevention, and monitoring. The envisaging of interacting devices combined with smart cards, the latter serving as a key for the holder, would be the next step in utility and convenience for healthcare, serving both the provider and the service recipient. Interacting handheld devices and mobile phones are merging to monitoring devices of the (near) future.

The papers discussing m-health are:

1. A. Kropp, "Wireless communication for medical applications: the HEARTS experience" discusses the HEARTS wireless network, in the frame of which biometric and environmental data measured from patients during both hospitalization and in their normal lifetime activities, is gathered.

2. S. Pavlopoulos *et al.*, "A web-based system for personalized patient education and compliance monitoring" presents an integrated health telematics platform to enhance chronic patient compliance to therapy and interactive communication with their attending physicians, developed by the C-Monitor project.

3. A. Prentza *et al.*, "Cost-effective health services for interactive lifestyle management: the PANACEIA-iTV and the e-Vital concepts" presents two different technical and business concepts in the provision of telemonitoring services, PANACEIA-iTV and e-Vital.

4. F. Ortu and S. Andreassi, "Psychological implications of the application of health state continuous monitoring systems in cardiovascular pathologies" provides an insight of the constant monitoring psychological impact by analyzing the interactions between situational attributes and personality dispositions (for instance, trait anxiety).

3. Medical education

Medical education concerns the diffusion of scientific information with the aim to educate and train healthcare professionals as well as citizens. On-line learning enables physicians to access timely and flexibly accurate and aggregated information and benefit from continuing education and teleconsultation. ICT advances in the medical field create new opportunities for life-long learning and provide the necessary tools for bridging the gap between the available medical resources and the needs of the healthcare professionals. Not only that, it also offers the opportunity of a more self-reliant informed citizen.

It should be noted that one target of eEurope 2005 is that member states and the commission should ensure that citizens can access online health services (information on healthy living and illness prevention, electronic health records, teleconsultation and e-reimbursement, etc.) by the end of 2005.

The papers dealing with the medical education issues include:

1. S. Pavlopoulos *et al.*, "Remote medical education via Internet enhanced services – the REMEDIES platform for distant training" presents the remedies medical education system for healthcare professionals.
2. G. Stalidis *et al.*, "Information and e-learning services for the efficient management of allergy and asthma, employing an integrated environment monitoring network" presents a distributed telematic platform, which is implemented to support health information management and innovative services to people suffering from allergies, asthma and rhinitis: the citizen approach.

4. Health grid

Grid technology is promising, both for computing intensive applications and knowledge discovery. The goal of health grid is to meet the growing computing needs of health actors. The first challenge is to integrate grid technology into health practice, by the deployment of pilot biomedical applications for example, the second challenge is to integrate specific health requirements into grid technology, such as standards, interfaces, protocols and data heterogeneity and the third challenge is to address the dispersion of the biomedical community.

In regards to health grid the paper from F.-S. Salloum, "Health applications and grid technologies" presents the current status of standardization activities and working groups, which are currently involved with the specification of health applications and the standardization of needed components such us security, functionality, etc., which are being introduced by the use of grid technologies.

5. Wearable devices, personal health management systems and services based on biosensors

Innovative computer and software technologies are deployed to provide vital patient data monitoring and connect clinicians with mobile patients via workstations, wireless devices and the Internet. Technology progresses to produce virtually invisible biosensors, implantable or integrated in the patients clothing or to small, portable devices, which enable continuous vital data transmission and allow the development of personalized treatment plans for the patient.

The following papers concern issues relating to wearable devices and biosensors:

1. P. Celka *et al.*, "Wearable biosensing: signal processing and communication architectures issues" focuses on issues in wearable biosignal processing and communication architecture currently running at the Swiss Center for Electronics and Microtechnology (CSEM) in the framework of several European projects.
2. R. Paradiso *et al.*, "WEALTHY, a wearable healthcare system: new frontier on e-textile" presents the wealthy health monitoring system, which is based on a wearable interface implemented by integrating fabric sensors, advanced signal processing techniques and modern telecommunication systems, on a textile platform.

6. Tools for health professionals

Physicians, healthcare organizations managerial force, medical auxiliary personnel and administrative personnel, as well as a range of other professionals (e.g., pharmacists, etc.) may benefit from the ICT tools designed to enhance the communication capabilities of the healthcare professionals, to facilitate the completion of every day tasks, to reduce paperwork and eliminate errors, as well as to assist medical practice. The tools for healthcare professionals include (among others):

– computer-aided diagnosis;
– electronic prescription;
– electronic records;
– digital libraries;
– on-line registries;
– hospital information systems;
– electronic ordering (e-procurement, e-lab ordering, etc.).

Tools for health professionals are presented via the following papers:

1. B. Blobel and P. Pharow, "Tools for health professionals within the German health telematics platform" describes the German health telematics platform, based on an architectural framework and a security infrastructure, as well as its tools based on smart cards.
2. A. M. Demiris and N. Ioannidis, "Context awareness and nomadic devices featuring advanced information visualization in clinical routine" presents an IT platform, which emerged from applications in the cultural heritage domain, that can be used to deliver context-aware services and advanced visualization of information to medical personnel in a clinical environment. Along with the description of the platform and its components, two application examples/medical use cases are presented.
3. H. F. Kwok *et al.*, "Improving interpretability: combined use of LVQ and ARTMAP in decision support" discusses the use of LVQ in ST analysis and describes the overall architecture of the rule-based disease-specific approach of automatic detection of ischaemia from ECG signals.

References

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[3] eEurope 2005/e-health, http://europa.eu.int/information_society/eeurope/2005/all_about/ehealth/index_en.htm#Setting%20the%20Targets

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[6] V. Breton, "Health grid", ISGC 2003.

[7] D. Sibler, "The case for eHealth", in *European Commission's first high-level conference on eHeatlh*, 2003.

[8] "eHealth 2004", in *Conf. & Exhib.*, Cork, Ireland, 2004.

[9] "eHealth Interoperability Workshop – the Government and Expert View", Brussels, Belgium, 2004.

Pantelis A. Angelidis received his diploma in electrical engineering and his Ph.D. in telecommunications engineering from the School of Electrical Engineering, Aristotle University of Thessaloniki in 1989 and 1993, respectively. Since May 2001 he holds the position of the Director of INA. He has worked as a technology expert in the areas of telecommunications and biomedical engineering for the past 12 years. He has served as a project manager in over twenty research projects. He has presented more than 40 papers in international scientific conferences and has published 8 original articles in international research journals and over 10 in Greece. Dr. Angelidis is a member of the permanent consulting committee of the Technical Chamber of Greece on telecommunications, a certified consultant on telecommunications of the Technical Chamber of Greece (Central Macedonia chapter), a certified consultant on telecommunications of the Greek Courts (Thessaloniki), member of the CEN TC224/PT06 technical committee and vice president of the HL7 Greek Chapter.

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Paper

National, regional and international interoperability of Croatian healthcare information system

Mladen Mauher, Dragan Schwarz, Ranko Stevanović, and Siniša Varga

Abstract—Croatian national health ICT implementation strategy is determined by Croatian national health strategy and plan, Croatian ICT development strategy for 21st century, and requirements specifications for the health information system. National health ICT implementation strategy components are accented: purpose of the ICT implementation strategy, information principles, needs and ICT enablement in domains of patients, healthcare professionals, policy-makers and managers and public. Telemedicine and telecare positions and implementation steps are described. Based on the determinants, three organizational levels have been established – government, ministerial and project levels. General architecture of Croatian healthcare information system and respective pilot projects and results of pilot implementations as well as national ICT environmental accelerators for health ICT implementations are presented.

Keywords*— *health ICT implementation strategy, healthcare functional requirements, helthcare standards, electronic health record, integrated healthcare, agent based software technology, healthcare computer, communication network healthcare pilot implemetation.

1. Introduction

Conceptual design of national healthcare information system has been based on:

- national strategic documents:
  - Croatian strategy for health and health insurance reform [1],
  - Strategy of Information and Communication Technology Development – Croatia in 21st Century [2],
  - National Health ICT Implementation Strategy [3];
- international documents:
  - eEurope Action Plans: 2000, 2002, 2005,
  - EU eHealth Strategy,
  - The eEurope Smart Card (eESC) initiative,
  - National eHealth Strategies (GB and US);
- health information system conferences and forums:
  - Conference on Health Information System and Telemedicine Developments (Zagreb, May 2001),
  - National Health Information System Implementation Conference (Zagreb, Nov. 2002),
  - Cooperation on Sustainable Healthcare Strategies, 1st Central East and South East Europe Symposium (Zagreb, Sept. 2003): Implementation and Interoperability of Health Information Systems in Central and South East Europe: Major Issue of the Reform; Sustainable Cardiovascular Healthcare and Technology Strategies for CE&SEEurope – Leading health and economy problem.

Knowing the complexity of national healthcare information system and having experienced inefficiency and incompatibility of isolated legacy systems, competitive national pilot project approach has been implemented.

2. Project organization and management

Three-level project organization and management has been established.

Government level – Government Steering Committee for Internet Infrastructure Development (GSCIID) – responsible for national ICT policies and corresponding infrastructure developments. GSCIID established the health information system expert group as the advisory group of experts in the fields of medicine/health and ICT, with the responsibilities for advising and monitoring high level implementation policies.

Ministerial level – advisory teams to minister of health were appointed with the representatives from hospitals, national institute for public health, national institute for health insurance, faculty of medicine, chambers of health, as well as the regulatory bodies for public procurement for the health related ICT projects.

Pilot project level – central primary healthcare information system (PHIS) implementation team with 60 pilot implementation site teams, and hospital information system (HIS) implementation team with 4 corresponding pilot implementation site teams were appointed.

3. The requirements and functional specifications

3.1. National requirements

The strategic national requirement for the national health information system (NHIS) is to enable implementation of national health system (NHS) reform.

The strategic information requirements are:

- to ensure patients can be confident that NHS professionals caring for them have reliable and rapid access, 24 hours a day, to the relevant personal, medical and health information necessary to support their care;
- to eliminate unnecessary travel and delay for patients by providing remote on-line access to services, specialists and care, wherever practicable;
- to provide access for NHS patients to accredited, independent, multimedia background information and advice about their condition and to provide every NHS professional with on-line access to the latest local guidance and national evidence on treatment, and the information they need to evaluate the effectiveness of their work and to support their professional development;
- to ensure the availability of accurate information for managers and planners to support local health improvement programmes and the national framework for assessing performance;
- to provide fast, convenient access for the public to accredited multimedia advice on lifestyle and health, and information to support public involvement in, and understanding of local and national health service policy development.

The specific targets are:

- reaching agreement with the professions on the security of electronic systems and networks carrying patient-identifiable clinical information;
- developing and implementing a first generation of person-based electronic health records, providing the basis of lifelong core clinical information with electronic transfer of patient records between general practicioners (GPs) and medical specialists;
- implementing comprehensive integrated clinical systems to support the joint needs of GPs and the extended primary care team, either in GP practices or in wider consortia (e.g., primary care groups);
- ensuring that all acute hospitals have the ability to undertake patient administration, including booking for planned admissions, with an integrated patient index linked to departmental systems, and capable of supporting clinical orders, results reporting, prescribing and multi-professional care pathways;
- connecting all computerized GP practices to NHS virtual private network (NHS VPN);
- providing 24 hour emergency care access to relevant information from patient records;
- using NHS VPN for appointment booking, referrals, discharge information, radiology and laboratory requests and results in all parts of the country;
- the development and implementation of a clear policy on standards in areas such as information management, data structures and contents, and telecommunications, with the backing and participation of all key stakeholders;
- community prescribing with electronic links to GPs and the prescription pricing authority;
- routinely considering telemedicine and telecare options in all health improvement programmes;
- offering NHS direct services to the whole population establishing local health informatics services and producing hosted local implementation strategies;
- completing essential national infrastructure projects including the networking infrastructure, national applications, etc.;
- opening a national electronic library for health with accredited clinical reference material on NHS VPN accessible by all authorized NHS organizations;
- planning and delivering education and training in informatics for clinicians and managers.

3.2. International requirements

National requirements were strengthen by the requirements for functional, technological, regional and international interoperability of NHS and NHIS, focused to meet EU e-health goals by the end of 2005, and functionally and technologically, smoothly and cooperatively, serve any requirement for healthcare of residents and non-resident during the stay in Croatia followed by the open international participation of health professionals for health related processes in Croatia by the usage of telemedicine and telecare.

International requirements are stressing the implementation of international medical/health and corresponding ICT standards.

3.3. Functional specifications

Development of functional specifications resulted by 3052 detailed specifications for the HIS and high number of detailed functional specifications for PHIS.
Two stage aggregation processes derived mid and high level aggregated function specifications. In this paper we present high aggregated functional specifications.

3.3.1. Primary healthcare information system – high level functional specifications – central system

The central system contains:

- **primary healthcare information system management**: health insurance management, patient management, electronic health documentation management, extended communications management, health information system reporting management;
- **clinical information system management**: service management, data access and protection management, clinical documentation management, health related registers management (state, local), HL/7 communication system, clinical data management, "virtual" electronic health and electronic medical record management;
- **administrative and business support**: global registration management, health insurance database management, personal ID-management, national MKB-10 classification system, ICPC-2 classification system, drug, pills, orthopedic supplement list management, list of services and procedures;
- **privacy and security management**: smart card technology driven privacy and security for patients and healthcare professionals, user authentication system, role based data access control;
- **additional functionalities**: external database access (medical and health libraries, e-professional education, registers), intranet and Internet communication;
- **technical and technological integration with**: hospital information systems, institute for public health information system, institute for health insurance information system, central state treasury system, ministry of health and social care information system.

3.3.2. Primary healthcare information system – high level functional specifications – client system

The client system contains:

- **health professional**: role based health profession identification, authentication and administration services, patient care service workflow, diagnostics, referrals, prescriptions, medical services, automatization of patient health and medical document generation, professional navigation services, visit management, laboratory services, calendar and administrative management, comprehensive reporting system;
- **health and medical supporting services**: health documentation management, clinical documentation management, decease related drugs recommendations, drug retrieval;
- **patient oriented services**: visit registration and waiting room management, patient identification, authentication and administration services, patient related medical documentation (laboratory, images, other), task list, procedures and memos, patient relationship management;
- **patient management**: general patient data, health insurance related data, patient health data (anamnesis, risk factors, allergies, medical treatments, health problems, chronical deceases), patient medical data, vaccinations, administrative document issued, illnesses;
- **interoperability with core primary healthcare system**: XML/HL7 client agent communications services.

3.3.3. Hospital information system functional specifications

The general functional specification list contains:

- **management and control**: consolidated strategic, strategic, tactical and operational management, investment management, business intelligence, performance management, controlling;
- **general services**: accounting (managerial and financial) and general ledger, payroll, inventory management;
- **patient management**: patient administration, patient accounting and billing, patient scheduling, patient service management, marketing and health promotion;
- **diagnostics and therapy**: diagnostic support and ancillaries, clinical order management, medical and clinical documentation, treatment and operation, research and education;
- **care management**: care planning, clinical care, care documentation, after care management;
- **hospital and health system communication**: internal communication, communication with providers, communication with payers, communication with patients, communication with suppliers;
- **support services**: medical technology, environmental health and safety, transportation, facility services, health and medical document management, patient information center (help desk);

- **business support**: human resource management, procurement, treasury/corporate finance management, fixed asset management, real estate, equipment maintenance;

- **interoperability**: medical equipment data communication, external professional and administrative communications.

4. General architecture of Croatian healthcare information system

General architecture of NHIS consists of central components – the NHIS infrastructure, and contextual portals:

- **central components**: core networked healthcare repositories[1] (population, health insurance, public health, health financials) along with acting application service providers – ASPs (primary healthcare, secondary healthcare, public health, health insurance, health professional associations);

- **contextual portals**: ministry of health, public health, health insurance, primary healthcare, hospital, pharmacy, health professional associations, professional and public education, general health communications[2], other health related portals, as presented in Fig. 1.

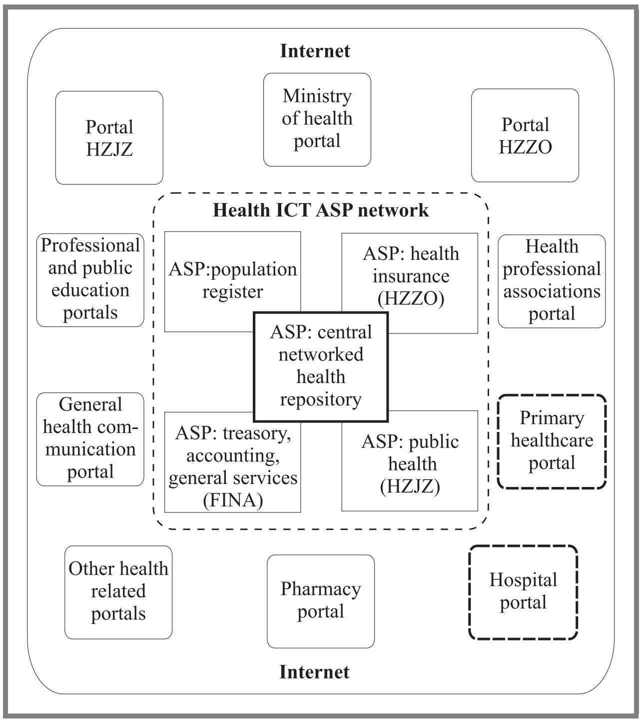

Fig. 1. General architecture of healthcare information system.

[1]With respective data, process and knowledge interdependencies.
[2]General health oriented communications and professional communications. Telemedicine is an example of event driven temporal multipoint professional health communications.

Portal implementations provide autonomy of professional functionalities and contextually "glue" all stakeholders in their mutual interactions.

5. Implemented pilot projects

Based on the general architecture and priorities given, public tender for two-staged competition (short list competition, competition throughout pilot implementations), following results of pilot competition were obtained.

5.1. Primary healthcare information system

Primary healthcare information system (PHIS) is designed and implemented as central and client components of PHIS.

5.1.1. G1 – central component of PHIS

Central component of PHIS implements functional requirements in the form of integrated system. Integration is based on interoperability standards.
Central component of PHIS integrates: information systems of the ministry of health, health insurance organizations,

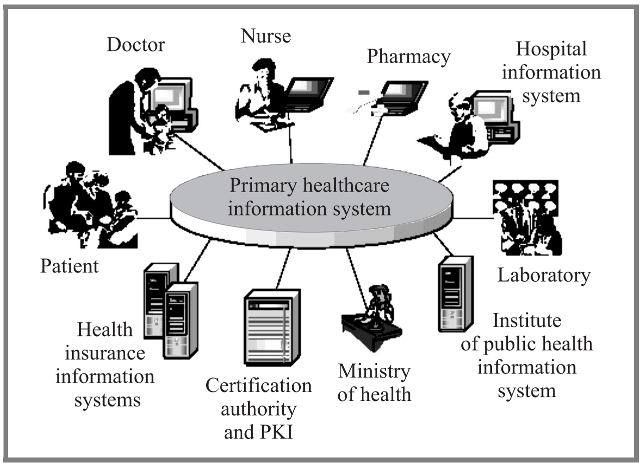

Fig. 2. Basic entities in primary healthcare information system.

hospitals, public health, national certification authority, pharmacies, laboratories, primary healthcare teams and patients (Fig. 2).

Central compotent of PHIS program architecture is implemented on three layers (Fig. 3):

- **open application layer**: applications related to PHC teams (doctors, nurses), laboratories, public health, other;

- **middle layer**: middle layer implements common health services (electronic health record management, patient record management, resource management, terminology services, authorization) and common general services (coding schemes, directory management, transaction tracing, message interchange, authentication);

- **communication layer**: standards driven authenticated communications.

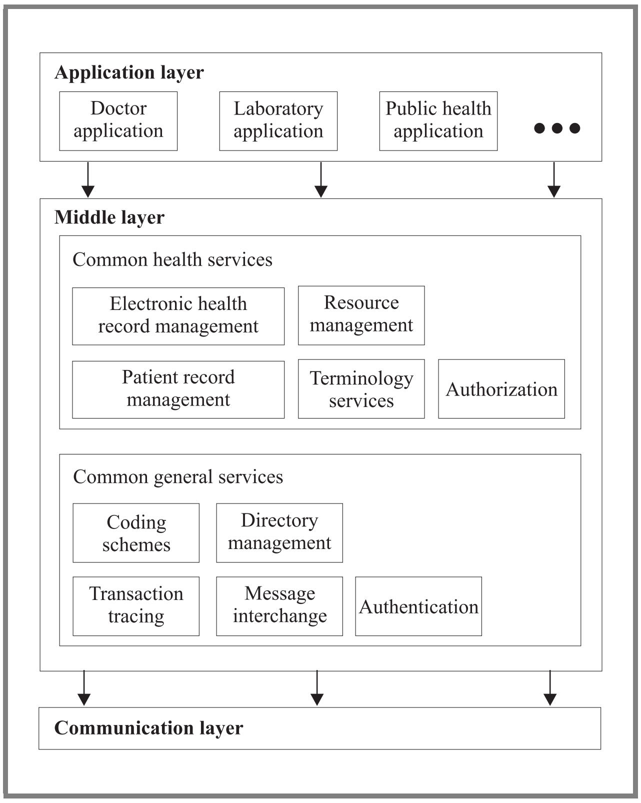

Fig. 3. Referent PHIS program architecture.

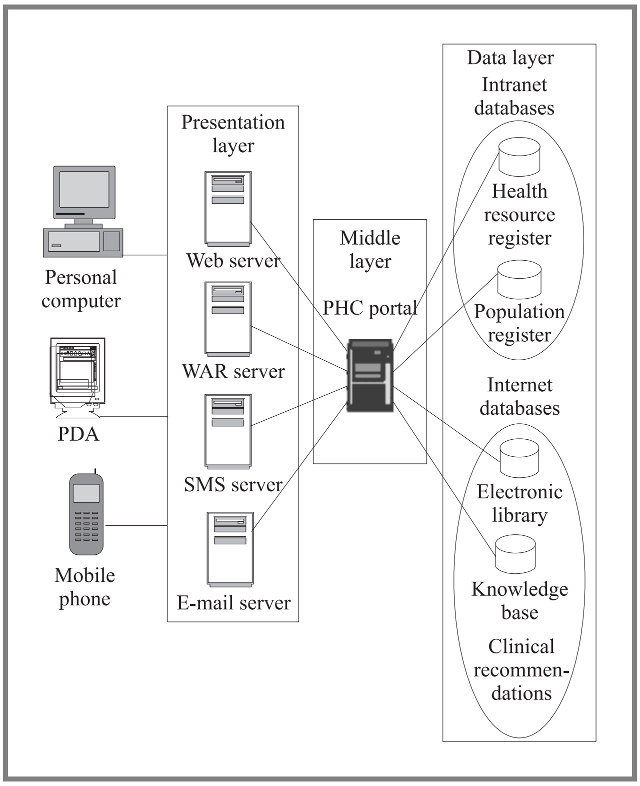

Fig. 4. PHIS portal architecture.

Portal technology implemented in middle layer integrates data layer (Intranet databases: health resource registers, population register; Internet databases: electronic libraries, knowledge bases, clinical recommendations) and presentation layer (web server, WAP server, SMS server, e-mail server). Figure 4 presents the implemented portal architecture.

5.1.2. Management potentials in central PHIS

Management and control in health system is implemented by strategic and operational patient relationship management, drug prescription, referrals, therapeutical processes performance and drug efficiency assessments.

Professional service management covers authorized access to distributed electronic patient records (EPRs) and related medical document resources (images, laboratory evidences, diagnostics, etc.), professional access for emergency and crisis management, professional and administrative messaging management, personal performance management, health and medical reporting system.

Public health management support facilitates healthcare intelligence, evidence based management in public health, public health dynamics management and management of many of public health dedicated segments.

Ministry of health and social care management support enables implementation of healthcare intelligence for ministerial purposes, NHS performance management, health resources management, NHS business and economic intelligence.

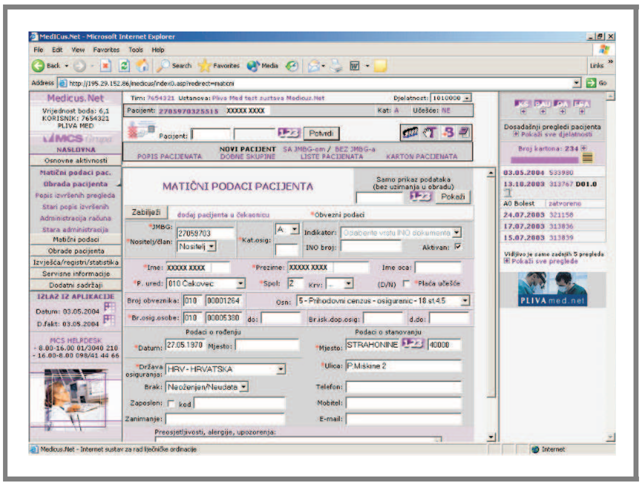

Fig. 5. Example of context sensitive navigation.

Health insurance institute management support – by implementation of direct HL/7 communication on healthcare activities, ICPC-2 activity based costing on daily base is enabled as well as pharmacy management, drug consumption management, evidence based planning, budgeting and monitoring.

Patient management implementations allows direct control on electronic patient record, access and usage, quality

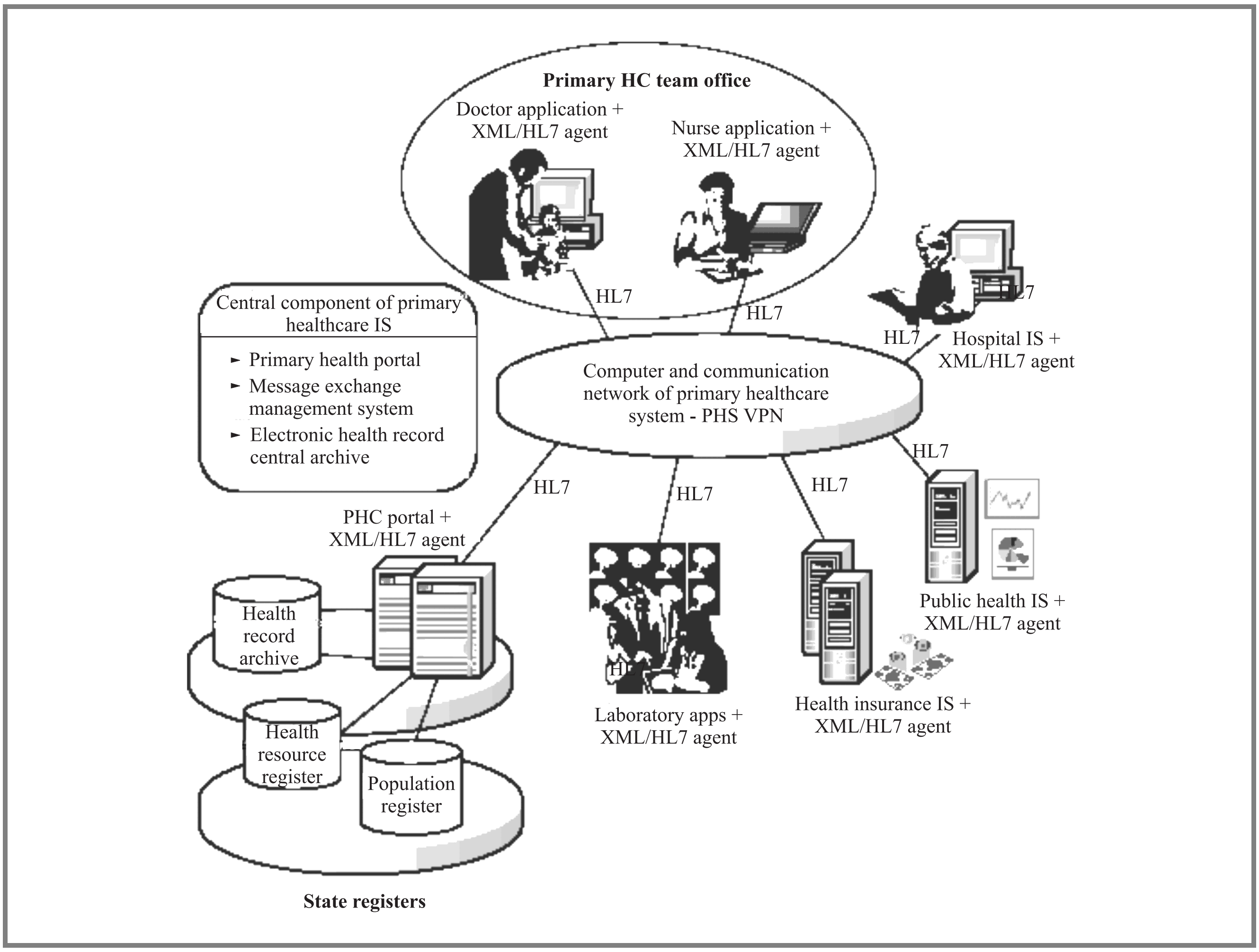

Fig. 6. Primary healthcare communication architecture.

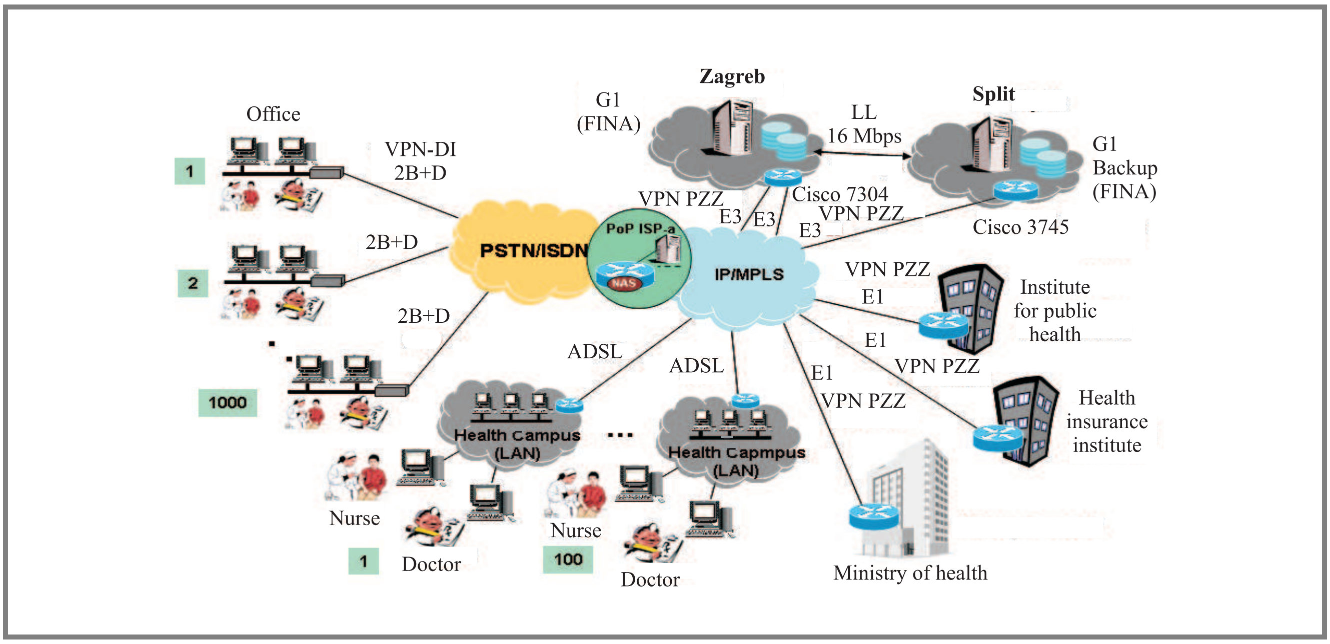

Fig. 7. System PHIS VPN.

of service (QoS) assessment and review, patient relationship management, privacy audit and reporting, healthcare service ordering system, public related health education, discrete selection/change of MDs.

Public is supported by the accurate information on health condition of the population, transparency and benchmarking of public health services.

5.1.3. G2 – client component of PHIS

Client component of PHIS implements client system functional requirements, customized for the dedicated application area.

Interoperability standards as the prerequisite for the integration in PHIS integrated system allow for open competition in application developments as well as implementations and maintenance.

Context sensitive navigation and correspondent workflow is applied for the patient, doctor, nurse. Illustrative example of patient context is presented in Fig. 5.

5.2. Communication system

Two components of communication system have been implemented for the pilot implementations.

Primary healthcare communication architecture (Fig. 6). Agent based software technology and implemented XML/HL/7 standards are supporting networked asynchronous execution of all health related activities.

PHIS virtual private network (VPN) – see Fig. 7. Pilot implementation is based on elaboration of government computer and communication network as one instance of it, thus enabling wide connectivity and interoperability of health as well as government and public services.

Structure of **computer resources** has been formed by central and backup PHIS computer resources, health insurance computer resources, public health computer resources, scattered small/medium/large LAN resources and standalone PC configurations. PHIS VPN connects all aforementioned resources into primary healthcare computer and communication network.

Pilot implemented **VPN services** were based on estimated pilot requirements and tuned as leased line, IP/MPLS over ATMs, ADSL, PSTN/ISDN, and PoP ISP.

5.3. Hospital information system

Competition for the national license for hospital information system was the primary purpose of two staged public procurement process. First selection was based on the given evaluating results of bidding proposals. Final selection was planned on results of measurement and evaluations of implemented functions in the given timeframe for selected pilot implementers (eligibility of implementers).

Hospital information system pilot implementations started on June 2003 in the following hospitals (Fig. 8): Clinical Hospital Dubrava (Zagreb), Clinical Teaching Hospital Rijeka, Clinical Hospital Split, General Hospital Sveti Duh (Zagreb).

Fig. 8. Location of HIS pilot hospitals.

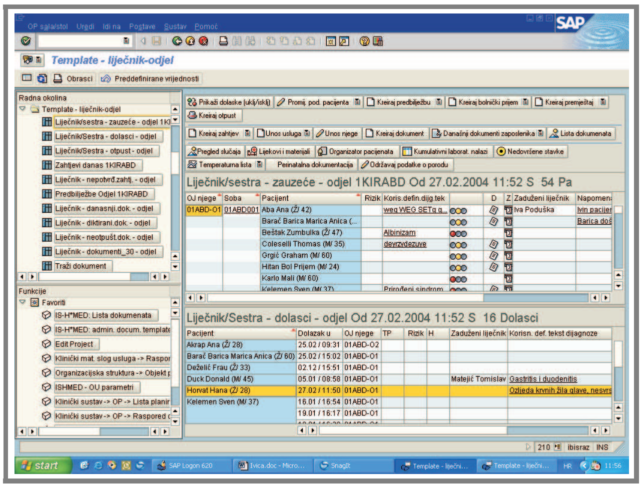

Fig. 9. Medical doctor's contextual working environment.

Requested functionality is implemented with dozens of related hospital and medical context screens. Figure 9, taken from Sveti Duh implementation project, illustrate such screens.

Implemented functionality covers following medical areas: internal medicine, pneumophthisiology, infectology, neurology, psychiatry, neuropsychiatry, dermatology and venerology, pediatrics, general surgery, neurosurgery, child surgery, maxillofacial surgery, plastic surgery, urology, orthopedics, otorhinolaringology, ophthalmology, obstetrics and gynecology, anesthesiology and resuscitation, transfusiology, radiology, radiotherapy, nuclear medicine, physical medicine and rehabilitation, cardiology, traumatology, sports medicine, emergency medicine, medical microbiology with parasitology, medical citology, pathology, clinical pharmacology.

5.4. National health card

Smart cards can add mechanisms to the Internet to implement security and protection (data protection and anonymity-confidentiality) which are easy to use. Any

IT system in healthcare, combining Internet and smart cards could claim to be more "human-centric" than the old typical models for two main reasons:

- citizen's and patient's own awareness of their health related data and information, because smart cards offer ubiquitous access to information;
- citizen's and patient's empowerment, because secured information can be circulated without prohibition.

National health card in pilot projects, based on smart card functionality, implemented two basic functionalities:

- for professional usage – health practitioner card for secure access to patient data stored either in a patient card or on a remote server, with security components (PKI, crypto-processor, data encryption keys, encryption algorithms, digital signature, authentication certificates) is implemented; by using smart cards, medical professionals are able to access the patient data they need much more quickly and reliably than conventional paper file and document methods, saving invaluable time and expense – and time may be at a premium;
- for citizen's/patient's usage – insured patient's card which include the following data addressed by remote data access pointers: **administrative data** (i.e., insured ID, name and address, health coverage "coordinates", period of entitlement, availability period, relevant regulation, etc.); **medical data** (emergency clinical data, protected private file); **security components** for reliable identification of the person covered and secure access to personal health data of the patient.

5.5. Pilot implementation metrics

5.5.1. Primary healthcare teams

Sixty primary healthcare teams, consisting of the physician and the nurse, were selected and trained to implement G2 component of PHIS. In order to reduce pilot costs, pilot locations were clustered in Zagreb, Čakovec, Požega, Split, Koprivnica.
Standardized hardware and communication equipment has been installed at the PHC team's premises.
Short list G2 competitors were the implementers (local companies ABA Informatika, MCS Group, IPT, ISD, In-2).

5.5.2. Health insured individuals

More than 100 000 health insured individuals were included in respective PHC team files.

5.5.3. G1 – central component of PHIS

Selected central component of PHIS has been designed and implemented by Ericsson Nikola Tesla d.d. with following subcontractors: ABA Informatika d.o.o., Helix d.o.o., Computech d.o.o.

5.5.4. Hospitals

Characteristics of selected testbeds and competitive pilot implementers for HIS:

- **hospital Dubrava** (Zagreb): 611 beds, 142 MD, with installed standardized database and application servers, desktop and communication equipment and Ericsson Nikola Tesla & Grad Pula as HIS implementers;
- **hospital Rijeka**: 1264 beds, 310 MD, with installed standardized database and application servers, desktop and communication equipment, and IBM Croatia (for cerner HIS application) as HIS implementers;
- **hospital Split**: 1455 beds, 367 MD, with installed standardized database and application servers, desktop and communication equipment, and AME Consortium (from Austria and Switzerland, with SYS d.o.o. as local partner) as HIS implementers;
- **hospital Sveti Duh** (Zagreb): 542 beds, 113 MD, with installed standardized database and application servers, desktop and communication equipment, and B4B – (SAP HIS solution) as HIS implementers.

5.5.5. National health cards

The 120 health professional cards were issued with implemented functionality: electronic ID, advanced electronic signature, attributes (roles).

5.5.6. Implemented security levels

For the pilot testing purposes following security levels were implemented:

- **smart health card**: identity card, advanced electronic signature, assigned attributes (roles);
- **application**: role based access control (HL/7, RBAC), certification of applications;
- **message and messaging agents**: digital signature of messages and message encryption;
- **equipment**: server security, desktop security, mobile desktop (authentication, integrity, encryption);
- **network security**: local area network access control (router/ firewall), virtual private network implementation of Internet protocol security with IPv4/IPv6 (IPSec – Internet engineering task force standard).

6. Embedded standards

International interoperability requires implementation and maintenance of a large set of international standards.
Two important subsets are presented as ICT related standards and health related standards.

6.1. ICT related standards

ICT related standards treated:

- **interoperability**: object management group OMG, W3C, XML, GIF (UK Government Interoperability Framework);
- **ICT and software engineering**: software engineering standards (IEEE SECS), Intemational Organization for Standardization/International Electrotechnical Commission (ISO/IEC JTC1/SC7), data interchange standards association, CENELEC – The European Committee for Electrotechnical Standardization, CEN/ISSS (European Committee for Standardization – Information and Communications Technologies) activities., FIPS (Federal Information Processing Standard), National Institute of Standards and Technology (US NIST), American National Standards Institute (ANSI), The Foundation for Intelligent Physical Agents (FIPA);
- **smart card**: identification cards – physical and electronic characteristics, dimensions and location of the contacts, inter-industry commands for interchange, system and registration procedure for application identifiers, inter-industry data elements, machine readable cards for healthcare applications, security categorization and protection for healthcare information systems, other healthcare cards specification standards: ISO/IEC 7816-1-10, 8824-8825; CEN/EN 726-1-7, CEN/ENV 1257 1-3, 1284, 1387, 1867, 12018, 12388, 12924, 13729; smart card interoperability specifications and "Open Smart Card Infrastructure for Europe" (OSCIE) common specifications[3];
- **telecommunications**: ITU (International Telecommunication Union), ETSI (European Telecommunications Standards Institute).

6.2. Health related standards

Health related standards[4] were specified as a set of requirements, and consequently implemented as a prerequisite for prevention of health hazards (e.g., drug hypersensitivity), patients starting to demand that "their" data should be available on-line, improved efficiency by enabling professional co-operation in new ways, quality management requirements on aggregated data, integration of modular systems from different suppliers, lowered costs and facilitated procurement, and primarily the national, regional, European and global interoperability and action.

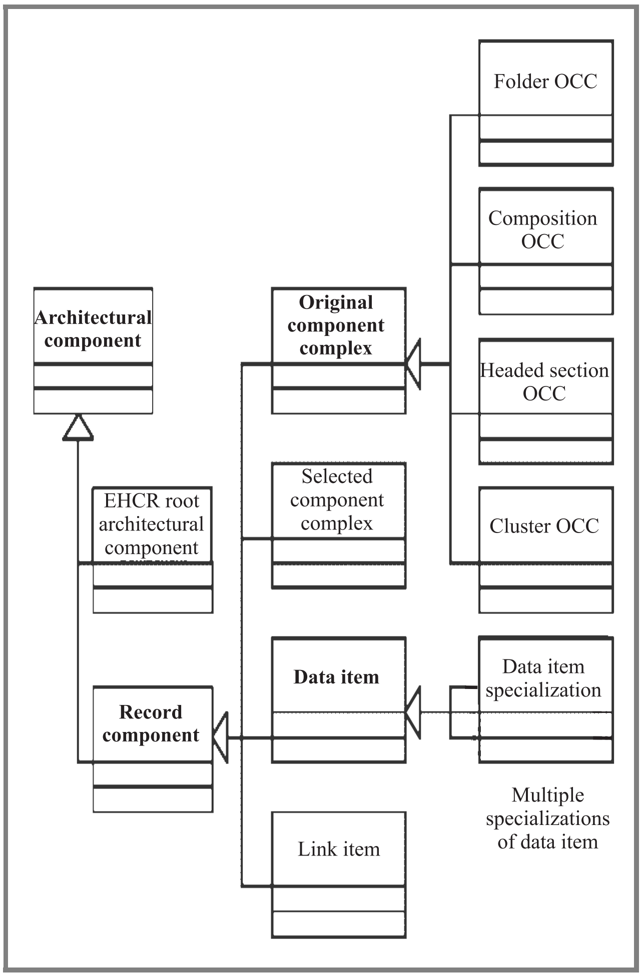

Fig. 10. Architecture of electronic health record ENV 13606.

Health standardization institutions treated:

- **CEN/TC 251** (Commite European de Normalization): European Standardization of Health Informatics Technical Committee 251 – Healthcare information interchange within Europe; **CEN/TC 224**: machine-readable cards, related device interfaces and operations;
- **ISO TC 215**: "Health Informatics" (Messaging standards for information exchange between healthcare information systems; WG 5 – Health Cards);
- **ASTM** (American Society for Testing and Materials – interchange of data between medical information systems);
- **ACR/NEMA** (American College of Radiology/National Electronical Manufactorers' Association: Digital Imaging and Communication in Medicine – DICOM; Program of Assertive Community Treatment – PACT).

[3]eEurope Smartcards – Open Smart Card Infrastructure for Europe, March 2003.
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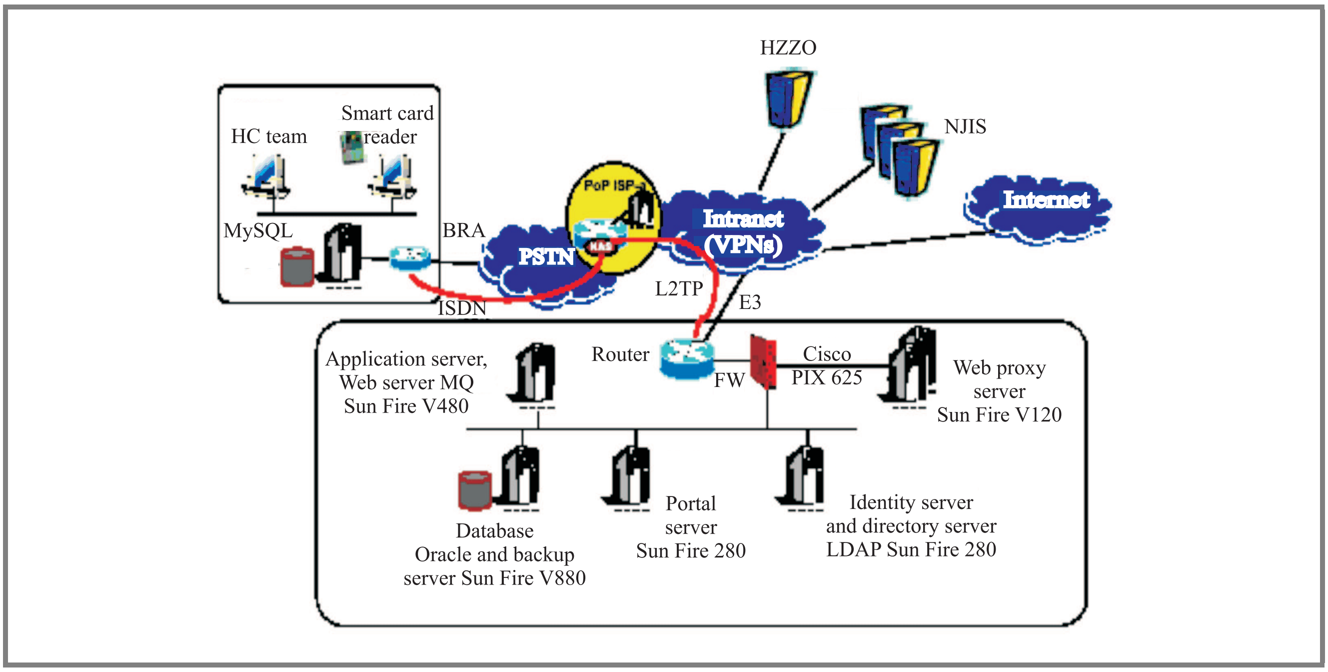

Fig. 11. Computer and communication architecture.

Here is the example of implemented standards and classifications during the pilot implementation:

- **GEHR** (Good Electronic Health Record): openEHR;
- **ICD-10**– classification of diseases for the collation of medical statistics;
- **ICPC-2** – International Classification for Primary Care;
- **LOINC** – Logical Observation Identifier Names and Codes;
- **DRG** – Diagnoses Related Groups;
- **ATC** – Anatomic Therapeutic Chemical Code;
- **IEEE/P1157** – standard for healthcare data interchange (standards for moving data from medical devices to computers and vice versa along standardized hardware buses and interfaces);
- **ANSI HL7** – standard for electronic data exchange in healthcare environments;
- **HER ENV 13606** (Fig. 10).

7. Technical and institutional interoperability

7.1. Technical interoperability

Technical interoperability is provided by implementation of technical standards and standardized hardware instances as well as standardized middleware software components enabling networked interoperability. Figure 11 illustrates one instance of implemented technical interoperability.

Software agent technology – asynchronous cooperative message processing is enabled by implementations message exchange management system on central site and XML/HL/7 agent as client site implementations.

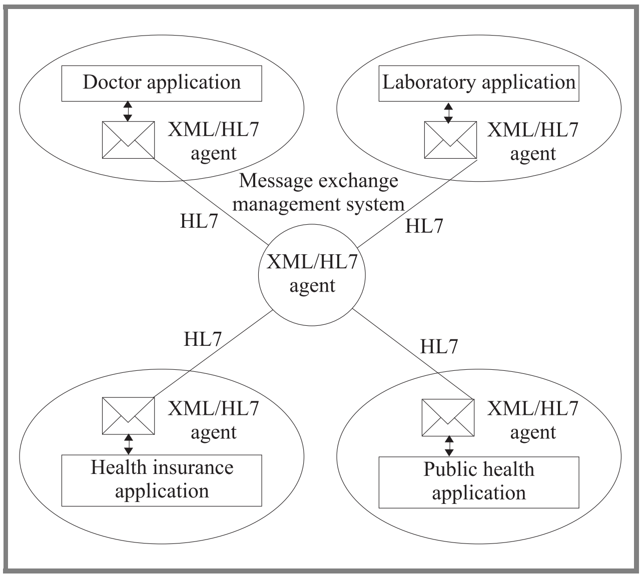

Fig. 12. Agent based message exchange system.

Figure 12 illustrates implementation of such interoperable and cooperative messaging system.

7.2. Institutional interoperability

Institutional interoperability, due to requirements of interrelated national public development projects (health and welfare system reform, reform of the government and public services), requirements for common ICT infrastructure (government computer and communication network, national smart card infrastructure), related cooperative IT projects (healthcare, healthy food, healthy environment – water, land, air, new personal identity card and personal identity management, national emergency system, to mention some of them), is implemented by the coordination committee for institutional interoperability appointed by the government.

Main institutional stakeholders are: **the government** – office for e-Croatia; **ministries**: Ministry of Health, Ministry of Interior, Ministry of Finance; **institutes and associations**: Institute of Public Health, health insurance institutes, health professional associations; FINA – National Financial Agency in the role of **government ICT outsourcing institute**.

8. The results

8.1. Implementation of primary healthcare information system

As a result of proven implementation of functional requirements, G1 and G2's are contracted for implementation by the minister of health in November 2003. Implementation was planned for 2004 i 2005 fiscal years.

8.2. Implemented functionality of hospital information system pilot project

Interim pilot implementation status estimation provided at Sveti duh General Hospital:

– management and control 70%,
– general services 70%,
– patient management 100%,
– diagnostics and therapy 100%,
– care management 100%,
– hospital and health system communication 80%,
– support services 70%,
– business support 70%.

For the areas indicated with les then 100% implementation, all customizations have been implemented.
New appointed government expert group has been started validation process for all pilot implementations.

9. National implementation scenario

National implementation scenario is based on ICT strategy recommendations and action plans, and corresponding government program and financial priorities.
G1 as a central component of PHIS is contracted for the period of 3 years.
G2 licenses are given to first 6 solution providers for competitive implementations for more then 2700 PHC teams in next 3 years. Competition for new set of G2 developments in areas of stomatology, pharmacy, laboratory and other areas are in preparations.
Development efforts on customizations in pilot projects for HIS will enable the implementation of national license for all hospitals in the Republic of Croatia.
Pilot project functionalities implemented and capacities built, will shift the focus of overall implementation to organizational, educational and financial resources rather than to ICT developments.

9.1. National ICT accelerators

Government computer and communications network, multifunctional national smart card project, and national license for HIS, are accelerators for fast deployment of projected and pilot-projects confirmed functionalities of NHIS.

9.1.1. Government computer and communications network

Standards and principles for government computer and communications network implementation (GCCNI) are elaborated in the study financed by the Ministry of Science in 2001, implemented in tender documentation, and proposed by Croatian Telecom to the government in 2003. GCCN is designed to serve as a backbone network and infrastructure for secure e-government services.
Implementation based on CCNI is applied for the PHIS pilot project. Final proposal of healthcare VPN complies with GCCN and formes the part of it.

9.1.2. Multifunctional national smart card

Multifunctional smart card, enabling the implementation of requirements from different government areas (national identity card, budget beneficiary card, social welfare card), health card (health insurance, patient identification, health professional), PKI requirements (advanced electronic signature) as well as group of ICT requirements (single user profile for role based access control) was selected.
Design to implement interoperability for national population register, national health card is starting instance for implementation of multifunctional national smart card.

9.2. National license for hospital information system

National license for hospital information system is planned to enable successive implementation for 37 hospitals in Croatia for the years 2005–2007.

10. Conclusion

Implementation of very complex national health information system is based on corresponding national and international strategic documents, precise definitions of functional requirements for primary healthcare information system and integrated hospital information system and the results of started pilot project implementations.

Development and implementation concepts are based on common government ICT infrastructure and project developments.

Hierarchical and functional project management is implemented to synchronize pilot implementation activities and resources as well as to build capacities for accelerated implementations in the years to come.

Aligned with international standards and implementation policies for information societies, healthcare information system provides the drivers for national, regional and international interoperability.

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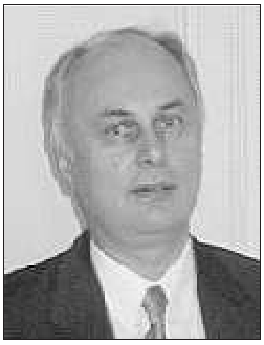

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Paper

The use of HL7 as an interoperability framework in a regional healthcare system in Greece

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Abstract—The integration of information systems represents one of the most urgent priorities of a regional healthcare authority in order to meet its clinical, organizational and managerial needs. Current practice shows that the most promising approach to achieve a regional healthcare information system is to use a health level 7 (HL7) message-based communication system implemented by an asynchronous common communication infrastructure between healthcare sites. The system is a complete and integrated information system at a regional level that comprises all types of healthcare levels, that includes interoperability issues, that covers most of the needed components, and that is able to work efficiently in a secure wide area network to ensure data privacy and confidentiality. Another important feature of the proposed solution is that it creates an interoperability framework that can be replicated from one healthcare institution to another. In that sense, common interoperability messages can be used to interconnect heterogeneous information systems. In response to this strategy, more than 10 different consortiums have submitted proposals to the Greek government and the proposed interoperability framework seems to be widely accepted as a solution to enhance information and communication technologies developments in the healthcare sector in Greece.

Keywords—* *interoperability, HL7, regional healthcare information system.

1. Introduction

The advantages of the introduction of information and communication technologies (ICT) in the complex healthcare sector are already well known and well stated in the past [1, 2]. It is nevertheless paradoxical that although the medical community has embraced with satisfaction most of the technological discoveries allowing the improvement in-patient care, this has not happened when talking about healthcare informatics. Many reasons could be proposed for this matter, though with a short analysis it is rather clear that new ICT are having integration problems in healthcare because of the way this sector is organised. It is common knowledge that in order to install any type of information system in healthcare, six main groups of issues have to be dealt with [3, 4]:

- Organizational and cultural matters related to healthcare.
- Technological gap between healthcare professionals and information science experts.
- Legal requirements on the confidentiality of personal data, of patient related data and on data privacy.
- Industrial and market position of healthcare informatics and interoperability complexity.
- Lack of vision and leadership of the health care managers and health authorities.
- User acceptability and usability of the proposed information systems.

In 2001 a reform of the Greek national healthcare system [5] was introduced in order to enhance the performance and control of healthcare provision in Greece. One of the main changes was the division of the country in 17 autonomous healthcare regions where the regional healthcare authorities (RHA) are responsible for the regional healthcare strategy. In order to support this reform a series of ICT oriented interventions were introduced. After a period of analysis and design the Greek government started issuing a number of extremely detailed (more than 500 paged each) request for proposals (RFP) for each RHA [6].

The integration of existing and forthcoming information systems represents one of the most urgent priorities in order to meet the increasing clinical, organizational and managerial needs [7, 8]. In that context, the use of standards is essential since data processing needs vary widely in the complex regional healthcare environment. All RHA have a major concern in evaluating the existing operational hospital information systems and other information system infrastructure in order make a decision on whether to maintain or replace them. In Greece, more than ten distinct vendors have installed healthcare IT related products (hospital information system – HIS, laboratory information system – LIS, radiology information system – RIS, etc.) that mostly work independently as IT niches. It is known that the lack of healthcare information standards is one barrier to the broad application of IT in health care units. The inability to share information across systems and between care organizations is just one of the major impediments in the health care business's progress toward efficiency and cost-effectiveness, as well as, the absence of a unique national or even regional patient identifier in Greece. Integration of these existing diverse systems with the future information systems to come remains problematic with a number of competing approaches, none of which alone represent the perfect solution. Current practice shows that the most

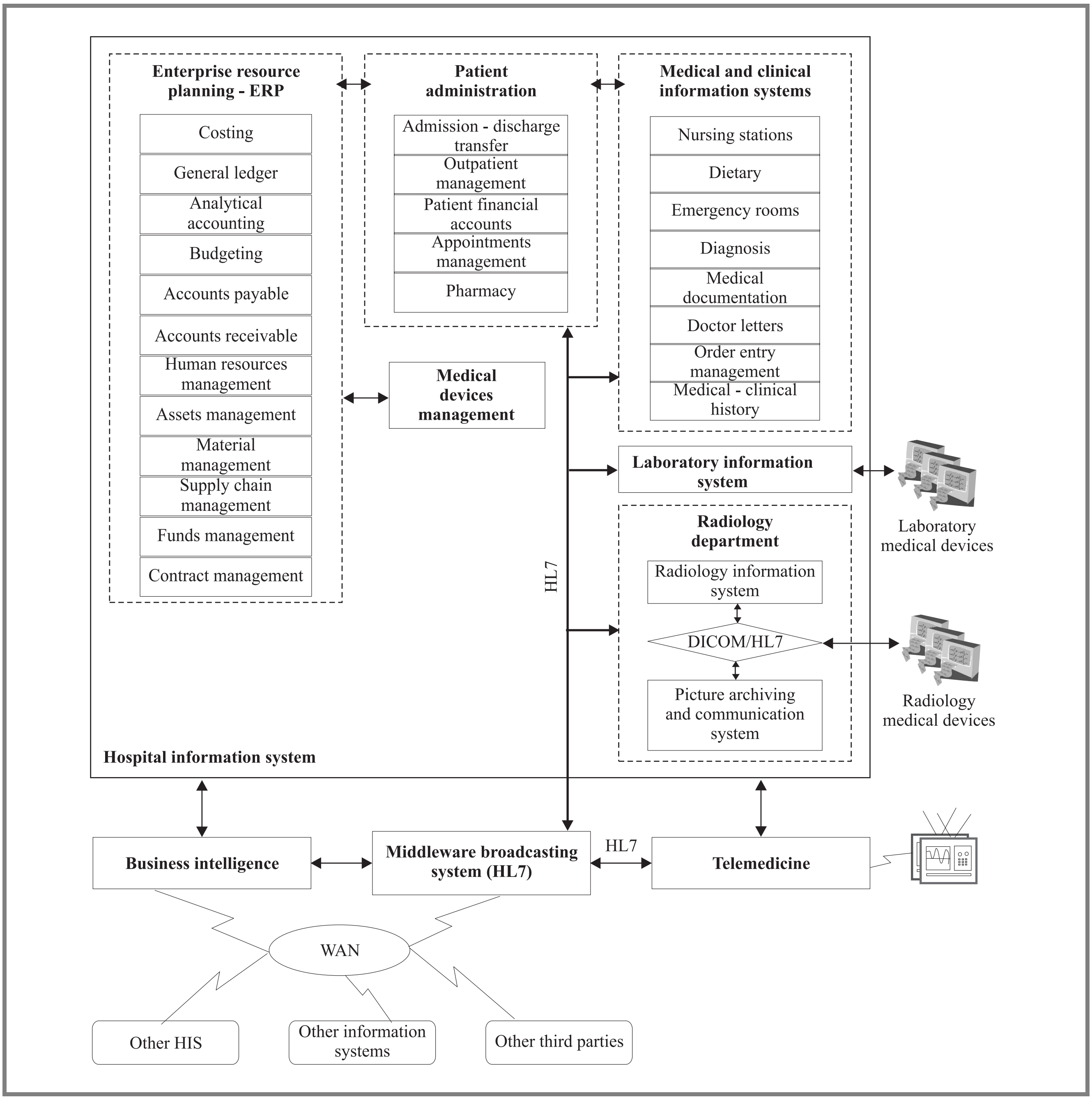

Fig. 1. Regional healthcare information system basic software components.

promising approach to achieve a regional healthcare information system is to use a HL7 message-based communication system implemented by an asynchronous common communication infrastructure between healthcare sites.

2. Methodology

The proposed information system in the RFP consists of a series of subsystems as depicted in Fig. 1, covering information management issues in a regional healthcare system. The system is innovative in the sense that it required the design and implementation of a complete and integrated information system at a regional level that comprises all types of healthcare levels (primary care, secondary care, home care, etc.), that includes interoperability issues, that covers most of the needed components and that could be able to work efficiently in a secure wide area network (i.e., a VPN) to ensure data privacy and confidentiality.

Through the aforementioned RFPs, the need has arisen to make healthcare information systems in Greece to work together as the components of regional healthcare network (RHN), where newly introduced information systems must communicate with systems already present in vari-

ous healthcare institutions. The proposed solution features the use of middleware broadcasting systems that are based on information exchange via messages utilising some application protocol (ISO-OSI level 7).
The proposed architecture fulfils at least the following requirements:

- Existing systems do not need to be altered.
- No significant extra (hence unanticipated) load on existing systems is introduced.
- Connecting existing systems is an economical viable activity.

The three requirements are met by an *asynchronous message based* information exchange infrastructure defining a uniform interface for any system that must or receive information. All systems are connected, through a uniform interface, to an interoperability framework or more technically to a common communication infrastructure (CCI). In an asynchronous message based CCI, information is exchanged between two systems by breaking up the information into chunks. These "chunks" are called application protocol data units (APDU). An APDU has an explicit structure that is defined by the APDU (or message) *syntax*. Additional encoding and decoding rules help sending and receiving systems to construct and to analyse APDUs. Sending systems can insert information into APDUs and receiving systems can extract information from the APDUs.
The APDUs are not transmitted directly; they are embedded in so called protocol data units (PDU). APDUs form the "payload" of PDUs. PDUs contain enough information for the CCI to be able to "route" the information sent to the receiving application. Additional "meta" data help the receiving side to understand if the PDU has been received intact and contains the APDU anticipated.
Using (A)PDUs to exchange information between systems bring a number of distinct advantages:

- All systems can be interfaced in a uniform way with each other.
- There is decoupling between systems which allows information to be routed, stored and forwarded, and processed independently from the actual exchange.
- Information exchanging does not need to reveal their internal structure to each other. This form of "information hiding" significantly improves the connectability of systems.

As depicted in Fig. 2, the use o a middleware broadcasting system is enabling the interconnection of information systems without creating extra workloads on existing information systems. When a system provide a uniform interface for sending and receiving information they can be connected easily and even routing of information becomes feasible. The latter is very important to connect remote system that cannot communicate directly. Clearly the third

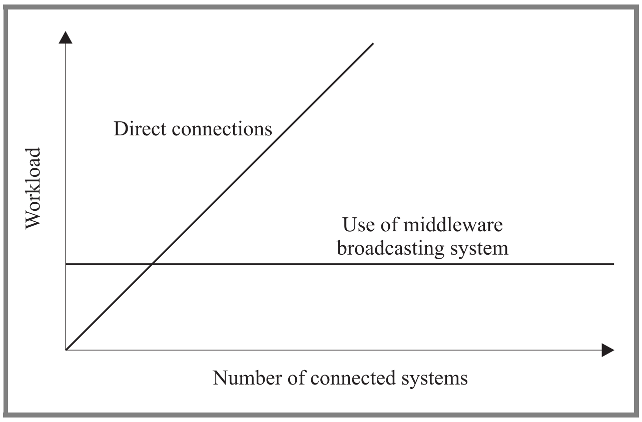

Fig. 2. Workload produced by connected systems.

advantage is the most important. The fact that two information systems do not need to know each others database schemata, database connection technology, tremendously simplifies the task of interfacing these systems. Figure 3 below depicts the change that occurs when introducing a middleware broadcasting system.

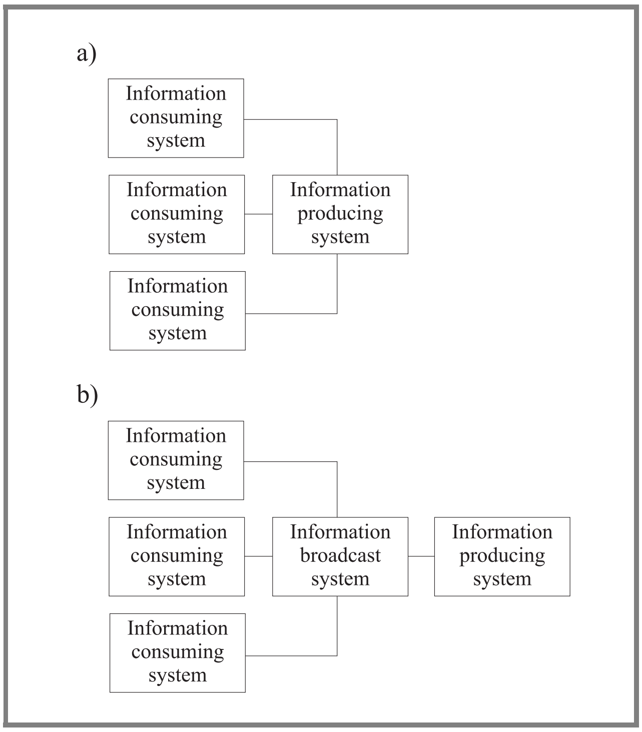

Fig. 3. Schematic representation: (a) direct connection; (b) use of middleware broadcasting system.

Another important feature of the proposed solution is that it creates an interoperability framework that can be replicated from one healthcare institution to another. In that sense, common interoperability messages can be used to interconnect heterogeneous information systems within a healthcare institution or even at a regional healthcare level if a centralized information system is in place, as depicted in Fig. 4.

Table 1

Basic HL7 based interoperability requirements

Requirement	Involved information systems
Patient identification (PID) master patient indexing (MPI)	From all healthcare institution and patient administration system to the MPI.
Order entry	From all departments internally in an institution and between institution (ordering from primary care to hospitals).
Admission – transfer – discharge (ADT)	Within an institution and between institution when a patient journey requires transfers (from primary care to a hospital, from a hospital to a specialized institution, etc.).
Collecting EHCR data	The electronic healthcare record is an aggregation of all data referring to a specific patient, of any type that have any clinical, medical, administrative or nursing value. Aggregation of such data is mainly done at a healthcare institution level but can be done at a regional level also.
Patient referrals	Within primary care settings and from primary care to secondary care.
Transfering information to another RHA	Gathering patient information at a regional level (raw data or pointers to specific data sources) enable the transfer of data to other RHA (for example many hospitals in Greece often transfer cases to specialized or universitary hospitals situated in another RHA).
Claim processing with insurrance companies and social security institutions	The interoperability framework can be used to settle claims from medical institutions towards social security funds to reach shorter reimbursment times.
Transfering medical documents	Medical documents (claims, patient referrals, doctors letters, etc.) can be processeed through an HL7 based interoperability framework by using HL7 clinical document architecture (CDA).
Telemedicine data transfer	The HL7 can be used as an interoperability framework between information systems residing within the healthcare institutions and information systems that manages specific telemedicine scenarios such as emergency telemedicine (from an ambulance to the emergency rooms in a hospital) or homecare scenarios (remote telemonitorimg).
HIS – LIS interface	Within a healthcare institution where the HIS requests laboratory tests to an LIS and the LIS responds by sending the results back.
HIS – RIS interfaces	Within a healthcare institution where the HIS requests radiology tests to an RIS and the RIS responds by sending the results back (imaging and doctor letters).
Appointment management	Appointments can be managed at an institution level but managing them at a regional level has a lot of advantages (shorter waiting lists, better resource combination, no overbooking, no doublebooking of a specific appointment to two or more practitionners, etc.). In that sense a master record of appointments created by a patient relationship management system (web portal and call centre enabled) needs to send appointment data to the healthcare institution and expect a positive or negative acknowledgment.

The proposed interoperability framework greatly simplifies the data exchange issue in a regional healthcare information system since a lot less interoperability connections are required and messages used are homogenized between all involved healthcare institutions.

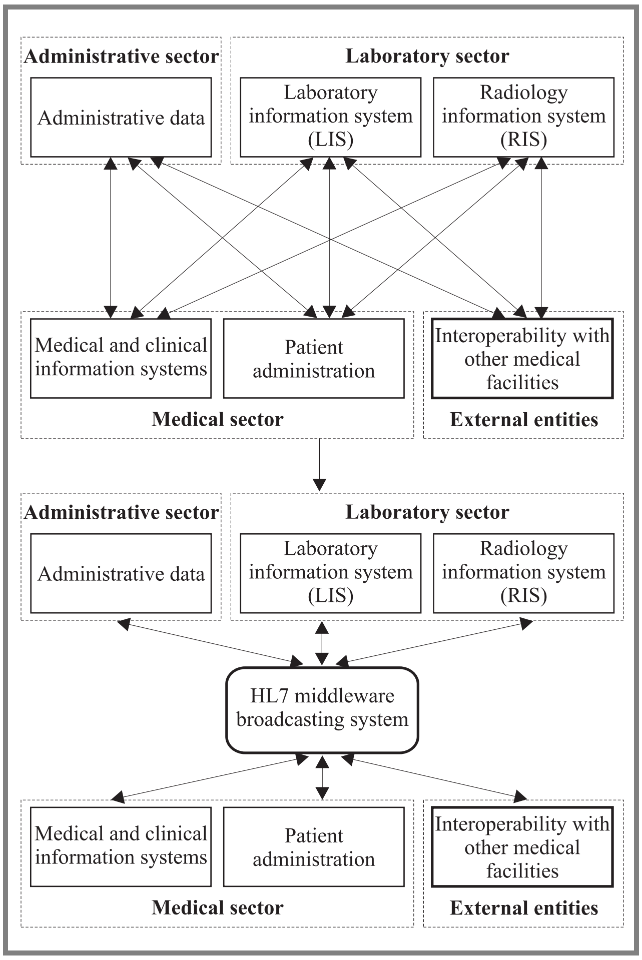

Fig. 4. Creating an interoperability framework.

Level HL7 [9] is by far the most widely used message based information exchange standard in the clinical environment. It is in use on all continents of the world. Also HL7 is clearly the most mature message based information exchange standard. As a consequence, HL7 was set as a mandatory requirement in the selection process for the implementation of the RHN for each RHA in Greece.

Level HL7 is the mostly the result of a pragmatic effort to come up with a mechanism to make it possible to exchange information between a variety of systems that communicate in a wide variety of ways. This has led to many ad hoc solutions that complicate the exchange of messages. Also the implementers of HL7 based communication between applications did have (and still have) a liberal view on the HL7 standard. In order to deal with this issue the proposed RFPs have included in the selection process the evaluation of an HL7 conformance statement based upon the work done by the "HL7 conformance special interest group" (SIG) established by HL7.

Figuers 3 and 4 mostly deal with interoperability issues within a healthcare institution where typically hospitals are mostly concerned since they produce the wider range of medical data. Figure 5 though is extending and describing the proposed interoperability framework and clearly depict the basic interoperability paths required at a regional healthcare level. As stated before, a regional healthcare system can be either an aggregation of interconnected distributed and variable information system, either a totally centralized system based upon an application system provider's (ASP model) approach or a combination of the aforementioned architecture. In all cases information flows, patient journey data, electronic healthcare record data (data collected from various institutions, in various formats and appointed to each individual based upon a mater patient index – MPI) are creating very important interoperability issues. Table 1 describes the basic HL7 based interoperability requirements within a regional healthcare information systems. It is without saying that data privacy issues are important when transferring or gathering data at a regional level and should be dealt with according to EU directives and additional national laws. Data privacy issues are addressed by the means of creating the proper patient consent mechanism, by creating and imposing strict and firm data manipulation and data storage procedures and by avoiding aggregation of sensible data when not strictly required.

Figure 5 depicts the interoperability point within a regional healthcare information system. The interoperability framework can be implemented either centrally with one middleware broadcasting system that interconnects all concerned information systems in a regional healthcare network (VPN based) setting or with an aggregation of interconnected and networked middleware broadcasting systems (one for each institution in the regional setting) that all communicate by an agreed numbers of HL7 based messages. In that sense, the cooperation of such middleware systems could be expanded nationwide, thus enabling patient mobility and data consistency within a nationwide electronic healthcare record.

3. Results

In order to assess the interoperability framework described before, a pilot project was implemented between two RHA and two hospitals one from each RHA [10]. This pilot tested two HL7 based interoperability scenarios: the creation of a central MPI at the RHA headquarters (by comparing 5 basic data elements of the PID segment of HL7) and the aggregation of specific financial data based upon a specific treatment billed at a packaged price in Greece. This pilot showed that HL7 could be used as a valid and operable interoperability framework that can integrate existing information systems into an interconnected regional healthcare information system.

In response to the aforementioned RFPs and the proposed interoperability framework, more than 10 different consortiums have submitted their proposals to the Greek gov-

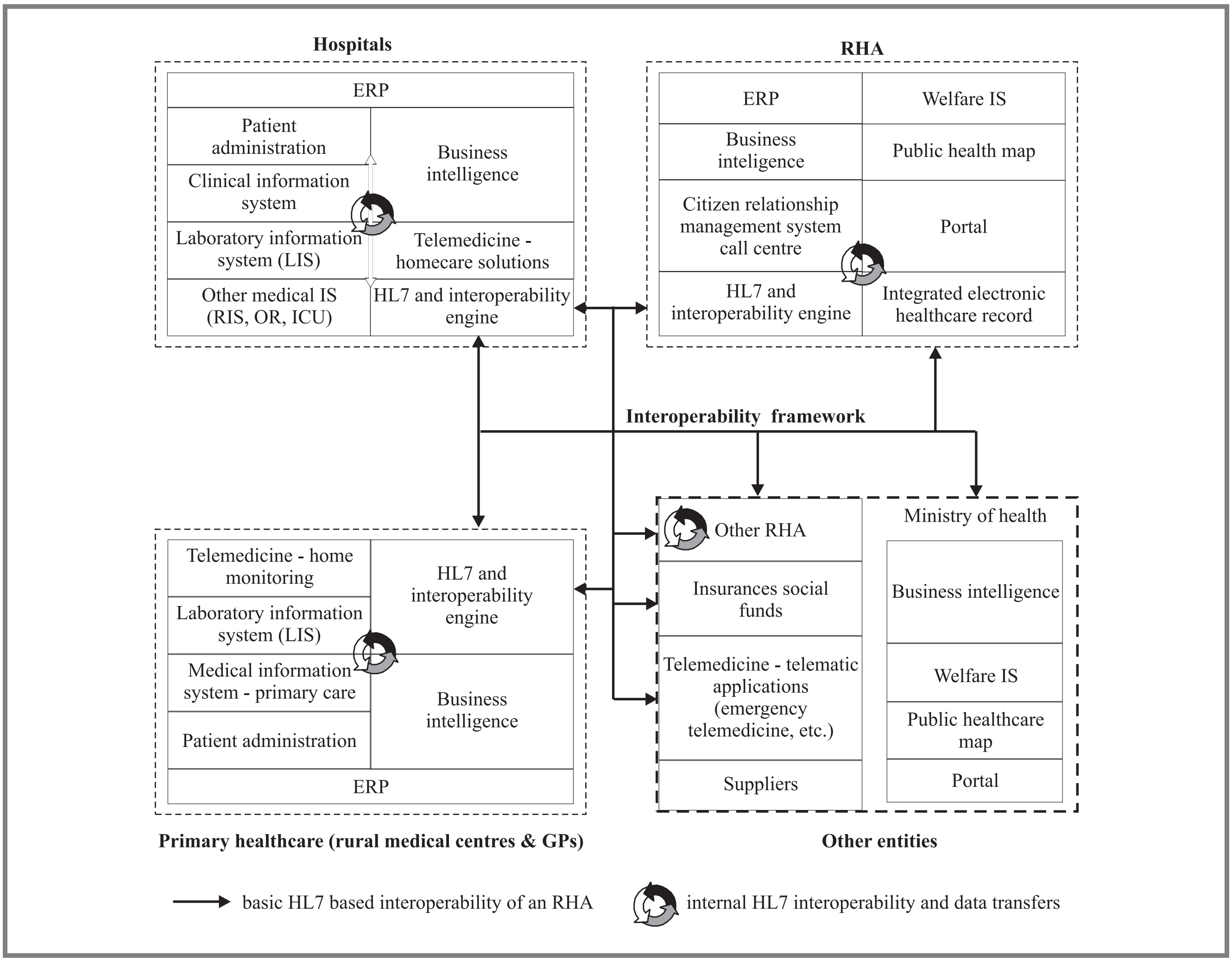

Fig. 5. Regional healthcare based interoperability framework.

ernment. Most of the solutions were based upon well-established IT products and the proposed interoperability framework was well taken into account. All proposals had a clear systems architecture which varied from a totally centralized solution where all information systems are common to all healthcare institutions to a totally distributed one were each hospital or other healthcare facility has its system that are interconnected with a common interoperability infrastructure. Many consortiums proposed a combination of the aforementioned solutions. As the interoperability framework is concerned three main implementation solution were proposed:

1. In the centralized solution the middleware broadcasting system is mainly used to interconnect with third party information systems.

2. In the distributed solution each institution has its middleware or other HL7 engine, while a master middleware broadcasting system is installed at the regional healthcare authority level in order to achieve a common communication infrastructure.

3. In combined solutions, where some existing information systems were maintained, other were centralized (for example the ERP modules) since data exchange can be achieved by internal processes (common database, etc.), while most medical information systems are distributed and interconnected via HL7 based middleware systems.

In all cases the proposed interoperability framework was integrated in each technological solution proposed. The proposed solutions had important variations such as:

– technological differences,

– the complexity of the proposed interoperability framework,

– the level of maintainability of existing information systems,

– the level of complexity in combining various vendors and products,

– the quality of the delivered conformance statements.

The latter point is of great importance since it is a proof of knowledge of each consortium as HL7 usage is concerned. Each consortium included in its proposal a series of HL7 conformance statements.

Table 2
Proposed HL7 messages (non-exhaustive list)

HL7 message profile	Description
ADT/ACK ^ A01	Admit/visit notification
ADT/ACK ^ A02	Transfer a patient
ADT/ACK ^ A03	Discharge/end visit
ADT/ACK ^ A04	Register a patient
ADT/ACK ^ A05	Pre-admit a patient
ADT/ACK ^ A06	Change an outpatient to an inpatient
ADT/ACK ^ A07	Change an inpatient to an outpatient
ADT/ACK ^ A08	Update patient information
ADT/ACK ^ A11	Cancel admit/visit notification
ADT/ACK ^ A12	Cancel transfer
ADT/ACK ^ A13	Cancel discharge/end visit
ADT/ACK ^ A23	Delete a patient record
ADT/ACK ^ A29	Delete person information
ADT/ACK ^ A34	Merge patient information – patient ID only
ADT/ACK ^ A45	Move visit information – visit number
ORM ^ O01	General order message
ORR ^ O02	General order response message
OSQ/OSR- ^ Q06	Query response for order status
OMG ^ O19	General clinical order message
ORG ^ O20	General clinical order acknowledgement message
OML ^ O21	Laboratory order message
ORL ^ O22	General laboratory order response
ORU ^ R01	Unsolicited observation message
OUL ^ R21	Unsolicited laboratory observation message
QRY/ORF ^ R02	Query for results of observation
SRM ^ S01	Schedule request message
SRR ^ S01	Scheduled request response

Table 2 is a short list of the most common message proposed to be part of the interoperability framework. In most of the cases, the quality of the HL7 conformance statements was high, thus increasing the probability of successful implementation of this complex interoperability framework.

4. Discussion

The results of the request for proposal is encouraging from a technological point of view since most of the targeted goals were met and understood by the vendors' community. The described framework requested a common communication infrastructure in order to achieve data exchange in a manageable manner between the different levels of the RHA (RHA headquarters, hospitals, primary care centers, homecare, etc.). Nevertheless, important issues have still to be faced and solved in the implementation process in order to achieve a successful interoperability framework. Some issues are purely technological, some are organizational and some refer to data quality and uniformity. Data quality means dealing, amongst others, with missing database schemata from existing information systems, making decision about common terminologies and taxonomies (i.e., use of ICD10, LOINC, or other classifications), solve the misuse of databases tables, fields and the inconsistent use of data types. From a technical point of view it is probable that databases are not accessible, local area networks are not reachable, communication protocol issues arise or even that computing environments are instable. Finally organizational issues are most likely to tamper the implementation process since there is not enough competent staff placed in healthcare institutions, there is a lack of individual co-operation, complex rules and procedures are in place and still executive officers lack of decision-making will.

5. Conclusion

An important set of ICT developments has started in Greece that intends to promote the quality and continuity of care. The designers of these developments have recognized that the establishment of a robust and mature interoperability framework has to be set up in order for information systems to interconnect and exchange valuable administrative and medical data. HL7 has been proposed as the most valuable solution since the advantages of HL7 clearly outweigh its disadvantages, namely: one standard for the exchange of information between medical applications, and systems, wide spread knowledge of HL7, word-wide acceptance of HL7 by the academic world and the industry and continuous improvement of the HL7 standard through the international HL7 standard organization.

The HL7 integration approach is pragmatic, achieves data integration and provides acceptable integration costs. Finally, the proposed interoperability framework seems to be widely accepted as a solution to enhance ICT developments in the healthcare sector in Greece.

Acknowledgments

This work was has been supported by Information Society SA, a non-profit company owned by the Greek government which is assisting 13 RHA in implementing their regional healthcare information systems and is also a founding member of HL7 Hellas, the Greek affiliate of Health Level 7 Inc. in Greece.

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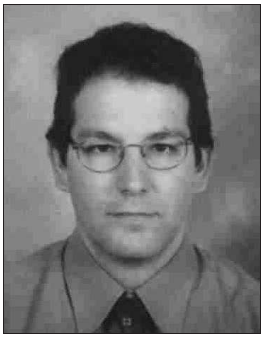

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Pantelis A. Angelidis – for biography, see this issue, p. 4.

Paper

An architecture for regional health information networks addressing issues of modularity and interoperability

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Abstract—A fundamental pre-requisite for the establishment of a scaleable regional health information network (RHIN) is the development of an architectural framework and tools for the integration of specialized autonomous systems and e-health service platforms supported by an underlying health information infrastructure (HII). In this context, HYGEIAnet, which is the RHIN of Crete in Greece, has identified and utilized a number of critical software components enabling integrated access to clinically significant information, based on an open architecture addressing successfully the various interoperability challenges at hand. HYGEIAnet provides the framework for the reuse of standardized common components and public interfaces, thus enabling integrated and personalized delivery of healthcare.

Keywords— regional health information networks, health information infrastructure, e-health services, interoperability.

1. Introduction

Healthcare is a sector that currently experiences a number of pressures, both from inside and outside. The continuing innovation in medicine and technologies results in new methods and tools in healthcare. The demographic changes of an ageing European population, combined with citizen empowerment, stretch the limits of what countries can afford to offer as services of their national health systems. Governments are confronted by the urgent need to find means to limit the rise in healthcare costs without compromising quality, equity and access. Consequently, new ways to organize and deliver health services are being investigated and experimented with. Citizens and patients are given more responsibility in the management of their own health and chronic illnesses.

Health consumes a significant portion of national budgets in developed countries. Between 1960 and 1996, the percentage of gross domestic product (GDP) spent on healthcare by the OECD countries nearly doubled, rising from an average of 3.9% to 7%. There is no sign of any slowing down, and countries such as the United States are predicting increases of over 15% per annum [1]. The expenditure on health in Europe was over 700 billion euros in 1999, of which an estimated 14 billion or 2% was spent on ICT. The prediction is that this market is set to double over the next 5 years [2]. This growth is due to many factors including the maturing of the market and the rapid developments in medical science itself, resulting in new treatments and therapies. The gap between the demand for healthcare from an increasingly well-informed and expectant public, and the ability of the state and healthcare organizations to meet this demand is widening all the time. Efficiency and cost-effectiveness are the two key drivers in healthcare today, with the twin aims of delivering enhanced quality of care at the same or reduced cost. There is documented evidence from a number of trials that patients who are encouraged to take responsibility and assume an active role in their own healthcare management do better, enjoy a better quality of life, have fewer complications, and cost less [3]. Paternalism is giving way to partnership; process centered healthcare is giving way to patient centric care; and consumer healthcare is emerging as a significant driver in the sector.

Other important trends in healthcare include the movement towards shared or integrated care in which the single doctor-patient relationship is giving way to one in which an individual's healthcare is the responsibility of a team of professionals across all sectors of the healthcare system. The shareable, ubiquitous and integrated electronic health record (I-EHR) is a fundamental requirement for integrated care [4]. This is being accompanied by a very significant growth in home care which is increasingly viable even for seriously ill patients through sophisticated e-health services facilitated by intelligent sensors, monitoring devices, handheld technologies, and the Internet. It is seen as better for patients by providing a more comfortable and familiar environment, and better for the healthcare system as a whole by reducing costs. The emphasis is gradually shifting to a system which is concerned with promoting wellness rather than treating illness.

At the same time, medical errors are a growing cause for concern and a number of countries and healthcare organizations are mounting major campaigns to significantly reduce the number of errors. Approximately 100 000 Americans die each year from preventable errors in hospitals [5] which is more than the combined number of deaths from breast cancer, acquired immune deficiency syndrome (AIDS) and motor vehicles [6]. Medical errors generally result from a complex interplay of multiple factors and reducing their frequency requires a combination of technical, social and organizational approaches. However, one single solution, which has been proven to significantly reduce medication errors, is the replacement of manual ordering systems by reliable automated ones [7].

In today's challenging, dynamic, information and knowledge intensive environment, it is not surprising that information and communication technologies (ICT) are increasingly viewed as central to any strategy aimed at increasing productivity, controlling costs and improving care. As a result networking of the various organizations delivering health and/or social care into RHINs is a central objective of many European administrations.

Such a vision was behind the development of HYGEIAnet in Crete, with the fundamental objective being to enable information sharing and medical collaboration among all stakeholders of the regional health economy and assist in the re-organization of the health care system based on innovative technological solutions and e-health services [4].

This paper begins with a brief overview of the identified application domains within a regional health information network (RHIN) and its services. Then, it focuses on the health information infrastructure (HII) required in order to support the efficient development of integrated services both within the context of a healthcare enterprise, as well as across co-operating healthcare enterprises that are part of a RHIN (RHIN infrastructure for integrated e-health services). Subsequently the case of HYGEIAnet is presented (HYGEIAnet: The RHIN of Crete) together with a range of novel e-health services deployed. Finally, it concludes by briefly discussing critical factors related to a successful implementation of a RHIN and observed benefits resulting from HYGEIAnet and its services (Section 5).

2. Regional health information network and its services

Today healthcare organizations, in most developed countries, are urgently trying to respond to the challenges arising from three global factors:

- changing operating environment comprising a number of issues like the *new economy* leading to institutional changes, informed citizens demanding personalized health services and the legislation and guidelines on privacy and security of personal information;
- changes in healthcare delivery comprising the move towards evidence-based care and, as part of that, best practice guidelines and care protocols, provision of integrated health services (citizen-centered services, seamless care) across organizational boundaries, making the patient a member of the care team (especially in the case of chronic diseases), and moving from care to health, or wellness management;
- technology push from the quick advancement in Internet and wireless technologies combined with the emergence of content providers and new business models for information technology (IT) services (e.g., application service providers, Internet service providers, Internet portals, e-health).

All these combined provide both the push and pull towards the development of RHINs. In the past, it was enough for the care providers in a region to collaborate loosely and to use electronic data interchange for administration commerce and transport (EDIFACT) and/or health level seven (HL7) based messages to support their electronic information exchange. Today the collaboration needs to be tighter. Tighter coupling in health services delivery requires the evolution of the regional healthcare information infrastructure by incorporating additional, regionally available common healthcare specific services.

2.1. The regional health economy

The structures within which healthcare is carried out vary from country to country – and sometimes even within national boundaries. In some European countries, the various healthcare entities, e.g., general practitioners (GPs), hospitals, payers, etc., are structured formally and hierarchically in a defined organizational context, headed by a regional authority of some form, usually with executive powers regarding the governance of the bodies within its jurisdiction. In other countries, the organization of the healthcare entities, which collectively provide healthcare into a (formally or informally) defined geographic *region* or population group are informally structured, i.e., they are a *loosely coupled* set of independent organizations, which have come together by mutual arrangement to co-operate in the delivery of healthcare to their client population.

It therefore follows, in the latter case, that the regional grouping of healthcare organizations will not behave in the manner of a classic *enterprise*, where major issues of policy and standards are prescriptively defined and enforced from the parent body at the top of the organizational structure. Furthermore, the funding model for care differs between countries. Accordingly, to define an umbrella term for the groups of organizations (both providers and payers or purchasers) that collectively form a *European healthcare region* the term *regional health economy* (RHE) is introduced [9], in order to embrace both the formal and informal structures that exist within Europe.

Another way to represent these relationships is presented in Fig. 1. From top-down, the healthcare organizations of a region form a RHE in order to co-operate in health service delivery. In doing so they implement laws, policies, goals and strategies defined by national and regional (if such exist) authorities. The result of this is a set of regional healthcare services (or processes) aimed at meeting the health needs of the population at an affordable cost and acceptable level of quality. For these selected processes (or health services) they will need ICT support in the form of a RHIN. To formulate their ICT needs they will have to develop and maintain a regional ICT strategy that guides

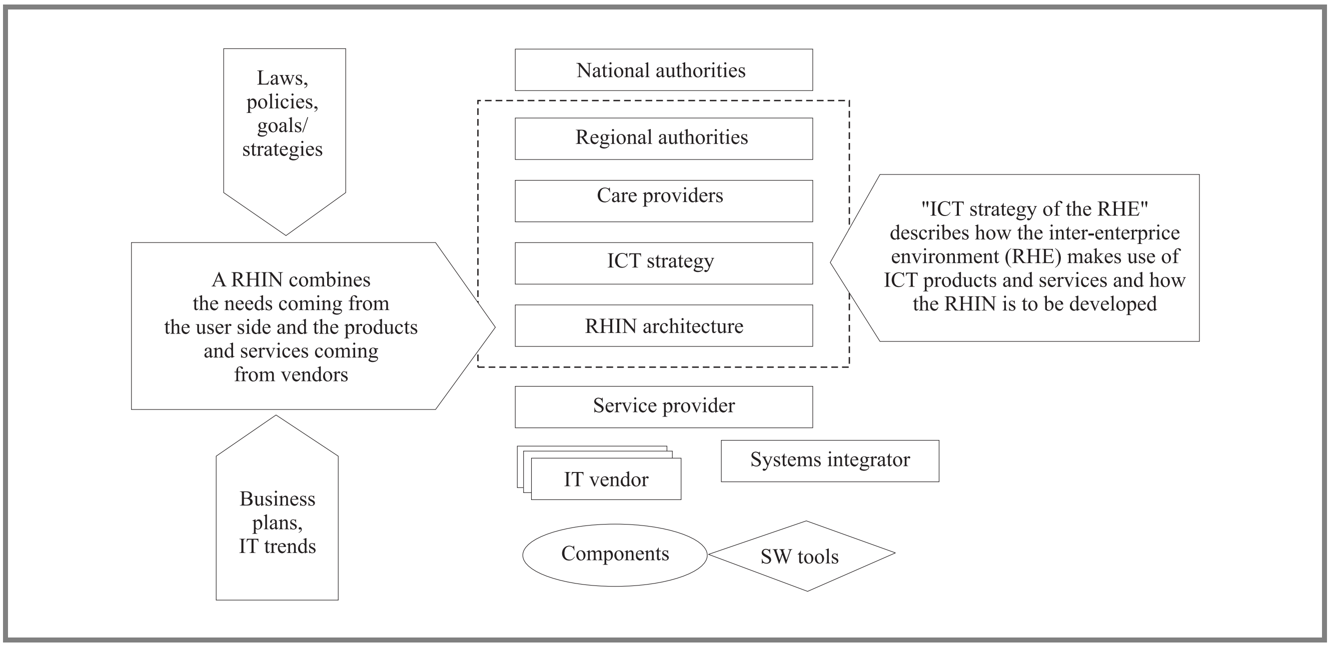

Fig. 1. The business model for creating the RHIN.

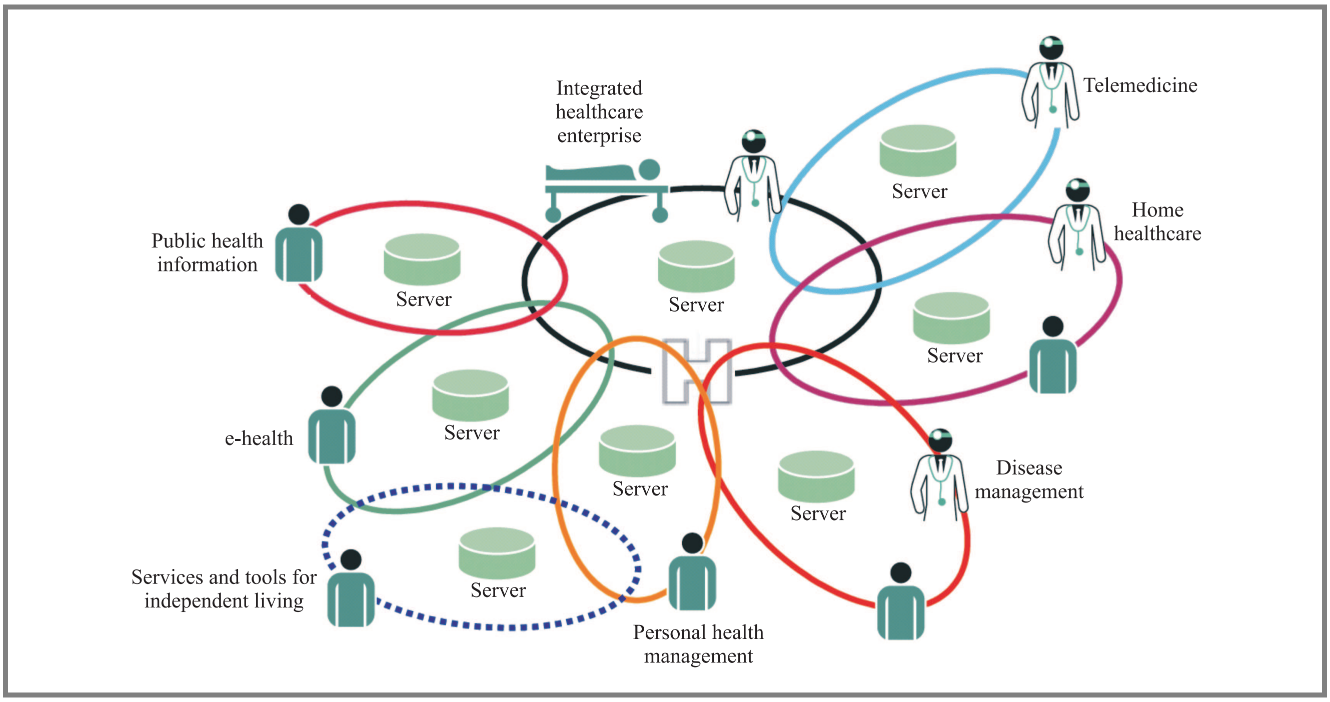

Fig. 2. Extension of care outside *hospital walls* creates additional needs for collaboration between providers in order to provide high quality, cost-effective services.

in the process of procuring new functionality to the RHIN that they deploy.

From bottom-up, the RHIN is a result of integrating products from different vendors into an interoperable HII using systems integration services and making this network available to users by a IT service provider, which is committed to maintain and manage it for the RHE.

The RHE concept has been used to emphasize that the regional grouping of healthcare organizations will not behave in the manner of a classic enterprise. Rather RHEs are formed by a loosely coupled set of independent organizations (enterprises), which have come together by mutual arrangement to co-operate in the delivery of healthcare to their client population.

The range of health services that can potentially be available in a RHE is illustrated in Fig. 2. The healthcare organizations are increasing their degree of integration through enterprise application integration and making use of existing generic and healthcare specific standards. The integrated healthcare enterprise (IHE) initiative is an example of the co-operation of industry and user communities in furthering this goal. Healthcare enterprise applications and their integration comprise a large set of clinical information systems for specific medical domains such as laboratory, radiology, intensive care, and anesthesia and operating rooms. Within these, someone can find another set of systems such as decision support systems and computer assisted or remotely guided diagnostic and therapeutic procedures based on, e.g., virtual reality. The integration of the systems includes interoperability and connectivity at the functional and semantic level, including vocabularies and, of course, standards. At the process level, it comprises clinical guidelines and pathways, protocol-based care, including evidence based medicine (EBM).

Parallel to this trend the number of healthcare services delivered outside the *hospital walls* has increased tremendously. Telemedicine has been a very popular field of experimentation in the last decade. Today it is mostly seen as a technology enabling the collaboration of healthcare providers over a distance in delivering a service to the customer. This can take place either in a store and forward mode or in real time. Home healthcare is often seen as a modality of telemedicine. Examples include the *home hospital* for episodic and chronic care and follow-up and monitoring of patients after hospital discharge. These operations can be performed with the real or virtual presence of care personnel in the homes. The main characteristics of these two are the extension of the hospital concept towards a virtual hospital (i.e., hospital without walls) and that healthcare professionals are clearly in the loop caring for the patients.

Disease management programs bring the patient to the centre of the process as the most important actor in the care team. Although disease management involves normally a large team of healthcare professionals from primary to secondary care the outcome of the process is determined mostly by the actions and activities of the patient in complying with the recommended care guidelines. In this area, a number of applications have been created to support collaboration and sharing of information. Disease management is a step towards a comprehensive health management regime. Its primary objective is to prevent disease episodes. Wellness or health management in general is a natural corollary of this where the objective is to assist an individual to maintain her/his health status. Today ITs that apply in this context include, e.g., smart environments utilizing ubiquitous computing techniques combined with embedded and wearable sensors.

2.2. The architecture of regional health information network

It is by now apparent that a RHIN, offering the range of services described previously, is a very complex system. In any system complex enough to ask for guiding rules for design and implementation, an architecture is needed. An architecture needs to create simultaneously the basis for independence and cooperation. Independence of system aspects is required to enable *multiple sources of solution parts*. Cooperation between these otherwise independent aspects is essential in any non-trivial architecture, since the whole is more than the sum of its parts.

An architecture, been a formal description of an IT system, should be organized in a way that supports reasoning about the structural properties of the system. It should identify the *components*, or *building blocks*, that make up the overall information system, and provide a plan from which products can be procured, and systems developed, that will work together to implement the overall system.

The purpose, therefore, of an architecture is to provide and enable:

– interoperability;
– modularity, so that the infrastructure can be assembled piece by piece;
– migration, so that pieces that are outdated can be replaced with new ones;
– stability, management and maintenance;
– cost-effectiveness by leveraging main stream technologies and products.

Therefore, the most promising approach to the development of a RHIN architecture is the adoption of an open systems approach (OSA). OSA is an integrated business and technical strategy that employs a *modular design* and, where appropriate, defines *key interfaces* using widely supported, *consensus-based standards* that are published and maintained by a recognized *industrial standards organization*.

Modular designs are characterized by the following:

– functionally partitioned into discrete, scalable, reusable modules consisting of isolated, self-contained functional elements;
– rigorous use of disciplined definition of modular interfaces to include object oriented descriptions of module functionality;
– designed for ease of change to achieve technology transparency and, to the extent possible, makes use of commonly used industry standards for key interfaces.

Open systems approach is a means to assess and implement widely supported commercial interface standards in developing systems using modular design concepts. It is an enabler that supports program teams to:

– design for affordable change;
– employ evolutionary acquisition;
– develop an integrated roadmap for an integrated system.

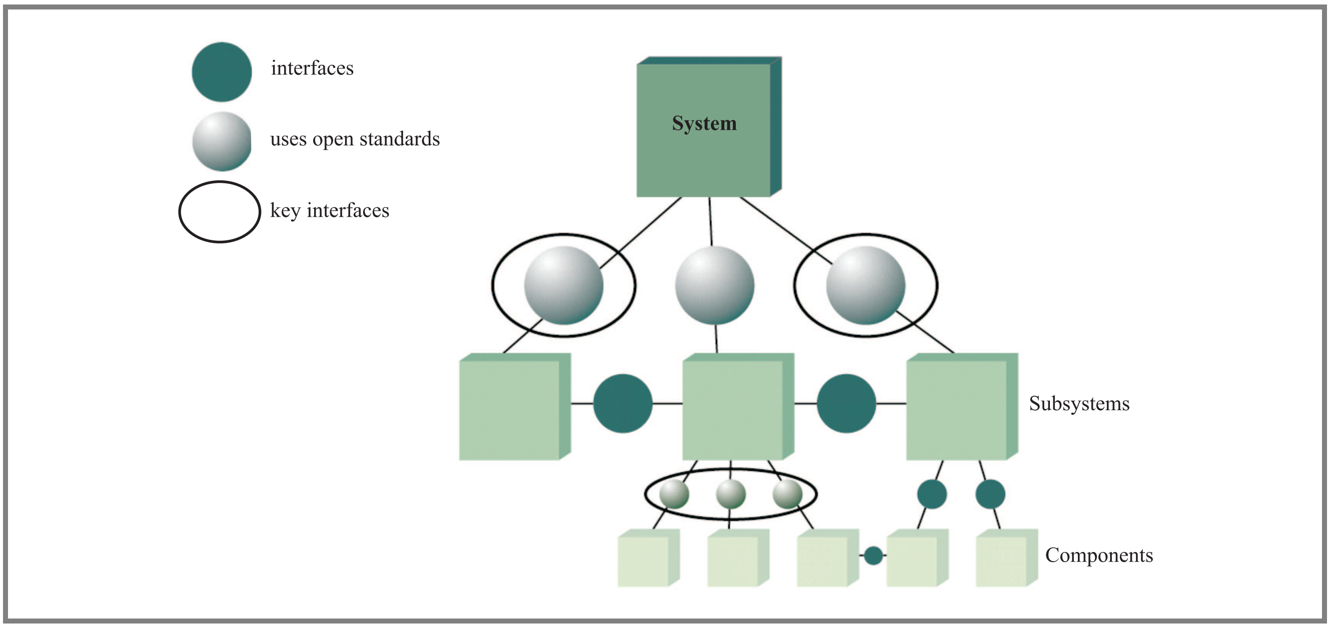

Fig. 3. Key interfaces.

This approach supports achieving the following:

– reduced acquisition cycle time and overall life-cycle cost;

– ability to insert cutting edge technology as it evolves;

– commonality and reuse of components among systems;

– increased ability to leverage commercial investment.

Partitioning a system appropriately during the design process to isolate functionality makes the system easier to develop, maintain, and modify or upgrade. Given a system designed for modularity, functions that change rapidly or evolve over time can be upgraded and changed with minor impact to the remainder of the system. This occurs when the design process starts with modularity and future evolution as an objective.

Interface standards specify the physical, functional, and operational relationships between the various elements (hardware and software), to permit interchangeability, interconnection, compatibility and/or communication. The selection of the appropriate standards for system interfaces should be based on sound market research of available standards and the application of a disciplined systems engineering process.

Special emphasis should be given to *key interfaces*. Key interfaces are interfaces between modules for which the preferred implementation uses open standards. Open specifications and standards are those that are widely used, consensus based, published and maintained by a recognized industrial standards organization. These interfaces are selected for ease of change based on a detailed understanding of the maintenance concepts, affordability concerns, and where technologies or requirements are intended to evolve. Key interfaces should utilize open standards in order to produce the largest life cycle and cost benefits.

Conceptually, key interfaces are illustrated in Fig. 3. Interfaces at and above key interfaces are those that should be designated on open interface standards. Standards for interfaces below this level may also be open; however, selection should be left to the supplier as part of detail design.

In order to take full advantage of modularity in design, interface standards must be well defined, mature, widely used, and readily available. In general, popular open standards yield the most benefit in terms of ease of future changes to the system and should be the standards of choice.

Standards should be selected based on maturity, market acceptance, and allowance for future technology insertion. As part of the open systems approach, preference is given to the use of open interface standards first, the de facto interface standards, and finally government and proprietary interface standards. Open standards allow programs to leverage commercially funded or developed technologies and to take advantage of increased competition. They also allow faster upgrade of systems with less complexity and cost.

The bottom line is that designing a system for affordable change requires modularity.

3. RHIN infrastructure for integrated e-health services

A RHIN focuses in inter-enterprise integration and provide integration for enterprises that want to share data and information for providing health services to patients/citizens in a regional setting (see Fig. 4). They are not concerned with how the enterprises are internally integrated, although the same principles can be applied to integrating healthcare organizations at a national level and across national borders (Pan-European).

Level 1 (local)	Enterprise wide integration
Level 2 (regional)	Inter-enterprise wide integration
Level 3 (national)	Inter-enterprise and inter-regional integration
Level 4 (European)	Inter-enterprise, inter-regional and inter-national integration

Fig. 4. Integration levels from local (enterprise wide) to Pan-European.

The basic principles behind the RHIN concept are the following:

- Healthcare organizations will retain their independence and their collaboration with each other is determined by their interests. There will be competing interests, i.e., healthcare organizations offering similar services.
- ICT technologies deployed by the various healthcare organizations will be different. They will have different technology platforms for the integration of their respective enterprise applications. There is no one technology platform that fits all needs.
- There is no single owner of the RHIN. Its development will depend on how the healthcare organizations can reach consensus and agreements on where to collaborate and where not. The task of the RHIN is to make data and information securely available in the inter-enterprise environment where it is needed, when it is needed and in the format it is needed.

The RHINs require the cooperation of healthcare facilities that offer complementary set of services and involve dealing with complex issues mainly related to patient data confidentiality, semantic heterogeneity, and the diversity of systems and services requirements.

This further urges for the creation and/or adoption of certain interoperability protocols and standards that will enable information exchange, and consequently raises the issue of developing an open, scalable and evolvable HII. The creation of an HII is also driven, among other factors, by the need for automating routine tasks to place the focus on patient needs rather than paperwork. It is also driven by the need to ensure continuity of care by providing flexible remote access to relevant information and resources and to support research in order to enable all involved stakeholders to make effective choices.

The HII must primarily provide the framework for the effective integration of distributed and heterogeneous components, ensuring overall integrity in terms of functional and information inter-working, while advances in network technology should enhance and extend applications, rather than replace them or make them obsolete.

3.1. Technological challenges

It is commonly accepted that care capacity, available at local level, is greatly enhanced when local practitioners have access to a patient's healthcare record and, as the need arises, when specialists can assist them. Important objectives in any effort toward establishing RHINs consisting of co-operating health enterprise networks involve:

– the promotion of the coordinated and harmonized development of healthcare enterprises;

– the adoption of a common architecture of reference for the development of advanced services within the health enterprise;

– the interconnection of cooperating health enterprises for the purpose of creating RHINs;

– the definition of medical and operational procedures for sharing resources and expertise over such inter-enterprise health information networks, so that patient mobility and improved care practices can be supported effectively;

– the development of environments for information exchange among health enterprises based on agreed information exchange protocols for the medical domain.

The most important initiative, with regard to enterprise application integration, is related to the integrating the healthcare enterprise (IHE) initiative [10]. IHE promotes the coordinated use of established standards such as digital imaging and communications in medicine (DICOM) and HL7 to address specific clinical needs in support of optimal patient care, by documenting the integration profiles supported by available products (statements of their conformance to relevant standards) at a hospital level, to support plug-and-play interoperability. Typical such example is the patient information reconciliation (PIR) profile that provides the means to match images acquired for an unidentified patient with the patient's registration and order history, involving enterprise-wide information systems that manage patient registration and services ordering, radiology departmental information systems that manage department scheduling and image management/archiving, as well as acquisition modalities.

Regarding inter-enterprise application integration, one of the most advanced approaches is the one that has resulted out of the European Union (EU) co-funded research and technology development (RTD) project PICNIC (professionals and citizens network for integrated care) [11], that developed a model for the future regional health care networks, in order to prepare the regional health care providers

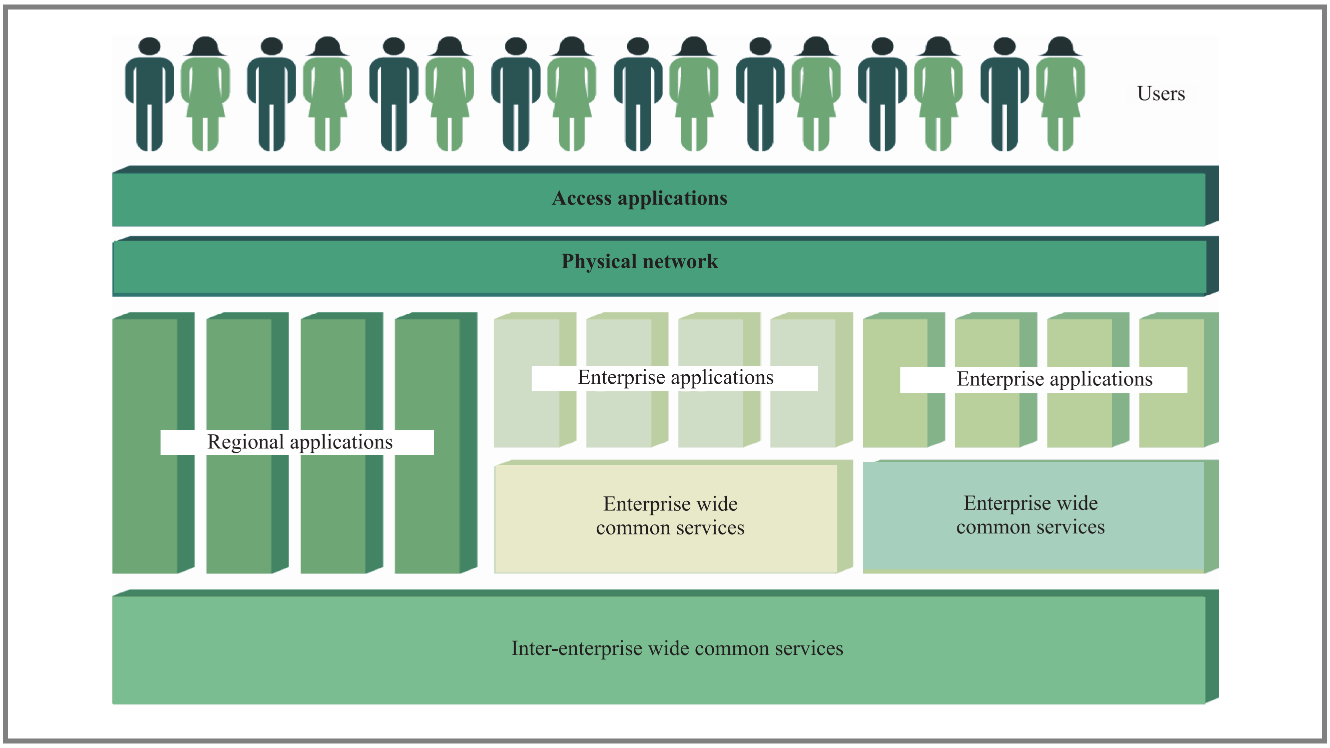

Fig. 5. Architecture of a RHIN.

to implement the next generation of secure, user-friendly health information networks. Basic characteristics of a typical architecture (see Fig. 5) include:

- Users (healthcare professionals and citizens) that have access to applications and services through alternative access devices. This access is performed through a secure physical network.
- Users that have access either to enterprise applications and services or to regional applications and services.
- Enterprise applications that are supported by enterprise wide middleware services.
- Regional applications and services that are supported by the corresponding common inter-enterprise wide services (regional HII).

This type of multi-tier approach depends heavily on the existence of both generic and healthcare specific middleware services/components, and imposes a level of common design that varies according to the actual composition of the platform.

Healthcare-related components are needed for the proper identification of the subjects of care, the exchange of I-EHR indexing and health data (utilizing appropriate health-oriented protocols like HL7), health resource(s) location(s), facilitation of collaboration between healthcare professionals and patients/experts, authorization for accessing healthcare-related resources, medical terminology, etc., whereas generic components are required to support low level, essential, platform-dependent functionalities like, e.g., concurrency control, event handling/notification, licensing, security (authentication, encryption, auditing, etc.), timing, transaction management, etc.

In practice the architecture tends to be much more complex. This is because healthcare providers in a region have applications running supporting their internal operations, as well as intra-enterprise wide integration platforms of messaging and common IT services. In addition, the functionality provided by the RHIN will depend on what IT services the organizations desire to provide to each other and what they are willing to give up in order to make this (i.e., tighter coupling versus federation). Therefore, the common IT services infrastructure depends on the existing health information infrastructures of the healthcare organizations that make up the RHIN of providers and related organizations. The same applies for regional applications. These will, in most cases, be created at the cost of enterprise applications. The healthcare organizations may agree that some functions can be supported by a joint, regional application.

3.2. Component view of a RHIN architecture

As software systems grow larger, healthcare delivery systems become more complex and interdependent. Today software component technology has emerged as a key enabling technology. "A component is a nontrivial, nearly independent, and replaceable part of a system that fulfils a clear function in the context of a well-defined architecture. A component conforms to and provides the physical realisation of a set of interfaces" [12].

Essential components that have been identified [8] to be required for the proper delivery of integrated e-health services in the context of RHINs include:

– patient identification (ID) components used for the unique association of distributed patient record segments to a master patient index;

– collaboration components used for establishing a collaboration context that enables not only the active sharing of clinically significant information, but also receiving feedback, feed through and awareness information from all participating actors;

– resource components used for identifying available resources and the means for accessing them;

– I-EHR indexing components used locating clinically significant information dispersed throughout the RHIN;

– I-EHR brokers used to provide prompt and consistent propagation of indexing information to the I-EHR indexing components;

– clinical observations access components used for obtaining clinically significant information captured at the point of care, directly from the corresponding clinical information systems;

– message brokers used for message validation, transformation and routing using a set of built-in and/or user-defined message formats and message processing rules, which may include functionality such as publish and subscribe, message auditing, message flow analysis, and message enrichment;

– user profile components used for tracking the long-term interests of users and maintain personalized preferences;

– terminology components used for information acquisition, information display, mediation, indexing and inference, and composite concept manipulation.

Beyond relational databases that today are used extensively for storing enterprise data, technologies for the integration of information related to the electronic health record (EHR) also involve directories for creating distributed, hierarchical structures of accessible resources (with the most promising being X.500 and light directory access protocol – LDAP of the International Telecommunication Union – ITU), distributed object computing to implement advanced modular functionalities (like, e.g., the platforms of common object request architecture – CORBA or Java two enterprise edition – J2EE), Internet and Java to glue pieces of information scattered throughout the world, portable devices and mobile communications to enable access from anywhere at any time, extensible markup language (XML) technologies to allow for dynamic browsing according to personalized preferences and authorities, together with human computer interaction (HCI) technologies to support access for all.

3.3. Security issues in RHINs

The main focus in dealing with RHIN security is related to control of the information, especially as it deals with private and confidential patient information. Security (resilience) of the hardware, operating system and the application software, while being equally important, is an issue that must be solved in the selection of the software platform and the tools used to create the execution environment and the applications.
The concept of an *information domain* provides the basis for security protection. An information domain is defined as a set of users, their information objects, and a security policy. Security within each information domain must be established in accordance with the respective security policy. For communication between the information domains, a trusted end-to-end communication policy must be established.
Additionally, security policies must deal with the *informed consent of patients* (customers), which is required for legal access to patient data. Consent may also have qualifiers, e.g., restricting access to only part of the patient data or restricting the period of time that the consent is given. Finally, the choice of what security features to implement must be based on *risk assessment* in the context of the intended service.
In order to access system resources and patient data users must be identified (i.e., access to resources and data must be controlled so that unauthorized access is prevented). Access rights can be managed on two levels:

– authentication (the person is who (s)he claims to be);

– authorization (permitting access to resources and data based on a qualified role, role-based access).

Information may not be made available or disclosed to unauthorised individuals, entities or processes without the consent of the patient. This is a fundamental right of individuals that they shall have the power to keep information about themselves from being disclosed to anyone. Therefore, the individual (patient) must agree/consent to disclosing her/his private information.
Audit trails are needed to ensure *accountability* of actions of individual persons or entities, such as obtaining informed consent or breaching confidentiality. These records can be used to reconstruct, review, and examine transactions from inception to output of final results. The records can also be used to track system usage and detect and identify intruders.

A public key infrastructure (PKI) is used to describe the processes, policies, and standards that govern the issuance, maintenance, and revocation of the certificates, public, and private keys that the encryption and signing operations require. PKI is used in order to enable two entities that do not know each other to exchange information using an insecure network such as the Internet. The infrastructure is based upon asymmetric cryptography and each entity (user, information system, etc.) is provided with a pair of keys (a private and public key).

A certification authority (CA) is a trusted party that can vouch for the binding between names or identities and public keys. In some systems, certification authorities generate public keys. The public key certificate binds a user's name to a public key signed by a trusted issuer.

Smart cards are mostly associated with PKI and CAs as an access card containing encoded information and sometimes a microprocessor and a user interface. The information on the code, or the information generated by the processor, is used to gain access to a facility or a computer system.

Digital signature is a means to guarantee the authenticity of a set of input data the same way a written signature verifies the authenticity of a paper document. Digital signatures are required in many cases during the provision of health services to a citizen. It comprises a cryptographic transformation of data that allows a recipient of the data to prove the source and integrity of the data and protect against forgery. To sign a document, the document and private key are input to a cryptographic process, which outputs a bit string (the signature). To verify a signature, the signature, document, and user's public key are input to a cryptographic process, which returns an indication of success for failure. Any modification to the document after it is signed will cause the signature verification to fail (integrity). If the signature was computed using a private key other than the one corresponding to the public key used for verification, the verification will fail (authentication).

Digital signatures can be attached to any electronically transmitted message, including ones transferring EHR data. The digital signing of XML based clinical documents is a special instance where the nature of the clinical workflow may require that each participant only signs the portion of the document for which they are responsible.

4. HYGEIAnet: the RHIN of Crete

HYGEIAnet represents a systematic effort towards the design, development and deployment of advanced e-health and m-health services at various levels of the healthcare hierarchy, including primary care, pre-hospital health emergency management, and hospital care on the island of Crete, Greece (Fig. 6). Specifically, e-health and m-health services support the timely and effective management of patients, the synchronous and asynchronous collaboration of healthcare professionals, and the remote management of selected patients at home. Finally, e-health services are being used to support continuity of care across organizational boundaries by providing access to the life-long I-EHR.

HYGEIAnet is fundamentally designed to provide access to health information when and where this may be required, and to facilitate communication among all actors committed to informed decision making in the health sector. From the technological point of view, a diverse set of state of the art technologies have been developed and deployed as part of the scalable HII of HYGEIAnet. These include fixed, as well as wireless and mobile communications, distributed computing and middleware, web technologies and services (i.e., XML, simple object access protocol – SOAP, universal description, discovery and integration – UDDI), peer-to-peer computing, H.323, X.500, X.509, and also a number of other healthcare specific standards.

The deployment and use of HYGEIAnet services has demonstrated significant economic and clinical benefits. Specifically, a reduced number of referrals to specialists has resulted in less travel and fewer days of hospitalization, while the number of workdays lost by family members and relatives is reduced. Furthermore, unnecessary duplication of medical examinations is avoided, while access to care and quality of service are greatly improved in all cases in which e-health services are employed.

In the course of designing and implementing HYGEIAnet, special efforts are being made to meet the requirements of the various user groups involved and to use state-of-the-art technology and standards at every stage of development. Alternative patient, location, and problem-oriented views for the I-EHR have been considered in an attempt to provide transparent access and secure communication of information between medical specialty areas, as well as in a variety of situations from community to hospital care across the region.

4.1. Integration at the inter-enterprise level

The development of the HII services of HYGEIAnet was based on CORBA, since it seemed to offer a unique combination of advantages over other distributed object oriented technologies. Such advantages include:

- platform independence;
- programming language independence;
- efficiency;
- rich horizontal and vertical service repertoire.

In particular the work of health domain task force (DTF) of the object management group (OMG) [13] was very important in the definition of the information integration architecture for creating the I-EHR. This architecture was based to the following services defined by the health DTF:

- person identification service (PIDS), enabling the unique identification of patients;
- lexicon query language (LQS), enabling efficient management of medical terminologies and coding schemes;
- clinical observation access service (COAS), enabling seamless access to the various clinical information systems, the primary sources of medical information.

Moreover, in the context of the PICNIC project the following services were specified and designed:

- I-EHR indexing service (I-EHR IS), for managing indexes to the primary information sources so that the efficiency and scalability aspects of the architecture are reinforced;

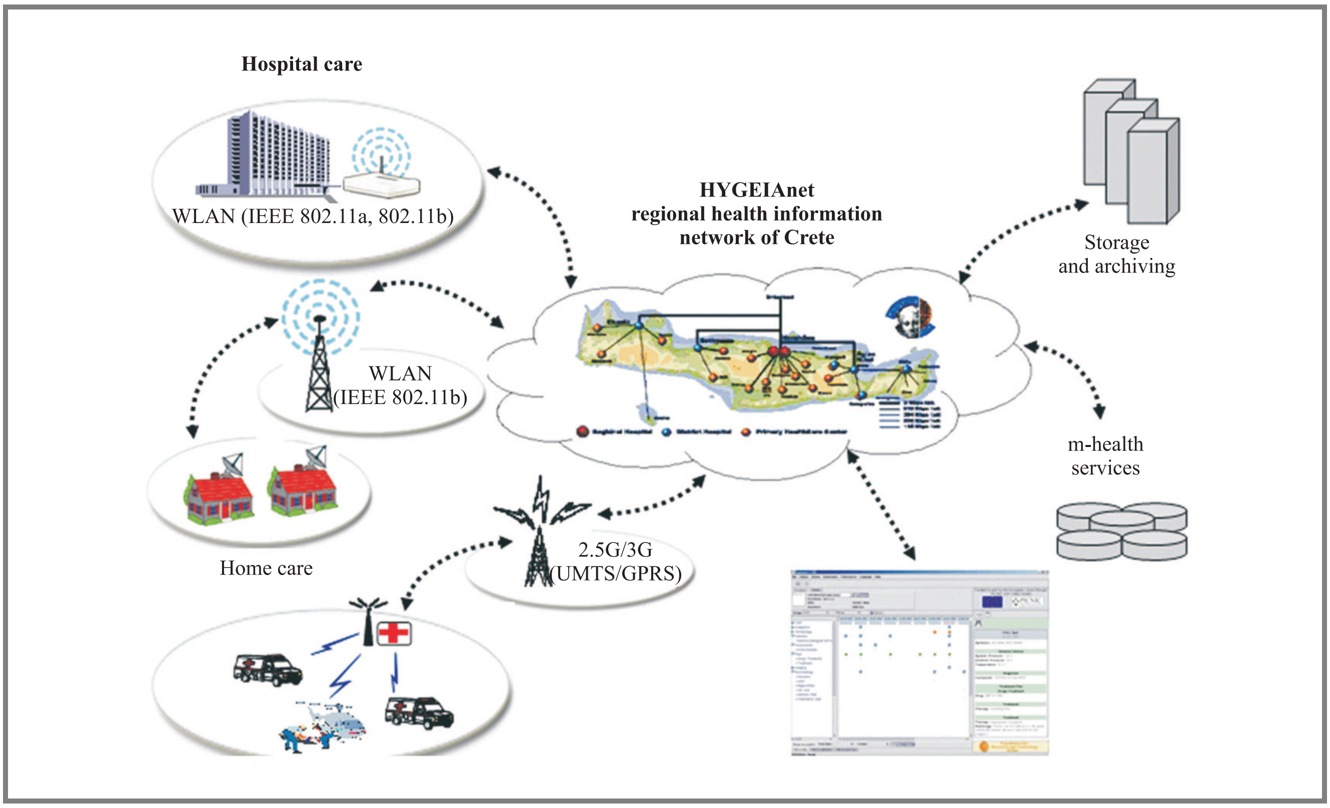

Fig. 6. E-health and m-health services in HYGEIAnet.

– I-EHR update broker (I-EHR UB), for keeping I-EHR IS up to date with new or modified information and consistent with the information accessible through COAS;

– health resource service (HRS), for the unique identification and management of clinical resources in the context of I-EHR, such as medical stuff, health care facilities;

– collaboration service (COLS), to support collaboration among healthcare practitioners.

At the inter-enterprise level, web services technologies have been utilized in HYGEIAnet, over the already existing enterprise service components, comprising the backbone of a component based computing environment, that treats medical information systems and services as information sources to be integrated at a regional level. Currently, within the context of HYGEIAnet, a number of subdomains attract attention:

- **Home care**. Aiming at providing e-health services for the remote management of chronic diseases [14]. Various such services have been delivered, ranging from the provision of telemonitoring for patients undergoing kidney hemodialysis to asthma suffering children.

- **Primary care**. A primary healthcare network is already in operation. The primary health care centers of the island are all fully equipped and support efficiently all patient related clinical processes.

- **Pre-hospital health emergency care**. An integrated system has been developed and is currently operational providing e-health tools and services for the optimal planning, and response management of prehospital health emergencies.

- **Hospital care**. Clinical information systems have been developed or acquired and installed in various clinical departments.

- **E-health**. E-health services in the domains of cardiology [15] and radiology are available today throughout HYGEIAnet, making medical expertise instantly available to remote and isolated populations.

- **The integrated electronic health record**. The required infrastructure is in place and a large number of clinical information systems are currently supported, ranging from primary health care and nursing to specialized departmental information systems [16].

- **Education and information to the citizen**. The development and operation of any RHIN is not only a matter of applying new ICT technologies. Above all, it requires the continuous education and innovative training of medical, nursing and administrative personnel from all involved healthcare organizations.

- **Health monitoring and surveillance**. A fundamental objective is to provide the technological infrastructure (networks, information systems, analysis tools, etc.) for the routine collection of primary health data and their analysis for the extraction of the relevant health indicators [17].

4.2. Role-based access to information

The use of any RHIN service that transcends enterprise boundaries requires careful consideration of the security issues that may arise. Some of the security aspects like information integrity are enforced by integration and communication technologies used, like the transport layer security (TLS), or the CORBA security service. However the need for authorization and access control requires security measures at the application level in addition to those offered by the communication platform.

For all RHIN service access control lists are maintained within the HYGEIAnet authentication server. All HYGEIAnet applications and services are declared within the HYGEIAnet's HRS and are issued a unique ID. Each user of the RHIN services must also register within HRS, and is issued with a unique username, together with the corresponding password, which are used for the facilitation of single-sign-on all applications and services within a RHIN. Groups and permissions are maintained and managed locally by each individual RHIN service. Passwords are maintained and managed by the corresponding RHIN authentication server, while certificates are provided and maintained by the regional certification authority. The role of each involved actor is listed in Table 1.

Table 1
The role of regional certification authority

Actor	Role
Certification authority	Issues certificates.
Authentication service	Maintains and manages passwords; issues passwords for every new healthcare person; performs user authentication.
HYGEIAnet HRS	Maintains and manages public health resource information; activates all applications and services by issuing them a unique ID; registers all healthcare persons and organizations; issues a unique user name for all healthcare persons it maintains; associates healthcare persons and organizations.
Any RHIN service	Maintains and manages roles (groups) and role-based permissions.

Two user management modules may be in place; one from within the RHIN service environment and handles all RHIN service specific access rules, and one through the overall domain management administration GUI. Those modules cooperate with a set of infrastructure components like HRS, CA, the authentication service (AS), and the certificate revocation list (CRL).

An IT service user is authenticated through the appropriate AS and gets his/her access rights validated through the individual RHIN service specific access control manager. When a new *healthperson* is added in HRS, the user management module automatically creates an active account for him in AS and provides him a digital certificate from CA. A new user account for any RHIN service can only be created for a user that has already been registered within the RHIN HRS. This includes assignment of roles (and associated permissions) at the IT service level. In order for the whole process to guarantee maximum security a user must have an account activated in three different places:

- HRS;
- AS;
- CA (activate a revoked certificate).

This permits a new user to access the RHIN service, and allows the administrator to find and select all users associated with any particular RHIN service from the RHIN HRS.

The user is then assigned to certain roles based on organizational (i.e., his/her position in a health care provider) or other criteria. The roles are granted permissions and rights that are expressed by allow and deny rules. Each rule conveys the following information:

- the type of rule, i.e., if it is allowing or denying access;
- the source of health information (clinical information system) that this rule applies;
- the kind of clinical information that this rule applies.

It is therefore feasible to grant access to users based on the location that the information is hosted and also based on the type of the information. This model in spite of its simplicity has been proved to be powerful enough for the most common use case scenarios. Extensions to the definition of the rules that, for example, allow combination of rules and creation of more complex rules using conjunctive and disjunctive constructs, although feasible, have not needed in practice.

5. Discussion

HYGEIAnet takes advantage of the increasing capacity of terrestrial networks, wireless and mobile communications and the development of advanced e-health services, to provide continuity of care in the different phases of healthcare, from prevention to care itself, to rehabilitation.

In the framework of HYGEIAnet, medical information systems and services are treated as information sources to be integrated under the common reference architecture. To meet this challenge, an execution architecture was defined and implemented in order to support the seamless integration of information.

A large number of re-usable software components (middleware services) have been identified and developed so far, capable of supporting the ICT evolutionary and migration strategy at the regional level. Our experience has shown that re-usable components make the deployment of new clinical information systems and e-health services easier and faster, while at the same time allowing for a more efficient management of the ICT infrastructure. Still, decisions have to be formulated about how and when to upgrade the platform itself and whether the expected benefits and savings outweigh the costs involved.

However, the deployment and use of HYGEIAnet services has to date demonstrated significant economic benefits. Referrals of patients to specialists were significantly reduced, since expert opinion was available through services provided over the RHIN, and hospitalization days have been reduced. Loss of workdays of family members has also been reduced, while unnecessary examinations have been avoided. Considering the rather limited use of technology in the region of Crete prior to the deployment of HYGEIAnet systems and services, the actual economic benefits can be accurately quantified after the transients die out and the regional system of health is allowed to operate as a RHIN in a steady state. However, the evaluation of the cost benefits of e-health services, relative to patient outcome, is and ought to be a continuous process.

Access to care has greatly improved in all categories where e-health services have been employed. The findings to date are extremely encouraging and suggest that e-health services can benefit not only the patients, but also health professionals by fostering their collaboration and serving as a tool for continuing education. In tele-cardiology, 10% of the cardiac patients were involved in a tele-consultation session during a period of 6 months, thus making medical expertise instantly available to remote and isolated populations. Furthermore, 65% of pre-hospital health emergency episodes are managed by paramedics. Given that the first 60 minutes (the golden hour) are the most critical regarding the long term patient outcome, the ability to remotely monitor the patient, thus allowing experts of the coordination centre to guide the paramedical staff in their management of the patient, is facilitating access to care by specialists. In addition, different evaluation studies have demonstrated improvements in the quality of care itself, with respect to the application of e-health services in pre-hospital health emergency management, the remote management of chronic diseases, and in supporting teleconsultation in selected clinical disciplines.

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Paper

Wireless communication for medical applications: the HEARTS experience

Andrea Kropp

Abstract— Wireless networks provide all the functionality of wire-line networks without the physical constraints of the wire itself giving an interesting alternative to phone-line and power-line wiring systems. With a wireless network, physicians can actively monitor a patient's vital signs from anywhere in a hospital. HEARTS (health early alarm recognition and telemonitoring system) is a research project having the major aim to provide support for prevention and monitoring heart disease, based on advanced technology. The HEARTS idea is to gather biometric and environmental data coming from patients during both hospitalization phase and in their normal lifetime activities, using wireless networks. The wireless network and its composing devices are called personal health network (PHN). WPAN and WLAN technologies have been investigated, each with its pros and cons, for use in health monitoring activities inside hospitals and at home, for improving patient mobility, and to provide patients for "last interconnection hop" to the infrastructure network. Technological and operational problems have been addressed concerning bluetooth, IEEE 802.11b (WiFi), GSM/GPRS/UMTS wireless transports, all of them tested and some of them concretely adopted inside the HEARTS framework.

Keywords*— *bluetooth, wearable 802.11b, wireless networks, sensor data, DSP, medical devices, dehospitalization.

Wireless networks provide all the functionality of wire-line networks without the physical constraints of the wire itself giving an interesting alternative to phone-line and power-line wiring systems. With a wireless network, physicians can actively monitor a patient's vital signs from anywhere in a hospital.

Wireless technologies are generally based on radio transmissions within a network area; radio transmissions comprise of two distinct technologies, using narrowband or spread-spectrum radio. Most wireless networking products are based upon the spread-spectrum technologies. There are three types of network, each one with a different coverage area suitable for different applications:

- wireless personal area network (WPAN);
- wireless local area network (WLAN);
- wireless wide area network (WWAN).

The bluetooth technology, suitable for WPAN, is the result of a cooperation between leaders in the telecommunication and computer industries; it delivers opportunities for rapid ad hoc connections using a low-cost, short-range radio link built into a single microchip.

Bluetooth radios establish radio links in the unlicensed ISM band at 2.4 GHz, using a low RF power of some milliwatts; designed to operate in a noisy radio frequency environment, bluetooth radio modules operate using FHSS (frequency hopping spread spectrum) transmissions, avoiding interference from other signals by hopping to a new frequency after transmitting or receiving a packet. A collection of digital appliances that are connected to a home network via bluetooth technology is called a piconet. A piconet is composed of up to eight devices with one acting as master; all devices participating on the same piconet are synchronized to the same hopping sequence, determined by master. The range of a bluetooth device for typical uses is about ten meters.

Bluetooth has a maximum shared data capacity, in a piconet, of about 1 Mbit/s, which translates to a real throughput of 780 kbit/s once the protocol overhead is taken into account; according to link type and number of other active devices, each device in a piconet will have a capacity varying from 64 to 780 kbit/s.

Specific characteristics or common applications for the bluetooth standard are called bluetooth profiles; examples of profiles are: dial-up networking (DUN), serial, local area network (LAN), headset, file transfer.

The IEEE 802.11 is the worldwide adopted standard for wireless LAN communications, since 1999; the 802.11b extension operates in the 2.4 GHz unlicensed ISM band; with an RF power of 30 mW it can reach 100 m of operating range; it uses a direct-sequence spread spectrum (DSSS) transmission type, and reach data rates of 11 Mbit/s in a single operating frequency; interoperability of different brands 802.11b devices is certified from WECA (Wireless Ethernet Compatibility Alliance) consortium tests; products that pass these tests are stamped with a WECA seal of approval, called WiFi (pronounced Y-Phi) for "wireless fidelity".

The health early alarm recognition and tele-monitoring system (HEARTS) is a research project having the major aim to provide support for prevention and monitoring heart disease, based on advanced technology; the objective of using wireless communications in HEARTS is to reduce the amount of cabling necessary to collect sensor data, and therefore increasing the user mobility in his real-life activities.

The HEARTS idea is to gather biometric and environmental data coming from patients during both hospitalization phase and in their normal lifetime activities, using wireless networks. The wireless network and its composing devices are called personal health network (PHN).

The serial profile used in the personal health network is an emulation of serial communication (RS-232) over a wireless link. Bluetooth modules implementing serial profile can exchange data at a distance up to 10 m.

The wearable device is mainly a data acquisition subsystem, collecting all the data coming from biomedical and environmental sensors; it also apply some basic computation to the collected information, such as filters and data normalisation algorithms.

The bluetooth connectivity in wearable device is realized by mean of customized bluetooth modules; these modules implements serial profile functionalities and are controlled by a set of AT commands. An embedded microcontroller provide both the data acquisition, normalization, digital filtering and bluetooth connectivity logic.

The discovery protocol embedded in bluetooth modules give to the entire personal health network an high degree of adaptivity, because new sensor sets could be seamlessly activated and added to the network at runtime.

The *master station* of the personal health network is called integrator device. It acts like a gateway between the personal health network and the HEARTS core services; it can be deployed on a PDA or a panel PC and provides a link with infrastructure network by mean of a wired (Ethernet) or wireless (WiFi) link. When needed, it could show ECG signals directly to the medical expert, acting like a traditional monitor; no significant interferences were found during the simultaneous usage of bluetooth and WiFi interfaces in HEARTS system.

The combined use of bluetooth technology and WiFi infrastructure, at home, in the office, or in a hospital, is capable to cover all possible monitoring scenarios:

– patient lie on his bed in a hospital room (typical of intensive care units);

– different patients are followed in a limited area (like a cardiology unit room).

Patient not only can lie in a bed, but is also capable to walk across a limited area (like an apartment, a hall, or a court).

Different solutions have been prototypically implemented, in order to evaluate the different scenarios, taking into account the typical throughput produced by a PHN, generally up to 15 kbit/s per second throughput produced by a full-featured personal health network; a single WiFi access point is capable to collect up to 10 PHN data, and when using a 100 Mbit network infrastructure the entire system is capable to collect up to 50 patients data (typical coverage of an entire cardiology unit).

Several WWAN technologies, like GSM/GPRS/UMTS are theoretically suitable for PHN operations, but due to limited bandwidth or technical limitations on using it, like asymmetrical bandwidth of GPRS, implemented to privilege the download functionality more than the upload, they don't perfectly fit HEARTS needs. Even the cost of these technologies is an hard obstacle to the deployment of continuous remote monitoring systems.

The major challenges for the future of the remote monitoring systems like HEARTS are substantially:

– easy setup of network connections and handover (especially for PDAs);

– more computational power for next generation handheld devices (data compression, smart DSP);

– remote control of terminal node (PHN) operations;

– remote control of wearable devices acquisition rate and DSP stuff;

– agreements with major telecom providers to guarantee at-home monitoring using existing and new broadband access at lowest possible costs.

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Paper

A web-based system for personalized patient education and compliance monitoring

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Abstract—The economic importance of therapy compliance has grown steadily in recent years, not only because of the efficacy of newer therapeutic methods but also because of the increased costs of treating the consequences of poor compliance. Improved compliance can lead to significant savings by preserving or restoring a patient's health, improving quality of life, by reducing the number of medical services required when therapy fails or appears ineffective, and by helping limit the rise in national health care costs. Within the framework of the TEN-Telecom European Commission Programme, C-Monitor project developed an integrated health telematics platform to enhance chronic patient compliance to therapy and interactive communication with their attending physicians. The overall aim of the project was to study the potential benefits, both in clinical and financial aspects, of such innovative systems and services along cost-efficiency of care provision. The platform developed has been validated in controlled small-scale trials in a number of European countries. The Greek pilot involved installation of the system in a private hospital in Athens and the validation scenario dealt with morbid obesity patients that have undergone surgical operation. A number of 30 patients were recruited for the trial. Results of the trial indicated the technological robustness of the proposed system and the potential clinical and economic benefits of running such services. Further trials are required to better address cost-efficiency issues with respects to the service goals.

***Keywords—* therapy compliance, patient education, health telematics.**

1. Introduction

Hospitalizations is the largest component of health care costs. Among hospitalized patients, high cost users are mainly those with repeated admissions [1]. In 1998, it has been reported a 22% readmission rate within 60 days of hospital discharge in the medicare population at an estimated cost of 8 billions $, the 24% of all inpatient expenditures [2]. Several studies suggest that 9% of all readmissions and up to 50% of readmissions by high risk patients are preventable [3–5]. Inadequate patient education, unrecognized clinical deterioration and noncompliance have been implicated as causes of preventable admissions [3–5]. Noncompliance with long term medication regimens is more than 50% [6]. The use of multiple prescriptions is closely related to noncompliance. This is particularly important in those with chronic diseases as heart failure and chronic obstructive pulmonary disease who consume a high amount of medications [7, 8]. In those patients noncompliance to drug therapy is approximately 90% and the percentage is probably worse for diet therapy and life style changes [9].

Several other studies have documented the cost of patient noncompliance with therapeutic procedures. According to the national council on patient information and education (NCPIE) (http://www.talkaboutrx.org/compliance.html), the annual cost of non-compliance to therapy is about 100 billions $. Furthermore, NCPIE suggest the following recommendations to be addressed to improve compliance:

- **for physicians** – involve the patient in treatment decisions:
  - monitor compliance with prescribed treatment at every patient visit;
  - document patient compliance using a compliance-monitoring form that can be incorporated into the patient's record;
- **for patients:**
  - become active participants in making treatment decisions and solving problems that could inhibit proper medicine use;
  - talk to health professionals about why and how to use their prescription medicines;
  - recognize, accept, and carry out their responsibilities in the treatment regimen.

The economic importance of therapy compliance has grown steadily in recent years, not only because of the efficacy of newer therapeutic methods but also because of the increased costs of treating the consequences of poor compliance. Improved compliance can lead to significant savings by preserving or restoring a patient's health, improving quality of life, by reducing the number of medical services required when therapy fails or appears ineffective, and by helping limit the rise in national health care costs.

Within the activities of the C-Monitor project, funded by the TEN-Telecom European Commission Programme, an integrated health telematics platform has been developed to enhance chronic patient compliance to therapy and interactive communication with their attending physicians. Overall aim of the project was to study the potential benefits, both in clinical and financial aspects, of such innovative systems and services along cost-efficiency of care provision.

The C-Monitor system was designed to allow patients to organize daily activities with respect to therapeutic needs in a personalized and friendly manner. It collects patient clinical and non-clinical data and reminds them about therapy needs/plan (drugs, exams, weight control, etc.). In the same time, the responsible doctor is informed not only about the patient's condition but also about patient compliance to therapy and deviations.

2. Design considerations

2.1. Platform description

The C-Monitor platform comprises of the following subsystems:

- The web server hosting the ASP.NET web pages that expose the C-Monitor functionality over the Internet to the web clients (browsers) of both physicians and patients.
- The application server exposing web services that are consumed by the ASP.NET web pages on the web server and are responsible for the communication with the database server.
- The database server built on a MS SQL Server 2000.
- The C-Monitor desktop applications that enable the customization/maintenance of each clinical scenario and the definition of treatment plans.
- The notification services module that is responsible for notifying physicians or other subscribers whenever an event that a subscriber is interested in occurs (by distributing e-mail notifications to an SMTP server).

The overall system architecture is depicted in Fig. 1. As shown in figure, the C-Monitor platform supports a four-tiered distribution of the software modules exposing functionality over the Internet and a two-tiered distribution (client/server) for the C-Monitor desktop applications running inside the boundaries of the hospital/clinic intranet. In case that hardware limitations exist, the C-Monitor platform can also be implemented easily as a three-tiered solution, with the web and application server hosted on the same computer. The physician and patient web client tier uses the web browser environment for the interaction with the users, so that minimal configuration and tuning is required, other than adjusting network connectivity (dial-up) parameters and browser settings. The ASP.NET web pages on the C-Monitor web server communicate with an ASP.NET web services façade hosted on the application server. The application server is responsible for the communication with the database containing all medical data. The notification services modules interact with the SQL server engine and allow the distribution of e-mail alerts to the various subscribers through any available SMTP server (hosted within the healthcare institution or provided by an external ISP).

The C-Monitor desktop applications are entirely built on the .NET framework platform and support two-tiered (client/server) architecture. These applications run within the boundaries of the health care institution intranet and are responsible for the definition and maintenance of each clinical scenario and for performing the main tasks requiring rich client capabilities in terms of user interface and advanced security environment. There are four main desktop applications available:

1. The scenario management application enables the customization of the platform for different scenarios. This application allows the users to define and maintain each clinical scenario. The main elements of a clinical scenario are: risk factors, which are questions that help the physician identify the patient's needs for on-going treatment, define medical guidelines and retrieve relevant information regarding his/her medical problem, the parameters of the scenario, such as medical measurements, medication, measurement units, etc., the medical staff and the patients participating in the scenario.
2. The therapeutic schema application allows physicians to create the personalized patient therapeutic schema including information regarding diagnosis, medication plan, examination plan (including in-house controls such as blood-pressure measurement, weight control, etc.), dietary plan, exercise and lifestyle guidelines, and any other information or direction to the patient that forms part of the therapeutic schema. This application allows physicians to define a personalized therapeutic schema by taking into account the values of risk factors that are relevant to the specific patient. After completing the review of the developed therapy plan, the physician forwards the plan to the patient, which will then allow the patient to register data and keep track of therapeutic steps to follow.
3. The document management application allows the physician to store and characterize documents intended to be published for patients. These documents can be later automatically retrieved according to their relevance to the patient's medical problems.
4. The translator utility enables the easy translation of the user interface for both web and desktop applications into any language.

2.2. Security issues

It is conceivable that a system handling medical data should be compliant to directives for protection of data and other security requirements. As discussed earlier, the C-Monitor platform comprises of an Internet part, which exposes functionality over the Internet to web browsers and an intranet

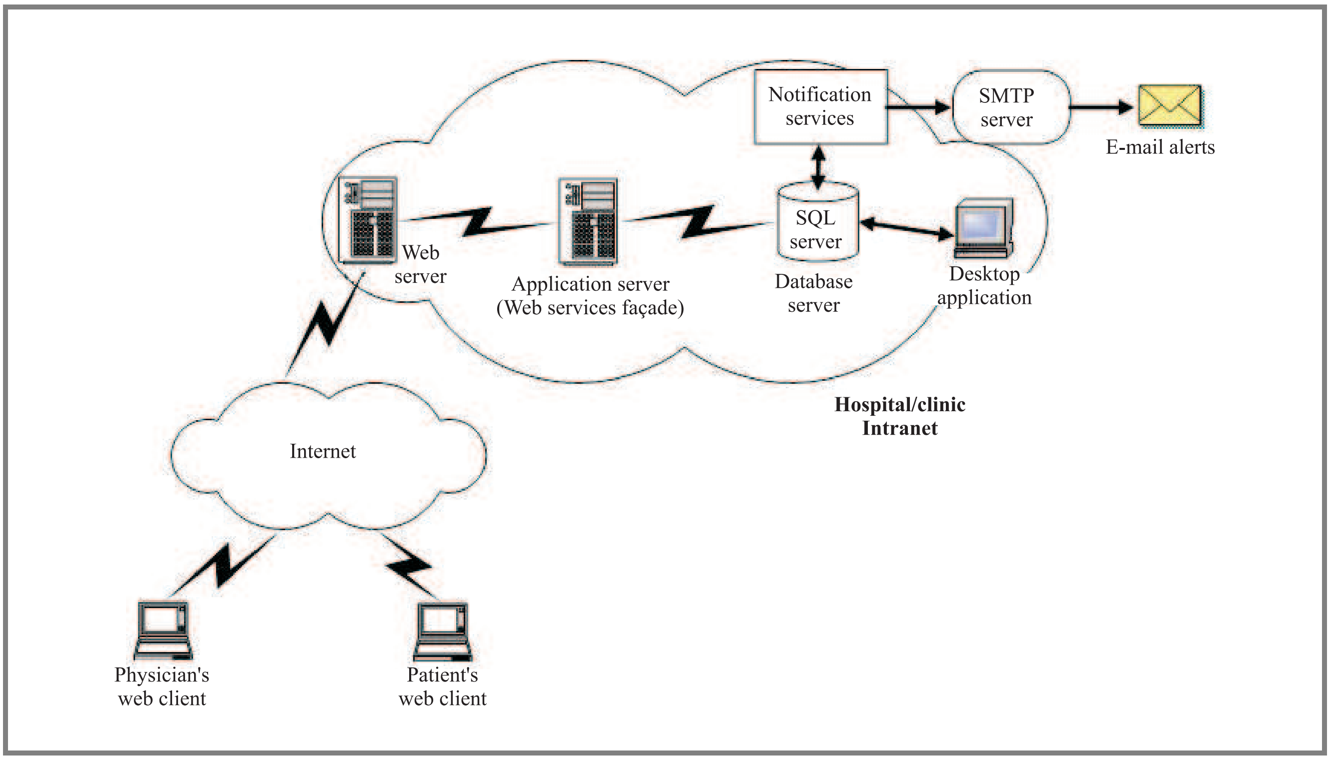

Fig. 1. Overall C-Monitor system architecture.

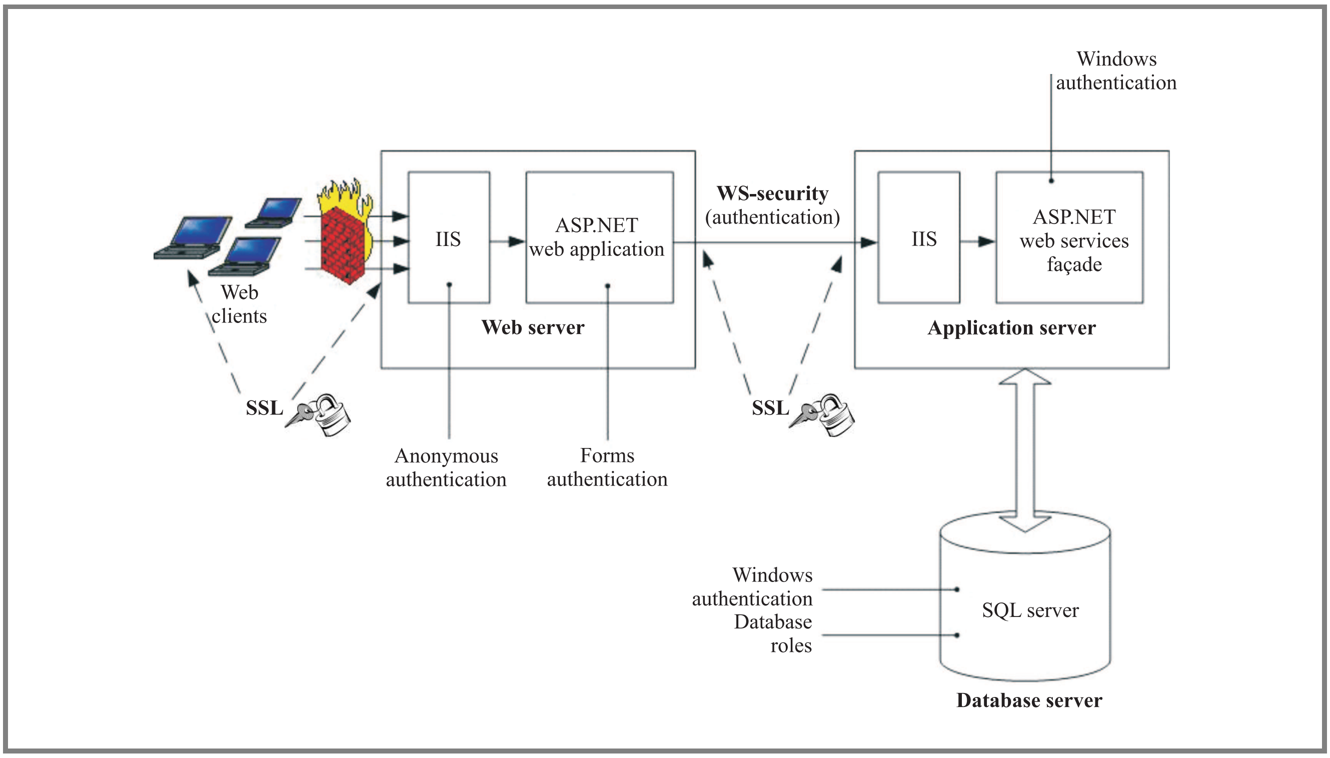

Fig. 2. C-Monitor overall system security.

part, which offers services within the boundaries of the hospital/clinic intranet. The overall system security model is depicted in Fig. 2.

The security model for the Internet part includes the use of secure sockets layer (SSL) for privacy and integrity and forms authentication where users' credentials are forwarded to a web service that authenticates them against a user list stored in the C-Monitor database. The web clients communicate with the C-Monitor web server over a secured SSL connection. Secure sockets layer is a set of cryptographic technologies that provides authentication, confidentiality, and data integrity. The use of server certificates has been chosen for simplicity, as a main objective of the platform is to require minimal configuration and tuning on the client side. For enhanced security the web administrator can use client certificates as well. However, the use of client certificates requires issuing client certificates for each web client and installing them on the client's computers.

The intranet security model includes:

- WS-security to prevent unauthorized users from accessing the web service functionality. WS-security describes enhancements to SOAP messaging to provide quality of protection through message integrity, message confidentiality, and single message authentication. These mechanisms can be used to accommodate a wide variety of security models and encryption technologies. The web service functionality is exposed only to authorized users of the platform because each web service method request must also provide a valid usernametoken, which is authenticated against the C-Monitor database.

- SSL connection between the web and application server. The communication channel between the web and application server can be secured using SSL connection. The configuration steps are already described in the Internet security section. The web service method calls use the HTTPS protocol.

- Windows authentication for the web service façade. The web service's virtual directory is configured for integrated Windows authentication. Web services authenticate the web-based application's process identity.

- Windows authentication for the SQL server connection. The recommended authentication mode for the SQL server database is Windows authentication. Windows authentication is more secure than SQL authentication for the following reasons:

  – credentials are managed for every user and the credentials are not transmitted over the network;

  – embedding user names and passwords in connection strings is avoided;

  – logon security improves through password expiration periods, minimum lengths, and account lockout after multiple invalid logon requests; this mitigates the threat from dictionary attacks.

  However, if the SQL server database is not configured for Windows authentication mode or is protected behind a firewall, the C-Monitor platform offers encryption/decryption for the secure storage of the connection string.

- Secure storage of the SQL connection strings. If desktop applications or the web services façade need to use SQL authentication for the connection with the database server, an encrypted connection string is generated and stored in a "config.xml" file. Each time a connection to the database is initialized the connection string is read and decrypted by the desktop applications or the called web services.

3. System validation results

For a health telematics infrastructure to be applicable extended clinical validation and testing is required. In order to validate the C-Monitor platform, trials were set-up in different European countries including Spain, the UK and Greece. In this paper the system validation results of the Greek pilot are presented. The system has been installed in a private hospital in Athens and the validation scenario dealt with morbid obesity patients. In particular the C-Monitor platform was used to assist medical professionals monitor morbid obesity patients following surgical operation. The C-Monitor platform has been used to assist medical professionals monitoring the following parameters:

– body weight (daily),

– nutrition (daily),

– quantity of urine (daily),

– blood pressure (daily),

– body temperature,

– urine kerones-glucose,

– blood glucose, cholesterol, triglycerides.

The criteria for patient inclusion to the trial were:

– poor operative state after gastric by-pass and laparoscopic adjustable gastric bandage,

– obesity according to BMT criteria (BMI > 29),

– biochemical markers indicative of metabolic syndrome related to obesity,

– high blood pressure,

– patients being computer literate and having internet access at home,

– patients able to manage medical device use at home.

Table 1

Platform validation results

Criterion	Very friendly	Friendly	Somehow friendly	Less friendly	Not friendly
User interface	13.8%	41.4%	34.5%	6.9%	3.4%
Navigation	17.9%	39.3%	28.6%	10.7%	3.6%
	Yes			No	
Access problems	17.2%			82.8%	
	Very easy	Easy	Somehow easy	Less easy	Difficult
Ease of service	10.3%	58.6%	31.1%	0	0
	High	Good	Average	Below average	Poor
Fault tolerance	44.8%	34.5%	20.7%	0	0
	Very easy	Easy	Average	Somehow difficult	Very difficult
Ease on training	4.2%	33.3%	20.8%	29.2%	4.2%
	Very high	High	Medium	Low	Very low
Overall performance	0	60%	40%	0	0

For the purposes of the trial, 30 patients have been recruited. The performance of the platform has been evaluated using structured questionnaires with respect to the following parameters:

- friendliness/operability: measure how well the patients like to use the system and their ability to navigate around the system;
- access control: measure the ability to restrict access to certain sections of data from particular users;
- fault tolerance: measure of bugs existence within the system;
- learning requirements: measure of time required for user training and measure of ease in data entry to the system;
- responsiveness and overall system performance: measure of the overall opinion of users on the system performance both from the technical side and from the clinical side.

Table 1 summarizes the system validation results. From the data provided it is clear that without any doubts the majority of participating users ($> 89\%$) agreed that the platform is easy-to-use and to navigate around the information provided without serious problems in accessing the needed information. Furthermore, users were satisfied with system fault tolerance (around 80% rated it above average) and no major bugs were identified during the validation phase. Overall system performance was rated high (60%) and the remaining 40% as medium, thus indicating the potential benefits of the use of the system. The second part of the validation dealt with assessment of cost-efficiency issues. From the initial validation phase it is apparent that the estimated cost-saving from the use of the system is estimated to be more than 30 € at least in 75% of the cases considered. Furthermore, half of the patients involved in the study expressed their willingness to pay a 10 € fee for using the C-Monitor platform although traditional healthcare services are for free in Greece. Of course, within the framework of the project, validation of the system was only to a limited depth and width, and it is clear that a more detailed cost-efficiency analysis is needed to estimate the economic benefits of using such a system.

4. Conclusions

The increasing development of informatics around the world as well as the recent explosion of the world networking and communication technologies (Internet, mobile communication) could significantly improve quality of care and the health standards leading to a level of health that would permit all individual citizens to participate in a satisfactory manner in every aspect of family, social or financial life. Important attention should be given to the reduction of the inequalities among European countries in order to achieve a common minimum level of health care restricting risks and proving assistance not only at country level but also to the different social or ethnic groups within each member state.

The proposed architecture takes advantage of recent technological advances in computing, networking and mobile wireless telemedicine to provide an integrated platform for patient compliance to therapy with messaging regarding drug plan, examination plan, and actions with respect to treatment in a personalized manner. Further, the system helps patients to be informed and educated on the their medical problem, participate actively, in close collaboration with their health care provider, to their on-going care, and to respond to risk factors through lifestyle changes or other appropriate means. Physicians would be continuously informed about their patient compliance with therapeutic procedures, as well as monitoring their basic risk factors, remotely and off-hours. As far as healthcare providers are concerned, the proposed system leads to cost reduction due to compliance to therapeutic procedures and helps them to create more "personal relation" with the patients. Thus, the proposed platform enhances the effectiveness of health care and improves health standards and in the same time helps the patient to continue some normal and work activities in order to be an "active" citizen. All the above have been indicated by a small-scale controlled clinical trial study implemented in different European countries including Greece. Further and more detailed analysis is needed to better assess the potential clinical and economic benefits of such a system.

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Dimitris Koutsouris – for biography, see this issue, p. 25.

Paper

Cost-effective health services for interactive lifestyle management: the PANACEIA-iTV and the e-Vital concepts

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Abstract—Information technology applications in medicine are rapidly expanding, and new methods and solutions are evolving since they are considered pivotal in the success of preventive medicine. In this paper two different concepts will be presented, the PANACEIA-iTV and the e-Vital concept. PANACEIA-iTV is a home care service provision system based on interactive TV technology and supported by the IST programme of the European Commission. The e-Vital service, supported by the eTEN programme of the European Commission, regards an integrated home care and telemonitoring service chain aimed at large sensitive parts of the European population, the "at-risk" citizens, who are usually patients with a stable medical condition that allow a near normal life but may suddenly deteriorate and put life at risk.

Keywords— telemedicine, telemonitoring, homecare, health information.

1. Introduction

European health care systems are facing a period of unprecedented changes prompted by a confluence of events. From the patients' side, the health care demands are in continuous evolution since the demographics structure is evolving. Europe is the area of the world, which faces the fastest ageing of the population, considerably higher than in the United States. This fact, together with a high prevalence of concurrent chronic disorders is generating an extensive use of health care and social services. The advances in information and communication technologies are foreseen to have substantial impact on health care.

Information technology (IT) applications in medicine are rapidly expanding, and new methods and solutions are evolving since they are considered pivotal in the success of preventive medicine [1]. In the past days, IT applications were mainly applied at the secondary health delivery level, and even at specialised hospital departments. These applications were difficult to use, maintain, and they were quite expensive. Today, due to the fast growing and penetration of the Internet and mobile telephone technology, the IT applications in the health care environment are focused at e-consultation [2] and home care delivery [3] and the use of triage systems [4]. Home care delivery is a very important issue, covering the management of chronic diseases, wellness, education and information delivery on-demand and addressing socially delicate targeted problems such as infertility. Thus, there is a demand for continuous monitoring of basic parameters of the patient, as well as timely delivery of educational material, so as to avoid complications and to prevent the advent of serious diseases. IT-based applications for home care delivery are important media to increase health care quality, increase quality of life and create a better educational platform with carefully designed and customisable patient prompting which in turn is expected to be instrumental in increasing the collaboration degree between the patient and the physician, something which is beneficial to both [5, 6].

New models are being proposed that promote patient's active participation, redefine physician's tasks and enhance nurses' roles. For the first time, the health care sector is becoming a significant driving force in the technology evolution process. In this new scenario, integrated delivery systems based on patient-centred care, supported by an intensive use of information technologies, will facilitate the most efficient use of the existing resources in the health care system.

Several points are very important in the definition of this new health model. First, it must be noted that the different patient's conditions should be treated from a holistic approach, not each one of them separately. Secondly, the patient must be active in the control and treatment of the illness. Thirdly, the co-ordination among the different health actors must be enhanced to ensure a better decision making process.

In this paper two different and at the same time very similar concepts will be presented, the PANACEIA-iTV and the e-Vital concept.

The use of interactive TV for citizen centred health and lifestyle management system is considered by use of the PANACEiA-iTV paradigm. The main concept is to exploit the digital iTV advantages for home care services and for increasing health care quality and safety. The technological innovation of the proposed platform resides in the use of DVB-MHP technology for the development of iTV applications and the communication of the set-top-box (STB) with the monitoring medical microdevices using infrared (IR) communication.

On the other side, the e-Vital project [7] focuses on the implementation and exploitation of a modular and ambulatory secure telemedicine platform, which is using easily wearable vital signs monitoring devices, causing minimal

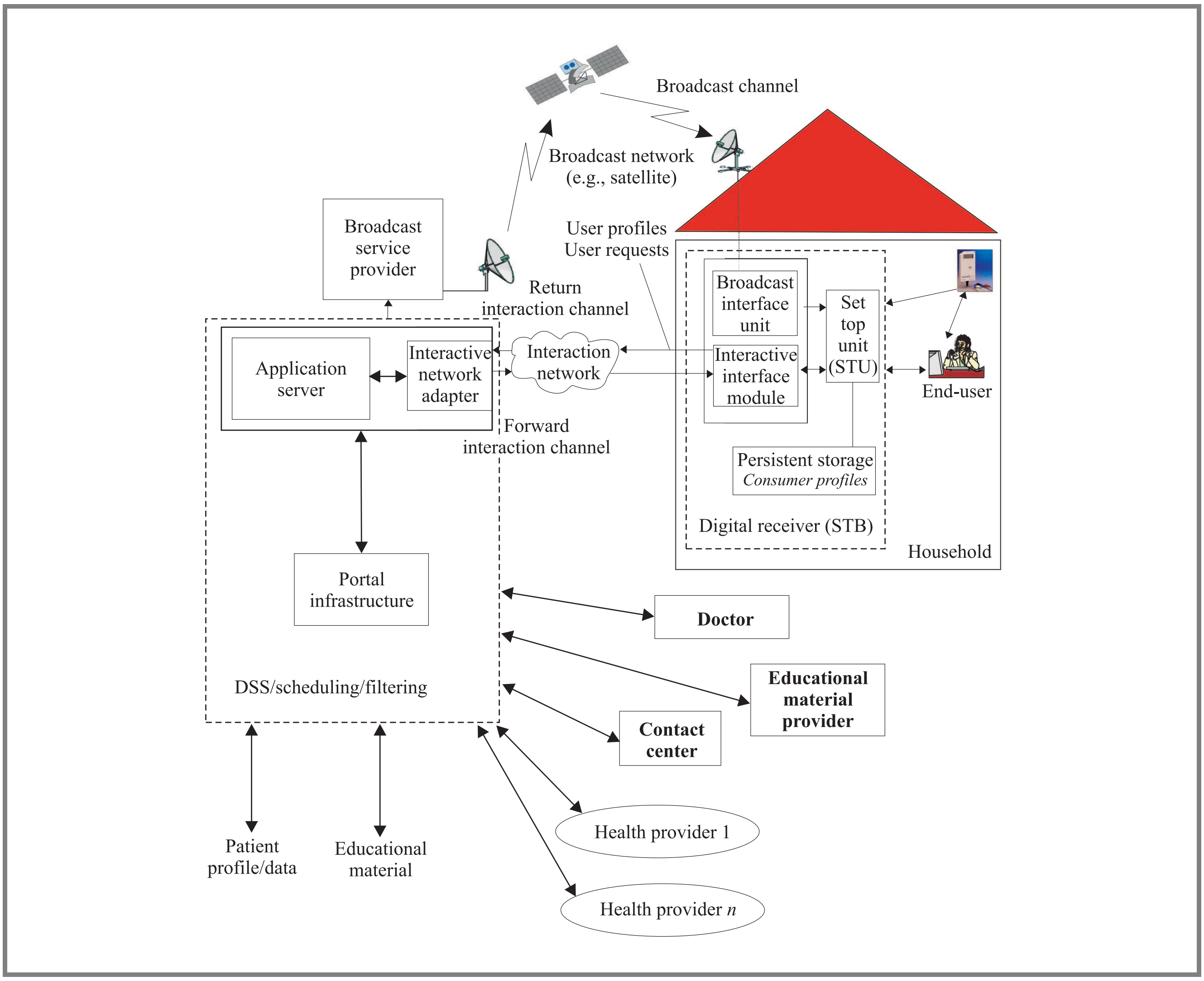

Fig. 1. The PANACEIA-iTV system overview.

discomfort to patients, and which transfer in real time and on-line critical vital parameters to doctors and/or medical experts/consultants, regardless of their location, while getting feedback to increase their feeling of comfort or in case of alarm. It also helps physicians to determine a better care strategy, collecting data previously only available in intensive care units (ICU). The interactive continuous monitoring, as proposed, promises cost effective health services, more active involvement of patients in their own care, and a new sense of realism in making a diagnosis.

The tests and validation tasks of both projects are taking place in a wide geographical area, namely: Greece (PANACEIA, e-Vital), UK (PANACEIA, e-Vital), Spain (e-Vital), Belgium (PANACEIA) and Italy (e-Vital). These countries constitute samples of different cultures and healthcare systems, and this will help to assess the validity of the chosen market approach. The benefits of both services are being assessed both for patients and physicians. Assessment includes reliability, usability, effectiveness, conformance with requirements and specifications, and user acceptance and satisfaction.

2. Methods

2.1. The provided services

2.1.1. The PANACEIA-iTV service

An overview of PANACEIA-iTV system is presented in Fig. 1. The basic communication means used in the current work are satellite TV for the patient and Internet for the clinician. The patient needs a very simple interface that will guide him through the different services provided and will be handled with the remote control. The clinician needs a more sophisticated interface for the monitoring of patients' condition.

At the end users' environment, the patient's interface is managed through the STB, which communicates via an IR link with the medical microdevices. The patient is able to interact with the PANACEIA-iTV service provider receiving educational videos, messages and other patient related info, either over satellite transmission or via the return channel. Patient data, entered with a remote control

unit and by the medical microdevices, are submitted to the PANACEIA-iTV server via the return channel.
The application server of the architecture is mainly responsible for adapting PANACEIA-iTV to the broadcaster's environment and to handle interactive applications.
The portal is the principal access point to the system functionalities for all actors. It provides the interfaces needed by those actors in order to perform their tasks. Web interfaces are provided to the contact center, the clinicians and the educational material providers.
Databases exist for storing patients' profiles and clinical data, educational material related info and also profile info of the rest of the PANACEIA-iTV actors.

2.1.2. The e-Vital service

The e-Vital concept is based on the supply of homecare and telemonitoring. The elements, the integrated homecare and telemonitoring service chain (see Fig. 2) consists of, are the following:

- devices and/or sensors connected to the patient (external hardware),
- service enabling applications at the e-Vital patient module (e-Vital and/or external software),
- service management applications at the e-Vital server module (e-Vital software),
- service facilities and operations (combination of processes/services/personnel),
- technical and organisational support (services),
- organisational models (consultancy).

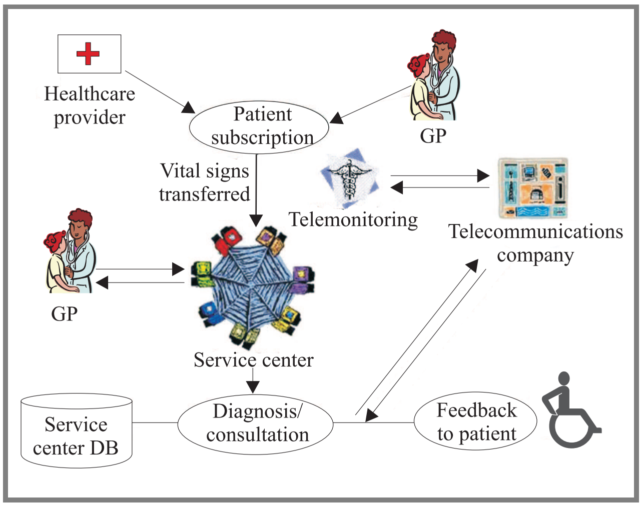

Fig. 2. The e-Vital service chain.

The e-Vital service consists of the following subsystems:

- The patient's module consists of the monitoring devices and the patient's phone. The patient or a nurse, following the care protocol created by the physician, takes the measurements. The data are then sent to the e-Vital server via the phone. In case of emergency and supplemental to the program, measurements can be taken and sent to the server.
- The e-Vital server is the core of the e-Vital service. Here the physician is able to design the personalised care protocol of each patient, to monitor the application of the protocol and the measurements already taken by the patient. In case of emergency, when the measurements are out of limits, an alarm message is generated and is sent to the physician, who in turn is able to inform the patient and rearrange the schedule of the programmed measurements. The e-Vital server collects the data from the monitoring devices, compares the measurements with the given limits and if there is a problem sends the appropriate messages.
- The hospital module consists of the hospital server and the hospital database. The interconnection with the hospital module is used to retrieve patient's medical record, when it is necessary.

Each monitoring device is connected to the phone, which sends the collected data to the e-Vital server. The e-Vital server establishes a communication with the phone, in an emergency or non-emergency situation, and the data are sent to the e-Vital server via GPRS and TCP/IP. The received data are then transformed in an XML file in order to be compatible to the format of the DB and are forwarded to the database centre.
Since the monitoring devices are different due to the various manufactures, the formats of the data files that are sent to the e-Vital server are different from each other. For that reason different applications run in the e-Vital server, to transform the incoming data files to the format compatible to the DB.
Physicians and patients have access to the service from PC, PDAs or mobile phones connected to the Internet.

2.2. Scenarios of use

2.2.1. The PANACEIA-iTV scenario of use

Four different scenarios of use have been defined for PANACEIA-iTV including diabetes II patients (chronic condition), congenital heart disease patients (chronic condition), prenatal group-high risk pregnancy (general population), and infertility couples (sub acute condition).
The users and stakeholders have been defined as following for the system. The users are the citizens/patients, the clinicians and the contact centre personnel. The stakeholders are the technology providers, e.g., broadcaster, medical device manufacturers, educational material providers. In the following, each role is described in more detail.

Citizens/patients. Users who want to manage their own health and/or need specialized healthcare services. Users at home may be either patients or healthy people who use the PANACEIA-iTV services such as data exchange, prompting and querying for communicating with the medical professionals through their TV sets and STBs. An important aspect is that users at home are able to receive educational material in the form of tips, digital videos or interactive hypertext.

Clinicians. Doctors and nurses. The clinicians are responsible for monitoring their patients' condition by checking the transmitted measurements and scheduling the patient's activities and communication protocol via the PANACEIA-iTV system. Using a customized web interface they are able to view the values of the measurements that the patients perform at home, as well as to check whether the patients follow their schedule. Finally, medical staff is responsible for reviewing any educational material submitted for broadcasting.

Contact centre. Provide the communication between the clinicians and the patients/citizens. The main role of the contact centre staff is to administrate the PANACEIA-iTV application and specifically all the patients that are registered with the PANACEIA-iTV service, as well as to register new patients and train them. In addition, the contact centre personnel receives the educational multimedia material from the educational material provider, defines its scheduling and finally delivers it to the broadcaster.

Educational material providers. This entity provides the educational material to the PANACEIA-iTV system. This material is in the form of tips, hypertext/images or videos and it is associated with specific patient groups and group categories. This association is defined by the educational material provider.

Broadcaster. This is the owner of the digital broadcasting platform and its role is to receive the content and the digital TV applications and to broadcast them to the households that are registered with the PANACEIA-iTV service.

Besides the aforementioned functional specifications, there are some general system requirements, including security, multilingual support and possibility for integration with existing systems. The system offers user customization and has event logging capabilities.

2.2.2. The e-Vital scenario of use

Two different scenarios are provided by the e-Vital service.

Routine operation. The first scenario is the programmed one where the measurements are made according to the specific care protocol of the patient. After the completion of the measurements the patient or an accompanying person (nurse, relative of the patient, etc.) is calling the e-Vital server in order to send the data. Then, after a connection is established, the appropriate application runs. The task of this application is to validate if the patient is registered in the system, to identify the type of the monitoring device, which sends the data and to collect the data. This information will be available either in the header of the data message, which will be sent to the e-Vital server or will be sent in an individual message after the establishment of the connection. After that the input data are transformed to an XML file that is compatible to the DB of the database server, and the data are stored in the DB.

In the application server the data are processed and checked if they are out of range. In the DB existing medical information about alarming parameter combinations are stored. It has also access to patients' medical records, which are stored in the hospital module. It then combines these two sources of information with the received patient's data and defined decision flowcharts, it appreciates the patient's condition (excellent, good, average, warning/reason, alarming/reason, or death/reason). If the condition is warning or alarming the notification services will be activated to send an alarm message to the patient, to the physician who attends the patient and to the associated people (that is personal GP, relatives, special requested experts in their respective language) of the patient. These messages maybe SMS or e-mail messages and are also stored in the DB.

Emergency operation. The second scenario concerns the emergency or alarm events. In this scenario in case of emergency, where the patient doesn't feel well, he/she takes some measurements, supplemental to the programmed ones, and sends them to the web server. After the validation and transformation of the data, the web server sends the data to the DB of the service centre, which by turn sends the alarm messages to the physician and to the associated people.

The e-Vital server can communicate with the hospital information system (HIS) of the collaborator clinic. In that case the e-Vital web server is able to ask only for some patient data (mainly the patient medical history) in order to present the data in the physician or patient's web page. The web server does not restore data to the hospital DB. The e-Vital server and HIS communicate through web services, which are located in the web server. The data from the web server are then transferred to the web pages through services centre as an XML file.

The e-Vital can be offered to public health authorities, healthcare providers (hospitals and primary-care units) and physicians.

2.3. System architecture

2.3.1. The PANACEIA-iTV system architecture

The PANACEIA-iTV is a multi-component system (Fig. 3). Much of its innovation lies in the integration of different modules and technologies, which are described in the following section.

The PANACEIA-iTV front-end. Patients' STB receives the broadcasted data (audio/video plus the PANACEIA-iTV application). The STB de-multiplexes the incoming transport stream and sends the audio/video to the decoders

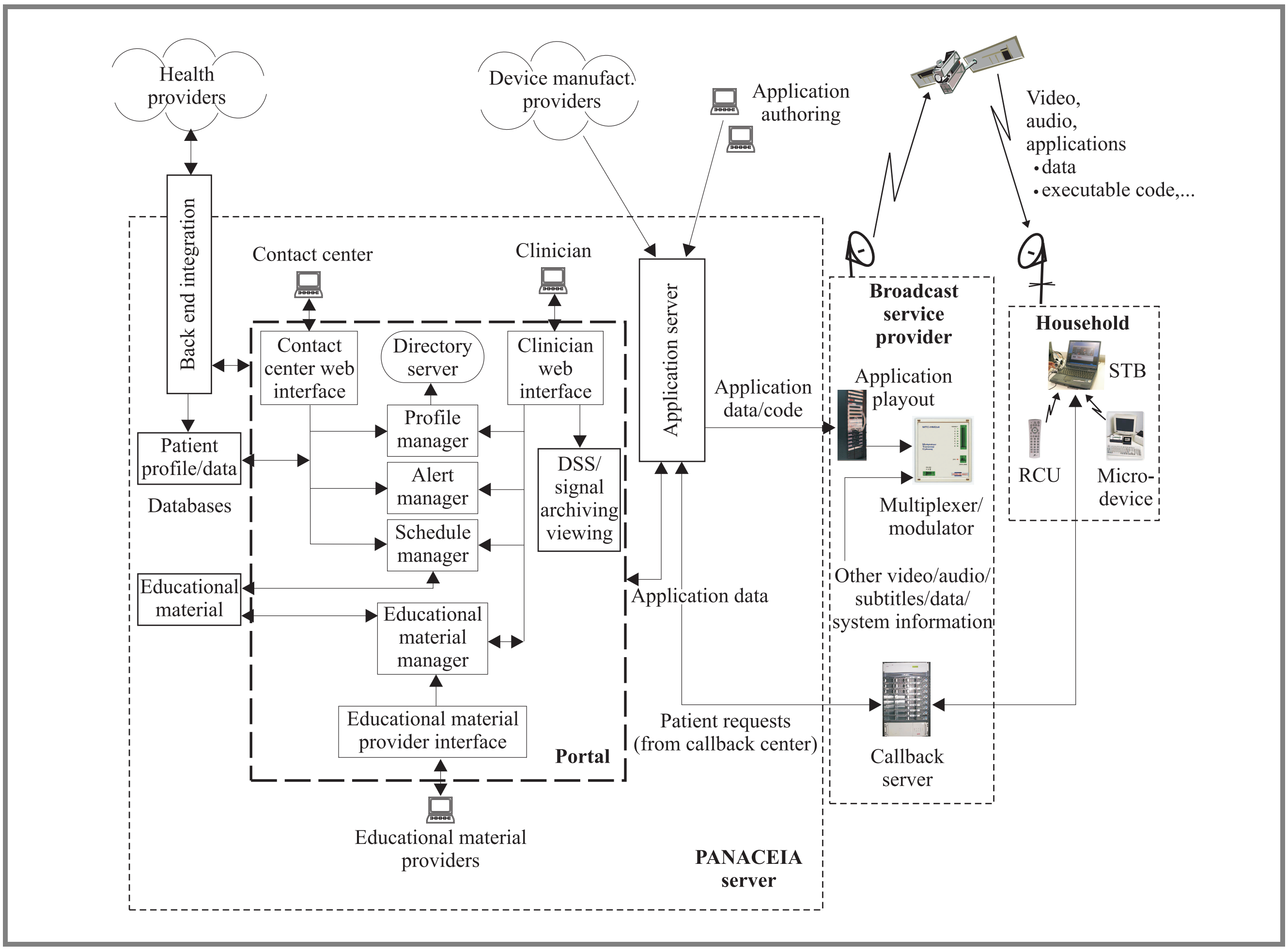

Fig. 3. The PANACEIA-iTV system architecture.

and executes the application according to the user's profile. This scheme allows the user to interact with the application and communicate with the PANACEIA-iTV server (full two-way interaction). Furthermore, it allows IR communication between the STB and the medical microdevices.

The equipment available for the patient is the STB, the microdevices and the remote control. IR communication with the STB is mandatory for signal and vital parameter transmitting microdevices, such as the 12-lead ECG and CTG microdevices.

Broadcaster. The broadcaster owns bandwidth on a broadband network and possesses the infrastructure for broadcasting. This part is assigned the task to schedule events and allocate bandwidth for their transmission. The event's video and audio streams are multiplexed with the PANACEIA-iTV application and broadcasted through a broadband network (like cable, satellite or terrestrial) to the users at home.

The PANACEIA-iTV server. It controls and provides communication links between the different PANACEIA-iTV users. Its basic tasks are:

– to regulate the information and request flow using various purpose software agents;

– to aggregate content and service modules and provide multiple modality access to users;

– to incorporate the potentially distributed databases holding educational material and citizen/patient data and potentially;

– to deliver the same application on different platforms, through the use of different application servers.

Application server. The PANACEIA-iTV application server is the component of the PANACEIA back-end, which is aware of the target platform and the network operator environment. It holds the executables and the data of the target platform and schedules them for delivery to the network operator. It handles HTTP requests coming from the STB (dial-up networking – TCP/IP protocol) related to either data extraction or insertion in the PANACEIA-iTV databases, which are accessed through the portal using XML based schemas. Periodically, it receives content (educational tips, sessions or data) from the portal, converts it to the appropriate format and delivers it to the broadcaster. It checks the delivery status of a particular content to a particular patient, through the return channel. It converts the data into the appropriate format that is understood by the target application (DVB-MHP compliance).

Portal. The portal provides membership management, i.e., the creation and management of users, groups, roles and domains. It also provides integration services allowing deployment of HTML and non HTML applications via the portal. It has mechanisms for reporting/accounting/logging, as well as for handling of all data requests.

Multi-agent system. Additional intelligence and advanced functionalities are provided to the medical personnel by Java-based software agents [8]. Three multi-agent systems are proposed: the alert manager, the schedule manager and the educational material manager. These systems are proposed for the facilitation of patient monitoring.

The alert manager triggers alert messages to the clinicians, when patients' measurements fall beyond predefined limits or their schedule is not followed. Furthermore, it notifies the clinicians for non-scheduled measurement sessions.

The schedule manager controls the frequency of the patient's pre-planned activities (measurements, educational videos, reminders, educational tips). It may provide suggestions to the clinicians by evaluating patient's measurements values.

The educational material manager provides workflow management of the educational content. It notifies the contact center personnel when new educational content is uploaded and automates the selection of educational content.

DSS/signal archiving and processing. Decision support systems (DSS) are interactive computer-based systems that support clinicians in their daily duty and research activities. They provide the means to create and apply complex rules concerning the medical data provided by the patient; helping to identify patients whose data follow specific patterns. Additionally, tools for signal (e.g., ECG) processing and interpretation (denoising, filtering, information extraction) are available.

The signal archiving and processing module includes archiving mechanisms and viewers for ECG and CTG signals.

Databases. The PANACEIA-iTV databases have an expandable and parametric structure. In the patient database, patient's demographic data, medical data and details about the services provided to the patient are stored, while sessions of educational videos, text and short textual tips are stored in the educational material database. The portal resources are used for data exchange between the databases and various applications. The databases and the portal may reside at different platforms using an RDBMS system with network support (Microsoft SQL with ODBC/JDBC drivers).

2.3.2. The e-Vital system architecture

As depicted in Fig. 4, the e-Vital architecture consists of the following modules:

- The patient module, which includes:
  - the monitoring devices, which record, process and send the data at regular time intervals or at alarming situations, when the patient does not feel well, with or without patient intervention;
  - the mobile phone or personal digital assistant (PDA) application; the mobile phone application is software residing into a mobile phone; the application has two basic tasks: to manage the transmission of data to the server and to interact with the service management applications (residing at the e-Vital server) as requested by the protocol; more specifically, after having received the data from the monitoring device, the PDA application converts them to an XML file, compatible with the e-Vital database and connects to the e-Vital server; when the connection is established, the PDA application logs the patient to the server; if the login is successful the application sends the XML file with the measurements and gets the appropriate response from the server; otherwise, an error message is shown on the PDA's monitor; the use of XML technology improves modularity and standardizes the communication between the patient's module and the e-Vital server; the XML document helps to organize the received measurements in a way that is independent of the type of monitoring device and the format of their output;
  - the signal reception and transmission application; this application is necessary when devices communicate only their signals and not to a mobile phone or directly with a server; it also applies in home-based but not mobile monitoring scenarios; the role of the signal reception application is to substitute the specific software implemented by the manufacturer of the monitoring device, which is responsible for its communication with the PDA; the signal reception application is, by all means, device-oriented, and depends on the type of communication supported by the monitoring device; in any case, this application does not interfere to the data transmission to the e-Vital server; it acts as a transparent module.
- The hospital module consists of the hospital server and the hospital database system. The hospital module has been implemented independently to the e-Vital project. It already exists in the hospital or the private clinic that each pilot site cooperates with.

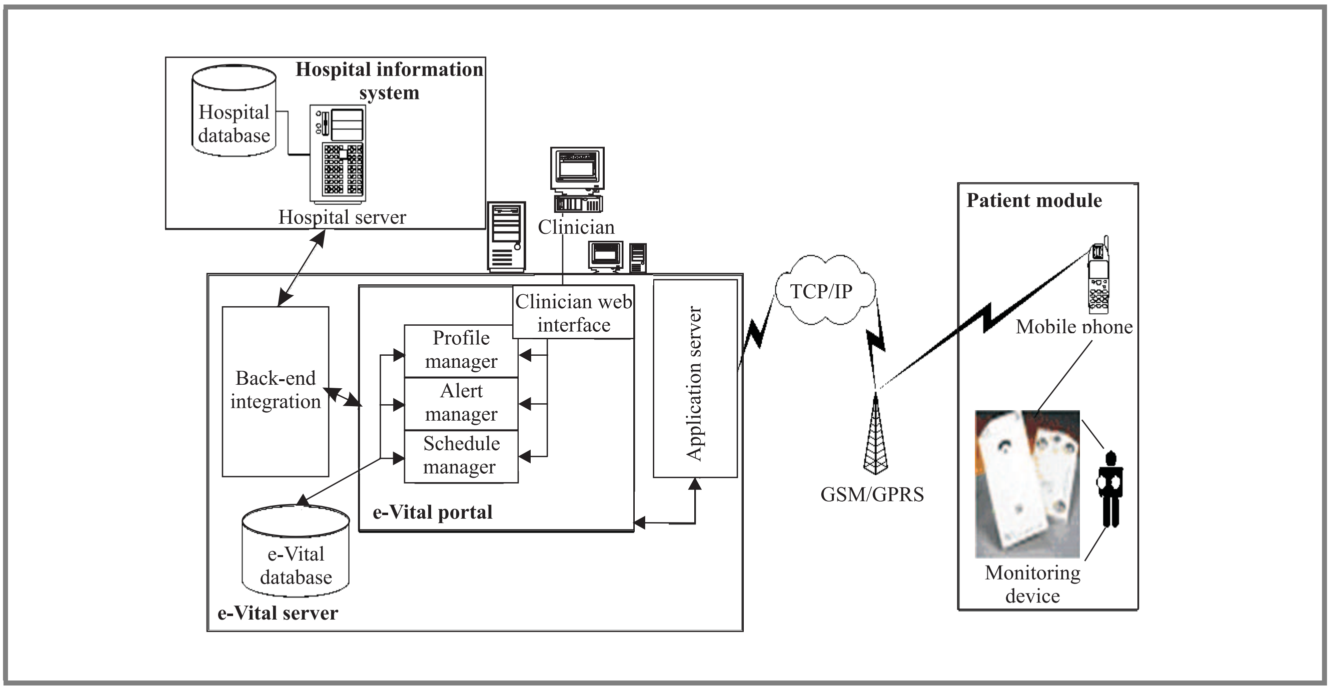

Fig. 4. The e-Vital system architecture.

- The e-Vital server is the core of the e-Vital service and holds the whole functionality of the service. The e-Vital server architecture is based on the PANACEIA-ITV back-end architecture. The e-Vital server consists of:
  - the application server which provides the communication links among the different participants of the e-Vital system (i.e., patient-clinicians), and controls and regulates the data flow among the technical components of the platform;
  - the e-Vital portal which is responsible for the aggregation of content and service modules, for providing multiple modality access to users, for front-end integration for linking to the e-Vital application server and back-end integration;
  - the back-end integration for links to the hospital information system, which access medical records and other data/knowledge repositories;
  - the multi agent system for providing additional intelligence and advanced functionality to the system and guaranteeing a high level of quality of services;
  - the database server which contains information about patients registered with e-Vital service, along with details about the services provided to each patient and the medical data transferred through the system to the contact centre.

3. Discussion

The proposed services provide both the patient population and doctors with complete mobile management of their diseases and a monitoring mechanism and management system that delivers benefits to patients, clinicians and payers. Some of the key features include:

Patient empowering. The services put patients in control of their own healthcare and support them in working with their clinical team. The technology is easy to use, and portable.

Real-time communications. The services will also provide a patient with confidence, knowing that their clinician is reviewing their data and can provide meaningful advice, based on quality data, when it is needed.

Clinical guidelines. The system can help operationalise clinical standards and guidelines so patients are managed in a consistent manner.

Better health outcomes and benefits to patients. Through a strong feedback loop that includes regular reporting, data analysis and clinical intervention, the network provides better compliance to care guidelines. The results are reduced complications, reduced costs, and better data for clinical intervention, research and policy development.

Patient awareness. It has been shown that better patient education and self-management on heart failure and other chronic diseases may increase the mean time to re-admission and decrease the number of days in hospital and the annual health care cost per patient [10].

Financial benefits. A British study indicated that about 15% of home visits could be replaced by telecare because of the absence of hands-on procedures (estimated as high as 45% in the USA) [11]. This implies that the utilisation of the services can significantly reduce the cost of treatment as it is expected that it reduce the number of home visits required for chronically ill patients.

The proposed systems take advantage of recent technological advances in computing, networking and mobile wireless telemedicine to provide an integrated platform for continuous patient monitoring. Further, both systems help patients to be informed about their clinical condition, participate actively, in close collaboration with their health care provider, to their on-going care, and respond to risk factors through lifestyle changes or other appropriate means. Thus, the proposed platforms enhance the effectiveness of health care and improve health standards and in the same time will help patient to continue to some normal and work activities in order to be an "active" citizen.

Acknowledgements

The authors would like to thank the European Commission for the financial support provided to PANACEIA-iTV project (IST-2001-3369) and e-Vital project (C 27979) under the IST and eTEN Programmes respectively. They would also like to thank all the project participants for their significant contribution and fruitful collaboration.

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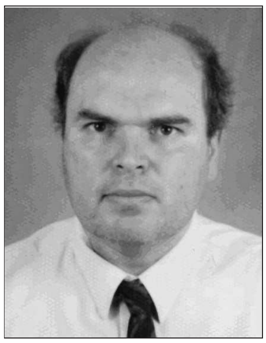

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Andriana Prentza – for biography, see this issue, p. 47.

Pantelis A. Angelidis – for biography, see this issue, p. 4.

Dimitris Koutsouris – for biography, see this issue, p. 25.

Paper

Psychological implications of the application of health state continuous monitoring systems in cardiovascular pathologies

Francesca Ortu and Silvia Andreassi

Abstract— In recent years, specialist literature has particularly focused on the understanding of the modes of psychological adaptation to organic pathologies. A number of close investigations within the fields of medical and health psychology have been devoted to the analysis of situations characterised by a state of chronicity of organic pathology. Relying on the data deriving from such studies, the different authors tend to point out that illnesses represent a threat to the subject's psychophysical and relational integrity, thus constituting as a source of frustration and anxiety. Researchers belonging to different theoretical approaches raise a number of questions as to the role of personality and/or the subjective mode to react to tough, stressful, unexpected, negative situations, such as the emergence of a severe physical illness. Current research approaches essentially intend to explain the individual differences in the reactivity to negative stimuli by analysing the interactions between situational attributes and personality dispositions (for instance, trait anxiety).

Keywords— personality, cognitive style, appraisal, defences, mastery, coping.

1. Introduction

In recent years, specialist literature has particularly focused on the understanding of the modes of psychological adaptation to organic pathologies. A number of close investigations within the fields of medical and health psychology have been devoted to the analysis of situations characterised by a state of chronicity of organic pathology [2, 5, 17, 21, 23, 29]. Relying on the data deriving from such studies, the different authors tend to point out that illnesses represent a threat to the subject's psychophysical and relational integrity, thus constituting as a source of frustration and anxiety. Moreover, it is stressed that somatic illness, though it may potentially induce maturative responses leading to new forms of personal adaptation and balance, and apart from its objective degree of severity, is lived as a hinder preventing the subject from the achievement of the physical, psychological and social well being. Both in the case of acute pathology and chronic pathology, the person is compelled to commit herself to the vital task of the preservation of her own physical and psychological identity. It is also underlined the need to pass from a view entirely centred on illness to a view focused on the ill individual. From this new perspective, it is important to evaluate the outcomes of pathology: not as much in terms of the objective characteristics of the morbid process, as in terms of an array of complex and closely related variables such as the physician-patient relationship, the influence of psychological factors on pharmacological compliance, the impact of the illness on the patient's personality.

The specialist knowledge seems now to address the adaptive tasks which the illness imposes to the subject, forcing her to integrate a new reality, to accept a higher degree of dependence, to create a new organization for her interpersonal relationships, to modify, though only temporarily, her self-image. Hence, it is pointed that illness entails a psychological change beside a somatic one, and that such more or less stable psychological modification is brought about by the activation of specific defence mechanisms.

Researchers belonging to different theoretical approaches raise a number of questions as to the role of personality and/or the subjective mode to react to tough, stressful, unexpected, negative situations, such as the emergence of a severe physical illness. These authors hold that the evaluation of the patient's defensive style provides important indication as to her compliance to the treatment, her response to the physical illness and the possibly ensuing complications. In particular, the problem of the possible complications deriving from a physical illness seems to be very relevant to predict the type of adaptation or maladjustment developed by the patient in response to a chronic illness (such as cardiopathy), an event radically transforming her life, or to the communication of a diagnosis of severe or invalidating or fatal pathology [2, 5].

Researches on the responses of psychological adaptation to pathologies such as AIDS, various forms of cancer, diabetes, or cardiovascular diseases have highlighted how the use of defensive strategies otherwise considered pathological represents a good psychological adjustment to such environmental situation. Denial, generally considered as a low level defensive mechanism, insofar as it prevents a part of experience from having access to consciousness, is to be regarded as a resource and is highly correlated to a better capacity for adaptation in neoplastic pathologies.

The majority of researches, though directly addressing the psychological coping with organic pathologies, do not pay enough attention to the psychological implications of the therapeutic strategies and the medical interventions employed in the treatment of the diverse types and different degrees of pathologies. Literature on the topic ideally places the different medical interventions on a continuum ranging from a highly invasive extreme to a non-invasive one. It also stresses the importance of taking into account the specific defensive strategy employed by the patient. The strategy includes coping not only with the disorders and modifications produced by the organic pathology, but also with the specific conditions and limitations imposed by the kind of treatment administered to the patient. The application of a system of control aiming at the continuous monitoring of the health condition, for instance, will necessarily entail some psychological adjustment. In this case, it is duly to conceive of the source of psychological stress as coming not only form the cardiovascular pathology, but also from the monitor system employed to keep such a kind of pathology under control.

Hence, the element considered as pivotal by the whole scientific literature is represented by the relationship between the coping skills in traumatic and stressful conditions and personality.

Numerous empirical studies support the hypothesis according to which it is the peculiar aspects of personality to exert a major influence on the interpretation of events as traumatic and stressful, rather than neutral or pleasurable.

We shall now present a brief review of the theoretical positions and empirical researches which seem more relevant for the goals of this work.

2. Some definitions

Since the term *personality* is employed with many different hints of meaning, it seems necessary to clarify that in the present work we refer to the definition proposed by the World Healt Organization (1992) describing *personality* as: "*A structured modality of thought, feeling and behaviour which characterises a subject's type of adjustment and lifestyle and which results from constitutional, developmental factors and from social experience*".

Furthermore, we use the definition of personality traits proposed by the Diagnostic Statistic Manual of Mental Disorders (DSMIV) of the American Psychiatric Association. Thus, by *personality traits* we mean:

"*The stable modes of perceiving, relating to and thinking with respect to the environment and the self, which become manifest in a wide spectrum of social and personal contexts*".

The basic assumption relative to the notion of traits is that **people have wide predispositions to react in peculiar ways, which are named traits**. In other words, people can be described in terms of the likelihood they have to behave, feel, think in a particular way; for instance, the likelihood to act in a friendly and demonstrative way or to feel nervous or worried or to think about a project or an artistic idea. Even though they use diverse modes to determine the basic personality traits, the various authors supporting this approach unanimously believe that the traits are the fundamental constituents of personality.

3. Cognitive style and negative events

Current research approaches essentially intend to explain the individual differences in the reactivity to negative stimuli by analysing the interactions between situational attributes and personality dispositions (for instance, trait anxiety).

Starting from the fifties, different authors have begun to stress the importance of the "competence by which each individual explores and attempts to master the environment" [44], and to focus on the subjective perception of one's own capacity to react or respond to the event. In particular, Rotter proposes the notion of **locus of control**, defining it as a more or less generalised system of expectations characterised by the tendency to attribute to the external – which is, to the fate, the chance – or, rather, to the internal – which is, by referring to one's will, responsibility determination – the causality of one'own success [34, 35, 38].

This perspective has gained a position of prominence in the empirical studies aiming at identifying the conditions increasing the probability that an event has a negative impact on the subject's health. These studies lead to consider a series of factors which affect the subject's capacity to develop adequate strategies of coping with the events. The factors include a **giving-up attitude** and a feeling of being abandoned or blamed (**being given up**), all resulting in the subject's feelings of **helplessness** and **hopelessness**.

In particular, within the field of **health psychology**, the dimension of locus of control has appeared to be **strongly associated to the compliance with the treatment** in diverse pathologies, as well as to the **prognosis** of the pathologies themselves. Indeed, the evidence of the researches seem to prove that the more one believes that her own health is determined by her own behaviours, the more one is bound to take care of it.

The importance of the **subject's modality to cope with anxiety** in situations of stress is highlighted by a series of studies focusing on the relationships between personality characteristics and incidence and the course of neoplastic illnesses. These studies evidence that a modality of response which is characterised by helplessness and hopelessness negatively interferes with the person's capacity to effectively cope with the stressful event and is highly correlated to the future relaplse of the illness. A totally opposed style of reaction is characterised by a *fighting spirit*, which, according to some authors, is linked to the biological system of attack.

Moreover, it is pointed out that it is possible to identify those personality dimensions allowing to predict the increase in the emotional reactivity in conditions of stress. Such dimensions or traits seem to influence the baseline of negative emotions even in case of absence of stressful conditions [13].

From a constructivist point of view, Rahe and Arthur [32], for instance, claim that the effects exerted on the subject by various stressful events may be considered as a function of the characteristics of the event, the subjective perception of the event itself (subject's personal history, cognitive style, internal/external locus of control), the defences used to cope with anxiety, the evoked psycho-physiological response, the cognitive and emotional strategies employed by the subject to manage such reactions, as well as her behavioural reactions.

The model proposed by Rahe and Arthur, therefore, allows to link the perception of the stressful event to the effects produced by the event itself on the organism, and stresses the **connection between the subject's affective and cognitive strategies** and **the possible onset of a somatic illness, starting from the way the event is perceived to end with the possible onset of the illness**.

This approach, underlining the importance of **appraisal** (the subjective appreciation of the event) is thus based on the assumption that the perception of an event is an active and constructive process, and the attribution of a positive or negative connotation is the result of a subjective construction. The individual response to a negative and/or stressful stimulus-situation may so be predicted taking into account that:

– the behaviour is function of a process of bijective and continuous interaction between the individual and the environment;

– the individual is an active and intentional agent;

– motivational, affective and cognitive variables are fundamental to determine the way a person will react to a specific situation;

– the psychological meaning which a person attributes to a situation is essential in determining her behaviour.

Regardless of the theories of reference, all empirical works emphasise the personality characteristics with respect to the definition and identification of an event as traumatic. In particular, the hypothesis seems to be maintained which, within certain limits, an event acquires its traumatic/stressful, positive or neutral connotation only within the encounter with the person perceiving it. In this hypothesis a specific reference is made to the subject's psychological, cultural and socio-demographic characteristics. The connotation of the events, thus, seems to substantially depend on the peculiar modality of encounter with the events characterising the subject. Moreover, in this perspective the subject's type of reaction would mainly rely on the individual characteristics more than objective characteristics of the event.

4. The response to stress

Hence, literature underline a strong individual variability with respect to each subject's mode to cope with stressful situations. Such variability concerns not only the specific behavioural reaction to a certain situation or class of traumatic/stressful events, but also the type of processing to which the diverse stimuli referring to such situations are subdued. It is held that these general modalities of response to stressful situations and to internal or external aversive conditions, predict the kind of information processing of the stimuli as well as the attentive strategy employed by a particular subject in a specific situation.

In the past twenty years, studies have intensified which concern the human response to stressful events, with a specific focus on the modes of psychological adjustment to physical illness. The researchers' interest has been progressively shifted from a view of the human being as beset with unpredictable and uncontrollable events to a more adaptive view in which stressful events are regarded as challenges or situations to master through the resort to thought and to the psychological and social instruments available to the individual [6, 28]. From this perspective, in fact, it is possible to identify modes of response of which adaptive value, which is, efficacy, depends on the peculiar interaction between the subject's personality characteristics and the environmental or situational characteristics. In particular, White [45], Holland and Rowland [18] believe that the objective of adaptation can be pursued as well by resorting to automatic responses evoked by situation of threat or safety (**defences**), as using specific capacity to face one's own psychological states and processes as problems to solve (**mastery**), or developing strategic actions and effective behaviours to tackle difficult and unusual situations (**coping**). In particular coping responses are meant:

– to reduce the negative affect;

– to facilitate the return to the baseline functioning;

– to increase the capacity to face and solve the problem [1].

While the responses based on defence mechanisms would, instead, play a double role which can be described as:

– avoiding the load of anxiety or other disrupting emotional responses;

– re-establishing a comfortable level of functioning.

Some authors maintain that coping strategies would be characterised by a hierarchical organization of transversal type and would develop according to a predictable temporal sequence [9, 15, 33, 41]. Reecently, Aspinwall and Taylor have further carried on the analysis of such strategies and individuated a "**proactive coping**", the set of processes apt to detect potential stressful agents and to act on advance to reduce their impact [3].

A further investigation of the notion of coping is proposed by Kobasa who distinguishes between a **regressive coping** and a **transforming coping** [24]. The regressive coping refers to a mode of facing the negative event characterised by the basic denial of one's own responsibility, self-devaluation and devaluation of both the objective and subjective importance of the event, and by the search for narcissistic reinforces reducing the personal capacity to be constructively in charge of the problem. The transforming coping rather refers to a more effective strategy: the problem is evaluated in less global terms, the area of its impact is circumscribed (work, physical health, social and relationship context) and apt behaviours are adopted in order to modify the situation. While **regressive coping**, mainly founded on attempts to shift attention from the problem, does not allow to adequately tackle the situation-problem, the **transforming coping enables the person to implement a series of more effective measures and functional behaviours**. The latter strategy, according to Kabasa, produces an increase in the **hardiness**, which is, it enhances the individual capacity to "resist" the negative events, individuating objectives and priorities. The construct of hardiness has been empirically translated in terms of **commitment**, the capacity to identify the objective and priorities and to trust in the efficacy of one's own actions, **control**, the trust in one's capacity to positively and favourably influence one's own life events, and **challenge**, the capacity to live stressful events as chances for personal development rather than as a threat to one's own security. Such operational definition has led to create specific instruments of evaluation of hardiness (**scales of hardiness**) and paved the way to a series of empirical studies. These works have enabled to prove the existence of a positive correlation between hardiness and the personal state of health. More specifically, the empirical data have highlighted that people with high scores on hardiness scales show a better capacity to use the environmental support for a transforming coping. For instance, in case of onset of a chronic pathology (a condition requiring the active management of the pathology and the therapy on the part of the patient's), subjects with low scores on hardiness scales tend to delegate others to deal with their problems, continuously seek for reassurance and patronizing, tend to reduce their interests and activities and to establish a relationship of dependence with the people taking care of them. The hardiness dimension has proved its buffering effect, specially in those conditions characterised by the presence of numerous and recurring stressors. Hardiness has resulted to be highly correlated to the course of HIV infection, in which the stressor is represented not only by the infection, but also by the kind of treatments which the patient has to undergo, the situation of uncertainty in which she plunges and the necessity to reorganise her lifestyle.

In particular, Solomon *et al.* have evidenced that AIDS patients who are still alive five years after the diagnosis (*long survivors*) show a higher hardiness in comparison with people living for a shorter period of time [39]. Apart from demonstrating the capacity of hardiness to change the individual response to the events, this study, also shows that this kind of patients tend to perceive their social environment as particularly able to provide support and to concretely relieve their life conditions.

Also Horowitz, from a different theoretical perspective, stresses the importance of the modes of reaction to a specific event and proposes to measure them on the basis of a specific scale [19, 20]. This author, more specifically, claims that the **individual modes of response to a traumatic event** can be placed on a continuum ranging within two extremes. The first extreme is characterised by an **avoidant mode** in which there is a costant **effort to avoid thinking of the events and to exclude from the perceptive field anything which may remind of it**, besides counterphobic behaviours. On the other extreme there is an **intrusive mode, consisting of the incapacity to exclude from consciousness the thoughts regarding the unpleasant event**, and the emergence of repetitive behaviours.

Many empirical studies referring to this theoretical model have analysed the relationship between the modes of reaction to the diagnosis of a severe illness and the efficacy of clinical treatments. In particular, Epping-Jordan *et al.* have noted that subjects with high scores of avoidance showed a poorer clinical situation one year after they had been diagnosed with cancer [14].

What appears to be relevant to the purpose of this presentation is the commonly held idea of the importance of the function played by the diverse reactions to the specific situation. In this sense, the different reactions are meant in terms of self-regulatory efforts and it is only their efficacy to determine their adaptive value. As previously noted, behaviours which would be generally regarded as severely pathological immature and maladaptive, can be seen as normal and even appropriate and adaptive in case of the intense stress produced by a physical illness. From this perspective [10]. The diverse strategies of response (coping, defence, mastery) are, therefore, regarded as essentially corresponding to self-regulatory efforts. The possible bad functioning of the process is, then, interpreted as a failure in the mechanism of self-regulation rather than in terms of the activation of more or less pathological mechanisms. Thus, the emphasis is posed on the circular interaction of four elements:

- triggering stimulus or input; such stimulus is represented by any element from the subject's perceptive field and can concern internal subjective states as well as aspects of the external reality;
- value of reference, which is, the subject's term of comparison; it essentially refers to what is to be pursued (attractors and goals) or avoided (repulsors or anti-goals);
- a system matching the input with the value of reference; it is variable in sensitivity;
- output or accomplished behaviour, meaning not only the overt enactments, but also the internal modifications as to the way of thinking and feeling.

The match between the stimulus, meant as the current situation, and the value of reference triggers the conducts aimed at reducing or enhancing the perceived discrepancy, dependent on whether the value of reference exerts an attraction or a repulsion. Objective, therefore, assume a pivotal role in the organization of conducts. They direct and fuel the action, and implicitly or explicitly attribute a meaning to the individual conduct. According to Carver and Scheier, self-regulatory mechanisms tend to interrupt the stream of action and to evaluate the chance of success on the basis of the available information. If expectations are favourable enough, the aptest response should be represented by the intensification of the efforts to pursue the desired objective. In case of unfavourable expectations, a reaction of total or partial disengagement is expected to take place, with the abandoning or retrenchment of the objective. Coping strategies then consist in both the effort to pursue the desired goals, if actually reachable, and in the effort to modify, reduce or substitute them, in case they are out of reach.

Relying on such premises, three categories of coping strategies or adaptive processes are commonly described:

– **coping focused on the problem**: the whole of the attempts made to remove the obstacle or to buffer its impact;

– **coping focused on emotions**: the whole of the attempts made to reduce emotional suffering caused by aversive circumstances, by reconsidering the obstacles or focusing on the emotion itself;

– **avoidance coping**: the whole of the responses aiming at avoiding the awareness of the obstacle (by resorting to an active devaluation of actual impact of the event or to self-distracting fantasies), or blocking any attempt to tackle the problem (for instance, by early abandoning).

The choice between these three classes of adaptive processes varies depending on situations, individual expectations, the more or less optimistic-pessimistic general attitude (Carver and Scheier [9]). The optimist is thought to more frequently use active coping strategies focused on the problem, privileging constructive thought, the acceptation of reality; the pessimist, rather, would privilege the avoidant type of coping.

The failure of the adaptive processes and the ensuing pathological and maladaptive consequences are explained by the authors in terms of:

- **Misregulation**. An inadequate functioning of any of the components of the self-regulatory feedback process. All this leads to actions and feelings to be based on the wrong or irrelevant information, with a consequent more or less massively biased perception of reality [7]. Misregulation in itself does not produce stress, since the subject is unaware of it. The stressful experience is due to the often clearly pathological consequences of the enacted behaviours, for which any responsibility is disavowed.

- **Conflicts between objectives**. The desire to reach more hierarchically equivalent objectives can produce stress, when it is not possible to pursue all of them with the same commitment and success. The strategies enacted to avoid or reduce the conflict is represented by the attempt: a) to alternate between conflicting objectives, which is in itself fatiguing and may convey the sense of acting in a totally inadequate manner; b) to chose between objectives, reorganizing the personal hierarchy of value. The former strategy is substantially successful, although it is more difficult to apply, specially in case of high level goals concerning self-image.

- **Automatic doubts**. It is the residual sense of doubt or inadequacy emerging after repetitive failures in the same area of experience. If the doubt is strong enough, the person experiences the impulse to give up after the first aversive signs, given the negative or frankly "catastrophic" expectations on her own chances of success [42]. An internal more or less paralysing hinder is created which prevents from the moves towards the desired goals.

- **Premature interruption of the effort**. The doubts can induce the retrenchment of the objectives or their complete abandoning. When the sense of inadequacy in a certain area of experience is particularly pervasive, a recurring behaviour of precocious renouncement and distraction to other situations develop, resulting in a difficulty in actually reaching this objective. Sometimes the renouncement is only temporary and partial. In this case it, above all, represents a flee from adversity, based on behaviours of cognitive interference and, also physical, distancing from what is associated to the desired goal [36]. Nonetheless, the subject still invests in the goal which retains its affective importance and relevance. In such cases, a profoundly stressful vicious circle can set up, made of attempts,-doubts-flees.new attempts [8, 10, 31].

- **Incapacity to abandon or substitute goals which cannot be achieved**. As opposed to the previous situation, the subject continues to pursue objectives which are out of her reach, collecting failures and preventing herself from noticing, realising and embracing new opportunities [4, 22].

5. Conclusions

In the light of the previous review of literature, *it results vital to identify some personality dimensions which have proved to be predictive of the person's capacity to use the information referring to a situation of probable subjective risk in an adaptive and effective manner.*

These dimensions refer to both the cognitive style and the coping strategies employed by the subject. The identification of such dimensions will, thus, allow for a *preliminary evaluation of the subjects which may benefit from* a state of health continuous monitoring system.

An initial screening of the subjects is then to be hoped for. The screening should be accomplished by administering a battery of appositively created tests which allow to evaluate and identify the cognitive style (locus of control) and the modalities of coping. It is plausible to hypothesise that it is preferable to orient the choice of the subjects to whom apply such system to the ones characterised by an internal locus of control and by a coping focused on the objective. Moreover, the **setting-up of a system of signalling which increase the likelihood of the subject's effective response**. This system should enhance the likelihood of employment of strategies of adaptation allowing the subject to focus her/his attention on the task (to follow the prescribed controls and the operations) and **decrease the likelihood to resort to strategies focused on emotions or avoidant strategies**. In this context, the latter strategies, even though they enable the subject to deal with the emotional suffering, would turn out as not only scarcely effective but also dangerous. As a consequence, it seems fundamental to employ a communicative style aiming at increasing the subject's **Mastery** and her/his resort to effective coping strategies, focusing her efforts on the problem solving. The subject will have to be informed of about the objectives of the project and the procedures to be followed in case of alert. Particular attention should be paid to carefully explain and to provide detailed information about the value and meaning of the diverse signals of alert and the adequate behaviours and attitude to adopt in the various situations. The patient should be trained to correctly detect the symptomatic indexes.

Moreover, the patient should be offered the possibility to directly contact with the medical and paramedical personnel, in order to receive an adequate guide to the reading of the diverse signals and effective indications for the specific situation.

Particular attention will also have to be paid to the characteristics of the selected monitoring system: it should not be invasive and should not interfere with the subject's capacity of movement and lifestyle. It should thus appear on the background, attracting the subject's attention only when the detected indexes hint for the resort to any kind of intervention.

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Paper

Remote medical education via Internet enhanced services – the REMEDIES platform for distant training

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Abstract—Continuing medical education is considered as a very important aspect in the development of skills of practicing physicians and the introduction of new concepts and developments in health care provision. Studies have shown that conventional CME techniques including self-studying and lecture attending have limited impact on clinical practices. The world wide web provides a very efficient and cost-effective delivery system for conveying anywhere and anytime multimedia information to large user groups. Although there are a number of CME web sites available today, the majority of them are static and text-based thus not offering interactive functionality and multiple content. To exploit modern telematics technologies and within the framework of the Leonardo da Vinci programme, the REMEDIES project developed an interactive web-based distance-training infrastructure. The REMEDIES system incorporates two training modules – a web-based training platform and a teleconference training platform. The system has been validated in terms of technical performance and user functionality in a controlled target group comprising of young medical doctors and medical students in the specific areas of radiology and laparoscopic surgery. The results of the trial have demonstrated the compliance of the system to the defined functional requirements and the potential usefulness to the defined training goals. Trial results have also demonstrated the need of extension of the educational material within the platform especially for the purposes of continuous education.

Keywords— e-learning in health, continuing medical education.

1. Introduction

The professional development of practicing physicians is a lifelong procedure that is based upon opportunities to expand theoretical knowledge and apply newer methodologies and techniques to patient care. Continuing medical education (CME) is one of the elements in this lifelong procedure and has a long history in supporting physicians expand their knowledge. Traditional CME programs include attendance of conference and lectures, participation in training workshops and self-studying. However, these types of conventional CME activities have shown limited impact on clinical practices and healthcare outcomes [1, 2]. On the other side, activities that simulate actual work conditions or implement interaction between trainers and trainees along with actual case data have proved to improve results [3, 4]. In the past years, the developments of telecommunication and informatics technologies have demonstrated their feasibility in supporting and enhancing CME programmes [5–7]. Furthermore, the world wide web has led to the rapid growth of medical information and continuing medical education services. In January 2004, there were more than 270 CME sites with more than 21 000 hours of CME credits offered online [8]. However, a large number of these sites (30%) contain only textual information, 15% contain slides with video, and only 3% are guideline based [8]. In that sense it is clear that in most cases the benefits of web-based CME, especially the benefits arising from the use of computers, are not fully exploited.

To address the issues related to the use of modern telematics technologies applied to medical distance learning, we have introduced the REMEDIES project implemented under the Leonardo da Vinci EU programme (http://europa.eu.int/comm/education/index_en.html). The aim of the REMEDIES project was to design and validate a web-based technical platform for distance training applications within the medical community. Modern Internet technologies and current trends in computer-based training were the basic technical requirements for the system design.

2. System design and integration issues

In the initial project phases a thorough user requirement analysis has been performed to define end-users requirements. To aid the requirement analysis, a structured questionnaire has been designed and distributed to the target group along with interviews to selected key-users. The analysis during the requirements phase revealed the necessity of an easy-to-use interface, in order to comply with the needs of users that may not be familiar with computer. Other conclusions from the requirement analysis included:

- reducing health and safety risks;
- easy, comprehensive user interface for the e-learning platform;
- ability to use the system in each individual's workplace;
- tools for evaluation and supervision of students;
- high quality video capabilities especially for the on-line surgery scenario.

Based on the results of the requirement analysis the specifications of the system were subsequently defined and the system architecture was defined. The REMEDIES system design requirements incorporate two main training modules: a web-based platform and a interactive teleconference platform.

In the following sections the components of the REMEDIES platform are presented in details.

2.1. A web-based training platform design

The web-based e-learning environment was built using the Lotus Learning Space 5 (LLS5) [9] software as the core-developing environment. Figure 1 depicts a schematic overview of the e-learning platform.

The LLS5 is the core e-learning platform. LLS5 consists of two major interfaces, the administration interface and the student interface. LLS5 utilizes a Microsoft SQL server (MSSQL) database in order to keep all the essential information for the courses and the Internet information services (IIS) platform to publish the LLS5 interfaces to the Internet. LLS5 handles any available web-based material like for example HTML pages, multimedia content, etc. It has a built-in course constructor where every detail about a course can be adjusted to the teachers needs. To serve platform consistency and contingency, courses physical data are kept separately to the hard disk under the IIS publish directory.

The IIS is a Microsoft Windows service that broadcasts the LLS5 interface to the Internet and can be customized to meet every technical and security requirement. IIS retrieves the lesson outline from the MSSQL via ODBC (FILEDSN) and publishes the corresponding web pages from the hard disk. Additionally, to enable video web streaming, Microsoft Windows media services were employed and the appropriate parameters were configured.

The MSSQL server is the database used by LLS5. It contains every lesson detail including courses descriptions, metadata for the courses and user information and of course link to the "virtual path" of the IIS, which in turn links to the material (web pages, video, sound, etc.) located at the hard disk. The LLS5 is capable of monitoring every lesson activity, such as students' participation, grades received during examinations, etc. Furthermore, the MSSQL server interface provides with backup capabilities to archive all handled information.

The hard disk is the physical part of platform. It contains every web page, designed as lesson, announcement, etc. It is being used by IIS to access training material. It contains the HTML pages, courses, multimedia content and video with metadata files. The material has to be sent to the hard disk before the creation of a lesson and the organization of the hard disk data is responsibility of the system's administrator.

The administrator interface provides an intuitive web based platform to create and manage courses and access student information. In order for a course to be completed, the physical creation of the lesson to the hard disk is required and the correct set of all necessary parameters (such as "virtual paths") should be established.

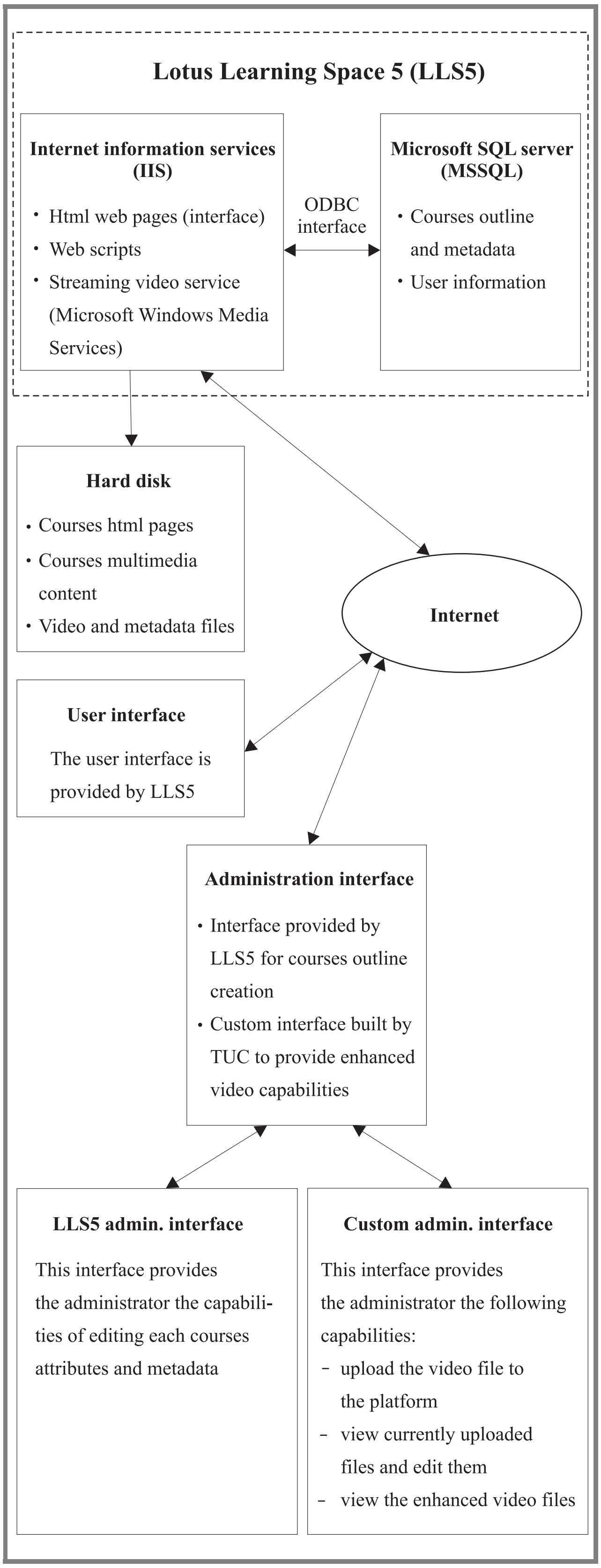

Fig. 1. E-learning platform system architecture.

The custom administration interface provides the platform with video editing and playing capabilities. It consists of three main parts: the enhanced-video program player, the enhanced-video program editor and the web-based enhanced-video interface.

The user interface is a web-based interface that handles all user activities. This interface can access all course material available from the server. In order to access lesson information the user must be an enrolled user. All user activities are being kept to MSSQL and are available to the trainer.

Finally, the Internet is the medium by which all these can be made available to the public and implements the virtual classroom.

2.2. Interactive teleconference platform – components and configuration

The second main component of the REMEDIES training system is the interactive teleconference training platform. This system utilizes Microsoft media encoder and Microsoft media services software for capturing, encoding and broadcasting video signals. In order for the audience under training to receive a better conception of the procedure being presented, both the medical video sequences (e.g., laparoscope video signal) and the operating room video image (showing the participants in the operation) are being captured with the use of appropriate grabbers. After capturing and encoding, both videos are transmitted to a multicast streaming video server responsible for broadcasting. End users are able to connect through local area network (LAN)

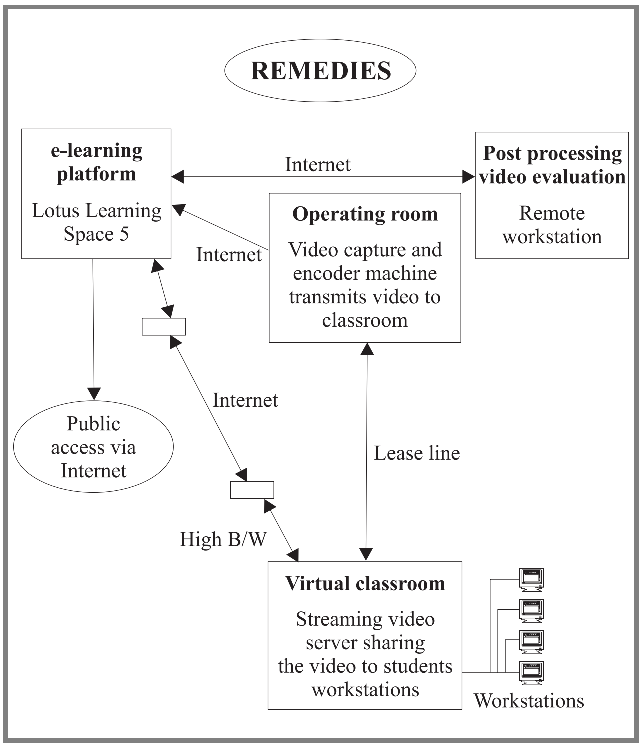

Fig. 2. Teleconference platform design.

at given URL using media player software and watch an endoscopic operation in real time. Additionally all videos are stored in order to be also accessible at a later time on the REMEDIES e-learning platform.

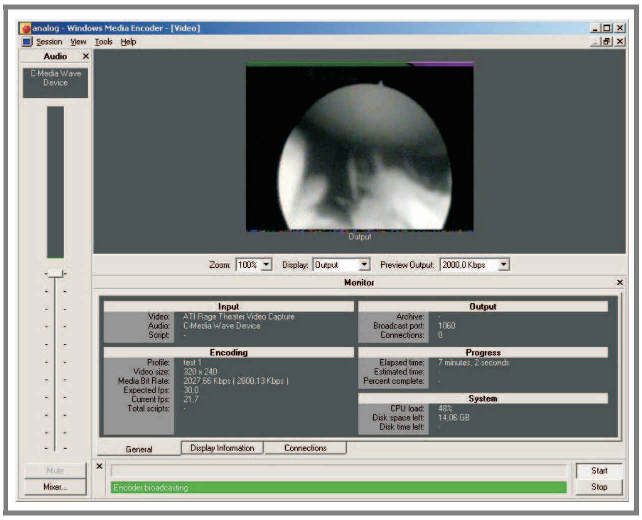

Fig. 3. Video captured from the endoscope and broadcasted.

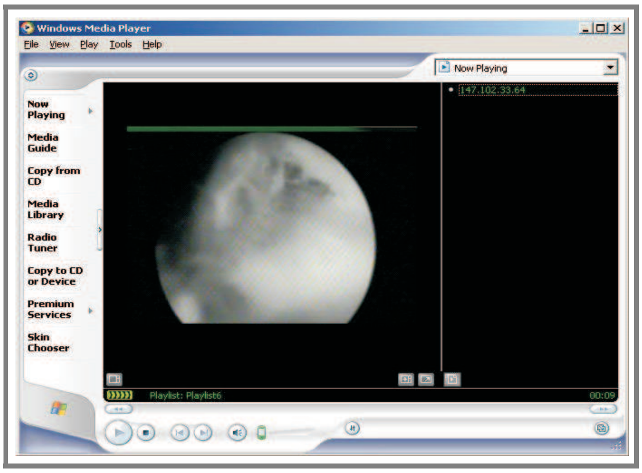

Fig. 4. The end user's view of the video signal.

Figure 2 depicts the design of the videoconference platform including the operating room and the virtual classroom. Figure 3 presents real-time encoding and broadcasting of the endoscope's video signal whereas Fig. 4 illustrates the end-user's view.

3. Pilot set-up and demonstration

The pilot demonstration of the REMEDIES training system was performed at the premises of National Technical University of Athens (NTUA), demonstrating the e-learning platform functionality and a real-time transmission of an endoscopic operation performed at ARETEION hospital in Athens through the interactive teleconference platform.

The whole system functionality was demonstrated during the pilot in order to test and evaluate the application under real operating conditions. The system was presented to an audience of both technical and medical oriented staff, and the evaluation was made mainly through questionnaires completed by them at the end of the procedure. A second evaluation procedure was performed over the Internet, involving users of the e-learning training platform that were also supplied with the videos captured during the real-time teleconference.

3.1. Web-based training platform

Following the design and development of the REMEDIES platform, a controlled system validation and demonstration phase has been performed. The web-based training platform has been established and hosted at the following URL: http://morfeas.systems.tuc.gr. In terms of content and for the purposes of the pilot demonstration phase, the application was populated with the following training courses:

- **HDR brachytherapy as a monotherapy for prostate cancer**. The course provides an overview of essential information on prostate cancer pathology and a number of relative links in which the trainee can search for more information. A presentation describing an HDR brachytherapy treatment is also provided, consisting of diagnostic images and implementation procedures.

- **Traumatic dislocation of the patella and osteochondral fractures of the knee**. The course provides basic information related to the traumatic dislocation of the patella accompanied by diagnostic images and 3 videos presenting the procedure of arthroscopic removal of the osteochondral fractures of the knee.

- **Endoscopy of the pancreaticobiliary tree**. The course provides the basics of endoscopic retrograde cholangiopancreatography (ERCP), a video presenting an ERCP operation and a video presenting a laparoscopic cholecystectomy operation.

Online courses can be easily updated with more information (images, videos) or modified by the trainer providing the course material. The need for platform updating and enrichment with new content (especially videos) was successfully addressed by the development of the REMEDIES administration interface. This software, accompanied by the corresponding administration interface manual, provides the trainer with the capability to easily upload new videos and respective explanatory information on the platform. Apart from this, the available courses can be easily managed and maintained through the dedicated user friendly and easy to use software.

3.2. Interactive teleconference platform

Initially the teleconference platform was successfully tested on a local area network environment with a pre-recorded video from an endoscope. The test has revealed the system potentials and minor modifications dealing with system operation were implemented. After the successful implementation and operation of the videoconferencing platform on a LAN environment, successive tests were performed at the ARETEION hospital, using real time video from the endoscope and the digital camera to record images during the operation. A computer was installed in the operating room and connected to both the digital camera and the endoscope/laparoscope's output. The digital camera was placed on a tripod near the operating table, ensuring stability and specific angle of view. This camera recorded and transmitted real time video and audio from the operating room environment. The endoscope's video signal was also simultaneously transmitted. All video and audio signals were encoded and broadcasted by the computer. Videos captured were also saved on hard disk in order to be accessed at a later time.

The operating room and the hospital's network infrastructure were thoroughly analyzed during the initial trial phases. The operating room could provide a fiber optic and an UDP connection but due to the limited financial resources available by the project, UDP connection has been used. In parallel to network connection testing, successive tests were performed in the operating room to define the optimum configuration parameters. Tests resulted in a reliable video grabbing encoding and broadcasting procedure of the laparoscope signal and the digital camera signal. Both videos were successfully broadcasted from the PC in the operating room and accessed via Internet by registered users with the use of media player. The main difficulty encountered in the testing phase was that access procedures to the operating rooms were very complicated and slow because the operations' daily program was not known until the night before the operation. Furthermore, hygiene rules that should be ritually followed imposed some additional problems.

For the pilot demonstration, a gastrointestinal endoscopy procedure was selected. A gastrointestinal endoscopy is the visual examination of esophagus, stomach and first part of the intestine using a fiber optic instrument. In some cases tissue may be taken for further tests. The REMEDIES videoconference platform was placed in the endoscopy room of ARETEION and configured to capture the video signal of the endoscope and the video of the camera recording the room environment and the actions of the doctor performing the endoscopic procedure.

The endoscopic procedure (gastroscopy) demonstrated was covered by the two video signals, one coming from the digital camera mounted on the tripod and capturing the operating room environment and the procedures and actions of the doctor and the second was the signal from the endoscope itself, showing the same view as the one appearing on the doctor's monitor. The doctor was also describing the procedures he was performing and what the endoscope was showing, providing attendees with audio information as well.

After the end of the endoscopic operation, the attendees were requested to access the REMEDIES web-based e-learning platform and the courses included in that. Besides familiarizing themselves with the navigation tools and options they downloaded images and videos relevant to cases studied. At the end of the training session, each attendee was required to complete the evaluation questionnaire.

In order to collect feedback from more people, both videos transmitted during the live videoconference were encoded and stored in order to be sent at a later time through Internet. In this way, the exact videoconference procedure (apart from the real-time parameter) was presented to a wider public to evaluate it together with the web-based platform and provide us with feedback. Evaluation feedback was mainly collected through the questionnaire that was delivered to the attendees during the pilot and via e-mail afterwards. The questionnaire was also available in the e-learning platform itself, to collect feedback from web-users as well.

4. Pilot evaluation results

Evaluation feedback was mainly collected through the questionnaires that were completed by the attendees during the pilot phase. The questionnaire was also available in the e-learning platform itself, to collect feedback from web-users as well. The questionnaire comprised of two parts, the first including questions to evaluate the REMEDIES training system in terms of functionality and the second in terms of medical content. During the pilot demonstration 36 questionnaires were collected from the attendants. Another 80 questionnaires have been completed during the second evaluation procedure that took place over the web. A total of 116 questionnaires were gathered, which is considered an adequate number to ensure evaluation results statistics. Table 1 consolidates the results of the pilot study.

The analysis of the above-presented results demonstrates that the majority of participants have evaluated very positively the technical and usability characteristics of the system. In particular both the user interface and the navigation and content handling issues were given positive responses by more than 97% of the participants. This is very important given the fact that a significant percent of users (29%) were not familiar to computer based training tools and had small or no computer use experience. These results have been extremely important since the main aspect of our work has been focusing on the system functionality and the technical constraints imposed.

Regarding the medical content evaluation, results were not as high as in the previous section. Actually 58% of users evaluated medical content as being average or below average whereas 42% considered as good or above. The reason for this is that users were of different academic level some of them being trained physicians and some being students. Therefore their educational needs differ significantly and these evaluations were also different.

Table 1

Results of the pilot evaluation phase

General questions	
Trainee sex distribution	71% male 29% female
Use of computers	42% once a day 58% once a week
Familiarity to electronic training tools	42% very familiar 29% somewhat familiar 29% not familiar
Access to web	41% work 33% home 26% school
Usability features	
User interface	29% excellent 68% very good 1%good 1% average 1% poor
Ease in navigation and content handling	4% excellent 89% very good 4% good 3% poor
Medical content	
Content quality	19% excellent 23% good 30% average 28% poor

Although the main efforts of the project were along the technical development issues, the results of the evaluation with respect to the content indicate the importance of the material implemented within the platform. It is conceivable however, that in order for the system to be used routinely, the content should be significantly advanced both quantitatively and qualitatively in order to serve the needs of life-long training of medical professionals in their everyday clinical practice. For this, we are currently in collaboration with medical scientific bodies and organizations to collect and populate the system with extensive educational material appropriately selected for the needs of users currently being medical students and trained physicians undergoing CME.

5. Conclusions

Within the framework of the REMEDIES project we have designed and developed an interactive web-based distance-training infrastructure. The REMEDIES system incorporates two training modules: a web-based training platform and an interactive teleconference distance-training platform. The system has been validated in terms of technical performance and user functionality in a controlled target group comprising of young medical doctors and medical students in the specific areas of radiology and laparoscopic surgery. The results of the trial have demonstrated the compliance of the system to the defined functional requirements and the potential usefulness to the defined training goals. Trial results have also demonstrated the need of extension of the educational material within the platform especially for the purposes of continuous education.

In conclusion, while preliminary user testing has shown highly positive results, a formal evaluation study is necessary to determine the educational validity of the proposed technologies. For this the preparation of a large database of educational material is required. This is a planned activity that will be performed in collaboration with the Athens University Medical School as well as other medical scientific bodies. Next phase of the project is to design and implement a controlled evaluation of the CME platform in specific medical cases where cost-effectiveness, clinical practice transformations and healthcare outcomes will be assessed.

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Paper

Information and e-learning services for the efficient management of allergy and asthma, employing an integrated environment monitoring network

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Abstract—In this paper we present a distributed telematic platform which is implemented to support health information management and innovative services to people suffering from allergies, asthma and rhinitis. The developed system establishes a trans-European information network offering specialized services to health professionals, patients and the public, by collecting, processing and distributing specialized data and informational content. An integrated monitoring and reporting system of aero-allergens is used to collect Pan-European environmental data and produce allergy maps, forecasting and danger level alerts. Informational content and e-learning resources are also consolidated and combined with personalized health management services. Through the created network, health information is supplied to sufferers via WWW and SMS technologies, and informational and learning resources are offered to health professionals. Sets of services were implemented in pilot form and offered to real users for testing purposes. The results were encouraging towards expansion to fully blown service at a Pan-European level.

Keywords*— *telematic services, environment monitoring, health information, teleeducation.

1. Introduction

The European citizen is nowadays more concerned about his health and he wishes to participate actively in dealing with his health problems. In the era of information, the patients want to know more about their diseases and problems, possible precautions and evolutions in medicine, and they are willing to make use of any type of support to improve the quality of their life. Professionals as well, need to have reliable information in order to help their patients and also the ability to use technology as a tool of quality service provision.

One of the most common distressing and life threatening conditions that impact inimically on the quality of peoples' lives, is allergy and asthma which – with all its complications – have influence not only to the sufferers but also to their families. It affects hundreds of thousands of European citizens with an impact on economic indices. The EU geographical area is characterized by different environmental conditions that affect the health of citizens and generate a wide range of epidemiological and allergiological diseases. There is obviously a necessity to study, analyse, organize electronically and disseminate the information related to the environmental factors, which have impact on health. There is also a strong demand for health information both from citizens and health professionals. Sufferers need and request information in order to increase their knowledge, to improve health, prevent disease and support their own decision-making. Health professionals are seeking resources of specialized information and continuous medical education.

Nowadays, the evolution of the Internet and mobile technology provides the appropriate technological infrastructure for spreading the above information in the user groups, while it facilitates the information flow between hospital and health centres. Furthermore, it enables the web-based education and training, which can be easily accessed by citizens and professionals.

In this paper, an integrated system is presented for the provision of environmental monitoring and management of allergies, asthma and rhinitis in a Pan-European perspective. The system establishes an electronic workspace and offers specialized services to health professionals, and sufferers, by collecting, processing and distributing specialized information. The related work was done within the project "Integration of Regional Environment Monitoring and Management for Asthma (IREMMA)", which is partly funded by the EU eTen program. The proposed system provides telematic services to health professionals and sufferers to support disease management, prevention and education. The services include live information about environmental conditions (aeroallergen measurements, alerts), support for disease management (self-management tool, e-learning), information (library, news) and training (continuous medical education sessions). The IREMMA system supplements the existing information networks on allergy by offering high data integration, multi-modal access and personalized information and disease management tools. The system aims at Pan-European coverage by integrating existing information networks and establishing additional data acquisition points. In this way, it sets the ground for establishing a wide integrated network for environmental monitoring and diffusion of health information.

2. The IREMMA approach

2.1. Objectives and technologies

The starting point of IREMMA is to offer innovative telematic information services on allergiological issues in order to improve prevention and public awareness, to improve the quality of healthcare, to reduce hospitalization costs and to offer specialized knowledge to citizens and health professionals. The services are designed and built according to a business-oriented approach in order to achieve financial viability and efforts towards standardization will improve the prospects for wide acceptance and dominance in the field.

The IREMMA uses the latest information and communication technologies. An integrated web-based environment offers friendly access from mobile and fixed locations to integrated information on allergiological diseases and in particular asthma and rhinitis. Internet-based communications are preferred in order to ensure universal user access and high expandability of the services. The mobile phone is also used as highly available medium.

In order to support the above services, IREMMA is building a Pan-European information network on allergies and allergy-related conditions. This network comprises data collection points, either pre-existing or created, that may be located and operated at a national/local level. In other words, IREMMA provides the means for interconnecting national sources of information, such as pollen measurement stations, weather report agencies, medical experts, etc., and integrating the collected information. In this way, information from various sources is concentrated in a standard format, is processed and normalized and then redistributed to users with central control. Additionally, provision is made to expand the network with additional nodes and to create data collection sites where they do not exist.

Important elements of technical feasibility which were investigated are:

- the connection with databases of historical data on aero-allergen measurements;
- the connection with existing agencies providing live aero-allergen measurement data;
- the installation, operation and connection of new pollen measurement stations;
- the importing of weather forecast data and producing pollen level forecasting;
- the coding and normalization of pollen measurements in a standardized way within Europe.

The IREMMA technical approach is based on the following principles:

- Internet-based communications are used both for the exchange of data among the system nodes and for user access;
- multiple access devices are offered, including web (through PC or public access locations), mobile phone (SMS) and PDAs;
- flexible, modular and expandable design ensures that the system is able to support updated services, new technologies and expansion to additional target groups and application sets;
- mature and reliable technologies are used to reduce risk and time to market;
- business oriented issues are taken into account in all technical decisions (e.g., cost, support, dependencies);
- efforts towards standardization will improve the prospects for wide acceptance.

Three different levels of service provision were identified, each one being targeted to a different end user group, namely general information services, services to patients and services to health professionals. A web-based user environment, in combination with an access control component, gives access to individual user interfaces for each user group. The specific functionality offered by the system has been defined according to the needs of the specific user group. Differences also exist in the informational content, presentation of data and level of information depth.

2.2. The services

Based on the results of the user requirements phase, the market investigation tasks and the feedback received from user trials, IREMMA concluded to a specific set of services. The services offered by IREMMA through the developed platform are addressed to both people suffering from allergies and to health professionals (e.g., allergologists, GRs), as well as travellers, so that IREMMA becomes a common reference point on allergies, rhinitis and asthma.

A set of services in the IREMMA site is directly accessible without registration. They are common for all, that is every site visitor, including sufferers, professionals, travellers and potential users can access the IREMMA web-page and get general information about the dominated environmental conditions concerning asthma and allergies. These are valuable services, such as pollen levels for any location, forecasts, information library, links, etc., which are however not personal and are offered free of charge to any user in order to attract his interest about the site.

However, if someone wants to access personalized and more specialized services, he has to register himself and get a personal account. There are different personalized

services depending on the profile of the user. As regards the health professionals, they can access e-learning material, teleeducation sessions that are eligible for CME credits and participate in discussion lists. Additionally, sufferers can receive SMS alerts about increase pollen levels in the atmosphere, view their personal allergy map, download informational material, change their profile and plan their travels according to the allergy information they get.
In the following, all the services offered by the IREMMA platform are presented in more detail.

2.2.1. Public services

Allergy maps. The use of IREMMA Pan-European pollen trap network data from the IREMMA web site provides mapping of allergens concentration in each European country. Following collection of data from pollen traps across Europe, aero-allergen data from each country are stored. Collection of historical data, according to the area and the season, is used for forecasting purposes. The user, through a web-based application has the ability to search for all or a specific allergen existing in a geographical area.
The service provides pollen measurements for selected aeroallergens and for selected location and time. The result can refer to the latest actual measurements, the prediction for next week or to a specific date around the year. In the latest case, estimation based on statistical data is used. A high-medium-low indication per aeroallergen is displayed and in the case of actual measurements, also the precise pollen count is available. It is also possible to display the yearly distribution of aeroallergens for a specific location, according to statistical data.

Information library. The purpose of IREMMA information library is to provide to each user, Internet based information on allergies and asthma on demand like:

- reference medical information in the form of a medical encyclopedia;
- new advancements/developments in rhinitis and asthma;
- description of most common allergens;
- list of precautions and useful tips for sufferers;
- specialized medical centres across Europe;
- information on medicinal products in collaboration with pharmaceutical companies.

Latest news. The user can access scientific news on allergies, rhinitis and asthma in the form of short articles that are updated on a daily basis.

Frequently asked questions. The frequently asked questions (FAQ) screen displays a set of questions and their corresponding answers. It is accessible by all users and intended as a basic reference of information. It is frequently updated as new questions and information arise.

Useful links. A set of frequently updated links to relevant sites is offered, such as allergiological societies and organisations, medical sites, pharmaceutical companies, health organizations, etc.

2.2.2. Services to patients/sufferers

SMS and e-mail alerts. The user (sufferer) can receive SMS or e-mail alerts when increased pollen levels are expected in the atmosphere. He defines the corresponding preferences in his profile, including allergens of interest, e-mail address, mobile phone, location, etc. The user can also activate or deactivate the alarms and he is able to view the messages he has received and the corresponding charging.

Personal allergy map. The personal allergy map service provides the user with aeroallergen levels for the area where he lives, as selected in his profile. Only the allergens, which the user has selected in this allergy profile are displayed. The displayed data can be the latest live measurement or the forecast for next week. In the displayed report a list is provided with aeroallergens, counts for the date and location and color indication for danger. Only the allergens which are selected in the patient's profile are shown.

E-learning. The e-learning service offers information that is useful for the patients in order to increase their knowledge on specific issues related to their health problem. The information is organized as downloadable files (e.g., presentations) and a charging mechanism applies. The corresponding page displays a list of e-learning items available to the patient and provides a search facility for e-learning titles according to category (e.g., posters, presentations, research papers, etc.), date or keyword.

Self-management tool for asthma. The IREMMA self-management tool for asthma helps patients to monitor their asthma by measuring their peak flow. The measurement of their breathing flow helps in assessing their current breathing status. A common peak flow meter is used to measure the peak flow. The user can then send the obtained measurement to IREMMA in order to monitor his condition. The self-management tool uses a personal best value (calculated according to the sufferer's age, sex and body measures) and peak flow history in order to:

- inform the user immediately if he is ok or need to take actions;
- show him a chart which presents his progress; a chart shows in graphical form the history of the patient's measured values; the graph can be 15-day, or 6-month; there are 3 color zones, the green zone which means that everything is going well, the yellow zone which suggests to take additional measures to control his asthma and the red zone which is an emergency situation and urges the patient to ask for medical help.

Travel planning. The travel planning service allows travelers with allergy problems to view pollen levels for a specific location in Europe, in order to plan their travel. It is particular relevant to frequent travelers and tourists. Pollen levels can be displayed as follows: the latest live measurement, the forecast for next week, the yearly distribution or the expected levels at a specific date. The yearly graph allows the user to view the occurrence of specific allergens in the specific area around the year and plan for the best period to visit the specific location or he can choose a different location. The user can also view pollen levels on the specific date of interest, according to statistical estimation. In case he is interested for an immediate trip, he has access to live measurements and forecasting for next week. The registered user can view pollen levels at the location of interest according to his own allergy profile, i.e., for the specific allergens relevant to him. After selecting the location, the user can also access local information, such as a presentation of the allergy profile of the area and information on the local health system.

Profile. The registered user can view and update his allergy profile and personal preferences. The information contained includes:

– the allergens in which the patient is sensitive;

– the area for which he wants to be informed;

– the presentation of his personal allergy maps;

– information necessary for the self management tool;

– preferences about SMS or e-mail alerts;

– info about his subscription and chargeable services.

Discussion list. The users can enter the discussion list, either to read comments and contributions on issues that may interest them or to participate actively in posing questions and commenting on ongoing discussions. An expert assigned by IREMMA enters the discussion list on a frequent basis and adds comments to ongoing discussions. In this way, certain posed questions are also answered by an expert and the attention of the users is drawn to opinions that have been expressed and are not acceptable by the medical expert.

2.2.3. Services for health professionals

Medical education. Medical education (teleeducation) is offered to health professionals through recorded training sessions, ground rounds and recorded telemedicine sessions. The material is transmitted through ISDN lines between a teleeducation provider and rooms with teleconferencing equipment. Participants are able to attend in teleconferencing rooms close to the area where they live and work. The event is organized by IREMMA with the collaboration of local organizers who provide the room and specialized centers in Europe, who provide the training sessions. The web platform is used to announce scheduled sessions and professionals are able to register their participation. Teleeducation sessions are eligible for CME credits and have a specific cost. Users can be informed about the cost, summary, provider and place/date of each session through the site. Users are also informed about the sessions for which they applied for participation.

E-learning. The e-learning service offers information that is useful to the health professionals in order to increase their knowledge on specific issues related to their specialization. The information is organized as downloadable files (e.g., presentations) and a charging mechanism applies. The corresponding page displays a list of e-learning items available to the health professional, together with their description and price and provides a search facility for e-learning titles.

Profile. The health professionals are able to define, view and update their profile information and preferences. The data screen is accessible only by the corresponding professional after successful login. The displayed data are derived from the record of the specific doctor who enters the screen. The displayed items are:

– personal information, address, medical specialization, contact information, username and password;

– information about the professional's account, such as charging info for medical education and e-learning (date downloaded, title, price and total).

Discussion list. The professionals can enter the discussion list, either to read comments and contributions on issues that may interest them or to participate actively in posing questions and commenting on ongoing discussions. The discussion list for health professionals is separate from the discussion list for sufferers and the discussions are on a professional level.

2.2.4. Services for travelers (includes the visitors of the olympic games in Athens)

The services to travelers and in particular to the visitors of the olympic games are in principle the same as those for all other allergy sufferers. However, in order to address in a better way the needs of this special user group, additional designing features are added to the IREMMA website. More specifically, a link has been added in the home page with the symbol of olympic games, which links directly to special information about the olympic sites and the health system in Greece.

3. Methods

3.1. Overall architecture

The IREMMA architecture is based on the concept of information technology (IT) center and of national sites. The procedures of data collection and presentation are decen-

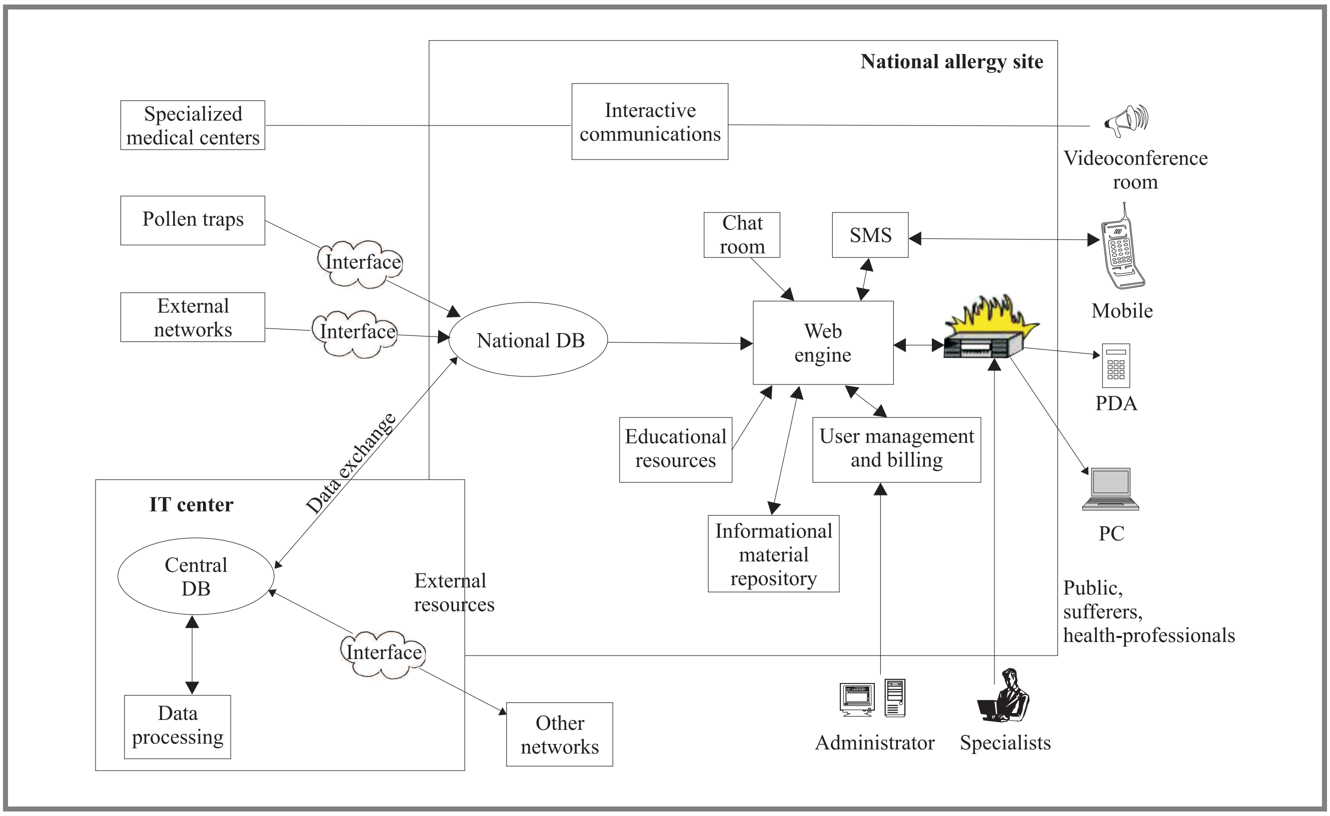

Fig. 1. System architecture.

tralized through the national sites, while information integration and processing are done centrally in the IT center. Each national site acts as an interface between the local data sources and the information center. The data communicated between the national sites and the IT center is standardized. In this way, additional national sites can be easily connected. On the other hand, the communication between the national sites and the data sources are specific to the data sources, not only technically, but also organizationally.

As depicted in Fig. 1, the heart of the IREMMA information network is the IT center, while the service provision and user management point is the set of national sites. An integrated data processing scheme includes collection of all allergiological information (e.g., pollen measurements throughout Europe) together with additional information that may be useful (e.g., meteorological data). The data are then normalized, stored in a standardized format, processed to define alerts and dangerous conditions, and are prepared for uniform presentation. The integration of all data from many local sources into a single point and its centralized processing is one of the strong points of the architecture and increases the capabilities of the system.

The allergiological data and informational material are distributed to the end users of the system through the national sites. Each national site is responsible for collecting local information and for this reason is connected to different data sources (pollen measurements, weather report agency, experts). It is also connected with the IT center to which it forwards all local information. The national sites are finally the access point of users and provides for this purpose web-based user interfaces. The infrastructure allows the existence of any number of national sites, according to the expansion of the system.

The end users are connected to national sites:

– through Internet connections of any type (e.g., dial-up through ISP, xDSL, etc.) using PC from fixed location of mobile location (through GSM modem);

– through SMS messaging using mobile phones; the corresponding service is implemented in collaboration with a GSM operator (in our case COSMOTE);

– special web-based interfaces will be considered for access through PDAs;

– expansion to additional media such as e-mode or satellite/cable TV is open.

Each national site must provide also informational resources for national – local users with a specific decentralized service provision. National sites are developed in order to meet the needs of national e-learning applications and telemedicine support.

The national allergy sites play a double role:

– the one is of the intranet application that will be browsed by professional users for storing the data into the sub-system's database;

– the other role of national sites is that of the main IREMMA interfaces forming a presentation layer for the local national end users accessing the data through desktop computers, laptops, mobile phones, PDAs.

A large amount of data will flow back and forth to/from the national allergy sites, either in raw form or processed by the appropriate components. Direct access and data interaction with end users is also foreseen. The maintained and circulated data is however of diverse nature and is relevant to different types of users and subsystems. For this reason, information management procedures ensure that each data item is visible only by the appropriate actor. The IREMMA system provides a secure, scalable, highly available, reliable, manageable, and easily usable environment suitable to the heterogeneous and distributed healthcare field.

3.2. Technical architecture of national sites

The developed platform is based on a three level approach. The lower level is the allergy warehouse which comprises the infrastructure for information collection and management, user administration, inbound data management and security issues. The second level is the multi-service tool provider, which acts as the service implementation level. This is an intermediate level which accesses internal procedures of the allergy warehouse and provides processed data to support the provision of general information services and personalized services for professionals and sufferers. The third level is the end-user applications which provide telemedicine, teleeducation and e-learning services, access to the information library of the system and a self-management tool for the pollen profile administration of each patient.

3.2.1. Allergy warehouse

The main purpose of the allergy warehouse is the manipulation of allergy data, derived from measurements that come from specific pollen networks and will be processed and presented appropriately for environmental monitoring purposes. The format and the conditions of this information differ for various such networks and the allergy warehouse applies an integrated structure for them. Distinct entities support the services of information library, e-learning, news, discussion list and medical education. The common element of these services is that they provide informational data, that can be faced either as simple data-types within the warehouse or as special objects. Their discrimination regards their different content, context and type and lead to the design of different entities.

Aeroallergen counts and meteorological data are the basic data used to offer allergy maps and to initiate alerts. The consortium has concluded to a specific coding, rules for transmission and procedures for processing and displaying this data. There are two basic categories, statistical data and live data. Live data is introduced daily or weekly and includes forecasting. Statistical data is static but also needs certain updating, e.g., storage of new data, expansion to additional locations, etc. It has been decided that aeroallergen levels are recorded and communicated as actual levels measured as spores/m^3 and not as danger levels. The danger levels are estimated by the end-user level of each national site individually because they involve a degree of subjectivity according to other environmental conditions. Additionally, recorded measurements are stamped with the time period and the location to which they correspond. More specifically, the location of each pollen trap is numbered and named uniquely so that there is no overlap of measurements coming from different sources. Measurements can also be daily or weekly.

Informational material can be in a variety of formats, which makes integration with other information systems difficult. It is also expected that some kind of editing will be needed in any case, even if the file format of the informational content matches between provider and IREMMA. For this reason, technical integration between information systems in order to automatically exchange information has not been considered. The IREMMA platform uses certain templates for informational material, in order to store the content in the database and automatically present it through the web. These templates can be refined in the future and be used for standardized exchange of content between national sites and IT center. However, during the pilot phase, the existing material was in diverse formats and it was decided not to spend many resources in transforming this material. The information was thus provided to the user in its original format, by allowing him either to download it as a file or open it through the common plug-ins of the web browser (e.g., for MS Word, MS PowerPoint, Acrobat Reader, etc.). The allergy warehouse also contains user profile information in order to allow user management, access rights management and effective service provision. User profile data include, apart from demographic information, their allergy profile, service provision preferences, charging and billing information.

The file management is a critical issue for the allergy warehouse and a special protocol has been established [1, 2]. To use the available information formatted in binary files, including multimedia files and textual data effectively, efficient methods for storage, browsing, indexing and retrieval are implemented. The base for all of these is the fact that the physical data and the features of files are not both included in the allergy warehouse. A special indicator object is used as an encrypted alias name of the physical path, where the file is located and it is registered to the corresponding entity in conjunction with the rest features of the specific file. The users who attempt to collect the available files follow an assessed set of steps. The users undergo the constraints of the authentication data; call an already fixed special query for the context and indicator; and then the host's operation system restrictions are enforced to them. It is recommended that the three steps must be passed successfully as to obtain the target information. Finally, for the maintenance of the system the allergy warehouse in-

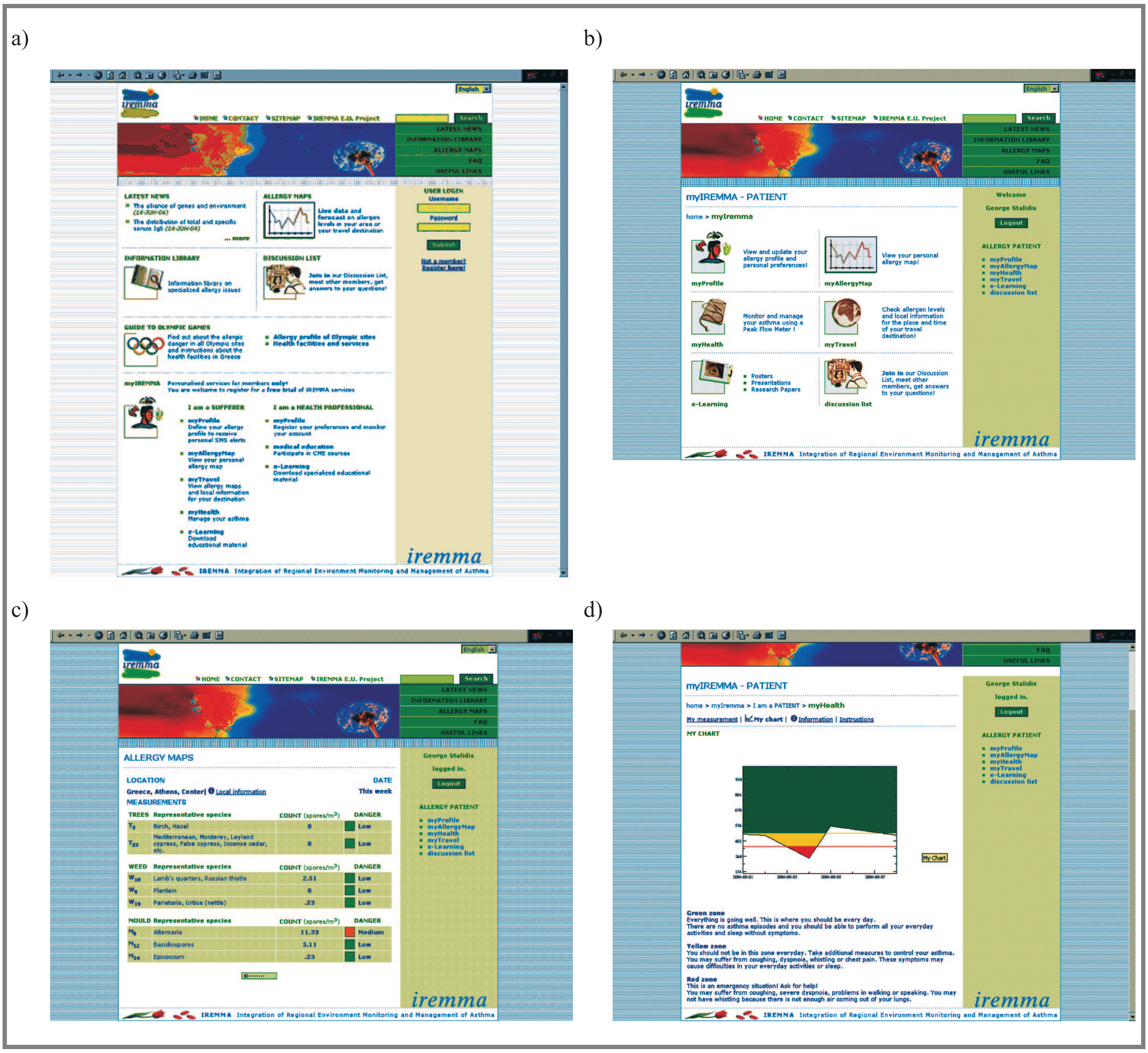

Fig. 2. User screens: (a) main home page; (b) home page for registered patients giving access to personalized services; (c) personal allergy maps; (d) the progress chart presented by the self-management tool for asthma.

cludes procedures for backup and restoring of the application data, the application programs and the exact structure of the repository entities in case of a failure. More frequently the backup will be applied for information related with users' attributes and allergy data, imported from the pollen networks.

3.2.2. Multi-service tool provider

The multi-service tool provider is the middle level in the proposed architecture. It is the core of the application layer and implements the functionality and application logic of the supported services. It performs a number of tasks in order to manage the users' data and transactions, routing the application data and translate the users' requests to understandable statements for the functional interface of the allergy warehouse. The first consideration is to identify the users and access their profiling information, ensuring that the appropriate access rights are enforced and the necessary information to provide personalized services is obtained. The appropriate mode of usage is defined, depending on the user identification. Secondly, it channels the information to and from the users according to their preferences, location and access mode [4].

In order to perform the routing and transfer of application data, apart from the above mechanism, the definition of the participating entities for each communicating session is required. The conversion of information to the appropriate mode according to the participants' access modalities is being performed based on a logic table, which implements the correspondence between the supported transactions and the array of services. The lower layer of the multi-service tool provider performs the translation of the application user requests to sets of multiple statements, defined using a high level data manipulation language (DML) [5]. This mechanism makes a search for the appropriate already fixed functions and addresses their specified interfaces as calls to the communication interface of allergy warehouse.

3.2.3. End-user application

The end-user application level, including the user interface is web-based. The users of the services are mainly using PCs to access the information needed and mobile phones to receive SMS alerts. The use of devices such as PDAs with mobile access is foreseen, which are also web-based. The user access for all types of users is through an Internet browser window, which contains all the information, navigation capabilities and functionality (Fig. 2). Three different levels of service provision are identified, each one being targeted to a different end user group, namely general information services, services to patients and services to health professionals. An access control component, gives access to the functionality corresponding to the specific user group. Differences also exist in the informational content, presentation of data and level of information depth. An additional set of applications is offered to experts who maintain the content and to the administrator (Fig. 3). These comprise a set of tools for information and user management and they are accessed through a similar web-based interface, which however has slightly different designing than the end-user interface.

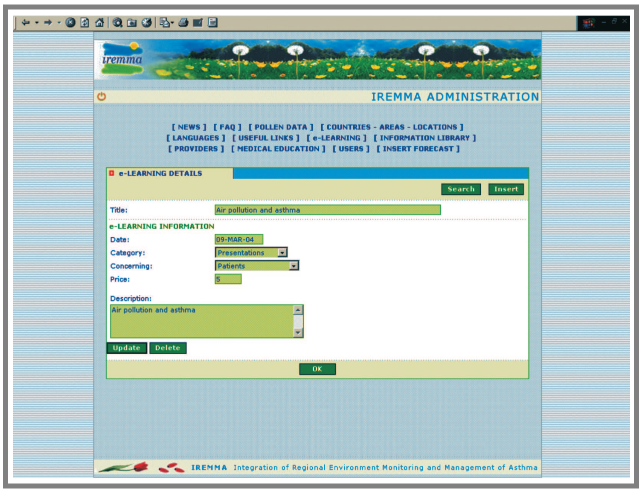

Fig. 3. The administration tool. The updating of an e-learning item has been selected.

3.3. Integration with data sources

The implemented IREMMA prototype is a complete national site which supports service provision to end users by collecting, storing and delivering allergy information. During pilot trial, all data and informational material was collected by a limited number of providers and was made available to the users. However, at the future Pan-European perspective it is foreseen that a number of independent national sites will be operational. Information collected by each national site will be sent to the IT center which will act as a hub controlling the data flow. Integration between national sites and the IT center is thus necessary, related to the following issues:

- pollen data collected and owned by the national site is sent to the IT center;
- pollen data collected by the IT center from all European sites is provided to each national site;
- informational material produced and owned by a national site is sent to the IT center;
- informational material collected by the IT center is provided to a national site on demand;
- transactions involving the exchange of information between a national site and the IT center are recorded and the value of these transactions is calculated according to a fixed pricing policy.

In order to deal with the above issues, the following has been defined and/or implemented.

A standardized codification of aeroallergens has been defined, which includes all the types of aeroallergens that may appear throughout Europe. Although it is still subject to revision, the produced codification is usable and possible causes of confusion regarding the naming or categorization of individual species have been clarified. Using this codification, it is possible to exchange and integrate data on aeroallergen levels at Pan-European level.

A template file in MS Excel and a definition of XML message have been produced allowing the easy transfer of measurement data through Internet-based communication.

It has been decided that aeroallergen levels are recorded and communicated as actual levels measured as spores/m^3 and not as danger levels. The danger levels are estimated by each national site individually because they involve a degree of subjectivity according to other environmental conditions. Additionally, recorded measurements are stamped with the time period and the location to which they correspond. More specifically, the location of each pollen trap is numbered and named uniquely so that there is no overlap of measurements coming from different sources. Measurements can also be daily or weekly.

The collection of pollen data is performed by TCP/IP based communication between pollen networks, pollen traps and national sites. Aeroallergen data is received either by pollen traps through the hospital or institute which operates them or by existing networks which act as providers. A survey was performed in pollen trap technology and it was found that in most of them the measurement is acquired after manual processing and can not be automatically transmitted (usually sent by fax or e-mail). The result is expressed in standard units (spores/m^3) and the only subjectivity lies in the categorization and naming of the aeroallergens. There

are also different types of pollen traps, according to the measurement period (e.g., one day, one week, etc.). Pollen networks collect data from many pollen traps and keep them in their own format.
The solution given in order to integrate existing and new pollen data sources into a unique allergy data repository as:

- to standardize the coding of aeroallergens;
- to develop a web interface for manual insertion of the measurement by the pollen trap operator directly in IREMMA database;
- to propose a file template which can be used by the data provider in order to insert the data and upload it to IREMMA, where it is automatically imported in the database;
- to propose an XML schema to allow pollen data exchange through http connection;
- to develop filters that import data provided by pollen networks, according to the format used by the providers.

The scientific partners within the IREMMA project consortium concluded to a specific codification of allergens and technical partners have implemented a message format for data transmission. Live pollen measurements and forecasting are sent by the operators of pollen traps (usually a hospital clinic or an allergiological institute) to the national sites with which there is an agreement for data provision. This can be done either by sending a message in an agreed format (defined in XML and alternatively in Excel file) or by using the provided web interface, which allows the manual insertion of the pollen data directly by the experts to the database. In addition to live measurements and forecasts sent on a regular basis, there is provision for the exchange of statistical data covering the pollen levels at specific locations during past years. Such data has been successfully exchanged within the pilot phase by developing a configurable importing component which has been adjusted to the format of origin. Since the format of pre-existing data can not be controlled, such interfacing components are necessary in order to import external data. A standard coding of aeroallergen types is also used, such as the one proposed within this project.
Informational material can be inserted, edited and revised directly on the national sites by authorized experts through a web interface dedicated to information management. The corresponding functionality is offered by the administration tool of IREMMA, which is addressed to information providers, experts and the IREMMA administrator. The implemented tool offers the required functionality to experts in order to insert and manage news articles, frequently asked questions, e-learning items, useful links, descripiton and schedule of medical education sessions. It also allows them to edit or upload content for the information library. The tool offers the ability to the administrator to define new languages, areas and locations of pollen traps, providers of medical education sessions and a user management window for viewing and managing user accounts. Finally, a usable web interface is offered to experts acting as providers of pollen data to insert manually live measurements and forecasts and to upload already prepared files with measurements.

3.4. Implementation issues

The IREMMA services are offered through a telematic platform that is designed, implemented using mature technologies and operated in pilot form within this project. This platform is the basis for future expansion to fully blown commercial services. Information delivery and supporting transactions are offered over both wire line and wireless links to a set of end devices, such as desktop PC, laptop PC, mobile phone and PDA. Modular design allows future expansion to additional user devices, such as digital TV, MMS and others. The telecommunication infrastructure is based on public switched digital networks and data networks. Internet-based communications ensure universal user access and high expandability of the services.

The hardware and communications infrastructure of OTE were used in order to run the services for pilot trials. The platform used is UNIX-based which was considered as the most appropriate for future expansion to wide scale service provision. The database has been implemented in Oracle 9i and the implementation language of the web application is php. An Apache webserver was used [3].

4. Results

The IREMMA platform is currently operational in pilot form and services are offered to groups of trial users in Greece and Spain. The prototype is currently implemented in English, while the multilingual edition has not yet been implemented. Data is collected by aeroallergen networks with the participation of Corporacio Sanitaria Clinic – Spain, Royal Brompton Hospital – UK, Venizeleio hospital – Greece, Sotiria hospital – Greece, Laiko hospital – Greece, Municipal Institute of Medical Research – Spain and the Italian National Research Council, who also provide the medical expertise and informational content.
The system has initially been evaluated by expert users regarding usability and completeness of functionality and by developers regarding technical issues, such as reliability, correctness and performance [6]. Evaluation results have been used to perform a second development cycle and lead to updating of the services and prototype implementation. The major points which required update were: it was decided to add or modify certain services in order to emphasize the specialized and personalized nature of the IREMMA and differentiate it from medical information sites on the Internet. More specifically, the self-management tool for asthma was implemented, the structure of travel planning service was changed to make it more easily accessible by travellers and the link to "Guide to

Olympic Games" was added. It was also specified that patients/sufferers must be registered on their own, even if their doctor recommends IREMMA to them and the doctor is not responsible for maintaining the profile of his patients in the system. For this reason, the patient archive initially implemented as a service to the health professionals was removed. Minor changes in the interface were also carried out, such as the replacement of certain icons, the change of colouring and the refinement of the layout of the home screen.

Full user trials with real sufferers and health professionals are being performed since the spring 2004 and all the services are freely available to the public until the end of September 2004, with the collaboration of National Greek Telecom provider (OTE). During this period, all paid services, including SMS alerts are offered free of charge and the site is publicised to allergic patients and travellers, and especially to tourists and travellers to Athens 2004 Olympic Games. Additionally, three testing groups of patients have been formed, in Greece, Spain and UK and formal evaluation procedures are carried out by the collaborating hospitals [7]. The first cycle of results which are now available show high degree of satisfaction and intention to use. The basic principles of IREMMA have been verified as a promising approach with high potential of leading to a successful and financially sustainable service with considerable socio-economic impact. The selection of service sets seems successful and appealing to the users and the interfaces were found as well structured and usable.

5. Conclusions

The work presented in this paper intended to perform a feasibility study and market validation for the public health information services concerning environmental and allergy issues. The project's aim is to establish a trans-European network, providing a wide range of services related to environmental diseases, asthma and allergy, such as allergy forecasts, real time alert reports, self-management for asthma and medical education.

A technological platform has been implemented to support sets of services provided via world wide web and SMS technologies, based on an integrated monitoring and reporting system of aeroallergens. IREMMA has set the ground for establishing a trans-European network to support, through telematics solutions, groups concerned with common environment-related allergic diseases. Based on this network, it will supply health information to citizens with allergy and asthma problems, support the management of environmental diseases, and will finally collect, organize electronically and disseminate information on environmental factors.

Sets of services to sufferers and health professionals were implemented in pilot form and offered to real users for testing purposes. The approach and designing of these services were successful and a promising architecture has been proposed for creating a sustainable and efficient integrated network for information collection, processing and diffusion. The ambition of IREMMA is to expand its network of data sources throughout Europe and to collect credible informational content. In this way, it can be realistically transformed from a pilot service into a fully blown high-quality service of considerable value to an extremely high number of users.

Acknowledgements

The authors would like to thank the European Commission (eTEN Programme) for the financial support provided to IREMMA project (http://www.iremma). They would also like to thank all the project participants for their significant contribution and fruitful collaboration, namely, the "Greek Telecommunications Organisation S.A. (OTE)", "Pouliadis Associates Corp." – Greece, the "Royal Brompton & Harefield NHS Trust" – UK, the "General Hospital of Heraklion – Venizeleion – Pananeion – Greece, the "Corporacio Sanitaria Clinic" – Spain, the "Municipal Institute of Medical Research" – Spain, the "Italian National Research Council – Institute of Neurobiology and Molecular Medicine" – Italy, the "Laiko Hospital" and "Sotiria Hospital" – Greece.

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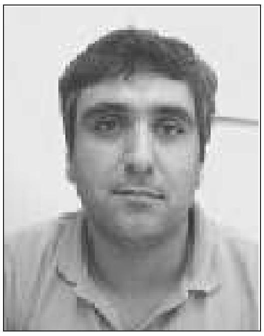

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Paper

Integrated analysis of communication protocols by means of PLA formalism

Henrikas Pranevicius

Abstract—Aggregate approach and its possibilities for specification and analysis of computer network protocols are presented. The theoretical basis of the aggregate approach is a piece-linear aggregate (PLA) for formal specification of systems. The advantage of that approach is that it permits to create models both for analysis correctness of specifications and simulation. Some methods that can be used for validation and verification of aggregate specifications are presented also.

Keywords— piece-linear aggregates, ESTELLE/Ag specification language, validation, simulation, communication protocols.

1. Introduction

The stage of formal specification is one of the most important during the design of software of communication protocols. Such formal specification is usually used for analysis and implementation purposes. In the stage of analysis it is necessary to resolve two tasks: analysis of logical correctness and evaluation of the system functioning parameters.

Different mathematical schemes are used for creating formal descriptions of systems, such as: different automate models, Petri-nets, data flow and state transition diagrams, temporal logic technique, abstract communicating methods and other [1, 2].

When a formalization method is chosen, it is desirable that both above mentioned analysis tasks could be resolved on the bases of a single formal description. The aggregate approach has such property and it has been successfully used both for correctness analysis and for simulation of computer network protocols [3–5]. Specification language ESTELLE/Ag and the specifications analysis tool PRANAS-2 have been created on the base of the aggregate method (Ag). There are some differences between ESTELLE/Ag and the ESTELLE standard ISO: the piece-linear aggregate model is used in ESTELLE/Ag. The use of such a model instead of a finite-state automate, which is the formal background of the standard ESTELLE, enables to create models both for validation and simulation. This is possible due to the special structure of the piece-linear aggregate. Apart from the discrete components describing the state of the modules, there are also continuous components to control event-sequences in the module. These continuous components are called operations. By means of operators, sequences of actions are described, the intermediate results of which are invisible on the outside. If such operation sequence is being performed at a given instance of time the corresponding operation is called "active". Thus, an individual module involves two types of events: arrival of an input signal and completion of an active operation. The specification analysis system PRANAS-2 consists of the following software tools: a specification editor, a validation subsystem and a simulation subsystem. The editor provides the capability to create a specification in ESTELLE/Ag. The validation subsystem permits to construct a validation model for the program generating the reachability graph. After completing the construction of the reachability graph, it is possible to verify the following specification characteristics: completeness, deadlock freeness, boundedness, absence of static deadlock, absence of dynamic deadlock, termination.

The same specification changes are carried out when the simulation model is creating. This is necessary in order to define the duration of operations and to introduce additional variables for gathering statistics about the evaluated system parameters.

Section 2 describes the general principles of piece-linear aggregates (PLA) formalism. Methods used for correctness analysis of PLA specification are presented in Section 3. Section 4 illustrates the use PLA formalism for formal specification and integrated analysis of event driven local computer network protocol.

2. General principles of the aggregate approach

In the application of the aggregate approach for system specification, the system is represented as a set of interacting piece-linear aggregates. The PLA is taken as an object defined by a set of states Z, input signals X, and output signals Y. The aggregate functioning is considered in a set of time moments $t \in T$. The state $z \in Z$, the input signals $x \in X$, and the output signals $y \in Y$ are considered to be time functions. Apart from these sets, transition H and output G operators must be known as well.

The state $z \in Z$ of the piece-linear aggregate is the same as the state of a piece-linear Markov process, i.e., $z(t) = \big(\upsilon(t),\, z_\upsilon(t)\big)$, where $\upsilon(t)$ is a discrete state component taking values on a countable set of values; and $z_\upsilon(t)$ is a continues component comprising of $z_{\upsilon 1}(t),\, z_{\upsilon 2}(t), \ldots,\, z_{\upsilon k}(t)$ co-ordinates.

When there are no inputs, the state of the aggregate changes in the following manner:

$$\upsilon(t) = \text{const}, \ \frac{dz_\upsilon(t)}{dt} = -\alpha_\upsilon \, ,$$

where $\alpha_\upsilon = (\alpha_{\upsilon 1}, \alpha_{\upsilon 2}, \dots, \alpha_{\upsilon k})$ is a constant vector.

The state of the aggregate can change in two cases only: when an input signal arrives at the aggregate or when a continuous component acquires a definite value. The theoretical basis of piece-linear aggregates is their representation as piece-linear Markov processes.

Aggregate functioning is examined on a set of time moments $T = \{t_0, t_1, \dots, t_m, \dots\}$ at which one or several events take place, resulting in the aggregate state alternation. The set of events E which may take place in the aggregate is divided into two non-intersecting subsets $E' = E' \cup E''$. The subset $E' = \{e'_1, e'_2, \dots, e'_N\}$ comprises classes of events (or simply events) e'_i, $i = \overline{1,N}$ resulting from the arrival of input signals from the set $X = \{x_1, x_2, \dots, x_N\}$. The class of events $e''_i = \{e''_{ij}, \ j = 1,2,3,\dots\}$, where e''_{ij} is an event from the class of events e''_i taking place the $\boldsymbol{j}$th time since the moment t_0. The events from the subset E' are called external events. A set of aggregate input signals is unambiguously reflected in the subset E', i.e., $X \to E'$. The events from the subset $E'' = \{e''_1, e''_2, \dots, e''_f\}$ are called internal events, where $e''_i = \{e''_{ij}, \ j = 1,2,3,\dots\}$, $i = \overline{1,f}$ are the classes of the aggregate internal events. Here, f determines the number of operations taking place in the aggregate. The events in the set E'' indicate the end of the operations taking place in the aggregate.

The events of the subsets E' and E'' are called the evolutionary events of the aggregate. The main evolution events are sufficient for unambiguous determination of the aggregate evolution. Apart from the basic evolutionary events, auxiliary evolutionary events may be considered, which are simultaneous to the basic ones and determine the start of the operations.

For every class of events e''_i from the subset E'', control sequences are specified $\{\xi_j^{(i)}\}$, where $\xi_j^{(i)}$ – the duration of the operation, which is followed by the event e''_{ij} as well as event counters $\{r(e''_i, t_m)\}$, where $r(e''_i, t_m)$, $i = \overline{1,f}$ is the number of events from the class e''_i taken place in the time interval $[t_0, t_m]$.

In order to determine start and end moments of operation, taking place in the aggregate the so-called control sums $\{s(e''_i, t_m)\}$, $\{w(e''_i, t_m)\}$, $i = \overline{1,f}$ are introduced, where $s(e''_i, t_m)$ – the time moment of the start of operation followed by an event from the class e''_i. This time moment is indeterminate if the operation was not started; $w(e''_i, t_m)$ is the time moment of the end of the operation followed by the event from the class e''_i. In case of no priority operations, the control sum $w(e''_i, t_m)$ is determined in the following way: $w(e''_i, t_m) = s'(e''_i, t_m) + \xi_{r(e''_i, t_m)+1}$, if at moment t_m an operation is taking place, which is followed by the event e_i; in the opposite case $w(e''_i, t_m) = \infty$. The infinity symbol (∞) is used to denote the undefined values of the variables.

Control sums determine only the possibility conditions for the events after the moment t_m, while the event occurrence moments are not determined.

Let us specify the meaning of the co-ordinates of the aggregate state. The discrete component of the state, $\upsilon(t_m) = \{\upsilon_1(t_m), \upsilon_2(t_m), \dots, \upsilon_p(t_m)\}$, presents the system state:

$$z_\upsilon(t_m) = \{w(e''_i, t_m), w(e''_2, t_m), \dots, w(e''_f, t_m)\}$$

are control co-ordinates specifying the moment of evolutionary events occurrence.

The control co-ordinate $w(e''_i, t_m)$ corresponds to every each e''_i from the subset of events E'', while always $w(e''_i, t_m) \geq t_m$.

The state co-ordinates $z(t_m)$ can change their values only at discrete time moments $\boldsymbol{t_m}$, $m = 1,2,\dots$ of event occurrence, remaining fixed in each interval $[t_m, t_{m+1}), m = 0,1,2,\dots$ where t_0 – the initial moment of system functioning.

When the state of the system $z(t_m)$, $m = 0,1,2,\dots$, is known, the moment t_{m+1} of the following event is determined by a moment of input signal arrival to the aggregate or by the equation:

$$t_{m+1} = \min\{w(e''_i, t_m)\}, \ 1 \leq i \leq f.$$

Class of the next event e_{m+1} is specified by an input signal if it arrives at the time moment t_{m+1} or is determined by the control co-ordinate, which acquire minimal value at the moment t_m, i.e., if $w(e''_i, t_m)$ acquires minimal value, then $e_{m+1} = e''_i$.

The operator H states the new aggregate state:

$$z(t_{m+1}) = H[z(t_m), e_i], \ e_i \in E' \cup E''.$$

The output signals y_i from the set of output signals $Y = \{y_1, y_2, \dots, y_m\}$ can be generated by an aggregate only at occurrence moments of events from the subsets E' and E''. The operator G determines the content of the output signals:

$$y = G[z(t_m), e_i], \ e_i \in E' \cup E'', \ y \in Y.$$

Further transition and output operators will be denoted $H(e_i)$ and $G(e_i)$.

3. Correctness analysis of aggregate specifications

3.1. Reachable states approach for aggregate model validation

An essence of the reachable states method is a use of the global state which is considered as a joint state of a system after aggregate system composition. A graph of the reachable states is created as oriented one: its nodes stand for global states of the system, its arcs indicate the possible transitions from one state to another. Initial and final states must be specified in working out the graph. The resulting states graph is used for an analysis of defined properties of a system, as some of them are closely related with the graph structure. The given validation method allows to investigate general properties of a system such as boundedness, absence of redundancy in specification, completeness, absence of static deadlocks, absence of dynamic deadlocks, termination.

3.2. Invariant approach for aggregate model validation

A system invariant (I) is the assertion, which describes correct system functioning and it must remain true in spite of the events taking place and system transition from one state to another.

The essence of the method is as follows: assertions are formulated in relation to the co-ordinates of the aggregate model so as to express the requirements for the system functioning.

On the base of a conceptual model of an analysed system we can describe system functioning by the event sequence, which may be represented by the graph $G(V)$, where V is a set of vertices and $\mathbf{A} = \{a_{ij}\}$ is an adjacency matrix. In this case $V = \{e_1, e_2, \ldots, e_n\}$, where e_i is ith event, n is a number of events. $(e_i e_j) \neq (e_j e_i)$, i.e., the graph is oriented.

The set of states, which the system may enter after the event e1, is called as the ith set of possible states (SS_i – symbolic state). $SS_i = \Big\{ z \in Z | (\exists z')\big((z' \in Z) \wedge EP_i(z') \wedge (z = H_i(z', P))\big)\Big\}$, where Z is a set of all possible system states, $EP_i(z')$ is an enabling predicate of the event $\boldsymbol{e_i}$ in the state z', P is a set of probabilistic parameters of the system and H_i is a transition operator determining the new system state when the event e_i occurs.

The system considered being in the symbolic state SS_i only if it is in the state z and $z \in SS_i$. Relying this SS_i definition, every event e_i is related to the symbolic state SS_i, therefore replacing the set of vertices V in the graph $G(V)$ by $V' = \{SS_1, SS_2, \ldots, SS_n\}$ while the adjacency matrix $\mathbf{A}$ remains unchanged. We obtain the graph of symbolic states $G(V')$ which describes the system operation by determining the possible set of states and transitions from one symbolic state to another.

The presented formalization and analysis method will be illustrated by example of specification and integrated analysis of timed protocol with slot reuse.

4. Specification, validation and simulation of event-driven local computer network protocol

4.1. Conceptual model of on event-driven local computer network protocol

There are many computer communication applications requiring high bandwidth and high reliability in operation, which still allow simple and low cost implementation. This type of network exists in robotics, vehicles, homes, etc. These applications set restrictions on the system in terms of usable hardware, cost, and cabling. Such networks are in many cases meant for one special application and not for a general purpose use. The number of stations is generally small compared with typical LAN applications, and the variation in the number of stations is small during the life cycle of the network.

Typical requirements for the media access protocols in these applications are: high reliability of the environment, where the electrical disturbance level is a high scalable bandwidth: self-stabilizing properties; and simplicity combined with low cost of implementation. Solutions based on the existing media access standards do not meet these requirements in many cases.

The protocol described by Sintonen is design to offer high bandwidth while keeping the structure simple. The configuration is a physical bus, where stations form a logical ring. The algorithm is based on the noticeable events on the bus (hence the name event-driven bus protocol). The protocol is distributed, except in the initialization phase. Every station listens to the bus and receives both the destination address and the source address, and stores them in the registers *DA* and *SA* respectively. A station is also capable of sending the bus and detecting the event frame ended. The algorithm for sending and receiving is as follows.

Receiving:
When a station notices it's own address in the *DA* field, it receives the frame.

Sending:
When a station has a frame to send, it waits until it receives the address of it's predecessor in the *SA* of the frame. Then it waits for the event frame ended. After that event, it waits a time period $D', D' \leq 2d$, where d is the end to end delay of, the bus. Then it sends its frame, and waits for a time delay $D', D' > 2d$ to hear the next station begin sending. When this happens, the sending phase is ended. If a station has nothing to send its turn comes, it sends an empty no data frame, a kind of a token, to pass the turn to next station in sequence.

There is one station which initializes the ring, known as the fixed control station. The control station can also detect a failed station and is capable of executing a reconfiguration algorithm to restore the normal operation of the ring.

5. Aggregate specification of on event-driven local computer network protocol

An aggregate schemes of a specification of an analyzed event oriented protocol is depicted in Fig. 1. The aggregates $Station\_0, Station\_1, \ldots, Station\_(n-1)$ depict the stations which are switched on to the network, and the aggregate *Bus* describes the performance channel. *Station_0* is the controlling one. The signals that are transmitted between the aggregates have also been shown in Fig. 1.

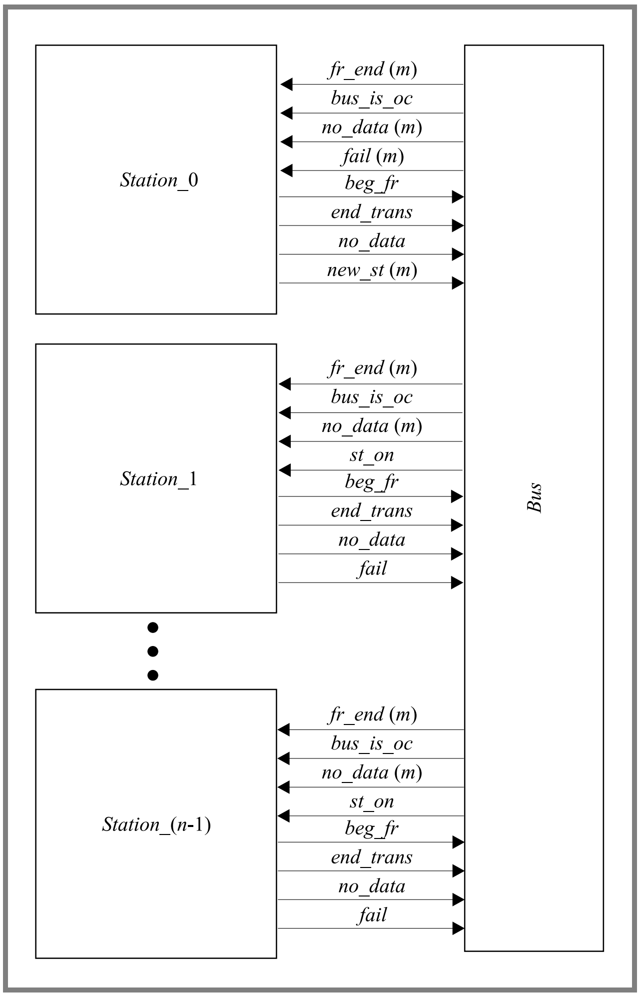

Fig. 1. Aggregate scheme of a model.

Aggregate *Station_nr*, $nr = \overline{1, n-1}$

1. Set of input signal

$$X_{nr} = \{fr\_end(m),\ bus\_is\_oc,\ no\_data(m),\ fail\};$$

where: $fr\_end(m)$ – end of the transmitting; bus_is_oc – bus is occupied; $no\_data\_(m)$ – no data for transmission; st_on – switching on of the station; n – number o station; m – the number of station where packet is sending.

2. Set of output signals $Y_{nr} = \{y\}$,

$$y \in \{beg\_fr,\ end\_trans,\ no\_data,\ fail\};$$

where: beg_fr – beginning of the frame transmitting; end_trans – end of the frame transmitting; no_data – no data for transmitting; $fail$ – station is switched off.

3. Set of internal events

$$E''_{nr} = \{e''_1(taim\_DI),\ e''_2(taim\_D),\ e''_3(trans\_fr),\ e''_4(arr\_fr),\ e''_5(swit\_of)\};$$

where: $e''_1(taim\_DI)$ – end of timer *DI*; $e''_2(taim\_D)$ – end of timer *D*; $e''_3(trans\_fr)$ – end of the frame transmitting; $e''_4(arr\_fr)$ – moment of a frame arrival; $e''_5(swit\_of)$ – moment of the station switching.

4. Controlling sequences:

$$e''_i(\ldots) \rightarrow \{\xi_{ij}\},\ i = \overline{1, 5},\ j = \overline{1, \infty};$$

where ξ_{ij} – duration of an operation, followed by the event $e''_i(\ldots)$.

5. Discreet component of state

$$\upsilon(t_m) = \{st(t_m),\ actD(t_m),\ sw(t_m)\};$$

where: $st(t_m) \in \{0, 1\}$; 0 – no frame for transmitting, 1 – there is a frame for transmitting;

$$actD(t_m) = \begin{cases} 0, & \text{timer } D \text{ is switched off;} \\ 1, & \text{timer } D \text{ is switched on;} \end{cases}$$

$$sw(t_m) = \begin{cases} 0, & \text{station is switched off;} \\ 1, & \text{station is switched on;} \end{cases}$$

6. Initial state: $st(t_0) = 0$; $act\_D(t_0) = 0$; $sw(t_0) = 0$;
$w(e''_1(taim\_DI), t_0) = \infty$;
$w(e''_2(taim\_D), t_0) = \infty$;
$w(e''_3(trans\_fr), t_0) = \infty$;
$w(e''_4(arr\_fr), t_0) = t_0 + \xi_{4j}$;
$w(e''_5(swit\_of), t_0) = t_0 + \xi_{5j}$.

7. Transfer operators:

$H(e'(fr\_end))$: (The end of packet sending)
$w(e''_1(taim\_DI), t_{m+1}) = t_m + \xi_{1j}$
if $sw(t_m) = 1 \wedge m = nr$.

$H(e'(bus\_is\_oc))$: (Bus is busy)

$$\left.\begin{array}{l} w(e''_2(taim\_D), t_{m+1}) = \infty, \\ w(e''_4(arr\_fr), t_{m+1}) = t_m + \xi_{4j}, \\ act\_D(t_{m+1}) = 0 \end{array}\right\},$$

if $sw(t_m) = 1 \wedge act\_D(t_m) = 1$.

$H(e'(no\_data))$: (There are no data for sending)
$w(e''_1(taim\_DI), t_{m+1}) = t_m + \xi_{1j}$
if $sw(t_m) = 1 \wedge m = nr$;

$$\left.\begin{array}{l} w(e''_2(taim\_D), t_{m+1}) = \infty, \\ w(e''_4(arr\_fr), t_{m+1}) = t_m + \xi_{4j}, \\ act\_D(t_{m+1}) = 0 \end{array}\right\},$$

if $sw(t_m) = 1 \wedge act\_D(t_m) = 1$.

$H(e''_1(taim\_DI))$: (Timer *DI* has expired)

$$\left.\begin{array}{l} w(e''_3(trans\_fr), t_{m+1}) = t_m + \xi_{3j}, \\ y = beg\_fr \end{array}\right\},$$

if $st(t_{m+1}) = 1$;

$$\left.\begin{aligned} &w\big(e_2''(taim\_D), t_{m+1}\big) = t_m + \xi_{2j},\\ &act\_D(t_{m+1}) = 1,\\ &y = no\_data \end{aligned}\right\},$$
if $st(t_{m+1}) \neq 1$.

$H\big(e_2''(taim\_D)\big)$: (Timer D has expired)
$y = fail$.

$H\big(e_3''(trans\_fr)\big)$: (The end of packet sending)
$st(t_{m+1}) = 0$;
$w\big(e_2''(taim\_D), t_{m+1}\big) = t_m + \xi_{2j}$;
$act\_D(t_{m+1}) = 1$;
$y = end\_trans$.

$H\big(e_4''(arr\_fr)\big)$: (The packet has arrived)
$st(t_{m+1}) = 1$.

$H\big(e_5''(swit\_of)\big)$: (The station is seething of)
$sw(t_{m+1}) = 0$;
$w\big(e_1''(taim\_DI), t_{m+1}\big) = \infty$;
$w\big(e_2''(taim\_D), t_{m+1}\big) = \infty$;
$w\big(e_3''(trans\_fr), t_{m+1}\big) = \infty$;
$w\big(e_4''(arr\_fr), t_{m+1}\big) = \infty$;
$act\_D(t_{m+1}) = 0$;
$st(t_{m+1}) = 1$.

Aggregate *Station_0*

The functioning of this aggregate is similar to that of the aggregate ***Station_nr***. Therefore, only the differences are presented in respect to the agregate ***Station_nr***.

1. Set of input signals:
   $X_0 = X_{nr} \setminus \{st\_on\} \cup \{fail(m)\}$;
   where: X_{nr} – set of input signal of aggregate *Station_nr*; m – is the number of the stations switched on.

2. Set of output signals:
   $Y_0 = Y_{nr} \setminus \{fail\} \cup \{new\_st(m)\}$;
   where: Y_{nr} – set of output signal of aggregate *Station_nr*; m – the number of the switched on station.

3. Set of internal events:
   $E_0'' = E_{nr}'' \setminus \big\{e_5''(swit\_off),\, e_7''(taim\_T)\big\} \cup \big\{e_{8i}''(swit\_on), \ldots, e_{8,n-1}''(swit\_on)\big\}$;
   where: $e_7''(taim\_T)$ – end of timer T; $e_{8i}''(swit\_on)$ – ith station switched on.

4. Controlling sequences for the events are introduced $e_7''(\ldots)$ and $e_{8i}''(\ldots)$:
   $e_7''(taim\_T) \mapsto \{T\}$;
   $e_{8i}''(swit\_on) \mapsto \{\xi_{ij}\},\ i = \overline{1, n-1},\ j = \overline{1, \infty}$;
   where: ξ_{8ij} – the operation duration after finishing of which the ith station is switched on; T – the duration of timer T.

5. Discrete component of state
   $\upsilon(t_m) = \big\{st(t_m),\, actD(t_m)\big\}$.

6. Initial state:
   $act\_D(t_0) = 1$; $st(t_m) = 0$;
   $w\big(e_7''(taim\_D),\, t_0\big) = t_0 + T$;
   $w\big(e_{8i}''(swit\_on), t_0\big) = \infty,\ i = \overline{1, n-1}$.

7. Transfer operators:
   $H\big(e'(fr\_end)\big)$: (Bus is busy)
   $$\left.\begin{aligned} &w\big(e''(taim\_DI),\, t_{m+1}\big) = t_m + \xi_{1j},\\ &act\_DI(t_{m+1}) = 1 \end{aligned}\right\},$$
   if $m = nr$;
   $w\big(e_7''(taim\_T),\, t_{m+1}\big) = t_m + T$,
   if $m \neq nr$.

$H\big(e'(bus\_is\_oc)\big)$: (Bus is occupied)
$$\left.\begin{aligned} &w\big(e_7''(taim\_T)\big) = t_m + T\\ &w\big(e_2''(taim\_D),\, t_{m+1}\big) = \infty,\\ &w\big(e_4''(arr\_fr),\, t_{m+1}\big) = t_m + \xi_{4j}\\ &act\_D(t_{m+1}) = 0 \end{aligned}\right\},$$
if $act\_D(t_{m+1}) = 1$.

$H\big(e'(no\_data)\big)$: (There are no data for sending)
$$\left.\begin{aligned} &w\big(e_1''(taim\_DI),\, t_{m+1}\big) = t_m + \xi_{1j},\\ &w\big(e_7''(taim\_T),\, t_{m+1}\big) = \infty,\\ &w\big(e_2''(taim\_D),\, t_{m+1}\big) = \infty,\\ &act\_DI(t_{m+1}) = 1,\\ &act\_D(t_{m+10}) = 0 \end{aligned}\right\},$$
if $m = 0$;
$$\left.\begin{aligned} &w\big(e_2''(taim\_D),\, t_{m+1}\big) = \infty,\\ &w\big(e_4''(arr\_fr),\, t_{m+1}\big) = t_m + \xi_{4j},\\ &act\_D(t_{m+1}) = 0 \end{aligned}\right\},$$
if $m = 0 \wedge act\_D(t_m) = 1$;
$w\big(e_7''(taim\_T), t_{m+1}\big) = t_m + T$.

$H\big(e'(fail)\big)$: (The station is)
$w\Big(e_{8m}''\big(swit\_on(m)\big)\Big) = t_m + \xi_{mj}$.

$H\big(e_1''(taim\_DI)\big)$: (End of timer DI)
$act\_DI = 0$;
$$\left.\begin{aligned} &w\big(e_3''(trans\_fr),\, t_m\big) = t_m + \xi_{3j},\\ &y = beg\_fr \end{aligned}\right\},$$
if $st(t_{m+1}) = 1$;
$$\left.\begin{aligned} &w\big(e_2''(taim\_D),\, t_m\big) = t_m + \xi_{2j},\\ &act\_D(t_{m+1}) = 1,\\ &y = no\_date \end{aligned}\right\},$$
if $st(t_{m+1}) \neq 1$.

$H\big(e_2''(taim\_D)\big)$: (The end of timer D)
$act\_D(t_{m+1}) = 0$;
$w\big(e_1''(taim\_DI),\, t_{m+1}\big) = t_m + \xi_{1j}$,
$act\_DI(t_{m+1}) = 1$;
$w\big(e_4''(arr\_fr),\, t_{m+1}\big) = t_m + \xi_{4j}$;
$y = fail$.

$H\big(e_3''(trans\_fr)\big)$: (The transmission of packet has ended)
$st(t_{m+1}) = 0$;
$w\big(e''(taim\_D),\, t_{m+1}\big) = t_m + \xi_{2j}$,
$act\_D(t_{m+1}) = 1$;
$y = end\_trans$.

$H\big(e_4''(arr\_fr)\big)$: (The packet has arrived)
$st(t_{m+1}) = 1$.

$H\big(e''_7(taim\_T)\big)$: (The timer T has expired)
$w\big(e''_1(taim\_DI),\, t_{m+1}\big) = t_m + \xi_{1j}$;
$act\_DI(t_{m+1}) = 1$.

$H\Big(e''_{8k}\big(swit\_on(k)\big)\Big)$: (The station is switching on)
$y = new\_st(k+1)$.

Aggregate *Bus*

1. Set of input signals:
$X = \big\{[beg\_fr,\, end\_trans,\, no\_data,\, new\_st(m)]_0,$
$[beg\_fr,\, end\_trans,\, no\_data,\, fail]_1, \ldots,$
$[beg\_fr,\, end\_trans,\, no\_data,\, fail]_{n-1}\big\}$.
2. Set of output signals:
$Y = \big\{[fr\_end(m),\, bus\_is\_oc,\, no\_data(m),\, fail(m)]_0,$
$[fr\_end(m),\, bus\_is\_oc, st\_on, no\_data(m)]_1, \ldots,$
$[fr\_end(m),\, bus\_is\_oc, st\_on, no\_data(m)]_{n-1}\big\}$.
3. Set of internal events $E'' = \varnothing$.
4. State $\upsilon(t_m) = \big\{q_i(t_m),\, i = \overline{1,N},\, kan(t_m)\big\}$;
where: $q_i(t_m) \in \{1, 2, \ldots, N\}$; $q_i(t)$ – the number of successor for the ith station;
$kan(t_m) = \begin{cases} 0, \text{ channel is idle;} \\ 1, \text{ channel is occupied.} \end{cases}$
5. Initial state:
$kan(t_0) := 0$; $i := 1$;
while $i < n$ do begin $q_i(t_0) := i+1$; $i := i+1$; end.
6. Transfer operators:
$H\Big[e'_{1k}\big(new\_st(p)\big)\Big] : k = \overline{2,n}$; (New station)
$i := p$;
if $i = n$ then $i := 0$;
while $q_i(t_m) = 0$ do begin $i := i+1$;
if $i = n$
then $i := 0$; end;
$j := 1$;
while $q_j(t_m) \neq i+1$ do $j := j+1$;
$q_j(t_{m+1}) := p$; $q_p(t_{m+1}) := i+1$;
$y_p := st\_on$.

$H\big[e'_{2k}(beg\_fr)\big] :\ k = \overline{1,n}$; (The start of packet sending)
$kan(t_{m+1}) := 1$;
for $i := 1$ to n do
if $i \neq k$ and $q_i(t_m) > 0$ then
$y_i := bus\_is\_oc$.

$H\big[e'_{3k}(end\_trans)\big] :\ k = \overline{1,n}$ (The end of packet transmission)
$kan(t_{m+1}) := 0$;
for $i := 1$ to n do
if $i \neq k$ and $q_i(t_m) > 0$ then
$y_i := fr\_end\big[q_k(t_m)\big]$.

$H\big[e'_{4k}(no\_data)\big] :\ k = \overline{1,n}$ (There are no data for sending)
for $i := 1$ to n do
if $i \neq k$ and $q_i(t_m) > 0$ then
$y_i := no\_data\big[q_k(t_m)\big]$.

$H\big[e'_{5k}(fail)\big] :\ k = \overline{2,n}$ (The station is switching of)
$y_1 := fail[k]$;
$i := 1$
while $q_j(t_m) \neq k$ do $i := i+1$;
$q_i(t_{m+1}) := q_k(t_m)$;
$q_k(t_{m+1}) := 0$.

5.1. Results of validation and simulation

The correctness of the created specification was investigated by means of protocol analysis system PRANAS-2. This system permitted one to investigate general protocol properties such as: completeness; deadlock freeness; boundedness; cyclic behavior; termination.

Table 1
Example of validation

```
{32}     L:  2 3 1 0
         MO:  1 0 1 1 0 1 3
           Tim_T Arr_fr Taim_DI
         M[1]:  2 0 0 0 1 1
           Swit_of Arr_fr
         M[2]:  3 0 0 0 1 1
           Swit_of Arr_fr
  ↓      Taim_DI in MO
{58}     L:  2 3 1 1
         MO:  1 0 0 1 1 1 3
           Tim_T Arr_fr Trans_fr
         M[1]:  2 0 0 0 1 1
           Swit_of Arr_fr
         M[2]:  3 0 0 0 1 1
           Swit_of Arr_fr
  ↓      Trans_Fr in MO
{104}    L:  2 3 1 0
         MO:  1 1 0 1 0 0 3
           Tim_T Arr_fr Taim_D
         M[1]:  2 0 0 1 1 1
           Swit_of Arr_fr Taim_DI
         M[2]:  3 0 0 0 1 1
           Swit_of Arr_fr
  ↓      Taim_DI in M1
{79}     L:  2 3 1 1
         MO:  1 0 0 1 0 0 3
           Tim_T Arr_fr Taim_D
         M[1]:  2 0 1 0 1 1
           Swit_of Arr_fr Trans_fr
         M[2]:  3 0 0 0 1 1
           Swit_of Arr_fr
  ↓      Trans_fr in M1
{150}    L:  2 3 1 0
         MO:  1 0 0 1 0 0 3
           Tim_T Arr_fr Taim_D
         M[1]:  2 1 0 0 1 0
           Swit_of Arr_fr Taim_D
         M[2]:  3 0 0 1 1 1
           Swit_of Arr_fr Taim_DI
  ↓      Taim_DI in M1
{92}     L:  2 3 1 1
         MO:  1 0 0 1 0 0 3
           Tim_T Arr_fr
         M[1]:  2 0 0 0 1 0
           Swit_of Arr_fr
         M[2]:  3 0 1 0 1 1
           Swit_of Arr_fr Trans_fr
```

In Table 1, some validation results are represented. The numbers included in brackets $\{\ldots\}$ refer to the number of the state. Numbers written after `L`, `MO` and `M[i]` have the following meanings of discrete and continuous coordinates of state:

```
L:    q1; q2; q3; kan;
M0:   nr; act_D; act_DI; act_T;
      act_trans_fr; st; n_act;
M[i],i=1,2:  nr; act_D;
      act_trans_fr; act_DI;sw;st.
```

5.2. Simulation results

Simulation results are represented in Table 2. The parameters of the model are the following: `Taim_Frame` – duration of frames; `Taim_Head` – duratin of the head of frames; `Taim_D` – duration of the timer *D*; `Taim_DI` – duration of the timer *DI*; `Taim_T` – duration of timer *T*; `V` – velocity of the channel; `n` – number of stations; `Arr_Frame` – parameter of a puasonian input stream; `T_swit_on` and `T_swit_off` – intensity of operations `swit_on` and `swit_off, which have exponential distributions.`

Characteristics of the model: `T_Wait` – the mean value of transmitting a frame including the waiting time; `L_Wait` – mean value of the waiting time; `K_Useful` – coefficient utilization of a channel; `K_Full` – coefficient of full utilization of a channel.

Table 2
Simulation results

`Taim_Frame` = 800 `bit,` `Taim_Head` = 160 `bit,` `Tau_Data` = 4 `bit,` `Taim_D` = 0.0000025 `s,` `Taim_DI` = 0.0000012 `s,` `Taim_T` = 100 `s,` `T_swit_on` = `T_swit_of` = `0.`

1. `V` = 10000000 `bit/s,` `Arr_Frame` = 0.001 `s`

n	*T_Wait*	*L_Wait*	*R_Useful*	*K_Full*
2	0.00011	0.00001	0.1418	0.8323
4	0.00013	0.00003	0.2806	0.8639
6	0.00016	0.00006	0.4118	0.8939
8	0.00019	0.00010	0.5297	0.9207
10	0.00025	0.00016	0.6304	0.9437

2. `V` = 50000000 `bit/s,` `Arr_Frame` = 0.001 `s`

n	*T_Wait*	*L_Wait*	*R_Useful*	*K_Full*
2	0.00002	0.00000	0.0307	0.4639
4	0.00002	0.00001	0.0611	0.4831
6	0.00003	0.00003	0.0917	0.5025
8	0.00003	0.00001	0.1219	0.5217
10	0.00003	0.00001	0.1529	0.5413

3. `V` = 50000000 `bit/s,` `Arr_Frame` = 0.000135 `s`

n	*T_Wait*	*L_Wait*	*R_Useful*	*K_Full*
2	0.00002	0.00000	0.0212	0.5921
4	0.00003	0.00001	0.3848	0.6882
6	0.00004	0.00002	0.5399	0.7864
8	0.00006	0.00004	0.6513	0.8569
10	0.00009	0.00007	0.7160	0.8979

6. Conclusions

The presented method of formal specification permits on the base of single specification to carry out validation general and individual properties and simulation. It permits to investigate the analysed system more thoroughly.

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Paper

Wearable biosensing: signal processing and communication architectures issues

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Abstract—Long-term monitoring of human vital signs is becoming one of the most important fields of research of biomedical engineering. In order to achieve weeks to months of monitoring, new strategies for sensing, conditioning, processing and communication have to be developed. Several strategies are emerging and show different possible architectures. This paper essentially focuses on issues in wearable biosignal processing and communication architecture currently running at the Swiss Center for Electronics and Microtechnology (CSEM) in the framework of several European projects.

Keywords— wearable sensors, wireless BAN, biosignal processing, low-power DSP.

1. Introduction

Wearable sensing of human physiological signals is becoming an essential part of nowadays monitoring systems [1–3] (see references in the same issue of the IEEE EMB Magazine), [4–8]. These revolutionary systems should allow clinicians, physiologists, psychologists, social institutions and people themselves to have access to a lot more information on the human body function than ever before. Long-term monitoring, from days to months, is envisaged in these systems. Several questions arose then from psychological, clinicians and technical views and should be addressed carefully in order to obtain a useful, reliable system. Social implications and psychological impacts of such systems will not be discussed in this paper, but should be kept in mind. Rather, this paper will focus on the technological aspects of such wearable biosensing systems, from the low-level physiological signal sensors to the highest level of interpretation of the extracted information and possible biofeedback to the user, and power delivery and management issues.

Figure 1 shows a generic platform for monitoring patients. Thanks to the transmission of data over mobile communication (GSM and GPRS), full mobility is offered to the patient. The system comprises sensors, processing and communication functions worn by the user, interconnected with a portable base station, which is the gateway to the Internet where the collected data are made available to the authorized professionals, i.e., doctors, nurses, etc. The portable system includes local pre-processing close to the physiological signal collection nodes and global processing which takes benefit of the availability of various types of physiological (electrocardiogram (ECG), partial oxygen blood saturation (SpO_2), skin temperature, etc.) and physical activity signals (acceleration, position, etc.) to perform efficient denoising and classification of the biosignals.

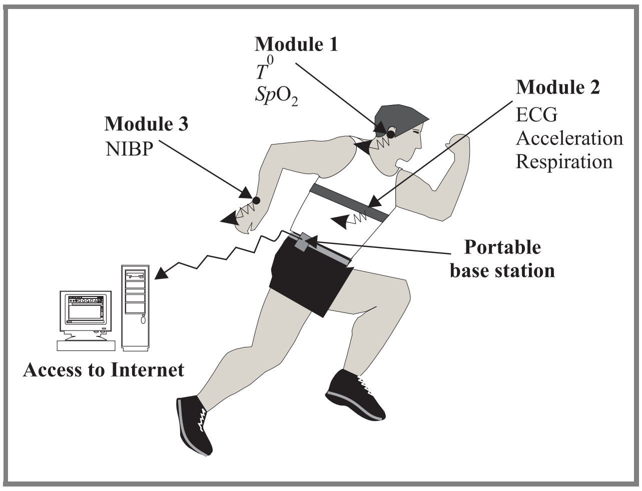

Fig. 1. Overview of a possible architecture comprising, sensors, processors and communication units (© CSEM).

The use of discrete units interfacing groups and family of sensors (e.g., electrocardiogram, respiration belts) is not practical for continuous use due to volumes, sensor placement and consequent discomfort. To make the sensors and processing really wearable, they have to be embedded in the clothes or worn in natural units such as watch earring, finger rings, headset; which are tailored for the specific heath monitoring needs of the users (sickness, professional, sports).

The architecture of the system may be described as a number of discrete layers. Distribution of functions in the layers and communication between the layers must be done in such a way that the relevant information is always properly extracted and transferred at the appropriate rate. If simultaneous recording of the signals is necessary, synchronization issues between the different sensing units have to be addressed. Figure 2 shows the different possible layers and the interconnections. The low-level *sensing* layer is divided into three localized sub-layers: sensors, signal conditioning and signal processing. The highest-level *processing* layer is divided into two global sub-layers: feature extraction layer and the personalized application layer. The processed signals are then fed to the therapists and/or the user himself.

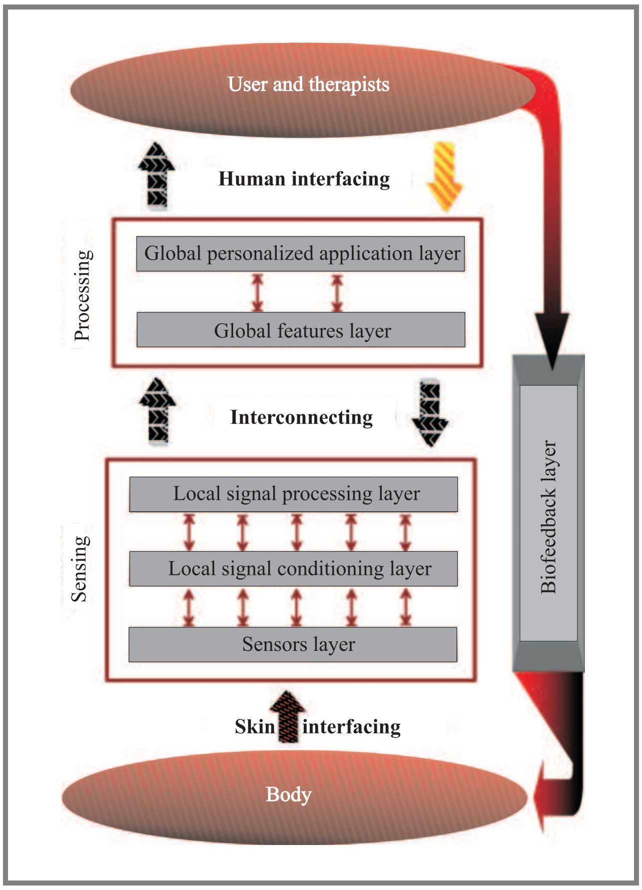

Fig. 2. Different layers appearing in the architecture of Fig. 1.

In the low-level sensor layer, new fiber materials and soft electronics technologies allowing convenient long-term monitoring are required. Textile sensors, integrated into garments, are very well suited for long-term monitoring solutions, but also provide lower quality signals implying an increase in the complexity of the analog and digital processing of the signals [5]. Typical textile sensors include: ECG, breathing, galvanic skin response, and actuators for biofeedback. Soft electronic sensors are for instance scalp electroencephalogram (EEG), accelerometers, temperature, heart rate, and SpO_2. Integrating sensors and electronics into garments in a convenient and reliable way is not an easy task and requires a high degree of miniaturization requesting the development of ASICS for mixed analog and digital techniques. Unobtrusive integration of sensors and actuators also includes the provision of adequate connector solutions to interface the electronics and the interconnection (textile or wired) of sensors and connectors. Low-level signal processing in this layer includes noise cancellation algorithms. This close-to-sensor DSP strategy is essential with low-amplitude physiological signals, to increase the signal-to-noise ratio and the channel-coding algorithm, which depends upon it. Algorithms with minimal complexity should be used due to the restriction in computing resources, i.e., memory and instructions flow rate. Packaging problems in terms of soft and wearable electronics with user-friendly power supply solutions is also to be tackled. Bi-directional flow of information in the sensing layer is meant for possible re-adjustment of the sensing device for optimal performance.

The sensing layer is then interconnected to the processing layer. Textile wiring or wireless connection is possible. The processing layer consists in high-level signal processing: feature extraction and personalized algorithm parts. The personal profile algorithm determines the current health condition and compares it to the personal reference profile, which also contains personal standard values for the collected parameters. The reference personal profile can be supported by data from external resources. If strong deviations occur, the respective therapy or biofeedback is given. Observable output variables are collected by the application layer and are used to derive the therapy recommendations.

Fig. 3. Prototype of shirt with electrodes for movement measurement at shoulders and respiration bands (plethysmography) from the IST European project WEALTHY (wearable health care system).

Target users of the intelligent biomedical clothes include patients during rehabilitation and early release from hospitals, professional personnel at risk and people during sport activities (professional or leisure). Sensing biomedical wearable can for instance:

– provide an integrated view of normal and abnormal patterns of activity, which would be otherwise difficult to detect and in situations that are usually uncontrollable by physicians;

– improve the quality of care for patients by monitoring health status during rehabilitation activities, allowing them to perform their everyday activities;

– monitor professional workers operating in extreme environmental conditions;

– support citizen and athletes by providing monitoring and processing of physiological parameters while they are performing sport activities.

In the last years, several major sport and leisure electronics companies have developed alliances with clothes industries to combine electronic functions and fashion into the clothes as shown in Fig. 3, where respiration and shoulder movements are captured by sensors in the fabric [5].
This paper is organized as follows: Section 2 will describes a selection of textile and soft electronic systems, parts of the sensing layer, including the analog processing of the signals; Section 3 will focus on one possible architecture for the processing layer. Section 4 will address the communication issues in the wearable biosensing paradigm. Section 5 will conclude this paper.

2. Sensing and analog electronics

As mentioned in the introduction, many different biosensors can be implemented depending on the type of applications. We will focus in this paper on ECG, activity and SpO_2 sensors. As most of the biosensors have an interface to the skin of the subject, artifact originating from the movement of the body is of major implications for the overall system robustness from the quality of the data to the transmission flow rate and coding strategies. As such, artefacts have to be reduced to a minimum. Analog filtering is the second step in the sensing layer (Fig. 2), and is to be designed with great care to minimize as much as possible these artefacts, typically by limiting the bandwidth of the measured signals to their frequency band of interest, by notching unwanted frequencies and by amplifying the useful signals. Other noise sources have also to be taken into account in the design of the signal conditioning layer. This section will introduce some concepts related to fiber sensors and soft electronics sensors.

2.1. ECG sensors in the garment

Electrocardiogram is a signal of primary importance in biomedical monitoring. Integrating the electrodes into a garment, miniaturizing and eventually distributing the electronics in the clothes are challenging goals which aim at strongly increase user comfort, and therefore ease and enhance the long-term monitoring of ECG signal (longer than 24–48 hours). The classical electrode patches are very efficient but not suited for integration into a garment. An innovative solution consists in alternating normal yarns and metallic yarns in the fabric at the location of the electrodes. Optimization of this technique has led to sufficiently good

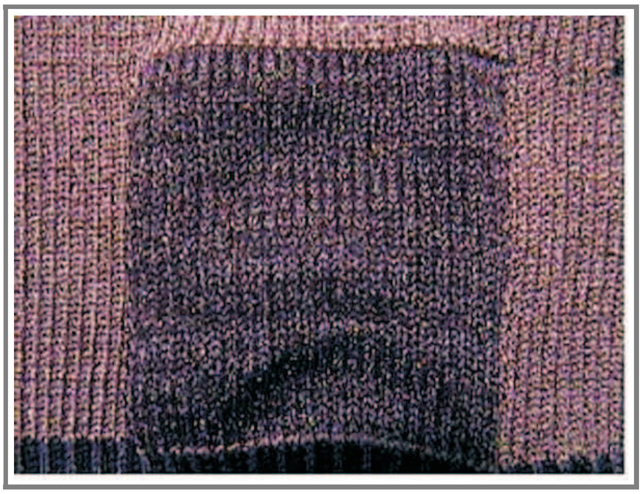

Fig. 4. ECG electrode woven in the fabric, as implemented in the IST European project WEALTHY.

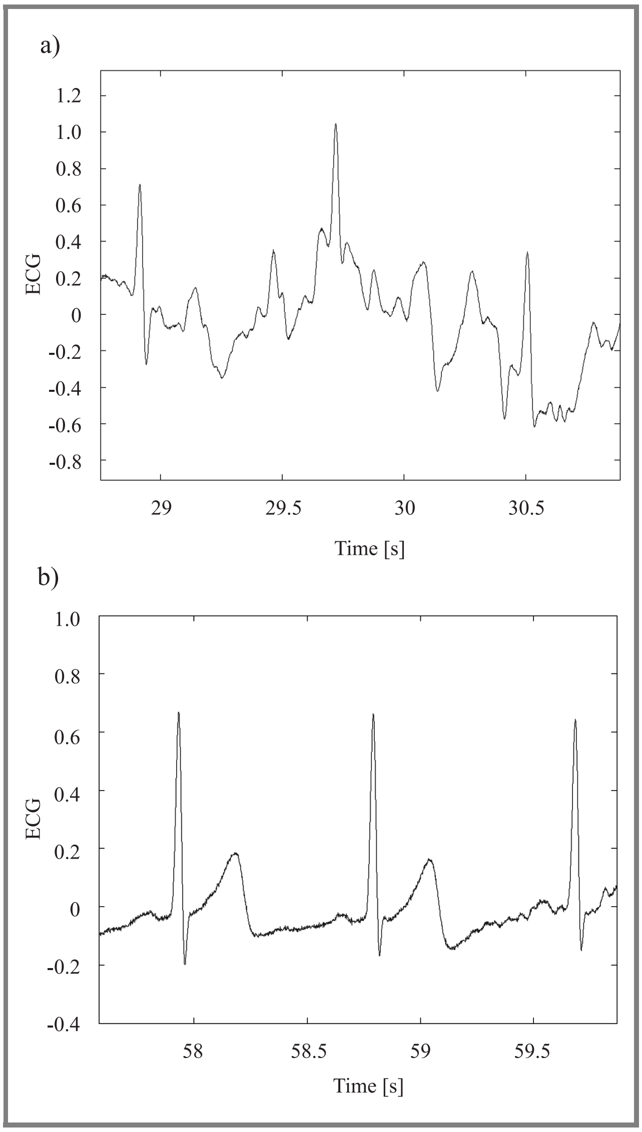

Fig. 5. ECG signal as recorded at rest with torsion artifacts: (a) without the membrane and (b) with the membrane. Signals have been recorded at Smartex in the IST European project WEALTHY framework.

signal quality, compared to classical electrode patches. Figure 4 shows an example of ECG electrode woven in the fabric [2, 5].
Two major problems have to be solved in addition to make the acquired signal useable:

– the signal acquisition must be performed while the subject is moving;

– good contact with the body skin is necessary.

Since it is not possible or wanted to ask the user to remain quiet during the measurements, signal processing has to be used to remove signal artefacts due to movements during the acquisition. Information about the activity and movements of the persons can of course be very efficiently used to really enhance the ECG signals (refer to Subsection 3.1.1). Their acquisition requires additional tissue and non-tissue sensors. Furthermore, the contact between the body skin and the fabric electrodes can be strongly improved by using a hydrophilic membrane during the measurements [5].
The ECG measurements obtained are of satisfactory quality under mild movement as seen in Fig. 5.

2.2. Activity and posture sensors in soft electronics

Two types of sensors can be used, depending of the required accuracy versus the power consumption and their location:

– piezoelectric sensors are directly woven in the fabric (fabric sensors);

– non-tissue sensors are monolithic integrated circuit such as solid-state accelerometers.

The former ones are completely buried in the fabric, and represent a good solution when activity measurement includes not only the activity of the body as a whole, but also and separately, the measurement of the movements of the arms, shoulders, legs, knees and other body areas. The drawback is a lower signal quality compared to those obtained with more complex solid-state devices, which often directly include also signal conditioning, power supply decoupling, etc. Sensor chips and very small sensors have to be encapsulated in special packages that are affixed to the textile fabrics.
In both cases, fine conductive materials woven into the fabric provide the necessary electrical connections for the signals, sensor control and power supply. The interconnection between the sensors, the electronics and the textile is still a challenge. Several solutions have been proposed in the literature. The Georgia tech wearable motherboard (GTWM) has represented a significant step in the connection of sensors and the communication modules [6, 7]. The routing of data communication and power supply was for instance further addressed in [8]. The electrical impedance of the yarns is much higher than standard wires making more difficult the acquisition of sensor signals and the transfer of data with limited sensitivity to the electromagnetic environment. Two technologies are summarized in [1]:

– conductive yarns of the fabric are prepared for contact with the electronic circuit by soldering tiny metal contacts to wire-bond the circuit. The module and the wires are then molded for mechanical protection;

– thin flexible circuit board with electrodes is glued to the textile before being molded.

2.3. SpO_2 sensors embedded in an earphone

To measure SaO_2 optically, two light-emitting diodes are used to illuminate the tissue, such as a fingertip. One light is red (e.g., 660 nm) and the other is infrared (e.g., 940 nm). The absorption of the infrared light is very dependent on the SaO_2, and the red light is less dependent of this value. Therefore the ratio of the light intensity as detected on corresponding photodetectors can be used to drive an output display calibrated to give the SaO_2 value. This method is referred to pulse oximetry and is nowadays the standard non-invasive way of estimating the SaO_2, which we refer as SpO_2 for saturation pulsed oximeters. The emitter (LED) and receiver (photodiode) can be placed either side by side on the surface of the skin tissue, or on each sides of it leading to the two techniques: reflectance and transmittance. The transcutaneous reflectance oximeter has the advantage to allow monitoring of SaO_2 transcutaneously at various locations on the body surface, including more central locations such chest, forehead, limbs, that are not accessible via trans-illumination oximetry.

Fig. 6. Earphone-based sensor together with a recorder (© CSEM).

Oximeters present important errors due to light attenuation by absorption, refraction, and multiple scattering from undesirable organs. And because of differences in the properties of skin and tissue, variation from individual to individual in attenuation of light causes calibration problems. Problems with both transmission and reflectance oximetry include poor signal with body movement [30, 31]. These artifacts can be generated in different ways: when the subject is performing body movements, hence modifying the physiology of the tissue under gravity and probe pressure on the skin, when the different layer of the sensed tissues are modified by small muscle or nerve activities induced by strain or stress, and when the light probe-tissue coupling is modified through the time by displacements of the probe on the surface of the sensed tissue. Also, a reduced perfusion (hypoxemia) of the tissue leads to wrong estimates of the SpO_2 value. A new sensor encapsulated in a standard earphone system (see Fig. 6), which can improve the reliability of such sensor under daily activities, is under development [28, 29] (see Subsection 3.1.1).

The sensor device comprises standard red and infrared lights working in trans-illumination, and is accompanied by a two dimensional accelerometer for motion compensation using digital signal processing algorithms. The final design of the SpO_2 sensor will include an interconnection layer to transmit the signals to the processing layer. Artefact removal is described in Subsection 3.1.1.

2.4. Signal conditioning and connectors issues

"Non-tissue" sensors are to be conditioned as recommended by their manufacturers, with special care on miniaturization and low-power consumption of the conditioning circuits. The same care must of course also be brought to the conditioning of tissue sensors. The non-idealistic characteristics of the latter, for instance impedance, bandwidth, linearity and passive nature (compared to integrated circuits), make the signal conditioning even more critical: on one side the signal conditioning has to damper the characteristics limitations of the sensors and on the other side it has to allow the extraction of the significant physiological signals from usually weaker acquired signals.

Interconnections, power supply and packaging require very special care, since the garment has to be soft and washable: interconnections have to be very small and robust and packaging should provide temperature, shock and water resistance while remaining small and not incommodious for the user. The problem of interconnection has to our knowledge not been satisfactorily solved yet, while some solutions have been proposed (see [1] and references therein). The main problem is bonding fabric sensors to soft/hard-electronic boards where data path connectors are discrete in space. Wire bonding methods are tedious and are still to be hand made and thus not suitable for production.

3. Digital signal processing

3.1. Noise and artifact reduction, feature extraction and classification

3.1.1. Noise and artefact reduction

Digital signal processing (DSP) algorithms for noise and artefact reduction have been used in many applications. Biomedical engineering uses these techniques more and more often since the data recorded are often corrupted by environmental noise sources (intensive care units) or from undesirable physiological sources, or from the fact that the sensor-tissue interface is not reliable and stable in the time. Such sensor-tissue interface problem is even more dramatic when sensors are embedded in the garment. If the number of signals extracted from the sensors is not too large, DSP algorithms can be implemented in the sensing layer. Otherwise, the DSP should be performed in the processing layer. Advantages of performing the DSP locally are that the information to be transmitted to the processing layer can be amplified and denoised for optimal performance of the transmitter/receiver coding/decoding strategies. Also, the source and channel coding algorithms are performing better when the noises and artefacts are reduced to a minimum. Another reason to perform the noise reduction at the local level is the possibility to reduce the number of signals to be transmitted for further processing, especially when sensors-in-the-garment are used. Indeed, sensors placed in the garment are not reliable by essence but the redundancy is used to compensate for that. An increased number of signals are thus acquired and local digital processing is used to extract a reduced number of enhanced information signals. "Voting"-like algorithms like data fusion are thus used to this purpose.

Noise reduction techniques have always to be adapted to the signals at hand, and also depend on the features to be extracted from them. Well-known techniques are for instance based on Wiener filters (WF) [6], wavelet decomposition (WD) [10] and principal component analysis (PCA) [11]. The use of one or the other depends on the nature of the signal such as the stationarity, the statistics of the information and the noise signal. Figure 7 shows a denoised ECG using WF, WD, and PCA. The WF gives the worst result, while WD and PCA give similar good performances. In most of embedded solutions, recursive or adaptive implementations of the above-mentioned signal processing techniques are necessary. For instance, adaptive PCA algorithms like APEX are quite appropriate for enhancing rhythmical signals [40], as well as other adaptive blind source separation techniques [41, 42].

Artefact reduction techniques are often based on linear filtering algorithms [32]. An artefact-correlated signal is most of the time needed for the removal. The estimation of these filters also depends on the number of signals at hand and the hypothesis of the origins of the information signals. Correlation techniques based on the Gaussian hypothesis leads to the well-known least square solutions, while the non-Gaussianity of the signals can be a good reason to use independent component analysis tools [42]. The resulting filters are anyway always linear. Adaptive implementation of these filters is often used because they require less computing and memory resources than their block-based counterparts (see Subsection 3.2 for details about implementation) [40, 41]. In ambulatory conditions, movement artifact removal can be done using acceleration signals measured close to the sensor. Artifact removal is aimed at recovering the information signal that is masked or distorted due to body movement and resulting in modification of physiological properties of life tissues or organs.

An example of artefact reduction is presented hereafter for heart rate and possibly SpO_2 estimation. Artefact reduction/rejection techniques for robust SpO_2 estimation during

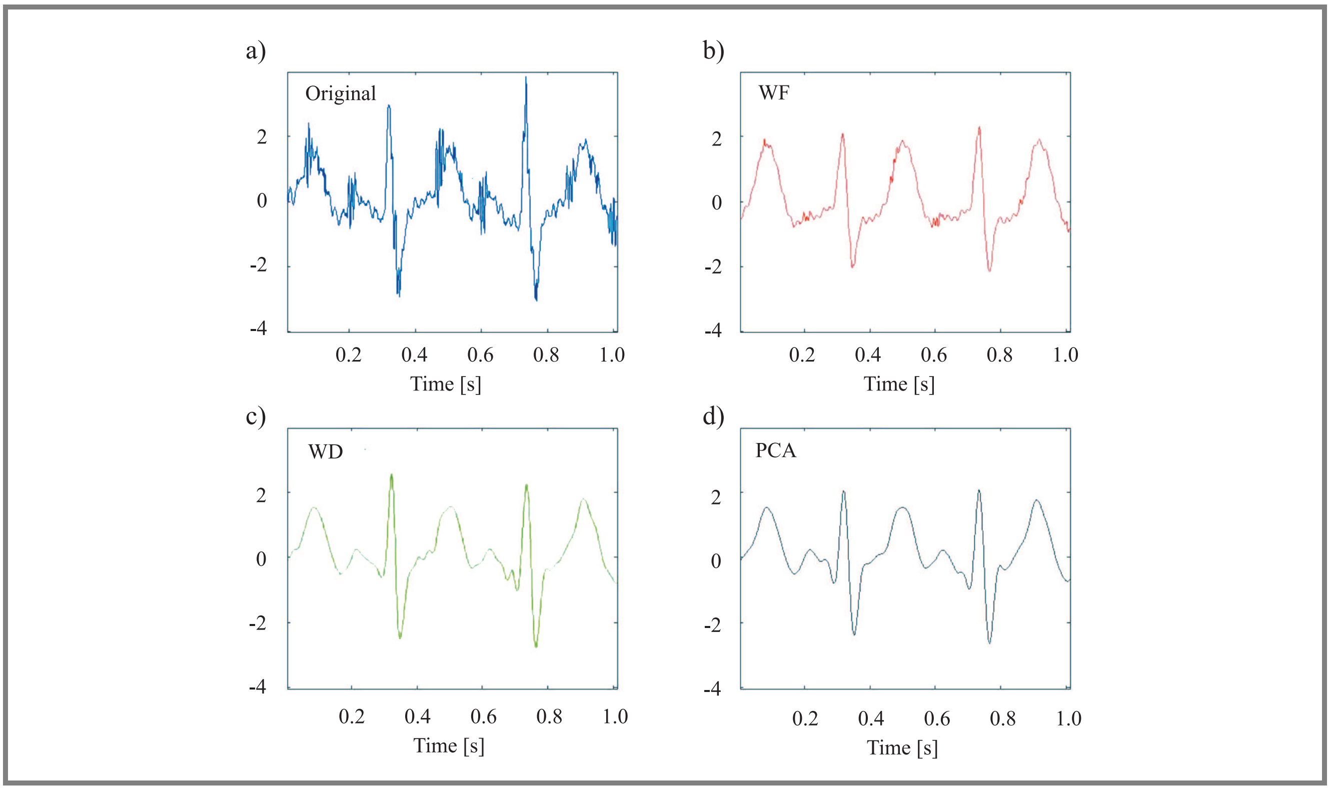

Fig. 7. Example of denoising algorithms: (a) it the noisy ECG; (b) is the WF denoised; (c) is the WD denoised, and (d) is the PCA denoised.

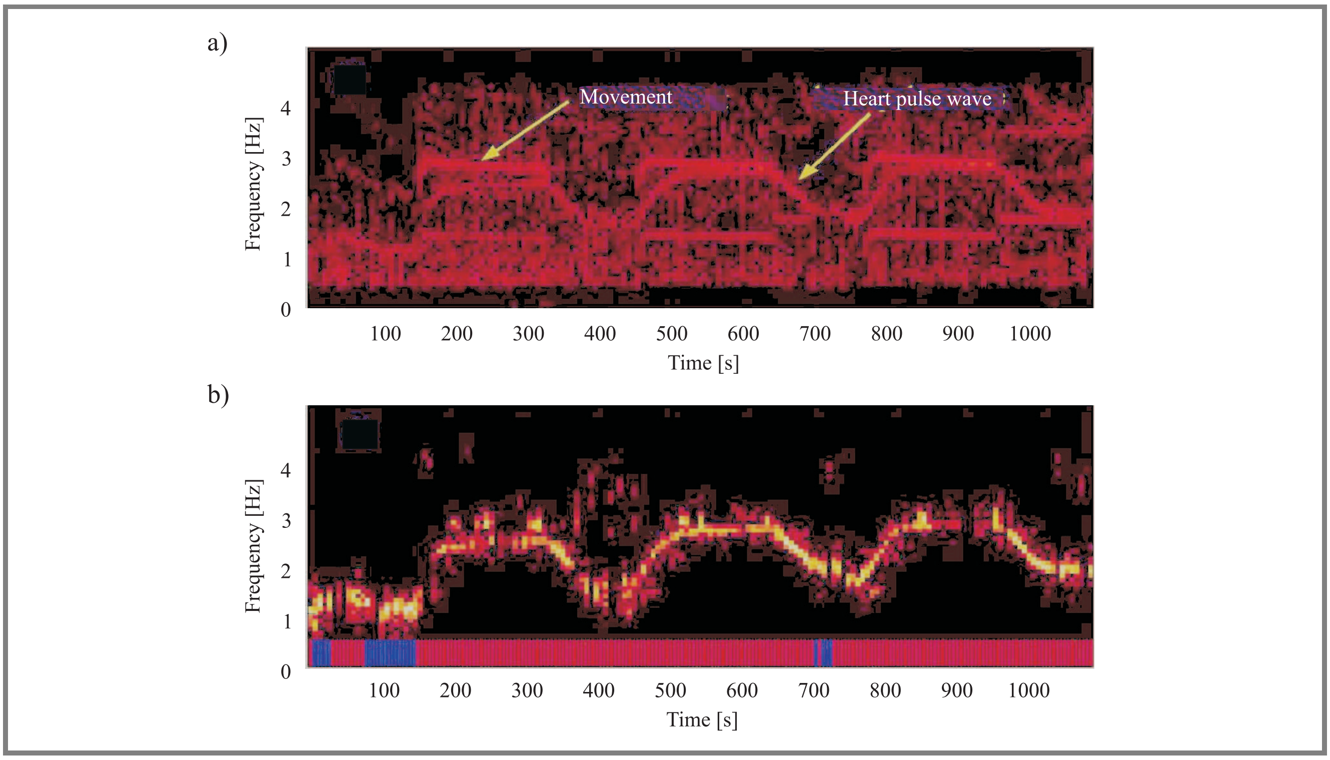

Fig. 8. Spectrograms of the infrared signal: (a) before, and (b) after artifact removal.

low perfusion and movement artefacts have been developed since about 20 years. The first technique dealing with artefacts is the rejection method that use an artefact detection followed by a rejection of the corrupted data. This technique is well suited for short time period but not at all for ambulatory applications where periods of corruption can extend to several minutes. For this reason, signal enhancement techniques have been developed [22, 29, 30, 31]. Figure 8 shows the spectrogram (joint time-frequency representation) of band passed (0.5 Hz – 8 Hz) infrared signals before and after artifact removal, acquired on a subject who was performing alternatively jogging and walking activities. We clearly distinguish the heart pulse wave together with rhythmical movements in Fig. 8a, while only the heart pulse wave can be seen in Fig. 8b after movement artifact have been removed.

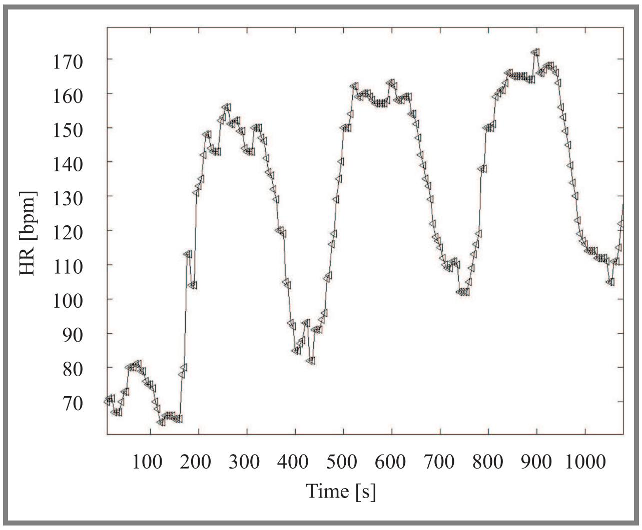

Fig. 9. Estimated heart rate from the enhanced signal who's spectrogram is shown in Fig. 8b.

It is also possible to extract the heart rate from these enhanced signals using robust statistical signal processing [22, 29]. The calculated heart rate is showed in Fig. 9. Note also that the head movements, extracted from accelerometers placed in the earphone, have been recorded and processed to extract some information concerning the type of activity the subject is performing. The color bar at the bottom of Fig. 8 indicates the type of activity: red means that the subject is walking or running, and blue that he is not performing movements. Finer analysis of body movement can be performed and is presented in Subsection 2.2.

3.1.2. Feature extraction and classification

Feature extraction is the essential part of the processing prior to any classification schemes. Features depend on the signals and can be signals variability indices, power densities in physiologically relevant frequency bands, signal model's coefficients (i.e., autoregressive or lumped models), transfer and coherence function, or entropies. The choice of a pertinent small size feature set can improve a lot the personal classifiers task. Many classification algorithms exists such as: linear vector quantization, C-mean, fuzzy C-mean, support vector machine (SVM), hidden Markov models (HMM), self organizing maps (SOM), artificial neural networks (ANN), Bayesian learning (BL), decision trees (DT), discriminant analysis (DA) [37–39]. Some of them are much too complex to be thought of being implemented in DSP processors. Mainly three approaches can be retained for low-power wearable applications: DA, HMM, BL, and ANN.

For instance, if we are interested by cardiovascular dysfunction monitoring, the ECG and its related QRS-T complexes time series such as RR and QT, gives much information on a beat-to-beat basis. Fluctuation analysis of such signals and extraction of features lead to a finer analysis of the behaviour of the cardiovascular system. For instance, so-called HRV indices including power in the very low frequency (VLF: 0 Hz – 0.04 Hz), low frequency (LF: 0.04 Hz – 0.15 Hz) and high frequency bands (HF: 0.15 Hz – 0.4 Hz), and LF/HF ratio have been used for monitoring sympathetic/parasympathetic dysfunction [20], and anesthetic level. Wearable systems have used HRV for monitoring stress level as presented in [21]. Figure 10 gives an example of such indices for RR and QT time series extracted from a subject in walking and running conditions. The cardiovascular response to the physical activity is clearly indicated by all indices. In particular the walking activity from 0 to 10 min and from 25 to 35 min is distinguishable in the LF/HF ratio in the RR time series, while not in the QT ones. The walking activity is also different after the running activity than before it. The running activity from 10 to 25 min gives rise to LF/HF changes in both RR and QT data.

Other stochastic features can be used for HRV analysis such as, renyi, spectral and approximate entropies. Nonlinear features have been shown to be much more sensitive to noise and signal distortions and are not recommended. For most of them, they require lots of computing power and are thus not recommended for online implementation on low-power DSP.

Human movement monitoring is essential because it gives information about body gesture and movement. Acceleration signals gives important information regarding the type of activity the subject is doing.

The aim of the classification of the activity signals is to detect non-stationary segments and to provide information about the physical activity of the subject. Typical activities that can be classified are: static, running, walking, cycling, and non-rhythmical movements. Features are extracted from the acceleration signals using dedicated signal processing and information theory such as variance, spectral frequency power and entropy estimations [24, 29]. Actigraphy is aimed at long-term monitoring of activity. Someren *et al.* have presented such a system in [24] using a single-axis accelerometer. Other approaches have been proposed using three single-axis PCB mounted device for 3D acceleration sensing [25, 26].

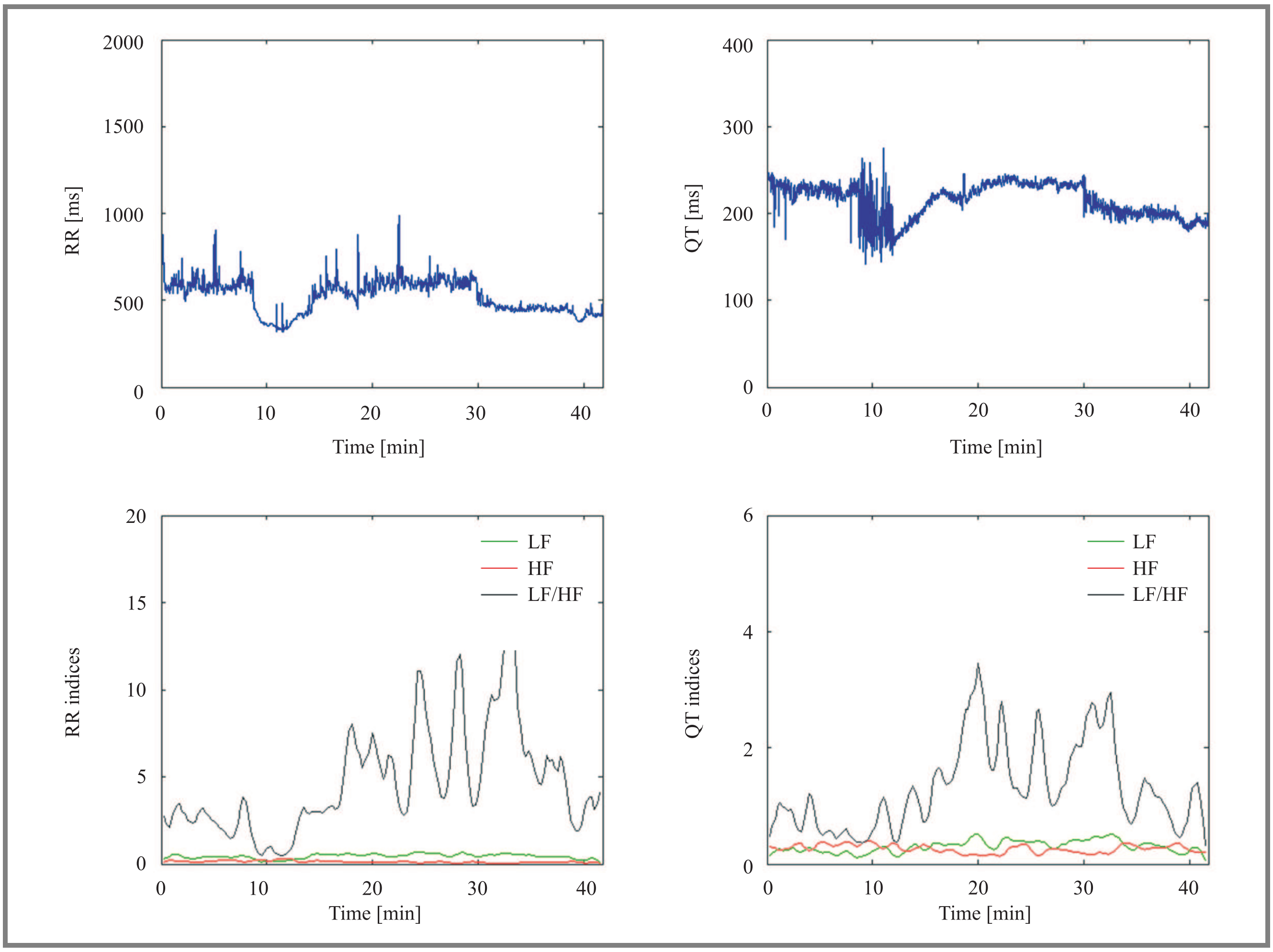

Fig. 10. Online extracted RR and QT time series on a running and walking subject together with the LF, HF and LF/HF features.

We developed a three two-axis accelerometer system and used hidden Markov model to classify the features according to the previously defined classes [23]. This choice was motivated by the fact that hidden Markov models includes temporal information into the model. Figure 11 shows an example of activity classification. Due to discomfort caused by sensors attachment, in certain cases, current kinematic systems are not easy to use during long term monitoring of physical activity. We have worked on a two-axis acceleration sensor located in a headphone for movement artefact heart rate cancellation and also actigraphy [29]. For this reason, we intend to locate the kinematic sensors along with the ECG and respiration sensors in the same wearable (see Subsection 2.2).

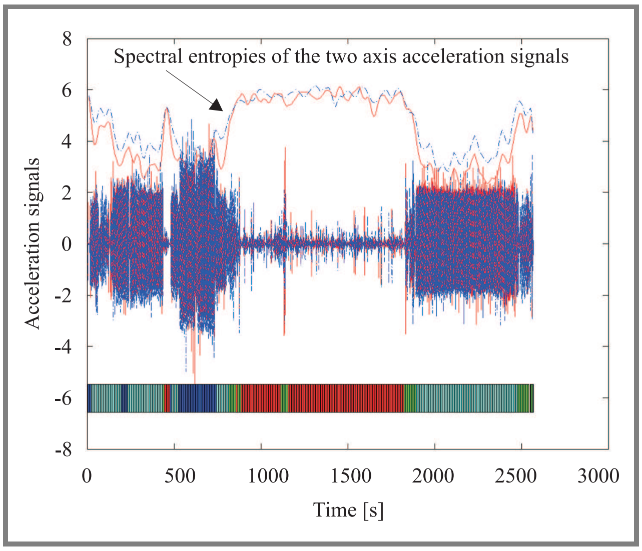

Fig. 11. Example of activity classification together with 3D acceleration signals as measured on the chest with ADXL202.

3.2. System architectures for low-power processing

3.2.1. Energy per operation and energy per transmitted bit

A body area network (BAN) is a collection of nodes that all contain sensors, on body wires or RF link and some digital processing. Some sensors capture the physiological signals. Processing is then performed on the data and transmitted by wires or wirelessly to other nodes or base stations (Fig. 12). The main challenge is the reduction of the power consumption of each node and of the overall system.

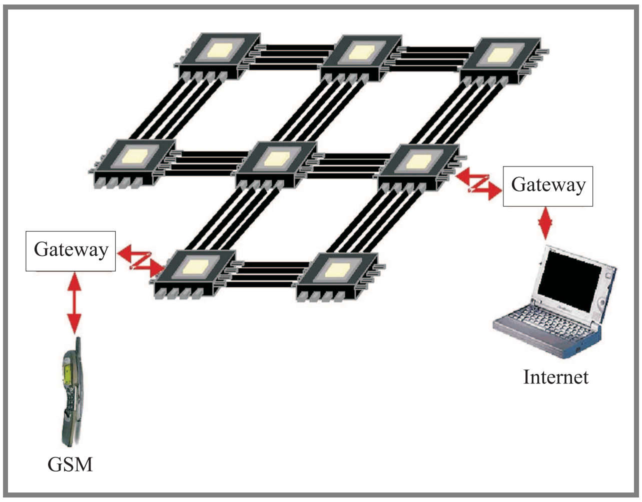

Fig. 12. Sensor array architecture for processing and transmission of biosignals.

The total power has to be optimized by analyzing the trade-off between the energy cost of computing and transmission. Since the wire or radio transmission per bit is very power hungry, the low-power constraint does not allow transmitting the whole physiological data captured for doing the required processing remotely. This processing has therefore to be done locally and hence requires very low-power techniques for the chip design. This dramatically reduces the energy required for the extraction of the desired information as explained below.

The I/O power is roughly 50% of the total power of a chip. The capacitance of an I/O wire on a board is roughly between 50 to 100 pF. Some low power techniques have to be used, for instance a low voltage swing an a wire; at 200 mV, the power per wire could be 1 mW at 1 Gbit/s while it would be 20 times more at full swing [18]. The peak current is also an issue, as there is no decoupling capacitance to absorb large current spikes. The latter generate a lot of noise and it is a good practice to separate the supply voltages of the I/O and of the chip core [18].

On the wireless communication side, a bluetooth link is assumed to consume 80 mW in sending mode and 10 mW in receiving mode and is therefore not a low-power transceiver. In ISM bands (434 and 868 MHz), low-power RF front-ends are reported, consuming about 1.8 mA at 0.9 V in receiving mode and 10 mA in sending mode in a 0.18 μm technology [19].

However, the average power consumption is mainly related to the duty cycle of the transmission process. If the nodes are most of the time in sleeping modes, the average power could be acceptable. So the tradeoff between the numbers of transmitted bits and the possible local computation achieved in the SoC itself has to be defined taken into account the duty cycle.

The energy per transmitted bit compared to energy for processing is an interesting feature:

– roughly about 100 nJ/bit is required for radio transmission (short distance, about 1 m);
– roughly 1 nJ/bit is necessary for wire transmission on a printed circuit board (at full swing);
– it could be more than 1 nJ/bit for wires embedded in clothes;
– the energy per operation in a general purpose processor is roughly 1 nJ/operation;
– 0.25 nJ/operation or less is required for a DSP core;
– 0.001 nJ/operation or less is necessary in specific co-processors and random logic blocks.

In most of the applications in the e-health domain, the electrocardiogram (ECG), respiratory pattern (RESP) and activity (3DACC) are essential. If we assume that one node capture these signals and that ECG, RESP and 3DACC are sampled at 500, 40 and 40 Hz at 16 bits giving a total of 10.56 kbit/s, and sends these data without processing through 10 nodes and finally by RF link to a base station, the total energy per second or power consumption is:

10 nodes · 10.56 kbit/s · 1 nJ (wires) + 10.56 kbit/s · 100 nJ (radio) = 1 160 000 nJ/s = 1 160 000 nW.

Let us assume now that this given node performs a local processing with a low-power DSP core to extract the heart rate (HR), QT and ST, breath rate (BR), and activity class (4 classes) which represents the information. The number of bits to be transmitted per second is reduced to 100. To perform this parameter extraction, the DSP needs for instance 100 000 operations per second (as well as some operations to receive-send data in each node, i.e., 10 000 operations per second and per node). The total energy per second or power consumption is the following:

100 000 operations/s · 0.25 nJ (operation) + 10 nodes · 10 000 operations/s · 0.25 nJ (receive-send) + 10 nodes · 100 bit/s · 1 nJ (wires) + 100 bit/s · 100 nJ (radio) = 70 000 nJ/s = 70 000 nW.

The power consumption is reduced by a factor of 16 in the second case. The radio energy is generally the largest one, but in the second example, using a DSP core instead of a general purpose processor helps to reduce the total energy from about 3 000 000 nJ to 25 000 nJ (a factor of 120, from 3 000 000 operations at 1 nJ per operation (as a microcontroller, compared to a DSP, requires about 30 times the number of operations for the same task) to 100 000 operations at 0.25 nJ per operation). It is therefore mandatory to design very low-power DSP cores for such applications.

3.2.2. Implementation issues

Digital signal processors implemented in modern submicron CMOS technologies require many transistors. The MACGIC DSP core [16] has 500 000 transistors and up to 1 million with memories. However, in 0.18 μm technology, the silicon area is a few mm^2. The main problem is definitively the power consumption for a given level of performances for battery-powered application. It is why the supply voltage is drastically reduced, as power consumption is proportional to Vdd^2. The MACGIC DSP, at very low supply voltage (0.8 V) but at low speed (5 MHz) consumes about 1 mW executing 60 millions of operations per second (MOPS). It can be translated in 60 000 MOPS/W or 0.02 mW/MOPS.

According to [12], Table 1 shows the evolution of DSP processors. To succeed in the mentioned performances end 2012, very new ideas have to be proposed and tradeoff between performances, power consumption and flexibility.

Table 1
Performances of DSP processors

Parameters	Years			
	1982	1992	2002	2012
Technology [μm]	3	0.8	0.18	0.02
Nb MOS	50K	500K	5M	50M
Vdd	5.0	5.0	1.0	0.2
MHz	20	80	500	10K
MOPS	5	40	5K	50K
MOPS/W	4	80	10K	1M
mW/MOPS	250	12.5	0.1	0.001

Some interesting implementation techniques can be introduced at power management level. The goal is to provide variable and very low supply voltages and reduced operating frequency for dynamic voltage scaling (DVS) as well as bias voltage to increase transistor threshold voltages (V_{th}) in idle modes. The power management strategy has to take into account many parameters, such as the tasks of the application, task deadlines and the number of cycles of the tasks. It can be implemented on a micro-operating system executed in an embedded micro-controller [17]. It is based on the state transitioning times, i.e., the overhead for turning off (save processor state) and wake-up in a finite (how long) amount of time. This requires predictions about the workload of the tasks that have to be executed.

4. Communication

If we look at Fig. 2, communication takes place between any two adjacent sub-layers. At the lowest layer, between the sensors layer and the local signal conditioning layer signals from the sensors are transported in raw analogue or digital form. Between the local signal conditioning and the local signal processing layers and above the information is likely to be carried in a digital form. This opens the door to communication using local area network technologies such as fieldbusses [33] or wireless sensor networks. In the sequel of this chapter, we will restrict our discussion to networked digital communication and address the issues raised when introducing networks to transport the information at the various levels depicted on Fig. 2. Communication may use wires or be wireless. Both cases will be discussed. Communication may also take place between the person and its environment as in Fig. 1 between the portable based unit and some fixed computer giving access to the Internet. This type of communication that operates in parallel with the communication between the worn units is more conventional and will not be detailed here. We will however discuss its impact on the storage of data within the whole system.

4.1. Advantages of network based solutions

As compared to conventional point to point links, networked based solutions exhibit a number of interesting advantages:

- It is possible to transport control information in addition to the process data. In particular, this permits remote access to diagnosis and calibration functions.
- Cabling costs are reduced. This includes cables, connectors, planning, installation, commissioning and maintenance.
- Acquisition and processing may be easily separated. Changing a sensor will not affect the rest of the system if the interface does not change.
- Extensions may be performed much quicker and at lower cost because few cabling if not no cabling at all is necessary.
- Values from a sensor or any application may be transmitted to any other node. This avoids duplicating sensors and cables.
- Better signal quality as analog values are converted close to their source.

There is however a price to pay. The main drawbacks are:

- Slower data transfers as the medium is shared by all transfers (as compared to a dedicated line for each transfer). This also directly impacts the temporal consistency (see below).
- The network is a single point of failure.

4.2. Requirements

Since the advent of sensor networks in the mid 80 s, a number of studies have addressed the requirements that such networks should fulfill. The work done under the International Standard Organization is a good example of them [34]. The main requirements are the following:

- Handle periodic traffic with different period durations. This is due to the nature of most signal processing applications that are based on periodic sampling of the inputs.
- Handle sporadic traffic with bounded latency. Sporadic traffic, sometimes called aperiodic, corresponds

to transfers on demand of an application. For instance, a number of applications are triggered by events occurring at their inputs. The events should hence be transported as soon as they appear (not a in a periodic manner) whereas the occurrence in time of the event is not known a priori.

- Provide indication for temporal consistency. The fact is that control or acquisition systems expect that different sensed values correspond to sampling instants that should be close to each other (within a few percents of the sampling period). This is very easy to achieve when the inputs are connected directly to the computer on which the application runs. When using networks, latencies are such that this property is lost if no additional mechanism is present. The network should hence provide ways to support this property, named temporal consistency, and to know if a set of values exhibits the property. Note that solutions based on clocks are not sufficient to support the property. Sometimes the age (time elapsed since sampling) of a data, also called absolute temporal consistency, is also important to its users.
- Allow for quasi-simultaneous sampling of a number of inputs. This is a direct consequence of the temporal consistency requirement. This applies most of the time to periodic traffic but may occasionally be required for on demand transfers.
- For sporadic traffic, provide ways to know the order in which events have occurred. An application will take different decisions depending on the order in which events have occurred. As the events are potentially detected on different nodes of the network and may be transported in a different order than the occurrence order, there should be a way to find out the order.
- Transfer data from one node to another or simultaneously from one node to a number of others.
- Be resilient to interference, vibrations, etc.
- Offer a low cost solution. The cost picture includes the devices (nodes, connectors, cables, hubs, switches) as well the planning, installation, commissioning and maintenance expenses.

Although these are not the only requirements, they are the major ones that make sensor networks different from other networks found in the office environment.

4.3. The special case of wireless transmission

Wireless transmission means (optical, radio, induction, etc.) are very appealing because they suppress the interconnection problems caused by wires. The typical example is the SpO_2 sensors at wrist, finger or ear, and blood pressure sensor at the wrist level which preferably would need wireless link. However, they add a number of constraints that should not be underestimated. The properties that have the strongest impact are:

- Compared to cables, radio transmissions suffer from bit error rates (BER) that are some orders of magnitude higher. BER of 10^{-3} to 10^{-4} are usual whereas in cables one may expect BER ranging from 10^{-7} to 10^{-9}. Error detection schemes should hence be enhanced accordingly.
- Radio transmissions suffer from frequency selective multipath fading. Waves may follow different paths that interfere destructively at the receiver site. This results in impossibility of communication at some point in space. Using spread spectrum techniques can mitigate this effect.
- Perturbing systems can easily jam radio transmission. This is especially true in the ISM (instrument, scientific and medical) bands. For instance, in the 2.4 GHz band, high power medical devices are allowed. They may completely suppress all communications for long periods of time.
- The signaling rate is most of the time limited to a few tenths of kilobits per second and seldom exceeds 10 Mbit/s.
- Spatial reuse is low as spectrum is limited. This means that coexistence of several systems in the same area should be either planned (code or frequency allocation) or the medium access control should be designed in a way that takes care of the interference between systems.
- Transmission distances are smaller but this is not a problem in our case.
- Higher cost. Due to its intrinsic complexity, radio transmission is more expensive than cable transmission. However, this cost may be offset by lower installation costs.
- The radio bands cannot be used freely. There are a number of "free" bands, most of them ISM, but their use is governed by a number of rules. For instance, some bands are not allowed to be used 100% of the time. Duty cycles as low as 0.1% can be found. Finally, the number of bands that are available world wide is very restricted. The 2.4 GHz ISM band is among this few.
- While taping a cable requires physical access to the installation, spying radio communication can be done easily. If required, special measures should be added to ensure confidentiality.
- When is wired transmission is used, power can be transported in the same cable. With wireless, nodes may have to operate on batteries. This calls for special battery conserving transmission techniques.

Wireless light transmission may also be used. It is however less common because direct visibility is required. Generally speaking, solutions designed assuming a wired connection cannot be used on wireless transmission without important modifications [35]. In addition, contrary to wired communications, it is wise to design solutions that are able to withstand absence of communication for long periods of time. This is a direct consequence of the first three properties depicted above.

4.4. Communication architecture

Communication takes place on the person (body area network) between all the worn devices and between the person and the external world for instance between the portable base station and a fixed computer that gives access to the Internet (Fig. 1).
In the first case, as mentioned above, a communication network may be inserted between any two adjacent layers (Fig. 2). This suggests that more than a single network may be used. However, in the context of wearable systems, it seems unlikely that multiple networks will coexist on the same person. This means that, either communication may violate the layered approach, or all the connected devices comply with the layered approach in such a way that communication takes place at a single level. A logical solution would hence be to put the network between the sensing layers and the processing layers. Violating the layered approach is also possible. It would however put more constraints on the network.
The above subsections may give the impression that communication must be either wired or wireless. This is by no means implied here. On the contrary, it is perfectly possible to build a solution that combines both types of medias [36].
Communication between the person and the external world may use conventional networks such as wireless LANs provided the application is able to comply with the limitations of such networks in particular in terms of real-time guarantees and consumption. This has strong implications on the presence of local storage on the body worn units as discussed in the next subsection.

4.5. Storage and transfer of data

Generally speaking storage is a necessary evil to compensate for the asynchronisms in the overall system. In other words, would the applications and the communication systems be predictable, storage could be reduce to a minimum if not suppressed. With the use of wireless networks, buffering may also be necessary to cope with the periods of inaccessibility in which the units cannot communicate. In such a case, transfers will occur in bursts when the units can communicate. The normal throughput of the network should hence be larger than the average throughput required by the applications. Between bursts, processed data should be stored locally. An extreme case would be a worn unit that communicates with the care center once a week. Obviously, the local storage should be large enough to retain a week of data. Furthermore, the connection between the patient and the center should provide enough throughputs to transfer the stored data in a reasonable amount of time (a few seconds or minutes).
Even in the case of a permanent connection between the patient and the care center, storage should be planned on the patient to account for the possible losses of connections.

In the context of wearable systems, buffering may occur at different places. It may occur within the sensing layers, within the processing layers or both. The first case is less frequent for at least two reasons:

- Algorithms in the processing layers are executed in a periodic manner. If data is missing, it is not possible to wait until it is retransmitted at a later instant.

- Retransmissions when the first attempt did not succeed create unpredictable behavior and potentially double the necessary network bandwidth. This in its turn increases the cost and should be avoided.

There are however cases in which all data should be kept and storage should be performed at the sensory level. Storage in the processing layers is more common because asynchronism is possible (off line processing) and units at this level tend to be in lower numbers making the storage comparatively cheaper.

5. Conclusions

Wearable sensing is far from being mature and needs lots of improvements concerning the power distribution and the ergonomics of the systems. User functionality performances and clinical relevance of the extracted information will impinge on the final market potentials, rather than the individual sensor technical performances.
Communication between wearable units is largely governed by the special needs of signal processing of sensory information. If there are adequate solutions running on wires, existing wireless solutions do not comply with the requirements. Even in the case of wireline solutions, some progresses should be made to reduce further the power consumption and cope with the special nature of fabric embedded connections.
This paper has shown the emerging technological architectures, possibilities and limitations of wearable biosensing. Without doubts, within 5 to 10 years, some of these systems will become available on the market, and CSEM is aimed at playing a central role concerning the electronic and signal processing in wearable biosensors and systems.

Acknowledgements

We are grateful to R. Paradiso from Smartex s.r.l who has provided us with ECG measurements in the framework of the IST European project WEALTHY. At CSEM, this work is currently financially supported by three European projects: U_R_SAFE, WEALTHY and MyHeart.

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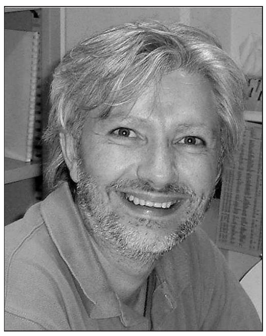

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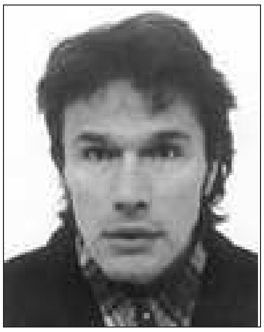

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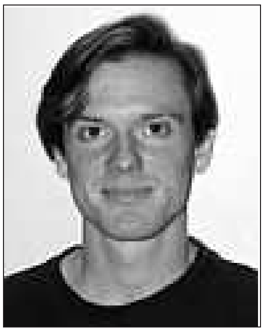

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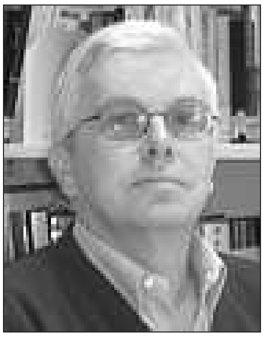

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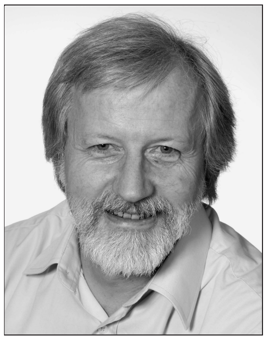

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Paper

WEALTHY – a wearable healthcare system: new frontier on e-textile

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Abstract— A comfortable health monitoring system named WEALTHY is presented. The system is based on a wearable interface implemented by integrating fabric sensors, advanced signal processing techniques and modern telecommunication systems, on a textile platform. Conducting and piezoresistive materials in form of fibre and yarn are integrated in a garment and used as sensors, connectors and electrode elements. Simultaneous recording of vital signs allows extrapolation of more complex parameters and inter-signal elaboration that contribute to produce alert messages and patient table. The purpose of this publication is to evaluate the performance of the textile platform and the possibility of the simultaneous acquisition of several biomedical signals.

Keywords— fabric sensors, fabric electrodes, physiological signs.

1. Introduction

One of the emerging new tendencies for healthcare monitoring systems is rising from areas relatively far away from the traditionally involved technologies.

During the last decade we have assisted at a revolution in telecommunication domain, while during 80's the electronic devices scale has shifted from a micro to a nano dimension. Nowadays, a new generation of monitoring devices based on the growth of the knowledge derived from the past research experience and on the use of textile multi sensing interfaces is rising.

The systems have to combine the advances of telecommunication, microelectronics and material science to guarantee a continuously remote monitoring of multiple physiological functions, as well as comfort and wearability. The spotlight is shifting from external environment control to human oriented systems, where the subject-actor is constantly virtually linked and interactive.

This tendency is changing dramatically the common life style, as well as the needs of people. Citizens are becoming more and more used in telecommunicating and in managing information, and the idea of a surrounding virtual world is no more an alien concept. New tools are being developed to be used every where, during normal life, capable to help people to increase their health status awareness, to train them to act at a preventive level by modifying their life style, to give them the feeling of a reassuring link. The interaction between physician and patient is growing in quality and the contribution is coming from both sides.

New systems designed to be minimally invasive, based on flexible and smart technologies conformable to the human body are conceived to improve the autonomy and the quality of life of patients. They are also cost-effective in providing around-the-clock assistance, in helping physicians to monitor cardiac patients during rehabilitation phase, in decreasing hospitalization time.

The system can also assist professional workers subject to considerable physical and psychological stress and/or environmental and professional health risks.

The aim of the work presented is to set up a fully integrated garment system, able to acquire simultaneously, in a "natural" environment a set of physiological parameters. The system is designed to be minimally invasive, comfortable and wearable, to this aim conductive and piezoresistive materials in form of fibre and yarn are used to realize clothes where knitted fabric sensors and electrodes are distributed and connected to an electronic portable unit, the acquired signals can then be transmitted to a remote monitoring system.

The simultaneous recording of vital signs allows parameters extrapolation and inter-signal elaboration [1, 2] that contribute to produce alert messages and personalized tables of user's health.

2. The WEALTHY system

Strain fabric sensors based on piezoresistive yarns, and fabric electrodes realized with metal based yarns, enable the realization of wearable and wireless instrumented garments capable of recording physiological signals and to be used by the patient during everyday activity. Breathing pattern, electrocardiogram, electromyogram, activity pattern or behaviour, temperature, can be listed as physiological variables to be monitored through the proposed system. A miniaturized short-range wireless system can be integrated in the sensitive garment and used to transfer the signals to the WEALTHY box/PCs, PDA and mobile phones. An "intelligent" system for the alert functions, able to create an "intelligent environment" by delivering the appropriate information for the target professional is the complementary function to be implemented. The system is targeting the monitoring of patients suffering from heart diseases during and after their rehabilitation.

3. WEALTHY functions

The WEALTHY system has been developed as the integration of several functional modules. The main functions are shown in Fig. 1, namely: sensing, pre-processing, transmission, processing and data management.

The garment interface is connected with the portable WEALTHY device where the local processing as well as the communication with the network is performed. A knitted fabric platform containing insulated conductive tracks connected with sensors and electrodes has been implemented to make the cloth. Most signals are transmitted unprocessed to the monitoring system where they can be analyzed off-line. In order to reduce the needed data capacity of the wireless link to the central monitoring system, some sensor signals are processed by the portable patient unit (PPU) to extract essential parameters. Local pre-processing of signals has to be decided in a trade-off between the gain in term of wireless link occupancy and the increase of needed local processing power.

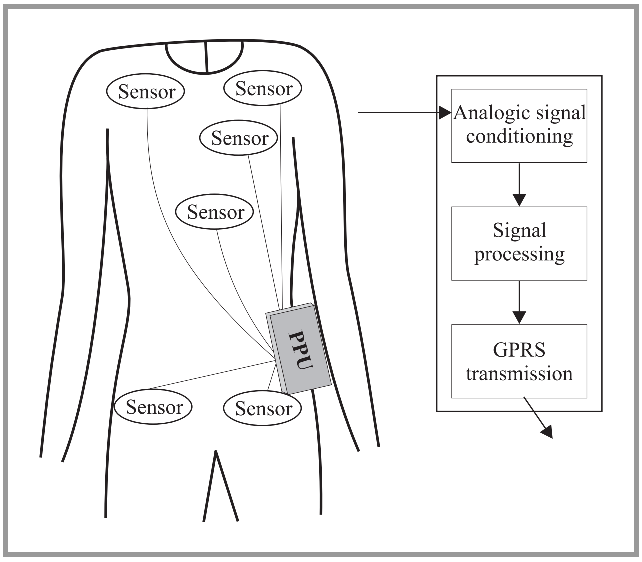

Fig. 1. Overall WEALTHY function.

The ECG leads that can be gathered are:

– precordial V2 and V5;

– einthoven D1, D2, D3.

ECG signals are sampled on the PPU at 250 Hz, a local processing is applied in order to extract parameters with a higher sampling rate, so that ECG parameters, such as heart rate (HR) value and QRS duration can be computed with a significant number of samples.

In order to decrease the amount of data transmitted by GPRS, the ECG signal is decimated to obtain a sampling rate of 100 Hz, and the operator at the monitoring centre can view and record only one ECG signal by selecting the desired one.

Respiration and movement activity come from piezoresistive sensors, sampled at 16 Hz. The signals from these sensors are transmitted without local processing.

The PPU is designed to have a simple user interface, a few LEDs and a buzzer for user warning purpose and a button to let him manually trigger an alarm. The PPU electronics is built on an "Europe" form factor board (first prototype dimension: 160 mm × 100 mm, first prototype weight: 400 g) and packaged in a metallic enclosure. It contains the necessary functions to condition physiological signals, such as filtering, digital analysis and to perform specific higher level processing like HR extraction, run the application, as well as communicate over GPRS with a monitoring centre. All the circuits, sensors and communication module are powered by a 1100 mAh/3.6 V lithium battery. The battery autonomy ranges between a few hours and eight hours, depending on the level of use of the GPRS link. It can be recharged using a dedicated front panel connector.

The WEALTHY central monitoring system is a s/w module interpreting physical sensor data received from the PPU and representing them in simple, graphical forms. It will be used by the proper staff in order to judge the automatically generated alerts and forward only the critical alerts to the doctors and the patients.

The central monitoring system performs the following tasks:

– coordinates and controls the data flow between the different actors;

– collects and stores the data transmitted by the sensors integrated in the WEALTHY garment through the portable patient unit;

– continuously monitors vital health parameters of the patients;

– generates alerts to inform doctors for critical health situations;

– gives access to the central database to doctors and other health professionals;

– presents to the qualified users the health situation of the patients using different user-friendly interfaces.

All the monitoring system modules are able to run on a single computer without the need of dedicated high-end servers.

The final aim is to recognize those parameters that define an event. Several statistical tools based on a multifunctional analysis, such as principal component analysis (PCA) or independent component analysis (ICA), may be used for this purpose. In order to offer full mobility to the patient or the user, the acquired signals are transmitted wirelessly from the PPU to the remote monitoring system. The communication is based on TCP/IP that is the standard protocol for GPRS communication. For GPRS bandwidth limitation reason, the monitoring centre shall select the ECG lead to be transmitted (one at the time). All signals are sent in quasi real-time to the remote monitoring centre.

Off-line processing, depending on the application, is carried out at the monitoring centre. A preliminary list includes:

– tachogram;

– ST deviation;

– T wave area;

– spectral analysis of RR signal.

Combining these parameters and the information obtained by the other signals (movement, respiration, HR, etc.) the system generates automatic alerts. A set of rules for the determination of the alert criteria has been implemented in the alert module. New alerts are also possible to be included by authorised personnel, as well as modification of the alert criteria [3].

The user will be able to watch the health status of all patients connected to the central monitoring system (through the WEALTHY garments). The definition of the monitoring profiles will provide an easy to use monitoring of the patients' health status in real time and with different fully customisable views.

Simultaneously, the user will be able to review the generated alerts and using past medical data will determine the true and false alerts and correspondingly contact doctors through direct phone calls and online alerts. This central control module is not necessary in order for the monitoring system to work. It is an optional module ensuring the minimal generation of false alerts to the doctors and will be necessary for large scale hospitals dealing with hundreds of patients.

The WEALTHY platform will give the possibility to monitor and assist patients through a remote medical advice service. The use of intelligent systems provides to physicians the data to timely detect and manage health risks, diagnose early illness or injury, recommend treatment that would prevent further deterioration and, finally, to make confident professional decisions based on objective information all in a reasonably short time.

4. WEALTHY interface

Strain fabric sensors based on piezoresistive fabric or yarns, and fabric electrodes made with metal based yarns, enable the realization of wearable and wireless instrumented garments capable of recording physiological signals, to be used during the routinely activity, to be worn instead of a classical garment without discomfort for the user. Respiration, electrocardiogram, electromiogram, activity sensors, temperature, may be listed among the physiological variables that can be monitored through the proposed system.

Piezoresistive fabric sensors have been realized by using lycra® fabric coated with carbon loaded rubber, as well as by weaving a commercial electroconductive yarn (PAC 250 dtx x 1, by Europa NCT, Poland). These fabrics behave as strain gauge sensors and show piezoresistive properties in response to an external mechanical stimulus. The coated lycra® fabric has been used to detect respiration signal, due to the higher efficiency shown in term of quality of the signal, compared with the other fabric sensor. The Europa yarn has been used for the activity sensors and knitted in the multifunctional fabric. The behaviour of a knitted piezorestive sensor is different when stretched towards warp or weft direction. Preliminary tests have been done to select the more efficient technique of knitting and the direction of stretching. The fabric sensor have been integrated and oriented in a way to maximize the gauge factor according with the response shown during the preliminary tests.

Electrodes have been realized with a yarn where two stainless steel wires are twisted around a viscose textile yarn (Elitè by Lineapiù s.p.a., Italy). Electrodes were knitted by using the tubular intarsia technique [4] to get a double face, using the external – non conductive – part to isolate the electrode from the external environment. The basal yarn (not sensitive) was the same yarn used as core for the conductive electrode yarn. To improve the electrical signal quality in dynamic condition a hydro-gel membrane purchased by ST&D Ltd (Belfast-UK), has been used. The use of the membrane affects also the comfort as electrodes have a rough surface and a prolonged contact with the body can give rise to skin irritations. The contact between conductive fabric and skin can be improved by increasing the adherence of the garment with the use of a higher percentage of elastic component in the yarns. Another approach is the use of conducting rubber or silicon as coating layer for the electrodes; in our future work both the approaches will be investigated.

Connections have been realized by means of the tubular intarsia technique. A supplementary layer has been woven by using of vanise technique. The final connection is a multi layered structure where the conductive surface is sandwiched between two insulated standard textile surfaces. The same conductive yarn is used for the electrodes as well as for the realization of connections, a particular of the textile prototype is shown in Fig. 2.

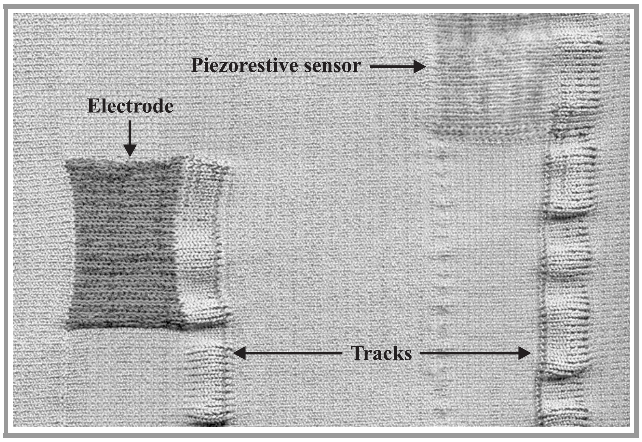

Fig. 2. Part of the WEALTHY interface.

The knitting fabric has been made with a flat-knitting machine (Vesta Vx 12 – Steiger, Switzerland). A draft position of sensors was implemented on the knitted fabric, and then by means of the use of models was possible to cut the fabric in a way to get the sensors in the desired configuration. The garment was finally sewed, which means that the final position of sensors and connections was achieved in the manufacturing phase.

The prototype model [5] is shown in Fig. 3 where the electrodes position is highlighted. In Fig. 3 the Einthoven

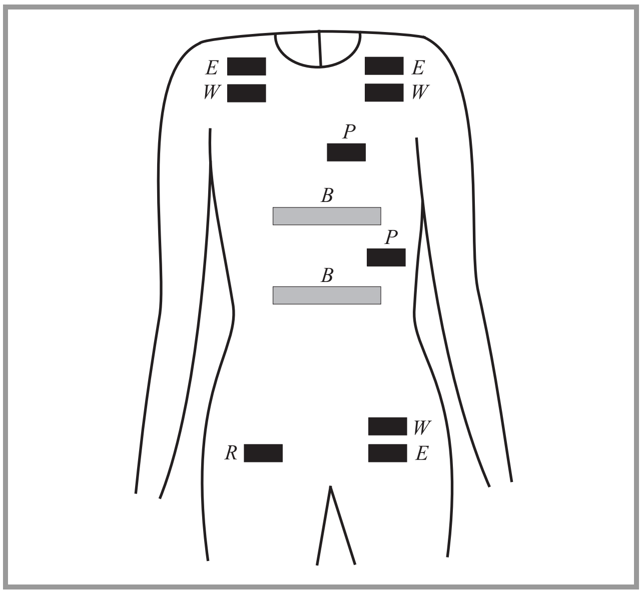

Fig. 3. Prototype model: *E* – Einthoven, *W* – Wilson, *R* – reference, *P* – precordial leads, *B* – breathing sensors.

and Wilson derivations (*E, W*), V2 and V5 as precordial leads (*P*) and the reference electrodes (*R*) are shown, while two breathing sensors (*B*) are positioned one on the thorax and the other on the abdomen. In Fig. 4 the position of the 6 movement sensors is shown.

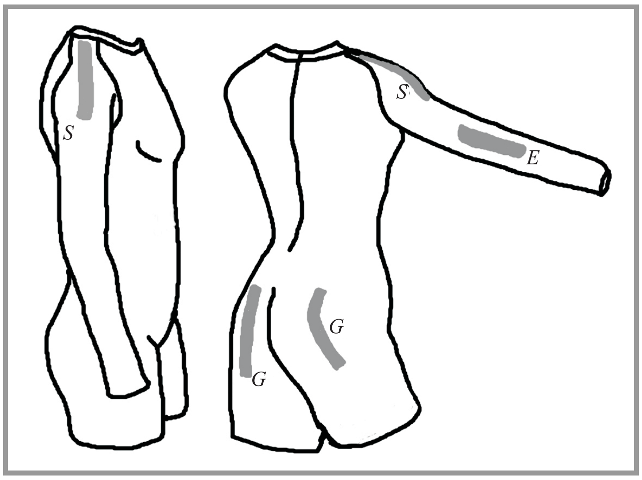

Fig. 4. Prototype model: *S* – shoulder movement, *E* – elbow movement, *G* – gluteus movement sensors.

The stainless steel threads have been selected for the realization of fabric electrodes for a series of reasons: first of all they are compatible with industrial textile processes, they are inert and stable in the presence of O_2, finally the cost of steel is very competitive compared with pure silver, or pure gold.

Naturally the fineness and flexibility of metal components have been chosen to get a final conductive yarn suitable for knitting, weaving and more in general for textile processing, which means that the metal threads used are washable, flexible and biocompatible. The same approach has been used for all the sensorial yarns and fabric developed in the project. It is also possible to work with silver coated threads that are occasionally employed for special fashion effects or for antibacterial purposes in textile world. Preliminary tests done with fabric containing polyester yarns coated with silver have shown that the use of stainless steel threads is more convenient: in fact during the experiments it has been observed that the conductivity of the silver electrode was lower than the stainless steel ones, when samples with the same dimension were compared. This is probably due to the small amount of metal components localized only in the coating layer of the threads. It is important to underline that the fabric cannot be realized only with metal yarns otherwise this region of the garment will be too rigid and not conformable, the amount of metal in the fabric is a compromise between the demand to increase the conductivity and the necessity to improve the touch sensation (the hand) of the cloth. Moreover the quality of silver adhesion was very poor, after several tests large metal coating regions looked removed; the electrodes need to be used with gel or conductive past and finally the electrodes have to be chlorinated.

Conductive and piezoresistive yarns are resistant to repeated washing in aqueous solutions, the physiological signals detected after washing have shown that the performances of the fabric sensors are not affected by the process.

5. Methods

The purpose of this publication is to evaluate the performance of textile sensors, electrodes and connections integrated in a garment (sensing part of the WEALTHY system), and to prove the possibility of the simultaneous acquisition of several biomedical signals during training session.

All the tests have been effected using the WEALTHY textile interface, adding two electrodes, not integrated but sewn, on the right leg, in order to monitor the EMG activity of the quadriceps muscle.

Piezoresistive signals have been conditioned by a voltage divider, followed by a Butterworth low pass filter (cut frequency at 10 Hz).

Signals from fabric electrodes have been conditioned by a GRASS-TELEFACTOR mod. 15LT device equipped with differential amplifiers mod. 15A54, with settable gain and band pass filter, notch filter at 50 Hz.

The ECG signals from fabric electrodes were conditioned setting gain 1000 and band pass filter with frequency range between 1 and 100 Hz. Surface EMG signals from fabric electrodes positioned on the right leg (quadriceps) were conditioned setting gain 2000 and band pass filter with frequency range between 10 and 500 Hz.

Every analogic signal has been acquired by an acquisition card (National Instruments PCI 6036) with sampling rate of 1000 Hz.

The experiments have been performed according the following experimental paradigm.

The baseline conditions were recorded when the subject was lying in supine position (R1) for a period of 10 minutes, followed by a control period of 2 minutes with the subject sitting on a cyclette (R2). This was followed by a period of progressively increasing physical exercise (cycling with increasing frequency and force) M1, M2, M3, M4, 5 minutes each. Then the period (R3), still in vertical position on the cyclette, for 2 minutes, as in R2.

R1	R2	M1	M2	M3	M4	R3	R4
10 min.	2	5 min.	5 min.	5 min.	5 min.	2	10 min.

Fig. 5. Experimental design.

Finally, the subject was asked to stand up and to lie in supine position for other 10 minutes (R4) as in R1. The experimental protocol is summarized in Fig. 5.

6. Results

The ECG leads used to evaluate the performances of the WEALTHY textile interface are:

– precordial V5;

– precordial V2;

– Einthoven D2.

These signals are acquired simultaneously with the respiratory activity (abdominal and thoracic) and the activity of the right quadriceps.

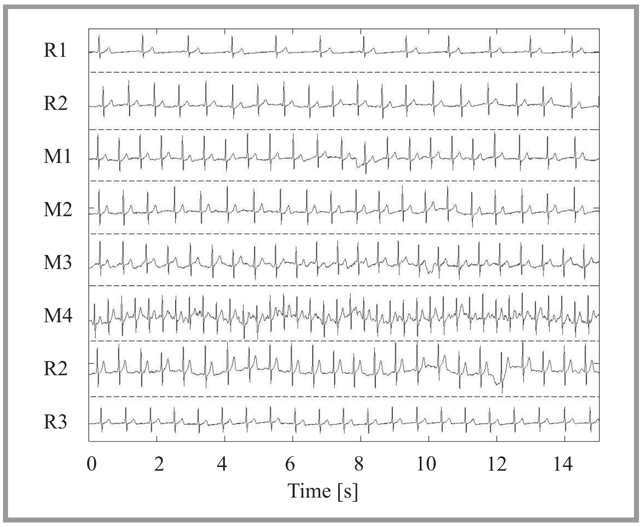

Fig. 6. V5 precordial lead signal in each experimental condition.

The results obtained in the whole sessions have been analyzed in order to demonstrate the robustness of the system.

In Fig. 6 the recordings from the V5 leads are shown, acquired according to the protocol previously described, for a period of 15 s each.

The analysis of the precordial leads shows that the quality of the signals is not affected by movement artefacts, in the frame of this trial.

In Fig. 7 it is possible to notice that the response of D2 lead is still satisfying for regular movement (M3). In fact only during M4 (very intense activity) the signal is noisy and could be very hard to get useful parameters (heart rate).

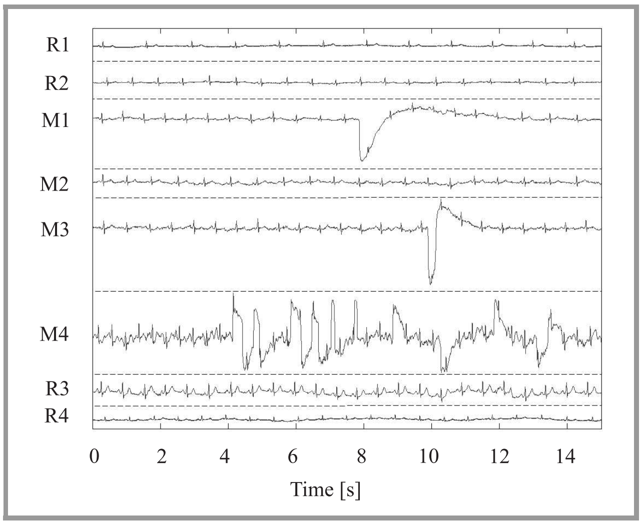

Fig. 7. D2 Einthoven lead signal in each experimental condition.

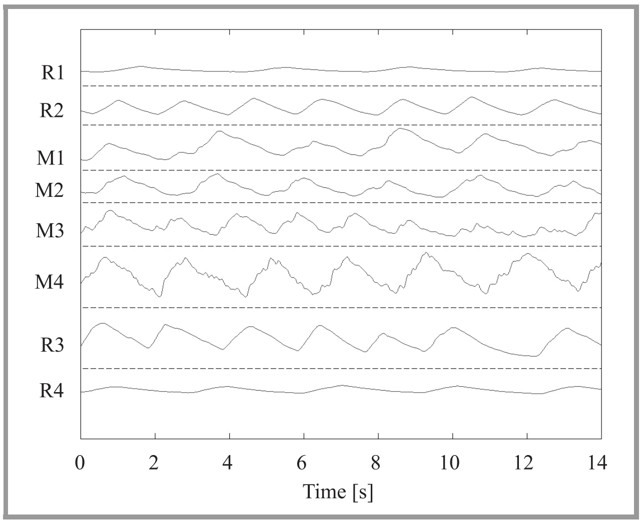

Fig. 8. Respiratory activity, reading plethysmography in thoracic position, in each experimental condition.

The signal obtained by the piezoresistive sensor placed on the thoracic position is shown in Fig. 8. It is affected by noise during the M-phase, but is still possible to obtain the respiratory rate and to have information about the plethysmography of thorax with an appropriate algorithm of analysis.

In Fig. 9 it is possible to notice the increasing of muscular activity by analyzing the results of surface EMG signal.

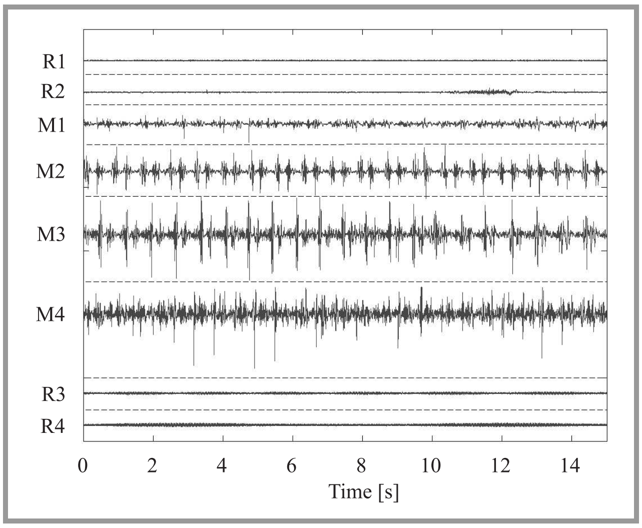

Fig. 9. Surface EMG signal from right quadriceps in each experimental condition.

The amplitude of signal and median frequency, defined as the frequency below which lies 50% of the total power of the PSD, increases with the speed of spinning movements and the effort required by the increasing resistance set on the cyclette, as shown in Table 1.

Table 1
Median frequency of PSD of the surface EMG during movements

Experimental condition	M1	M2	M3	M4
Median frequency [Hz]	17.58	24.41	25.39	28.32

7. Discussion

The achieved results show that fabric electrodes endowed in the sensing shirt allow a continuous and simultaneous monitoring of bioelectrical and biomechanical physiological signals in a behaving subject. In a previous work [6] has been shown that the signals recorded by fabric electrodes are comparable to those acquired with gold-standard electrodes commonly employed in research and clinical use. The electrical and mechanical properties of fabric electrodes have not been modified by their integration in the wearable shirt, as the characteristics of electrocardiographic (ECG), electromyographic (EMG) and respiratory (RESP*) signals are comparable to those obtained with standard electrodes in similar conditions. The response of the system during the different activity phases are clearly observable in Fig. 6, where the EGG data indicate that precordial leads exhibit a remarkable stability and are free from artefacts even during the maximal exercise intensity (M4), when also the background noise appears negligible. In the standard D2 derivation the signal is less stable and the amount of artefacts related to movement clearly increases (Fig. 7). This may be related to the lack of adherence of the garment to the upper chest when the subject had to grab the cyclette handle bar during exercise. Moreover, the strong engagement of the pectoral muscles in this type of exercise may be responsible for the higher background noise observed. The signal to noise ratio can be improved by trying to set the fabric electrode position on a rigid surface such as the clavicle and the sensing shirt will be modified accordingly in the future. The good quality of the ECG signal allows the computation of heart rate and its variability throughout the experimental cycle. As described in the literature during physical exercise there is a progressive increase of heart rate (Fig. 10), correlated to a parallel decrease of heart rate variability (Fig. 11).

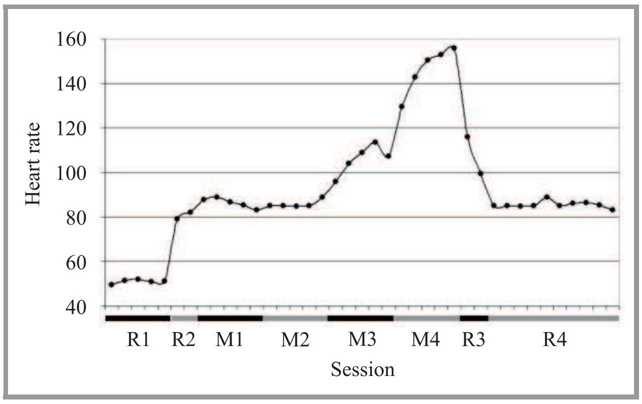

Fig. 10. Heart rate obtained analyzing V5 signal in each experimental condition.

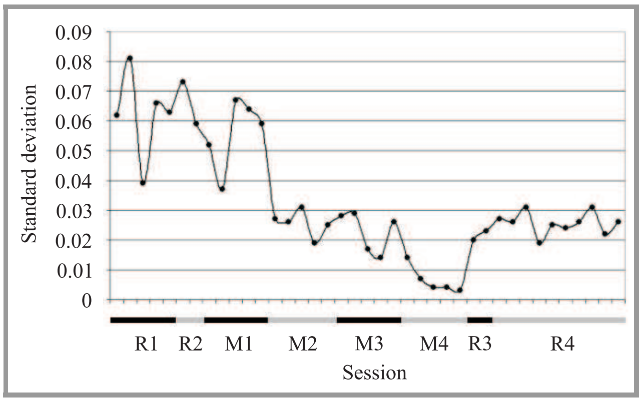

Fig. 11. Heart rate variability.

Due to the good quality of recorded signals, the ECG can be adequately employed to study non invasively and in behaving conditions more complex functional indexes related to the sympatho-vagal balance, such as low frequency and high frequency components derived by spectral analysis of RR interval variability [1], respiratory sinus arrhythmia and area under T wave of the ECG.
In Fig. 8, respiratory signals are shown detected through piezoresistive sensors. Also in this case is evident a remarkable stability and an excellent signal to noise ratio during

the experimental session. Moreover the signal time course is adequate to reproduce the thoracic excursions without detectable phase shifts. Thus the respirogram yields accurate information about respiratory rate while the variations of signal amplitude can give only a qualitative estimation of the respiratory depth.

The surface activity of selected lower limb muscles such as the quadriceps can easily be recorded by fabric electrodes similar to those used for recording ECG. The EMG shown in Fig. 9 exhibits bursts of activity synchronous with the pedalling cycle which rise by increasing the frequency and the force required by the exercise.

As shown in Fig. 12, the sensing shirt makes possible a simultaneous and multi-parametric acquisition of several physiological variables in different behavioural conditions. This possibility represents a significant advantage when it is necessary to monitor the vital asset of workers in extreme environmental conditions as well as sportsmen during high physical performance or military personnel engaged in war sites.

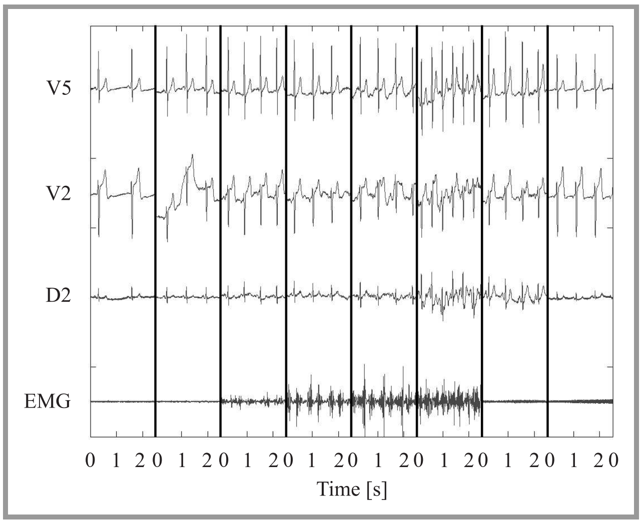

Fig. 12. Overview of changing in all electrical signal during experiment.

The most innovative feature of this system consists of the use of functionalized materials in form of fibres and yarns, which can be knitted or woven into a sensing fabric. Preliminary results [7] show that the basic sensing features on which vital sign recording is based can be implemented using integrated knitted sensors and electrodes. Previous authors works [8, 9] have shown that low frequency mechanical signals of cardiopulmonary origin (respiratory signals, ballistogram) or generated by body segments relative motion (kinaesthesia) could be recorded by textile strain gauges. Finally bioelectric potentials related to cardiac or skeletal muscle activity (ECG, EMC) have been faithfully recorded by metal based fabric electrodes. The integration of these different components with appropriate elastic electrical conductors and properly designed connectors to the wearable electronic unit, leads to a comfortable wearable cloth which has no counterpart in any existing monitoring system. These new integrated knitted systems enable applications extending even beyond the clinical area and open new possible applications in sport, ergonomics and monitoring operators exposed to harsh or risky conditions (fire fighters, soldiers, etc.). The possibility of simultaneously recording different physiological signals provides an integrated view of normal and abnormal pattern of activity which could be otherwise impossible to be detected by recording each signal in different time. Finally it must be outlined that the possibility of recording physiological variables in a more "natural" environment may help to identify the influence of the psycho-emotional state of the subject in the performance of a physical activity. This is not easily detectable when recording is done within a protected (medical) environment. A further innovation is the in-context data interpretation. While a simple telemonitoring system would just transmit or record real-time physiological signs, the WEALTHY system will be able to process physiological parameters in context, so that appropriate feedback can be given to the patient.

8. Conclusions

The innovative approach of this work is based on the use of standard textile industrial processes to realize the sensing elements. Transduction functions are implemented in the same knitted system, where movements and vital signs are converted into readable signals, which can be acquired and tele-transmitted. In our fabric sensors, electrodes and bus structure are all integrated in textile material, making possible to perform normal daily activity while the clinical status is monitored by a specialist, with a comfortable wearable cloth which has no counterpart in any existing monitoring system [10, 11]. WEALTHY system benefits from the performance of the textile sensing interface to guarantee a continuously remote monitoring of user vital signs, the signals are acquired and elaborated on body and a set of signals and parameters are teletransmitted and managed by a remote control system. The philosophy of this approach is focused on the realization of a friendly, human oriented textile based system, where the choose of sensing material is a compromise between comfort for the users and signal quality for the specialists.

Acknowledgments

The authors would like to thank the European Commission for funding (IST-2001-37778) and all partners involved in the project, University of Pisa, Italy; Centre Suisse d'Electronique et de Microtechnique, Switzerland; Atkosoft S.A., Greece; Institut National des Sciences Appliquees de Lyon, France; Istituto Scientifico H San Raffaele, Italy; Centre de Recherces du Service de Sante des Armees, France; Messe Frankfurt GmbH, Germany; Centre National de la Recherche Scientifique, France.

A special acknowledgement to Dr. Roberto Orselli for his useful contribution to the drawing up of the manuscript.

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Paper

Tools for health professionals within the German health telematics platform

Bernd Blobel and Peter Pharow

Abstract— Shared care concepts such as managed care and continuity of care are based on extended communication and co-operation between different health professionals or between them and the patient respectively. Health information systems and their components, which are very different in their structure, behaviour, data and their semantics as well as regarding implementation details used in different environments for different purposes, have to provide intelligent interoperability. Therefore, flexibility, portability, knowledge-based interoperability and future-orientation must be guaranteed using the newest development of model driven architecture. The ongoing work for the German health telematics platform based on an architectural framework and a security infrastructure is described in some detail. This concept of future-proof health information networks with virtual electronic health records as core application starts with multifunctional electronic health cards. It fits into developments currently performed by many other developed countries. The paper introduces into the German health telematics platform and its tools based on smart card.

Keywords— health telematics, model driven architecture, electronic health record, smart cards, patient health card, health professional card, security, privacy.

1. Introduction

Any communication and co-operation between healthcare providers must be supported by intelligently interoperable health information systems. This challenge needs to be met especially for managed care and continuity of care concepts widely introduced in most of the developed countries to improve quality and efficiency of patient's care. In shared care environments – health professionals belonging to different healthcare establishments with different legal background, using different methods to perform different procedures, supported by different applications provided by different vendors and following different protocols, applied at different time – have to be deployed for co-operatively caring the same patient in an optimal way.

Interoperability might be provided at different levels. Those interoperability levels are ranging from simple data exchange and meaningful data exchange with agreed vocabulary to a functional interoperability with agreed communicating applications' behaviour, or finally to a service-oriented or semantic interoperability directly invoking the applications' services.

Health information systems enabling such advanced co-operation mentioned above in the managed care context are characterised by openness, scalability, flexibility, portability, distribution at Internet level, service-oriented interoperability, as well as appropriate security and privacy services. Finally, they have to be based on standards [1].

2. The German health telematics platform

As many other countries, Germany has launched a national programme for establishing a health telematics platform supporting seamless care [2, 3]. This platform combines card-enabled communication mediated by the patient with network-based interoperability between all actors involved. For the patient data card, called the German electronic health card, a multi-purpose microprocessor card is used. It will serve as a health insurance card, an immunisation and vaccination passport, emergency data and electronic prescription carrier, a carrier for pointers to the patient's electronic health record (EHR) components or related information such as drug information distributed on the net, and an information carrier for facilitating managed care and quality assurance.

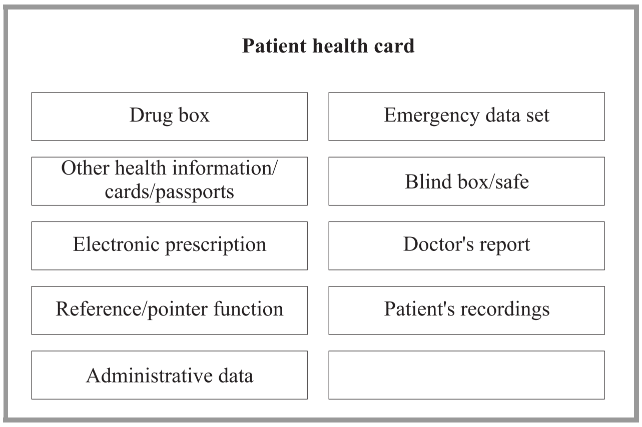

Fig. 1. Functional blocks of the electronic health card.

A specifically protected compartment contains information the patient likes to hide from reading by others. Additionally, the electronic health card provides basic security services based on cryptographic algorithms, such as strong authentication, integrity, accountability, and encoding/decoding services deploying the qualified electronic signature [4] and a related public key infrastructure (PKI). To support trustworthy interoperability between patients and health professionals, the latter use health professional cards (HPC) for adequate security services. For any access to data others than the emergency data set and the blind box/safe (the latter can only be opened by the patient as

mentioned above), the HPC as electronic doctor's license is required providing personal and role authentication. Security services support both communication and application security services for any principals such as users, devices, systems, applications, components, or objects.
The health card should be rolled out by 2006. It complies with the corresponding European health insurance card, which will be implemented in all EU member states until 2008. As important tool, the aforementioned HPC is a prerequisite for the health telematics platform and should be rolled out before 2006 too. The HPC is described in more detail in the following section.
Figure 1 shows the functional blocks of the German electronic health card. The blocks can be separately protected at different levels.

3. The German health professional card specification

Based on results of the European TrustHealth project [5] and the first HPC standard CEN ENV 13729 [6], the German HPC V 1.0 specification has been approved at 1999 [7], combined with political decisions setting up the legal and organisational framework in December 1997 already. The electronic physicians' ID is intended to completely replace the currently used paper based classical physicians' ID. For this reason the physicians' ID will have a distinctive card cover with the following general layout (Fig. 2).

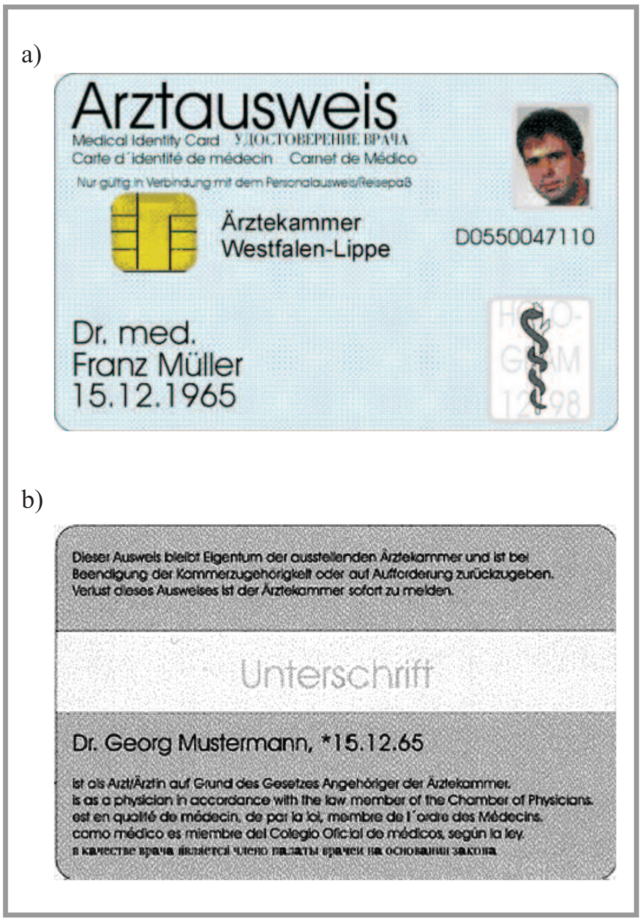

Fig. 2. Surface of the German health professional card for physicians (HPC). Front side (a) and reverse side (b).

The general structure and the dependency hierarchy for potential communication in the German health care system are indeed defined in an extremely heterogeneous manner (Fig. 3). There are many different players involved, i.e., medical associations, statutory health insurance (HI) administrations, physicians, hospitals, pharmacies, and insurers – only to name just a few. Definitely, a considerable number of communication pathways are already in place. However, the number of paths and the amount of information transmitted may easily be considered minor when compared to the potential needs of all of the other communication expected in health care. If just 10 000 physicians (of more than 380 000 registered in Germany) would possibly wish to exchange electronic data items of their patients among at least one another, this amount would completely surpass any of today's volumes by far. A well-established infrastructure is necessary to cope with the expected amount of information circulated among Germany's health professionals.

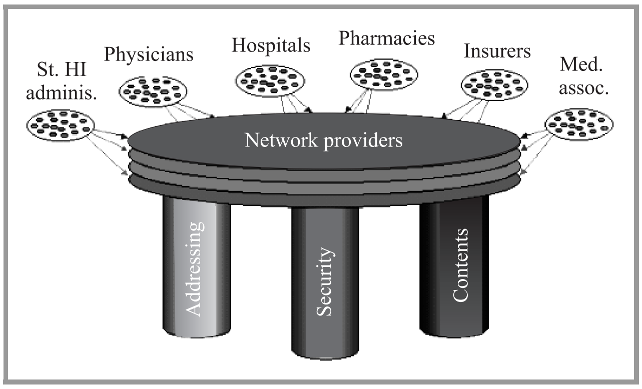

Fig. 3. Communication pathways.

It seems to be reasonable that at least three major factors need to work together, for any communication to work:

- basically, health professionals need to have a reliable method for addressing each other; this constitutes a nearly solved problem, since the majority of physicians already have some type of unique e-mail presence; the HPC will fill the remaining gaps by providing all health professionals with a distinguished name (DN);
- secondly, any communication in healthcare and welfare has to take place securely and confidentially; the participants must know and be able to prove who they are "talking" to; this is another major issue addressed by the German HPC development;
- finally, once health professionals can actually exchange data, this has to be done in a form which

allows them to really make use of the data transmitted; a basic consensus concerning content standards for verbal data, images, lab results, etc., has to be achieved for transmission to be interoperable; here, industry and standardisation initiatives like ISO, CEN, DICOM, HL7, IEEE, etc., play an increasingly important role.

All three factors need to work together, like the pillars supporting a platform. This platform itself consists of the interoperable connections between different network providers who offer their customers transmission facilities. A reduction of providers is neither feasible nor desirable and so interoperability on all of these levels becomes paramount.

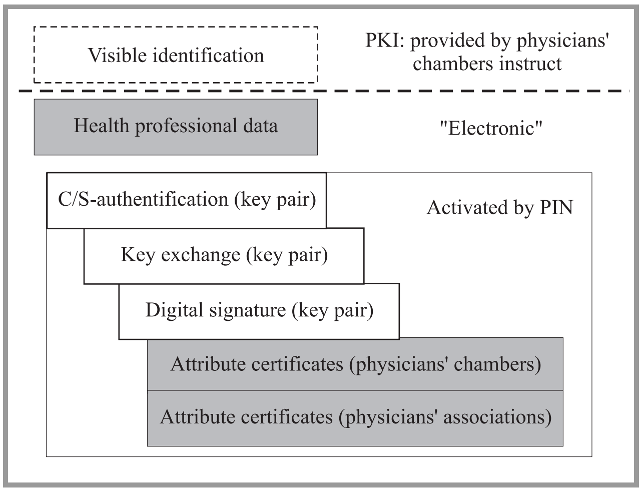

Fig. 4. Functional structure of German HPC.

Looking more closely at the details, the German physicians' ID contains a total of five different functions (Fig. 4).

1. The first function is that of a classic identification card which a physician can use in a number of different settings, e.g., when ordering prescription drugs in a pharmacy where he is not known. To this purpose the card is personalised with name and picture, completely replacing the classic paper ID which any physician can apply for today.

2. The first electronic function is that of a simple basic certificate providing authentication to any digital device this card is presented to. Here, a fast and simple method for easy identification was realised taking into account that this approach can only be used in an otherwise already secure setting, since there is no special security against theft. This trade-off between security and simplicity will certainly find its use, since it is intended as a direct electronic analogue to the physical presentation of the classic identification card.

3. The second electronic function is that of being carrier of an asymmetric key pair (more specifically, the private key of the key pair) for the strong authentication in a client/server environment. A public key infrastructure has to be put into place, where virtually any unit can look up or download the public key of a health professional and can then make use of it to check the private key of the person presenting his identification in any type of clinical setting. This enables the implementation of strong security in an otherwise untrusted environment.

4. The next major element is bearing another key pair (again, the private key of an asymmetric key is stored on the card) for the implementation of a hybrid (symmetric/asymmetric) transport encryption. This is where transportation protocols like HCPP, S/MIME, etc., can come into play by defining how the messages interchanged are to be encrypted and decrypted.

5. The final element of the HPC is the private key of an asymmetric key pair for the production of a legally binding electronic signature according to the German signature law (SigG). The specifics of the health professional are contained in a number of attribute certificates which he can append to his signature, specifying his role in medicine.

From a more technical point of view, the HPC is a contact-based smart card capable to process public key (PK) algorithms. The physical characteristics shall comply with ISO/IEC 7816-1 and related standards. An HPC is a normal size card (ID-001 card). Another card layout is the so-called institutional card (SMC) that could easily be considered a plug-in card (ID-000) for secure devices, e.g., in pharmacies.

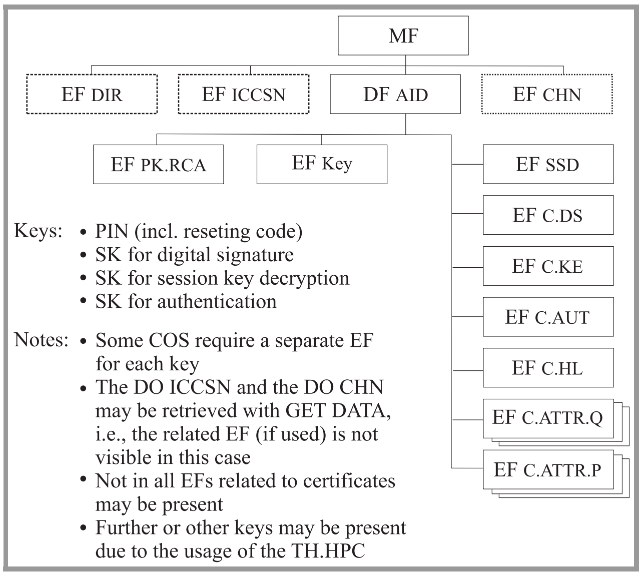

Fig. 5. Internal structure of German HPC.

As shown in Fig. 5, the HPC contains:

- some elementary files (EF) at the master file (MF) level for some general data objects and the card verifiable (CV) certificate;

- the HP application (HPA) providing the following services:
  - electronic identification of the health professional,
  - electronic signature creation,
  - client/server authentication,
  - document decipherment,
  - card-to-card authentication (HPC/eGK and HPC/SMC);
- the cryptographic information application (CIA) providing information for the primary system (e.g., a doctor's office system) to support the communication between the system and an HPC.

The HPC security mechanisms require different types of end user certificates:

- electronic (digital) signature certificate(s) (X.509 v3, type: electronic signature certificate(s), i.e., public key certificate and attribute certificate(s)), here called C.DS;
- authentication certificate (X.509 v3, type: authentication certificate), here called C.AUT;
- key encipherment certificate (X.509 v3, type: key encipherment certificate), here called C.KE.

In addition to the aforementioned certificate types all containing a key, additional certificates without a key (so-called attribute certificates) complete the card infrastructure. Attribute certificates in the context of the German HPC do rule certain aspects of permission (C.ATTR.P) and qualification (C.ATTR.Q).

4. The bIT4health project

To guarantee future-proof principles for designing and implementing common basic services of the aforementioned health telematics platform, an architectural framework and a security infrastructure have been defined and demonstrated as a proof of concept within the German project for improving the German healthcare system through the deployment of information and communication technology. This project has been called bIT4health (better IT for health) [8].

This architectural framework is characterised by different paradigms such as:

- distribution for openness;
- component-orientation for scalability and flexibility;
- interoperability at service level reflecting concepts and knowledge expressed through formal models for enabling conformance agreements;
- separation of platform-independent and platform-specific modelling separating logic and technologic views on system components as well as;
- installation of reference and domain models.

The latter properties enable openness, portability and future-proof investments for the solutions provided. The approach completely complies with the advanced paradigms including the model driven architecture presented in this paper.

5. Modelling systems

For describing systems and their behaviour in an appropriate way, real systems need to be modelled. A model might hide internal structural complexity, or might be focused on specific aspects of the system such as form or special functions. Beside this way of simplification of complex systems by modelling them, grouping elements of a system according to specific commonalities in structure and/or function makes system design, development, and maintenance manageable, realisable, and eligible for financing. The result are components which can be designed, manufactured, improved separately from other components, however keeping in mind and enabling reasonable interoperation between related components.

To reduce the complexity of the whole healthcare system consisting of many subsystems following the shared care paradigm, a single unrealistic comprehensive information system covering every thinkable procedure, fact and result will be realised by subsystems constraint to specific tasks, content, etc. In other words, we move from systems to components.

An information system is reflecting processes happening in the real world, by that way on the one hand establishing an information-related model of reality and on the other hand implementing a real system. Models are systems consisting of components, too. The component paradigm is a basic paradigm which is applicable to real systems but also to models of reality [1].

6. MDA-based architectural framework and security infrastructure

For keeping such complex national project's specification and implementation manageable, the architectural framework including the security infrastructure as its integral part is strictly based on the ISO 10746 reference model – open distributed processing (RM-ODP) [9]. This concerns all newly developed applications, common services components, but also analysis and migration of legacy systems.

The ISO RM-ODP considers every component in distributed interoperable systems from different viewpoints, thereby abstracting from complex reality to interesting constraints such as concepts, contexts, structure, or behaviour (Fig. 6). Thus, a component's purpose (business view, scenario, policy), the information needed to describe the content (attributes) and function (operations) of a component (information view), component's functional aggregation (computational view), physical distribution (engineering view), and implementation and operation principles (technology view) have been specified.

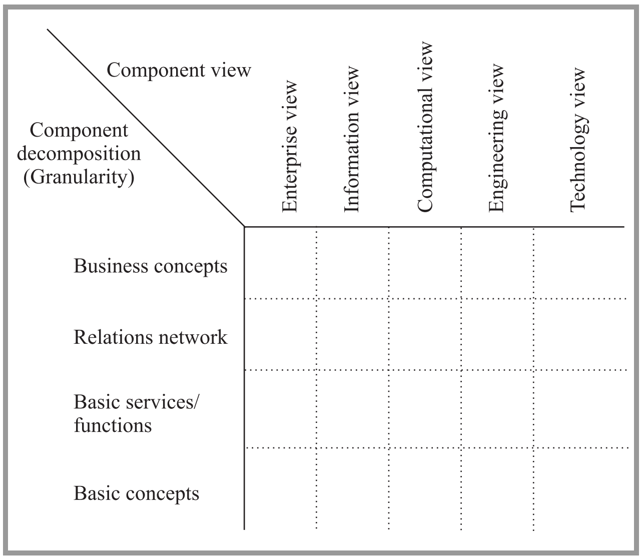

Fig. 6. Abstraction matrix of components.

Components can be composed/decomposed providing different levels of details or granularity. Starting from the granularity level of basic concepts of the corresponding domain, the complexity of aggregated components reflecting the application needed may be increased according to the users' needs. By that way, stand-alone applications, distributed applications or even highly complex networks can be implemented. In that context structural and functional complexity has to be considered as well. Components and their level of granularity can be selected according to the users' needs [1, 10].

In the first phase of modelling, the platform-independent specification of the components' properties is performed describing the business, the information, and the computational viewpoint of every component needed. Those models are portable to any environment with specific database models, operating systems' requirements, etc. This specification is transferred into the second phase of platform-specific modelling, covering the engineering and the technology viewpoint.

The separation of platform-independent and platform-specific models, distinguishing logic and technologic aspects is the core idea of Object Management Group's model driven architecture (MDA) for component-oriented information systems [11]. The specification of platform-independent models (PIM) is supported by appropriate tools. The transfer into platform-specific models (PSM) is automatically performed by tools. Both phases describe system components at meta-level using, e.g., the unified modeling language (UML) still abstracting from implementation details. The resulting graphical vocabulary can be transferred into verbal constraint models using the extensible markup language (XML). All models are developed starting from coarse description up to fine grained specialisation.

Thereby, the models follow the approach of the generic component model based on the ISO reference model – open distributed processing. For model management and the automatic development of running application at runtime, corresponding tools will be deployed. In a model driven architecture, the implementation is automatically performed using tools as demonstrated in the HARP project running at the Magdeburg Medical Informatics Department [12]. In the next section, this project will be shortly introduced.

Because different views can be described independently by domain experts, available knowledge can be exploited and specific terminologies can be applied correctly. For example, the concepts knowledge of medical doctors or procedural experience of administrators will be expressed in domain models referring to an information reference model established by IT experts. Beside agreed methodologies and tooling, accepted terminology maintained in a repository is a basic requirement. This terminology and ontology will be reused from SNOMED® with its extensions SNOMED_RT® and SNOMED_CT® as well as from the UMLS® created by the US NLM and meanwhile internationally maintained with important contributions by the British NHS. The outcome is transferred considering engineering aspects related to, e.g., the specific database model, which can be managed by DB experts.

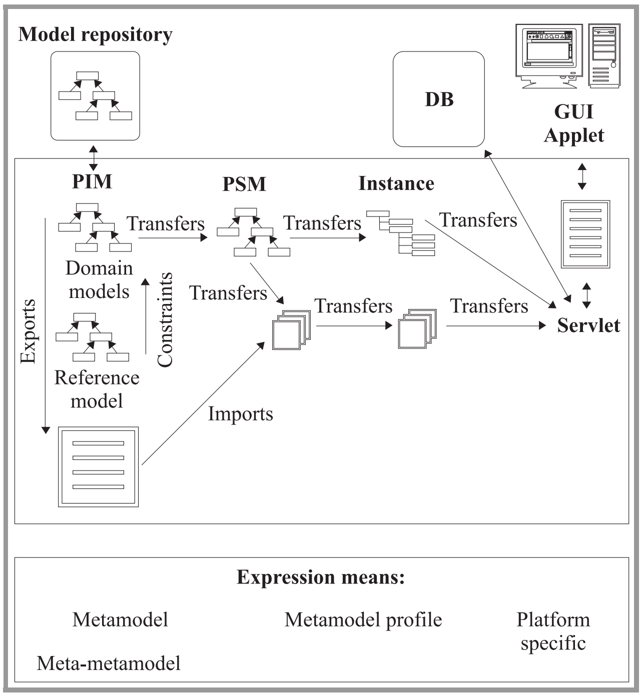

Fig. 7. MDA development nd expression means.

All different development phases from general requirements analysis over domain-specific views up to implementation and maintenance of any HIS can be described by MDA. Therefore, MDA allows also dealing with legacy systems to define interfaces and levels of interoperability. Figure 7 presents the MDA schema including the expression means used. As meta-languages, UML and XML have been introduced as mentioned already. Because of some weaknesses of the approved version UML 1.4, tools supporting the emerging UML version 2.0 have been used.

7. System integration and migration paths

Keeping in mind that systems consist of hierarchically built subsystems or capsules as shown in Fig. 8, at least three different levels of interoperability can be modelled and implemented starting at the highest level of service-oriented collaboration between directly related components (Fig. 9).

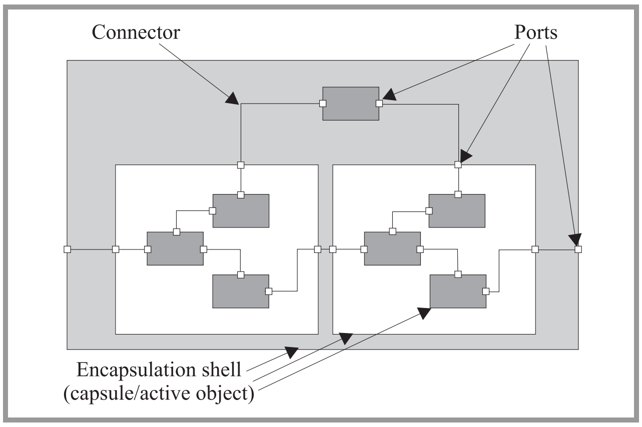

Fig. 8. Hierarchically built capsules.

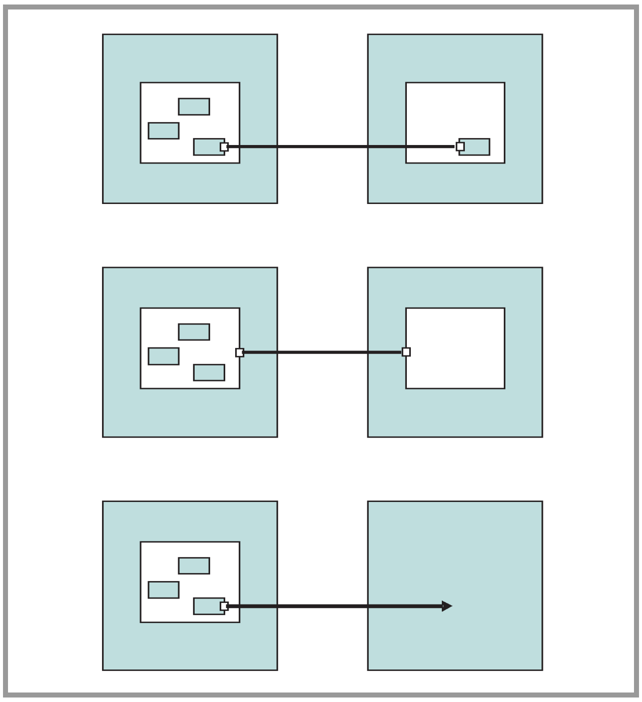

Fig. 9. Interoperability level.

The next level comprises aggregated services mediated either by super-component interactions or by the exchange of messages via architecture-independent interfaces (e.g., HL7 V2.x) [13]. Finally, proprietary communication or database import/export functions might be established. The aggregation of components and – by implementing them – services is mediated by components, in analogy to CORBA establishing horizontal or vertical services depending on the usability of those services by all domains or by a special one.

Platform-specific issues are kept out of scope as long as possible to enable a future proof HIS characterised by the aforementioned properties. For final implementation, they have to be realised, however.

8. Electronic health record

Because all facts directly or indirectly established during patient's care are needed for its optimised management, shared care information systems and networks have to be based on a comprehensive and lifelong virtual EHR system as the HIS core application. Therefore, the German health telematics platform must be completed by a modern EHR architecture, which is also open, component-based and model-driven, etc.

The EHR architecture deployed in the German health telematics project will be based on specifications provided by the revised CEN ENV 13606 "Electronic Health Record Communication" [14] and international projects and initiatives such as the openEHR Foundation [15]. Accordingly, the German electronic health card provides a tiny EHR extract. Furthermore, it establishes a tool (pointer facilities) for managing EHR systems in a patient-controlled way.

9. Architecture and security infrastructure implementation

Beside the definition and demonstration of an architectural framework and security infrastructure as German health telematics platform, the roll-out of that approach first manages the card-enabled environment, and second provides basics and migration path for a future-proof ICT supporting shared care.

In that context, the acceptance of the solution by patients and health professionals including responsible and influencing bodies within the German healthcare and social system is inevitable. For that reason, the creation of acceptance by public relation activities, support of the ministry in creation of positive opinions and resonance is an important work package. Additionally, the project management, quality assurance and quality management as well as an appropriate scientific accompaniment of the project are crucial success factors.

10. Conclusion

Modelled as a multi-model approach at meta-model level, the future-proof secure health information system (HIS) is

a virtual, at runtime self-organising architecture consisting of certified components which exchange digitally signed and attributed XML messages.
Reference model, constraint models, terminology, and methodology have to comply with international standards or must be standardised.
Following the challenging example of other countries such as Australia, Denmark, Finland, the USA, and certainly some others, Germany launched a programme for establishing a health telematics platform, which has to comply with the advanced paradigm of component-based MDA systems. First feasibility studies have been performed within the European HARP project the Magdeburg Medical Informatics Department being responsible for the modelling part has been involved in.

Acknowledgments

The authors are indebted to thank the European Commission and the German Federal Ministry for Health and Social Security for supporting their activities as well as the partners from the TrustHealth project, the GEHR/openEHR Foundation and the Object Management Group for collegial collaboration.

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Paper

Context awareness and nomadic devices featuring advanced information visualization in clinical routine

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Abstract— The demand for ubiquitous and efficient information delivery is increasing rapidly, as the majority of access to professional data, information and knowledge is increasingly relying on the use of technology. Mobile workers become more efficient, if equipped with access means similarly powerful to stationary workplaces. All types of work exhibiting inherently nomadic characteristics are even more affected by these developments. Healthcare personnel in a clinical environment are definitely one of the typical examples, where the access of information is vital and bound to location. Additionally the information needs to be processed in very short periods of time. For this purpose it is of great advantage to deploy advanced information visualization technologies in order to communicate larger amounts of data in a shorter period of time. In this work, we present an IT platform, which emerged from applications in the cultural heritage domain, that can be used to deliver context-aware services and advanced visualization of information to medical personnel in a clinical environment. The location combined with usage profiles for each member of the stuff are used to make the decision about the type and amount of information as well as the visualization type delivered to the handheld devices. Along with the description of the platform and its components, two application examples/medical use cases are presented.

Keywords— context aware services, healthcare support, ubiquitous computing, information visualization, nomadic devices, service platforms.

1. Introduction

Numerous applications in the past decade deploy handheld devices, such as personal digital assistants. The initial versions of this ultra-mobile computers, were aiming at a segment of the consumer market, where more expensive digital tools are often used as support of daily work. In a second stage of maturity, when the processing power of such devices grew to resemble PC processing, peripheral devices were integrated into the portable digital assistants (PDAs), their application domains expanded from simple office support to all possible areas. The mobility of these devices led to the term nomadic, indicating the ability of their users to change places without losing their access to basic e-mail connectivity and some additional business-oriented functionality.

One of the most obvious application domains, since the first days of nomadic devices, were so called multimedia guides for cultural heritage sites. Enhancing their predecessors, acoustic guides, multimedia devices started appearing in exhibitions, museums and archaeological sites, providing an easy to access pool of audiovisual information to visitors. They provide major advantages over existing acoustic guides and booklets related to sites, such as the attractiveness of the presentation and the richness of the expression means for the museum curators that offer a significant competitive advantage to cultural heritage institutions.

We have been developing solutions for mobile devices in cultural heritage institutions for a series of years and in a variety of versions, as presented in [1, 2], featuring more expensive high-end solutions as well as inexpensive, simple multimedia guides. The basic system for the creation and valorisation of content, as well as the infrastructure necessary to support the deployment of such systems in daily routine, may have been developed based on experiences gained in the cultural heritage domain, but they may easily be adapted to any other domain, where the application of such nomadic devices would provide a solution to the easy and fast access to information (mostly in audiovisual formats). Such an application domain are intra-hospital information management systems.

In our case we present a platform for context aware services on nomadic devices that is easily attached to the central hospital information system (HIS), or in the case where such a system is not present, some of its functionality may be taken over by the platform itself. The system may be used by different users within a clinical environment serving different purposes. The initial version of such a system is aiming at delivering information to medical personnel, i.e., mainly physicians, while they are visiting their patients. The medical record of these patients may be retrieved instantly, while the physician approaches the bed of the patient.

The same device may be used for communication purposes of different types. A typical application scenario is the notification of the medical practitioner by the ward personnel about an important call or appointment, etc. Additionally two physicians may communicate with each other consulting on a specific case, e.g., the surgeon visiting a patient performs a quick dialup of the radiologist in order to ask for some clarifications related to the imagery found in the retrieved patient record. Finally when a physician visits a patient followed by trainees, they are capable of “locking” the screens of their devices to the screen of the physician, in order to follow the processing of the case, as conducted by the teaching physician. Hence they learn what type of information is retrieved by the experienced personnel, in what order, etc.

Context aware services in a clinical environment may also serve the purpose of optimizing the workflow of nursing personnel. When entering a room, the scheduled tasks for all patients found in the room are presented in a task list. Each task completed is then checked and removed from the list with a concrete time-stamp, which might help them to capture the exact sequence of medical acts on every patient upon request.

Context aware systems may come as a natural extension of any information management infrastructure and help communicate the information to the interested practitioners in the right time and place. Especially in the clinical environment the introduction of such systems may result in a significant improvement of clinical workflow. In our contribution we will be demonstrating the architecture of the system as well as two sample use cases in clinical environments, which significantly enhance and correct all shortcomings of current workflow.

2. State of the art in context aware services and related medical applications

Context aware computing is an emerging field, where most of the attempts thus far where directed towards the solution of basic problems. Nevertheless, there are already some systems appearing in everyday use. One example, which happens to be the outcome of a European research activity, is presented in [3]. The main goal and the major difference to our approach, is the creation of generic framework for context aware services on the client platform with the focus on the handling of various sensor inputs, as well as the linking of these sensors to events. In our case, we very much focus on the back-office infrastructure to support and publish context-aware services, while on the client side we assume a reduced set of sensors (the wireless LAN positioning and additional sensors for increased accuracy in the location detection, such as radio-frequency (RF) tags and/or infrared sensors).

Applications of mobile computing in medicine are focusing mainly on patient monitoring and decision support. Hence in [4] the notion of pervasive healthcare is introduced focusing mainly on the pervasive monitoring of the health situation of a patient. A similar work related to wearable sensors is presented in [5].

A work presenting scenarios very similar to the ones in our work can be found in [6]. The authors introduce the idea of the context-aware pill-container, a device that helps avoid errors in drug administration, and the context aware bed, which uses the same resources (such as a built-in display) in a different way for different users, e.g., in order to display the electronic patient record (EPR) to the medical personnel or a TV station to the patient. The work presented in [6] is purely conceptual and in a series of workshops, with the participation of healthcare professionals, the integration of such context aware devices in clinical routine was investigated and judged a driving factor for further improvement in the clinical routine.

A solid theoretical framework for the modelling of context-aware services in a clinical environment is presented in [7]. The authors introduce the means for contextual modelling of processes and demonstrate the usage on the basis of medicine administration. The process of evaluating the overall idea is the same as in [6], namely user workshops, something that is related to the fact, that the authors originate from the same institution.

In [8] the use of personal digital assistants is described in the context of medical education and practice. Although an aspect, which is of interest to our solution, it is definitely not the focus of the platform we are describing in the present work, since our focus is the daily clinical routine. Both cases are extremely interesting and there are definitely many common aspects mainly in the choice of platforms. Nevertheless, our approach is clearly aiming at the support of clinicians and their nomadic work behaviour.

In [9] the notion of collaborative systems is introduced in the medical context and the resulting advantages are discussed. The main focus of this work is in communications across the boundaries of hospitals and collaboration is interpreted mainly in the sense of tele-medical applications. In our case, we are presenting a system that is aiming at the support of clinicians within one hospital, while the communication with other practitioners outside the boundaries of their hospital are possible, but not the primary goal.

In [10] a very good analysis of the nomadic character of the clinical routine is introduced. In this approach presented by Bharadwaj *et al.* mobile devices are also deployed within the clinical environment and there are clear similarities with the approach presented here. The focus of the work by Bharadwaj *et al.* is the communication and exchange of information between clinicians and insurance companies for the benefit of the patients. A dedicated XML communication language is introduced for this purpose.

An application of mobile technologies can be found in [11]. In this work the main focus lies in the use of mobile technologies in clinical trials for the increase of accuracy and confidence in the results, as well as decrease of the time-to-market. Such efforts may be considered complementary to the work presented here, covering a different need.

3. The architecture of the intGuide platform

The intGuide provides the means for creating, managing and publishing multimedia content that is location-specific on various platforms, ranging from portable digital assistants to high-end mobile phones. For this purpose

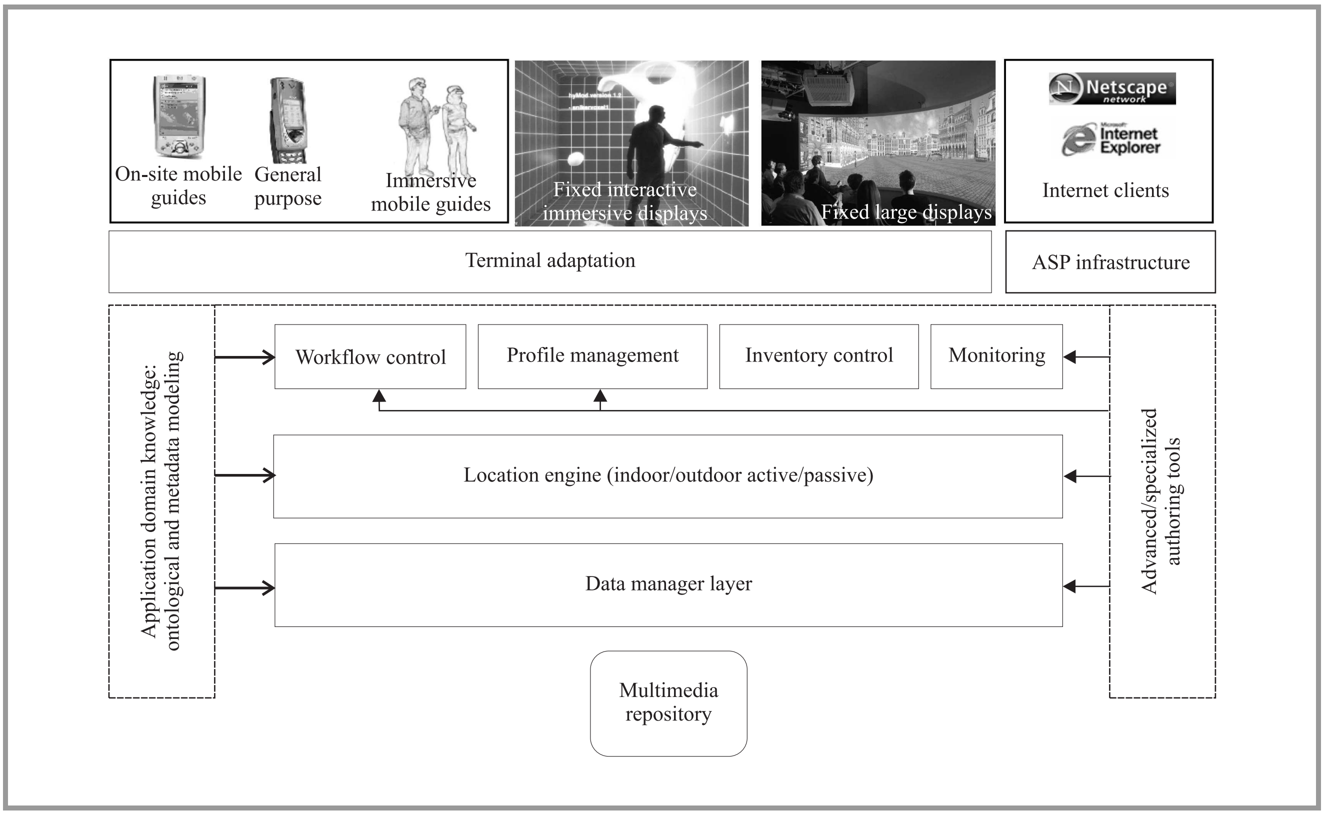

Fig. 1. An abstract schema of the layered architecture of the intGuide platform.

the intGuide platform unites a set of software tools necessary to:

- characterize, i.e., annotate, position in space and generally manage digital assets;
- combine various multimedia files to grouped presentation units;
- visualize information in an advanced manner, mainly by means of augmented reality;
- connect to other repositories to retrieve information, provided their structure is known to the system;
- publish the content on a rich variety of client device types;
- manage the inventory of hardware devices;
- monitor the operation of all devices attached to the central server, allow for their communication and collect, as well as present statistics.

The core of the back-office system is a specialized database management system, adapted to host multimedia data of different types. Moving towards the upper part of the Fig. 1 the functionality moves closer to the end user. In the upper layer, a set of supported client platforms is presented.

4. The usage of the intGuide platform in a clinical environment

We consider intGuide in a clinical environment as a supplementary infrastructure system, which extends the existing electronic patient management system (be it at ward, clinic or hospital level) introducing complementary functionality, which allows the information to become ubiquitously accessible.

Location and context awareness are features that have proven to significantly enhance the daily work situation of most nomadic users, such as the medical personnel in a hospital environment [10], but are not provided by any of the existing IT systems. The reason for that is that current information technology infrastructure systems are developed based on the hypothesis of information accessing by means of fixed terminals. The only differentiation is the one of roles within the hierarchy of the healthcare organization, or the responsibilities in healthcare provisioning, i.e., different access to the information for medical doctors and different to administrative personnel.

The introduction of such systems does not only restrict their usage to the information access, but may be extended to a set of other functions, which may enhance the work situation. An often encountered problem in the everyday life of nomadic users is the communication between them. An infrastructure that delivers location and context aware services may very well also use this information to establish communication links between different participants and transmit voice signals from one device to the other or multicast/broadcast information. The intGuide is featuring a voice and text communication model, allowing for the peer-to-peer exchange of information or the centralized multicasting of multimedia messages.

5. Content authoring

Using dedicated intGuide authoring tools, it is possible to enter all types of digital content and annotate it. The schema according to which this annotation takes place follows well known international standards for each application domain. In case a standard is not missing, or a potential user of the system is not interested in using a standard annotation but prefers to use a proprietary schema, it is possible to introduce a new definition. The reason for that is that the intGuide repository is hosting in its very core mainly multimedia related characteristics, while the rest of the documentation is kept in dedicated tables, which can be handled dynamically by the data manager. This is the major advantage of the content management system found in the core of the intGuide architecture.

The authoring tools rely on a dynamic template concept to allow grouping of the content in a way that allows for easier access of the users. An example in the medical domain could be the templates for different disciplines or different clinics, even different medical doctors. In such a template the head of the clinic can declare all types of information that are necessary to be displayed in a screen on a device. The system will use this template to dynamically load all information related to one patient at runtime. The system allows theoretically to introduce an arbitrary number of templates, hence it is possible to define a template for different types of diseases, even for every patient. Nevertheless such a practice is time consuming and reduces the efficiency of medical personnel, since they need to carry out a much more thorough documentation in order for the templates to be correctly identifiable.

6. Inventory control

The introduction of portable devices in a clinical environment is not straight-forward and needs very careful planning and administrative support to have a positive impact on the actual work carried out, as proven in numerous other domains. Taking into consideration that portable digital assistants are devices for personal office use focusing on simple business tasks (such as calendar functionality, contacts, simple voice memos, etc.), it is obvious that any other more demanding use needs to be planned carefully prior to being introduced in a daily routine.

Within intGuide there are tools addressing the administrative issues related to the use of mobile clients. Hence there is an inventory control unit, keeping track of the devices available, their characteristics, as well as statistics concerning their performance and usage. There is a dedicated registration-deregistration component that can be used when handing out the devices to the personnel and when collecting them at the end of their work (if such a model is selected for a hospital). Additionally the inventory control is featuring an online component, which allows for the monitoring of all devices and their parameters, such as their current location, their current battery status and any possible alerts that are related to their smooth operation. Hence if the battery level of a device is reaching a limit, the personnel responsible for the monitoring may bring an alternative device or backup battery to the user, e.g., medical doctor and thus support them without having them interrupt the operation.

Support of collaborative work. The portable devices may be used also as the ambient memory of the hospital. An important aspect in clinical workflow are appointments and scheduling. A centralized calendar, which is capable of holding the appointments of all personnel may be used to issue reminders in due time. The scheduling of the appointment can thus take place as the need for such an appointment occurs and can be transferred immediately to the account of the member of the staff and all other involved entities, so as to have it available during their work in their stationary workplaces, too.

Fig. 2. Current portable devices come in compact rugged cases and feature build-in wireless LAN connectivity.

In addition to the relatively static exchange of information based on appointment scheduling, another important feature, which increases significantly the advantages of the use of mobile devices within the clinical environment is the use as mobile phones (Fig. 2). Push-to-talk functionality after the selection of one or more addressees/participants allows medical personnel to communicate instantly within the hospital without any costs at all. There is no need for beeper devices and the installation of fixed line telephone lines for internal communication becomes obsolete. The communication possibilities offered by the new technology may even extend to the introduction of "bridges" to the external phone lines, thus redirecting the normal incoming voice traffic to the mobile devices. The latter requires nevertheless phone centres of a more recent generation, which will allow the forwarding of the voice calls along with some additional information, such as caller identification. The latter functionality will allow for a better screening of incoming calls by the medical personnel during work time.

Finally intGuide allows also for a different type of collaboration, namely education of medical trainees. The intGuide features client-side software, which allows for a mobile device to "couple" its display with another display and follow the interactions and information display on this "master" device. This is especially helpful during patient visits in the ward, when a senior medical doctor is joined by a group of younger interns. When approaching the bed of the patient the screens of the mobile devices of the interns may offer the possibility to display the content of the mobile device of the senior doctor and thus follow his/her decisions and information selection, while he/she explains why he follows the steps displayed. The current implementation allows for a relatively large number of clients to connect to a master device, hence enabling a smooth collaborative educational session in the clinical environment.

7. Security aspects

Currently most of the portable computers, PDAs and very recently also mobile phones are equipped with wireless LAN capabilities, thus making it easy for people to enter a wireless network and start using it. The intGuide platform introduces protective measures at various levels, starting with the obvious configuration (upon request) of all involved access points to accept traffic only from designated devices. For this reason the only restriction is the use of wireless access points that allow for configuration of allowed MAC addresses (nowadays a feature of the majority of access points in the market). Additionally the encryption of the data transmitted and the decryption on the viewing terminal is something easily incorporated into the intGuide platform. Finally the access to the content has to pass two levels of authorization, one of them being related to the database users and the other being granted by the profile of the user themselves. Hence although the rights of a medical doctor would normally allow him to access specific data in the database, within a given profile/template (a profile for the radiology specialist, when visiting the ward), might deactivate these access rights.

On the client side there are many ways to secure the access to the information. When a terminal has been idle for a given period of time, it is locked, while a warning/indication is transmitted to the centralized monitoring unit. The latter may be used in cases where the user of the mobile device has accidentally left the device somewhere unattended.

As far as the anti-theft security for the mobile devices is concerned, the intGuide clients always configure the devices to restrict the uncontrolled powering down. In a preferred mode of operation the devices are returned to their charging areas and then they may be switched off. Following this operation mode, it is possible to continuously keep track of the position of the mobile devices and issue an alarm when the mobile device is about to leave the permitted area. This feature may be deactivated. In such a case an alternative approach, such as RF tags on the mobile devices and RF reader installations in doors and windows could replace the security features mentioned before. In any case, there may be devices that certain members of the personnel will be allowed to take outside the permitted area. The suggested procedure in this case is to attend a deregistration station (e.g., at the entrance) and use a mode introduced for this purpose, namely "deregistration for exit". Upon return the device is registered again normally.

8. Necessary infrastructure

The major advantage of the intGuide solution is that it can be considered as an extension to existing information systems (Fig. 3). Hence it may complement existing infrastructure to offer the ubiquitous services within the hospital environment. Some additional components may even be assumed in nowadays implementations of information technology support in modern hospitals, such as the existence of a wireless local area network. The intGuide is a scalable, freely configurable platform and can thus be easily adapted to different situations and varying needs of end users.

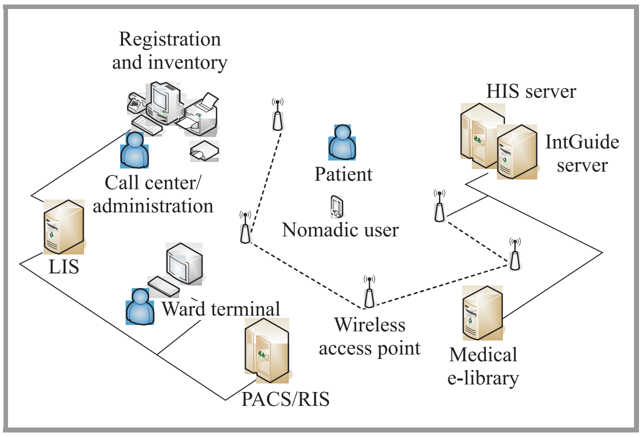

Fig. 3. The intGuide platform complements the existing infrastructure in the clinical environment in order to allow for context aware services in the clinical routine.

The intGuide platform is comprised of the following software and hardware components:

- wireless network, fully compliant with the IEEE802.11n standard – repositioning the access points within the space may be necessary in order to achieve higher accuracy in the WLAN detection;

- optional tags for increased accuracy in the location detection (e.g., RF tags or infrared LEDs);
- a central processing unit (see below), hosting the following software components:
  - WLAN positioning engine,
  - intGuide inventory software suite,
  - live monitoring software suite, featuring scheduling and communication control units,
  - software bridge to existing EPR,
  - authoring tools for the preparation of dedicated presentation profiles and templates,
  - software bridge to scheduling system,
  - registration and deregistration software,
  - a database management system or access to an existing one;
- portable devices, preferably portable digital assistants operating under Windows CE equipped with WLAN functionality, protected by a rugged case and featuring the following software:
  - communication and resource control unit,
  - WLAN positioning client,
  - position detection component,
  - playback control module,
  - synchronization unit,
  - voice communication module,
  - screen locking software (both server and client versions).

The system may operate with one single state-of-the-art PC. Nevertheless this is a solution that is not recommended. It is advisable to introduce a dedicated failsafe server, e.g., a cluster. The software systems may be operated on any terminal equipped with network access and conventional browsers. In the current implementation of intGuide, the authoring tools are dedicated software units that need to be installed on each terminal to be used. In future releases the authoring software will feature also a web-based access interface.

In case the system is configured to operate with increased location detection accuracy, i.e., with additional tags in the space such as RF tags, it is necessary to use a reader device within the mobile devices.

Advanced information visualization. One of the older yet only recently appreciated fields of research in information technology is information architecture and visualization. It is about communicating information in a visual manner and thus allowing for a faster and more efficient comprehension. Even very simple examples make it clear, that information visualization may increase the perceptual value of information and decrease the so called cognitive workload (Fig. 4). Especially in application domains such as medicine in the clinical routine, it is necessary to be able to perceive vast amounts of information within short periods of time, in order to reach fast and accurate decisions.

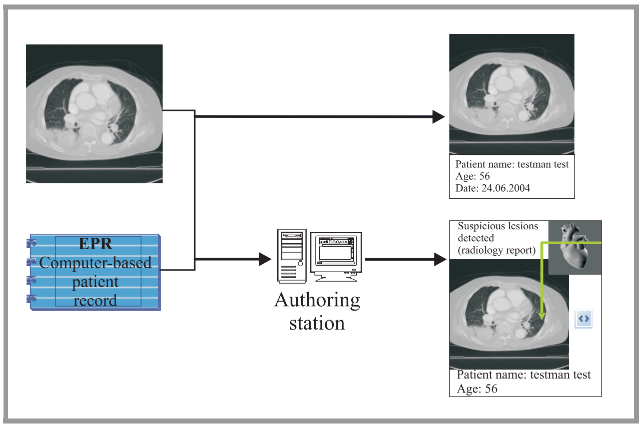

Fig. 4. Simple display of collected data related to a patient in the upper part, authoring tools for advanced visualization enhance the readability of the iamge in the lower part and visualize important information at a glance (light arrow line indicates both the position of the slice in the heart volume and highlights an area to more thoroughly investigate).

The intGuide is supporting possibilities of displaying multimedia information on mobile devices in a comprehensive manner. For this purpose it is necessary to use the corresponding authoring tools. The authoring of content may be time consuming and needs to be carried out by the respective specialist. An example can be medical images: the authoring tools may be used to annotate these images both graphically and textually. These annotations may be classified according to the intended audience, hence some of them will be presented on the devices of surgeons and different ones will be presented on the devices of anaesthesiologists.

The authoring tools of the intGuide platforms have not been developed especially for the medical domain. The modular way of development allows for the extension of the authoring tools by domain-oriented tools, such as visualization and rendering software for radiological departments, or laboratory results, etc. Nevertheless intGuide is capable of handling augmented reality information. It allows for the storage of 3-dimensional models and their matching against actual pictures of the real environment of the users. Hence, assuming that a different (embedded or not) tool is used for the creation of 3-dimensional views of medical information, it is possible to use the authoring environment to match these views against images found in the multimedia database of the system.

9. Application Scenario 1: medical visit in the ward

In order to better present the smooth integration of the intGuide features into everyday clinical routine, two simple examples are presented and the use of mobile devices with the intGuide features are highlighted.

In the first use case, we assume the visit of a patient in his/her room by a senior medical doctor along with three interns. Each physician is carrying a mobile device, which they have gotten at the collection point of their ward. The devices were handed out by a nurse in the ward, who registered the devices to the physicians in her terminal. The terminal is a simple PC connected to the intranet of the hospital, equipped with only a web-browser.

The senior physician approaches the bed of the patient, which features an RF tag in a hidden position. The doctor is provided automatically with a list of information items available for this patient. The information is structure according to a template, that this doctor has selected some time ago and found most useful. The senior physician selects additional information to be retrieved, such as the EPR, the fiver curves of the past days, etc.

The assistants "lock" their devices to the device of the senior physician and follow the actions. In order to do that they initiated a client session by selecting the "follow a collaborative session" option and highlighting the name of the senior physician. The senior physician sees the requests on his screen and allows the presentation of his device on the devices shown in a list by tapping the "allow" button. The session begins and the physician asks questions and then carries out actions using his device.

Suddenly an incoming request for tele-consultation is received by the senior physician only and is not displayed on the screens of the other devices. The physician taps on the graphical indication on his screen and checks the severity of the request by reading a brief description, the name of the initiators and the patient involved. He decides that the tele-consultation may be postponed for after the current visit and replies to the request by scheduling this activity for 15 minutes later. The initiator receives an indication on their screen, accept the postponed session and the rendezvous is registered centrally in the scheduling unit.

10. Application Scenario 2: nursing activities in the night time

The nurse is entering a room in her ward at night time, after she has been reminded by an alarming sound on her mobile device. The centralized system, which is constantly monitoring the schedules of all personnel has initiated this remote reminder. The device displays a list of tasks that need to be taken care of during this time in this room in a suggested order, immediately upon entrance of the nurse in the room. The nurse takes care of each task and indicates their completion by checking a box on her screen besides the task name. A high-level control of the validity of her actions is possible thanks to the location estimation component, which checks for the position of the nurse in the room and related to each of the patients. Hence it would not allow the checking and completion of a task related to patient B, if the reading of the position of the nurse is indicating her being at the bed of patient A. The processing of the tasks are captured by the workflow system and may be propagated to other HIS components (if configured to do so), thus allowing for a more accurate accounting.

Suddenly the nurse realizes that one of the patients needs immediate attention by a medical doctor. She activates the list of available doctors and selects the name of the one available in the hospital with the necessary specialty. She immediately rings him up and starts talking to him about the situation. The medical doctor starts walking towards the ward while talking on his device with the nurse and giving her instructions for immediate actions, until he has reached the room of the patient.

11. Conclusions and future work

It was discussed that hospital personnel exhibit nomadic work behaviour. Hence ubiquitous and uninterrupted access to existing information is a means for enhancing their work situation. Advanced information visualization is the means for effectively presenting information to the user. Context aware systems, featuring advanced information visualization may successfully address many shortcomings of the current routing of nomadic users in a clinical environment. We have presented a system, which was introduced in the domain of cultural heritage and is generic enough to be applied in the clinical routine supporting mobile devices for medical staff. We have presented a set of functions supported by the platform intGuide, as well as indicative use cases, showing the added value for the clinical environment emerging from the introduction of such a system.

A necessary prerequisite for the successful introduction of such a system is the interoperability with existing legacy systems in the clinical environment. Health level 7 (HL7) is one of the things that come to mind in this context. The HL7 information exchange is thus far not supported by the system. If the system is to be introduced as a successful extension to existing legacy systems and not an island solution, HL7 is one of the major priorities of the adaptation to the clinical routine. The main focus will be the connectivity to the EPR system.

Additional helpful features may occur by extending the workflow control system to cover for additional activities. One example in this direction is the monitoring of progress of registered activities, e.g., status of laboratory tests for individual patients. Other examples of important extension are the accessing of an e-library of the hospital or even an extranet of health.

Acknowledgements

The work presented here is mainly a concept work showing the introduction of the inGuide platform in a clinical environment. The intGuide platform is based on the outcome of a series of European research projects related to cultural heritage and augmented reality, all of them co-funded by the European Commission in the 5th and 6th framework of the IST program.

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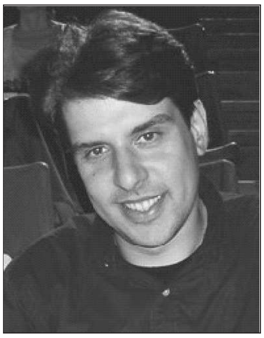

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Paper

Improving interpretability: combined use of LVQ and ARTMAP in decision support

Hoi Fei Kwok, Andrea Giorgi, and Antonino Raffone

Abstract— The learning vector quantization (LVQ) network was used to classify the ECG ST segment into different morphological categories. Due to the lack of data in the ST elevation categories, the classifier was only trained to identify different types of ST depressions (horizontal, upsloping and downsloping). The accuracies were 91%, 85% and 65% respectively for the training, validation and testing data respectively. Despite the low accuracy for the testing data, most of the mis-classifications were downsloping ST depression being classified as horizontal ST depression. We concluded that more data and more training are needed in order to train the LVQ to recognize other morphological types of ST deviation and to improve the accuracy.

Keywords—learning vector quantization, ARTMAP, decision support systems, ischemic heart disease.

1. Background

Cardiovascular diseases have long been recognized to be one of the major causes of morbidity and mortality in developed countries and myocardial infarction is one of the important causes of premature and sudden death in adults. The early detection and diagnosis of myocardial ischaemia allow early intervention and can improve the survival rate. Electrocardiogram (ECG) is an important component of the diagnosis of myocardial ischaemia. In the diagnostic process, the clinicians look at the rhythm of the ECG, the ST-segment deviation, the shape of the segment, the shape of the QRS complexes and the shape of the T wave. Then a decision will be made upon whether the ECG is suggestive of ischaemia supported by the clinical guidelines. Therefore, the diagnosis is usually made in a 2-stage process. Firstly, symptoms, signs and features from the ECG and laboratory investigations are sought. Then, a diagnosis is made using the rules derived from previous research and clinical guidelines.

The computer-assisted diagnosis of ischaemic heart disease has been a subject of research in the past two decades due to an increase in interests in artificial intelligence. However, most systems suffered from a lack of interpretability. Baxt [1] used the presence of a list of medical history, symptoms, signs and ECG features as inputs to an artificial neural network (ANN) but the ECG features were not extracted automatically and no explicit rule could be extracted from the ANN. Other works [3, 4] used different sets of input items but they still required the clinicians to interpret the ECG. Another approach is to use a one-stage approach (for example [2, 7]). The input is the ECG signal and the output is the diagnosis. Neural networks are used to classify the ECG into normal or ischaemic. However, this approach is a black-box approach that does not offer an explanation to the users as to why the system considers the patient having or not having myocardial ischaemia.

In order to improve the interpretability, a rule-based approach is required but in order to use the rule-based approach, one requires information about the inputs to the rules. The inputs to the rules, in the context of the diagnosis of ischaemia from the ECG, include the presence of ST deviation, shape of the ST segment and pathological Q wave, etc. The conventional approach of ST analysis and most standard ECG monitors can give information regarding the magnitude of ST deviation. It is known that ST deviation in itself can be due to other causes [9], therefore, it is important to take the shape of the segment and other information into consideration. However, the recognition of shape cannot be easily done using conventional ECG wave detection method due to the low signal-to-noise ratio. Although one can use a parametric approach by modeling the ST segment by first or second order equations, the segment is short and noisy and the parameters derived can be unreliable. Therefore, a neural network approach is adopted. We used the learning vector quantization (LVQ) network to classify the shape of the ST-segment. The classification can in turn be used as one of the input features to a rule-base system which is developed using the adaptive resonance map (ARTMAP).

2. Overall architecture

Before presenting the use of LVQ in ST analysis, we would like to describe first the overall architecture of the rule-based disease-specific approach of automatic detection of ischaemia from ECG signals. The overall scheme is shown in Fig. 1. The ECG signals are first processed by the ECG processor module. This module filters the ECG and then uses a wavelet-based algorithm to identify the ECG characteristic points (such as positions of R wave, J-point, T wave, etc.) [6]. The module also divides the ECG into segments containing only one beat based on the position of the QRS complexes. These segments can then by used as the inputs to the black-box ST morphology classifier, which is based on the use of the LVQ network.

The ST segment deviation and shape will then be supplied as inputs to the diagnostic rules module. Other features required by the rule-base can be derived from the positions of ECG characteristic points. These features include heart rate, T-wave inversion, tall R wave, widened QRS complex and pathological Q wave, etc.

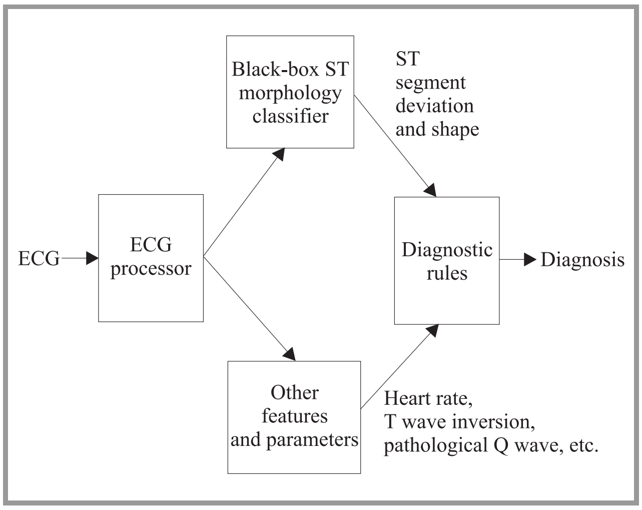

Fig. 1. The overall scheme for the ischaemic classification from ECG. The black-box ST morphology classifier is based on the LVQ network and the "diagnostic rule" module is based on ARTMAP.

The diagnostic rules module consists of a set of "if-then" rules. These rules were derived using the ARTMAP. A graphic user interface (GUI) was implemented and used for presenting the ECG to the cardiologists and recording their classification. ECG segments were presented to the cardiologists and they were asked to indicate on the screen the presence or absence of the input features and the diagnosis (i.e., normal, probably ischaemia, ischaemia, abnormal but not ischaemia, etc.). The data were then used for the ARTMAP training. After training, the rules were derived from the top-down weights of the ART_a module and were reviewed by the cardiologists. Unacceptable rules were excluded. In this paper, we will not go into the details of the ARTMAP as the primary focus is the use of LVQ.

3. Learning vector quantization

The LVQ network [5] is a neural network related to the vector quantization and can be used for pattern classification. Here we will only present the LVQ1 which was used in our system. The LVQ1 consists of an input layer and an output layer. The dimension of the input layer is the same as that of the input vector. Each node in the output layer represents one output class. The activity of each output node is the Euclidean distance between the input vector and the input weight vector. The output layer is a competitive layer and thus, the output from the node with the highest activity will be 1 and the outputs from the rest will be zeros.
During the training, the weight vector is adjusted according to the output class and the target class. The target class is the desirable target. Let $\mathbf{w_c}$ be the input weight vector of the output class node, $\mathbf{x}$ be the target class. The weights are adjusted according to the following equations:

$$\mathbf{w_c}(n+1) = \mathbf{w_c}(n) + \alpha(n)\left[\mathbf{x}(n) - \mathbf{w_c}(n)\right] \quad \text{if } \mathbf{x} \text{ and } \mathbf{w_c} \text{ belong to the same class,} \tag{1}$$

$$\mathbf{w_c}(n+1) = \mathbf{w_c}(n) - \alpha(n)\left[\mathbf{x}(n) - \mathbf{w_c}(n)\right] \quad \text{if } \mathbf{x} \text{ and } \mathbf{w_c} \text{ belong to different classes,} \tag{2}$$

where $\alpha(n)$ is the learning rate at the nth epoch. The input weights of other nodes remain unchanged. Using this algorithm, the input weight vector will get closer to the input vector as time progresses.
The network is modified in the MATLAB neural network toolbox. An additional layer of neurons is added to the output layer so that the output layer becomes the hidden layer. The number of nodes in this new hidden layer can be greater than the number of output classes (named subclasses). The dimension of the new output layer is the same as the number of output class. Therefore, a few subclasses can be associated with the same output class using a binary connection weight. This is the network structure that was adopted in this paper.

4. Methodology

4.1. Training and testing data collection

The ECG signals from the European ST-T database were used. Only those from V4 were used in the study as not enough data can be retrieved for the training purpose from other leads. The QRS complexes in the ECG signals were located and used as reference points for the truncation of the signals into individual beats. Each individual beat was presented to a clinician for the classification of ST morphological type. For the development and training of the LVQ network, each input-target data set consisted of the time-series voltage values from one ECG beat and the corresponding ST-morphology assigned by the clinician. The data were divided into training data set, cross-validation data set and testing data set.

4.2. Data preprocessing and network training

Each ECG beat was re-sampled to give 128 data points. The signals were then normalized to zero mean and unity standard deviation. The principal component analysis (PCA) was then applied to the data and the coefficients each principal component were used as the input to the LVQ network. During the PCA, only components accounted for more than 1% of the total variance were included. In this way, the input dimension was reduced to 15 from 128. LVQs with 16 to 30 hidden nodes were used and the LVQ which showed the best performance was chosen. The training was done in series of 100 epochs until a maximum of

1000 epochs. After every 100 epochs, the prediction error in the cross-validation data set was calculated. The training stopped when an increase in the prediction error was detected.

5. Results

The 486 beats were analyzed by the clinician; 7 beats were unclassified (due to large signal noise) and only 37 out of 486 beats showed ST elevation. Therefore, a decision was made not to include ST elevation as one of the output categories. The LVQ so developed could therefore only classify the ECG beat into "normal", "horizontal ST depression", "upsloping ST depression" and "downsloping ST depression". The LVQ with 27 hidden nodes was found to give

Table 1
The performance of the LVQ network with 27 hidden nodes

Target	LVQ output											
	Training data				Validation data				Testing data			
	1	2	3	4	1	2	3	4	1	2	3	4
1	31	2	0	1	25	3	2	1	49	6	0	0
2	9	37	1	6	9	36	3	6	5	17	1	2
3	0	4	40	1	3	7	36	4	3	0	0	0
4	0	8	0	30	0	7	0	28	1	15	2	0

Target: 1 – normal, 2 – horizontal ST depression, 3 – upsloping ST depression, 4 – downsloping ST depression.

the best performance. It gave the correct classification in 91% of the training data, 87% of the cross-validation data and 65% of the testing data (Table 1). Most of the mis-classifications in the testing data were classified as "downsloping ST depression" by the clinician and the network classifications were "horizontal ST depression".

6. Discussions and conclusions

The accuracy of the trained network on the training data and the validation was satisfactorily however, the accuracy on the testing data was poor. However, when one looks into the details of the make-up of the testing data, one can see that the data were not evenly distributed. Only three cases were classified by the clinician as upsloping ST depression. The mis-classification of downsloping ST depression into horizontal ST depression may indicate that the class boundary should be shifted more towards the downsloping ST depression. The performance may be improved by further training. Another solution is to use the LVQ2. In LVQ2, not only the weight vector closest to the input will be modified but the one second closest to the input may also be modified under defined circumstances.

As mentioned earlier, more data will be needed in order to train the neural network to recognize different types of ST elevation and to recognize the ST morphology in more leads. The LVQ network was chosen in this paper for this application because each ST-segment can only belong to one morphological class and the LVQ network can be trained to discover the class boundaries and the competitive layer ensures that only one class is chosen as the output. Despite this, the use of other types of neural network can be investigated in the future.

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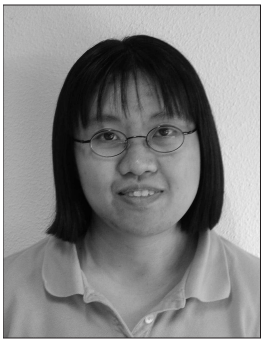

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Regular paper

Methodology to measure the quality of service in healthcare information and telecommunications infrastructures

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Abstract—The telecommunications industry in last decade went through the dramatic changes motivated by mobility, wireless technologies and miniaturization. The continuous increase in the complexity and the heterogeneity of healthcare telecommunications infrastructures requires reliable methodology to assess the quality of service provision. This article presents a cost effective methodology to assess the user's perception of quality of service provision utilizing the existing Staffordshire University network by adding a component of measurement to the existing model presented by Walker. This paper offers a cost effective approach to assess the QoS provision within the University campus network, which could be easily adapted to any campus network or healthcare organization in the world.

Keywords— user's perception of quality of service, assessment methodology, electronic health record, health care telecommunications infrastructures, Staffordshire University network communications infrastructure.

1. Introduction

The world today is driven by the information exchange providing support for the national and global cooperation. The supporting telecommunications infrastructures are becoming more complex providing the platform for the user driven real-time applications over the large geographical distances. The essential decisions made concerning the state welfare, heath systems, education, business, national security and defense, depend on quality of service (QoS) provision of telecommunications and data networks. Regardless of the technology supporting the information flows, the final verdict on the quality of service is made by the end user. The users' perception of telecommunications' network infrastructure QoS provision is critical to the successful business management operation of any organization. As a result, it is essential to assess the quality of service provision in the light of user's perception. The quality of service is one of the most elusive, confounding, and confusing topics in data networking today [1]. While research papers on QoS hardly ever questioning raison d'etre it is frequently the topic of heated debates. Why are so many publications and even workshops on a topic which is questioned vehemently while at the same time has so little impact on current products or services [2]? The term *service quality* may have a different meaning to different people [3]. This is perhaps more accurately called QoS, as opposed to service quality, which could be taken to mean the entirety of outcome and experience [4]. The great majority of users are not interested in the engineering of telecommunications networks or its QoS specifications; instead they expect fast, reliable, and easy access to online resources, applications and Internet (i.e., online databases, banking services, e-commerce, e-mails, web servers, etc.) [5]. Most doctors and medical staff today (i.e., clients) expect to have immediate access to various communications technologies (i.e., wireless, mobile, fibre optics, Ethernet, etc.) using almost any software application, following the banking principle of anywhere, anytime, and anyhow [6].

2. Staffordshire University network

2.1. SUN's overview

The SUN has three major sites including stoke-on-trent, Stafford and Litchfield and a number of buildings distributed around each site interconnected via leased communications lines shown in Fig. 1.

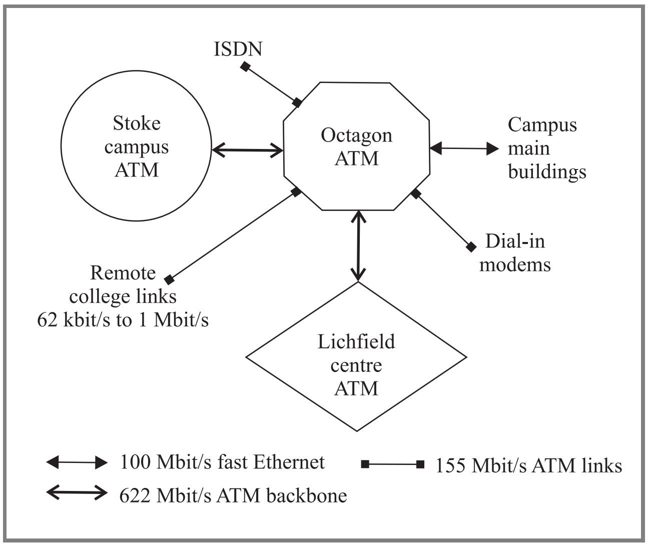

Fig. 1. Staffordshire University network diagram.

The SUN was installed by the Digital Equipment Corporation (DEC) more than ten years ago using CAT4 cables (up to 16 Mbit/s transmission rates), which are currently being upgraded to CAT5 (up to 100 Mbit/s transmission rate). The Catalysts 1900 series switches replaced the DEC 90T hubs. Each building has a router connected to an Ethernet, with concentration of switching in the wiring closets. Specialized networks for graphic arts and computer science are also connected behind firewalls, and these are based on 100 Mbyte connections. To provide support for users who do not have computers, all student mail and files are stored on shared network drives accessible from terminals in the various campus computer labs. Students with their own computers run e-mail clients that map to the remote e-mail server when connected. A network administrator accesses each student's computer at the beginning of the semester to set up the appropriate drive mappings and permissions. Every time the SU users send or receive anything over the Internet it travels through Staffordshire University and connects to the Net North West network, which is the gateway to the Janet network show in Fig. 2.

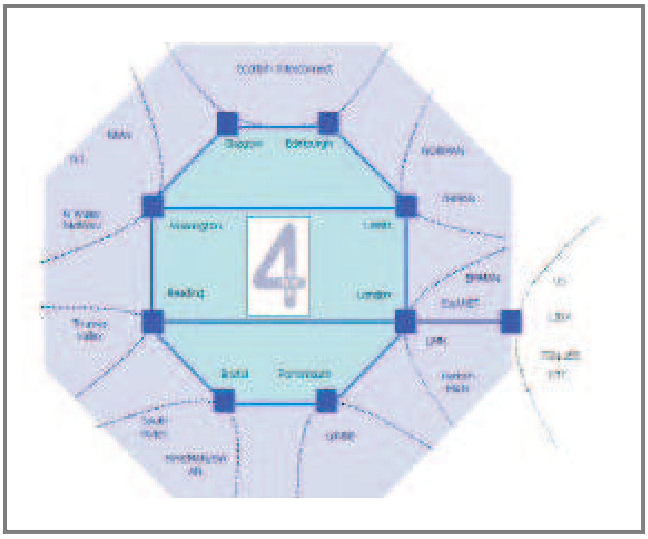

Fig. 2. SuperJanet4.

2.2. Quality of service

2.2.1. Information technology QoS framework

The ISO has produced a draft international standard ISO/IEC DIS 13236 [7], "is to provide a common basis for the coordinated development and enhancement of wide range of standards that specify or reference quality of service requirements or mechanisms". The framework is a structured collection of concepts and their relationships, which describes QoS and enables partitioning of, and relationships between, the topics relevant to QoS to be expressed by a common description. It is intended to assist developers of new and revised standards, which define and use QoS mechanisms, and users expressing requirements for QoS [8]. The typical QoS characteristics represent some aspect of the QoS of a system, service or resource, which can be identified and quantified. User requirements drive the QoS-management activities and originate with an application process that wishes to use a service. The requirements may be retained in an entity which may also analyze them in order to generate further requirements that are conveyed to other entities as QoS parameters, and so on. Examples of such parameters are given from network measurements:

- a measured value, used to convey historical information;
- a threshold level (i.e., the threshold for the users' perception of network QoS provision).

2.2.2. Enhanced disconfirmation model

The existing information technology (IT) definition of QoS lacks the clarity required to express separately the service provider's and customer's viewpoints. Disconfirmation model applied to assess the SUNCI QoS provision is illustrated in Fig. 3, which illustrates the enhanced disconfirmation model of customer satisfaction based on the original model [8]. The advancement of current measurement technologies and the results of this paper introduce a new model by comparing the performance measurements (M) with the expected (E) and perceived (P) performance. Empirical evidence suggests [8] that there are a number of key characteristics or attributes which customers will generally evaluate to determine the quality of any particular product or service. The disconfirmation model shows that

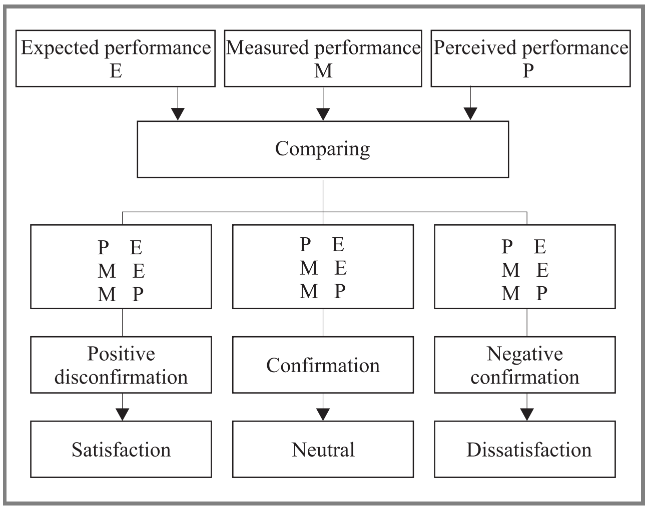

Fig. 3. The enhanced disconfirmation model of customer satisfaction.

customer's satisfaction will be dependent on both the size and direction of disconfirmation, with only three possible outcomes. When "perceived" is greater than "expected", customers will be very satisfied; when "perceived" is equal to "expected ", customers will be satisfied (i.e., the product is performing exactly as expected); when "perceived" is less than "expected", customers will be dissatisfied. The QoS required by the customer is a statement of the level of quality of a particular service required or preferred by the customer [9]. A typical customer is not concerned with how a particular service is provided or with any of the aspects of the network's internal design, but only with the resulting end-to-end service quality [8]. It must be recognized that the customer's QoS requirements are useful, although subjective.

A customer may judge the service based on his or her location, connectivity and means of access, as well as the computational processing power on his or her workstation. It is up to the service provider to translate this into something of objective use [9].

Quality as perceived by customers from a comparison of what they feel the product should offer (i.e., drawn from their expectations) with their perception of the actual performance of the product. When customers register with the campus network, they already have expectations of how network should perform and this will cover a whole host of criteria [8] including:

– conformance to specification (user accounts and privileges, accessibility);
– performance (primary network characteristics, such as utilization and error rate);
– reliability (probability of the network malfunction-free performance);
– availability (probability of the network being available);
– simplicity (ease of use);
– serviceability (speed, courtesy and competence of repair).

The network expectations may be considered as predictions, sometimes subconscious ones, which customers make about what is likely to happen during the use of it. In practice, this may differ significantly from the views of IT services, whose views of quality will be based on their perspectives of the network services offered. However, the most important evaluation of quality is that carried out by the customer and network real-time measurements. This evaluation draws on expectations and expectations introduced by Gronroos [10] in defining quality within the service environment as:

quality = customer's expectations – customer's perceptions.

This may be further analyzed and subdivided using the disconfirmation model, if quality is "conformance to requirements" and the real judge of quality is the customer, and then they must evaluate quality in relation to their satisfaction. For the purpose of clarity author defines the level of expectations being always greater that the level of perception. For example, the users' expectations of the services are very high equal to ten on ten, but their perception is only four on ten, which correspond to less than good.

However, if the user's perception reaches level of 10 on 10 then this considered to be an exceptionally good service. Given the SUN current technological and SU financial status it is quite unlikely that the level of user's perception of SUNCI QoS provision would exceed the level of their expectations. In other words, if the SU marketing strategy to attract the overseas students is based on offering them the best services, then the ultimate judgment will be carried out by the student once he or she had actually used the particular services. This may be further analyzed and subdivided using the disconfirmation model, if quality is "conformance to requirements" [11]. The real judge of quality is the customer, then they must evaluate quality in relation to their satisfaction. The "enhanced disconfirmation model" of customer satisfaction was based on the original model [11]. The advancement of current measurement technologies and the results of this work introduce a new model by comparing the measurements performance (M) with the expected (E) and perceived (P) performance. According to the IT service norms the SUN average utilization for half-duplex communications1 is 70%. Figure 4 illustrates the system utilizations measurements and the daily top talkers access to the IT network. The network utilization bounces from under utilized (i.e., from 10:00 until 14:00) to over utilized (i.e., from 14:00 until 19:00 with utilization decrease between 17:00 until 18:00). From the graphs captured, it is evident that the utilization increases in the late afternoon hours, due to the students' assignments submission deadlines. Results of SUNCI measurements show in Fig. 4, illustrate that system utilization reflects the users' utilization pattern and the error rate is equal to null, which constitute a good correlation with the survey questionnaire results.

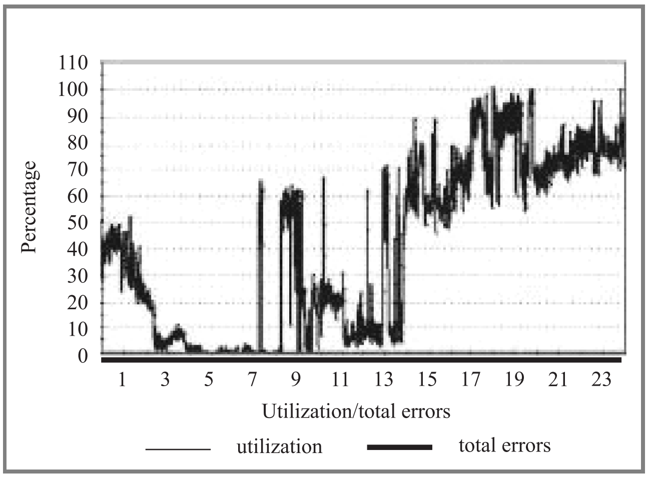

Fig. 4. The system utilization/total errors on Tuesday April 3rd 2002 at residency network.

Half-duplex communications systems are those systems where information is transferred on two directions, but only in one direction at the time.

Empirical evidence suggests [10] that there are a number of key characteristics or attributes which customers will generally evaluate to determine the quality of any particular product or service. The disconfirmation model shows that customer's satisfaction will be dependent on both the size and direction of disconfirmation, with only three possible outcomes. When "perceived" is greater than "expected", customers will be satisfied; when "perceived" is equal to "expected", customers will be neutral, neither satisfied nor dissatisfied (i.e., the product is performing exactly as expected); when "perceived" is less than "expected", customers will be dissatisfied.

2.2.3. Four quality cycles

There are two principal parties in the QoS cycle, the customers and the service providers as shown in Fig. 5. For the service provider, such a division leads to planned and achieved quality. For the customers this division leads to their QoS requirements or expectations and their perception of the performance experience.

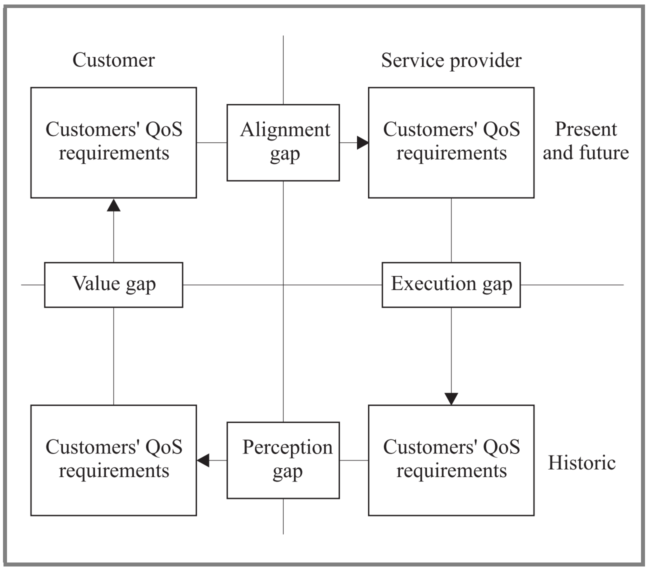

Fig. 5. Quality cycle [8].

The scale of customer satisfaction or dissatisfaction will be dependent on the difference between "expected" and "perceived" performance of these key characteristics or attributes. QoS offered by the service provider is a statement of the level of quality that is offered to the customer. This is the level of service that the service provider can achieve with the design of the network. The level of quality is expressed by values assigned to network performance parameters, which cover the network and network support [12]. The QoS achieved by the service provider is a statement of the level of quality achieved by the service provider. It is a record of the levels of quality that have been achieved. These are expressed by values assigned to the parameters specified for the offered QoS. These performance values are summarized for specified periods, for example, for the previous three months and/or on an annual basis. The QoS perceived by the customer is a statement expressing the level of quality experienced by the customer. The perceived QoS is usually expressed in terms of the degree of satisfaction and is assessed by the information technology survey questionnaire.

3. Users' perception surveys

This section presents results of the IT survey questionnaire used to assess the QoS. In order to assess SU users' perception of SUNCI QOS provision and their level of satisfaction, two IT surveys were conducted over a period of two consecutive semesters. The results of both surveys provided the IT management team with useful information about the users' perception. Generally there are two types of questionnaire: one to assess customer opinion of a particular service, the other to assess the overall opinion of a service provider [8]. The IT survey questionnaire was designed to address all major groups of SU users, their relation to the SU, access point location; means of access connectivity, the end workstation type the application access priorities and the critical time of network utilization for a specific type of application.

3.1. Survey results

Respondents were asked for their perceptions on response times on a scale from excellent down to very poor. If the response was scored such that: excellent = 10, very good = 8, good = 6, reasonable = 4, poor = 2, very poor = 0. The results illustrate clearly that the majority of average scores lie between 4 and 6, indicating that respondents typically see response time lying between reasonable and good, on average. The total number of respondents to both surveys was 1116, which represents more than 10 percent of SU users' community. The results show the evidence that most users tend to use their computer for a significant period of time, once they are online. Respondents were asked about the time of day they tended to use the University facilities. The only exceptions appear to be the use of ftp transactions, which are often seen as less than reasonable, particularly at a student residence or at home. Clearly there is the perception that there is better support on-campus compared with off-campus. Table 1 illustrates the users' perception of application performance

Table 1
User's perception of the application performance

Applications	Campus	Student residence	Home
Last use	5.5	4.3	4.9
FTP	4.7	4.0	4.7
Web	5.6	4.3	5.0
E-mail	5.9	4.4	4.9
Admin	5.3	–	4.9

while accessing the network from home, residencies and main campus.

The results demonstrate that the respondents' perception of IT support is that it is quite good on campus, better than reasonable at residences, but worse than reasonable off-campus (see Table 2). The majority of respondents' primary applications tend to be e-mail and the second most significant use is web browsing. The IT services are currently focusing on application performance management.

Table 2
The average scores

Places	Score
Off-campus	4.5
Student residence	4.6
On-campus	5.7

According to survey results the 56 K modem was the main type of remote access connection for the majority of users. In addition there was a variety of makes and models of computers, although the majority appeared to have a Pentium processor and be less than three years old.

4. Conclusions

The current technological evolution in the electronic health record presents new challenges and research problems to community of experts working in the field of medicine and information technology. However, despite of technological and medical research advancements it is essential that the computerized electronic health record systems will be available to all community of doctors, medical staff and patients worldwide as a tool that ultimately contributes towards the process of humanization of all aspect related to medicine. In the current climate of business-driven education with a focus on the user's satisfaction it is essential that the university campus networks provide support for a large number of software applications running reliably over very complex interconnection hardware with fast system response and high security. This requires a great deal of interoperability and dynamic resource allocation within the networks. The concept of assessing QoS provision is often represented in many different ways by various specialists groups including; computer scientists, network engineers, network administrators, Internet services providers, and university business managers. This paper discusses the theoretical background on QoS, SUNCI current network monitoring practices, and an IT survey questionnaire. In this paper the author presents a new cost effective methodology for assessing the QoS provision with a minimum effect on network performance and its functionality, while discussing the users' perceptions of SUNCI QoS provision. The results suggest that the level of users' satisfaction of SUNCI QoS provision is reasonable and that there is a good correlation between the users' perceptions and the traffic measurement of SUNCI QoS provision. This research further promotes future research in merging the engineering methods and business perspectives on the QoS provision. Speed and accessibility to any information at any time from anywhere will create global communications infrastructures with great performance bottlenecks that may put in danger human lives, power supplies, national economy and security. It is essential to measure all engineering and social issues with much faster speeds. The future of telecommunications industry will be driven by four major drives for prosperity starting with the differentiated networks, health informatics, advanced television and sensor networks. The continuous increase in complexity and the heterogeneity of university campus networks will require assessment methods that are capable of addressing all engineering and social issues with much faster speeds. Speed and accessibility to any information at any time from anywhere will create global communications infrastructures with great performance bottlenecks. To find the solutions to deal with network congestion and information overflow will remain an engineering, social and mathematical problem.

Acknowledgments

The author is grateful for the support received from the information technology management and network team, the Staffordshire University community, including students, academic administrative and technical staff, who responded to IT survey questionnaire.

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Regular paper

Stochastic DEMATEL for structural modeling of a complex problematique for realizing safe, secure and reliable society

Hiroyuki Tamura and Katsuhiro Akazawa

Abstract— In this paper we propose a revised Decision Making Trial and Evaluation Laboratory (DEMATEL), called stochastic DEMATEL, to extract structural model of a complex problematique and to represent the priority of each factor taking into account the uncertainty of structure. In the stochastic DEMATEL, the uncertainty of structure is expressed as a stochastic model. From numerical experiments and experimental analyses, the following results are obtained: when the structure is uncertain, stochastic DEMATEL could extract the features of structure by the degree of dispatching influences and the degree of central role; stochastic composite importance could express the uncertainty of priority and decide the priority taking into account the attitude of the decision maker; pessimistic, neutral or optimistic.

***Keywords—** safe, secure and reliable society, structural modeling, stochastic DEMATEL, stochastic composite importance.*

1. Introduction

Decision Making Traial and Evaluation Laboratory (DEMATEL) has been widely used to extract a problem structure of a complex problematique [1–3]. By using DEMATEL we could quantitatively extract interrelationship among multiple factors contained in the problematique. In this case not only the direct influences but also the indirect influences among multiple factors are taken into account. Furthermore, we could find the dispatching factors that will rather affect the other factors, the receiving factors that will be rather affected by the other factors, the central factors that the intensity of sum of dispatching and receiving influences is big, and so forth.

It is important and useful to get the structural model of a problematique from which we could find the priority among multiple strategies to improve the structure. This is the main aim of DEMATEL. However, the conventional DEMATEL is insufficient to obtain significant implication of the priority of the strategies for decision making as follows:

1. Shortage of information on the importance of each factor

   Suppose we got three factors; "to get enough income", "to get successor", "to improve productivity", in the problematique of agriculture. The decision maker is trying to find the order of priority among these three factors. Suppose the conventional DEMATEL found that "to improve productivity" is the most influential factor to improve the problem structure. However, if "to get successor" is the most important factor in the future agricultural problem, this factor should be the first priority for the strategic planning of agriculture. In the conventional DEMATEL it is hard to find the superiority of factors, since we could get only interrelationship of factors contained in the problematique. To overcome this difficulty we proposed a new criterion "composite importance (CI)" [4] combining the interrelationship of factors and the importance of each factor.

2. Shortage of flexibility to describe structural uncertainty

   Conventional DEMATEL describes the deterministic interrelationship among factors contained in the problematique. However, the strength of the interrelation among factors may be dependent on the various situations, and the fluctuation may depend on the factors taken into account. For example, in the agricultural problematique, "to improve productivity" may contribute "to get enough income", but to what extent may be dependent on each farmhouse. "To get enough income" may contribute "to get successor" uniformly.

In this paper in the context of finding priority among multiple strategies to improve the structure of the problematique, we aim at three objectives as follows:

- We propose a stochastic DEMATEL to deal with flexible interrelationship among factors in the problematique.
- We show usefulness and future problem of stochastic DEMATEL through an empirical analysis of a simple numerical example where we deal with structural modeling of uneasy factors of university students and unmarried adults.
- We try to extract effective strategies to realize safe, secure and reliable society as the results of empirical analysis of uneasy factors of university students and unmarried adults.

2. DEMATEL and composite importance

2.1. Outline of DEMATEL

Suppose, in a complex problematique composed of n factors, binary relations and the strength of each relation are investigated. An example of binary relation is such that "How much would it contribute to resolve factor j by resolving factor i?" We would get $n \times n$ adjacent matrix X that is called the direct matrix. The (i, j) element x_{ij} of this matrix denotes the amount of direct influence from factor i to factor j. If the direct matrix X is normalizes as $X_r = \lambda X$, by using $\lambda = 1/$(the largest row sum of X), we would obtain

$$X^f = X_r + X_r^2 + \cdots = X_r(I - X_r)^{-1}. \tag{1}$$

Matrix X^f is called the direct/indirect matrix. The (i, j) element x^f_{ij} of the direct/indirect matrix denotes the amount of direct and indirect influence from factor i to factor j.

Suppose D_i denotes the row sum of ith row of matrix X^f. Then, D_i shows the sum of influence dispatching from factor i to the other factors both directly and indirectly. Suppose R_i denotes the column sum of ith column of matrix X^f. Then, R_i shows the sum of influence that factor i is receiving from the other factors. Furthermore, the sum of row sum and column sum $(D_i + R_i)$ shows the index representing the strength of influence both dispatching and receiving, that is, $(D_i + R_i)$ shows the degree of central role that the factor i plays in the problematique. If $(D_i - R_i)$ is positive, then the factor i is rather dispatching the influence to the other factors, and if negative, then the factor i is rather receiving the influence from the other factors. We call D_i, R_i, $(D_i + R_i)$ and $(D_i - R_i)$ the degree of dispatching influences, the degree of receiving influences, the degree of central role and the degree of cause, respectively.

There exist many case studies [5–10] of DEMATEL to get an appropriate structural model. Some of them are trying to get a structural model identifying the central factors and the causing factors based on the evaluation of the degree of central role and the degree of cause. The degree of cause denotes whether the factor is rather cause or effect. It does not reflect the amount of dispatching or receiving influence. Since the objective of this paper is to find the priority of the strategy to improve the overall structure, we turn our attention to the degree of dispatching influences.

2.2. Composite importance

Suppose based on the degree of dispatching influences we found a factor that may contribute to improve the overall structure. In this case to resolve this factor is not necessarily the best choice, since the factor that could contribute to resolve some important factors may be more efficient to resolve even if it may not contribute to improve overall structure. Since the original DEMATEL is not taking into account the importance of each factor itself, it is not possible to evaluate the priority among the factors. Similarly, it is not possible to evaluate the priority of each factor by just looking at the importance of each factor. We need to take into account both the strength of relationships among factors and the importance of each factor. To reflect both viewpoint we proposed the composite importance z as [4]

$$z = y_r + X^f y_r = (I + X^f) y_r, \tag{2}$$

where y_r denotes the normalized n-dimensional vector of y that denotes n-dimensional vector composed of the importance of each factor, where "normalized" means to divide each element of y by the largest element in y.

3. Stochastic DEMATEL

3.1. Stochastic direct matrix

In the ordinary DEMATEL the direct influence from factor i to factor j is written in the (i, j) element x_{ij} of the direct matrix X. Suppose the structure of the problematique is uncertain and x_{ij} is a random variable. Furthermore, suppose the stochastic parameter values of x_{ij} are different for different pair of i and j. When each element of the direct matrix is a random variable, each element of the direct/indirect matrix X^f is also a random variable. Furthermore, the composite importance z is also a random variable. Therefore, it is necessary to extend the ordinary DEMATEL to deal with uncertainty in the problem structure. We propose a stochastic DEMATEL in which we could take care of various uncertainties in the problem structure.

In stochastic DEMATEL let G be a set of stochastic direct matrices X^s generated by a Monte Carlo method from the direct matrix X^v with probabilistic information. The direct matrix with probabilistic information is an $n \times n$ matrix with (i, j) element x_{ij} and probability density function $g(x_{ij}|\theta_{ij})$, where θ_{ij} denotes the parameter including expectation and variance.

As described above in the ordinary DEMATEL we could get the element of direct matrix by asking such a question as "How much would it contribute to resolve factor j by resolving factor I?" On the other hand in the stochastic DEMATEL we need to collect the information on the variance as well as on the expectation of influence. Possible methods to collect information on variance are as follows:

- **Method 1.** We ask a respondent the best value and the worst value, by asking "How much would it contribute to resolve factor j at most by resolving factor i, and how much would it contribute to resolve factor j at least by resolving factor I?" From the best value and the worst value we could estimate the variance.

- **Method 2.** We ask multiple respondents on the value of direct matrix and compute the variance from these multiple direct matrices.

- **Method 3.** We combine Method 1 and Method 2. We ask each respondent the best value and the worst value of each element of the direct matrix. Then, we aggregate these data and estimate the variance of each element of the direct matrix.

3.2. Manipulation in stochastic DEMATEL

We normalize the stochastic direct matrix as

$$X_r^s = \lambda \cdot X^s \,, \tag{3}$$

where

$$\lambda = 1/(\text{the largest row sum of } X^s)\,.$$

Then we obtain

$$X^{sf} = X_r^s + (X_r^s)^2 + \cdots = X_r^s (I - X_r^s)^{-1}\,, \tag{4}$$

where X^{sf} denotes a stochastic direct/indirect matrix that has the same property as the ordinary direct/indirect matrix. Stochastic composite importance is obtained as

$$z^s = y_r + X^{sf} y_r = (I + X^{sf}) y_r\,. \tag{5}$$

If we obtain stochastic direct/indirect matrices and stochastic composite importance for all the direct matrices contained in the set G, we could obtain the set G^f of the direct/indirect matrices and the set G^z of composite importance. Furthermore, we could obtain the set of the degree of dispatching, the set of the degree of receiving, the set of the degree of central role and the set of the degree of cause, respectively.

4. A simple numerical experiment

4.1. Structural modeling by stochastic DEMATEL

Suppose an overall structure is composed of three factors a, b and c, and the direct matrix is given by

$$X_e = \begin{bmatrix} 0 & 2 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}. \tag{6}$$

In this structure factors a and b are mutually influenced, factor c is influenced by factor a, and factor b is influenced by factor c. Therefore, factor b is influenced by factor a both directly and indirectly. The intensity of direct influence is the largest from factor a to factor b.

As the degree of dispatching influences and the degree of central role, we obtained for factor a: 1.85 and 2.80, for factor b: 0.95 and 2.80 and for factor c: 0.65 and 1.30. As for the degree of dispatching influences, factor a is the largest and factor b is the next. Both factors a and b are the central factors, factor a is a cause factor and factor b is an effect factor. Suppose the structure of this simple numerical example is uncertain. Suppose besides the information on expectation given by the direct matrix, variance for each element is given by

$$Var_e = \begin{bmatrix} 0 & 0.04 & 0.04 \\ 0.04 & 0 & 0 \\ 0 & 0.04 & 0 \end{bmatrix}, \tag{7}$$

where the dispersion of the influence from factor a to factor b is assumed to be relatively small. It is assumed that cutting normal distribution between zero and infinity is assumed for probability density function.

We generated 1000 elements of a set G by using Monte Carlo method. Then, for each element of the set G, that is, for each stochastic direct matrix X_i^s ($i = 1, 2, \ldots, 1000$), we could obtain stochastic direct/indirect matrix and a set G^f.

Figure 1 shows the degree of dispatching influences and the degree of receiving influences obtained from the stochastic direct/indirect matrices. As seen in this figure the degree of dispatching influences of factor a is big and the degree of receiving influences of factor b is big. As the expectation (and the variance in the parenthesis) of the degree of dispatching influences and the degree of receiving influences we obtained for factor a: 1.8907 (0.0694), 1.0006 (0.1079), for factor b: 0.9936 (0.0966), 1.9064 (0.1167) and for factor c: 0.6805 (0.0418), 0.6577 (0.0175).

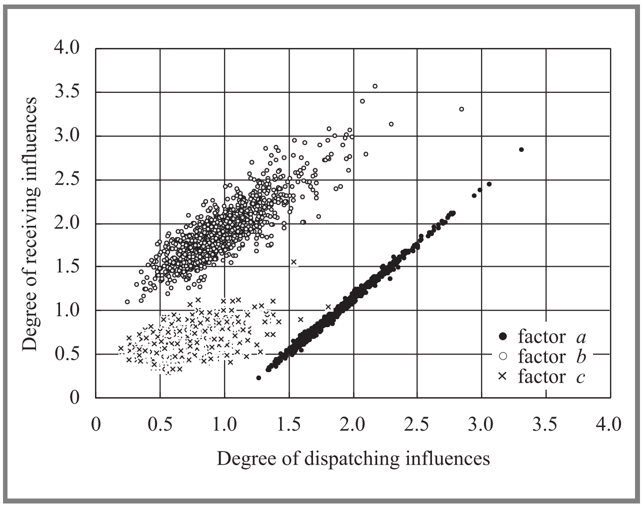

Fig. 1. Degree of dispatching influences and degree of receiving influences.

For factor a and factor b we found a big positive correlation between the degree of dispatching influences and the degree of receiving influences especially for factor a. The reason is that for both factors when they affect the other factor, the influence is fed back to themselves directly. On the other hand for factor c since the influence is fed back to itself indirectly, we did not find a big correlation (correlation coefficient = 0.51) between the degree of dispatching influences and the degree of receiving influences.

Table 1
Stochastic composite importance (numerical experiment)

Factors	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Importance	0.4	0.4	0.4	0.3	0.1	0.7	0.1	0.7	0.4
Expected value	1.1563	0.7974	0.6722	0.8332	0.3860	0.8320	1.0670	1.0670	0.7637
2.5 percentile	0.9910	0.5936	0.5411	0.7049	0.2409	0.7622	0.9011	0.8791	0.5949
25 percentile	1.0822	0.7125	0.6166	0.7825	0.3254	0.7993	0.9930	0.9869	0.6973
Median	1.1414	0.7778	0.6621	0.8252	0.3733	0.8247	1.0549	1.0521	0.7544
75 percentile	1.2114	0.8658	0.7158	0.8748	0.4373	0.8550	1.1216	1.1313	0.8192
97.5 percentile	1.4006	1.0882	0.8679	1.0079	0.5971	0.9403	1.3114	1.3354	0.9915
CV	0.0911	0.1559	0.1216	0.0902	0.2283	0.0560	0.0992	0.1093	0.1290

In Fig. 1 we could draw many lines with gradient -1. The points on the same line have the same degree of central role, and the point located upper right side has a bigger degree of central role than the points on the line. These lines denote the indifference lines of the degree of central role. By using these indifference lines we could find that factors *a* and *b* are the central factors. As the expectations of the degree of central role we found for factors *a*, *b* and *c*: 2.8914, 2.9000 and 1.3382, respectively.

Next, we draw a line passing through the origin with gradient 1 in Fig. 1. Then, the points located lower right side of this line are the "cause" factors and the points located upper left side of this line are the "effect" factors. This fact implies that in every stochastic direct/indirect matrix it is found that factor *a* is a cause factor and factor *b* is an effect factor. Factor *c* is a cause factor or effect factor case by case.

If we compare the degree of dispatching influences, the degree of receiving influences and the degree of central role for ordinary DEMATEL and for stochastic DEMATEL, these values are almost identical. The values for stochastic DEMATEL are slightly larger than those for the ordinary DEMATEL. If we could find a precise probability distribution function and if we could generate infinitely many random numbers precisely, the expectation for both DEMATELs should agree each other in principle.

We found that we could get a proper structural model of a complex problematique under uncertainty by using the degree of dispatching influences and the degree of central role of the stochastic DEMATEL proposed in this paper.

4.2. Stochastic composite importance

If we assign the value of importance of each factor, we could evaluate the stochastic composite importance. Since we obtain 1000 values for each factor, we summarize the result in Table 1: percentiles (2.5%, 25%, median, 75%, 97.5%), expectation and coefficient of variation (*CV* = standard deviation/expectation).

In the ordinary DEMATEL we could decide the priority of each factor based on the value of composite importance itself. In the stochastic DEMATEL we use three stochastic decision principles as follows:

- **Expectation principle.** We decide the priority based on the expected value or median of composite importance.
- **Max-min principle.** We decide the priority of each factor by maximizing the worst value (either 2.5 percentile or 25 percentile) of composite importance. This principle reflects a pessimistic decision.
- **Max-max principle.** We decide the priority of each factor by maximizing the best value (either 75 percentile or 97.5 percentile) of composite importance. This principle reflects an optimistic decision.

As seen in Table 1 when the importance of each factor is 0.4, the composite importance of factor *a* is the largest under any of these three decision principles, therefore, the highest priority is given to factor *a*. When the importance of factors *a*, *b* and *c* is 0.3, 0.1 and 0.7, respectively, the priority of factor *a* is higher under the expectation principle and max-max principle, and the priority of factor *c* is slightly higher under the max-min principle. When the importance of factors *a*, *b* and *c* is 0.1, 0.7 and 0.4, respectively, the priority of factors *a* and *b* is higher under the expectation principle, the priority of factor *a* is higher under the max-min principle and the priority of factor *b* is higher under the max-max principle. In this case under the attitude of pessimistic decision, factor *a* is chosen to be resolved, and under the attitude of optimistic decision, factor *b* is chosen to be resolved. In this case the expectation for factors *a* and *b* is almost identical, *CV* for factor *a* is smaller than that for factor *b*, and factor *a* is chosen under the max-min principle and factor *b* is chosen under the max-max principle. This implies that the priority decided by max-min principle and max-max principle depends on the variance of composite importance of each factor.

As seen above the stochastic DEMATEL could describe the uncertainty of the structure of complex problematique, could describe the uncertainty of priority by the stochastic composite importance and could decide the priority of each factor reflecting the decision makers attitude whether he/she is pessimistic, neutral or optimistic.

5. Structural modeling of uneasy factors by stochastic DEMATEL

5.1. Data

We use the data previously obtained from university students and unmarried adults [4].
For university students 10 uneasy factors are chosen as follows:

1. Career to pursue (CAR)
2. Scholastic performance (SCH)
3. Home economy (HOE)
4. Health of myself (HEM)
5. Health of family (HEF)
6. Marriage (MAR)
7. Looks (LOO)
8. Ability/character (ABI)
9. Human relations (HUR)
10. Job and work (JAW)

For unmarried adults 9 uneasy factors are chosen as follows:

1. Home economy
2. Health of myself (HEM)
3. Health of family (HEF)
4. Unemployment (UNE)
5. Marriage (MAR)
6. Looks (LOO)
7. Ability/character (ABI)
8. Human relations (HUR)
9. Job and work (JAW)

Respondents to the questionnaire are 10 university students and 10 unmarried adults. The importance of each factor is asked to the respondents by 5-grade evaluation where the importance of each factor means the degree of feeling uneasy for each factor. Then, the strength of binary relation for each pair of factors is asked by 3-grade evaluation, We look at the binary relation such that "How much would it contribute to resolve factor b (the anxiety for SCH) by resolving factor a (the anxiety for CAR)?"
The direct matrix is obtained by averaging the data of 10 people on the strength of binary relations. The data for the importance of each factor are first normalized between 0 and 1 and then averaged for 10 people.
Structural model for uneasy factors of university students is described as follows: the degree of central role for CAR (4.75) is high and CAR has the property of both cause factor and effect factor, but since the degree of cause for CAR (-0.35) is negative, CAR is rather an effect factor. Actually, CAR is greatly affected by ABI, SCH, HOE and JAW.
Besides CAR the degree of central role for HOE (3.63), ABI (3.63), JAW (3.54) and SCH (3.35) are high. Especially, the degree of cause for ABI (1.41) is high, this is a central factor with the property of cause factor.
Structural model for uneasy factors of unmarried adult is described as follows: the degree of central role for JAW (6.07) is high, and then ABI (5.79), HOE (5.40). JAW and ABI are mainly cause factor, however, they have the property of effect factor as well. On the other hand HOE is affected by UNE, JAW and others, and has the property of effect factor.
In Table 2 the degree of dispatching influences and composite importance of university students and unmarried adults are shown. Concerned with the degree of dispatching influences ABI, CAR are high for university students and ABI, JAW, HEM are high for unmarried adults with this order. Concerned with the composite importance CAR, ABI are high for university students and ABI, JAW, HEM are high for unmarried adults with this order. This implies that by resolving these factors overall uneasiness is resolved enormously.
We need to pay attention that for university students the order of factors for the degree of dispatching influences is different from the order of factors for the composite importance. The reason why is that in the composite importance the degree of dispatching influences as well as the importance of each factor and the importance of affecting factors are reflected. For example the degree of dispatching influences of CAR is not so high, but since the importance of CAR is high, the composite importance of CAR is high in consequence. Therefore, it is clarified that from the view point of importance CAR is to be resolved and from the view point of dispatching influences ABI is to be resolved.

5.2. Structural modeling by stochastic DEMATEL

Suppose the structure of the uneasy factors is uncertain. Expectation and variance of probability distribution is obtained by the dispersion of the data contained in multiple respondents reply in the direct matrix. Probability density function is assumed to be a cutting normal distribution defined on $[0, \infty)$. Based on these probabilistic information 1000 stochastic direct matrices are generated by using a Monte Carlo method.
Tables 3 and 4 show a structural model extracted by the stochastic DEMATEL from the uneasy factors of university students and unmarried adults, respectively. The ex-

Table 2
Composite importance

Factors		CAR	SCH	HOE	HEM	HEF	UNE	MAR	LOO	ABI	HUR	JAW
Students	*D*	2.200	1.643	1.825	1.052	0.607		0.866	0.753	2.521	1.510	1.826
	Importance	0.675	0.550	0.600	0.350	0.400		0.500	0.450	0.500	0.450	0.425
	CI	1.796	1.411	1.527	0.894	0.706		0.928	0.842	1.794	1.232	1.374
Adults	*D*			2.167	3.041	1.324	1.565	1.824	1.553	3.307	2.529	3.243
	Importance			0.475	0.550	0.550	0.400	0.425	0.550	0.600	0.425	0.475
	CI			1.528	2.028	1.182	1.163	1.316	1.299	2.189	1.659	2.048

Table 3
Structural extraction by stochastic DEMATEL (university students)

Values		CAR	SCH	HOE	HEM	HEF	MAR	LOO	ABI	HUR	JAW
D	Expected	2.248	1.818	2.217	1.613	0.948	1.422	1.063	2.523	1.859	2.296
	Median	2.140	1.679	2.156	1.472	0.861	1.290	0.947	2.456	1.730	2.254
	CV	0.359	0.422	0.347	0.427	0.466	0.439	0.511	0.263	0.404	0.342
$D+R$	Expected	4.934	3.799	4.286	3.044	2.112	2.706	3.209	3.939	3.762	4.223
	Median	4.689	3.570	4.031	2.809	1.926	2.505	2.953	3.753	3.454	4.023
	CV	0.339	0.366	0.341	0.368	0.398	0.381	0.383	0.294	0.365	0.337

Table 4
Structural extraction by stochastic DEMATEL (unmarried adults)

Values		HOE	HEM	HEF	UNE	MAR	LOO	ABI	HUR	JAW
D	Expected	2.181	2.630	1.661	1.734	1.970	1.813	2.772	2.268	2.703
	Median	1.992	2.551	1.490	1.571	1.767	1.634	2.665	2.089	2.601
	CV	0.453	0.345	0.486	0.484	0.476	0.498	0.341	0.447	0.362
$D+R$	Expected	4.820	4.283	3.347	3.987	4.495	3.696	5.074	4.575	5.182
	Median	4.453	4.015	3.035	3.656	4.136	3.372	4.779	4.305	4.815
	CV	0.405	0.368	0.433	0.422	0.416	0.427	0.368	0.405	0.385

pected value obtained in these tables did not agree with the results obtained by the ordinary DEMATEL. Since the expected value and median are little bit different, the assumption of cutting normal distribution may not be appropriate. However, since concerned with the order of the degree of dispatching influences (D) and the degree of central role ($D+R$) the result obtained by the stochastic DEMATEL gave a good agreement with the result obtained by the ordinary DEMATEL, the stochastic DEMATEL is appropriate to extract the property of the structural model.

Since the value of coefficient of variation (CV) is around 0.4, the uncertainty of the structure is fairly big. If we look at CV of D and $D+R$ for each factor, we find that CV of D and $D+R$ for ABI is smaller than for the other factors and CV of D and $D+R$ for LOO is large for university students. This implies that by resolving ABI university students could expect a stable effect, but by resolving LOO university students should anticipate uncertain effect. For unmarried adults CV of D and $D+R$ for ABI and HOM is small and the variation of CV depending upon the different factors is relatively small.

5.3. Stochastic composite importance

In Tables 5 and 6 stochastic composite importance of each factor for university students and unmarried adults is shown, respectively.

For university students composite importance, that is, the priority of CAR, ABI and HOE are large with this order under the expectation principle and max-max principle, where the priority of ABI and HOE is reversed for 97.5 percentile. This is due to the fact that CV for HOE is larger than that for ABI. Under the expectation principle the priority obtained by the stochastic DEMATEL gave a good agreement with the priority obtained by the ordinary DEMATEL. This result implies that reliability of the stochastic com-

Table 5
Stochastic composite importance (university students)

Values	CAR	SCH	HOE	HEM	HEF	MAR	LOO	ABI	HUR	JAW
Expected	1.804	1.482	1.708	1.171	0.880	1.201	0.994	1.775	1.394	1.593
2.5 percentile	1.170	0.935	1.079	0.719	0.561	0.777	0.630	1.188	0.841	0.914
25 percentile	1.495	1.207	1.425	0.917	0.722	0.969	0.807	1.561	1.124	1.293
Median	1.752	1.411	1.671	1.093	0.834	1.134	0.938	1.741	1.328	1.566
75 percentile	2.053	1.676	1.935	1.365	0.995	1.370	1.112	1.956	1.591	1.846
97.5 percentile	2.726	2.392	2.574	2.001	1.475	1.976	1.725	2.497	2.348	2.454
CV	0.226	0.266	0.228	0.300	0.254	0.259	0.280	0.190	0.274	0.252

Table 6
Stochastic composite importance (unmarried adults)

Values	HOE	HEM	HEF	UNE	MAR	LOO	ABI	HUR	JAW
Expected	1.540	1.836	1.351	1.252	1.394	1.434	1.942	1.540	1.795
2.5 percentile	0.898	1.104	0.855	0.736	0.827	0.895	1.195	0.856	1.050
25 percentile	1.186	1.541	1.078	0.970	1.075	1.124	1.645	1.175	1.458
Median	1.449	1.801	1.266	1.177	1.292	1.345	1.889	1.454	1.739
75 percentile	1.795	2.080	1.522	1.442	1.593	1.635	2.196	1.808	2.074
97.5 percentile	2.636	2.740	2.294	2.231	2.554	2.573	2.923	2.664	2.779
CV	0.314	0.243	0.290	0.329	0.331	0.309	0.239	0.324	0.268

posite importance obtained by the stochastic DEMATEL is quite high.

Under the max-min principle the priority of ABI is the highest and then that of CAR and HOE. The reason why the priority of ABI is the highest is that the max-min principle reflects the pessimistic attitude of decision and that *CV* of D for ABI is small, and as the result *CV* of composite importance is also small. This will lead to the expectation of certain effect by resolving uneasiness of ABI.

For unmarried adults the priority of ABI, HEM and JAW are large with this order under all the three principles except that for 97.5 percentile the priority of JAW and HEM is reversed. This order of priority obtained by the stochastic composite importance is different from that obtained by the composite importance of ordinary DEMATEL: ABI, JAW and HEM. The reason why we get this result is that for unmarried adults the elements of the stochastic direct matrices are smaller than those of the direct matrix. As the result each element of the degree of dispatching influences (D) is reduced to be relatively small. As we know the composite importance reflects both D and importance of each factor. Since the value of D is reduced to be relatively small in the stochastic composite importance, weight for D is reduced to be smaller than that for importance of each factor. As the result, in the stochastic DEMATEL the priority of HEM became higher than that of JAW, because the importance of HEM is larger than that of JAW for unmarried adults.

The reason why the elements of the stochastic direct matrices are smaller than those of the direct matrix may be due to the error arisen from inappropriate assumption of probability density function. Although this error does not cause serious defects when we evaluate the degree of dispatching influences (D) and the degree of central role $(D+R)$, we may get some defects when we evaluate composite importance. Therefore, to overcome this difficulties we need to develop a method of identifying appropriate probability distribution function or to develop a non-parametric approach.

6. Concluding remarks

In this paper a stochastic DEMATEL is proposed for structural modeling of a complex problematique taking into account the uncertainty of structure. This method is obtained by extending the deterministic variables in the ordinary DEMATEL to random variables. To show the validity of the method a simple numerical example and a structural modeling of uneasy factors are included for the purpose of realizing safe, secure and reliable society.

New knowledge obtained in this study is as follows:

- Stochastic DEMATEL could extract the characteristics of the structure even when there exist uncertainty in the structure.
- Stochastic composite importance could describe the uncertainty of priority arising from the uncertainty of the structure, and could decide the priority taking into account the attitude of the decision maker towards risk; pessimistic, neutral or optimistic.

- In order to resolve uneasy factors of university students uneasiness of CAR and ABI is efficient to be resolved. CAR is to be resolved from the view point of the importance of the factor and ABI is to be resolved from the view point of the degree of dispatching influences. When the decision maker's attitude toward risk is pessimistic, it is desirable to resolve the uneasiness of ABI, since certain effect can be expected by doing so.
- To resolve the uneasiness of ABI is the most effective for unmarried adults.

It is demonstrated above that the stochastic DEMATEL and the information obtained by the stochastic composite importance are quite useful for structural modeling of complex problematique.
For further study we need to develop a method of identifying appropriate probability distribution function or we need to develop a non-parametric approach. We also need to develop a method of collecting information on variance. For these purposes we need to experience more empirical analysis of various case studies.

Acknowledgement

This research was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) under Grant-in-Aid for Creative Scientific Research (Project No. 13GS0018). The authors would like to thank Ms. Haruna Nagata who was an undergraduate student of Osaka University for her kind collaboration with this research project.

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Regular paper

Personal communication services in wireless networks

Wojciech Michalski

Abstract—The paper presents modern personal services and new trends observed in evolution of wireless services. The article covers voice and data transmission services offered in mobile networks as well as information services delivered to users over Internet/IP networks. With reference to voice services, selected GSM services based on IN services platform, e.g., the services of flexible scenarios are described. Moreover, the status of VoIP service provided over WLAN is explained. Concerning data transmission services, selected UMTS services are presented as well. Among information services, presentation of wide scope of services offered to mobile users, e.g., messaging, location-based information, transferring text information, unified communications as well as Internet services, e.g., e-commerce, e-shopping, telebanking and micropayments is done. For both, voice and data transmission services, personal services are presented exclusively. Generally, the most attractive services with personal features are selected and described in this paper.

Keywords— personal services, information services, voice services, data transmission services, services of flexible scenarios, number portability, universal personal telecommunications, universal access number, messaging, location-based information, transferring text information services, unified communications, e-commerce, e-shopping, telebanking, micropayments.

1. Introduction

Until the early 1980s telecommunication networks have handled fixed-line telephones and have delivered plain old telephony service (POTS) services only. Telephony services have included voice telephony above all, but with some small additional (non-voice) complements like telefax, telex and data communications, mainly over private networks. Later, this situation has significantly changed and it is still changing. Today, thanks to digitization of information as well as the convergence of information and technologies, telecommunication networks carry voice, data and images.

Another fundamental change was migration from wireline to wireless communications. Although wireline (fixed) communications is still the main sector of telecommunication market, the role of cellular networks as well as wireless local area networks (LANs) and wireless personal networks becomes more and more important.

In the beginning, in traditional networks, access to high bandwidth has been provided to the corporations only (mainly via leased line solution). Later the virtual private networks (VPNs) were introduced instead of leased lines. For some corporations these solutions remained the norm. But for modern businesses as well as for mobile employees, wireless local area networks (WLANs) solution provided by either fixed or mobile operators or Internet service providers (ISP) is offered now. Its use has increased rapidly to meet the growing demand for private as well as personal communications, because high bandwidth and broadband services are seen as a major factor in pushing forward the information society now.

2. Wireless personal communications

Wireless personal communications is a hot topic in a whole world today. It is interesting concept both for the media and for the public. Therefore, it is important subject of several technical publications, conferences and seminars. Many people want wireless personal communications, but almost everyone prefers different version of them (someone wishes access to cellular mobile radio system, another one to wireless LANs, etc.).

Wireless personal communications include many different wireless networks, systems, technologies, services and applications as well as modes, functions and range of mobility or coverage in wireless personal communications (seven of them was described in *Journal of Telecommunications and Information Technology*, no. 3/2005). The main of them are: global system for mobile communications (GSM)/universal mobile telecommunication system (UMTS), wireless LANs (WLANs) and wireless personal area networks (WPANs). These networks support the standard-based platforms that provide and control the services offered to wireless subscribers. These are the application platforms that include built-in telecommunications features as well as such next generation applications as web-based control of subscriber features, unified messaging, etc.

Independently of all, it is clear that wireless personal communication is the fastest growing segment of telecommunications. It is clear also that among the different changes seen in communications, the main question is the change from wired communications between fixed locations to wireless mobile person to person communications, known as wireless personal communications.

3. Mobility and portability in wireless networks

Mobility and portability are the most significant attributes of wireless communications, thanks to which wireless networks have evolved from physical connections to communications networks. The possibility to be free and easily change location caused rapid growth of mobile technologies and wireless communications services. Development of technology enabled increase of speed of data transmission as well as security and privacy in wireless networks. Evolution of telecommunication services leads from voice services towards specialized wireless data applications offered in UMTS, WLAN, WPAN, etc. On the other hand, supporting voice and data transmission in one packet is the most important task today. The packet-oriented data transmission and circuit-oriented voice communications converge to similar solutions at large scale in many aspects, e.g., data transfer technology as well as hierarchical routing. With reference to data transfer technology, both transmission modes can be integrated in the asynchronous transfer mode (ATM)-based networks. Concerning hierarchical routing, some intelligent routers are able to handle delay-sensitive packets.

4. Personal communication services in GSM network

Because intelligent network (IN) services platform is separated from the physical level, it is very useful for creation and implementation of telecommunication services both in the fixed network as well as mobile and Internet protocol (IP)-based networks. Therefore, it was adapted in cellular network together with the concept of services implementation. In particular, the adaptation applies to significant group of services called flexible scenarios services being the most representative group of personal services. According to the concept of flexible scenarios services, users may participate in creation of their services. For this reason, these services are becoming more and more popular categories of telecommunication services today. Some of them have been provided widely for a long time (e.g., freephone, split charging, terminal portability), other will be provided over convergent network in the near future (universal personal telecommunications, user defined routing, etc.).

Call transfer services as well as voice mail services will probably be as attractive for users in the future as they are now. But it is expected that in the near future, mainly the convergent services will be developed. Currently, some operators offer application known as fix/mobile convergence, linking fixed and mobile network features within a single service. This application gives the mobile subscribers an integrated telephone service and enables to have one number and one bill for both fixed and mobile networks.

Great popularity of Internet and cellular networks causes that integration of IP and wireless technologies is required, too. It is required now that cellular networks provide access to Internet services and offer quality of service (QoS) for voice and data transmission services comparable to one guaranteed in fixed networks. Moreover, it is required that next generation mobile networks provide wider scope of telephone and information services, especially personal services, than existing 2G GSM.

As a result of services evolution, the new generation of IN networks plus new sets of IN services and service functions are developed. Evolution of telecommunication services is accompanied by separate trend concerning creation of IN in GSM environment. This trend, known as customized applications for mobile network enhanced logic (CAMEL) makes it possible to deliver full range of services registered in users profiles to subscribers being away from home network. Limitations in access to the services may be caused only by technological or functional barriers existing in foreign network. Thanks to this evolutionary path, the modern information services, especially location-based services, were deployed.

5. Personal communication services in UMTS network

Universal mobile telecommunication system provides wide bandwidth and appropriate broadband services provisioned in accordance with the user's needs and their location. As a convergence network, UMTS adapts different accesses, installed in particular hybrid networks, with mixed use for voice, data and video distribution. Moreover, it supports data transmission-oriented broadband services, which may be created as a personal services based on IN services platform. Mechanisms needed for creating of these services are delivered by functionality known as a service creation environment (SCE). With SCE, personal services may be created based on universal program modules called service independent building blocks (SIBs). Network operators and service providers may select and couple SIBs, according to subscriber needs or requirements, either themselves or in cooperation with their subscribers. Thanks to the SCE capabilities, specific telecommunication services, having personal features, may be created. Moreover, thanks to a rich of library SIBs, these services may have individual character and they don't recur. It should be underlined, that SCE functionality enables creation of services besides the offerings of manufactures.

Evolution of UMTS communications toward data transmission services. GSM built on traditional telecommunication network infrastructure operates in circuit-switched mode and it is designed in principle for voice services. Teleservices as well as data transmission services are treated as a complement to the main application, i.e., telephony. However at present, in 2G GSM+ (GSM integrated with general packed radio service – GPRS), more data transfer-oriented services, especially in Internet services area, will be offered.

The most significant application in UMTS is related to data transmission services delivered in packet mode. It is clear, that data transmission segment is highly dynamic in 3rd generation cellular networks. Development of data transmission applications is linked to the increasing transmission speed and implementation of new services. Thus, generally one can say that evolution of UMTS services leads toward packet data transmission services above all.

Another evolutionary path runs toward information services, especially toward multimedia services. Development of new applications and data transmission services includes new categories of information services, e.g., messaging (i.e., services delivering information required by users), location-based information, unified communications, e-banking, a-commerce, etc. In many cases, users want information delivered by multimedia services. Thanks to packet data transmission it is possible to increase the bit rate as well as to allow virtual connections and asymmetrical division of bandwidth. High speed of data transmission is necessary for implementing information services because they require wider bandwidth than others. Moreover, high speed is a great problem concerning multimedia services, especially services offered over the Internet. Therefore, the possibility of negotiating load characteristics of given stream before the connection is established and during active connection are especially important for providing required QoS. The possibility of negotiation by users of significant attributes for given connection, e.g., circuit or packet mode, bit rate, delays, BER, etc., is almost as important. Packet data transmission with high bit rate eliminates the limitations existing in GSM and provides UMTS users with access to the services on a global scale. Moreover, it allows to change channel transmission speed both up and down, which is specially needed for Internet services using asymmetrical streams.

Evolutionary path related to development of data transmission services toward Internet services leads from traditional cellular networks toward IP-based networks. From functional point of view, this direction of evolution is quite natural and evident, because in packet oriented networks (cellular networks and LANs) subscribers can be reached everywhere and are always-on. It should be underlined that IP-based networks provide their subscribers with different transaction services as well as unique applications, e.g., teleworking, supporting communication between home office and corporation resources.

Evolution of UMTS applications is (much like GSM ones) directed toward fixed/mobile convergence, which allows to provide unified services over both fixed and mobile network. One of them is unified messaging using one mail account for different information (voice, data, fax information, etc.). Access to the universal mailbox will be provided from fixed and mobile phones as well as by fax or Internet.

6. Personal voice services delivered by wireless networks

Today, access to voice services is provided by all wireless networks ranging from GSM through UMTS to WPAN. Recently, the voice over IP (VoIP) application over the WLAN has been introduced. New service gives to ISP, WLAN operators and service providers the possibility to provision selected voice services delivered over IP protocol in their networks. Generally one can say that voice services as well as data transmission services are dedicated to and are used by businessmen spending large proportion of their time travelling. Moreover, mobile local servants, trade employees and users of teleworking application are also significant group of users of the WLAN services.

6.1. Voice over IP in WLAN

Voice over IP in WLAN is an application known as voice over WLAN (VoWLAN). It provides basic telephone service in wireless LANs. This application works according to IEEE 802.11 standard and permits transmission of voice through the WLAN. New service corresponds to VoIP service in wired LANs and allows to establish voice connections based on IP telephony procedures coordinated by the SIP functions. Quality of service and security of communications is protected by some mechanisms included in 802.11e and 802.11i standards. Thanks to VoWLAN solution it is possible to transfer the voice connection between access points belonging to different WLANs as well as between WLANs and other networks. The new solution gives users the possibility to select type of network (GSM or WLAN) used in voice transmission. Due to this possibility, standardization processes concerning VoWLAN have a significant meaning for development of this technology. Introduction of this technology may be accelerated if IEEE 802.11f will be admitted as an obligatory standard and all basic problems concerning inter-network roaming will be solved.

6.2. Personal services in WPAN network

Wireless personal area networks (WPANs) like the WLANs provide access to the Internet and telecommunication services. WPANs offer speedy and easy access to wide selection of voice and data transmission services, especially information services.

Wireless PANs have a rich functionality, exceeding one of GPRS, and comparable only with UMTS capabilities. WPAN services are based on terminal intelligence, which plays the role of personal multifunction communicator including computers, notebook, mobile telephone, etc. Intelligent terminals allow to create ad hoc networks, built in, say, bluetooth standard. Depending on capabilities of terminals, WPANs can support some specific services like wireless home networking (WHN).

Wireless home networking enables grouping of different home electronic devices. The WHN is a collection of elements that process, manage, transport, and store information, enabling connection and integration of multiple computing, control, monitoring, and communication devices at home. Each element of WPAN may be made in different technologies and architectures and may include different features and technical solutions. One of practical solutions of WHN is the controller-based voice and data service. In this scenario, the microprocessor-based digital switch acts as the communications server, addressing and routing voice and data traffic throughout the household area. The controller is a bridge between the transport network element serving the home from the networks of the customer-selected service provider and the wireless home network. There are four distinct functional areas served by a controller-based voice and data WHN solution:

– home local area network (this allows sharing of computer files, printers, and disk drives and support multiplayer personal computer (PC) games via a wireless Ethernet and a transmission control protocol/Internet protocol (TCP/IP) local area network);

– Internet gateway (controller provides an Internet gateway addressing and routing function for sharing a single ISP account and connection between all PCs);

– wireless voice networking (each wireless handset can view and manage up to four POTS lines while the PCs are simultaneously being used on the LAN; this solution allows users to access caller ID and voice-messaging status information and make decisions regarding call management in real time);

– traditional wireline POTS networking (all telephone lines serving the household terminate on the controller and they are distributed to wireless handsets or wireless phone jacks with built-in transceivers to which standard phones, fax machines, or modem-equipped PCs can be connected).

Wireless home networking is based on several different formats, standards and specifications, which are emerging in home networking and transport between IEEE 802.11 and other networks.

Single radio ad hoc for ultra wide band (UWB) based on wireless personal area networks application includes specific distinctive features like ad hoc self-configuration, power level aware routing, dynamic latency/throughput control and multiple pico-net controller support.

6.3. Personal voice services in GSM and UMTS networks

The GSM and UMTS provide wide range of voice services generally determined as supplementary services and IN-based services. Supplementary services include many services divided into few groups, such a number identification services, call offering services, call completion services, multiparty services, charging services, community of interest services, call booking services, call restriction services and short message service. Among IN-based services is the flexible scenarios group of services, comprising universal personal telecommunication, number portability, freephone and premium rate numbers. Some of them have been provided for a long time (number portability, freephone service, split charging, virtual private network), while other will be provided in the near future (universal personal telecommunications, user defined routing).

Number portability (NP) in mobile networks has completely different means and functionality than in fixed networks. Address assigned to subscriber in mobile network does not include any valid information about his physical location within the network. This address known as a service number is always fixed, although the user moves across the network. However, in mobile networks exist also routing numbers, which are changed due to roaming. In these networks, routing number is assigned call by call, or session by session in IP-based networks. Service number provides access to the network anywhere; in the visited network of another operator it provides access to the same service profile as in a home network. Service profile moves through the network together with the user and number portability idea is related to virtual home environment (VHE) functionality based on unique service profiles.

Freephone service (FPH) allows making calls to certain numbers without payments by calling subscribers, because the cost is covered by called subscriber. Service may be provided with different additional possibilities, e.g., in one number version, with call forwarding on busy or non reply, with call barring, with call distribution, etc. In a case when FPH service customer has several regional divisions, scenario of the service may include routing of calls depending of geographical location of calling subscriber and time of the day (origin and time dependent routing version).

Split charging service (SPL) allows the cost to be divided between calling and called subscribers in any proportion. The customer using SPL service may have multiple regional divisions, which are reached by dialling the same number.

Virtual private network (VPN) permits the operators or selected users (administrators) to create private telecommunication networks using the resources of public network. The idea of virtual network is based on assumption that subscribers of private network may be registered in different home location registers (HLRs), but whole virtual network works like as a private network built on one PBX. It is possible to apply private numbering plan in such network, tailored to the structure of particular company. There are several versions of this service. One of them gives the possibility to assign the subscriber special facilities as well as possibility to create individual user profiles. Another one enables to add VPN subscribers belonging to others networks. The application allows associated subscribers to access VPN resources, after an authentication procedure is performed.

Universal personal telecommunication (UPT) enables to give the customer a personal telephone number to get access to any (fixed or mobile) network. Incoming calls are routed to destination indicated by UPT service customer. The destination is reached in accordance with customer requirements, thanks to the use of temporary forwarding number.

User defined routing (UDR) allows the users to define preferred routing paths for originating calls. Users are able to prepare appropriate preference lists containing selected public and private nodes. Selection of connections paths is based on preferences indicated by the users.

7. Personal information services delivered by Internet/IP networks

As it was said earlier, products of evolution of telecommunication networks toward IP-based networks include integrated services provisioned in circuit and packet modes, based on IN services platform. Part of them may be implemented as personal services. Personification of telecommunication services includes more and more groups of users of wireline and wireless networks.

Personal services, especially information services created using the mechanism and tools of IN services platform, i.e., open services platform (OSP) and personal services environment (PSE) as well as interactive voice response (IVR) and virtual home environment functionality, may be provided based on different applications.

Both standardized and propriety interfaces to mobile network are used to design and provision the services mentioned above.

Messaging services. Today's messaging services allow users to access, exchange and manage all their messages sent over all media more easily – saving time and increasing convenience. Messaging services include, e.g., services delivering information and instant messaging.

Location-based information services. Application works using current user location, obtained from network. It includes, e.g., information on demand (information about hotels, airports, stations, restaurants, cafes, shops, etc.) and home zone billing services.

Services for transferring text information. The group of services used for transferring text information consists of various types of voicemail and e-mail services (e.g., visual voicemail, voice e-mail service), SMS, paging and virtual phone services.

Unified communications. Unified communications encompasses all forms of call and multimedia/cross-media message management functions controlled by an individual user for both business and social purposes. This includes any enterprise informational or transactional application process that emulates human user and uses a single, content independent personal messaging channel (mailbox) for contact access. Unified communications comprises, e.g., voice/fax messaging and unified messaging services.

Speech enabled interactive voice response. Serving as a bridge between users and computer databases, interactive voice response platform implemented in IVR systems provide telephone users with the information they need, anywhere, any time. Today this application is used to support stock trade transactions, make travel arrangements and manage bank accounts. Most of today's IVR and transaction processing applications employ a touch-tone or dual tone multifrequency (DTMF) user interface. However, applications that allow callers to use their own voice rather than DTMF inputs to complete transactions are rapidly emerging as the latest innovation in telephony-based remote self-service.

Telebanking. Telebanking is an application making possible to implement all or some types of bank transactions in remote manner.

E-commerce. Electronic commerce solution is used for purposes ranging from fund raising to selling products. This application supports also services like hotel and flight reservation.

Micropayments. Micropayments are a part of prepaid services based on smart card solutions. These enable service subscribers to purchase preloaded credit, enabling instant activation of new category of wireless capabilities – and a new way to view the operator-subscriber relationship. Cards can contain micropayments and shopping services.

Mobile Internet. Mobile Internet is an application developing in direction new services implementation. Mobile Internet should provide the same scope of services as the fixed Internet. It will be possible in the UMTS system.

Portals services. Portals services, accessible via suitable servers, are application development platforms which allow service providers or third-party software developers to deliver services to the telephony users and to add new services and unique applications. Portals services include, e.g., web services, web surfing services, synchronized web surfing etc.

Voice portal services. In general, voice portal solution comprises all services concerning voice-controlled dialogues, voice-controlled information browsing and different enhanced Internet applications. In particular it supports applications such as: call waiting Internet, speech banking, mobile Internet (web by phone), call center, computer telephony integration (CTI), unified messaging, voice-mail, lotteries and televoting. Mobile Internet comprises such services as voice XML application, Internet call directory assistant (ICDA), free and premium call button and others.

Internet broadcasting. Internet broadcasting service called also a webcasting service allows delivering text and audio information to the user. It may be some information send in defined cycle, advertisements and radio or TV content associated with sport or music performances.

E-learning. E-learning is a category of service which gives its users the capabilities for changing type and conditions of work as well as forms and methodology of education.

E-publishing. Electronic publishing application allows the users serve the same purposes and tasks as traditional publishing, but in a more attractive form.

Video on demand. Video on demand is an application which gives the possibility to multiply signals received from various sources and present video content on demand. It allows users to receive information selected by the user from his location.

8. Conclusions

The market for telecommunication services is changing fast. Therefore, design of strategies for introducing new services must be done by identifying general trends and subsequently permanently analyzing the environment (social, technological, political and economic factors, as well as the competitive environment) for implementation and correlation of given strategy with changes that have occurred.

At present, it is a general trend indicating that the fixed telephony losses ground to the mobile one. In many European countries, the density of mobile subscribers has exceeded the density of fixed ones. Though the number of households accounts for the market of the fixed telephony, the potential for mobile telephony is larger. Currently, another trend is also clear indicating that only information services are really developed both in fixed and mobile networks. Moreover, it is evident that among the information services, mainly personal services are really needed by wide range of subscribers and this category of services has the highest growth rate today.

In this situation, it is expected that all information services concerning messaging and delivering of location-based information as well as transferring and delivering information needed by the users, will be depveloped towards full personalization. According to this idea, modern services will be more specialized and subscriber-oriented applications. They will be applied for the purpose of delivering the users selected information accompanied by current locations, requirements, interests and time. Based on his individual menu, the subscriber will be able to configure himself the scenarios for delivering preferred types of information.

From costs point of view, the text communications is in many cases very useful and much more profitable than voice communication. Delivery of information in SMS or e-mail form has often replaced direct voice communication. Transfer of text information may be applied in situations when the manager gives the orders to his workers being out of office or when someone wants to reserve doctor's visits or to book any products or services. In the near future mobile telephones will have capabilities for e-mail communications.

With reference to the technical means applied for transferring information, one can say that currently the fax technology has been replaced by computer technology, in spite of the fax machine ensuring moderate costs and acceptable quality. Thanks to use of fax/modem cards, fax transmission may be realized between two computers without a dedicated fax machine serving as transmission device and role of fax is considerably reduced. It is estimated that in the near future the role of fax and paging technologies will become marginal.

Education services will be used for specific service activities based on computer networks and general access to the Internet. It can comprise medical services as well as advisory and consultative services. This category of services enables change of methods and environments for working as well as the form and methods of education process. Higher schools in form of the open universities increase the chance of access to the knowledge for people living far from the town; remote access facilitates access to open medical centers, giving new access possibilities to specialized medical consulting offered by specialists being away from their potential patients. This category of services is provided in on-line mode, based on modern means and multimedia information tools.

Telebanking will deliver increased comfort of customer service in the area of the banking. Currently, only subscribers of fixed networks have access to banking services. In the near future, banking transactions will be offered for the subscriber from any location, because mobile telephones will be equipped with applications assuring security for mobile users, required for implementing financial transactions.

Electronic commerce will be a form of economic activity, relying on offering, reserving and purchasing different products and services over the Internet or other computer network. Currently, two forms of such activity are possible: indirect and direct commerce. In the first case, e-commerce service based on electronic capabilities supports any commercial activities. The second one is true electronic commerce, fully based on information technology. In case of indirect commerce all activities concerning business transactions (presentation of information, catalogs and lists of products as well as negotiation procedures and preparing a list of products ordered) coupled with financial matters are realized in Internet in electronic form based on specific applications. Products purchased are delivered in traditional manner. This form of product distribution is dedicated to sellers as well as ferrymans and owners of travel bureaux for reservation and sales of tickets and tour services. In the case of direct commerce all activities concerning sale, purchase and delivery of products are implemented within the framework of closed electronic procedure. Commercial products have an immaterial form, thanks to that they may be delivered to the clients by information tools and means. Subjects of such commerce are e-books, news, films and music as well as software, databases and on-line services.

Till now, Internet electronic shopping has developed mainly in fixed networks. It comprises wider and wider range of products and services. In some networks shopping is currently possible for mobile users, too.

The range of information services, especially personal services, accessible over the Internet to subscriber of wireless networks is expanding. These services will be developed toward increasing their functionality and accessibility. Introduction of UMTS and popularity of IP networks should improve access and quality of services, mainly due to increase of the transmission speed in radio channels.

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