Wireless World Research Forum (WWRF)

(a) Title of the research item: Body Area Networks for Healthcare

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(b) Subject Area: WG1: The User in the Driving Seat

(c) Objectives of the required research (Why has the topic been chosen? Where will the results be applied?)

The subject of this research proposal is the design and development of novel applications and services targeting 4G wireless technologies. In previous papers [1, 2] we presented a vision of two future healthcare applications which we call *Virtual Trauma Team* and *Virtual Homecare Team*. These are two instances of the wider concept of *Virtual Health Care Teams*. These applications are based on emerging and future wireless communication technologies. The technical research required to realise the vision of Virtual Health Care Teams (VHCTs) involves a number of areas including wireless transmission systems supporting broadband access, vehicle-based (fast roaming) networks (VANs), Body Area Networks (BANs), Personal Area Networks (PANs) and ambient intelligent environments, with ad hoc networking enabling communication between (roaming) professionals, clients and patients. In our vision of future delivery of healthcare by VHCTs we anticipate ubiquitous use of BANs by citizens in general and by health professionals, other carers and patients. This current research proposal focuses on applications relating to the BAN elements of the VHCT vision.

This vision of the future also anticipates advances in other technologicies, including the development of new non-intrusive, non-invasive physiological measurement techniques, nanothechnology (miniaturisiation of medical equipment and sensors), also new security mechanisms for wireless communications, dynamic quality of service management strategies, biometric and other advanced techniques for identification and authentication, development of new generation short range, low power devices, and other technologies needed to realise the vision of (mobile) ambient intelligence. The focus for us however is on how to develop applications and services based on these new technologies which meet the needs of the citizens whilst protecting their rights to security and privacy.

The clinical motivation for Virtual Trauma Team is to increase survival rates in trauma care during the vital first hour where correct intervention can greatly improve health outcomes. The motivation for Virtual Homecare Team is to improve quality of life and independence for patients by supporting care at home. The economic motivation is to replace expensive hospital-based care with homecare using ambient intelligent environments and patient BANs to support the patient and the carers.

In this research proposal we focus in particular on the concept of the body area network and propose a research agenda targetting the design of a generic BAN and specific instances of BAN applications, namely paramedic and patient BANs.

Results will be applied by our regional, national and international partners in healthcare and emergency services, by homecare services and by third party suppliers of alarm and emergency services. The overall research proposal, together with an application scenario and initial application requirements have been outlined in a previous research proposal to WWRF [1].

(d) State of the art in the area

Introduction
The first hour following trauma is the most crucial in determining the ultimate outcome for the patient. Previous trials have demonstrated that if the expertise of the on-site paramedics can be supported by communication with the specialists at the hospital, certain treatments can be initiated earlier and patient outcomes can be improved. The Virtual Trauma Team application of the future involves high quality wireless multimedia communications between ambulance paramedics and the hospital facilitated by paramedic BANs [3] and an ambulance-based Vehicle Area Network (VAN). The VAN supports bi-directional streaming audio and video communication between the ambulance and the hospital even when moving at speed.

After care also influences the patient's recovery. Post-operative care, and sometimes rehabilitation, occur in hospital in spite of the fact that care at home is cheaper, is usually preferred by patients and their families and has been shown to accelerate recovery (assuming of course that appropriate care and services can be delivered in the home). The VHCT application of the future enables home care coordinated by home nursing services and supported by a patient BAN in combination with an ambient intelligent home environment: the next generation eHome. The eHome and the patient BAN cooperate to provide intelligent monitoring and support functions with the additional possibility of ad hoc networking with the BANs of visiting health professionals. The environment also provides high quality multimedia communication links to remote (possibly roaming) members of the VHCT.

Virtual Trauma Team BANs
The first treatment received by a trauma victim is often administered by ambulance paramedics, who are specifically trained to perform emergency first aid treatment at the accident site in those vital first moments. Paramedics must usually perform these interventions in the absence of all the relevant medical knowledge and the specific patient information required to give optimal treatment to each individual case. Paramedics must sometimes make the difficult decision whether to try more procedures to help the patient *in situ* (“stay and play”) or to get the patient to hospital as quickly as possible (“scoop and run”). Normally communication between the paramedics and the hospital is limited to a brief report (eg. via two-way radio or cell phone) from the paramedics to hospital administrative staff giving basic information about the casualty's injuries and condition and their ETA. If the paramedics can access the medical record of the patient (or perhaps an emergency dataset) this can improve the quality of care (for example if it is known that the patient has certain chronic conditions or is allergic to certain drugs). Access to the patient’s electronic medical record (EMR) presupposes that the patient can be reliably identified. Such identification should also be rapid (the paramedics cannot afford to waste a second when administering initial treatment). In certain circumstances, for example in very serious accidents or where a patient is trapped, the patient must be treated by a doctor (possibly even operated) at the scene, and in these cases the paramedics request that a mobile trauma team (a traumatologist and an anaesthetist) be dispatched to the scene. Transporting the mobile trauma team inevitably involves some delay. Although this delay may be only of the order of minutes (if for example they are dispatched to the scene by air ambulance) any delay can have serious consequences for the patient. However, if direct intervention (eg. surgery) requiring the physical presence of a doctor is not required, the doctor can be immediately involved in the treatment of the patient by means of telepresence from the first moment that the paramedics reach the casualty. This is the case where the Virtual Trauma Team application is applicable. In the Maryland trials [4, 5, 6], for example, hospital stroke specialists were able to diagnose ischaemic stroke, where the diagnosis was made possible by watching (slow scan) video transmitted from the ambulance. Definitive diagnosis makes it possible to immediately initiate thrombolytic therapy within the short time window for successful treatment. Here the doctor’s added value for the team lies in the possibility of remote diagnosis enabling early initiation of treatment.

The situation is more complicated when the accident involves more than one victim, each of whom needs special treatment (for example at the site of a fire, one victim might be suffering burns, another fractures and a third may be suffering from smoke inhalation). Where there is more than one casualty a separate trauma team is dispatched to attend each patient. Air ambulances may also be deployed to deliver members of the mobile trauma team and/or to transport patients to the hospital. Coordination between several on-site trauma teams and the trauma unit and trauma theatre in the hospital is vital. Problems of communication and coordination are scaled up in the case of major accidents and disasters, where a large number of emergency teams from different emergency services, and possibly more than one receiving hospital, are involved. This was the case with the disaster in Enschede in the Netherlands in May 2000, when nearly 1000 casualties were treated, some in the regional trauma centre in Enschede (Medisch Spectrum Twente) and others in other hospitals including trauma centres across the border in Germany. After the event, the evaluation showed that the biggest problem for the medical services was communication and coordination between the teams involved [7].

A solution sometimes employed in complex accident situations is to equip paramedics with a wireless headset communications device [8]. Although this solution greatly improves coordination and communication between the on-site and on-base medical teams, emerging technologies offer more that just audio communication. The trials which have already been conducted using audio/video communication between ambulances and hospital (eg. [4, 9]) use low quality video (eg slow scan, low frame rate, short segments, with 10-15 seconds end-to-end delay [5]). Although current wireless technologies do not support high quality real time streaming video from fast moving vehicles, the use of even these low quality media has demonstrated the value of visual information conveyed to hospital medical staff in aiding early diagnosis and enabling early administration of drug therapy. For example the potential for reduction of morbidity in ischaemic stroke patients was demonstrated in the Maryland trials [6]. For our future vision, advances in wireless broadband technologies, supporting seamless high quality multimedia communication, promise a further evolution such that remote members of the (virtual) trauma team (whether based at the hospital or while in transit to the scene) can be fully and continuously involved in the treatment of the patient by means of telepresence from the first moment that the paramedics reach the patient. We envisage the on-site paramedics relaying not only audio but also high quality real time video, vital signs and test results, and receiving the EMR, by means of the specialised paramedic BAN.

Virtual Homecare Team BANs

Homecare is another area where emerging technologies offer the potential for dramatic improvements in quality of care. Due to the psychological effect of being in a familiar environment, long term patients in home care have a better chance of recovery than long term hospital patients. Furthermore the cost per day of care at home is a fraction of that of a hospital stay.

There are a number of demonstration projects involving *smart homes* for the elderly or for people with health problems, where assistive technologies and aids such as video-intercom systems and motion sensors for lighting control [10], emergency buttons for elderly and disabled, and pulse monitoring are provided. However due to the need for continuous observation of the patient's vital signs and control of his environment, home care treatment is currently restricted to patients in a relatively stable condition.

One trial involving home-based management of tuberculosis patients, coordinated by nurses equipped with mobile devices and wireless communications, proved to be a successful alternative to detention of persistently non-compliant patients in secure hospitals [11, 12]. Another trial involving virtual medical teams coordinated by nurses and facilitated by wireless communications involves home care for cancer patients [13]. In our vision of the future we envisage more patients (and patients with acute conditions) being cared for at home by virtual homecare teams supported by intelligent care systems based on wireless and nanotechnologies, body area networks and ambient intelligent environments.

Context for health professional and patient BANs: the Healthcare VPN

The environment of the applications can be viewed as a healthcare Virtual Private Network (VPN). The proposed hospital VPN consists of three basic network types: Hospital Intranet, Trauma Team Network and the eHome (see Figure 1). The ambulance VAN and paramedics' BANs form a Trauma Team Network. This network is connected via a "secure" – this implies guarantees for data integrity and confidentiality - wireless link (e.g. IEEE 802.11, GPRS, UMTS) to the Hospital Intranet. The eHome network hosts, amongst others, the patient care functions, and is connected to the Hospital Intranet via a "secure" wired (e.g., xDSL, cable modem) or wireless link (e.g., IEEE 802.11, GPRS, WLL).

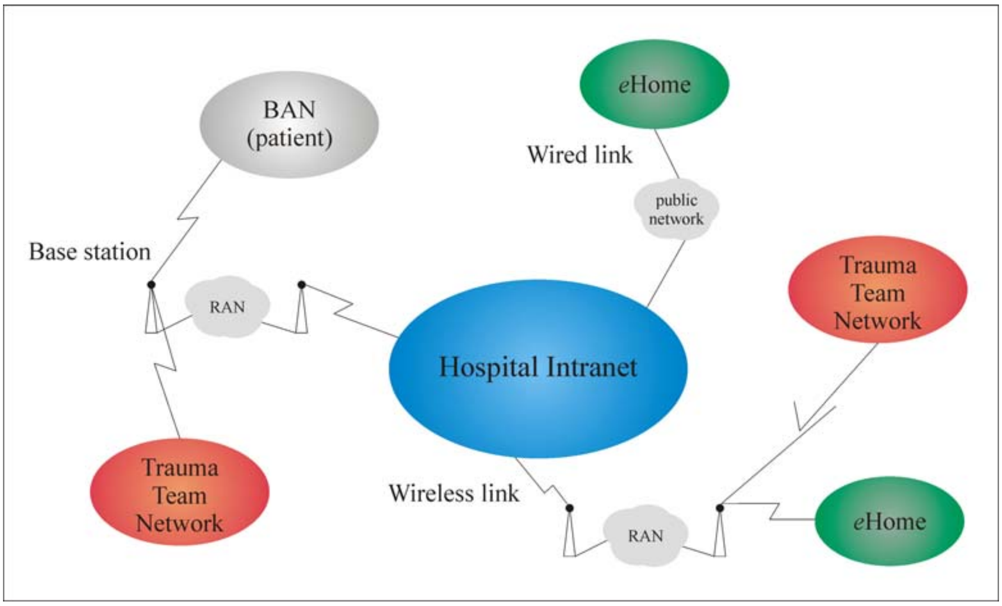

Figure 1 Healthcare VPN

BAN System Architecture

Our working definition of a BAN is formulated on the grounds of physical range, namely we see a BAN as a network which is literally worn on the body, as opposed to a PAN (Personal Area Network) which links devices close to the user but not necessarily (all) physically worn by him. We identify four basic functional elements of a paramedic/patient BAN: hub, sensors, audio/video and actuators (see Figure 2).

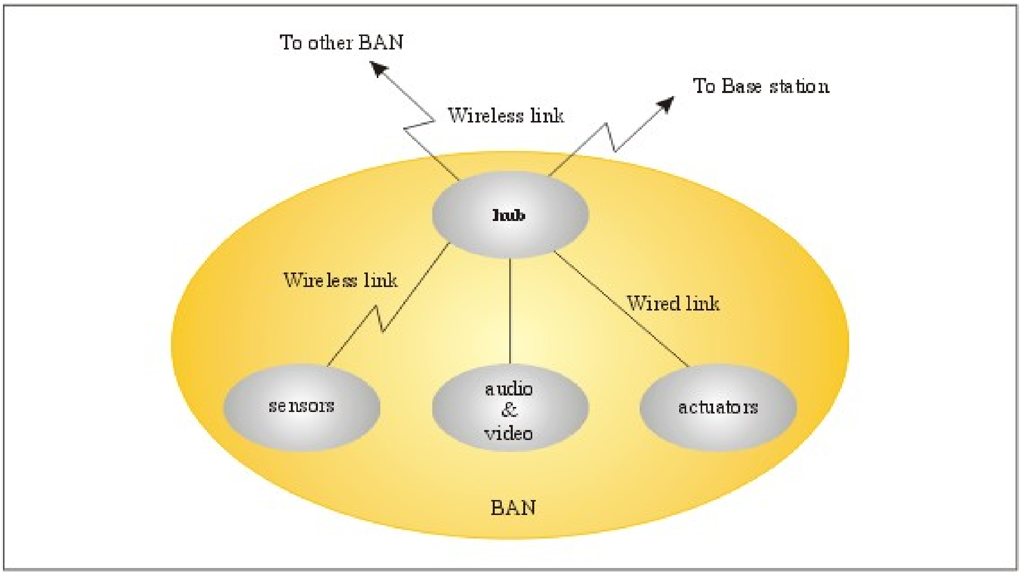

Figure 2 BAN System architecture

The "hub" includes computation and communication functions and is the main generic building block of the BAN. The hub is responsible for a) communication (intra-BAN and inter-BAN) and b) program execution and data processing. The BAN is basically a heterogeneous network, where different communication media are possible (e.g. infrared light, air - radio frequency, skin, wires). The hub incorporates one or more generic interfaces to support a number of specific medium and communication technologies (e.g. Bluetooth). The hub provides the "intelligence" to autoconfigure the BAN and to route (optimize) traffic from the BAN to other BANs and to other networks. Finally, the processing unit of the hub is able to process data such as multimedia information and physiological signals under control of downloadable applications.

The hub and the devices are worn on the body, perhaps embedded in clothing, jewellery, glasses, headsets or helmets, perhaps attached directly to the body (eg. a cardiac monitor). Specific BANS are created around the generic BAN by adding a specific set of devices as appropriate to a role (eg paramedic BAN) or for a certain (set of) needs. For instance a diabetic patient BAN would include a sensor to monitor blood sugar, plus possibly a insulin micropump. A cardiology BAN would include sensors to monitor pulse, oxygen saturation, BP and ECG. A particular individual, say a diabetic patient, may acquire another chronic illness, or have a temporary problem (eg require cardiac monitoring for a period of time) and his (diabetic) BAN can then be extended to incorporate further functions as appropriate (eg. cardiac monitoring) by addition of another (set of) device(s) and the associated embedded and non-embedded software components. The BAN is therefore intended to be an open, extensible platform which can be customised not only to a class of patients (eg. diabetic patients) but also to the particular set of (chronic and acute) problems of the individual person/patient.

Such a BAN could also be used in other applications, ranging for example from fire-fighting to sports training, in sports medicine and for physiotherapy in rehabilitation medicine. In the same way that we can measure vital signs we can also monitor environmental parameters such as temperature, humidity, pressure, air composition, visibility etc. The actual system infrastructure remains the same; only the interpretation of the measurements changes. For example in the case of fire-fighters temperature and air composition sensors can be connected both inside and outside the uniform and the firefighter will be informed by the operations centre to leave the area when the external temperature has risen above a certain level or the air composition is such that an explosive combustion might occur. Another area where a BAN system could provide help is psychology research. By equipping the "patient" with a set of sensors we will be able to measure body functions and data in different life situations and achieve a better understanding of how the body reacts in stress situations. Research in new pharmaceutical products could also be assisted with a BAN system applied both to human and animal subjects. The advantage would be that more parameters could be measured for longer periods in a natural environment. Thus the results and side effects of a product will be easier to identify.

(e) Possible approach

- Gather user requirements for services and applications
- Survey existing standalone and proprietary solutions (eg. GSM phones with added cardiac monitoring functionality)
- Specify technology solutions
- Use state of the art emerging technologies to build BAN from existing platforms (trialling GPRS and UMTS phones with Bluetooth and IEEE 802.11 interfaces, and for instance pocket computers as BAN hub), networking with existing devices such as monitors, alarms buttons, sensors, miniature cameras and audio equipment)
- Experiment initially with 2, 2.5 and ultimately 3G wireless technologies *in vitro* (lab experiments)

(f) Expected results

- Formal description of a generic BAN
- Systems architecture for generic BAN
- Software Architecture for BAN applications
- Prototype of generic open extensible BAN for patients/citizens, customisable to (temporary as well as long term) needs of the individual citizen
- Prototypes of two or more specific patient BAN applications

(g) Time frame to get the expected results

18 months

List of References

[1] Val Jones, Richard Bults, Pieter AM Vierhout, Virtual Trauma Team, *Proceedings of the Wireless World Research Forum (WWRF) Second Meeting*, Nokia Research Centre, Helsinki, Finland, May 10-11, 2001.

[2] Val Jones, Richard Bults, Dimitri Konstantas, Pieter AM Vierhout, Healthcare PANs: Personal Area Networks for trauma care and home care. Paper accepted for *Fourth International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Sept. 9-12, Aalborg, Denmark.

[3] Karen van Dam, Steve Pitchers, Mike Barnard, From PAN to BAN: Why Body Area Networks? *Proceedings of the Wireless World Research Forum (WWRF) Second Meeting*, Nokia Research Centre, Helsinki, Finland, May 10-11, 2001.

[4] David M. Gagliano, Yan Xiao, Mobile Telemedicine Testbed, Proc. 1997 *American Medical Informatics Association (AMIA) Annual Fall Symposium*, 383-387, 1997.

[5] Yan Xiao, David Gagliano, Marian LaMonte, Peter Hu, Wade Gaasch, Ruani Gunawadane and Colin Mackenzie. *Design and Evaluation of a Real-Time Mobile Telemedicine System for Ambulance Transport,* 1998. http://www.attp.ummc.umaryland.edu/amia98/
amia98.htm

[6] Gagliano,DM, A. Allen, MD, Cover Story: Wireless ambulance telemedicine may lessen stroke morbidity, p. 21, *Telemedicine Today*, Feb. 1998.

[7] Enschede Vuurwerk Ramp, May 2000. *The Investigation Report*, November 2000.

[8] *MAST installs new Motorola Emergency Medical Communications* System. 1997. http://www.motorola.com/LMPS/pressreleases/mast970715.html

[9] Curry GR, Harrop N., The Lancashire telemedicine ambulance, *J Telemed Telecare*, 1998, 4(4):231-8.

[10] Smart Homes Foundation. http://www.smart-homes.nl/

[11] New York City Department of Health, Tuberculosis Control Program, TB and The Law http://www.ci.nyc.ny.us/html/doh/html/tb/tb-law.html

[12] Applied Informatics (TIIAP #36-40-94065), Final project report, http://informatics.cpmc.columbia.edu/appldinf/final.txt

[13] Pitsillides, A, G. Samaras, M. Dikaiakos, DITIS: Collaborative Virtual Medical team for home healthcare of cancer patients, http://www.ditis.ucy.ac.cy/Reports/reports.html

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