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Body Area Networks in a Medical Environment

Verovko, M., Verovko, O., Kazymyr, V., Davies, J.N. and Bhalla, A.

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Body Area Networks in a Medical Environment

Mariya Verovko, Oleksandr Verovko, Volodymyr Kazymyr
Dept. of Information and Computer Systems,
Chernihiv National University of Technology,
Ukraine
miya.tevkun@gmail.com, averovko@gmail.com,
vvkazymyr@gmail.com

John N. Davies, Archna Bhalla
ARCLab, Glyndŵr University
Wrexham,
UK
j.n.davies@glyndwr.ac.uk, archnabhalla78@gmail.com

***Abstract*—There has been a great deal of development in the area of fitness / Activity Trackers which are now capable of measuring many useful human conditions e.g. heart rate. This paper investigates if the technology is suitable for use in a medical environment and in particular what systems would need to be introduced to supports it. The concept of an Intelligent Bed is introduced and a possible solution is provided. Due to the deployment in sensitive areas the issues of performance and reliability are addressed.**

Keywords— Sensors; Heathcare monitoring systems; Body Area Networks; Intelligent Beds; Raspberry PI

I. Introduction

A Body Area Network (BAN) is a wireless network, based around IEEE 802.15.1 standard, of wearable computing devices [1]. BAN devices may be embedded inside the body (implants), may be surface-mounted on the body in a fixed position (Wearable technology) or may be accompanied devices which humans can carry in different positions, in clothes pockets, by hand or in various bags [2].

Hospitals commonly use Multimodal monitors at the bedside in critical care units that simultaneously measure and display the relevant vital parameters. These allow for continuous monitoring of a patient by medical staff so that changes in general condition of a patient can be alerted. In recent years the technology associated with the monitoring of these vital parameters e.g. blood pressure, heart rate, pulse oximetry, respiratory rate etc. has been implemented in smaller devices and provided with a computer network interface. It is anticipated that the quality of the monitoring devices and the reduction in cost will enable this to be common place not only in a hospital but also remotely for instance in the patients home. This raises the question "is this technology suitable for use in professional medical environment?"

At present a readily available device can be bought on the high street in the form of a watch that provide useful information, including Heart Rate monitoring, calorie intake and usage, water intake etc. Embedded in this technology is Bluetooth (IEEE 802.15.1) wireless access that enables the information to be transferred via a network to a monitoring system. This enables a very simple and flexible system to be built from standard components to provide great overall benefits.

Clearly this is an area where there is going to be a great deal of research and development taking place in the future and so any system proposed needs to have a flexible design. Additionally the BAN in most cases is destined for a very sensitive area and so it is necessary to confirm reliable operation before installation takes place. Raw data and equations are obtained that will allow a deeper understanding of operation of the system. This will allow a simulator to be built to ensure reliable operation in such a medical environment. This simulator will enable the confirmation of the reliable operation of both the introduction of new sensors to the network and new physical layouts.

This paper investigates the feasibility of creating a flexible system from off the shelf components. Particular emphasis is placed on: Sensor / monitoring devices, system components, Bluetooth technology for use in Body Area Networks (BAN), the use of Wi-Fi to connect to a central monitoring point, connection to Metropolitan (campus) network and the Security of the information.

II. Problem Definition

A major problem that is being faced by medical systems is associated with global population and demographics. Using values obtained from the United Nations [3], it is predicted that there is an increase in the % population over the age of 65 and a decrease in the % of the population in the age range 15 to 65. This means that there are less people working and hence paying taxes. Hence the question of how health issues are going to be paid for. This leads to the question can Technology be used to reduce costs? There are a number of issues that need to be addressed before this can be answered and these are addressed in this paper by simulating the overall system.

A. Why is Monitoring Expensive?

At present hospitals use specialized measuring equipment designed and developed over many years e.g. ECG, EMG, Blood saturation, Temperature, Glucose Monitoring, motion sensor etc. By investigating developments that are taking place, particularly using silicon, then an indication can be obtained of which sensors are likely to be used.

B. Is it possible to mislead the doctors?

Diagnosis of patient's illness relies extensively on the verbal answers to questions posed by a doctor (GP). Consistency in answering the questions can be a great problem. Can technology help with this dilemma?

C. *Is this technology suitable for use in professional hospital environment?*

Sensors provided with Bluetooth interfaces can store a limited amount of data and so there has to be a local device that can collect this data and either store it locally or use a network to transfer it on. Storing the data locally is not very convenient and so the use of a LAN to provide the data at a central point, e.g. a Nursing station, is seen as being essential. Network connection sharing this data provides great advantages to the well-being of the patient.

D. *Can the information/ data be Secured?*

One of the most important issues associated with this type of application is the security of the information. Since security of the information is vital then the approach of using international standards enables the network to be easily upgradable. This is particularly important for applications suitability for use in the healthcare industry.

E. *Are Standards holding back innovation?*

Medical monitoring equipment is heavily regulated and rightly so. There are international standard bodies (ISO) that set out basic requirements of the operation, processes involved in the use of medical equipment. However, most countries choose to publish their own standards and guild lines. An example of this is U.S. Department of Health and Human Services (FDA) US Food & Drug Administration has a Wireless Medical Devices standard [4]. Unfortunately this all takes time to develop and get agreed.

III. BACKGROUND

A very simple design philosophy is adopted which incorporates flexibility. In this environment it is essential to have well defined interfaces since there will be continual development of sensors and other components.

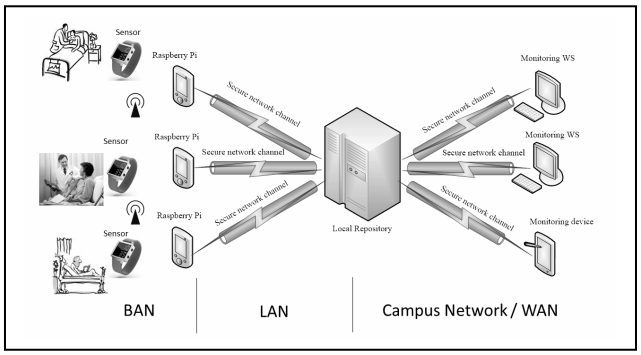

Fig.1. Components of BAN

Data is gathered from the patient using an attached sensor. Bluetooth is then used to transfer this data to a small computer e.g. Raspberry Pi for either storing or transferring, using a LAN, on to a Local Repository. This Local Repository computer would be situated in the Nursing station and has the ability to store and display data associated with all the patients being monitored on the ward. The Local Repository computer would have a connection to a WAN to allow for long term data storage and additionally the possibility of remote monitoring. Networks are divided into 4 main categories governed by the distances involved in the connection. Often specialized medical equipment are provided with specific connections but development of international standards have now seen these devices being provided with network interfaces. It is still rare to find devices provided with wireless connections.

1) *Body Area Network (BAN)*

Sensors used for monitoring patients conditions via a Bluetooth interface fall into the category of body area networks. These networks operate over very short distances. The advantage of this type of monitoring means that patients do not have lots of cables attached to their body. This removes the problem of damaging or disconnecting when they move around.

2) *Local Area Network (LAN)*

It is necessary to connect the BAN to a LAN due to the short distance that BANs are capable of operating over. Typically a LAN would provide a network that would operate over a ward in a hospital, a doctor's surgery or a patient's home. This can be provided using either a cabled network or a Wi-Fi wireless network.

3) *Metropolitan – Campus Network (MAN)*

Utilizing a Campus network in a hospital situation allows the monitoring of patients at a locally level or at a central point e.g. a Nursing station.

4) *Wide Area Networks (WAN)*

Once there is a connection to the internet then numerous advantages are gained. It allows remote Physicians to monitor patients or remote Patients can be monitored.

IV. RELATED WORK

Much of the research that has taken place in this area is associated with sensors. This is mainly due to the ability to improve their capabilities and to make them smaller.

A. *Sensors / monitoring devices.*

There are 2 categories of sensors, internal and external to the body. Both have their advantages & disadvantages. Internal sensors are able to measure different properties and are more accurate however they can interfere with the measurements and require a deeper understanding of the overall effects on the body. There are 2 parts those that pierce the skin and those that are swallowed. External sensors are much easier to deal with but at present are limited to their uses. The function that all these sensors have in common is that they are provided with a Bluetooth interface and hence can be incorporated into a BAN.

1) *Internal sensors*

Sensors that operate using a skin piercing technique have been available for many years and are the basis of many of the large devices found in hospitals. However recent research has focused on the area of swallowing devices. Traverso and Langer have built and tested many ingestible devices to measure conditions such as temperature, heart rate, and breathing rate. [5] Researchers at MIT and Brigham and Women's Hospital have designed and demonstrated an electronic pill that when ingested can use the acidic fluids in

the stomach to power circuitry. A prototype has been built as a cylinder about 40mm by 12mm and it is anticipated that using a customized integrated circuit it would be reduced in size and be able to contain a small microprocessor. [6]

Work is also being channeled towards looking for other ways of monitoring to make the continuous monitoring possible. Currently blood pressure measurements require the use of a cuff that temporarily stops blood flow by squeezing the arm. By using a pressure gauge built into a wristwatch situated above a wrist artery could sense the changes [7].

2) External sensors

An interesting associated research area is labelled lab-on-a-chip. It allows analysis normally carried out in a laboratory to be done by a single chip device. It is commonly used for the synthesis of chemicals in particular blood samples. This is such an import research area that the Royal Society of Chemistry produces a Lab-on-a-chip journal which is published 24 times per year [8]. Recent articles in this area show the use of networks to record results [9]. European researchers are developing a lab-on-a-chip wristwatch that monitors various bio-indicators intended on warning wearers of serious problems before they occur [10]. An example of its use is to inform an athlete that they are showing signs of dehydration.

Clearly some of these systems require further development and not all are suitable for integration into a wristwatch device. But advances in both polymer electronics and conventional sensors have made these lab-on-a-chip biosensors increasingly small and affordable.

3) Consumer sensors

Consumer Sensors are best described as the wide range of sensors built typically into wristwatches. The availability of these devices on the high street has had a profound effect. It is possible to obtain sensors capable of measuring temperature, amount of exercise, sleep patterns, heart rates etc. affordable by the man in the street. These generally come under the title of Activity Trackers.

There are many different makes and types of devices and due to the small amount of storage they have an associated BAN to store the data onto a mobile phone, tablet or computer. These in turn have an associated web site for long term storage, analysis and sharing. Fig.2 shows the typical information available. Most Activity Tracker applications provide an interface to food calorie monitoring applications via Bar-codes that can be integrated into the Activity Tracker applications.

Fig. 2. Typical information provided ©2017 Fitbit, Inc.

B. BAN

Kurunathan provides an overview of work carried out by Task Group 6, IEEE 802.15.6, on the development of a communication standard optimized for low power devices and operation on, in or around the human body [11].

C. Security & Privacy

Toorani published a paper "On vulnerabilities of the security association in the IEEE 802.15.6 standard", [12] which deals in detail with mechanisms to encrypt data.

Li, et al. published the paper, "Data security and privacy in Wireless Body Area Networks" address the privacy and process involved in E-Healthcare systems [13].

V. INVESTIGATIONS

Since the presented system is designed for medical purposes it is necessary to provide a stable reliable environment for each part of the system. Failures can have a significant effect on the efficiency of operation. To ensure the integrity of the system a number of areas need to be investigated in detail. This includes an Intelligent Bed, Computer systems including the Local processor for the BAN, the overall network and security.

A. Intellegent Bed

For a hospital environment the concept of an Intelligent Bed can be adopted since each bed would be fitted with a processor to collect data from the sensors attached to a patient. This forms the basis of the BAN. Costs associated with the Intelligent Bed need to be considered due to the quantities involved. Providing a simple and flexible system built from standard components should achieve the objective of low costs.

From the sensor point of view, by utilizing monitoring devices that use Bluetooth means that the patient does not have lots of cables attached to the body removing the problem of damaging or disconnecting when they move around.

As discussed previously the much of the development of sensors are provided with a Bluetooth wireless network interface and are intended to operate with Mobile phones. However in the case of a hospital a Raspberry Pi or similar could be used to collect the data instead of a Mobile phone, the Local processor. If each bed were fitted with a Raspberry Pi, this could monitor the patient via Bluetooth and then use Wi-Fi to connect back to the nursing station. This would allow the Intelligent Bed to be portable. Since this utilize commercially available equipment then the overall cost and installation is relatively low. Additionally with the provision of Raspberry Pi's in other areas of the hospital this would also allow for patients to move around and still be monitored e.g. in bathrooms.

B. Local processor

System component choice for creating an Intelligent Bed is vital since it is the data collector and is in a vulnerable physical position. A Raspberry Pi has been suggested since it is very low cost technology (<£50). It has a number of

advantages for data collection including it being fully programmable and has a Bluetooth and Wi-Fi wireless as well as an Ethernet cable network interface as standard. There are a number of disadvantages it would need to be physically protected and mounted on the bed. Even though it is low powered it still needs a power connection. Main concern however is performance and reliability which are considered in the following sections.

1) Reliability of Local Processor

The hardware reliability of the Raspberry Pi is not of great concern since it based on well-developed technologies. So the greatest concern is the Operating System (OS) that is used and the application running on it. A list of the most widely used and well supported OS can be found in Table I.

Comparison of OS is a complex task since there is no universal criterion, which can be used to estimate their level of reliability and security. Long-time support of the OS is preferred since installation of unstable or beta-version can lead to unpredictable behavior of the system. It is also necessary to have Stable versions of all packages required for services.

TABLE I. ASSESSMENT OF OS FOR RASPBERRY PI

OS	Features
Raspbian	User-friendly OS with great abilities for education, but no important advantages for presented goal. Contains problems not fixed for a long time mainly Debian vulnerabilities.
Arch Linux ARM	OS repository contains only stable and well-tested packages, but the reason could be that the packages not be updated for a long time.
Pidora	Last released on 2014, Pidora is not a project with good dynamics of development.
RISC OS	Very specific not Linux-kernel OS, not well-known by developers and hackers, which is an advantage for system security, but a drawback for development and usability.
Snappy Ubuntu Core	Large set of inbuilt abilities for IoT, but it also requires installation of redundant packages which Cn have vulnerabilities.
Ubuntu MATE	Using the first release is a good decision for Raspberry Pi 2, but with Raspberry Pi 3 some problems could appear. The second version was only released in March 2016 and contains many unfixed bugs at present.
Windows 10 IoT Core	Includes specific abilities to build an IoT network, but contains a lot of new vulnerabilities because of the near date of release and also some old vulnerabilities, not fixed in all types of Windows OS.

Kernel vulnerabilities are the most dangerous vulnerabilities and so must be avoided. Most vulnerabilities of an OS are in additional services and applications. To minimize their impact only required packages and applications with should be installed. The level of a particular vulnerability characterizes the possible impact on security. Dynamics of vulnerabilities detection is a criterion that is used to measure the evolution of OS and evaluate them in the current stage of development. OS with a rapid growth of vulnerabilities is typical for a new widely used OS, but for stable well-tested version of OS the number should be low. Additionally the Dynamics of vulnerabilities fixing is one of the most significant characteristics of any OS. An OS with outstanding vulnerabilities for long periods of time cannot be considered as secure and reliable.

2) Performance

Table II shows typical data rates based around equipment presently used in hospitals in the UK. It is anticipated that these rates are unlikely to get higher since the sensors will get more intelligent. However it is necessary to consider these to ensure the overall system is capable of handling the capacity required. The performance of the network is considered in section D. However it is also important to consider the performance of the Raspberry PI to ensure that it is capable of handling these data rates.

TABLE II. DATA RATES FOR MEASUREMENT EQUIPMENT

Application	Data Rates	Delay
ECG (12 leads)	288 kbps	250 ms
ECG (6 leads)	71 kbps	250 ms
EMG	320 kbps	250 ms
EEG (12 leads)	43.2 kbps	250 ms
Blood saturation	16bps	250 ms
Temperature	120 bps	250 ms
Glucose Monitoring	1600 bps	250 ms
Motion Sensor	35 kbps	250 ms
Cochlear implant	100 kbps	250 ms
Artificial retina	50-700 kbps	250 ms
Audio	1 Mbps	100 ms
Video	<10 Mbps	100 ms
Voice	50-100 kbps	100 ms

3) System Updates

Since the BAN is designed for medical purposes it is necessary to provide stable work of each part of the system without failures. Problems appear and often the fixes require software updates. These could have significant consequences and lead to the failure of the whole system or it parts. That is the reason why the task of introduction of new updates to applications and OS should be performed without impact on the system operation. Currently there are standard algorithms for updating software provided by OS or application developer using a public repository and are generally available via the Internet. This is not appropriate for this BAN application. The process for application and OS updating should be performed according to several requirements. a) A simulator should be used to test out critical timing operation. b) A testbed should be used to test new for reliability and operation in the presented system before installation on end devices. c) All possible updates, provided by a developer, should be filtered: redundant updates should be avoided; only required and valuable updates should be installed. d) Security of updates storage and delivery should be provided. Unstable versions of packages should be ignored. e) Provision of Local Repository

situated on the LAN of a hospital and protected by security policy from any unauthorized access should be used. f) Delivery of the packets with updates is performed via LAN. g) Network connections should be secured via VPN tunnels to solve security issues related with data transmission.

C. Data Storage

Storage of real-time data produced by the sensors is not a typical task for a common SQL database. That is the reason why the widely used databases such as MySQL, Oracle or Postgres are not appropriate to be used as data storage in the developed system. One of the methods to store large amounts of data is by using Big Data Cloud services. Well-known and widely used Cloud computing has a large set of significant advantages for data storage, such as it is not necessary to have own hardware and software resources (and associated costs), permanent high-quality support of provided services by a Cloud provider, availability of stored data. There are 2 main drawbacks of this, unknown physical location of the data and significant rental costs of large amount of storage. The conclusion can be made that storing large amounts of sensors data in the Cloud is comfortable, but expensive.

Other method of storing data from sensors is the application of Hadoop Distributed File Systems (HDFS). It is gaining increasing popularity lately. HDFS is a distributed file system designed to run on commodity hardware [14]. The main differences of HDFS from other exiting distributed file systems are its high fault tolerance and orientation on the low-cost equipment. HDFS is a good decision for storing large amounts of data since it provides high throughput data access, ability to enable streaming data access, parallel data processing and high reliability of stored data. Application of HDFS allows organizing high performance data storage system using only basic hardware (WS, laptops etc.), connected in a network. Current approach doesn't require high costs on hardware and software resources (Apache Hadoop is open-source project), however the system administration and support tasks appears.

These technologies provide the ability for large data storage along with high performance. However they require the application of either Complex Event Processing Systems (CEP) or Stream Processing Systems (SPS). Both CEP and SPS have been developed to solve the problem of the analysis of large amount of streaming data, but use different approaches. CEP systems use a method of analyzing streaming information based on event detection, processing, filtering and aggregation. Whereas SPS performs stream data processing using continuous SQL-type queries, which buffer windows [15].

To ensure a high level of reliability a hybrid approach is recommended which requires the usage of both system, for real-time data processing, CEP or SPS, and a system for data storage, such as Cloud or Hadoop.

D. Network

A great advantage of this approach is that IEEE standard network protocols can be used for the wireless and any cable networks required. The Wi-Fi can be protected by WPA2 and AAA for Authentication of users. Additionally, by using TCP/IP protocol then this allows the network to be secured using standard supported Virtual Private Networks (VPN). Configuration of IPSec allows the information to be secured over the network. Keoh et al. [16] provide an important discussion on Securing body sensor networks. Once the data is available at the nursing station this opens up many possibilities for group or specialist monitoring and recording. Since this system utilizes commercially available equipment then the overall cost and installation is relatively low.

1) Network Performance

Data rates for this IEEE 802.15.1 standard is 3Mb/s and for IEEE 802.11ac from 433Mbps to 1Gbps which is well within the requirements shown in Table II.

E. BAN (Bluetooth)

IEEE 802.15.1 has a very short range of operation which is an advantage for this particular application. However it is necessary to check whether this limitation is acceptable. A series of tests were carried out to identify the distance involved. Additionally Table III shows the signal loss through different materials since this is a concern when considering the placement of Raspberry Pi on an Intelligent Bed.

TABLE III. COMPARISON OF SIGNAL STRENGTHS AT DISTANCES

Distance	Signal Strength dBm			
	Free Space	*Wood*	*Wall*	*Glass*
5m	-69	4	8	3
10m	-77	5	11	3
15m	-85	3	3	2

Bluetooth uses Wireless technologies which are electromagnetic waves the propagation of which, in free space, is governed by the Friis transmission equation, which is:

$$P_r = G_r G_t \left(\frac{\lambda}{4\pi d}\right)^2 P_t \text{ which is } P_r \propto \left(\frac{1}{4\pi d}\right)^2 Or\ P_r = K\frac{1}{d^2}$$

Where: Pr = power received, Pt = power transmitted, Gr = receiver antenna gain, Gt = transmitter antenna gain, λ = signal wavelength and d = distance of the receiver from the transmitter. Since λ, Pt, Gr and Gt are all constant values, this equation can be reduced when, K = a constant. So, the power received varies inversely with the square of the distance in free space. However, Bluetooth technology in this application is used inside buildings where many other factors come into play as well. The signals can be affected by the phenomena of reflection, refraction and diffraction. These phenomena can lead to multi-path fading whereby the transmitted signal reaches the receiver through multiple paths.

By plotting a graph from Table III for free space, then it is found that it is governed by the linear equation with a gradient of -1.8. Putting this relation in terms of Friis equation, = $d^{-1.8}$ which is very close to Friis' interpretation d^{-2} . This also shows the point of -91dBm is the maximum distance for receiving acceptable signals which is at a point 15m.

A number of options are available for connection of the Intelligent Bed to the Nursing station. A convenient method is by using Wi-Fi. Carrying out similar work to ascertain a model for IEEE802.11ac a similar equation was obtained providing a distance of 75.37m.

VI. Conclusions

In section II the problems were stated and so each of these will be reviewed in the conclusion. Since the system has not been built in its entirety then a simulation of the system is needed to confirm the results. This investigation provides the raw data and equations for the simulator.

A. *Can Technology be used to reduce costs?* The design of this systems shows that the technology is now in a mature state and relatively low cost components can be used for the items like the sensors and Intelligent Bed.

B. *Why is Monitoring Expensive?* This research shows that equipment used in hospitals is very specialized and therefore are only manufactured in small numbers. However it also identifies a place for Consumer sensors and shows the developments that are taking place in the field of sensors.

C. *Is it possible to mislead the doctors?* While patients have to make judgments it is always possible, however by patients wearing equipment such as an Activity Tracker and providing it for the GP to analyse then this could be improved.

D. *Is this technology suitable for use in professional hospital environment?* The components of the system are identical to those used in banks and many other walks of life.

E. *Can the information/ data be Secured?* Using standard network protocols allow data from the sensors to be secured through to data storage. The privacy of this data once it is stored is no different from patient records.

F. *Are Standards holding back innovation?* There is always a difficult decision to be made associated with implementing technology. The Healthcare environment is very conservative due to the nature if the business. However there could be more corporation on a global basis for the introduction of this type of technology.

Clearly this is an area where there is going to be a great deal of research. Since this a very flexible design that is destined for a very sensitive area then it is necessary to confirm the operation before installation takes place. The simulator will enable the confirmation of the reliable operation of both the introduction of new sensors to the network and a new physical layout. Since security of the information is vital then the approach of using international standards enables the network to be easily upgradable. This makes this research and design suitability for use in the healthcare industry for monitoring patient diagnostics.

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