Wireless Body Area Network for Ubiquitous mHealth Mobile Patient Monitoring Systems: Architecture, Opportunities and Challenges

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ABSTRACT
A Wireless Body Area Network (WBAN) consists of intelligent and small invasive and non-invasive devices which are capable of establishing a wireless communication link. These WBAN devices provide continuous health monitoring and real-time feedback to the medical personnel and user. Furthermore, the measurements can be recorded over a longer period of time, improving the quality health care services. By means of a WBAN, the patient experiences a better physical mobility and is no longer compelled to stay in or visit regularly to the hospital. This paper offers an overview of Wireless Body Area Network concepts such as architecture requirements, organization, challenges, and opportunities.

General Terms
Wireless body area network (WBAN), mobile base unit (MBU), personal server (PS), Zigbee, invasive and non-invasive sensors/actuators, electrocardiogram (ECG), electromyography (EMG), electroencephalography (EMG), specific absorption rate (SAR), energy scavenging, intra – BAN communication, extra – BAN communication, medical server, network coordinator (NC)

Keywords
Wearable body area network, m-health, mobile patient monitoring systems, WBAN architecture, WBAN organization, mobile patient monitoring systems challenges

1. INTRODUCTION
A Body Area Networks contains a number of wireless sensors or actuator nodes located on the human body, inside the human body or in close proximity such as daily clothing's and shoes. Based on the information transmitted by a WBAN worn by some specific patient, the healthcare server draws some hypothetical results about the patient conditions. The medical server is continuously aware of the patient's vital functions and is capable of taking the suitable countermeasures in case of any trauma or medical alert situation. For this purpose the Wireless Body Area Network must be capable of storing data and communicating with other wireless devices/systems such as MBU or PS. Adoption of certain standards like IEEE 802.15.4a for sensors and actuator devices offers certain beneficial effect in maintaining the compatibility with new standards. Figure 1 shows a possible medical application of a Body Area Network.

The proliferated usage of wireless networks[1] and the continuous decrease in size and cost of electrical devices has empowered the development and growth of Wireless Body Area Networks (WBANs). The wide variety of sensors and the wireless nature of the network offer several new, practical and innovative applications to improve m-health and the Quality of Life. Using a WBAN, the patient experiences better physical mobility and is no longer forced to stay in the hospital. The System has to face many challenges even though it provides great opportunities and promises for healthcare application enhancement.

The rest of the paper is prepared as follows. Section II presents the system architecture of mobile patient monitoring systems based on WBAN. Section III proposes the implementation of Wireless body area network in two parts. Section IV presents the opportunities and requirements of the WBAN. Section V draws attention towards the limitations and challenges of the system, and conclusions and discussions are given in the section VI.

2. SYSTEM ARCHITECTURE
The mHealth system extents a network comprised of individual health monitoring systems that connect through the Internet to a medical server layer that resides at the top of this hierarchy. The top layer, centered on a medical server, is optimized to service thousands of individual users, and encompasses a complex network of medical personnel, interconnected services, and healthcare professionals. Each patient wears a number of sensors that are deliberately placed on his/her body. The most important functions of these sensor nodes are to discreetly sample Biosignals and transfer the relevant data to a personal server through wireless personal network implemented using Bluetooth or ZigBee[2]. The mobile base unit, implemented on a PDA, smartphone, or personal computer, controls the WBAN and provides audio or graphical interface to the user, and handovers the statistics about health status to the medical server through the Internet or mobile phone networks (e.g., GPRS, 3G)[3].

The medical server keeps medical records of listed users and provides various services to the users, informal care givers and medical personnel. It is the responsibility of the medical server to authenticate users, accept health monitoring session data uploads, format and insert this session data into corresponding records, analyze the data patterns, recognize serious health abnormalities in order to contact emergency care givers, and forward new directives to the users. The patient's doctor/caretaker/physician can access the data from his/her office and examine it to ensure the patient is within expected health metrics (heart rate, oxygen saturation level, blood pressure), ensure that the patient is responding to a given treatment. A server agent may examine the uploaded data and generate an alert in the case of a potential medical condition. The data collected through these services can be utilized for knowledge discovery through data warehousing and mining. Integration of the collected data into research databases and quantitative analysis of patterns and conditions could be proven priceless to researchers trying to associate symptoms and diagnoses with historical changes in physiological data, health status, or other parameters (e.g., age, gender, and weight). In an analogous technique this infrastructure could meaningfully contribute to monitoring and studying of medication effects[4].

The second layer is the mobile base unit or personal server that interfaces WBAN sensor nodes, communicates with services at the top layer and provides the graphical user interface. The personal server is typically implemented on a PDA or a smartphone, but alternatively can run on a personal computer. This is particularly suitable for in-home monitoring of patients. The personal server interfaces the WBAN nodes through a network coordinator (NC) that implemented using Bluetooth or ZigBee connectivity[5]. To communicate with the medical server, the personal server employs mobile networks (2G, GPRS, 3G) or WLANs to reach an Internet access point.

The interface of the WBAN includes the network management and configuration. The network configuration includes the following jobs: sensor node registration, sensor initialization, node customization and a secure communication channel[6]. Once the WBAN network is configured, the PS manages the network by taking care of data retrieval and processing, channel sharing, time synchronization, and data fusion. Based on synergy of information from various medical sensors and actuators the PS application should regulate the user's state and his/ her health status and arrange for feedback through a user friendly and intuitive audio or graphical user interface.

The MBU holds patient authentication information and is configured with the medical to provide various medical services to the user. If the communication passage to the server is available, the PS establishes a secure transmission channel to the medical server and sends reports that are to be integrated into the user's medical record. However, if a communication channel between the PS and the server is not available, the MBU should be capable to store the data locally and start data uploads when a connection becomes available. This organization permits full mobility to the users with secure and nearly real time health information monitoring[7].

A key part of the mobile patient monitoring system is layer 1 – wireless body area sensor network. It encompasses a number of intelligent nodes, each capable of sensing and accumulating, sampling, preliminary processing, and communicating of physiological Biosignals. For example, an ECG sensor can be used for monitoring heart activity, a blood pressure sensor for collecting blood pressure, an EMG sensor for monitoring muscle activity, an EEG sensor for observing brain electrical activity, a breathing sensor for monitoring respiration and a tilt sensor for monitoring trunk position, while the motion sensors can be used to differentiate the user's status and estimate his/her level of activity.

Every sensor/actuator node obtains initialization directions and responds to the requests from the personal server. WBAN nodes should essentially please the minimal requirements for miniature form-factor, nominal weight, and low power consumption[8][9]for prolonged ubiquitous monitoring; standards based interface protocols, seamless integration into a WBAN, and patient-specific calibration, customization and tuning. The wireless sensor nodes can be realized as tiny covers or combined into clothes or shoes. The network nodes uninterruptedly collect and process raw data, store them locally, and send processed event reports to the personal server. The frequency of relevant events like sampling, processing, storing, and communicating of Biosignals depends on the type and nature of a healthcare application[10].

The sensors should periodically transmit their status and events and therefore results in significant reduction the power consumption and extended battery life. When local analysis of data is unconvincing or designates an emergency condition, the raw signals should be transferred to the next layer of the system.

All the layers in the healthcare system should provide Patient privacy as a prime requirement[11]. The data transfers between the personal server and the medical server require encryption of all delicate information associated to the personal health. All data records must be stripped of all information that can link it to a specific user before its conceivable integration into research databases. The inadequate variety of wireless communications partially addresses security within WBAN; however, the data packets can be encrypted using either hardware or software techniques. Some wireless sensor platforms have already provided a low power hardware encryption solution for ZigBee communications.

3. BODY AREA NETWORK

The healthcare WBAN comprises of sensors, actuators, communication and processing facilities. Depending on type of the patient data should be collected and different bio-sensors must be incorporated into the WBAN. Communication amongst entities inside a BAN is known as intra-BAN communication. A short range Bluetooth is the excellent choice offered for intra-BAN communication. To use the BAN for mobile patient monitoring external communication is required which is known as extra-BAN communication. The gateway that provides extra-BAN communication is called the Mobile Base Unit (MBU) or Personal Server (PS). Due to High data processing ability and operating systems like windows and android makes smartphones, tablets and PDA a very promising alternative for the MBU. A high-tech and sophisticated WBAN can be implemented in two levels as:

3.1 Sensor Level

A WBAN should consist of a number of physiological biosensors depending on the patient's application. Information of various sensors can be combined to produce new information. An extensive set of physiological biosensors may consist of the following[12][13]:

- an ECG (electrocardiogram) sensor for accumulating heart activity
- an EMG (electromyography) sensor for accumulating muscle activity
- an EEG (electroencephalography) sensor for accumulating brain electrical activity
- a breathing sensor for accumulating respiration
- movement sensors provided to estimate patient activity
- a blood pressure sensor
- a tilt sensor for observing trunk position
- a sensor equipped with shoe insole provided to define stages of individual steps

These physiological biosensors typically produce analog signals that are interfaced with standard wireless network platforms to provide storage, computational, and communication capabilities. Multiple physiological biosensors can share a particular wireless network node. In addition, physiological biosensors can be interfaced to an intelligent sensor board which provides on-sensor processing competency and communicates with a typical wireless network platform over serial interfaces.

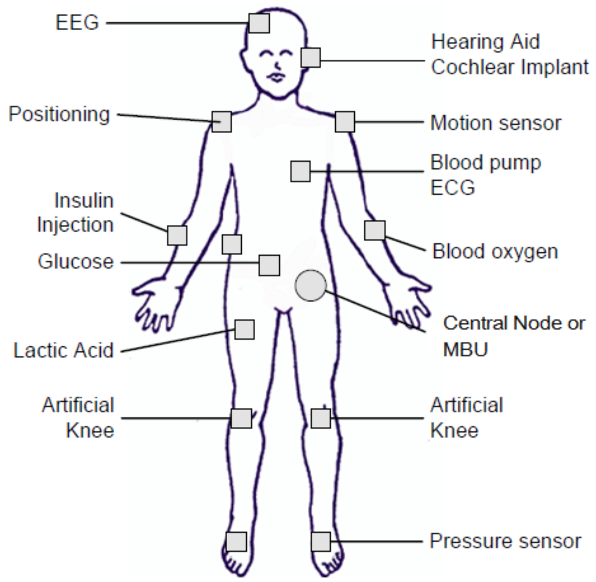

Fig 1: Wireless Body Area Network

The wireless sensor nodes[14] must satisfy the following requirements: miniature form-factor, minimal weight, low-power consumption to endure prolonged continuous monitoring, standard based interface protocols, seamless integration into a WBAN, and patient-specific tuning, calibration, and customization. These requirements represent a challenging job, but a hybrid implemented system by combining standard components, commodity software and hardware components, prepared by different vendors can accomplish these objectives.

The network nodes can be implemented as small patches or integrated into clothes or additional wearable accessories like shoes. The wireless network nodes continuously accumulate and process raw information, store data locally, and transfer it to the personal server. Category and nature of a healthcare application must define the frequency of relevant events (processing, sampling, communicating, and storing). Preferably, sensors periodically communicate their status and events, thus results in significant power consumption reduction and extended battery life. When local investigation of data is indecisive or designates an emergency condition, a request to transfer raw signals to the upper levels is generated where advanced processing capabilities and storage is available.

3.2 Central Node and Mobile Base Unit

The central node and mobile base unit performs the following tasks:

- Initialization, synchronization and configuration of WBAN nodes
- Acquisition of physiological sensor readings
- Control and monitor operation of sensor nodes
- Processing and integration of Biosignals from several physiological sensors providing better understanding of the patient's state
- Providing an graphical and audio interface that can be used to convey early warnings or guidance
- Secure communication with remote medical servers using Internet services

The mobile base unit or personal server can be implemented using a Smartphone, Internet-enabled PDA or 3G tablet. The MBU/PS can communicate with specific WBAN nodes using the Bluetooth or Zigbee wireless protocol which offers low-power consumption network operation and supports fundamentally limitless number of network nodes. A network coordinator, attached to the PS, can accomplish some of the pre-processing, organization and synchronization tasks. Other communication setups are also feasible for example, the MBU running on a Bluetooth or WLAN enabled smartphone can communicate with remote healthcare services.

Relying on standard mobile computing platforms is essential, as these platforms will continue to mature in their competencies and quality of services. The challenging tasks are to engineer robust applications that deliver simple and spontaneous services (data fusion, WBAN setup, questionnaires unfolding detailed symptoms, reliable and secure communication with remote servers, etc.). Total information integration will permit patients to obtain instructions from their healthcare providers based on their present circumstances.

4. ORGANIZATION AND REQUIREMENTS

Section 3 indicates that a WBAN consists of a number of heterogeneous devices. In this Section an overview of the different types of devices integrated in a WBAN has been given. Further the challenges and requirements are discussed. These include the wide-ranging variability of data rates, the need for reliability and quality of service, the restricted energy consumption, ease-of-use by healthcare professionals and privacy and security issues[15][16].

4.1 Types of Devices

4.1.1 Wireless Sensor Node:

A device that acquires data on physical stimuli, processes the data if required and reports the information wirelessly. It contains several components: a processor, sensor hardware, memory, a power unit and a transceiver or transmitter [17].

4.1.2 Wireless Actuator Node:

The behavior of these devices varies according to data received through the sensors or from user interaction. The components of an actuator are analogous to the sensors actuator hardware (e.g. hardware for medication monitoring, a reservoir to embrace the medicine), a processor, a power unit, memory and a transceiver or receiver.

4.1.3 Wireless Central Node or MBU:

A device that brings together all the information acquired by the sensors and actuators and informs the patient, doctor or caregiver via an external gateway or an actuator. The components of central node are: power unit, a processor with huge processing power as compare to the sensors or actuators, a memory and a transceiver. The device is also called a Mobile Base Unit (MBU), a sink or body-gateway. In most of the implementations, a smartphone or PDA is used.

4.2 Data Rates

The data rates of such applications will vary strongly due to strong heterogeneity in the applications, fluctuating from simple data at a few bit/s to video streams of several Kbits to Mbit/s. Data can also be transmitted in bursts, which means that data is transmitted at higher rate throughout the bursts period.

Table 1.Data Rate and Bandwidth Requirements of Different Sensing Units

Application Data	Rate	Bandwidth (in Hz)	Accuracy (in bits)
ECG(12leads)	288 kbps	100-1000	12
ECG(6leads)	71 kbps	100-500	12
EMG	320 kbps	0-10,000	16
EEG(12leads)	43.2 kbps	0-150	12
Blood saturation	16 bps	0-1	8
Glucose monitoring	1600 bps	0-50	16
Temperature	120 bps	0-1	8
Motion sensor	35 kbps	0-500	12
Audio	10-20 kbps	-	-
Voice	50-100 kbps	-	-

The data rates for the various applications are given in Table 1 and are considered by means of the range, sampling rate, and the preferred accuracy of the measurements [18] [19]. Overall, it can be realized that the application data rates are not very high. However, if the user has a WBAN with many of these devices (i.e. respiration monitoring, a motion sensors, ECG, EEG, EMG, glucose monitoring etc.) the combined data rate simply reaches a few Mbps, which is much higher than the raw bit rate of most existing low speed Internet.

The reliability of the data transmission is provided in terms of the bit error rate (BER) which is used as a measure for the lost number of packets. For medical devices, the reliability relies on the data rate. Low data rate devices can cope up with a high BER, whereas devices with a higher data rate necessitate a lower BER. The required BER is also reliant on the criticalness of the data.

4.3 Energy

The energy consumption for a device can be divided into three domains: sensing, data processing and communication[17]. The wireless communication is probably the most power consuming factor amongst the three. The available power in the nodes is often limited. In most cases the energy required by the sensing devices is contributed by the batteries. The storage capacity of a battery mostly depends on the both dimensions and weight. The size of the battery cannot be increased after a certain limit; as a consequence the power consumption of the devices has to be reduced. In some applications, a WBAN's sensor or actuator node must operate while supporting a battery lifespan of months or even years without intervention. For example, a glucose monitor would need a lifespan lasting more than 5 years. Particularly for invasive implanted devices, the lifespan is crucial parameter.

The need for battery recharging or replacement induces a convenience and cost penalty which is undesirable not only for invasive devices, but also for non-invasive ones. The lifespan of a node for a specified battery capacity can be improved by scavenging energy throughout the system operation. If the scavenged energy is higher than the typical consumed energy, such systems could run everlastingly. However, energy scavenging can deliver only a small amount of energy [20] [21]. Buta combination of reduced power consumption and energy scavenging is the optimal way out for realizing autonomous WBANs. For a Wireless Body Area Network, energy scavenging from on-body sources like body vibration and body heat appears to be very well suited. In the previous, a thermoelectric generator (TEG) is used to convert the temperature difference in-between the surroundings and the human body into electrical energy [22]. During communication the heat produced by the devices is absorbed by the nearby tissue which increases the body temperature of the patient. To limit this temperature rise and to save the energy, the power consumption should be regulated to a minimum. The quantity of power absorbed by the tissue is stated by the specific absorption rate (SAR). Since the device may be in close proximity to a human body, the localized SAR might be quite high. The localized SAR into the body tissues must be minimized and needs to conform to international and national SAR regulations. The guideline for transmitting close to the human body is analogous to the one for smartphones, with severe transmit power requirements [23] [24].

4.4 Quality of Service and Reliability

Appropriate quality of service (QoS) management is an important part in the framework of risk management for medical applications. Assurance that the accumulated data is received appropriately by the health care professionals is also a critical issue in the reliability of the transmission. The reliability might be considered on per link basis or end-to-end. The reliability also includes the guaranteed delivery of data considered as packet delivery ratio. Moreover, the messages must be delivered in reasonable amount of time. The network reliability has a direct impact on quality of monitoring and in a worst case scenario it might be fatal when a life threatening incident has gone undetected [25].

4.5 Usability

In most of the cases, a WBAN will be set up in hospital or healthcare center by a medical staff, not by an ICT-engineer. Subsequently, the network must be capable of configuring and sustaining itself automatically, that is self-organization and maintenance must be supported. Every time a node is placed on the body and turned on, it should be capable to connect the network and setup routes without any exterior intervention. The self-organizing and maintaining characteristic also embraces the problem of addressing the nodes. An address can be configured at setup time by the network itself or at the manufacturing time (the MAC address). Additionally, the network should be rapidly reconfigurable, for adding or removing the services. A backup path should be set up, when a route fails.

The devices might be scattered over and inside the whole body. The exact location of a device will be determined by the application, e.g. a temperature sensor could be placed almost anywhere, and however a heart sensor (ECG) must obviously be placed near the heart. Researchers appear to disagree on the ideal location for certain sensor nodes like motion sensors, because the interpretation of the measured data is keeps on changing almost every time[26]. The network should not be considered as a static one. The sensor nodes should have a minor form factor consistent by means of wearable and implanted applications. This will make WBANs unobtrusive and invisible.

4.6 Security and Privacy

The communication of health information over the Internet to servers and between sensors in a WBAN and is severely private and confidential [27] and must be encrypted to defend the patient's privacy. The medical staff gathering the data needs to be assertive that the data is not tampered with and certainly originates from that patient body. Further, it cannot be expected that a normal person or the medical staff is proficient of setting up and managing authorization and authentication processes. Furthermore the network should be accessible when the user is not able of providing the password (e.g. to assurance of accessibility by paramedics or medical staff in trauma situations). Privacy and security protection mechanisms consume a significant amount of the available energy so consequently they should be energy efficient and lightweight in nature.

5. LIMITATIONS AND CHALLENGES

There are some limitations of current wireless technologies that typically depend on GPRS and 3G technologies and on their deployment strategies in healthcare. Some of these issues are summarized as follows [28]:

- The lack of an existing integrated and flexible "m-Health-on-demand" linkage of the diverse mobile telecommunication options and standards for e-Health services. This lack of compatibility and linkage for remote monitoring services exists because of the difficulty of accomplishing operational compatibility amongst the telecommunication services, terminals, devices standards, and "m-Health protocols."[29]
- High cost of communication links, particularly between global mobile devices and satellites.
- The limitation of present wireless data rates specifically for the globally available 2G 2.5G (EDGE) and third-generation (3G) services for e-Health services. This is also combined with the accessibility of secure information access and mobile Internet connectivity specifically for e-health systems.
- Healthcare is a very complex industry that is hard to change. To benefit from e-Health and m-Health services many organizational changes are required for healthcare institutions.
- The working conditions and long term and short term economic consequences for health-care experts and physicians by means of these technologies are yet to be fully understood or properly investigated.
- The methods of imbursement and reimbursement issues for m-Health and e-Health services are yet to be fully developed and standardized.
- There is a lack of integration between existing information systems and e-Health services and, e.g., medical records, patient referral system etc.
- To this point demonstrated projects have failed to support the main motive of m-Health services i.e. cost effectiveness and user friendliness.

6. DISCUSSION AND CONCLUSION

WBAN is a very promising technology that can transform the next generation healthcare. WBAN carries out a new set of challenges in terms of energy efficiency, scalability, QoS, privacy and security, which are highlighted in the paper. The technologies which are important to WBANs, along with their merits and demerits are also discussed in this paper. Along with such technical issues there exist some non-technical issues such as controlling, affordability, legal and ethical issues like user comfort, friendliness, and acceptance, which will also play a crucial role in the success of WBAN technology. WBAN technology requires extensive acceptance of key stakeholders in the healthcare domain, which includes the patients, caregivers, medical-electronics industry, policy makers and patient advocacy groups for it to develop as a true pervasive technology. Researchers, Engineers and practitioners from various disciplines must come together and make every effort to overcome technical obstructions in order to carry the vision of pervasive and ubiquitous healthcare network to reality. Paper discusses the system architecture, applications, and design issues in detail [29]. It also briefs principal functional components for WBAN system design. Although various advances in these areas, there are several challenges that still requires to be addressed, particularly on energy efficient communication protocols, high bandwidth and interoperability between BANs and various wireless technologies.

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