BSNs: A Special Approach to Monitor Heart Rate

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***Abstract*—Advances in wireless communication technologies, such as wearable and implantable biosensorsare enabling the design, development and implementation of Body Area Networks (BANs). This class of networks is paving way for the deployment of innovative healthcare monitoring applications. In this paper, an overview of Body Area Networks and a discussion of BAN communication types and their related issues have been highlighted. The main concern for using BANs here is to monitor, detect and prevent heart related diseases. The accelerometerdata from the Body Sensor Networks (BSNs) are used to classify the patients' daily activity and provide the context information.**

***Key Words*—Cardiac arrhythmias, Electrocardiography (ECG), Intelligent Personal Digital Assistant (IPDA), Jitter, Microprocessor Control Unit(MCU),Mobile Cardio Outpatient Telemetry (MCOT), QRS Complex,Wireless Body Sensor Network (WBSN),Wireless sensor node for Motion Capture system with Accelerometers (WiMoCA) and ZigBee.**

I.INTRODUCTION

Heart disease is the leading cause of mortality throughout the world. The aging population makes heart disease and other cardiovascular diseases an increasing heavy burden on the health care systems of all nations. In today's world, in-home and personal prevention therapies of heart diseases are more in demand as compared to the traditional physician/hospital based heart disease therapies. In addition to the above, early detection and fitness health care services are also in need.

Owing to the drastic development in science and technology, wireless sensing/monitoring and wearable/implantable biosensors have been developed, enabling Body Sensor Networks (BSN's). In turn, BSN's provide a promising, personal and ubiquitous health care solution.

These BSN's are capable of sensing, communicating and processing several physiological parameters through biosensor nodes. A BSN usually consists of several implantable or wearable biosensors such as ECG, EEG, glucose sensors, accelerometers, blood pressure and oxygen saturation (SpO_2) sensors, temperature sensors and even ingestible camera pills. These sensors continuously monitor vital signs and report data to a powerful external device such as PDA, cell phone or bedside monitor station. Due to their miniature sized flexible nodes, Body Sensor Networks are able to provide real time context aware, non-invasive and ubiquitous health monitoring, thereby helping early detection, evaluation and diagnosis of heart diseases. Carefully placing sensors on the human body and wirelessly connecting them to monitor physiological parameters like heartbeat, body temperature, motion, etc., is a primary evolution. This system can reduce the enormous cost for patients in hospitals as monitoring can be done real time, over a longer period and at home. This type of network is called as Wireless Body Area Network (WBAN) or Wireless Body Sensor Network (WBSN).

A WBAN consists of several sensors and actuators equipped with a radio interface. Each WBAN has a sink or personal server such as a PDA that receives all information from the sensors and provides an interface towards other networks or medical staff. Connecting health monitoring sensors wirelessly improves comfort for patients but induces a number of technical challenges like coping with mobility and the need for increased reliability.

The rapid growth in physiological sensors, low power integrated circuits and wireless communication has enabled a new generation of wireless sensor networks, which are being used for purposes such as: monitoring traffics, crops, infrastructures and most importantly health. The BAN field is an interdisciplinary area which could allow inexpensive and continuous health monitoring with real time updates of medical records through the internet. A number of intelligent physiological sensors can be integrated into a wearable WBAN, which can be used for computer-assistor rehabilitation or early detection of medical conditions. This area relies on the feasibility of implanting very small biosensors inside the human body that are comfortable and do not impair normal activities. These implanted sensors in the human body will collect various physiological changes inorder to monitor the patient's health status, no matter their location. The information will be transmitted wirelessly to an external processing unit. This device will instantly transmit all the information in a real time to doctors around the world. If an emergency is detected, the physicians will immediately inform the patient through the computer system by sending appropriate messages or alarms. Currently, the level of information provided and energy resources capable of powering the sensors are limiting. While the technology is still in its developing stage, it is widely under research and once adopted, is expected to be a breakthrough invention in health care, leading to concepts like telemedicine and mHealth becoming real.

II.BIOMEDICAL SIGNAL PROCESSING

In a person who has had a heart attack or has undergone cardiac surgery, continuous monitoring of the function of the heart is very much essential. Neglecting the heart health will lead to many complicated problems, which if not attended within a specified time frame, will become irreversible causing hardship. In fact, a very minor asymptomatic variation in the heart rate or blood flow cannot be felt by the patient and also such indications like numbness of finger tips might be ignored attributing it to other general conditions i.e, cold weather etc. Since such persons are under continuous medication, these small and minor parameters have to be taken care of at the earliest. These symptoms cause small variations in the QRS complex. Real-time monitoring can lead to the better management of chronic diseases, earlier detection of adverse events such as heart attacks and strokes.Monitoring cardiac function can be used for diagnosing arrhythmia and mental stress. To identify the variation, a wearable sensor might be helpful.The sensor will immediately send a signal to the patients' care giver who in turn will help the patient.Wearable inertial sensors are a low-cost, low-power solution to track gestures and more generally, movements of a person. The implementation of a body-centric network mounting inertial sensors has been explored in many fields.

Biomedical signal processing is especially useful in the critical care setting, where patient data must be analyzed in real-time. Biomedical signal processing involves the analysis of these measurements to provide useful information upon which clinicians can make decisions. Engineers are discovering new ways to process these signals using a variety of mathematical formulae and algorithms. Working with traditional bio-measurement tools, the signals can be computed by software to provide physicians with real-time data and greater insights to aid in clinical assessments. By using more sophisticated means to analyze what is happening in our bodies, we can potentially determine the state of a patient's health through more non-invasive measures.

In most of the potential heart disease patients, abnormal cardiovascular symptoms such as chest pain, faints and shortness of breath can be detected before the occurrence of the fatal cardiac arrhythmia. Therefore it is important to have an effective measurement and reporting system to avoid deaths caused by heart attacks by providing immediate medical help. Several wireless Electrocardiograph (ECG) monitoring systems have been proposed [1], [2], [3], [4]. These systems use 802.15.4 (Zigbee) [4], [3], [4] or Bluetooth [2] as the radio interface for the ECG sensors to communicate with a hand held device.

III. ELECTROCARDIOGRAPHY

The electrocardiogram (ECG) is one of the simplest and oldest cardiac investigations available, yet it can provide a wealth of useful information and remains an essential part of the assessment of cardiac patients. With modern machines, surface ECGs are quick and easy to obtain at the bedside and are based on relatively simple electrophysiological concepts.

An ECG is simply a representation of the electrical activity of the heart muscle as it changes with time, usually printed on paper for easier analysis. Like other muscles, cardiac muscle contracts in response to electrical depolarisation of the muscle cells. It is the sum of this electrical activity, when amplified and recorded for just a few seconds that we know as an ECG.

*A. Basic Electrophysiology of the Heart:*The normal cardiac cycle begins with spontaneous depolarisation of the sinus node, an area of specialised tissue situated in the high right atrium (RA). A wave of electrical depolarisation then spreads through the RA and across the inter-atrial septum into the left atrium (LA) (Fig.1).

The atria are separated from the ventricles by an electrically inert fibrous ring, so that in the normal heart the only route of transmission of electrical depolarisation from the atria to the ventricles is through the atrioventricular (AV) node. The AV node delays the electrical signal for a short time and then the wave of depolarisation spreads down the interventricular septum (IVS), via the bundle of His and the right and left bundle branches, into the right (RV) and left (LV) ventricles. Hence with normal conduction the two ventricles contract simultaneously, which is important inmaximising cardiac efficiency.

After complete depolarisation of the heart, the myocardium must then repolarise, before it can be ready to depolarise again for the next cardiac cycle.

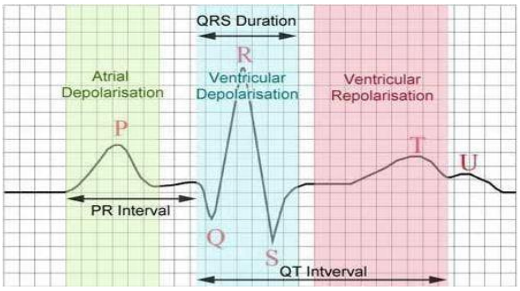

Fig.1 Normal ECG [12]

*B.The QRS Complex:*The QRS complex is a name for the combination of three of the graphical deflections seen on a typical electrocardiogram (ECG). It is usually the central and most visually obvious part of the tracing. It corresponds to the depolarization of the right and left ventricles of the human heart. In adults, it normally lasts for 0.06 - 0.10 s; in children and during physical activity, it may be shorter.

Typically an ECG has five deflections, arbitrarily named 'P' to 'T' waves. The Q, R and S waves occur in rapid succession, do not appear in all leads, reflect a single event and thus are usually considered together**.** A Q wave is any downward deflection after the P wave. An R wave follows as an upward deflection and the S wave is any downward deflection after the R wave. Deviation in deflections posses clinical significance (Table.1).

V.COMMERCIAL DEVICES[5]

Holter monitors (Fig.2) for ECG and EEG monitoring are among the first and most frequently used wearable sensors. Existing devices are limited, however, they are strictly data acquisition devices. CardioLabs based in Franklin, TN was founded in 1995 and offers a slight variation on Holter monitors by introducing event-based monitoring. Their recorders allow extended ambulatory heart

Fig. 2 Holter Monitor Device [13]

motoringand capture of cardiac arrhythmias and ischemic episodes [CardioLabs]. The devices are marketed to physicians with patients who report intermittent symptoms such as palpitations, chest pain,

TABLE.1CLINICAL SIGNIFICANCE DUE TO CHANGES IN QRS COMPLEX [15]

Parameter	Normal Value	Value Comments	Clinical Significance
QRS Duration	0.06 to 0.10s	Shorter in children and intachycardia	Prolonged duration indicates e.g.hyperkalemia or bundle branch block
QRS Amplitude	*S amplitude in V1+R amplitude in V5<3.5 mV *R+S in a precordial lead < 4.5 mV *R in V5 or V6 < 2.6mV		Increased amplitude indicates cardiac hypertrophy
Ventricular Activation Time (VAT)	*<0.05s in V5 or V6 *<0.03s in V1		Measured in increased QRS amplitude
Q wave	*Duration more than 0.04 s in leads other than III and AVR *Amplitude less than 1/3 QRS amplitude (R+S) *Amplitude less than ¼ of R wave		Abnormality indicates presence of infarction

shortness of breath, etc., but have been unable to provide an in-office diagnosis. The patient wears the device for extended periods and when experiencing a symptomatic [5]episode, presses the event button. The device will record up to 32 minutes of data surrounding the event. The data can then be extracted (at the physician's office) and analyzed by the physician to assist diagnosis.

CardioNet provides systems for Mobile Cardiac Outpatient Telemetry (MCOT). The system includes a three lead ECG sensor and electrodes, a portable health monitoring device (in PDA form factor) and a service center for collecting data from various users. The electrodes are placed on the chest and the sensor (transmitter) is worn around the neck or on the user's belt. The monitor can be placed on a desk or table nearby or can be worn when the user is mobile. The system is unique in that the sensor communicates wirelessly to the monitoring device and then the monitoring device uploads data to the service center using existing cellular infrastructure. The user can enter occurring symptoms so that theservice center can correlate the data, however, the monitoring device also performs some processing of the data and is capable of detecting certain abnormal heart rhythms. This represents a significant advantage over CardioLabs event-based heart monitors.

Polar Electro (or more commonly Polar)founded in 1977 has come to be one of the leaders in wireless heart rate monitors for personal health training. Polar has an extensive line of heart rate monitors primarily targeting fitness applications such as weight loss and digital personal trainers for athletes. The typical system includes a dry electrode ECG chest strap and a companion watch with wireless receiver. The watch [6] provides simple heart rate measurement and averaging functions. Polar's success and market share is evident with ongoing partnerships with a variety of wellness center-based gym equipment manufacturers. Many treadmill manufacturers integrate Polar heart monitor receivers into their equipment for display of real-time measurements or control of exercise while users are training. Polar has attracted a number of competitors in this field. Timex, Reebok and CardioSport offer similar products (Polar). Polar also markets its heart rate monitors to cardiac rehabilitation patients; however, the systems only offer a simple heart rate in beats per minute (bpm). While this is certainly important feedback for a recovering heart attack victim, the system is limited in that it is not integrated into a telemedical system and it offers no way of sharing data with the physician nor does it provide detailed heart waveform analysis. Finnish sports watch company, Suunto, has an impressive line of high end sports watches or "wrist top computers". In particular, a line of watches designed for fitness training includes a heart rate monitor belt. Similar to the Polar heart rate monitors, Suunto differentiates itself by its recent release of the Suunto team pod and team pack pro. The system is designed to work with their t6 models and allows the coach or trainer to monitor and collect heart rates from multiple athletes from up to 100 meters away (Suunto). Still in the spirit of fitness and wellness-based training, Polar Electro, Timex and Suuntoall offer high end heart rate monitors that provide multimodal monitoring. These systems typically include external wireless foot pods utilizing either GPS or accelerometers for useful real-time feedback of speed and distance (through the watch or [7] wrist-top computer) and also offer the ability for data upload for journal logging and some analysis of training sessions.

V.SPECIFIC REQUIREMENTS FOR THE APPLICATION

Medical monitoring applications have specific hardware and network requirements [8] to insure their functions and to solve encountered problems. Network requirements can be listed as follows:
A. Range: BAN allows the sensors in, on or around the same body to communicate with each other, so 2-5 meters range is sufficient.
B. Interference: Between the transmissions of different sensors from the same application and also from thedifferent applications (because it would be possible to have a lot of sensors on the same body) and with other sources (people close to each other can also have their own BAN), interference should be suppressed as much as possible to satisfy reliable wireless communication.
C. Network Density: With the diversification of BAN applications, people should be able to have sensors for different applications and different body area networks on them. BAN standard allows 2-4 networks per square meter.
D. *Sensors Number per Network*: Monitoring applications need a lot of sensors or actuators on the same body area network. BAN standardization group expects a maximum of 256 devices per network.
E. *Quick Time of Transmission*: The goal of monitoring applications is collection of information in the real time, so rapid transmission is necessary.
F. *In-body Environment*: Wireless network technologies have always been confronted to the problem of obstacle between transmitter and receiver and the path loss in the propagation medium. The problem here is more important because most of the time, signal must propagate through human tissue.
G. Security/Encryption: The transmitted data needs to be protected and integrity of received information should be provided.
H. Quality of Services (QoS) and reliability: They are crucial for the real time vital information and the alarm message transmission. BAN standard has to provide error detection and methods of correction. The QoS needs to measure delay and delay variation. It must be flexible as each application has specific requirements, and must support real time transmission. Latency (time delay) must be inferior to 125ms for the medical applications and to 250ms for the non-medical applications. Also, Jitter (variation of latency) must be controlled.
I. *Enabling Priority:* BAN has to support different type of traffics: periodical and burst traffic. Emergency traffic (alert in the case of heart attack or other serious problems) must have the priority over other messages on the network.
J. Support for Different Data Rates: Applications have very different requirements of the data rate (from 10 Kb/s to 10Mb/s). Most of the time, medical applications need lower data rate whereas non-medical applications (particularly multimedia applications) need the most important data rate.
K. Compatibility with other PANs: BAN should be able to communicate with devises using other PAN, such as Bluetooth.
L. Ultra Low Power Consumption: This depends on applications and on the nature of the sensors (in or on the body). This constraint exists to allow sensors to have the smaller batteries and to avoid frequent change of batteries. An effective power saving mode is desirable. However, parallel solutions like sensors utilizing power generated by body temperature or vibration can be opted. Another method could be to charge batteries by induction.
M. Suitable Sensors: Sensors should be small and must not hinder mobility and users' life. Monitoring should be as transparent as possible for them.
N. Lifetime: Sensors must have a long lifetime, particularly in-body sensors.
*O. Low Cost:*A cheaper monitoring system, particularly in applications using disposable sensors is the current need. The task group IEEE 802.15.6 is aiming to provide a cheaper monitoring than the current monitoring system.
P. Low complexity: It is associated with low cost. In order to make them cheap, they need to be easily produced in such a way soas to have low complexity. It supports an easier way to implementthe system which will help mass adoption, even by those who do not abide by the technology as they think it is difficult to use.

VI. SYSTEMARCHITECTURE OF BAN

This section describes the system architecture of wearable sensors for remote healthcare monitoring system. The system is composed of three tiers(Fig.3).
The system is composed of:
1) Wireless Body Area Network (WBAN);
2) Personal Server (PPS) using IPDA;
3) Medical Server for Healthcare Monitoring (MSHM).
A. First Tier: The core of this system is the user called the patient. Wearable sensors are attached to the patients' body forming wireless Body Area Network (WBAN) to monitor changes in the patient's vital signs closely and provide real time feedback to help maintain an optimal health status. The medical sensors typically consist of five main components:
(a) *Sensor*:Sensor is a sensing chip to sense physiological data from the patient's body.
(b) *Microcontroller:*Microcontroller is used to perform local dataprocessing such as data compression and it also controls the functionality of other components in the sensor node.
(c)*Memory:*Memory is used to store sensed data temporarily.
(d)*Radio Transceiver:*Radio transciever is responsible for communication between nodes and to send/receive sensed physiological data wirelessly.
(e) *Power Supply:*The sensor nodes are powered by batteries witha lifetime of several months [9].
Sensor nodes can sense, simple, and process one or more physiological signals. For example, an electro Cardiograph (EKG) sensor can be used for monitoring heart activity, a blood pressure sensor can be used for monitoring blood pressure, a breathing sensor for monitoring respiration, an electromyogram (EMG) sensor for monitoring muscle activity, and an electroencephalogram (EEG) sensor for monitoring brain electricalactivity. A sophisticated sensor is integrated into the WBAN called Medical Super Sensor (MSS).This sensor hasmore memory, processing and communication capabilities than other sensor nodes.MSS uses a radio frequency to communicate with other body sensors and ZigBee is used as a communication protocol to communicate with the Personal Server. Medical Super-Sensor (MSS) unobtrusively samples,collects multiple sensed vital signs by the body sensors, filtering out all redundant data thereby reducing large volume of data

transmitted by BSNs, store them temporarily, process and transfer the relevant patient's data to a personal server through wireless portal implemented using ZigBee/IEEE802.15.4. This improves overall bandwidth utilization as well as reducing power consumption of the BSs because each node does not need to transmit sensed data to the IPDA but to the cool-lector which is MSS and it is closer to the BSs than IP-DA and extending battery life of each sensor node.

B. Second Tier

(a)Personal Server: The personal server interfaces the WBAN nodes through a communication protocol using ZigBee. It is implemented on an Intelligent Personal Digital Assistant (IPDA). It holds patient authentication information and is configured with themedical server IP address in order to interface the medical services. It collects physiological vital signals fromWBAN, processes them, and prioritizes the transmission of critical data when there is sudden clinical change in the current patient condition and data content for example changes in cardiovascular signals, temperature, oxygen saturation, andforward it to the medical server. Moreover, the IPDA has the capability to perform the task of analyzing the physiological data intelligently and do a local reasoning to determine user's health

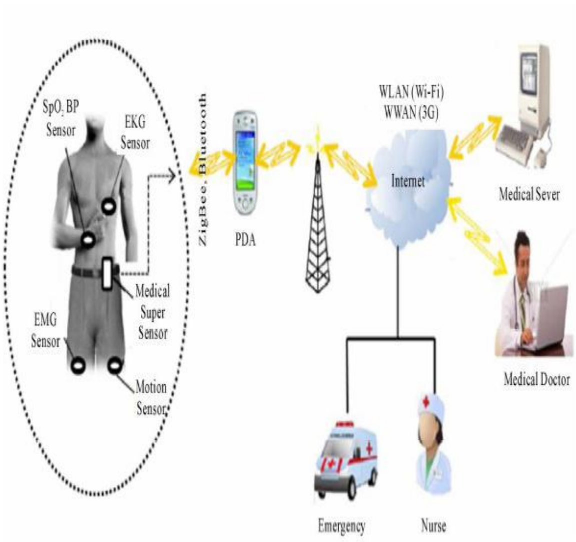

Fig.3 Architecture of BAN [14]

status based on data received from MSS and provide feedback through a user friendly and interactive graphical user interface. 3G communications is used to connect personal server and third tier together but other long range communications protocols can also be used like GPRS, WWAN. In order for IPDA to improve the overall quality of service for data transmission, in terms of latency, band-width and power consumption a differentiated service based on two schemes are presented. They are Priority Scheduling and Data Compression. This method reduces energy consumed by theIPDA during transmission since only the critical vital signswill transmit first while less critical signs are stored andtransmit later.IPDA is inactive mode when it has no data to receive fromMSS or send to the medical server in order to save energy butwake up immediately from inactive to active mode to receivetransmitted data and store it. It prioritizes all the receivedphysiological data and send it to the medical server based on thepriority order so that the medical staff will be adequatelyprepared before the patient gets to them or send ambulanceimmediately to pick the patient so as to save his/her life.

*B. Medical Server for Healthcare Monitoring (MSHM):*The third tier is called Medical Server for HealthcareMonitoring (MSHM). It receives data from the personal server. It is the backbone of the entire architecture. It is situated at medical centers where medical services are provided. It is intelligent because it is capable of learning patient specific thresholds and learns from previous treatment records of a patient [10]. MSHM keeps Electronic Medical Records (EMRs) of registered patients, which are accessible by different medical staff, including general practitioners, specialists and doctors from their offices in the hospital over the internet. The present state of the patient can be observed by the medical staff. MSHM is responsible for user authentication, acceptingdata from personal server, formatting and inserting the received data into corresponding EMRs, and analyzing the data patterns.The patient's physician can access the data and its patterns from his/her office via the intranet/internet and examine it to ensure the patient is within expected health metrics. If the received data is out of range (*i.e.* deviation from threshold) or recognize serious health anomalies condition, medical staff in the emergency unit can be notified to take necessary actions. However, if the patient is in the remote area, the specialist doctor will observe the physiological data of the patient, diagnose it, prescribe the necessary treatment and drugs for the patient. This information will be sent back to the doctor in the remote hospital via the internet. The MSHM
also provides feedback instructions to the patient, such as physician'sprescribed exercises.

VII. CONCLUSION

Challenges in monitoring the ECG parameter remotely has been outlined [11]. These challenges are listed below. In this paper, an attempt has been made to study the challenges posed, so that modifications can be deliberated for better and accurate measurement and monitoring the heart rate.

A. Sensor Node:

(a) Miniaturization of this node (to reduce the cost and enhance its wearability).

(b) Effective noise removal (to improve bit error rate and indirectly data rate and reliability).

(c) Dynamic/programmable power management (to fit in various environments/cases).

B. Gateway Node: The key challenges here include:

(a) Customizing the two transceivers (to reduce cost and power).

(b) A customized network protocol for sensor identification and communication.

(c) An encryption unit for security of transmitted data; and
(d) Memory backup possibility.

C. Server: The three vital tasks here are:

(a) Minimizing the probabilities of false positive and false negative signals (e.g. below 0.01).

(b) An intelligent content learning methodology that automatically profiles and monitors massive data collected for large number of individuals and sensors.

(c) A multi-level hierarchical graphical user interface allows the patient, doctor and selected individuals (e.g. relatives) to see part of the information and exchange data for comfort, monitoring, diagnosis and urgent/non-urgent response actions.

The above challenges need to be thoroughly studied and overcome to make it user friendly. At present 80% of the world's deaths from cardio vascular diseases occur in low and middle income countries/groups. Simplifications of the technology for mass adoption by making it cost effective, will not only help the individuals, but will also drastically reduce the death rate in potential work force. This inturn will help the respective nation indirectly.

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