Acquisition and Communication Requirements for Cardiovascular Signals

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Abstract- **Major objective of this paper is to focus on acquisition, retrieval and communication requirements for cardiovascular monitoring signals. These signals are multi-parametric and multi-dimensional in nature and therefore require comprehensive digital signal processing for feature extraction and analysis to detect the symptoms of cardiac diseases at early stage. Signal acquisition representing physiological parameters, processing for extraction of arrhythmia conditions and communication of relevant biomedical information from the subject body to the intended destination is accomplished with the help of Biomedical Sensor Network (BSN).In such type of networks BSN coordinator plays an important role in all the operations including acquisition of monitoring signals, information retrieval for feature extraction and communication of critical diagnosed cardiovascular adversities to the concerned medical care giver. This concept is modeled and simulated with the help of OMNeT++ discrete event network simulation environment. The BSN based medical diagnostic systems are highly demanded by medical professionals as they have potential to improve health care monitoring. The association of medical sciences with technological advances may increase frugal efficiency many times. The work proposed in this paper may help in developing in arrhythmia detection system for ambulatory patient monitoring in near future. Collective efforts are required to address design and development of cost effective ambulatory arrhythmia detection systems to report any severe condition for a person outside the hospital environment without compromising for his convenience and mobility.**

Keywords- Biomedical Sensor Network; Arrhythmia Detection; Dimensionality Reduction; Electrocardiogram; Cardiovascular Signals

I. INTRODUCTION

Technological advancements in the field of miniaturized Bio-sensors and Wireless Sensor Network technologies in recent years have made possible the development of Wireless Biomedical Sensor Network for ubiquitous and pervasive healthcare monitoring. Each BSN network consists of multiple interconnected sensor nodes which together provide sensing, processing and communication technologies. It is based on assessment of physiological parameters and providing necessary medical or clinical assistance to a remote person in need. This project figure outs network traffic model for telemetric healthcare services and how network resources and performance can be managed to deliver reliable and quality services to the concerned medical and non medical persons.

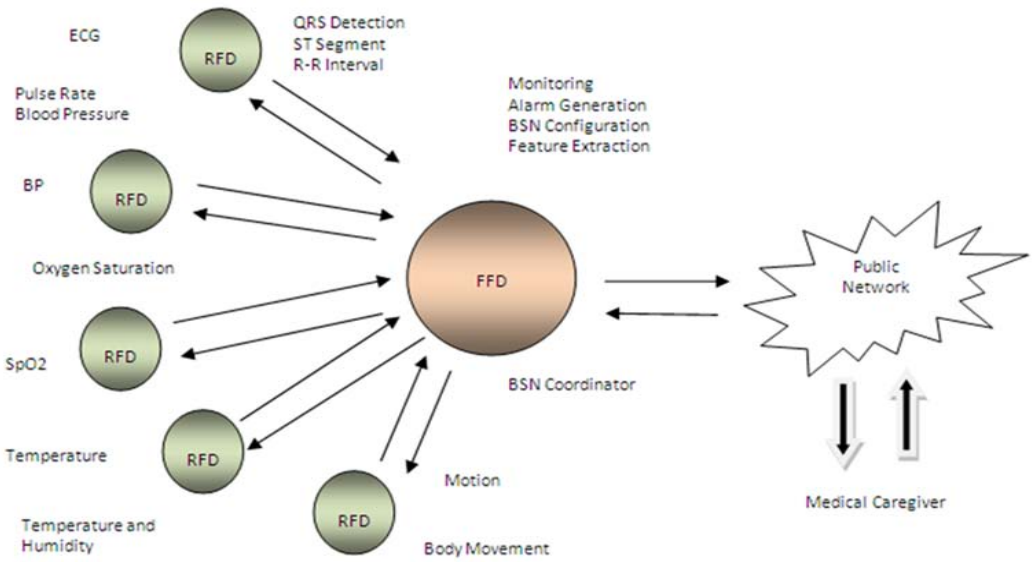

Fig.1. Biomedical Sensor Network

Major objective of this work is to focus on acquisition, retrieval and communication of cardiovascular monitoring signals. As far as cardio-respiratory signals used for arrhythmia detection are concerned they are multi-dimensional and multi-parametric time series data sequences. These signals are acquired with the help wireless sensors and transmitted to medical grade IEEE 802.15.4/ZigBee Biomedical Sensor Network (BSN) as shown in Figure 1. The detection and communication of

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adverse cardiovascular activities from the subject body to the concerned medical care giver, is a challenging task. The BSN designer community has to consider several issues related to the detection of onset for a critical cardiac condition and ensure reliable communication of the generated alarm signal for further medical interventions.

A BSN based arrhythmia detection system is shown in Figure 1. This proposed architecture is supported by four physiological sensors acquiring electrocardiogram (ECG), blood pressure (BP), blood oxygen saturation, temperature and humidity. This multi-parametric and multidimensional time series information is transmitted by each individual sensor node to the BSN coordinator. All detection decisions are taken at this stage with the help of advance digital signal processors and other integrated application software platforms. The Critical alarm signals and periodic diagnosis information is sent to medical professionals or concerned care giver for further actions. As far as design features for such networks are concerned they are given in Table 1, summarizing connectivity, topology and communication features.

TABLE-1. DESIGN FEATURES FOR BSN

Features	Options
Deployment	Random, Manual, Iterative
Mobility	Immobile, Partly, Occasional,
Network Topology	Single Hop, Star, Tree, Graph
Coverage	Sparse, Dense, Redundant
Connectivity	Intermittent, Sporadic
Network Size	Usually five to ten nodes
Communication	ISM Band RF-IEEE 802.15.4/Zigbee

Cardiovascular signals are immensely helpful better interpretations for diagnosis of cardiac diseases and risk factors. Each portion of the ECG waveform carries different information for cardiac analysis. For instance, the amplitude and occurrence of P wave and the duration of QRS complex are indicatives for cardiac muscles mass. A long delay in Atrio-Vanticular [AV] node activity is manifested by long R-R interval There exist many of arrhythmia conditions reflecting various cardiovascular disease patterns which can be easily diagnosed and communicated

II. CHALLENGES AND OPPORTUNITIES

The greatest challenge associated in the field of medical diagnosis is to find out relevant information from the bulk amount of sensor data. A typical BSN system used for acquisition of physiological parameters is shown in Figure 2 describing required functional blocks used for sensing relevant information. Biomedical sensors provide a huge amount of data that few meaningful pieces of information may be lost. Observers may have some problems as they have to stare at screens looking for the needle in the haystack. This chapter describes power efficient and reliable acquisition of physiological parameters accomplished with the help of “On Demand Awakening” of sensor nodes for transmission of episodic abnormalities resulted as physiological adversities. Flow chart for on demand awakening of the BSN is illustrated in the Figure 3 describing sleep and wake up states of s sensor node. Continuous transmission of any sensor node data (Hu et al, 2008) is never required for monitoring purpose and hence reduces amount of data transmitted from a BSN node.

Wireless Channel

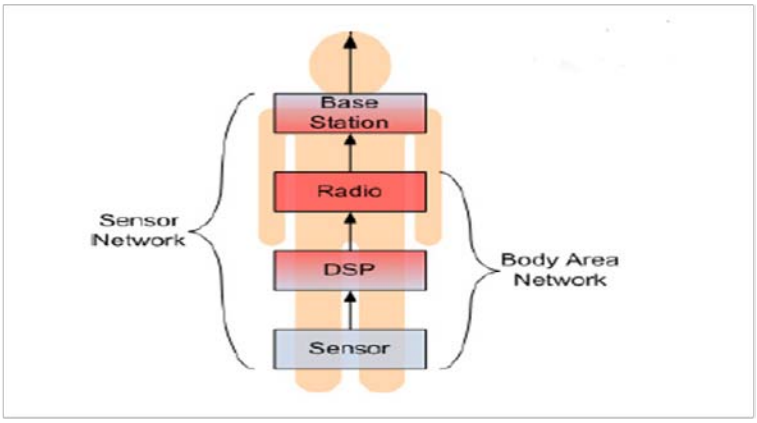

Fig. 2. Acquisition of Physiological Information

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Second major design challenge is to extract information from multiple sources in the form of multidimensional time series data with so many variations produced because of difference in sensor characteristics and different signal characteristics acquired from different persons under different environmental and physiological conditions (Tjensvold, 2008). Physiological data can vary widely depending on time, physical activity of subject and environmental conditions. This problem is resolved by context aware sensing (Zhen et al, 2008) and dimensionality reduction techniques (Astrin, 2010).

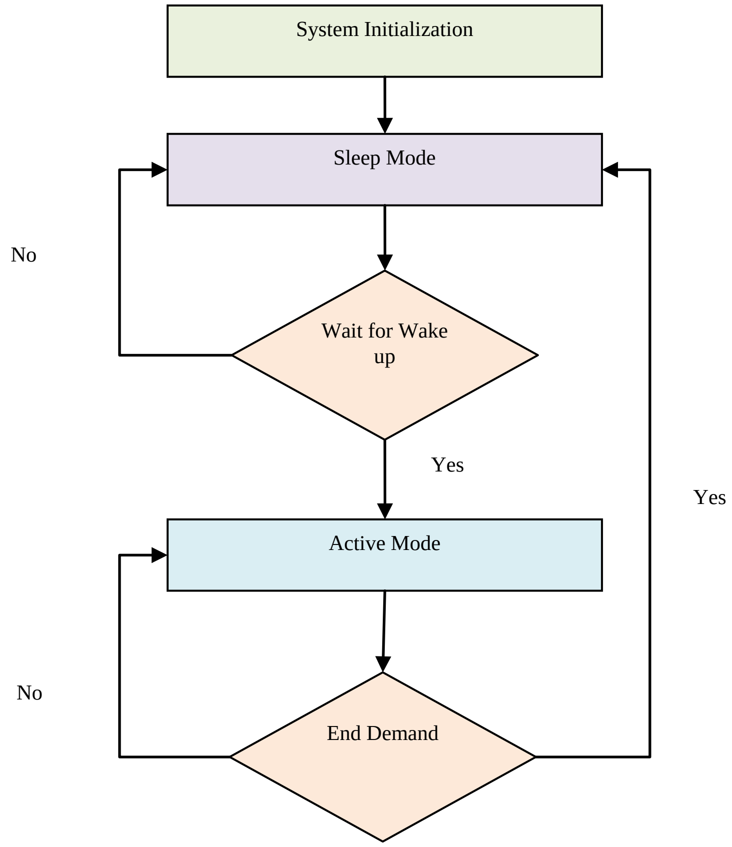

Fig. 3 BSN Sleep Mode Working Principle

III. ACQUISITION OF PHYSIOLOGICAL SIGNALS

Technological advancements in recent past years in the field of Micro-Electro-Mechanical-Systems (MEMS) and Photonics has supported the development of physiological sensors being capable to sense and communicate monitoring signals such as SpO_2 sensors, photo-plethysmogram, context aware ECG sensor etc (Yang, 2006). This section describes acquisition requirements for BSN data. The basic concept of the BSN is the fusion of compact wireless base unit and biomedical signal acquisition unit to form a wireless biomedical sensor node. The BSN node as a compact wireless device facilitates transfer of physiological parameters from the subject body to the BSN coordinator (Pradhan & Prabhakaran, 2008). This process includes several challenges and opportunities in the form of managing variability (Wu et al, 2007) of acquired multi-parametric and multidimensional time series data (Hudson & Cohen, 2001) from multiple biocompatible sensors.

The joint efforts of IEEE 802.15.4 task group and Zigbee aliance ended up with the specifications of a standard protocol stack for Low Rate Wireless Sensor Networks, an enabling technology for Biomedical Sensor Network. IEEE 802.15.4 covers PHY and MAC specifications, whereas ZigBee defines Network and Application layer specification (Hu et al, 2008). Protocol stack for physiological sensing operation is illustrated in Figure 4 covering cross layer functionality. Physical layer takes care for the issues related to control of biomedical sensor device. Medium Access Control and Data Link Layer performs elementary processing after fusing information obtained from multiple sources and incorporate error handling mechanism into physical data. Network Layer is responsible for trend analysis and event detection for acquired physiological information. Sensor node application layer defines applications associated a particular medical parameter. Application layer interact with physical process or sensor through sensor device manager for acquisition and Physical layer directly interacts with wireless channel for communication of acquired information. Elemetary data processing capability is incorporated into the sensor node to reduce communication cost and discard irrelvent data.

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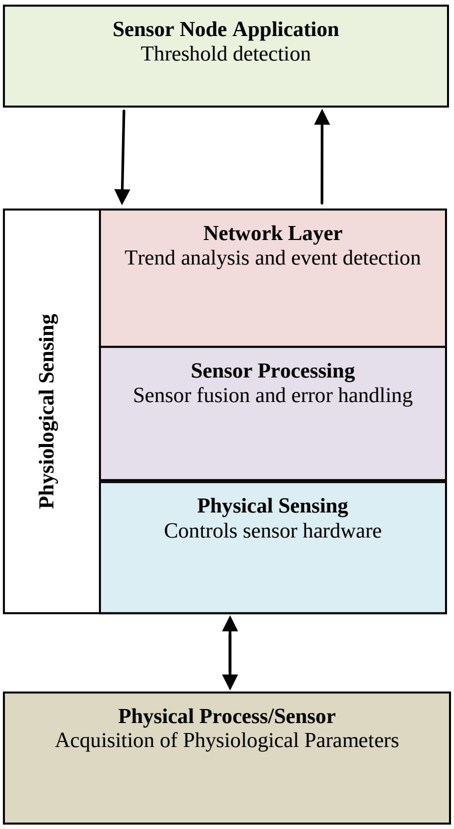

Fig. 4: BSN Sensing Operation Stack

IV. SENSOR NODE ARCHITECTURE

Sensor nodes have wireless communication capability and some digital logic for signal processing along with transmission handling to take care about encoding, encryption and error correction. Sensor node incorporates necessary data processing and signal conditioning operations that are performed before transmission to the next stage. In Figure 5, a prototype of the Full Functional Device (FFD) sensor node is presented. On body base unit functions as a BSN coordinator as well as portable clinical detection decision system. However a Reduced Functional Device (RFD) sensor node has limited functionalities to address application specific sensing operation. RFD sensor nodes interact with concerned Physical Process and acquire physiological parameters. The basic functionality of a BSN node depends on the application that is supported by the node. Application may define sensing operation for any of the physiological signal such as ECG, BP or body temperature. Each of the application decides a distinct physical process or corresponding physiological operation.

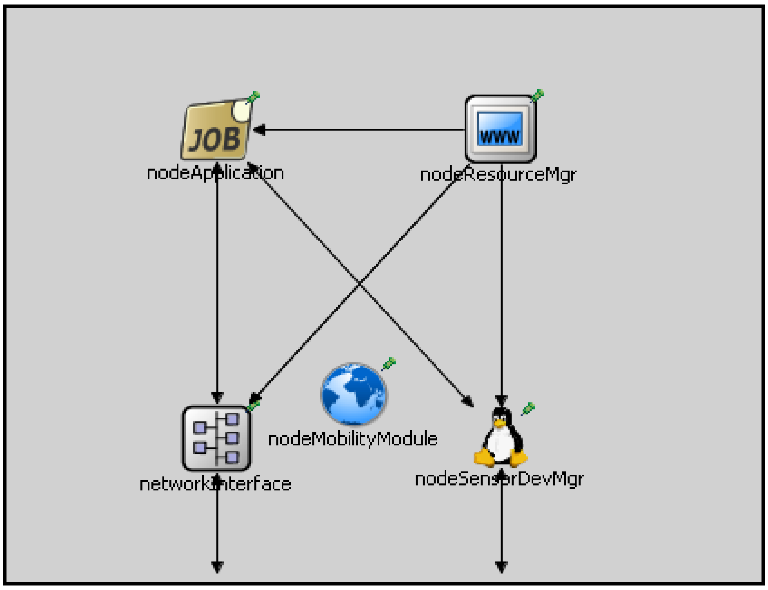

Fig. 5: BSN Sensor Node

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Sensors are either active or passive devices. Passive sensors are low power devices whereas active requires external battery to perform desired sensing operation. Small, cost effective, power efficient, robust and reliable sensors are needed to enable the realization of commercially viable BSN systems. Measurements carried out on human body are subjected to many complications. Some of the major problems are listed bellow

- Variability of data
- Biocompatibility of sensors
- Inaccessibility of signals to measure
- Lack of knowledge about interdependence of various organs and systems
- Effect of sensor errors on measurement and Artifacts
- Secure transmission of information
- Safety considerations
- Energy Limitations

All of these points must be taken in account for designing a practical BSN node. This makes the design work very complicated as human physiology and physical sensing both requires extensive research work to be completed.

V. COMMUNICATION REQUIREMENTS

This project work is based on IEEE 802.15.4/ZigBee wireless communication standard in star network topology, where each sensor node is one hop away from BSN coordinator. A ZigBee communication network is shown in Figure 6 illustrating a central base station and several other RFD nodes. The ZigBee network system consists of different components. The most basic is the sensor device. A sensor device can either be a Full Function Device (FFD) or a Reduced Function Device (RFD). A network has to have at least one FFD acting as the BSN coordinator. A FFD can operate in three different modes: a PAN coordinator, a coordinator or a device. RFDs on the other hand are intended for very simple tasks and can only act as a device. A FFD can communicate with other FFDs or RFDs, whereas a RFD can only communicate with a FFD. Today, most available hardware is implemented as FFDs, which is also the case for the hardware used for experiments presented later herein. RFDs are intended to be even simpler, more inexpensive and more power efficient and meant for low complexity sensor applications.

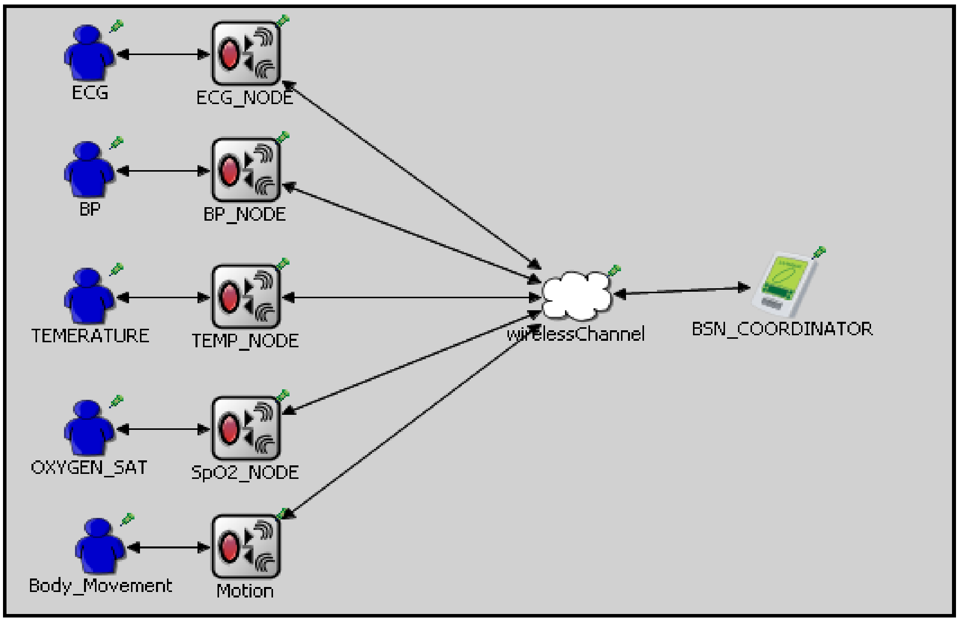

Fig. 6: Biomedical Sensor Network Simulation Model

The IEEE 802.15.4 standard is a Low-Rate Wireless Personal Area Network (LR-WPAN) standard. The ZigBee alliance was formed prior to the formation of the IEEE 802.15.4 group, but as they soon discovered, both camps were aiming at the same goal. Later, the ZigBee Alliance and the IEEE 802.15.4 group decided to join forces and ZigBee is today the commercial name for this technology [8]. However, the two groups still work on different parts of the technology. The IEEE 802.15.4 group has standardized the physical (PHY) and the medium access control (MAC) layers [10], whereas the ZigBee alliance concentrates on the development of the upper layers and the overall development. Cross layer communication model is shown in Figure 2.7 illustrating individual functions of each layer. Low power communication protocol stack is important design aspects for BSN Networks as it affect sensor life time.

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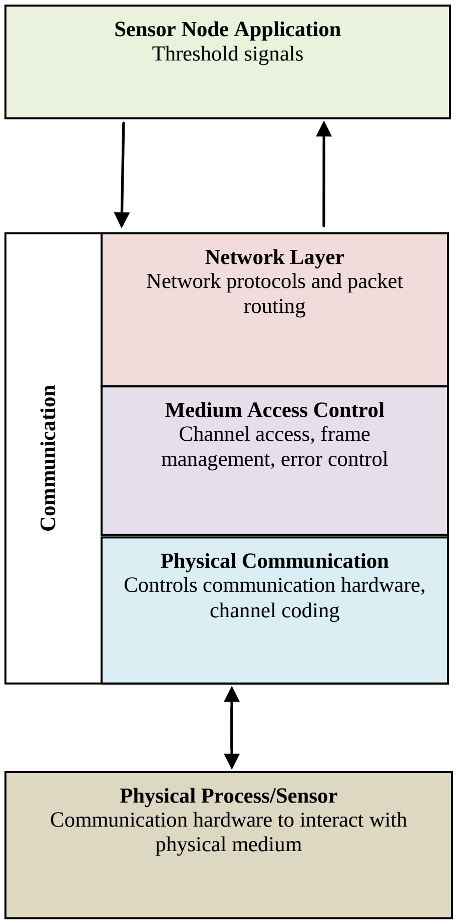

Fig. 7: BSN Communication Stack

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The main goal of the LR-WPAN technology is quite different from other Personal Wireless Networks. Instead of offering very high rates at long distances with high Quality of Service (QoS) requirements, it is intended to serve industrial, residential and medical applications with very low power consumption and cost requirements. This can be achieved as a result of the low data rate supported; for some applications a battery lifetime of 6 months up to several years is achievable.

A. Physical Layer

Basic requirements for BAN communication at physical layer are support for scalability for variable data rates and network size, ultra low power transmission with low complexity circuit for a very short range and regulatory compliance of transmission techniques. The PHY layer is responsible for the following tasks:

- Activation and deactivation of the radio transceiver
- Energy detection within the current channel
- Link quality indication for received packets
- Clear channel assessment for CSMA-CA
- Channel frequency selection
- Data transmission and reception

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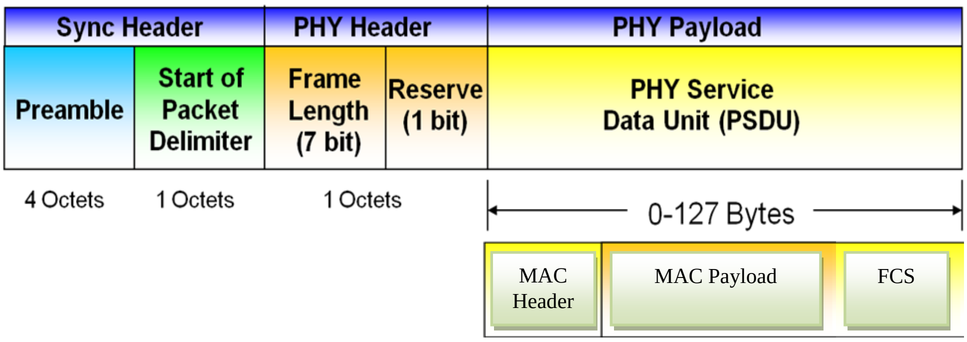

Fig. 8: Physical Layer Packet Structure

The PHY description also provides a method for transforming a physical-layer service data unit (PSDU) into a physical-layer protocol data unit (PPDU), shown in Figure 8. During the transmission, the PSDU shall be pre-appended with a physical-layer preamble and a physical-layer header in order to create the PPDU. At the receiver, the physical-layer preamble and physical-layer header serve as aids in the demodulation, decoding and delivery of the PSDU. The PSDU is the last component of the PPDU. This component is formed by concatenating the MAC header with the MAC frame body and frame check sequence (FCS).

The PHY layer consists of the data service and the management of the data service. The management part is the interface to the higher layers, and the data service part enables the transmission and reception of PHY protocol data units (PPDU) over the radio channel. The standard has two different modulation techniques, binary phase shift keying (BPSK) and offset-quadrature phase shift keying (O-QPSK), both used with direct sequence spread spectrum (DSSS) with a chip rate of 2 MChip/s on a 2 MHz wide frequency channel. The IEEE 802.15.4 standard operates in the unlicensed ISM bands, and the range is typically 5-75 m. Three frequency bands are supported, and have the following data rates: 250 kbps in the 2.4 GHz ISM band. O-QPSK modulation is used. In the 2.4 GHz band, the spectrum is divided into 16 equally spaced frequency channels as shown in Figure 9. The center frequency of each band can be found from

$$F_c=2404 + 5*(k-1) \tag{1}$$

Where k is the channel number in the 2.4 GHz ISM band.

The standard requires a receiver sensitivity of -85 dBm, and the defined transmit power steps are -25 dBm, -15 dBm, -10 dBm, -7 dBm, -5 dBm, -3 dBm, -1 dBm and 0 dBm. Also defined in the standard is dynamic channel selection, a scan function that steps through the supported channels in search for a beacon, receiver energy detection, link quality indication and channel switching.

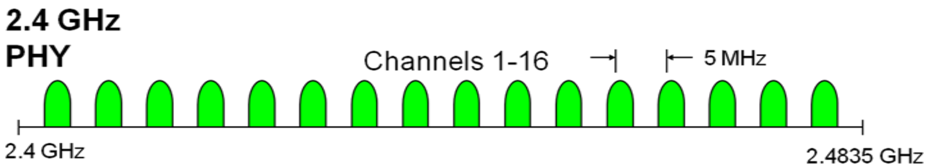

Fig. 9: IEEE 802.15.4 Operating Channels in the 2.4 GHz Band

B. Medium Access Control Layer

The MAC layer provides service to the upper layers, and enables the transmission and reception of MAC protocol data units (MPDU) across the PHY data service. Features of the MAC layer include beacon management, channel access, guaranteed time slots (GTS) management, frame validation, acknowledged frame delivery, association and disassociation.

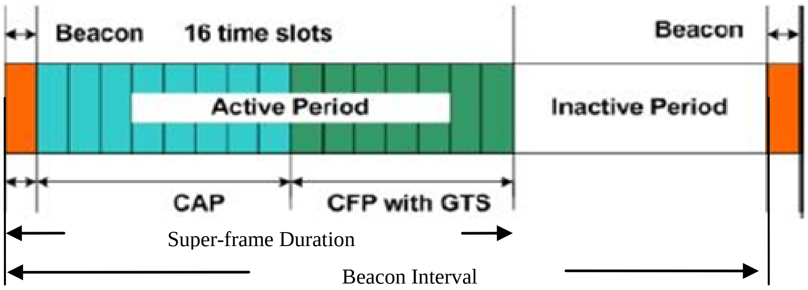

Fig. 10: CSMA-CA MAC Super frame Structure

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Two different modes of MAC operation are allowed in IEEE 802.15.4, the beacon mode and the non beacon mode. The more sophisticated mode is the beacon mode. As illustrated in Figure 10, the channel is divided in time into super-frames bounded by the beacon frames from the coordinator. The beacon frame is sent at the beginning of each super-frame and contains synchronization information, PAN identification and information about the structure of the super-frame. The super-frame is further divided into an active portion and an inactive portion. In the inactive portion the coordinator does not interact with its PAN and can enter a low power mode. The active portion is again divided into a contention access period (CAP) and a contention free period (CFP). The active part is also divided into 16 equally length timeslots. In the CAP the devices waiting to transmit have to compete with the other devices using a slotted CSMA-CA mechanism. The CFP is divided into guaranteed time slots which can be allocated to the connected devices. A device may only use a GTS if it is assigned one by the coordinator, and one GTS may span more than one timeslot.

In the beacon enabled mode the coordinator adds information about pending data to the devices in the beacon frame. Then the device polls the coordinator in the CAP and gets the data from the coordinator in the CAP. In the non beacon mode the devices poll the coordinator for data at an application defined rate. From devices to the coordinator the device use the slotted CSMA-CA in CAP or just send in its assigned GTS in CFP.

C. Network Layer

The main task of the BSN node is to sense and collect data from subject body, process it and transmit the information to the BSN coordinator, where underlying application resides. Achieving this task requires the development of an energy efficient routing protocol. However in case of intra-BSN communication routing does not play any role as source is just single hop away from the sink but for extra-BSN communication routing protocols play a significant role. Power limitations for the network makes routing problem very challenging.

The upper layers of ZigBee are responsible for the routing algorithms and for the gathering of data into packets. Several different topologies are possible, and the upper layers are responsible for the routing in the network. The different network topologies have some distinct properties. In the Star topology the communication runs between a single central controller, known as the BSN coordinator or Base Station, and devices. When the BSN coordinator is initialized it chooses a BSN identifier which is not used by any other network within the radio coverage.

D. Link Quality Indication

Zigbee offers Link Quality Indication (LQI) mechanism to manage efficient and reliable communication link by measuring signal strength and quality of received packet. Link Quality Information is exchanged with the help of Probe (PRB) packet. In wireless comunication packets are transmitted over the links that have highest probablity of success. Link quality Indication successfully handles this task. In this way the number of transmissions to ensure succesful transmission are reduced. Network Layer enables the measurement of link quality between neighboring nodes in the network. Link Quality indication is received with every packet successfully delivered. By averaging over several LQI values an estimate of the link quality can be obtained and therefore an estimate of the probability of successful transmission is available.

E. Interoperability in 2.4 GHz ISM Band

Interference avoidance is a significant design goal for BSN designer community. There exist many applications operating in the Industrial, Scientist and Medical (ISM) frequency band of frequency spectrum, such as wireless LANs and Bluetooth. IEEE 802.11b/g (Wireless Ethernet) operating in the same frequency band (2.4 GHz) and most of the microwave ovens also operate at 2.45 GHz. So there is a big problem in the form of interference and we have to deal with it to implement an operational and secure BSN (Tjensvold, 2008). There can be interference even from other BSN nodes of other person in the closer proximity. A BSN Base Unit and BSN Node can be configured to listen to only those devices which are part of the network by using device authentication. Biomedical signals which are unique for every person can also be used for device authentication.

VI. HANDLING BSN DATA

BSN have created new opportunities across the spectrum of heath care services, including disease management, fitness monitoring, ambulatory patient care and human performance improvement. Many applications exhibit strong similarity in the way that sensors are used to collect and disseminate data to carry out the objective for which they are deployed. The process of data collection is either triggered by the occurrence of specific events related to physiological activities or initiated in response to a query issued by underlying application. It is worth noting that in many cases it is useful to aggregate data collected by sensor node before forwarding it to the base station. Data aggregation reduces the amount of information to be transmitted, leading to significant decrease in power consumption required for communication.

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VII. SIMULATION AND PERFORMANCE ANALYSIS

BSN model, shown in Figure 11, consists of modules that communicate by passing messages. BSN network consists of three modules namely Sensor Node, Physical Process and Wireless Channel. However sensor node has some sub modules down the hierarchy. These modules are Application Module, Network Interface Module, Node Resource Manager Module and Sensor Device Manager Module. Network Interface Module is the most significant module that plays a pivotal role in modeling of various communication and data handling protocols and processes. It is further divided into Network Layer Module, MAC Layer Module and Radio Module. For the sake of simplicity without compromising general functional behavior of the proposed model only necessary functions are taken into account.

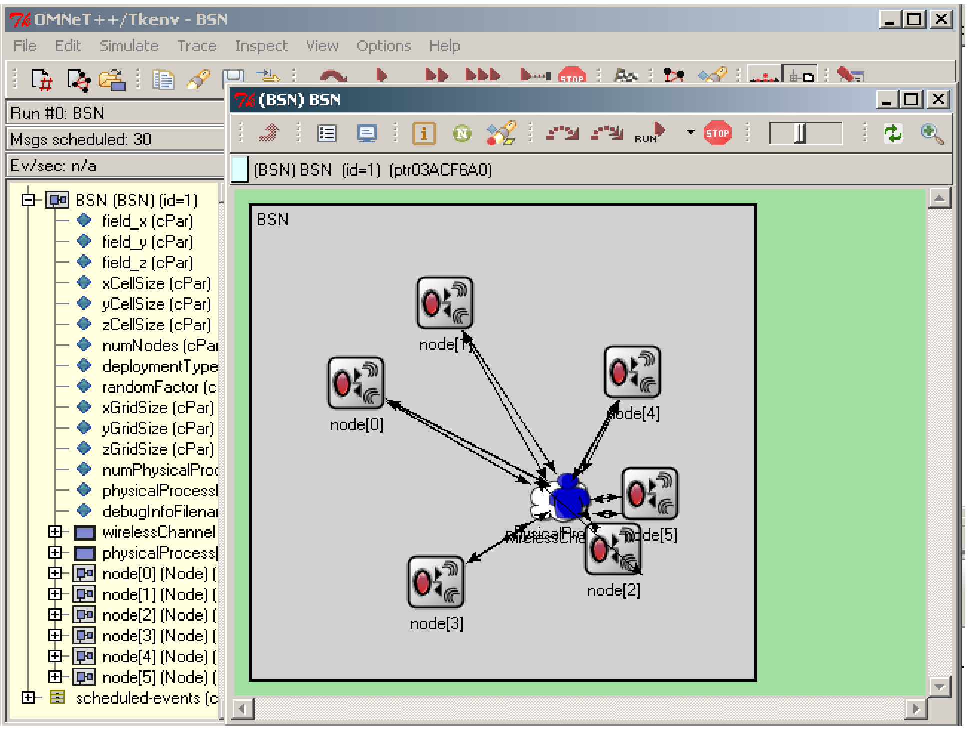

Fig. 11: BSN Simulation Test Bed

This work presents an empirical investigation on the performance of BSN network model using IEEE 802.15.4/ZigBee wireless communication. Simulation is required to validate proposed algorithms and protocols before physical implementation to save engineering resources and time involved in the process. BSN traffic verification using OMNeT++ simulation environment is carried out with the help of various simulation parameters and simulation class libraries.

Functional validation of BSN traffic and performance is based on IEEE 802.15.4/ZigBee protocol stack. Some related medium access control parameters are given as

BSN.node[*].networkInterface.macModuleName = Mac802154Module

BSN.node[0].networkInterface.MAC.isFFD = True

BSN.node[0].networkInterface.MAC.isPANCoordinato = Truer

BSN.node (Yang, 2006).networkInterface.MAC.requestGTS = 3

TABLE 2 DELAY AND PACKET RECEPTION RATIO FOR BSN MODEL

Sensor Node	Transmitted Packets	Received Packets	Packet Reception Ratio (%)	Average Delay (ms)
ECG Node(1)	400	395	98.75000	17.7143
Blood Pressure Node(2)	48	47	97.91667	17.7143
SpO2 Node(3)	60	54	90.00000	17.7143
Temperature Node(4)	16	15	93.75000	17.7143
Body Motion Node(5)	16	15	93.75000	17.7143

After performing the simulation various performance statistics are generated. Packet delay, delay histogram, packet reception information, loss of packets caused by interference, low sensitivity and non Rx state are major to quote here. This

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information helps in calculation of average delay for network nodes and overall throughput. Average packet delivery delay is calculated as

$$Delay\_avg = \frac{Total\_Delay}{Packet\_recived} \tag{2}$$

Average delay for simulation is found **as 17.71429 ms.**The information for Total_Dealy and Packets_Received is drawn from the delay histogram generated for application level latency as shown in Figure 12. Different packets reach the BSN coordinator with different packet delay profile ranging from as low as 1ms and up to 600ms. This Figure illustrates histogram values for packet delivery delay.

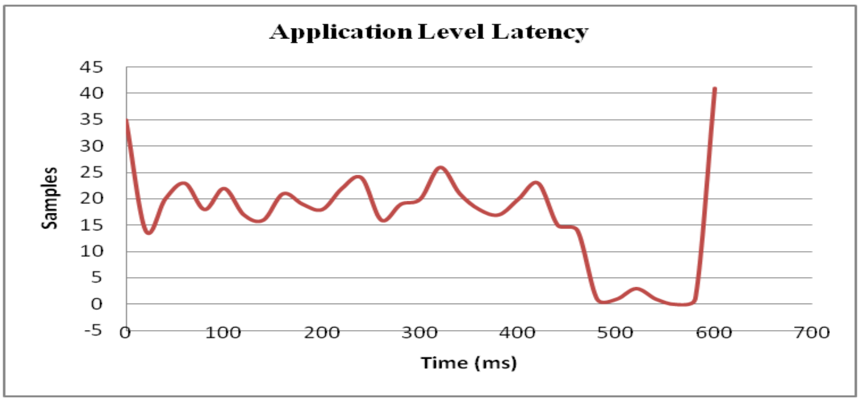

Fig. 12 Application Level Latency for Data Packets

Throughput for network is expressed as

$$Throughput = \frac{Total\_Data\_Bits}{Simulation\_runtime} \tag{3}$$

Total_Data_Bits can be calculated from number of number of Packets_receive and packet size. For the given simulation model packet size is 1024 bps and for simulation, run time of 50 seconds. If number of packets received is 525 then BSN network throughput is **10.50 kbps.** Packet Reception Ratio of all sensor node transmitting information to Node (0) or BSN coordinator is shown in the Figure 12. Node (1) has highest PRR whereas node (5) is having the lowest one.

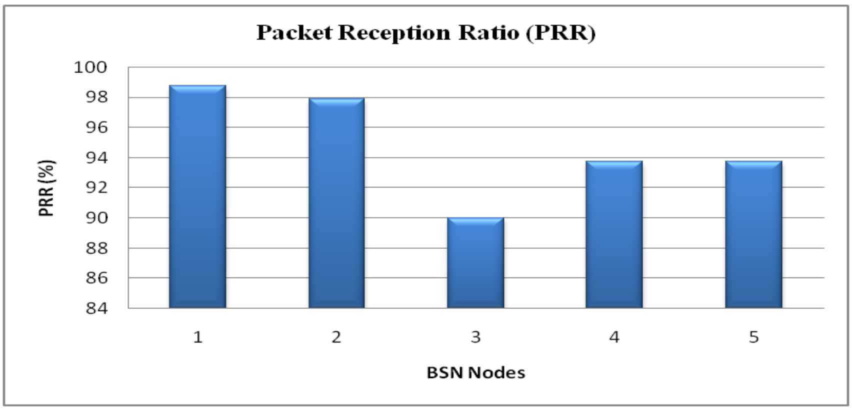

Fig. 13 Packet Reception Ratio for BSN Nodes

VIII. CONCLUSIONS

During last decade we discussed a lot about the pros and cons of using personal multimedia communication devices and their impact on human body (Martin, Jovanov, & Raskovic, 2000). RF power used for transmission of information certainly have some health related issue but as the perceived value related to personal communication and entertainment is increasing, personal area networks (PANs) are gaining popularity and even ready to provide healthcare monitoring solutions (Yang, 2006). However Bluetooth and ZigBee enabled devices are very common in our daily life but current PANs do not meet the medical (proximity to human tissue) and relevant communication regulations for some application environments (Tjensvold, 2008). They also do not support the combination of reliability Quality of Service (QoS), low power, data rate and noninterference required to broadly address the breadth of body area network applications. Still we require low power, short range and reliable communication technologies on or around human bodies for a variety of applications including healthcare, fitness monitoring, assistive technologies and entertainment.

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Currently, there are intensive activities worldwide on applying Information and Communication Technologies in a more active and direct way to support medical and healthcare services. Wireless communication Regulatory and/or medical authorities approved frequency globally available license free bands (Medical Implant Communication Services and Industrial Scientific Medical bands) for in and around human body BAN communication. BAN devices are technologically complaint with already existing IEEE 11073 and ZigBee healthcare monitoring devices (ZigBee, 2009). These devices communicate with extremely low power levels to protect human tissues in closer proximity. This work presented mainly traffic and performance management issues in context of IEEE 802.15.4/ZigBee communication protocol stack. However this work may further be extended for functional validation and verification of new IEEE 802.15.6 standard also.

This paper outlines major acquisition and communication requirements for a Biomedical Sensor Network. The prototype system uses power efficient event based data delivery model to report abnormalities in the cardiovascular signal for reduction of communication power requirements. Vital signs are acquired and passed on to the BSN coordinator on the basis of 'on demand awakening' of on-body sensor nodes by off-body HMS controller for transmission of sensor information. Power efficiency of the system was the major concern throughout entire discussion, which was addressed by on demand awakening, single hop star network topology and ZigBee protocol stack.

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