RESEARCH THESIS

Efficient Postural Change Aware Routing Algorithm for Wireless Body Area Network (EPARA-BAN)

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Session 2015 -2017

DECLARATION OF AUTHENTICATION

I, Iqra Khalid (Enrollment No. 01-244151-051), solemnly declare that my research thesis report entitled "Efficient Postural Change Aware Routing Algorithm for Wireless Body Area Network(EPARA-BAN)", is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person. All the references and acquired help in this study has been acknowledged. I testify that the material produced in this research work, either in whole or part has not been obtained or used for any other degree at this or any other institution.

Signature……………………..

ACKNOWLEDGEMENT

Being thankful to Allah, to Whom belongs all the powers and grandeur, this research work is materialized in final shape.

I am extremely grateful to my supervisor, Dr. Shagufta Henna, for the guidance, resolute support, valuable time, untiring efforts and confidence in me throughout the course of this thesis work.

I offer my best regards and prayers to all who supported me in any respect during the completion of this work. Last but not the least; I feel bound to pay homage to all those people who believed in me, gave me confidence and without whom I could never have achieved my goal; my family, especially my Parents. I thank them all for rendering their constant prayers and persistent support for me. At the end I would like to thank one of my friends who helped me throughout the completion of my thesis work.

May Allah bless them all with eternal happiness!

DEDICATIONS

To My Father, Mother, Family and friends.

ABSTRACT

One of the biggest challenges of our times is the quality and quantity of healthcare services being imparted to massive population all over the globe due to an increase in aging factor. More emphasis is on prevention and early risk detection like in US and European countries, where the family structures are not existent in societies. Existence of a system which is able to monitor and timely report the health conditions of aged people is inevitable now a days. This alarming situation makes the body area network (BAN) as a demanding technology to the pertinent institutions. BAN consists of devices including sensor nodes which are attached inside the body or outside the body of the subject patient being monitored. By this, People know their health condition without visiting their doctor and doctor can advise them according to their data. Before discussing most important aspect being faced recently is to design such algorithm which satisfies the Quality of service (QoS) requirements for different health care applications. Routing mechanism is a process for selecting best paths in a network with minimum route cost and ensuring less distance involved in communication. Energy Efficient Selection Next Hop Selection Algorithm (ENSA-BAN) uses the link cost and minimum hop count in order to select the next hop node. However, ENSA-BAN does not perform well under postural triggered mobility, like walking and running. In this thesis, next hop selection algorithm is proposed called EPARA-BAN which performs well under postural change as compared to ENSA-BAN. Performance of the EPARA-BAN is evaluated using extensive network simulation using ns-2 under different scenarios of arm and leg postural change with different sink positions. Experiments reveals that EPARA-BAN has better delivery ratio and is more robust under body movements with a little compromise energy and end-to-end delay compared to the ENSA-BAN.

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ABBREVIATIONS

WBAN	Wireless Body Area Network
BAN	Body Area Network
RF	Radio Frequency
CH	Cluster Head
PBRP	Postural-Movement-Based Routing Protocols
ENSA-BAN	Efficient next hop selection Algorithm
ECG	electrocardiogram
QoS	Quality of Service
WPAN	Wireless Personal Area Network
LQI	Link Quality Indication
ED	Energy Detection
CSMA-CA	Multiple Access with Collision Avoidance
GTS	guaranteed time slot
FFD	Full Functional Device
RFD	Reduced Function Device
QPRR	QoS-aware peering routing protocol for reliability-sensitive data
QPRD	QoS-aware peering routing protocol for delay-sensitive data
DMQoS	Data-centric multi-objective QoS-aware routing protocol
LO	Lexicographic Optimization
CP	Critical Packet
OP	Ordinary Packet
DP	Delay-driven Packet
RP	Reliability Driven Packet
EPR	Energy efficient peering routing protocol
RL-QRP	reinforcement learning and supports QoS aware routing
ETPA	Energy Efficient Thermal and Power Aware Routing
TDMA	Time Division Multiple Access
PRPLC	Probabilistic Routing
LLF	Link Likelihood Factor
PSR	Exploiting Prediction to Enable Secure and Reliable Routing
LCF	Link Cost Factor
HCQ	Historical connectivity Quality
LoS	Line of Sight
RTS	Request To Send
RAck	Receive Acknowledge

RSSI	Received signal strength indication
ECHR	Energy-aware Coverage preserving Hierarchical Routing network protocol
Eres	Residual Energy
Qempty	Free queue size
HOPmin	minimum number of hops
LinkR	Link Reliability
EWAD	Weighted moving average
SS	Signal Strength
PDR	Packet Delivery Ratio

Chapter 1

Introduction

1.1 Overview

A rapid growth in healthcare technology has resulted in an increased cost to the end users growing with technological developments, researchers are deemed to work on the human body and sensors can be placed on and in of human body. BAN is also called as Wireless Body Area Network (WBAN) or body sensor network (BSN) and it is a wireless network of wearable computing devices. BAN devices can be used in number of ways, i.e., implanted inside the body in a static position or it can be implanted on the body surface in such a way that it can be easily carried. Due to the above reasons, BAN is most desirable emerging technological innovation in the health care sector [2]. BAN is based on radio frequency (RF) which makes it possible to monitor the patients and also implementing the possibility to remotely acquire the health conditions of the patients for the doctors.

BAN communication architecture is divided into three major parts, i.e., intra-BAN, inter BAN and beyond BAN as shown in Figure 1. An intra-BAN comprises of sensors which are capable of sensing, processing, sampling, and communicating within the BAN, where various health related parameters and information is collected and transferred into the sink node. On the other hand, in inter-BAN, collected data from the subject patient's body is transferred to a gateway. While communication of this data from the gateway to some doctor is implemented in beyond-BAN, and it can also be used to authenticate the user, store patient's data into medical records, and analyze the data afterwards [2]. Figure 1 shows the typical BAN Architecture.

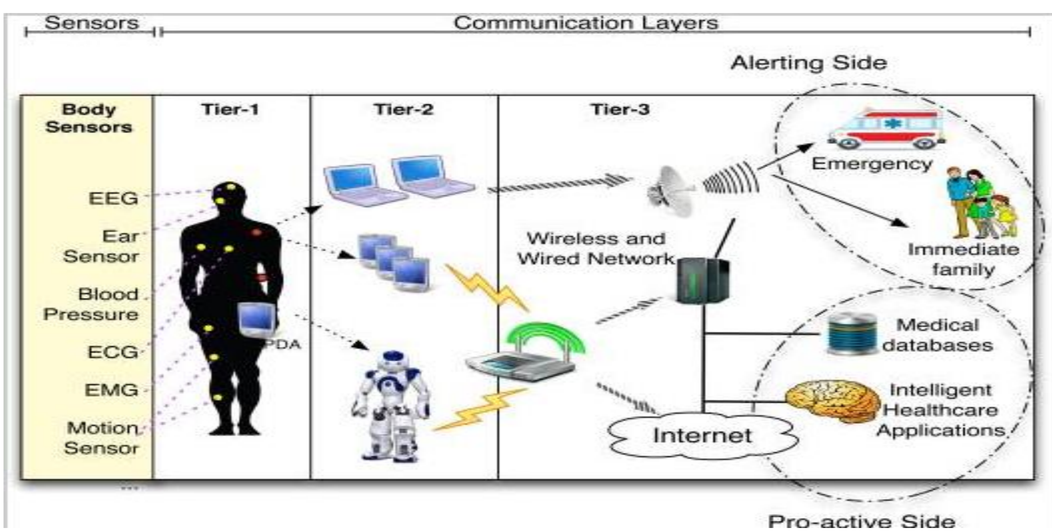

Figure 1: BAN Architecture [3]

The sensors deployed within the human body have their own advantages and disadvantages related to their routine maintenance, signal range, and type. There are usually one or more sensors which collects the data from other sensors usually referred as sink nodes. These sink nodes are responsible for the collection of data from all other sensors and communicate with the external devices which relay this information to the remote locations through internet for monitoring and recording purposes. The detailed BAN infrastructure deployment is shown in Figure 2 [2].

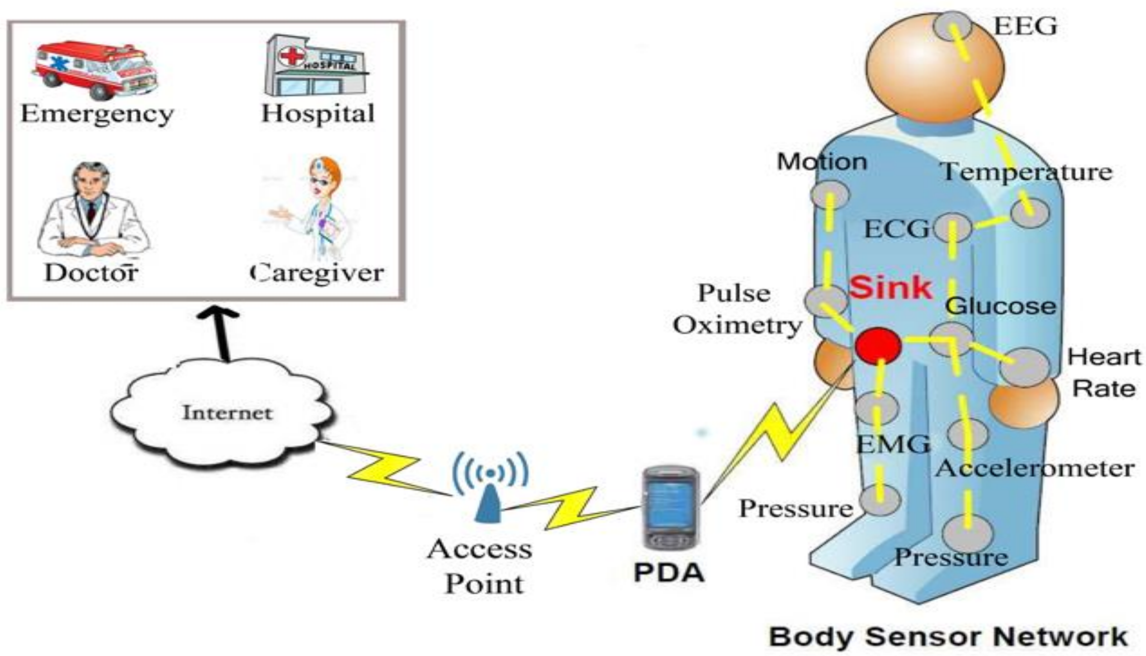

Figure 2: BAN Deployment [2]

There are number of factors which need to be considered in any BAN such as its range for communication, loss of path, and limited resources. The major problem in BAN is to implement all its components and layers with affordable and long lasting energy resources. In a multi-hop BAN, each node send packets to its neighboring nodes until the data reaches to sink node. BAN is implemented on hop by hop basis by using routing protocol, and the aim is to ensure energy conservation and efficiency. Resource limitation makes the end-to-end routing protocols not suitable for BAN. The main criteria for the routing protocols in multi-hop BAN is to select a best path between the sensor nodes and the sink nodes with minimum link cost and hop count. There are many routing protocols which are defined for BAN as shown in the Figure 3 [1].

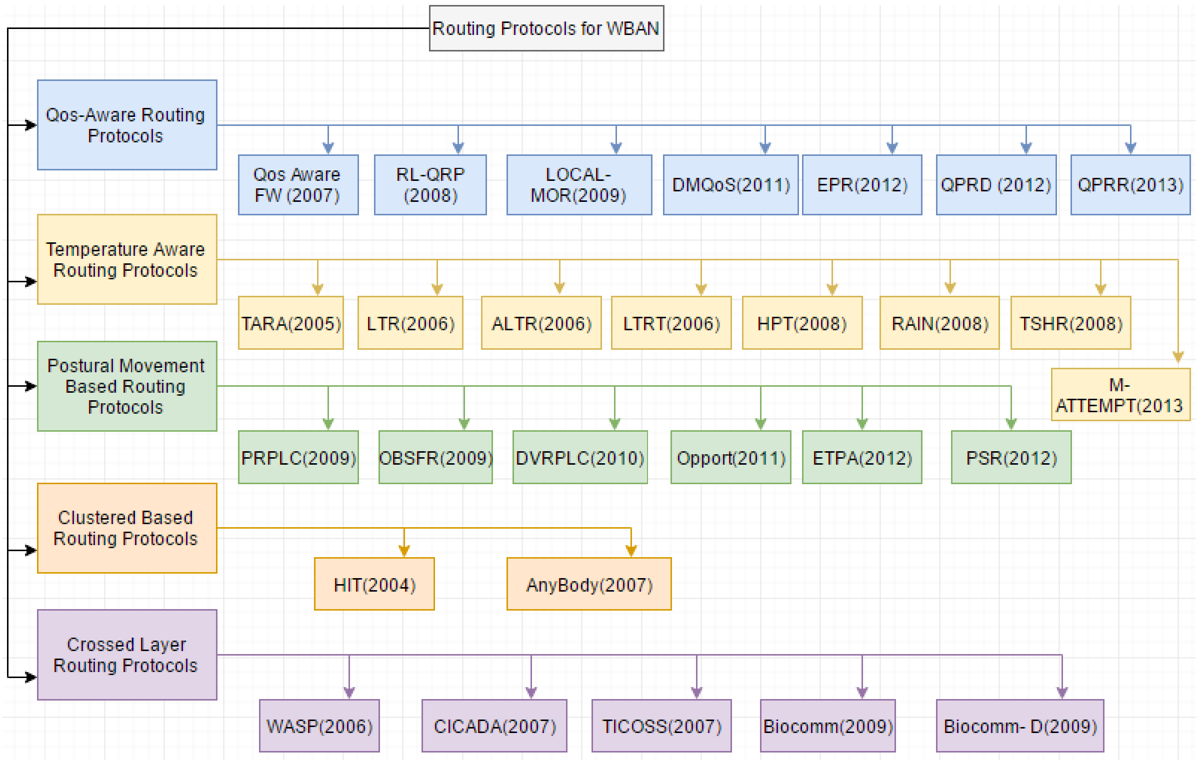

Figure 3: Routing Protocols for BAN [1]

QoS aware routing protocols use different types of modules according to QoS metrics. To design such type of protocol is a challenging task as the communication between QoS modules and the inter coordination for different modules for different QoS is required. On the other hand, cluster based routing schemes randomly selects a cluster head (CH) at a given fixed time interval. CH collects all the data and transmits it to the base station. Whereas, cross layer routing mechanism enhances the efficiency of communication and interaction between different protocols.

On the other hand, BAN topology suffers from several problems like partitioning. Postural Based Routing Protocols (PBRP) try to resolve the issues of interruptions which are caused by human body movements by using a cost function and packets are sent over the path which has minimum cost from source to a sink. Whereas, few researchers have tried to propose the solution of link disconnection by regularly updating the link cost, e.g., ENSA-BAN [2], measures different QoS parameters between the nodes. This protocol uses the minimum hop count and finds the link cost function for all the nodes and its purpose is to select the next node with minimum hop count for forwarding packets. Residual energy is taken into account in order to balance the energy consumption among sensor nodes.

1.2 Problem Statement

The idea of remote health monitoring has been revolutionized by a variety of applications developed on the basis of BANs due to its highly reliability, accuracy, and low power consumption. There are number of BAN applications which are utilized for patients of different requirements. Normally, physiological functions like respiration rate, electrocardiogram (ECG), blood sugar rate, constant blood pressure monitoring, heartbeat rate and temperature etc., are monitored, evaluated, and examined remotely by the use of specific sensors designed for all their pertinent uses and outputs. These sensors are responsible for the data collection for the above specific functions and report to a sink node through single hop or multi-hop communication.

One of the biggest challenge being faced recently is the shortest path selection to the sink node having the least cost path in terms of data packet losses, transmission time, and energy efficiency. To resolve this problem, a next hop selection algorithm is required which could satisfy the needs of various QoS parameters for healthcare applications. The second most important aspect is the consideration of body movements which implies that all these phenomena are to be handled assuming the movement of different body parts carrying the sensor nodes. Most important consideration for the majority of the routing algorithms is that they are not robust under body movements.

ENSA-BAN is one of the most recent next hop selection routing algorithm which evaluates the minimum number of hops and the associated link cost of the neighboring nodes to determine the best next hop node. ENSA-BAN provides good results for packet delivery ratio, energy efficiency, and end-to-end delay when the body movement is not considered. However, its performance degrades in terms of delivery ratio when body exhibits daily routine activities such as walking and running. Main contribution of this thesis is to propose a next hop selection algorithm which performs well and is robust under daily routine activities and is able to deliver more packets.

1.3 Thesis Organization

The thesis is organized as: Chapter 2 provides an overview of IEEE 802.15.4 and its applications. In Chapter 3, we discuss the related work. Chapter 4, presents the detailed design and operation of the proposed algorithm. Chapter 5, presents the simulation analysis of EPARA-BAN and compares with ENSA-BAN. Last chapter concludes this work and provides future directions.

Chapter 2

Overview of IEEE 802.15.4

2.1 Introduction

WPAN (Wireless Personal Area Network) based on 802.15.4 is a cost efficient, easy to implement communication network and provides a large application of wireless connectivity for high throughput requirements and limited power usage. Advantages of 802.15.4 WPAN covers power conservation, data transfer reliability, low cost of implementation, easy deployment and most importantly, practically realistic power usage.

IEEE 802.15.4 is a communication standard with the benefit of low power requirement for sensor nodes (in-body/on-body or around the body). It supports low data rates and low power consumption for many wireless applications. It is a packet based wireless communication protocol based on ZigBee design.

IEEE standard 802.15.4 intends to offer the fundamental lower network layers for WPAN. Basic framework for 802.15.4 is considered as a 10 meter communication range having a 250 kbits/s data transfer rate. Initially 20 and 40 kbits/s data transfer rates were defined and in current revision, 100 kbit/s data rate have been added [4].

2.2 IEEE 802.15.4 Protocol Architecture

Devices running on 802.15.4 protocol are inter-connected over a simple wireless network and have the capability to interact with each other. OSI model is used for network layer whereas the lower communication layers are mentioned in the standard only and are proposed for communication with upper layer. It can be implemented on the external wireless devices and it can also be deployed on self-functioning devices. IEEE 802.15.4 consists of two layers; the physical layer, and the MAC layer as illustrated in Figure 4 [4].

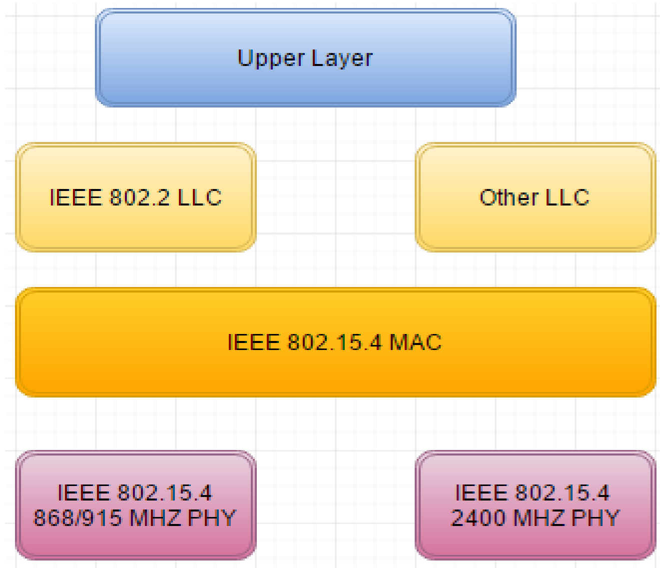

Figure 4: IEEE 802.15.4 Protocol Architecture [4]

2.2.1 Physical Layer

Physical Layer consists of the communication devices and hence the physical and electrical features of the network. The main function of the physical layer is to transmit and receive data from other devices, and to enable and disable radio transceivers. Physical layer is also responsible for link quality indication (LQI) for the received packets and within the current channel is also responsible for energy detection. It is also responsible for clear channel assessment [4].

2.2.2 Medium Access Control (MAC) Layer

MAC layer transmits MAC frames over the physical layer. It provides data services and interface management functions. One advantage of MAC layer is it controls the frame validation, and provides guaranteed time slots and also handles nodes association and disassociation requests [4].

2.3 Network Devices and Operating Modes

Network devices can be categorized as fully functional device and reduced functional device.

2.3.1 Full Functional Device (FFD)

FFD has the capabilities of routing and it can be configured as a BAN coordinator as well as a simple node. FFD can be used in a star topology as well as peer to peer network. In star topology, all the nodes communicate with the help of BAN coordinator and there is no compulsion whether it is FFDs or RFDs. In case of peer-to peer network, there should be one BAN coordinator. There are some FFDs which can communicate not only with the BAN coordinator but also with other FFDs and RFDs as well [4].

2.3.2 Reduced Function Device (RFD)

RFDs doesn't support routing capabilities. RFDs have to first communicate with the parent node to get network access. RFD node can be limited to only star topology. It cannot be deployed as a network coordinator and its implementation is very simple as compare to FFD. 802.15.4 can work on three network modes based on device types termed as BAN coordinator, coordinator and end device. FFD can support all operating modes of 802.15.4, whereas, RFDs doesn't support these modes.

2.4 Beacon and Non Beacon Enabled Operation

In IEEE 802.15.4 based protocol, periodic beacons from a coordinator is used to synchronize all nodes in the network to the coordinator. During the normal operation of IEEE 802.15.4 based networks, periodic beacons are not mandatory. Both beacon-enabled and non-beacon enabled modes of IEEE 802.15.4 based network are discussed below.

2.4.1 Beacon-Enabled

In beacon enabled mode, periodic beacon signals are broadcasted to all nodes in the network by the coordinator for synchronization. The information for the pending data to be sent to any node is also maintained by the beacon.

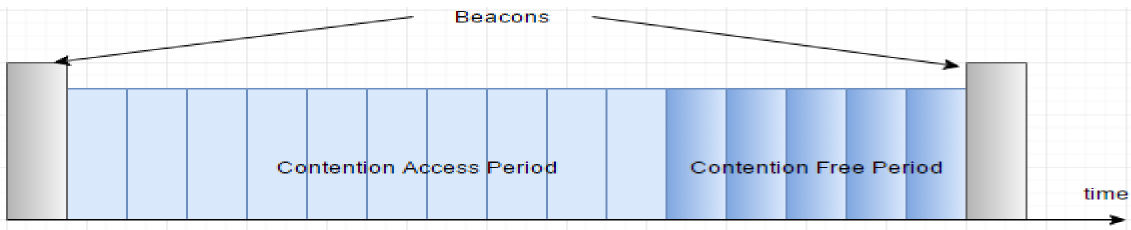

Figure 5: Beacon Enabled [4]

Frames are sent in one of slot of the total 16 slots in contention access period, and sensor nodes are connected through remaining slots of contention free period. Figure 5 illustrates the beacon-enabled mode.

2.4.2 NonBeacon-Enabled

In this mode, the coordinator doesn't send the beacons on regular intervals and it sends beacon to particular device only if some device sends an association request to the coordinator. This mode is based on asynchronous communication between the sensor node and the coordinator without any prior synchronization. Sensor nodes send any pending data to the coordinator by using polling [4].

Our main work in thesis is based on routing, however for the MAC layer we have used the non-beacon-enabled mode of operation to primarily focus energy conservation at the routing level.

2.5 Network Topologies and Routing

2.5.1 Network Topologies

Different types of network topologies can be used with 802.15.4. Some network topologies which can be used in 802.15.4 are discussed below.

2.5.1.1 Star Topology

In star topology, a central BAN coordinator is connected to other nodes of the network or end devices. These end devices have the capability to communicate and exchange data with BAN coordinator only. This implies that BAN coordinator is involved in all data transactions between source and destination. The function of a BAN coordinator is realized by its application program. Figure 6(a) shows a star topology [6].

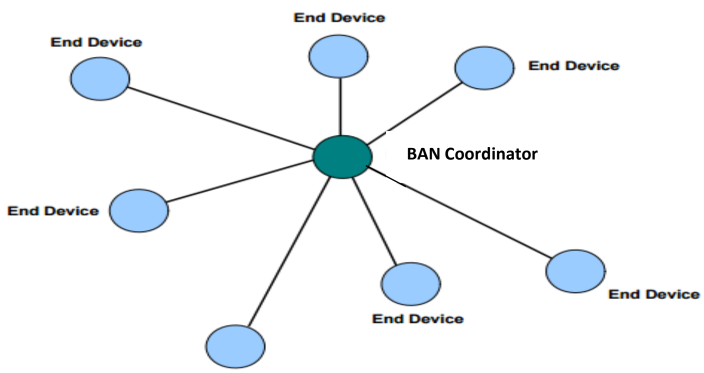

Figure 6(a): Star Topology [6]

This arrangement makes the BAN coordinator as a point of failure for data transmission. Apart from this, BAN coordinator has an additional disadvantage of congestion.

2.5.1.2 Tree Topology

The tree topology works on the principal of parent-child relationship where every network node may work as a parent except the BAN coordinator. All nodes including BAN coordinator can have more than one child nodes whereas each node has a constraint of exchanging data with its parent or child nodes. In tree topology, every parent node behaves like a local coordinator for its child nodes. Figure 6(b) illustrates the tree topology [6].

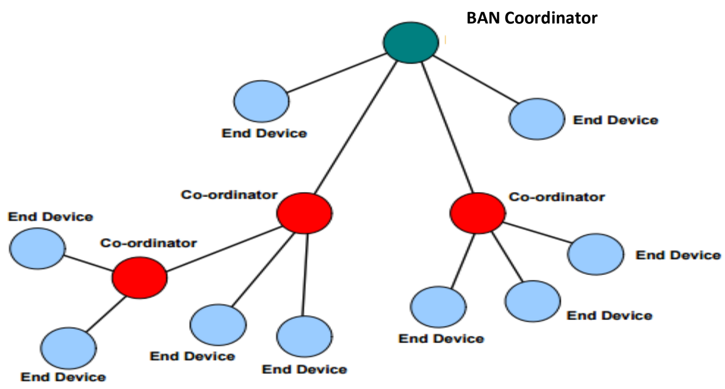

Figure 6(b): Tree Topology [6]

Cluster tree topology is a special case of certain parent-children nodes group defined as cluster where a specific cluster ID is assigned to each node in the cluster.

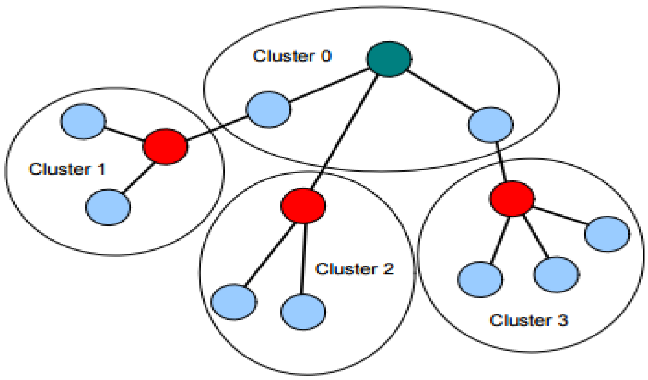

Figure 6(c): Cluster Tree Topology [6]

2.5.1.3 Mesh Topology

In mesh topology, identical network nodes are placed in an ad-hoc arrangement with no specific network structure whereas one node acts as a BAN coordinator. Some nodes in the mesh can directly communicate with each other while other nodes which are not directly connected can send the message to other nodes through directly connected nodes. In case of link failure between two nodes, alternate routes may be available in mesh topology for data transmission to destination node. Figure 6(d) illustrates the Mesh topology [6].

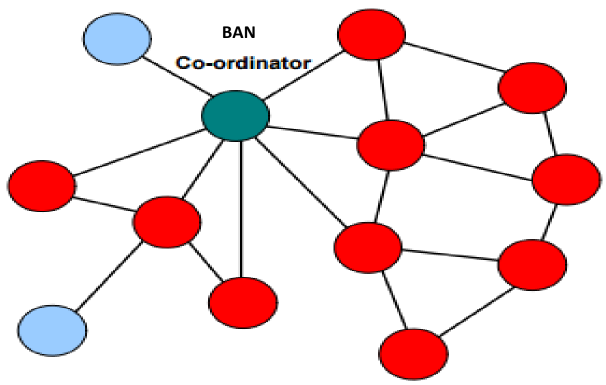

Figure 6(d): Mesh Topology [6]

Mesh topology is robust under link failures, therefore we have considered a mesh topology to evaluate the performance of our proposed next hop selection algorithm, i.e., EPARA-BAN.

2.5.2 Routing

Routing of messages from source node to destination node depends upon the network topology.

2.5.2.1 Star Topology Routing

In star topology, the central BAN coordinator is responsible for routing of all messages using the application program working in BAN coordinator [6].

2.5.2.2 Tree Topology Routing

The tree network structure is more efficient for message routing as the messages are not always directed through BAN coordinator. The message from the source node is sent to the parent of that node and if the destination node is the child of the same parent, the message will be sent directly to that child node by the parent. Otherwise, the message will be the sent to the next parent node in the tree. If the destination node is he child of this parent node, then it will be sent to the destination else, the message will be sent up the tree to next parent node. The propagation of message is carried out by this method. In the worst case, there is a possibility that the message is sent all the way up to BAN coordinator, and transferred down the tree to the destination node.

This routing mechanism is built upon the routing tables in BAN coordinator. The routing can also be achieved by addressing method using nodes position in tree having specific allocated addresses. Routing is realized through software layers (ZigBee software layers) above IEEE 802.15.4 protocol stack [6].

2.5.2.3 Routing in Mesh Topology

In a mesh network, some nodes have the capability to directly communicate but there exists no logical network structure for message routing. The available routing possibilities include the message to be broadcasted to all nodes but this is an inefficient practice. The more efficient method is of using routing tables stored in network nodes which are updated frequently with the data exchange between the nodes. The routing is realized through software layers (ZigBee software layers) above IEEE 802.15.4 protocol stack [6].

Chapter 3

Related Work

3.1 Introduction

In this chapter, we briefly describe the related work on routing protocols in BAN. The BAN are categorized into two different types on the basis of uses. First one is based on event detection which means the occurrence of some event will trigger the data transfer between nodes, e.g., a patient carrying the nodes falls. The second type is periodic event which means that at some periodic interval, nodes will send/receive data, e.g., node connected to patient's body is sending body temperature or blood pressure data after some fixed time interval. The most important aspect for any BAN communication standard is the balance of QoS during the normal operation.

BAN considers different factors which need to be evaluated for its deployment and execution like security, QoS, and routing. The main concern for the data transmission in a BAN is related with the data and information related to the patient's health which should be secure and secluded. There has been a good amount of research work conducted regarding the usage and applications of BAN [7–12]. There are five major routing approaches for BANs, known as cross layered, temperature aware, delay resistant, cluster based and QoS compliant routing [13, 14].Whereas, QoS is regarded as one of important consideration for routing due to sensors resource's scarcity and challenging requirements of QoS in the health care domain [5, 13, and 15].

ENSA-BAN [2], was proposed for multi-hop BANs and it supports basic QoS aspects like delay in packet delivery and reliability of link. This protocol uses the hop count and link cost for all the nodes and aim to select the next node with minimum hop count for forwarding the packets. Energy utilization between sensor nodes is maintained by considering the residual energy of nodes and the next hop node is selected by link cost function. Link reliability and energy consumption are two primary considerations of the QoS requirements. ENSA-BAN also partially meets the standards of energy utilization of the nodes.

QPRR (QoS-aware peering routing protocol for reliability-sensitive data) [16] selects the path according to the desired QoS output by evaluating all the paths which are available to some particular destination and choosing the most reliable path by QPRD [17]. It supports the real-time as well as non-real-time data carried in hospital. This protocol works by calculating the delay for each path and therefore selects an optimum path for the delay-sensitive packets.

DMQoS is Data-centric multi-objective QoS-aware routing protocol [18] and multi-objective lexicographic optimization (LO) method is used to determine the distance to the destination and the remaining energy and selecting the next hop node accordingly. In this technique, data packets are categorized in different types such as reliability driven packets (RP), critical packets (CP), ordinary packets (OP) and delay-driven packets (DP). All these kinds of packets are sent to the pertinent next hop nodes depending on the required QoS parameters.

EPR is Energy efficient peering routing protocol [19] and it supports peer routing for communication within indoor premises. This scheme consists of three parts; first is one is HELLO packet, second one is the construction of neighboring table, and third one is routing table based on the geographic and energy information in neighbor table. It calculates the communication cost of the node with its neighboring nodes, and store this information in the routing table. By using this technique, EPR reduces the traffic load and energy consumption while improving the delivery ratio.

RL-QRP [20] is a routing protocol based on reinforcement learning and supports QoS routing in biomedical sensor network. RL-QRP employs a mechanism to find the optimum and shortest path to the sink considering the QoS requirements. LOCALMOR considers the geographical aspects in routing and is derived from QoS routing protocol [21]. It was also developed for body sensor networks forming a BAN and categorizes the data packets in different types depending on their QoS requirements. LOCALMOR evaluates the QoS matrix on the basis of consistency, latency, and remaining energy of the sensor nodes. This process results in high overhead resulting in additional energy requirements.

RTRE [22], provides data reporting in real time and task execution. It is a novel framework and was devised to collect information through mobile actuators and sensors. This mechanism, using properties of sensors and actuators is more efficient and has less delays, conserves energy, and achieves accuracy.

All above mentioned protocols except DMQoS and EPR are the delay sensitive routing discovery protocols that need an extra amount of energy. However, DMQoS and EPR are the protocols different from the rest and have no direct requirement for the link reliability between the nodes. Furthermore, DMQoS requires specific hardware components for evaluating the geographical information of the nodes which results in additional energy consumption. So, the major challenge is the selection of a protocol which is QoS aware as well as energy-efficient in multi-hop BANs routing.

ETPA (Energy Efficient Thermal and Power Aware Routing) [23], is a routing protocol for evaluating the change in posture of a human body movement. This protocol is energy efficient and thermal aware. ETPA reduces the rise in temperature of devices and their energy usage while deploying the same network architecture used by PRPLC [24]. This routing scheme divides the framed into time slots using Time Division Multiple Access (TDMA). All nodes broadcast their HELLO message consisting of temperature and residual energy information, to neighboring nodes after every four frames in a cycle. Each node estimates the received power from its neighboring nodes. ETPA will calculate the cost function by evaluating temperature, remaining energy, and transmission power of the node. Packets will be transmitted based on the most efficient and cost effective route. Packets are buffered incase no efficient route is found but they are discarded if packets are buffered for more than two timeslots.

PRPLC (Probabilistic Routing) [24], a packet store and forward mechanism is used and it divides the postures into various partitions to improve the dynamic route selection and to reduce the end-to-end packet delivery delay. Its network architecture is mainly composed of seven basic biomedical sensor nodes having their positions as, two nodes each on the upper arms, ankles and one node deployed around the waist area, thus forming a mesh network topology. Sink node is deployed on the right ankle and collects data from other nodes and transmits it to some sink deployed outside the human body. The movement detection is evaluated by performing a set of predefined postural based postures. Link Likelihood Factor (LLF) is the changes observed on regular intervals in any link between two nodes exchanging data for a particular time. All the nodes have to send their updated LLF with neighboring nodes and the sink node by exchanging HELLO messages at regular intervals. Each node will first check its own LLF with the sink node and compares it with its neighbor's LLF toward the sink. If it's LLF is less than or equal to its neighbor's LLF, it will forward the packet to its neighbor. The packet is buffered, otherwise another appropriate next hop node is selected for packet transmission.

PSR uses Prediction for Secure and Reliable Routing [25], is a secure routing protocol which is based on distributed prediction and this protocol is compatible other protocol to enhance the overall security and reliability. In this protocol, a backbone link is established between two neighboring nodes placed on a fixed distance and this backbone link selects the nearest path to the sink node. This protocol uses less resources for source and data authentication for secure reason. PSR also deploys some techniques such as exhaustive source authentication attacks (for detecting false authentication requests), exhaustive data authentication attacks (for finding date packets with wrong attributes), and data replay attacks (detecting fake data packet attacks for security enhancement). PSR consists of two algorithms based on prediction: firstly, the algorithm for next hop selection and secondly, the algorithm for data transmission. The next hop selection algorithm features the link quality which has been stored with predefined time slots and stored in a matrix form and this matrix evaluates the best link quality in prediction based model. Whereas, the packets would be transmitted via backbone through shortest path in case of absence of prediction model. The second algorithm is data transmission algorithm where data authentication is used to identify the source. Source authentication is done by two methods. The identity based signature scheme discussed in [26] can be used to send the source authentication request by any node. The signature is check for each neighboring node and after that authentication is performed. In data authentication part, a valid authentication token is checked for all the received packets. And if the valid token is not present then source authentication is started. Each node starts source authentication for multiple times and uses maximum number of times is to avoid any transmission failure.

DVRPLC (DTN Routing with Dynamic Postural Partitioning) [27], firstly stores the data packets and then forwards them depending on posture and the function of this protocol is to select a route with highest possibility for the purpose of reducing the delays in end-to-end packet delivery. Link cost factor is the routing cost of link between two nodes in a discrete time slot and updates this dynamically after the mentioned time slot. With the help of Historical Connectivity Quality (HCQ), constant is calculated which were discussed in [28]. DVPRLC uses the same routing mechanism as deployed in PRPLC [24], with lowest cost to reduce the overall end-to-end link cost.

Opportunistic Routing [29], proposes an opportunistic routing protocol depending on body movements. This protocol uses a simple network model, where sensor node are placed on the chest. First it sense the data and after that they send it to the sink node and sink node is placed on the wrist and relay node is used for the interaction of the sink node and other network nodes. In case of human body movement of a normal walk, wrist moves back and forth resulting two kinds of communication; Line of sight (LoS) communication occurs while the wrist is positioned ahead of body and when the wrist moves toward the back side of body, there will be Non line of sight (NLoS) communication. The probability of both LoS and NLoS communication is equal. RTS (Request to Send) packet is transmitted by sensor node and if a CTS packet is received within a predefined time it indicates that sink node is in the LoS of the sensor node, and afterwards data packet is transmitted. On the other hand if no response received from RTS during predefined time interval, it means sink node is NLoS of the sensor node, it sends a wake up request toward relay node. If relay node is ready for receiving and transmitting data, it updates the sink and the sensor node to initiate data transfer. Once all the packets are received, the sink node transmits Receive Acknowledge (RAck) message to that sensor node. And the same steps are repeated if the sensor node doesn’t receive RAck packet.

OBSFR (On-Body Store and Flood Routing) [30], is a customized flooding protocol designed for partitioned networks. In this protocol, multiple copies of the packets are sent multiple times to a sink. In this protocol, network architecture is composed of seven sensor nodes distributed as: two nodes placed on upper arms, two sensor nodes on thighs, two nodes positioned at ankles and the last one node is fixed at the waist area. This makes a mesh topology which can be further divided into one or multiple real time network partitions or sections. In this formation, the sink is defined as the node placed on right ankle. The collection of data from all sensor nodes is responsibility of the sink node and further transmitting this date to some server installed outside body. In OBSFR, node ID is attached to every data packet which shows its path from the source node along with a unique identifier. After a data packet is received at any node, it is buffered at that node and the node triggers a search for the nodes having IDs which are not present in the received packet's IDs list. The packets are sent after finding one or more such nodes.

Based on the related work, which is discussed above, Table 1 and Table 2 shows a summary of different routing protocols for BANs and compares them in terms of network throughput, mobility, delay, overhead, and energy consumption.

Protocol	**Network Throughput**	**Mobility Support**	**Delay**	**Overhead**	**Energy Consumption**
ENSA-BAN[2]	Low	No	Low	High	Low
QPRR[16]	High	Yes	Very Low	Low	Low
RL-QRP[20]	High	Yes	High	Low	Low
LOCALMOR[21]	High	Yes	Low	Low	High
DMQoS[18]	High	Yes	Low	Low	Medium
QPRD[17]	High	Yes	Very Low	Low	Low
EPR[19]	High	Yes	Very Low	Low	Low

Table 1. QoS-aware Routing Protocols

After a detailed study of QoS aware routing protocols and their comparison of energy consumption, packet delivery ratio and end-to-end delay caused in data transmission, we conclude the following results:

QPRR [16], QPRD [17], and EPR [19] performs the better performance in terms of energy consumption as compared to all others protocols and all the protocols uses the same technique to reduce the energy consumption. On the other side, RL-QRP [20] does not consider the aspect power consumption. DMQoS has relatively better performance with reduced overall packet delivery delay and improved link reliability for large networks but it provides relatively low network throughput [17]. QPRD has better performance in terms of less delay incurred in packet delivery in case of small scale networks but provides high network throughput, and QPRR [16] provides improved data delivery reliability.

Protocol	**Network Throughput**	**Mobility**	**Delay**	**Overhead**	**Energy Consumption**
ETPA[23]	Very High	Yes	High	Low	Low
DVRPLC[27]	Medium	Yes	Medium	Medium	Low
OBSFR[30]	High	Yes	Low	Low	High
PSR[25]	Medium	Yes	High	Medium	High
PRPLC[24]	Medium	Yes	High	Medium	Low
Opportunistic[29]	Very Low	Yes	Very Low	High	Very Low

Table 2. Postural Movement based Routing Protocols

After a detailed study of PBRP and comparing them in terms of energy consumption, end-to-end delay in packet delivery and packet delivery ratio, we conclude the following results:

OBSFR [30] increases packet delivery ratio, decreases the average delay, and achieves high energy consumption and is useful for a network which have only few nodes because a list of IDs is made for each packet. PRPLC [24] performs better as compared to OBSFR considering the results of end-to-end delay and packet delivery ratio. DVRPLC [27] provides better performance as compared to PRPLC in terms of delay and PDR, it reduces the delay and enhance the PDR. On the other hand OBSFR [30] performs better as compared to DVRPLC protocol in terms of delay and PDR. ETPA [23] provides improved performance in terms of thermal awareness only. Routing protocol using opportunistic postural movement [29] technique, provides better energy conservation as compared to other routing protocols discussed above.

We have studied existing routing protocols which are designed for BANs and I have critically analyzed two classes of routing protocols QOS and Postural Movement routing Protocols. Different challenges are being considered in different categories but still lots of work needs to be done. The postural aware routing protocols don't not have the capability to cater the issues of temperature rise and are mostly data-centric in operations. Most of the QoS based routing protocols focus on the data related to the physiological aspect of patients but neglect the changes related to the posture changes during movement of patients. In particular, ENSA-BAN is for static BAN, however its performance is not known under postural movement in BAN.

Chapter 4

EPARA-BAN
Design and Operation

4.1 Introduction

In this chapter, we propose an efficient algorithm called EPARA-BAN to cater QoS requirements of real life monitoring of physiological parameters of a patient's health condition in BAN. The proposed algorithm is robust under human body movements focusing arms and legs movements. This is more practical approach toward the actual application of BAN as many health parameters may vary with the postural changes by the patient. This chapter gives the details of the design and operations of EPARA-BAN along with the network model and energy model used.

4.2 Network Model & Assumptions

In our protocol, there is one sink and multiple sensors nodes which form an intra-ban communication. Our proposed routing protocol is based multi-hop mesh topology. Each sensor node and the intermediate node can send the packets to its neighbouring node and this procedure follows until the packet reach to the destination, the sink node. All nodes are in active state and each node can compute its cost, residual energy and the free queue size, and can also compute neighbouring nodes cost as well. The basic notations, used for the proposed routing algorithm are mentioned in Table 3.

Symbols	**Description**
N	Number of sensors
$S = \{s_1, s_2, ..., s_N\}$	Set of sensors
s_i	i^{th} sensor, $1 \leq i \leq N$
$N_i = \{n_1, n_2, ..., n_k\}$	set of neighboring node s_i, $1 \leq k \leq N$
$E_{res, i}$	Remaining energy of the node s_i
$Q_{empty, i}$	free size of the node s_i
$HOP_{min, i}$	minimum hop count to the sink from sensor node s_i
$LinkR_{ij}$	link reliability for nodes s_i and s_j
$Cost_{ij}$	link cost for nodes s_i and s_j
TH	Set one threshold value
SS	Signal strength of the nodes
SN_i	selected set of N_i

NH_i	next hop node of N_i
NH_j	next hop node of N_j

Table 3: Symbols used for EPARA-BAN and their Description [2]

4.2.1 Neighbour Table

All the sensor nodes generate HELLO packets towards its neighboring nodes. The structure of HELLO packet is shown in Figure 7[2].

2 byte	1 byte	4 byte	1 byte	1 byte
Packet ID	Source ID	E_{res}	Q_{empty}	HOP_{min}

Figure 7: Structure of Hello Message [2]

Where Packet ID is the sequence of HELLO packet, source ID shows the ID of source/sensor node, remaining energy of the node is represented as Residual Energy (E_{res}) and it is computed by Equation 3, Q_{empty} is the available queue size and HOP_{min} is the minimum number of nodes on the path toward the sink node and it is calculated by Equation 1 [2].

$$HOP_{min,\,i} = \{minimum\ (HOP_{min,\,j}) \mid j \in N_i\} + 1 \qquad (1)$$

Where HOP_j shows the minimum number of hops for node s_j to send data to sink node. And the above Equation represents the minimum number of hops for the neighboring nodes as the hop count of node s_i to its neighboring nodes is 1.

After exchange of a HELLO packet, an entry of HELLO packet is added into its neighboring table and if the entry of the node is already present in neighboring table then neighboring table is updated accordingly to the new HELLO packet is received. The structure for the neighboring table is shown in Figure 8 [2].

1 byte	4 byte	4 byte	1 byte	1 byte	4 byte
Neigbor ID	$LinkR_{ij}$	E_{res}	Q_{empty}	HOP_{min}	$Cost_{ij}$

Figure 8: Structure of Neigbor Table [2]

NeighborID represents the ID of the neighboring node, $LinkR_{ij}$ shows the reliability of the link between two nodes and it is computed by Equation 2, E_{res}, HOP_{min}, and Q_{empty} fields are included in HELLO packet. $Cost_{ij}$ denotes the link cost of all the intermediate nodes and it is computed by Equation 7.

4.2.2 Link Reliability

Link reliability is one of the important factor as it effects the energy consumption and QoS requirement because if the link reliability is low then the ratio of transmitted power is high which results in higher energy consumption. EPARA-BAN computes link reliability between two nodes through exponentially weighted average using Equation 2 [2].

$$LinkR_{ij} = (1- \lambda)\, LinkR_{ij} + \lambda\, (Tx_{succ,ij} / Tx_{total,ij}) \qquad (2)$$

Where $\mathbf{Tx_{succ;ij}}$ is successfully transmitted packet count between s_i and s_j , $\mathbf{Tx_{total;ij}}$ represents the number of send and resend attempts of all the packets between s_i and s_j , and $\boldsymbol{\lambda}$ is the weighting average factor and value of $\boldsymbol{\lambda}$ is assumed as 0.4 in this simulation.

4.2.3 Energy Model

To balance the energy between two nodes, the concept of residual energy is deployed. Residual energy of node s_i ($E_{res,\, i}$) is computed by Equation 3 [2].

$$E_{res,\, i} = E_{init,\, i} - E_{con,\, i} \qquad (3)$$

Where $E_{init,\, i}$ is the initial energy of the node and Econ,i is computed by Equation 4.

$$E_{con,\, i} = A_i * E_{tx} + B_i * E_{rx} \qquad (4)$$

Where A_i and B_i is the number of bits transmitted and received and E_{tx} and E_{rx} is computed by Equation 5 and 6 [2].

$$E_{tx} = E_{txelec} + E_{amp} * d^2 \qquad (5)$$

$$E_{rx} = E_{rxelec} \qquad (6)$$

Where E_{txelec} and E_{rxelec} is the energy used by the radio device for the transmitting and receiving data respectively. E_{amp} represents the energy consumed for the transmitted signal amplification, and d is the distance between the nodes s_i and s_j. Table 4 shows the parameters which are used by the energy model in the proposed protocol.

Parameters	**Values**
$E_{init,i}$	2 Joules
E_{txelec}	16.7 nJ/bit
$E_{amp\ (3.38)}$	1.97 nJ/bit
E_{rxelec}	7.99 nJ/bit

Table 4: Parameters for Energy Model [2]

4.2.4 Link Cost

Link cost is used for each node to find the next hop node and link cost function which includes the residual energy of node s_j, free queue size, and link reliability between nodes s_i and s_j. $Cost_{ij}$ is computed by Equation 7[2].

$$Cost_{ij} = C_E * (E_{res,\ i} / E_{init,\ i}) + C_Q * (Q_{empty,\ j} / Q_{total,\ j}) + C_L * LinkR_{ij} \qquad (7)$$

C_E, C_Q and C_E are three constant co-efficient.

QoS requirement in the link cost function are met by using three factors i.e., residual energy factor, Queue size is the second factor because queuing delay plays an important role in end-to-end delay and link reliability shows the reliability of the network. Link cost function for node s_i is calculated by Equation 8 [2].

$$Max\ (Cost_{ij}),\ j \in SN_i \qquad (8)$$

Where N_i is the neighbouring list of node s_i, $HOP_{min,j}$ is the minimum hop count between s_j and the sink node and SN_i is the selected set of neighboring nodes of N_i .

4.2.5 Signal Strength (SS)

SS function is used to check the signal strength of all nodes and compared with a predefined algorithm and threshold value and select the next hop node accordingly. The proposed SS is computed by Equation 9 [31].

$$SS = P_t * G_r * G_t * (1 / (4 * p * d))^2 \quad (9)$$

Where G_t is the transmitter antenna gain , G_r represents the receiver antenna gain, and P_t is the transmit power and, distance is computed by Equation 10 [31].

$$d = (X_2 - X_1)^2 + (Y_2 - Y_1)^2 \quad (10)$$

4.3 Operation of the EPARA-BAN

EPARA-BAN is based on two algorithms. Algorithm 1 is designed for the calculation of signal strength and Algorithm 2 selects the next hop with minimum cost.

Algorithm 1 firstly computes the signal strength of all the nodes and after that it compares the SS value with the predefined threshold value (TH) and if the value of SS is less than TH, it sets the Flag as ‘true’ and call Algorithm 2 otherwise it simply calls Algorithm2 with Flag as a ‘false’ value.

4.3.1 Algorithm 1: Signal Strength Computation

Input: N_i, Flag

Output: NH_i , NH_i

1: Flag ← False

2: TH ← TH_{min}

3: While (the list of neighboring nodes is not equal to empty)

4: Calculate signal strength (SS) of all the neighboring nodes

5: if SS < TH then

6: Flag ← True

7: Call Algorithm 2

8: Else

9: Call Algorithm 2

10: End if

11: End While

In this algorithm, threshold value is initialized as a predefined value (for our experiments it is set to 270 nW) and after that algorithm calculates the signal strength of the neighboring nodes until the neighboring list is empty. Algorithm 1 evaluates the signal strength against the predefined threshold value and if the value of signal strength is less than the predefined threshold value then it set the Flag as True and Algorithm 2 is called and if value of the signal strength is greater than or equal to the predefined threshold value then it simply call Algorithm 2. Flowchart for Algorithm 1 is shown in Figure 9.

4.3.2 Algorithm 2: Next hop Selection Algorithm (EPARA-BAN)

Input: N_i, Hop_{min}, Flag, $SN_{i,}$

Output: NH_i , NH_i

for (each node in the list of N_i) do

    Calculate $Cost_{ij}$ $j \in N_i$

end for

$j \leftarrow$ first element in the list of N_i

while (list of N_i is not empty) do

    if ($Hop_{min,j}$ +1 == $Hop_{min,i}$) then

        $SN_i \leftarrow j$

    end if

    $j \leftarrow$ next element of the list of N_i

end while

Sort the list of SN_i in descending order in form of $Cost_{ij}$

if Flag $\leftarrow$ False

    $NH_i \leftarrow$ First element of the list of SN_i

Else

    $NH_j \leftarrow$ First two elements of the list of SN_i

end if

In the first loop of Algorithm2, first it computes the link cost of all the intermediate nodes and then it calculates the smallest hop count to the sink node and store it for the selected neighboring node (SN_i). Hop_{min} is calculated by HELLO packets. After sorting the neighboring nodes SN_i according to the Cost, Algorithm2 selects one or two next hop nodes according to Flag set by Algorithm1. EPARA-BAN algorithm satisfies the QoS requirement as it computes the link cost of all neighboring nodes and the number of minimum hops for selecting one or two relay nodes according to the body movements. Flow chart for Algorithm2 is shown in Figure 10.

4.3 Flow Charts for EPARA-BAN

4.3.1 Algorithm 1 : Signal Strength Computation

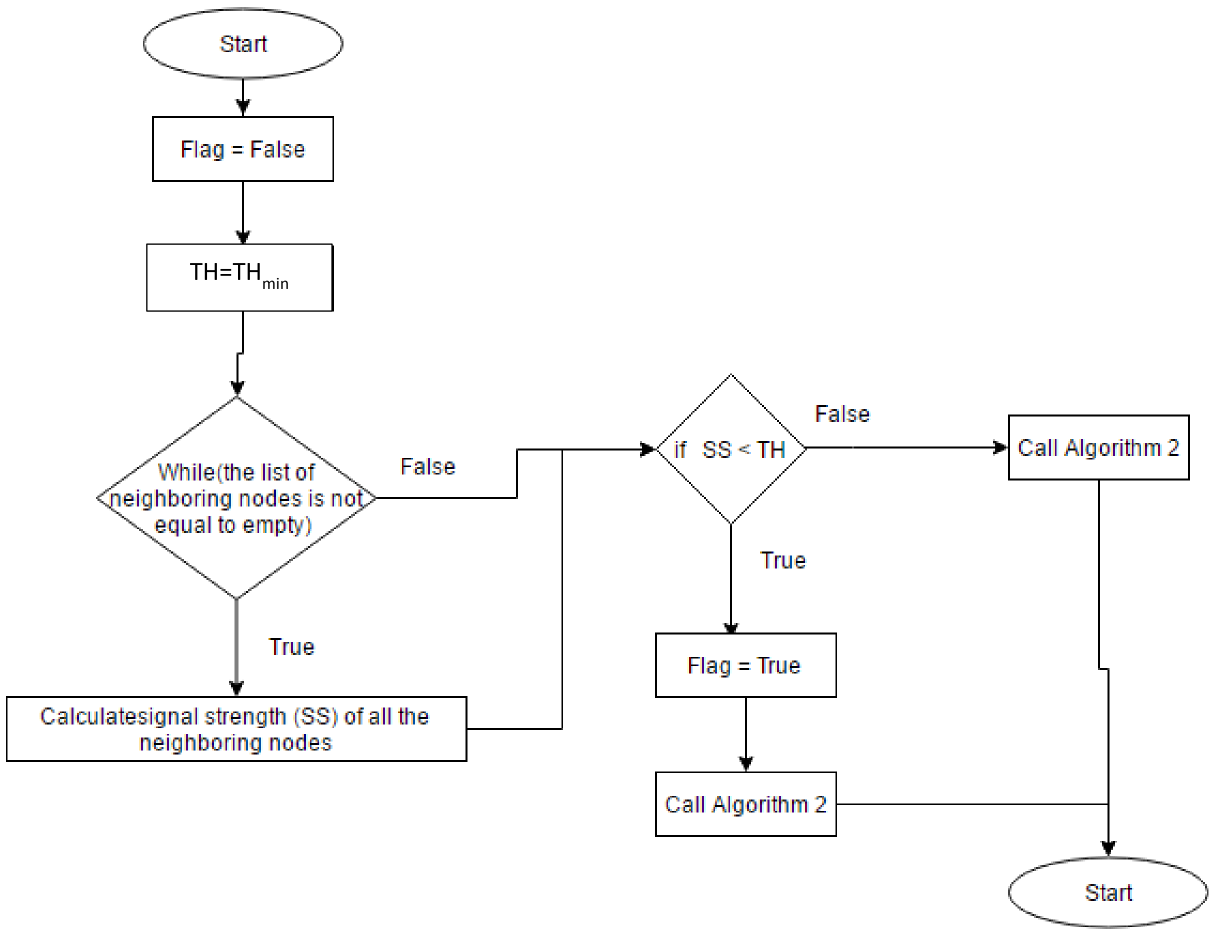

Figure 9: Signal Strength Computation

4.3.2 Algorithm 2: Next hop Selection Algorithm (EPARA-BAN)

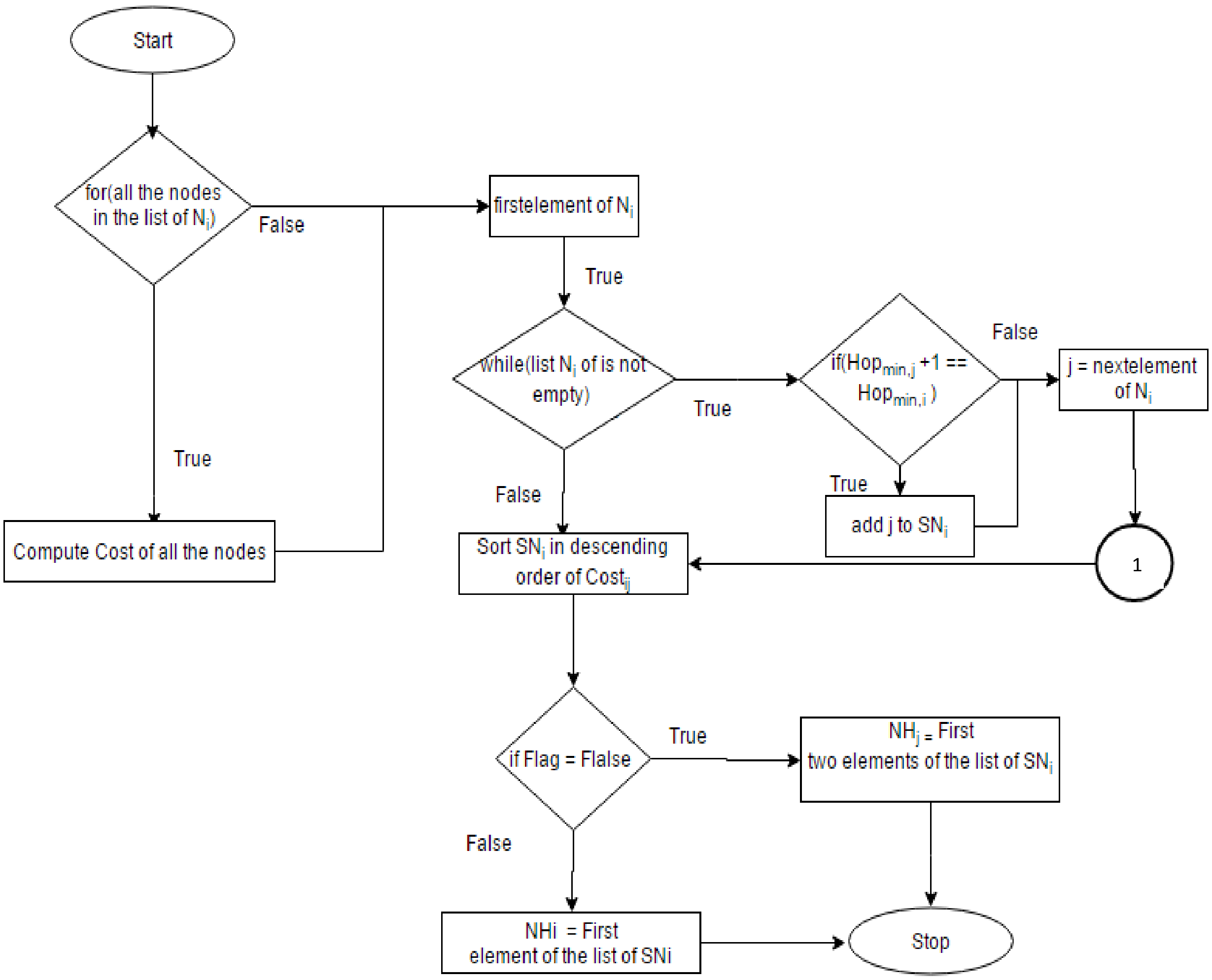

Figure 10: Next hop Selection Algorithm (EPARA-BAN)

Chapter 5

Results and Analysis

5.1 Introduction

In this chapter, detailed simulation analysis and performance evaluation for EPARA-BAN is discussed and compared with ENSA-BAN. EPARA-BAN is introduced to cope with the postural change due to movement of human body. The application of this protocol is conceptualized on the body of a patient having the BAN based sensor nodes installed at various positions and all of these sensor nodes transmit data according to some particular physiological aspect of a patient to a centralized node called sink.

There are two experiments performed with two different locations of the sink node, i.e., sink node installed on the waist of a patient, and a sink node deployed on an ankle. All the performance metrics are evaluated separately for these sink node positions.

5.2 Performance Metrics

Performance of EPARA-BAN is evaluated by a set of performance parameters by using simulation in Network Simulator 2 (NS-2). The below mentioned performance metrics are used to judge the performance of proposed postural change based protocol and the same set of metrics are used for the results of ENSA-BAN.

5.2.1 Energy Consumption

Energy consumption of the sensor nodes deployed in any BAN is one of the most important parameters to be considered in the development and implementation of any BAN as the sensors are to be installed on the body or carried with in the body. These sensors are responsible for transmission of important information related to the health condition of the individual. A high power consumption could result in higher drainage of the batteries in the sensors and eventually may cause some disaster.

5.2.2 Packets Forwarded

The total number of the data packets forwarded by the intermediate nodes between the transmitting sensor node and the sink is measured by this metric. If the number of the intermediate nodes is increased, it will cause higher energy requirement and will also increase the overall delay for the data transmission from source node to sink node.

5.2.3 End-to-End Delay

Average latency suffered by a packet during transmission from sensor node to sink node is measured by this metric. This metric is one of the most important QoS parameters to be taken care of, in any BAN especially in case of applications like remotely held surgical operations. End-to-end delay is calculated by adding all the incurred delays in transmission and consists of delays of data queuing, data processing delay, transmission delay and propagation delay.

5.2.4 Packet Delivery Ratio (PDR)

PDR is the percentage of the total number of received packets at a sink node to the total numbers of the packets transmitted by all source nodes to that sink. This metric shows the link reliability in case of higher percentage of packet delivery ratio which depicts overall better QoS. The importance of this parameter in BAN can easily be understood by the fact that any vital information regarding the health condition of a patient carrying BAN could be missed out and in turn could case hazardous results.

5.3 Simulation Network Topology

We have simulate and compare the performance of EPARA-BAN using ns-2. Network topology design is shown in Figure 11 which shows the number of sensor nodes deployed at various positions in a patient's body. The network used in simulation analysis is mesh topology based BAN, in which all the nodes are connected with each other. We follow the IEEE 802.15.4 standard for physical and MAC layer specifications. ZigBee routing is modified to EPARA-BAN and ENSA-BAN over the IEEE 802.15.4 protocol stack [6].

Figure 11 shows that 13 sensors nodes were deployed at different body positions with one sink node deployed on two body positions, i.e., sink node attached to the waist of the patient and the sink node attached at the ankle of the patient. Two set of simulation parameters were used at both of these locations of sink node.

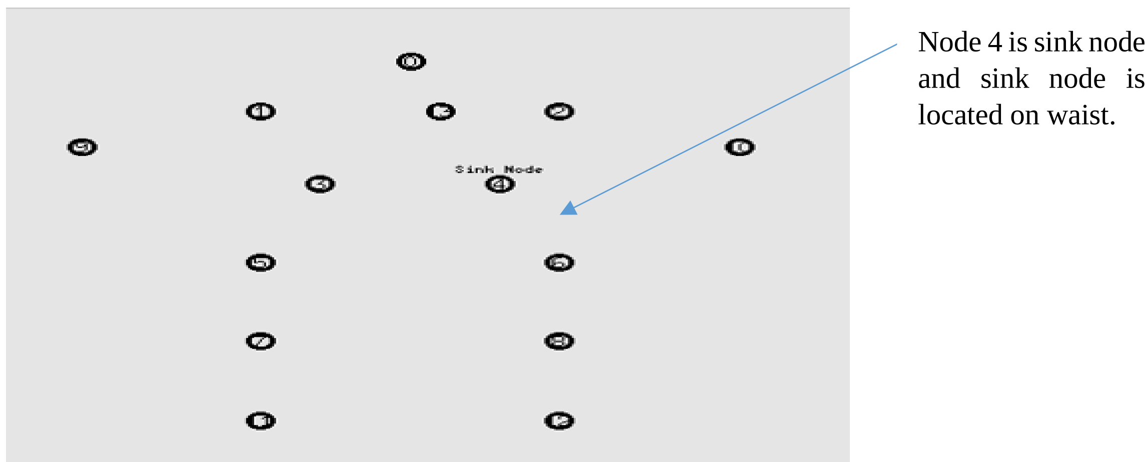

Figure 11: Simulation Network Topology

When the simulation is run, initially connectivity of different nodes is established as shown in Figure 12. Which shows that each node is connected with other neighboring node, i.e, Node 1 is connected with Node 3, Node 3 is connected with Node 4 , Node 4 is connected with Node 6, Node 13 is connected with Node 4, and so on. Figure 12 depicts the position of sink node at patient's waist.

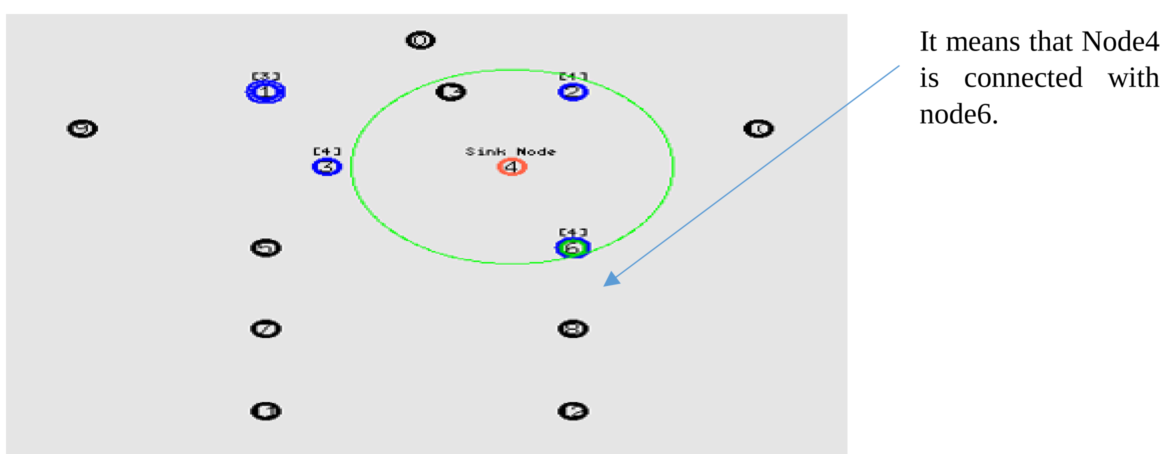

Figure 12: Connectivity between Nodes

Figure 13 depicts the postural change for the sensor nodes in the same scenario. As we discussed in section 5.4 , postural changes are based on arms and legs movements for the evaluation of both EPARA-BAN and ENSA-BAN. Figure 13 shows an arm based postural change.

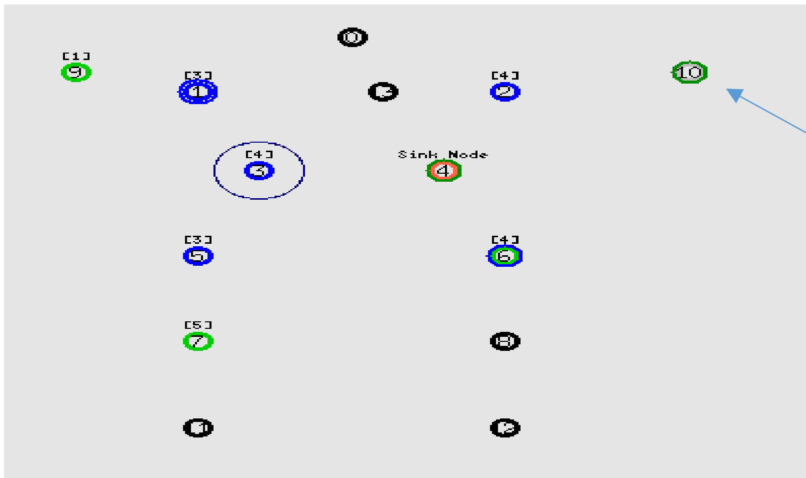

Figure 13: Arm based Postural Change

5.4 Experiment Results

Two experiments are conducted to evaluate the effectiveness of EPARA-BAN which takes into account the postural change of human body and the comparison is done with ENSA-BAN. We evaluate the performance of EPARA-BAN with ENSA-BAN by considering the performance metrics discussed in section 5.2. In the case first experiment, the sink node is assumed on the waist of a patient and in the second experiment, sink node position is on the ankle. Both experiments are simulated in the same scenarios. EPARA-BAN performs well under postural change due to body movements in a BAN, compared to ENSA-BAN.

5.4.1 Network Model and Simulation Parameters

Figure 14, shows the network model of EPARA-BAN. Network model consists of thirteen sensor nodes and one sink node. Number of sensor nodes were deployed at various positions in a patient's body. Two experiments are executed rigorously to judge the performance of EPARA-BAN. In experiment 1, the sink node is positioned at the waist of patient as shown in Figure 14(b) and experiment 2 assumes the sink node positioned at the ankle of patient as shown in Figure 14(a).

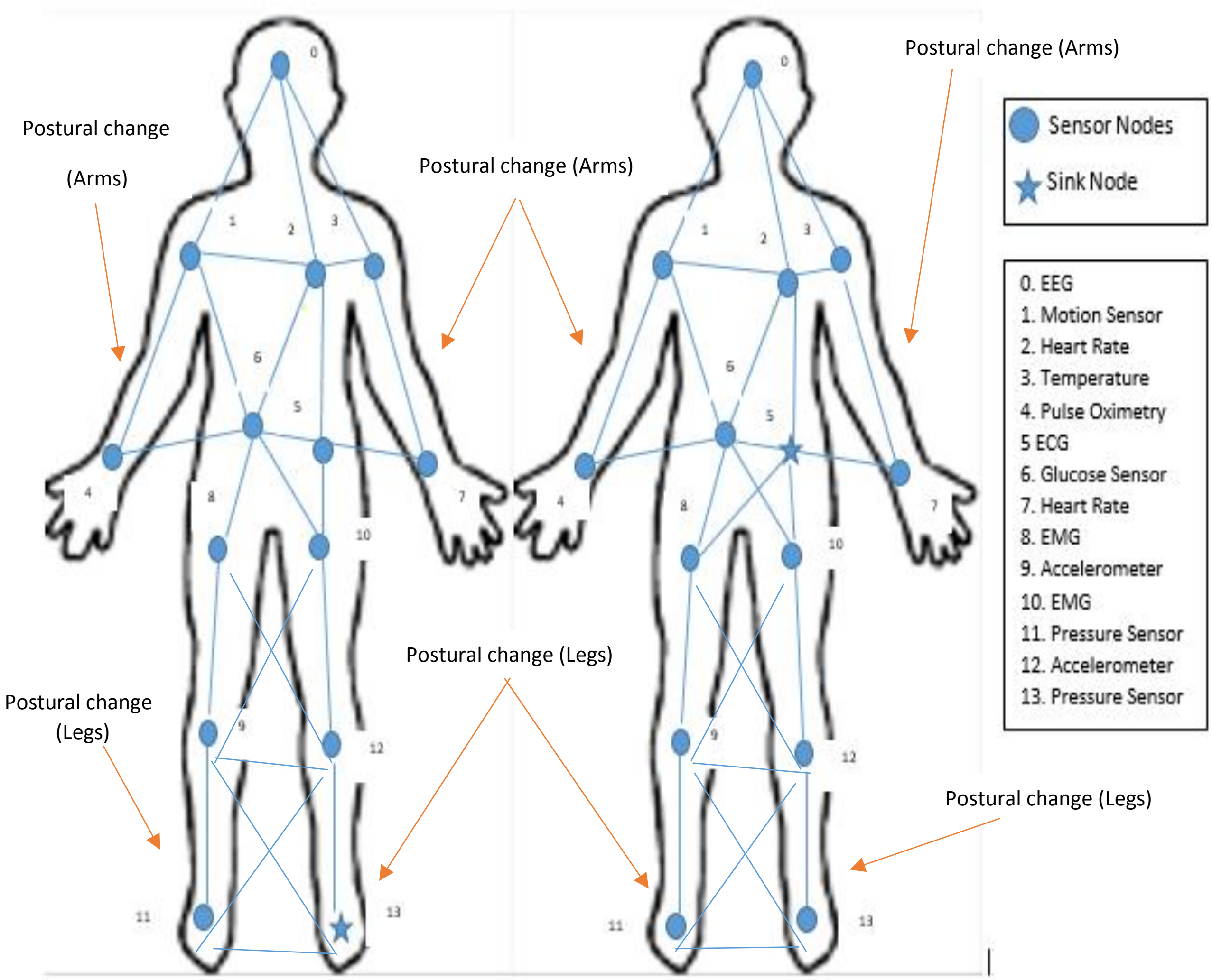

Figure 14 (a) Sink Node at Patient's Ankle (b) Sink Node at Patient's Waist

Two set of simulation parameters are used for both of these locations of sink node. Both the simulation experiments were run for more than 50 times and results show an overall average of all the runs.. Nodes interact with each other over a coverage range of 70cm, maximum data transmission rate is 250Kbps, the frequency band is 2.4GHZ, propagation loss is set to 2dB and **λ** is 0.4. All other simulation parameters which are used for the two experiments are shown in Table 5.

Parameters	**Values**
Traffic Type	CBR
No of Nodes	14
Postural Change	Yes
Threshold value (TH_{min})	270nW
Queue Length	50
Packet Size	32 Bytes
Initial Node Energy, $E_{init, i}$	2 Joules
Simulation Time	200 sec
Transmission Power	0.3 mW
C_E, C_Q and C_L	3,2,3
MAC Protocol	IEEE 802.15.4

Table 5: Simulation Parameters

5.4.2 Experiment 1 Results: Sink Node positioned on Patient's Waist

5.4.2.1 Energy Consumption

Figure 15 shows the energy consumption of the sensor nodes in EPARA-BAN with postural change of the human body. In EPARA-BAN, we have two relay nodes and we can see in the results that the energy consumption of EPARA-BAN is slightly more compared to ENSA-BAN. Figure 15 shows that EPARA-BAN is less energy efficient as compared to ENSA-BAN with an increase in number of interconnected sensor nodes which means the energy requirement for the sensor nodes in a body tends to increase in case of postural change as two relays forward the packets.

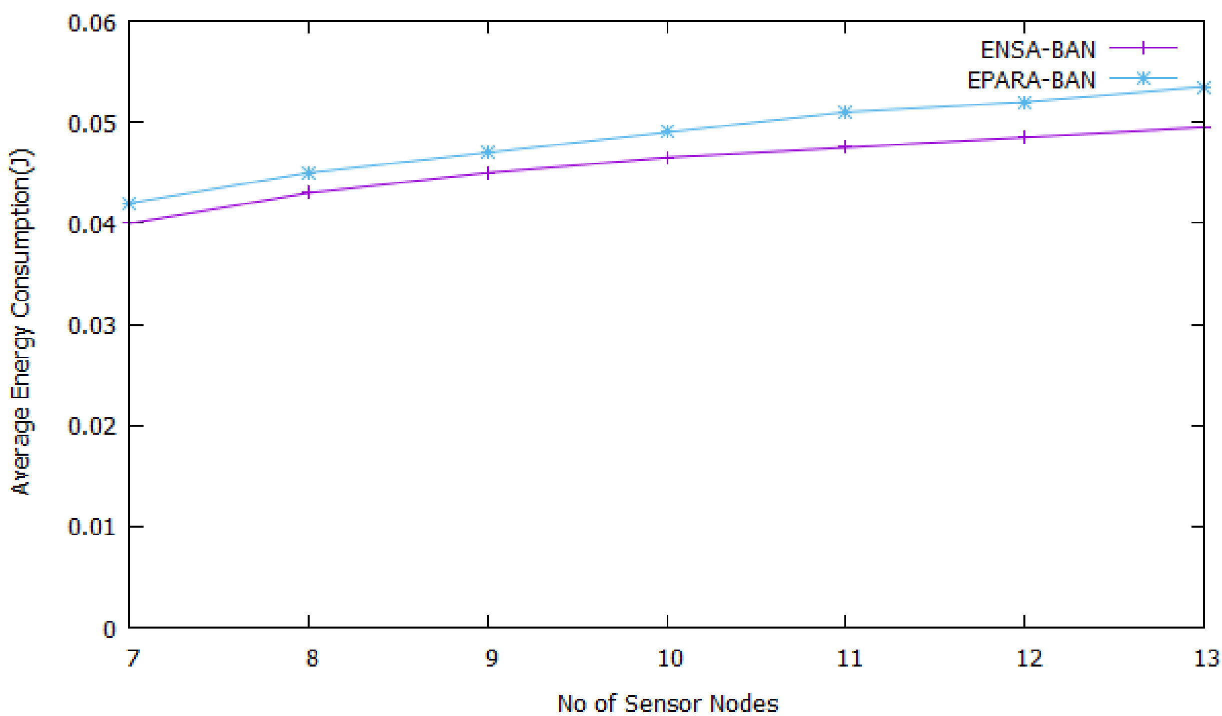

Figure 15: Energy Consumption at Patient's Waist

5.4.2.2 Forwarded Packets

Figure 16 shows the forwarded packets by neighbouring nodes using EPARA-BAN and compares with the packets forwarded by the neighbouring nodes using ENSA-BAN during end-to-end packet transmission between source node and sink node.

The performance of EPARA-BAN is better as compared to ENSA-BAN due to its two relay nodes as compared to ENSA-BAN with only one relay node. EPARA-BAN forwards more packets as compared to ENSA-BAN due to its robustness under postural change. If one relay node is not able to forward the packet, then that packet is forwarded by the second relay node, however in case of ENSA-BAN packets are forwarded by one relay node resulting in reduced performance in terms of less forwarded packets.

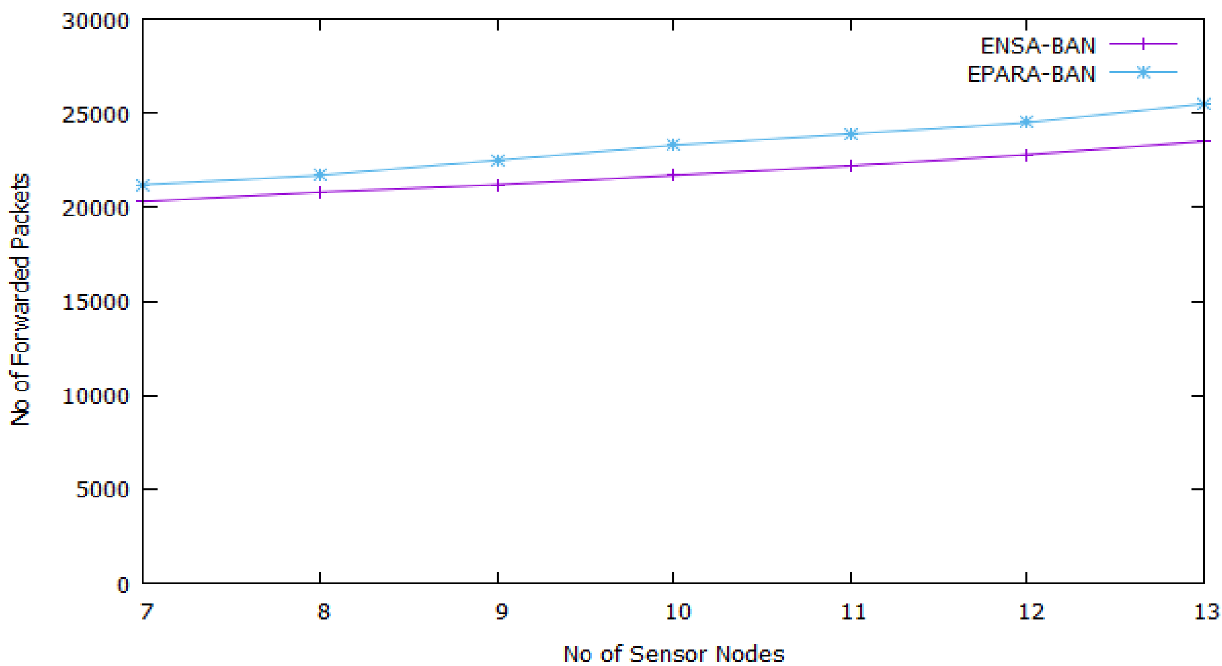

Figure 16: Packets Forwarded at Patient's Waist

5.4.2.3 End-to-End Delay

In the graph shown in Fig. 17, average end-to-end delay indicates latency in packets delivery from source node to the sink node. Figure 17 shows that average latency of EPARA-BAN is higher as compared to ENSA-BAN. As this metric considers all the incurred delays in packet delivery, so it is one of the most important QoS factor in calculation of link cost.

EPARA-BAN has higher delay as compared to ENSA-BAN because of two relay nodes being deployed and packets forwarded by two relay nodes, end-to-end delay is higher as compared to ENSA-BAN. We can see in Figure 17, difference of delay for both the protocols is not that significant and the fact is that each sensor node is connected to multiple nodes and all the nodes are connected to the sink node through multiple hops. Figure 17 depicts that delay is high but the strength of EPARA-BAN is that it forwards more packets under postural aware BAN.

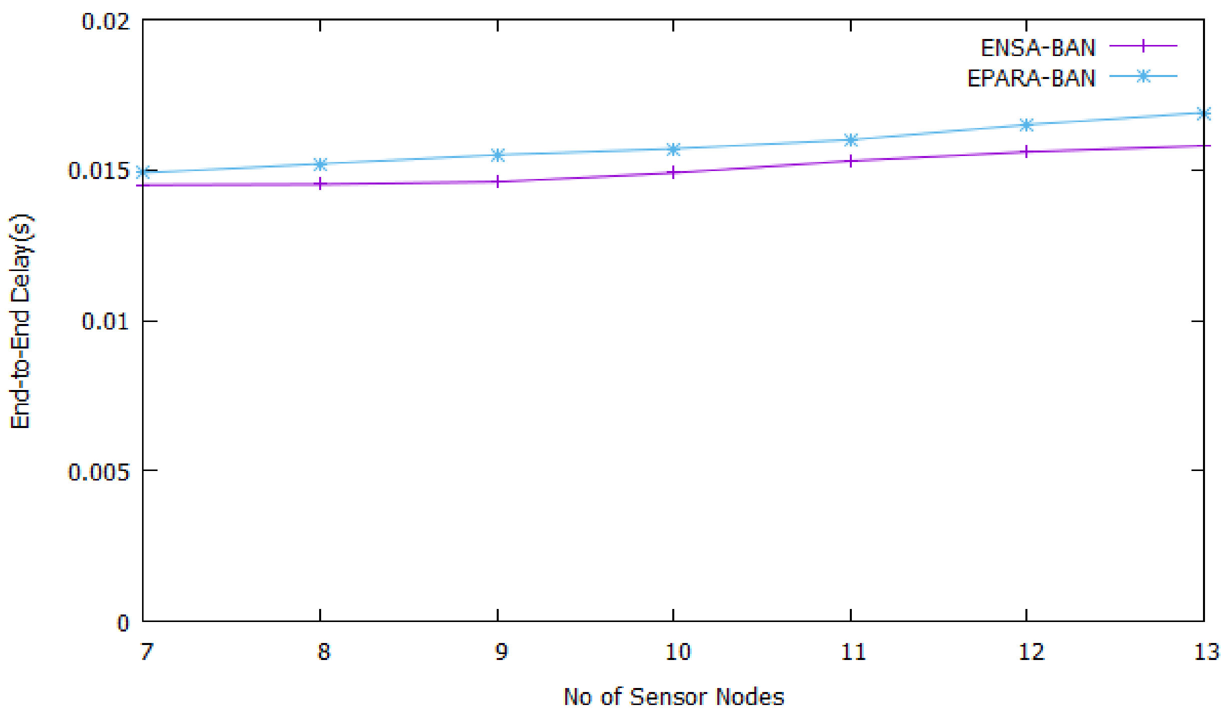

Figure 17: End-to-end Delay at Patient's Waist

5.4.2.4 Packet Delivery Ratio (PDR)

Figure 18 shows the packet delivery ratio in percentile form which represents the ratio of the total packets received at sink to the total packets transmitted by all nodes in a BAN. Figure 18 shows that PDR of EPARA-BAN is better as compared to ENSA-BAN. EPARA-BAN shows better result because it uses two relay nodes and forwarded packets are more as shown in Figure16. If one relay node is not able to forward the packet, then that packet is forwarded by the second relay node, however in case of ENSA-BAN packets are forwarded by one relay node effecting its performance in terms of PDR.

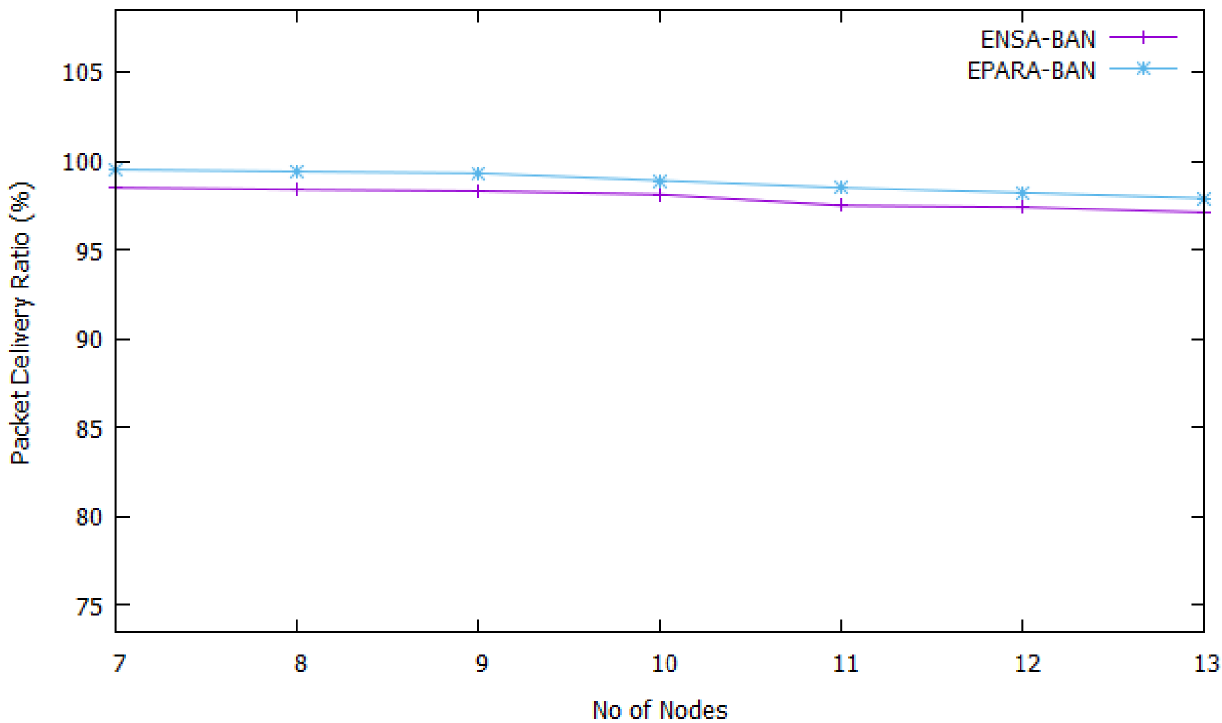

Figure 18: PDR at Patient's Waist

5.4.3 Experiment 2 Results: Sink Node Positioned on Patient's Ankle

5.4.3.1 Energy Consumption

Figure 19 shows and compare the energy consumption of sensor nodes in EPARA-BAN with ENSA-BAN. When the sink node is positioned on the ankle, energy consumption for EPARA-BAN is higher as compare to ENSA-BAN due to relay node selection process and energy is consumed at two relay nodes in this process. Figure 19 shows that EPARA-BAN protocol is less energy efficient as compared to ENSA-BAN and the energy requirement for the sensor nodes in a body tends to increase with movement.

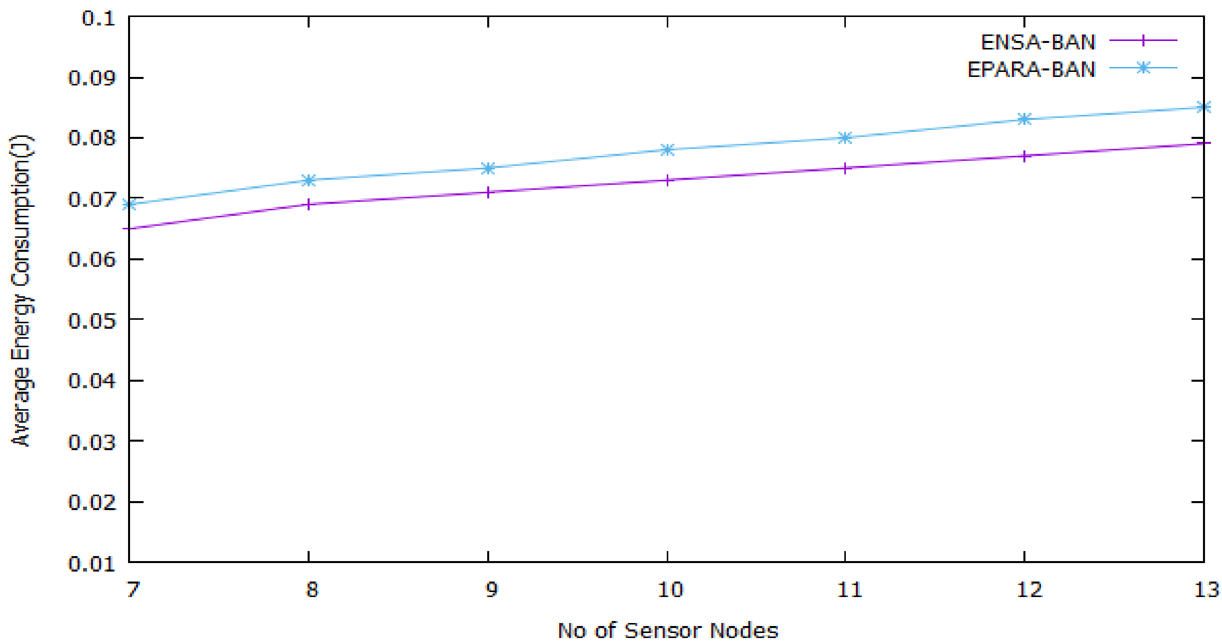

Figure 19: Energy Consumption at Patient's Ankle

5.4.3.2 Forwarded Packets

Figure 20 shows the forwarded packets by neighbouring nodes using EPARA-BAN against the same metric for ENSA-BAN. The trend in this experiment is also the same as it was found in experiment 1 (5.4.2.2). The reason for this change is also the same, i.e., two relay nodes used in EPARA-BAN increases number of forward packets.

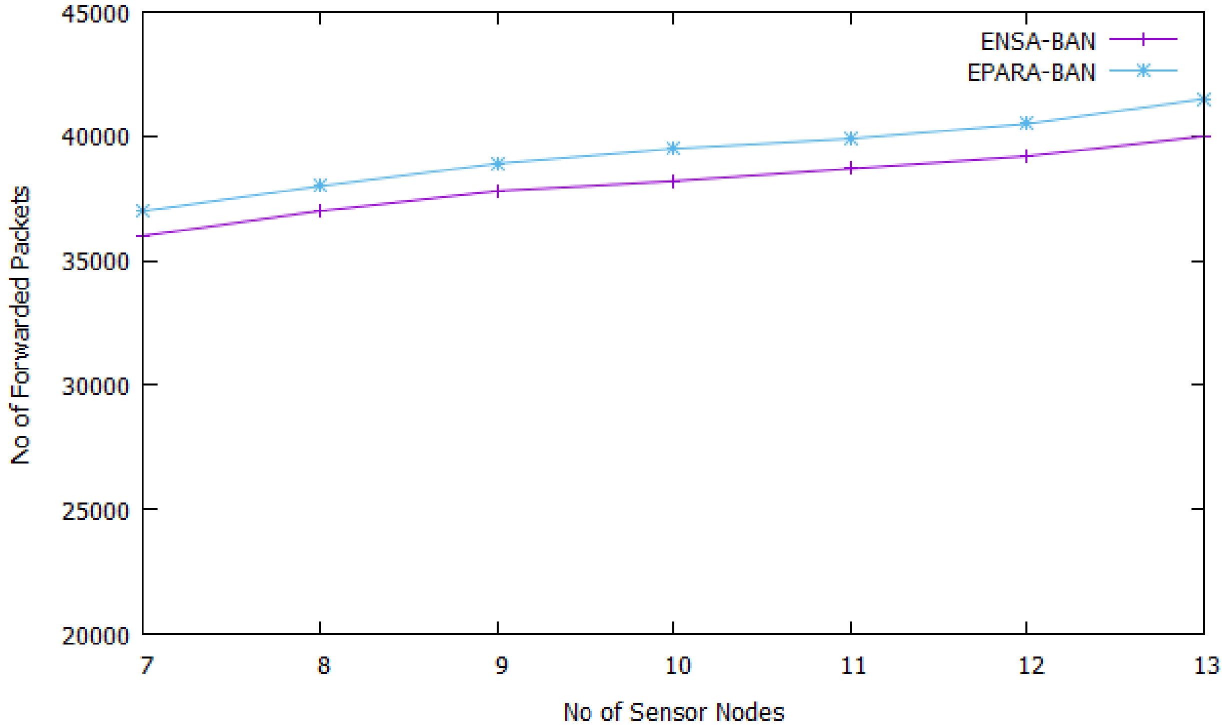

Figure 20: Packets Forwarded at Patient's Ankle

5.4.3.3 End-to-end Delay

The comparison of the end-to-end delay in packet delivery from source to the sink node in case of EPARA-BAN and ENSA-BAN is shown in Figure 21. It is found that average latency of EPARA-BAN is higher as compared to ENSA-BAN. The plot for End-to-end delay in experiment 2 is similar to the one in experiment 1 and the connotation for the increase in delay for packet delivery for EPARA-BAN is also the same as discussed in 5.4.2.3.

However, in Figure 21 (end-to-end delay in experiment 2) shows high delay as compare to Figure 17 (end-to-end delay in experiment 1). This change is because the sink node is located at the edge of mesh topology of the nodes in experiment 2 whereas it is located in the centre of mesh in experiment 1.

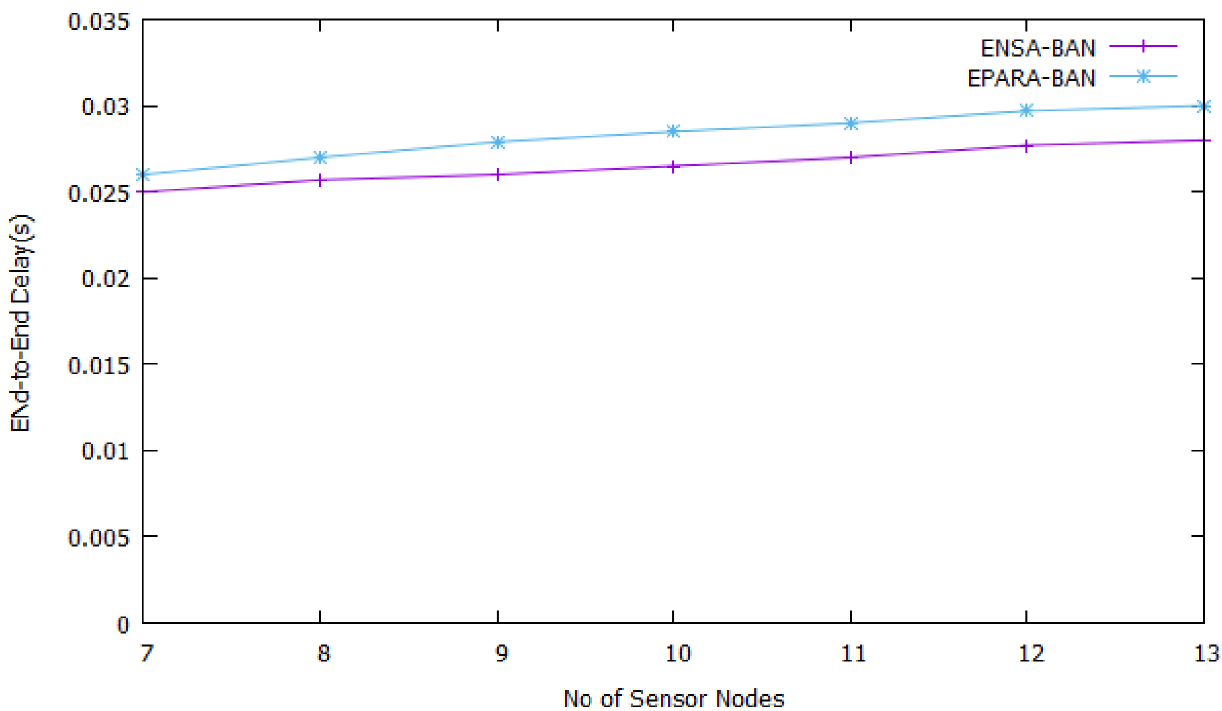

Figure 21: End-to-end Delay at Patient's Ankle

5.4.3.4 Packet Delivery Ratio (PDR)

Figure 22 shows that average packet delivery ratio for EPARA-BAN is better as compared to ENSA-BAN in experiment 2. EPARA-BAN shows better result because its uses two relay nodes and forwards more packets and achieve better delivery ratio due to the redundancy of the packet delivery route.

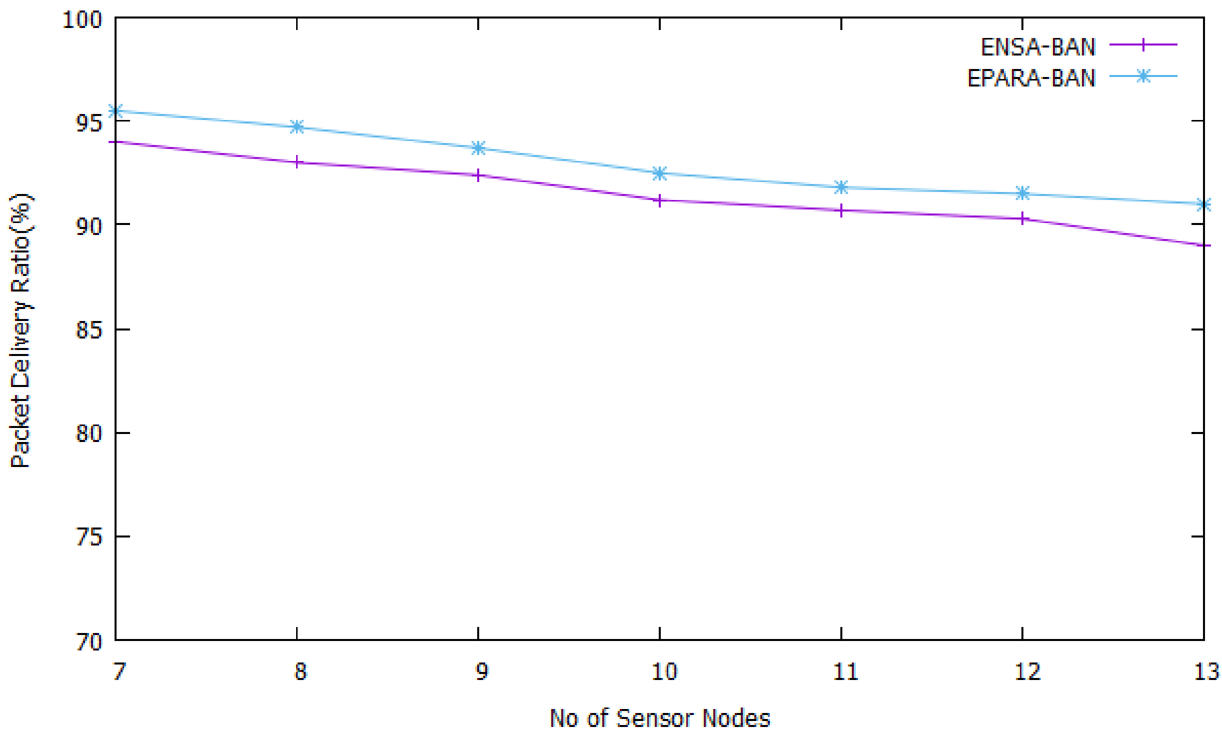

Figure 22: PDR at Patient's Ankle

Chapter 6

Conclusion and Future Work

6.1 Conclusion

This work presents a next hop selection algorithm which is robust under body movements. The results for ENSA-BAN are taken under same simulation environment. The changes in the results are basically due to robustness of EPARA-BAN under body movements. The applications of ENSA-BAN in BANs deployed in health care scenario is limited as in real life the depiction of the relayed physiological values will only show the values when the patient is not having any movement which is practically very unusual case. The proposed EPARA-BAN can support postural change on arms and legs which means that we can receive the same physiological information of the patient even when he is walking, jogging, or doing routine daily activities. We can easily apprehend this by a practical example in case of a patient with hypertension problem and the healthcare monitoring center can get the real time values of blood pressure and heart rate during daily life activities.

The performance evaluation of EPARA-BAN under two different scenarios using ns-2 is conducted. EPARA-BAN forwards more packets and achieves high packet delivery ratio as compare to ENSA-BAN. On the other hand EPARA-BAN consumes more energy and more delay than ENSA-BAN as EPARA-BAN uses two relay nodes.

The metrics used in this study for the evaluation of the proposed protocol covers all the major aspects of protocol efficiency and QoS. EPARA-BAN shows a little compromise in terms energy consumption and end-to-end delay but on the other hand, it provides more efficient results for forwarded packets through intermediate nodes and average packet delivery ratio. So the real time practical application of EPARA-BAN in health care sector makes it more useful. It is also concluded that EPARA-BAN will work more efficiently when the sink node is attached to the waist (experiment 1) of the patient as compared to the case of sink node attached at patient's ankle (experiment 2).

6.2 Future Work

Detailed studies can be carried to further improve the efficiency of EPARA-BAN especially for reduction of power consumption and delays incurred in transmission of packets. The same experiments can also be conducted using some different communication standard and some other routing scheme which could be implemented and further improves the aspects of energy consumption of sensor nodes and end-to-end delay for packet delivery.

References

1. Iqbal.J. A Survey of Routing Protocols in Wireless Body Sensor Networks. 14:p.1322-1357:doi:10.3390/s140101322,Sensors 2014.

2. Sharif Jb, Abdullahi M. An Efficient Next Hop Selection Algorithm for Multi-Hop Body Area Networks, January 15, 2016.

3. Acampora G, Cook DJ, Rashidi P,Vasilakos AV ,A survey on ambient intelligence in healthcare.Proceedings of the IEEE.101(12):p.2470–2494.doi: 10.1109/JPROC.2013.2262913 PMID: 24431472 ,2013

4. Dr. Jose A. Gutierrez, IEEE Std. 802.15.4, Enabling Pervasive wireless sensors networks, p.23–36,2005.

5. Chen M, Gonzalez S, Vasilakos A, Cao H,Leung VCM. A survey of Mobile Networks and Applications.16(2):p.171–193,2011.

6. IEEE 802.15.4, Stack User Guide, JN-UG-3024 V2.6, 22 June 2016.

7. Zhou J, Cao Z,Dong X, Xiong N, Vasilakos AV.4S. A secure and privacy preserving key management scheme for cloud assisted wireless body area network in m-healthcare social networks. 314:p.255-276.doi:10.1016/j.ins.2014.09. 003,2015.

8. Wei L,Zhu H, Cao Z,Dong X,Jia W,Chen Y,et al. Security and privacy for storage and computation in cloud computing. 258:p.371–386. doi: 10.1016/ j.ins.2013.04.028, 2014.

9. He D, Chen C, Chan SC, Bu J, Vasilakos AV. A distributed trust evaluation model and its application scenarios for medical sensor networks. IEEE Transactions on Information Technology in Biomedicine. 16(6):p.1164–1175. doi:10.1109/TITB.2012.2199996 PMID: 22623434,2012

10. Zhou J, Cao Z, Dong X, Lin X, Vasilakos AV. Securing m-healthcare social networks:Challenges, countermeasures and future directions. Wireless Communications, IEEE. 20(4):p.12–21. doi: 10.1109/ MWC.2013.6590046,2013.

11. He D, Chen C, Chan S, Bu J, Vasilakos AV. ReTrust:Attack resistant and lightweight trust management for medical sensor networks.IEEE Transactions on Information Technology in Bio medicine. 16(4):p.623-632,2012. doi:10.1109/TITB.2012.2194788 PMID:22531816,2012.

12. Wei L, Zhu H, Cao Z, Jia W, Vasilakos AV. Seccloud: Bridging secure storage and computation in cloud. In: 30th IEEE International Conference on Distributed Computing Systems Workshops (ICDCSW). p. 52–61, 2010.

13. Movassaghi S, Abolhasan M, Lipman J. A Review of Routing Protocols in Wireless Body Area Networks.Journal of Networks;8(3).doi:10.4304/jnw. 8.3.559-575,2013.

14. Ben Elhadj H, Chaari L, Kamoun L. A survey of routing protocols in wireless body area networks for healthcare applications.International Journal of E-Health and Medical Communications (IJEHMC). 3(2):p.1–18. doi: 10.4018/jehmc.2012040101,2012.

15. Ullah S, Higgins H, Braem B, Latre B, Blondia C, Moerman I, et al. A comprehensive survey of wireless body area networks.Journal of medical systems. 36(3):p.1065. doi: 10.1007/s10916-010-9571-3PMID:20721685,2012.

16. Khan ZA, Sivakumar S, Phillips W, Robertson B. A QoS-aware Routing Protocol for Reliability Sensitive Data in Hospital Body Area Networks. Procedia Computer Science. 19:p.171–179.doi:10.1016/j. procs.2013.06.027,2013.

17. Khan Z, Sivakumar S, Phillips W, Robertson B. QPRD: QoS-aware Peering Routing Protocol for Delay Sensitive Data in hospital Body Area Network Communication. In: Proceedings of the 2012 Seventh International Conference on Broadband, Wireless Computing, Communication and Applications. IEEE Computer Society; p. 178–185,2012.

18. Razzaque MA, Hong CS, Lee S. Data-centric multiobjective QoS-aware routing protocol for body sensor networks. 11(1):p.917–937. doi: 10.3390/ s110100917 PMID: 22346611,2011.

19. Khan Z, Aslam N, Sivakumar S, Phillips W. Energy-aware peering routing protocol for indoor hospital body area network communication. 10:p.188–196. doi: 10.1016/j. procs.2012.06.027, 2012.

20. Liang X, Balasingham I, Byun SS. A reinforcement learning based routing protocol with QoS support for biomedical sensor networks. In: First International Symposium on Applied Sciences on Biomedical and Communication Technologies ISABEL–08. p. 1–5,2008.

21. Djenouri D, Balasingham I. New QoS and geographical routing in wireless biomedical sensor networks. In: Sixth International Conference on Broadband Communications, Networks, and Systems (BROADNETS). p.1–8, 2009.

22. Zeng Y, Li D, Vasilakos AV. Real-time data report and task execution in wireless sensor and actuator networks using self-aware mobile actuators. 36(9):p.988–997. doi: 10.1016/j.comcom, 2012.07.016,2013.

23. Movassaghi S, Abolhasan M, Lipman J. Energy Efficient Thermal and Power Aware (ETPA) Routing in Body Area Networks. In Proceedings of IEEE 23rd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC),p.1108–1113,Sydney, NSW, Australia, 9–12 September 2012.

24. Quwaider M, Biswas S. Probabilistic Routing in On-Body Sensor Networks with Postural Disconnections. In Proceedings of the 7th ACM International Symposium on Mobility Management and Wireless Access. p. 149–158,Tenerife, Canary Islands, Spain, 27–30 October 2009;

25. Liang X, Li X, Shen Q, Lu R, Lin X, Shen X, Zhuang W. Exploiting Prediction to Enable Secure and Reliable Routing in Wireless Body Area Networks. In Proceedings of the 31st Annual IEEE International Conference on Computer Communications, Orlando. p. 388–396, FL, USA, 25–30 March 2012;

26. Hess F. Efficient Identity Based Signature Schemes Based on Pairings. In Proceedings of 9th Annual International Workshop Selected Areas in Cryptography. p.310–324,Newfoundland, Canada, 15–16 August 2002;

27. Quwaider M, Biswas S. DTN routing in body sensor networks with dynamic postural partitioning. 8, p.824–841,2010.

28. Otto C, Milenkovic A, Sanders C, Jovanov E. System architecture of a wireless body area sensor network for ubiquitous health monitoring. J. Mobile Multimed. 1,p.307–326,2006.

29. Maskooki A, Soh C.B, Gunawan E, Low, K.S. Opportunistic Routing for Body Area Networks. In Proceedings of IEEE Consumer Communications and Networking Conference (CCNC). p.237–241, USA, 9–12 January 2011

30. Quwaider M, Biswas S. On-Body Packet Routing Algorithms for Body Sensor Networks. In Proceedings of 1st International Conference on Networks and Communications. p.171–177,Chennai,India,27–29 December2009.

31. Park J.G., Curtis D., Teller S., Ledlie J. Implications of Device Diversity for Organic Localization.. Proceedings of 2011 International Conference on Computer Communications (INFOCOM 2011); Shanghai, China. 10–15 April 2011; pp. 3182–3190.