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Designing insistence-aware medium access control protocol and energy conscious routing in quality-of-service guaranteed wireless body area network

by

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Ph.D. Thesis

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DEDICATION

I wholeheartedly dedicate this thesis to my beloved parents, A.I.G. Ibrahim Abdu, (rtd.) and Hajiya Fatima Ibrahim for their overwhelmingly continuous spiritual, moral, emotional and financial support. I could not have done it without them.

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ABSTRACT

Designing insistence-aware medium access control protocol and energy conscious routing in quality-of-service guaranteed wireless body area network

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Wireless body area network (WBAN) is a type of wireless sensor network that enables efficient healthcare systems. To minimize frequent sensor replacement due to resource restrictions, it is necessary to improve energy efficiency in WBAN. This thesis deals with energy efficiency and QoS improvement together in novel WBAN architecture. A novel WBAN architecture is designed with dual sink nodes in order to minimize delay and energy consumption. A novel insistence aware medium access control (IA-MAC) protocol which is aware of criticality of sensed data is presented in proposed WBAN. Prior-knowledge based weighted routing (PWR) algorithm is responsible to select optimal route for data transmission. In PWR, weight value is computed by considering significant metrics such as residual energy, link stability, distance, delay, etc. in order to improve energy efficiency and QoS in the network. Energy consumption is further minimized by incorporating graph based sleep scheduling (GSS) algorithm. In GSS, criticality of sensor node also considered as major metric. In coordinator, split and map based neural network (SMNN) classifier is involved to perform packet classification. After classification, packets are assigned to corresponding sink node accordance to packet type. Then, throughput and delay metrics are improved by frame aggregation process which is involved in sink node. Extensive simulation in OMNeT++ shows better performance in network lifetime, throughput, residual energy, dropped packets, and delay.

Keywords: WBAN, QoS, coordinator, MAC, emergency data, OMNeT++.

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LIST OF ABBREVIATIONS

1.	AP	Access Point
2.	API	Application Programming Interfaces
3.	BAN	Body Area Network
4.	BAN ID	Body Area Network Identification
5.	BSN	Body Sensor Network (BSN)
6.	CBBAP	Cluster Based Body Area Protocol
7.	CD	Critical Data
8.	CR	Coordinator
9.	CW	Contention Window
10.	DT	Data Type
11.	ECG	ElectroCardioGraph
12.	EDA	Electrodermal Activity
13.	EEG	ElectroEncephaloGraph
14.	EMG	ElectroMyoGraph
15.	EQ-WBAN	Energy aware QoS guaranteed WBAN
16.	E-SN	Emergency sink node
17.	E-SN	Emergency Sink Node
18.	FCS	Frame Check Sequence
19.	FDA	Food and Drug Authority
20.	FSM	Finite State Machine
21.	FSM	Finite State Machine

22. GSS	Graph based Sleep Scheduling
23. HBC	Human Body Communication
24. HIT	Hybrid Indirect Transmission protocol
25. HT	High throughput
26. IA-MAC	Insistence Aware Medium Access Control
27. LEACH	Low Energy Adaptive Clustering Hierarchy
28. MAC	Medium Access Control
29. MBAN	Medical Body Area Network
30. MSDU	MAC service data unit
31. NB	Narrow Band
32. N-SN	Normal sink node
33. PA-MAC	priority based adaptive MAC
34. PDA	Personal Digital Assistance
35. PHY	Physical
36. PS	Packet Size
37. PWR	Prior-knowledge based weighted routing
38. QoS	Quality of Service
39. QS-PS	Quasi-Sleep-Preempt-Supported
40. SAR	Specific Absorption Rate
41. SEQ CTRL	Sequence control
42. SMNN	Split and Map based Neural Network
43. SN	Sink Node
44. TDMA	Time division multiple access

45. TICOSS Timezone Coordinated Sleeping Mechanism

46. TTL Time To Live

47. UWB Ultra-Wide Ban

48. WASP Wireless Autonomous Spanning Tree Protocol

49. WBAN Wireless Body Area Network

50. WPAN Wireless Personal Area network

51. WSN Wireless Sensor Network

52. ZEQoS A New Energy and QoS-Aware Routing Protocol for Communication of Sensor Devices in Healthcare System

CHAPTER 1

INTRODUCTION

Today, four extraordinary events in the history of humanity are happening; 1) dramatic increase in the population worldwide 2) death due to chronic and fatal diseases 3) increase in health care cost and 4) mobile and wireless technologies are undergoing remarkable growth. The global population is increasing due to decrease in death rate than increase in birth rate and increase in average life expectancy. Figure 1 shows that in 1650, the population of the world was just 0.5 billion but by the year 1900 the population of the world had risen to 1.5 billion. However, the population growth began to decline from 1960 to 2000 due to decrease in birth rate [1], [2].

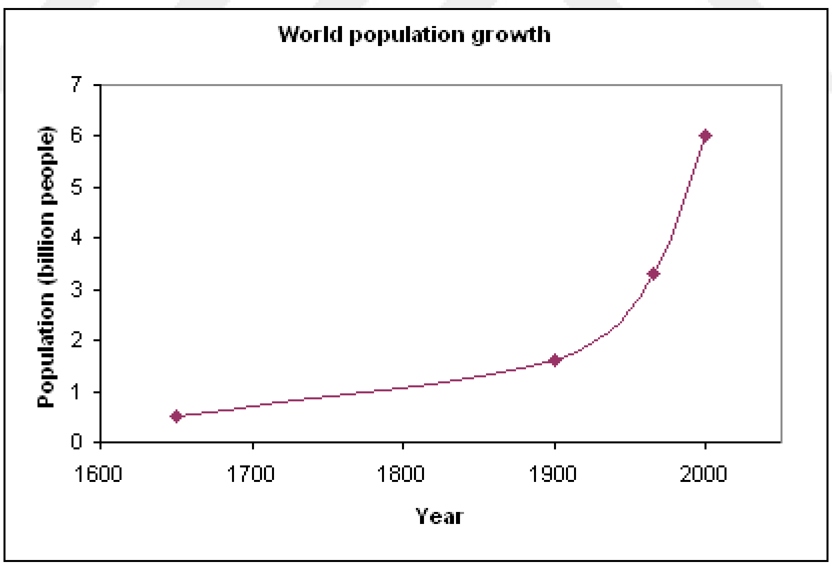

Figure 1.1:Population growth [2]

Based on the report from WHO (World Health Organization), the population of seniors (60 years and above) around the world especially in advanced counties is increasing by 2% yearly as a result of decrease in number of birth per woman and increase in average life span. Additionally, it is expected that this rate will increase to 2.8% by 2030. According to United Nations (UN) World Population Prospects 2015 Revision for the period 2010 - 2015, Hong Kong has the world's highest life expectancy of 84.0 years, followed by Japan 83.7 years, Switzerland 83.4 years, Turkey 74.84 years, and Nigeria 54.5 years, while the world's average is 70.5 years [3].

With regards to death due to chronic and fatal diseases, poor lifestyle decisions such as smoking, poor diet, alchohol misuse, lack of excercise etc. leads to the increase in preventable chronic disease affecting adults and elderly. Examples of these diseases as are cardiovascular disease (hearth attach, hearth failure, stroke), chronic respiratory diseases, diabetis, Parkinson's, asthma, obesity and cancer. The main issue with all the current deadly illnesses is the fact that a lot of people feel and see the signs and have the illnesses detected when it is too late. Many researches have been conducted and their conclusion show that a significant amount of these deadly illnesses can be avoided if they are discovered in their early phases.

Medical sector grow more rapidly than any other sectors of the U.S. economy. For example, other sectors advance as fast as the whole economy, however, medical sector does not. Moreover, US overall medical sector expenditures have significantly increased from $75 billion, or only $356 per person to $2.6 trillion, or $8,402 per person from 1970 to around 2010 [2].

Due to the above mentioned reasons, the current health care system will be overloaded and needs to change to be able to accomodate the dramatic increase in world's population, chronic diseases and high cost of health care.

The major solution to these issues is a health care system that enables wearable technology network that is scalable, proactive, affordable and will be able to early detect chronic diseases and abnormalities in the patients before they become irreversable, resulting to improvement of quality of life. Furthermore, the network should be able to monitor the patient remotely while the patient carry out his/her normal daily activities without infringing in the freedom of movement of the patient. The wireless technology that is expected to serve this purposed is named as Wireless Body Area Network (WBAN).

1.1. INTRODUCTION

A Wireless body area network (WBAN), which is similarly called as a *body area network* (BAN) or a *medical body area network* (MBAN) or a *body sensor network* (BSN), is a network of tiny computers with sensing capabilities that can be located inside the body (implant), or mounted on the body (wearable technology) or may be placed around or near the body, such as hand bags and cloth [3]. These tiny computers (sensors) are able to take the reading of the physiologic parameters of the human body for instance, body temperature, pressure, heart rate, electrocardiography etc., then process, route and then transmit these parameters to a personal device also known as a coordinator or sink. In addition to improving the quality of life, saving life, facilitating detection and treatment of chronic diseases, and reducing visit to hospital, WBAN helps to reduce health care cost tremendously by reducing in-hospital treatment of patients [2], [4], [6].

There are many applications of WBANs and they are grouped into non-medical and medical applications. Medical applications are subcategorized into wearable, implant and Remote Control of Health Devices applications. Applications which are wearable can be used for assessing soldier’s tiredness and combat enthusiasm, problems of sleep, asthma and health monitoring which is wearable. Implant applications are for monitoring cardiovascular diseases and cancer discovery. Remote Control of Medical Devices applications can be used monitoring of patients and telemedicine. Non-medical application on the other hand can be for streaming in real time, entertainment and non-medical emergency [3].

Many years ago, Wireless Personal Area network (WPAN) was used to connect devices attached to the body however, it was not able to satisfy the medical requirement due to its closeness to the human body tissue, hence the need for a standard that will satisfy the medical requirement became paramount. Thus IEEE task group 6 developed a standard called 802.15.6 to meet all the WBAN requirements [3], [6], [7].

1.2. PROBLEM STATEMENT AND MOTIVATION

An important concern in WBAN is the improvement of an energy efficient routing protocol which guarantees Quality of Service (QoS) however, this is not a trivial job because of the constraint and the characteristics of the WBAN environment. Despite the fact the Wireless Sensor Network (WSN) and Ad Hoc network have proposed solutions to the above mentioned problems, they are not suitable for BSNs due to the limited constraints in the network [8]. Some of the design challenges of BSN are security level, data rate, temperature rise, postural body movement, resource constraints and QoS requirement. This research takes into account resource constraints and QoS requirements [8], [9].

Due to the space constrains in the body of the human, the size and the amount of the nodes deployed in the body of the human are limited. This result to nodes that are inadequate with respect to energy, computation, storage and communication. Limitations especially in term of energy severely affects the life time of the network because the source of energy is battery and it has a short life span. After the battery is depleted, to make the node work again, the battery will have to be replaced or recharged which is not always feasible especially in implanted sensor nodes because this will lead to surgical procedures any time node is dead.

Normally, each BSN is heterogeneous because each sensor node is different as each node monitors different data with different QoS requirement. However, resource constrains and limitation due to size constraint of the human body, QoS is challenging to achieve.

To this end, because the solutions provided by researchers to improve the energy management and quality-of-service of wireless body area networks are not satisfactory enough, it becomes imperative that we develop a better energy efficiency and QoS improvement for WBAN that is superior to well-known ones such as [10], [11], and [12] with respect to throughput, network lifetime, dropped packets, delay and energy depletion. We start by defining our major objectives in wireless body area network as given below:

- To extend the network lifetime
- To reduce the energy depletion
- To advance quality-of-service metrics for example, throughput and delay

Based on all the literature that I have studied, this research is the first of its kind and has never been done before by anyone or group.

1.3. CONTRIBUTIONS

The most important contributions of this thesis is provided below:

- A novel wireless body area network architecture which has two sink nodes is developed to increase quality-of-service and energy management. The two sink nodes are termed as normal sink node (N-SN) and emergency sink node (E-SN). The normal sink node is in charge of aggregating normal data packet. The emergency sink node however, is in charge of aggregating emergency data packets.

- With regards to ascertaining emergency stage of data packets, the medium access control protocol is modified and improved to IA-MAC. Since the emergency level of packet is represented in binary values, the modification of the format of MAC does not increase the overhead.
- During the process of data transmission, PWR algorithm selects the optimal route based on the computed weight value. The weight value is calculated based on important metrics. At this point, by taking into account the previous information in order to select route, overhead is reduced.
- In addition, to minimize the energy consumption, optimal sleep scheduling is enables in sensor nodes. GSS algorithm supports sleep scheduling and It is performed by the coordinator.
- Lastly, SMNN classifier classifies all the incoming packets that is received by coordinator into normal and emergency data packet. In addition to packet classification, SMNN classifier contribute to minimize delay. In other to further improve QoS, frame aggregation mechanism is incorporated.

1.4. THESIS OUTLINE

This thesis is made up of nine chapters. Chapter one includes the background information and the details of the contributions. The remaining part of the thesis proceeds as follows:

Chapter 2: Body Area Networks

The background information of BSN is will be first explained in this chapter. Some of the information consist of historical development of WBAN, BANs and WSNs comparison, the components and topologies that exists in BAN, BAN applications, characteristics of WBANs**,** design considerations in BAN, technical requirements of WBAN, a brief discussion of current BAN standards, different BAN application environments, then concludes by summarizing the chapter.

Chapter 3: Literature Review

BAN routing protocols was discussed in the beginning of this chapter, then it sheds light on the grouping of BAN routing protocols, then briefly discusses their subcategories, and their advantages and disadvantages. In the last section, the discussion of different types of systems for monitoring patients is provided.

Chapter 4: EQ-WBAN architecture

In this chapter, the motivation, important related works, our proposed energy and quality-of-service architecture with two sink nodes and performance analysis of our work using OMNeT based Castalia 3.2 is described in detail.

Chapter 5: Conclusions and Future Work

This chapter provides conclusions which summarizes the entire work and then gives insights into future directions for research.

CHAPTER 2

This chapter provides a comprehensive overview of the concept and background information of BSN to help us understand this thesis. The chapter is made up of seven sections. In section 2, the historical development of WBAN was discussed, section 3 explains the most important BAN applications related to this thesis section, section 4 discuss the characteristics of WBANs, section 5 and 6 compares BAN with WSNs, and discussed the technical requirements of WBAN respectively, then concludes by summarizing the chapter.

2.1. BODY AREA NETWORK (BAN)

As mentioned in the Introduction, BSN is a wireless network which comprise of intelligent, low-power, light-weight, invasive and non-invasive micro devices called sensors, which have the ability to monitor the vital signs such as temperature, pressure, glucose etc. of a person and send this information in real time to the doctor or care giver [1] – [12]. It is expected that these nodes should be able to detect chronic diseases such as cancer, diabetes, cardiovascular diseases etc. in their early stages and inform the caregiver, thus leading to early diagnosis and treatment of the patient. Additionally, sensor nodes are less obtrusive, hence, giving the patient the freedom to move around freely rather than staying at indoor or close to a health facility. The implementation of BAN reduces the expense of medical care, by reducing the need for costly in-hospital patient monitoring. This has lead researchers and experts in other areas, for example in sporting, soldierly and entertainment area to implement BAN in their respective fields [13]. A classic WBAN is can be seen in Figure 2.1. The figure shows a BAN with various sensors nodes positioned in, on or around the body of the human to measure physiological parameter.

2.2. HISTORICAL DEVELOPMENT OF WBAN

The concept of WBAN as a subfield of WSN was initially presented in 1995 by a scientist known as Zimmerman [9] whereby he introduced an idea in which data can be exchange between electronic devices positioned in/on or close to the body of the human. He utilized WPAN for information exchange. Since energy management is one of the most crucial metric in BSNs because sensors are anticipated to work for a long period of time. Moreover, wireless personal area networks do not fulfill the health communication conditions due to short distance to the tissues of the body of the human. Consequently, a prototypical was essential that will meet all the requirements of BANs addressing both its non-medical and medical applications [3], [15].

In April 2010, the first draft of the communication standard of BSNs was developed by IEEE802.15.6. The standard was ideal for nodes which have low transmission power, and can be position on, in or close to the body of the human for various consumer electronic and medical applications [16].

In February 2012, the IEEE802.15.6 standard version was accepted and confirmed [17] and it defined its goal as follows: “To improve a transmission and reception standard for tiny, low-power electronic devices which have the ability to function close to, in, or the body of a human (or animals) and to handle different medical and non-medical applications” [3].

2.3. BAN APPLICATIONS

Although BAN is predominant in medical applications, it can be used in non-medical applications such as security, social networking, sports, safety and entertainment [14]. In fact, all BAN applications are categorized into health and non-health applications as it is depicted in table 2.1. Although the scientific needs of BANs depend on specific types of application, improving quality of life is the main aim of all WBAN applications.

Figure 2.1: WBAN [13]

The use of BANs in medical applications allows the person's vital signs for example hotness of the body, heart-rate, and pressure of blood to be continuously monitored. In a situation where abnormalities are detected, information that are sensed and collected by the sensor nodes can be sent to a coordinator also knows as sink or gateway. After that, the coordinator then sends the gathered information through the Internet to a central data base where the authorized person or authorized health care provider can access it and take necessary action [18] [19]. Furthermore, BSN is the best way to prior detection, analysis, observing and curing of people inflicted with chronic illnesses like cancer, asthma, diabetes, and cardiovascular diseases.

2.3.1. Medical applications of BSNs

BSNs of medical applications are further grouped into three subgroups which are wearable, implanted and remote control medical devices.

2.3.1.1. *Wearable BAN*

This group of BAN is further categorized into the two subgroups: a) Human Performance Management b) Disability Assistance. Below is a list of some of the applications of wearable BAN:

Asthma – The nodes in the sensor network are capable of observing sensitive particles in the environment and giving real time updates to the doctor. This is capable to assisting millions of sick people suffering from this disease.

Evaluating Soldier Tiredness and Battle Enthusiasm – The works of soldiers in the theater of war, policemen and other emergency services can be observed more thoroughly by BSNs. The application of BSNs in tough locations can be helpful in decreasing the possibility of getting wounded in addition to providing enhanced monitoring and maintenance in case there is sustained wound [20] [21]. Refer to figure 2.2 for a detailed info on WBAN applications.

Sleep Staging: WBANs are capable of monitoring patients sleep patterns and transferring these patterns to a remote location e.g. doctors' offices for further analysis. Conventional sensors had wires which further hinders a person's sleep, but WBAN is capable of monitoring without hindering patients sleep because its wireless and obtrusive [22].

2.3.1.2. *Implant WBAN*

In this type of application, sensors can be implanted in the blood stream, underneath the tissue or in the body of human.

Cardiovascular Diseases: Through BAN technology and monitoring episodic events Myocardial Infarction (MI) can be significantly decreased.

Cancer Detection: Sensor nodes in BAN are capable of monitoring cancer cells that will enable doctors diagnose tumors without biopsy and provide treatment on time.

2.3.1.3. *Remote Control of Medical Devices*

Active Assisted Living (AAL) formerly known as Ambient Assisted Living includes methods, products and services that assists the daily life of the elderly and needy people in an unnoticeable way whereby every BSN wirelessly sends and receives data packet with a health network which is located at the back-end [23]. The aim of AAL is to elongate and ease the care of patients that are supported in an indoor environment, decreasing the reliance on thorough individual supervision, improving quality of life and reducing the fee of health care expenditure [24].

Telemedicine Systems: Which is the provision of medical care from a remote location uses a protocol that demands lots of power e.g. Bluetooth, that is prone to distortion from additional equipment operating in a comparable frequency. Hence, they control continuous observing. Where incorporating BANs in a telemedicine system permits for extended duration of time of unnoticeable patient's health monitoring.

2.3.2. Non-Medical Application of BSN

The application can be grouped into five categories as given below:

2.3.2.1. *Emergency*

Sensors that are placed off-body (e.g. built into the house) are able to detect emergency situations such as fire or poisonous gas emission in office or households and send and receive this information with the biosensors [25].

2.3.2.2. *Entertainment Applications*

Entertainment appliances for example cameras, MP3-players, microphones etc. can be included in BSNs. Item tracking systems, gaming and virtual reality etc. can use in BSN integrated appliances.

2.3.2.3. *Secure Authentication*

Biometric for example facial patterns, iris recognition and fingerprint are utilized by this application. Due to duplication and counterfeit that has inspired the use of novel behavioral and physique of the human, secure communication is one of the main applications of BSN.

2.4. CHARACTERISTICS OF WBANS

2.4.1. Types of nodes in a WBAN

A sensor node can be referred as a device with sensing, processing and transmission and reception capability. Classification of nodes base of their functionality are follows:

1. *Sensor* – Sensors are capable of measuring certain parameters on a person's body either internally of externally. There are three types of sensors; physiological, ambient biokinetics sensors [26] [27]. Body nodes can be incorporated in person's wrist watch, cell phone, or earphone and accordingly, permit wireless observing of an individual wherever he maybe and at any time. The following is a list of dissimilar types of sensor node can be obtainable in the market: Humidity, Electrocardiograms, Blood glucose, electroencephalogram, electromyography, $CO2$ Gas sensor, DNA Sensor, Blood pressure, Temperature etc.
2. *Actuator* – The responsibility of the actuator is to act on the sensor data and provide feedback in the network. For example, just as the case of insulin pump. Pumping the correct amount insulin in the bloodstream of a diabetic patient to restore the patient's health [28].

Grouping of body sensors according to their implementation inside the body are as follows [29]:

1. *Implant Node* – As mentioned before, it is implanted below the skin or in the blood stream.

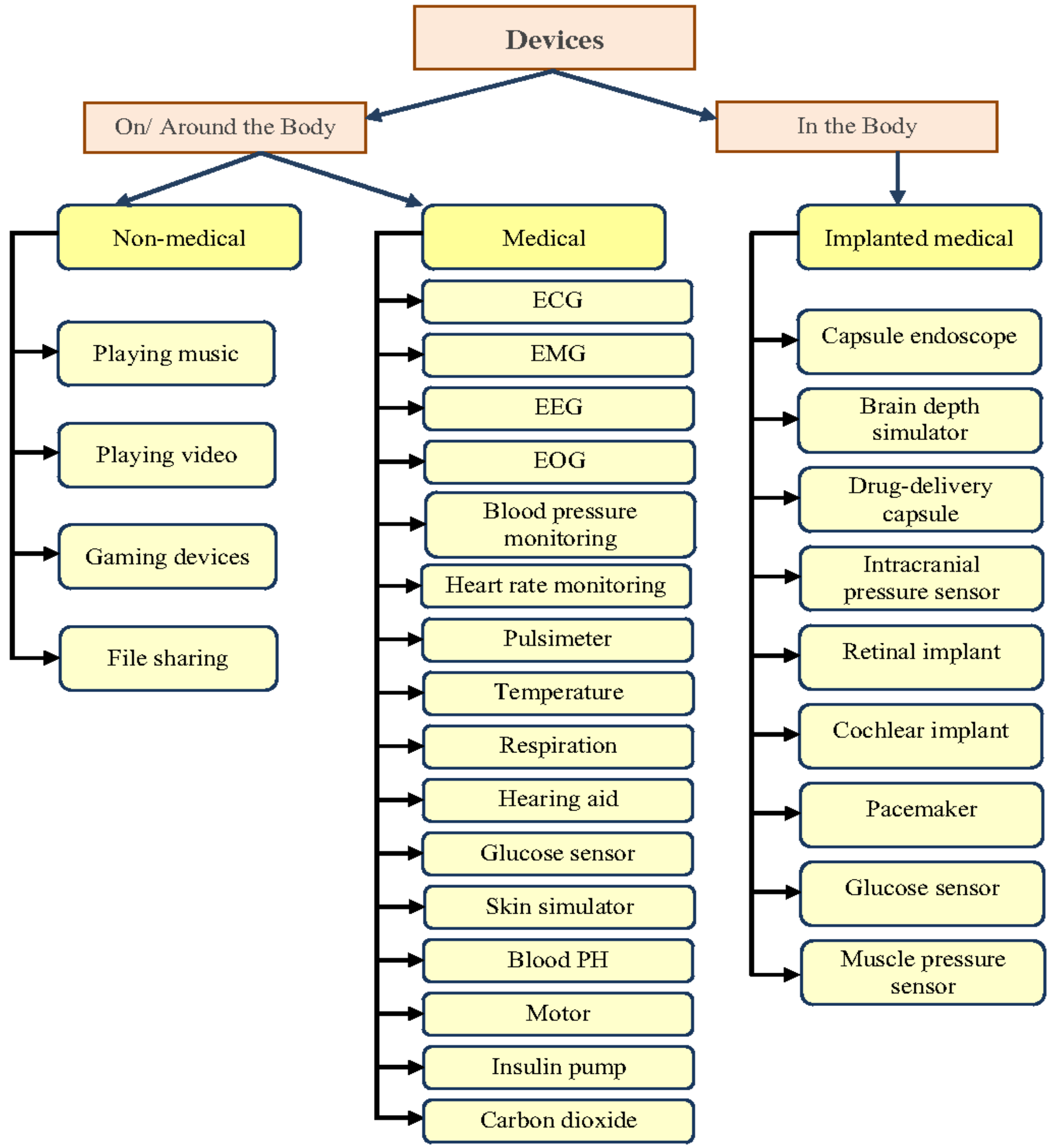

Figure 2.2:WBAN applications[15]

2. *Wearable sensor nodes* – This node is positioned on the skin or 2 centimeters far from the skin
3. *External Node* – This node is normally placed 5 centimeters away from the skin

Grouping of body sensors according to their function in the network are presented below:

1. *Coordinator* – Also known as the PDA, sink, or gateway to other networks.
2. *End to End nodes* – They are responsible for performing their jobs and do not relay messages like intermediate nodes or relay nodes.
3. *Relay* – These nodes is also capable of sensing and forwarding data to the coordinator.

2.4.2. Topology used in WBANs

Based on IEEE 802.15.6 standard, only single-hop or double-hop star topology is possible in WBAN. The body sensor in the middle of the star is the sink node and it is placed on the waist of the person. The comparison of Single-Hop and Double-Hop Star Topology Network [30].

Table 2-1:One-Hop and Multi-Hop Star Topology Network [30]

Evaluation criteria	Single-hop Star Networks	Two-Hop Start Networks
Energy Depletion	Nodes that are further away from the sink in this topology deplete more energy than nodes close to the sink,	In this topology, the nodes closer to the sink consumes more energy because they forward their data and that of other nodes.
Node Failure and Mobility	When one nodes fails, it may affect the entire network performance but the network will still work.	When one nodes fails, it may affect the entire network performance but the network will still work.
Transmission Delay	Since there is only one hop, this topology provides the least possible delay.	Only the nodes closest to the sink are able to forward to sink without delay. But the overall network delay is high
Interference	The amount of interference increase with the distance to the sink.	The interference is low since the nodes forward to their neighbors before getting to the sink.

2.4.3. WBANs Communication Architecture

The wireless body area networks communication architecture can be divided into 3 dissimilar tiers as detailed below:

• Tier-1: Intra-wireless body area network communication: In this tier, the nodes communicate with each other and with their sink. The packet is then sent to the AC in tier-2. This interaction is depicted in figure 2.3.

• Tier-2: Inter-wireless body area network communication: This is the connection amongst sink and the AP. The transmission and reception goal is to interconnect BSNs with different networks. There are two subcategories of tier 2 architecture. Infrastructure based and ad-hoc based architecture.

• Tier-3: Beyond-WBAN communication: The aim of the design of this transmission and reception tier is to be used in metropolitan area. The picture is illustrated in figure 2.3.

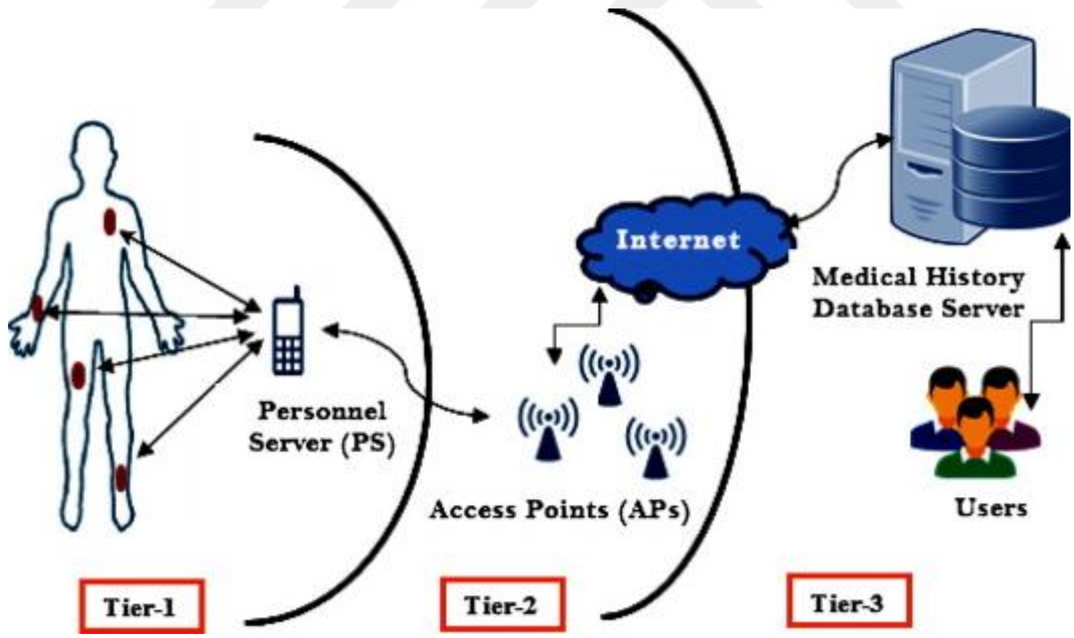

Figure 2.3:Communication Architecture of WBANs [31]

2.4.4. Layers used in WBANs

The only layers that was defined by IEEE 802.15.6 working group for WBAN were physical and medium access control layers. The layers are responsible for limited power, limited cost, low complexity, great trustworthiness, small transmission range wireless transmission and reception in/on and/or close to the human body. The physical layer's main responsibility is for data transmission and reception. There are three types of physical layer defined by IEEE 802.15.6 are as follows: HBC, NB and UWB.

Controlling Channel access is the main aim of medium access control layer. The main aim of medium access control layer is to organize channel access. The main responsibility of the sink or coordinator is to divide the entire channel into a sequence of superframes for resource allocation that deals with time. The coordinator also selects beacon phases of the same length to bound the superframes. Additionally, channel access coordination is the responsibility of the sink through one of the resulting 3 mode of access: 1) Beacon Method with Beacon phase Superframe, 2) Non-beacon method with superframe restrictions, and 3) Non-beacon method short of superframe restrictions [33].

2.4.5. Channel Model

Body Sensor in BANs are distributed in, on and/or near the body, that has the ability constructs numerous transmission channels amongst the nodes according to their locations to each other.

2.4.6. Security in WBANs

Although the concern of security is of a high significance in wireless networks and many solutions have been provided, insufficient study has been carried out in the area of BAN. The security solutions provided by other networks is not suitable for BAN because of its strict resource constraints with respect to power, memory, computational capabilities and communication rate. In order to get a secured BSN, the following requirements must be provided:

1. Availability – The information of the patient should be made available to the physician at all times. An attack on the availability of ECG data of the patient for example, can lead to loss of life. Therefore, ability to change to a different BSN in a situation of availability loss is crucial.
2. Data authentication: - All kinds of applications such as health and non-health need verification whereby, all the body sensor in the network are required to be verified so as to be sure that the data packet being sent is from a trusted node not a false adversary.
3. Data integrity – Data can be altered by an adversary when it is being sent. By using authentication protocols, the receiver node will ensure that the data it has received it the correct data.
4. Data confidentiality: - By encrypting data of patient through shared key on the channel. Data confidentiality can be accomplished.
5. Data freshness: - Since an adversary has the ability of altering data in transmission, data freshness is required so as to ensure that data is not used again and again and its frames are arranged accordingly.

2.5. COMPARISON BETWEEN WBAN AND WSN

2.5.1. Resource limitation

The power source, the memory, computational power and the communication rate are limited in WBAN nodes. When the battery of a node is dead, it is mostly not possible to recharge or change the battery especially in the case of implanted sensor node. Due to the extremely small size of the node (1cm^3), each and every node has a tremendously low transmit power. These limitation minimizes the health care concerns and interference [20]. Table 2.2 below shows the comparison between WBAN and WSN.

2.5.2. Data Requirements

Sensor nodes are mainly heterogeneous and hence have dissimilar requirement according to trustworthiness, energy depletion and data rates [8]. Additionally, one of the key requirements of WBAN applications is latency however, WSN are usually homogeneous.

2.5.3. Network Structure

The nodes in WBAN are mostly mobile especially the nodes placed in the hands, legs and head, therefore they must to be extra robust and act more rapidly to modifications in their topology However, nodes in WSN are stationary because they are placed in a specific place to monitor the environment. Further, the nodes in WBAN are few and densely placed whereas, nodes in WSNs can reach up to tens of thousands and placed in area ranging from meters to kilometers.

2.5.4. Security

Since WBAN operate in hostile environment and collect life-crucial information, their data must be confidential and private, therefore requires strict security measure, whereas in the case of WSN, the data collected is of low security level and application specific [20].

Table 2-2:Difference between WBAN and WSN

Challenges	WSNs	WBANs
Types of Node	Homogeneous	Heterogeneous
Mobility Range	Environment monitoring in meters (m) and kilometers (km).	Human Body monitoring in centimeter (cm) and meters (m)
Number of nodes	Many redundant nodes for wide area coverage	Fewer, limited in coverage
Network Topology	Fixed and static	Dynamic (due to body movement)
Wireless Technology	Bluetooth , Zigbee, GPRS	Low power Technology
Biocompatibility	Not considered	Considered for implanted and external sensors
Energy Requirement	High but easy to provide	Limited but difficult to provide
Node replacement	Easy to replace	Difficult to replace
Node Size	Small is preferred but not necessary	Small in size
Node Lifetime	Several months/ years	Several years/ months, with small battery capacity
Source of Energy	Mostly wind or solar power	Vibration (body movement), Thermal (body heat)

2.6. TECHNICAL REQUIREMENTS OF WBAN

Due to tough environmental requirements and diversity in applications, BANs face technical requirements different from its counterpart WSN. Table 2.3 shows the requirements of BANs.

Table 2-3: Requirements of BANs [66]

	Expected Range
Lifetime	It takes about five years for implants and one week for wearable sensors
Setup Time	Setup time range should be less than 3 seconds
Fault Management	In case of node failure, It should be able to self-heal
Topology	Start topology with one and two hops
Power and Energy	0.1mW power is consumed for standby mode and up to 30mW for full time active mode
Ergonomic Concerns	Being harmless, having a tiny size, light weight and non-invasive is a main concern
Frequency Bands	Bands allocated for health devices and other international unlicensed.

Data Rate	Rate at which data is transferred is from a few kbps to 10Mbps and its scalable
Operative Region	Within 0-5 meters
Security	Confidentiality, Verification, Privacy, Information reliability, Encryption, Approval, Endorsement
Biocompatibility	Fulfilling the guidelines of FDA and other regulatory organizations
Quality of Service	Consideration of reliability and delay control mechanisms
Compatibility	Capable of sending and receiving using some devices around body and simultaneous co-located operation of up to 10 different BSNs
Medium Access Control	Lower power during listening and wakeup modes

2.6.1. Data Transmission

According to authors in [3], different BAN applications require different data transmission parameters such as battery lifetime, number of nodes, data rate, BAN topology, setup time, latency, Bit Error Rate (BER). The values of these parameters with respect to different applications are given table 2.4:

Table 2-4:Selected BAN Sensors and Requirements [66]

Sensors	**Data Rate**	**Nodes Required**	**Network Topology**	**Setup Time**	**Latency**	**BER**	**Battery Life**
EMG	<1.536Mbps	<6	Star	<3 sec	< 250ms	$<10^{-3}$	>7 days
Glucose Sensor	<10kbps	2	Star	<3 sec	< 250ms	$<10^{-10}$	>7 days
Drug Dosage	<1 Mbps	2	Peer-to-peer	<3 sec	<250ms	$<10^{-10}$	>1 day
EEG	86.4kbps	< 2	Star	<3 sec	<250ms	$<10^{-10}$	>7 days
ECG	72 kbps	< 6	Star	<3 sec	<250ms	$<10^{-10}$	>7 days

2.6.2. Power consumption

Due to the fact that the senor nodes are tiny in size, their source of energy (battery) is much tinier which means it will store very minimal energy. During wireless communication, different techniques are used to save power. Some of them are as follows; avoiding unnecessary retransmissions, reducing the frequency of sending network control messages, reducing the size of message headers, and using the standby or sleep mode whenever possible [20].

2.6.3. Quality of Service (QoS)

Different data require different QoS, therefore important QoS parameters such as transmission delay, reliability, link quality are always different so as to fulfil the requirement of the data being monitored.

2.6.4. Compatibility

There must be compatibility for example between radio frequency transmission and communication standard compatibility, interface between biomedical equipment and Food and Drug regulatory Authority (FDA) compatibility, and bio-sensors need biocompatibility [20].

2.7. SUMMARY

This chapter presents an overview of BANs. Section 1 defines WBAN in details and explains what it can do. Section 2 highlights a brief history of BSN, starting from 1995 till date. Section 3 gives a detailed information on WBAN applications which are broadly medical and non-medical applications. Section 4 lists and explains the characteristics of WBAN such as types of nodes, various types of topologies to deploy the sensors, communication architecture, types of layers that are used in BSN and security. Section 5 highlights the comparison between WBAN and WSN. Section 6 mentions the technical requirements of WBAN.

CHAPTER 3

This chapter surveys previous literature works carried out in the area WBAN in the perspective of routing protocols and it will provide more detail in QoS and energy efficiency. In this chapter, several important methods are studied and shortcomings of those methods which will lead to the development of new algorithms in WBAN are provided.

3.1. CHALLENGES OF ROUTING IN WBAN

Due to stringent resource constraint and the harsh environmental condition of WBAN and because it is similar to WSN and Ad-hoc networks, WBAN has its own challenges in addition to that of WSN and Ad-hoc. Routing challenges of WBAN are given below:

3.1.1. Local Energy Awareness

The transmission and receiving between the sensor in the network needs to be distributed fairly to balance the power usage and avoid hole in the network.

3.1.2. Postural Body Movements

Body movement especially of the arms, head and legs affect the link reliability of the network. For that reason, routing protocols that are adaptive should be considered in proposing a routing protocol.

3.1.3. Global Network Lifetime

BSN network life time can be referred to as the period the network begins operating to the period it becomes severely damaged, which results to hole in the network such that the destination becomes unreachable. Network life time is more important in WBAN than WSN and Ad-hoc because recharging or replacing batteries in implanted is infeasible [36].

3.1.4. Temperature Rise and Interference

The sensor's transmission power need should be minimized to a avoid interference and tisue damaging by heating as a result of high transmission power.

3.1.5. Limitation of Packet Hop Count

The only topology that is allowed in BAN is single hop and multi-hop star topology, according to the IEEE 802.15.6 standard. Single hop results to significant energy depletion and low delay however, multi-hop result to low energy depletion and significant delay. Therefore, it is essential to consider the pros and cons of both topologies while designing a routing protocol.

3.1.6. Resource limitation

BSN has a strict resource constrain in terms of memory, communication rate, power, computational capability causes the nodes to fail.

3.1.7. Heterogeneous Environment

Different sensors sense and monitor different data, therefore, they require different QoS requirements. For that reason, quality-of-service provision in WBAN can be reasonably tasking.

3.2. CLASSIFICATIONS OF BAN ROUTING PROTOCOLS

During the past decade researchers proposed numerous BAN routing protocols [37]. The most common classification of BSN routing protocols found in literatures are: cluster based, QoS based, cross-layer based, and thermal based routing. The classification of BSN routing protocols can be seen in figure 3.1. The following sub-section gives an overview of different BSN routing protocol classes:

3.2.1. Cluster based routing protocols

The first category of routing algorithms in WBAN is the cluster based routing protocol. The sensor nodes are in the network form smaller groups called clusters and only one node is selected in each cluster and that node is called the cluster-head of the cluster. The sensor nodes in every cluster sends their data packet to their respective cluster-heads and the cluster-head sends their respective accumulated data to the coordinator. The goal of this routing protocols is to reduce the amount of single-hop communications from the body nodes to the sink [37]. Significantly high overhead and delay in relation to choosing a cluster is the main limitation of cluster based routing. The different type of cluster based routing protocols provided as follows: (i) Anybody protocol (ii) HIT, and (iii) Cluster Based Body Area Protocol. A brief overview of the protocol is giving in the sub-section below.

3.2.1.1. *A self-organization protocol for Body area networks (AnyBody).*

A self-organization protocol for Body area networks was designed to limit the number of single-hop transmission of sensor nodes to sink. The proposed protocol is based on LEACH routing protocol [38]. It evenly distributes energy depletion by selecting its cluster-head at fixed period of time. However, the work is limited by lack of information on reliability and energy-efficiency.

3.2.1.2. *Hybrid Indirect Transmissions (HIT)*

Another development to the LEACH technique is HIT [39] that procedures connection by joining the clusters that increase energy management. It is the hybrid of clusters and chains. The technique used in HIT improves the energy efficiency however, network reliability is a major issue.

3.2.1.3. *Cluster Based Body Area Protocol (CBBAP)*

The duty of each node is to sense and monitor the vital signs while, the coordinator collects that sensed data packets and forward them to the data base server. The power control model depends on the transmission distance and it consumes huge amount of energy while transmitting.

3.2.2. Cross-Layer Algorithms

This class of routing protocols bring together the issues of the network layer and the MAC layer. Although these protocols provide little power depletion and interaction between the protocols, they cannot guarantee great performance in cases of great path loss and body movement. Some examples of cross-layer routing techniques are outlined in the following sub-sections.

3.2.2.1. *Wireless Autonomous Spanning Tree Protocol (WASP)*

The protocol reduces power depletion and end-to-end delays in a circulated way to deliver average access format and traffic algorithm, resulting in greater throughput and lesser power consumption [40].

3.2.2.2. *Cascading Information retrieval by Controlling Access with Dynamic slot Assignment (CICADA).*

The technique is the upgraded form of WASP. This method is dependent on multi hop mobile BAN [41] and TDMA scheduling. It minimizes end-to-end delay and power depletion.

3.2.2.3. *Timezone Coordinated Sleeping Mechanism (TICOSS)*

The proposed protocol configures the shortest path route to the wireless body area network sink, conserves power and reduces concealed terminals that increase IEEE 802.15.4 operational life for great traffic situations and enhances IEEE 802.15.4 to maintenance mobility [42].

3.2.2.4. *Biocomm and Biocomm-D (BIOCOMM).*

The Biocomm and Biocomm technique was proposed to improve entire network operation.

Every sensor employs the shortest route to transfer packet to its cluster-head. Each body sensor node data contains a predefined number of hops and the body sensor data is dropped if the number of predefined jumps exceeds.

3.2.2.5. *Cross Layered Broadcast Protocol (CLBP)*

The Cross Layered Broadcast technique was designed in [43]. The CLBP protocol is designed for movement and a multi-hop topology. This powerful protocol for accurate human body postures in order to improve synchronization and medium access.

3.2.3. Temperature-based Algorithms

When the biosensors are operating the human body, because they the nodes communicate wirelessly, they generate electromagnetic field. This field leads the radiation absorption, resulting to temperature rise, possible damage of sensitive organs, and reduction of blood flow [44]. Specific Absorption Rate (SAR) can be referred to as the quantity of radiation power taking in by the body tissue as the shown in (3.1) [45].

$$SAR = \frac{\sigma |E|^2}{\rho} \left(\frac{W}{kg}\right) \tag{3.1}$$

In eq. (**3.1**), E represents the electric field, σ is the electrical conductivity, and ρ is the tissue density. As mentioned in [45], contact with Specific Absorption Rate of 8 W/kg for 15 minute results to grave tissue destruction. The primary goal of all temperature based routing protocol is to avoid hot-spots. Traffic control protocol and reducing the radio's communication energy can be used to limit the tissue heating. This objective can be achieved by balancing the communication between the sensor node.

3.2.3.1. *Thermal Aware Routing Algorithm (TARA)*

The aim of this technique is to reroute the data packet from high temperature zones to a low temperature zones. Shortest path algorithm is selected when the number of hops reach three. However, the protocol does not consider low network lifetime, reliability and packet loss ratio.

3.2.3.2. *Least Temperature Routing (LTR)*

This technique is an improvement on TARA. In this protocol, every node has a predetermined number of hops that it is allowed. The aim is to avoid unnecessary looping and hoping. Moreover, in order to further reduce unnecessary loops and hops information has been communicated to a "coolest" neighbor node then, it will be communicated to "another coolest" neighbor body sensor so as to evade looping.

3.2.3.3. *Adaptive Least Temperature Routing (ALTR)*

The working principles of LTR is the same as ALTR with some modification. In this protocol, If the information's number of hops is less than MAX HOPS ADAPTIVE then, the information will be communicated as least temperature routing, however, if number of hops surpasses the MAX_HOP_ADAPTIVE then, the information will be delivered to its target location by using Shortest Hop Algorithm [46].

3.2.3.4. *Relay-based Thermal-aware and Mobile Routing Protocol (RTM-RP)*

The protocol was designed in 2016 to find a solution the challenge of great temperature rise, high power depletion, throughput, and latency by handling critical restraints for example movement and priority of data. However, reliability of not considered in the protocol.

3.2.3.5. *Thermal Aware – Fail Safe Fault Tolerant (TA-FSFT)*

This protocol was proposed in 2016 as well, its aim was to avoid the to harm to the tissues of body of the human being and find a solution to the thermal dissipation. In the algorithm, the patient's situation is categorized as ordinary, above ordinary and not ordinary. The ordinary state means the patient's health is optimum. While, in the case of beyond ordinary state, the patient needs round the clock monitoring. In case of unusual state, patients in a life-threatening state and need to be hastily given medical attention. The FSM is used to model the condition whereas, the Markov model is used to examined the condition of the sick people.

3.2.4. QoS-based Routing Algorithms

QoS routing technique is the final class of routing protocol to be explained. They can be observed from two perspectives; network (reliability, delay and energy efficiency) and user perspective [47]. QoS-based routing protocols are modular based, whereby, each module represents a different QoS metric and they function by coordinating with one another. The widely used modules are reliability-sensitive, power efficiency, and delay-sensitive module. While these algorithms provide low end-to-end delay, high reliability, and high packet delivery ratio, the packets undergo difficulty from high complication because of the design of numerous modules according to dissimilar QoS metrics. Below is a brief description of some of the QoS-based and Energy efficient routing techniques.

3.2.4.1. *Routing Service Framework (RSF)*

RSF was proposed in 2007 so as to offer precedence based routing function to user applications. Functions of RSF are as follows; prioritized packet routing, quality-of-service conscious route construction and preservation, adjustive network traffic, offer response to the employer applications on specific network situations, and Application Programming Interfaces (APIs). RSF is also modular and made up of for modules [48].

3.2.4.2. *LOCALMOR protocol*

The LOCALMOR protocol is a QoS and geographic based routing protocol proposed in 2009. Its purpose was to classify the traffic of data into various classes according to the necessary QoS performance metrics where dissimilar methods and routing metrics were provided for each class. The system architecture of this protocol is provided in the figure 3.1 [49].

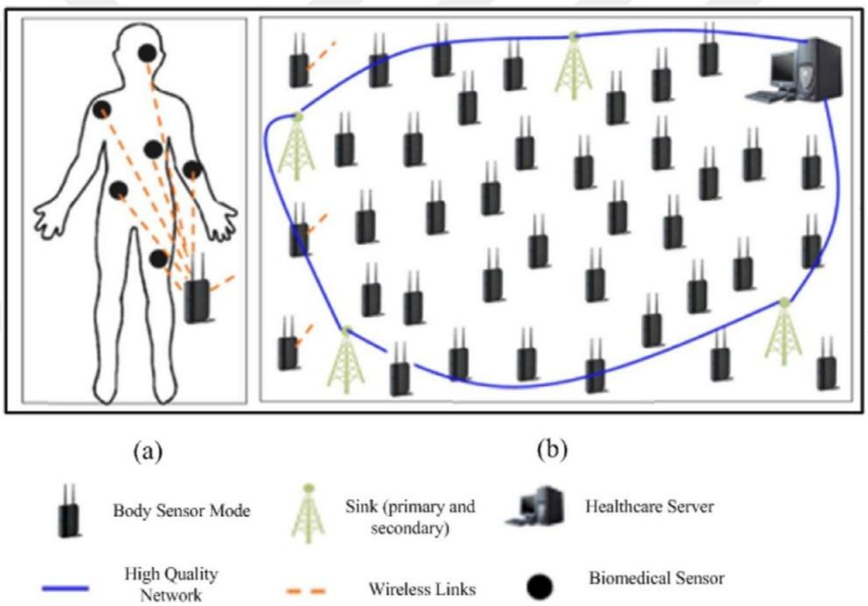

Figure 3.1: Network architecture of the LOCALMOR protocol: (a) Biosensor network architecture and (b) indoor network architecture [49]

3.2.4.3. *Data-centric multiobjective QoS-aware routing protocol (DMQoS)*

The aim of Data-centric multiobjective QoS-aware routing protocol routing technique was to improve reliability and decrease delay, however, it provides little or no discussion on energy management. Data traffic are categorized into different categories according to their data types. The goal of the protocol is to deliver QoS services for each traffic category [50].

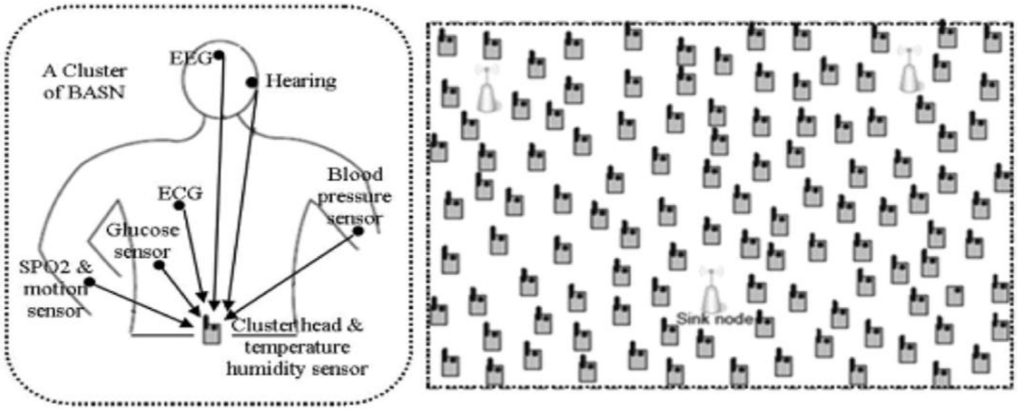

Figure 3.2:The network structure of DMQoS protocol [50]

3.2.4.4. *Energy aware Peering Routing (EPR)*

Authors in [51] proposed an Energy Aware Peering Routing technique to increase the network lifetime and total network traffic. The data of patient is classified into normal, emergency, delay sensitive, and reliability sensitive data to prevent network traffic. The aim of the technique is to observe the health of the patient in an indoor environment.

3.2.4.5. *QoS aware Peering Routing for Delay sensitive data (QPRD)*

QoS aware Peering Routing for Delay sensitive data is a modification of EPR in which the data packet of patients is grouped into DSP and OP. The aim of the protocol is to decrease the end-to-end delay and offer a method to find the optimum path for the two types of data based on their Quality-of-service requirements.

3.2.4.6. *Link aware and energy efficiency protocol for WBAN (LAEEBA) and cooperative-LLEEBA (Co-LLEEBA)*

Link aware and energy efficiency protocol for wireless body sensor network (LAEEBA) and cooperative-LLEEBA (Co-LLEEBA) are presented for power capable routing [52]. In two of the protocols, best route is picked. At this point, cost function for separate body sensor is computed by sink node according to distance and remaining power. This cost function is calculated in making choice in which every body node makes choice to be the intermediate node that forwards the data. Additionally, sensor nodes which are termed as advanced partook in communication so as to implement Co-LAEEBA protocol. In two of the protocols, decision to forward data packets made by sensor node is efficient (i.e.) if several nodes decided not to be forwarded nodes sensor nodes, then communication in the sensor network is regarded as unreliable. Further, cooperative Link aware and energy efficiency protocol for wireless body sensor network algorithm needs extra nodes that are advanced to have high energy but will lead to rise in cost.

3.2.4.7. *An Energy Efficient Routing Protocol for WBAN*

A routing algorithm which was energy effective is presented in wireless body area network to decrease energy depletion as well as to optimize stability [53]. Sensor node which have greater outstanding power, shorter distance to coordinator as well as other sensor nodes is designated as ideal forwarder node aimed at communication. Additionally, scheduling scheme based on time division multiple access based was incorporated to minimalize depletion of power. In this algorithm, binary sensor nodes were allocated for sensing only data that are critical. On the other hand, there is no evidence to suggest that critical data is generated or not it is not. Critical data similarly follows time division multiple access scheduling which result to rises in delay for communication of critical data.

3.2.4.8. *A Novel Energy Efficient medium access control Protocol for WBAN*

Power capable information communication in WBAN is attained by a quasi-sleep scheduling based medium access control technique [54]. In this technique body nodes hardware is improved so as to maintenance capable important communication information. In this technique, body sensors are arranged in tree topology to maintenance equal based time division multiple access scheduling. The nodes obtainable in bottommost ranks were allocated using fewer quantity of time periods and quantity of time periods is enlarged with rise in stage of body sensors in tree. Accordance to allocated interval periods nodes were moving back and forth amongst sleep and communication states simultaneously. Through exploiting improved sensor hardware, sink was capable to wake-up the whole body sensors for emergency information communication. Life-threatening information communication via tree topology rises communication delay. Similarly, body sensors existing in high-level of tree have limitation of higher power depletion because of concurrent data forwarding.

3.2.4.9. *MAC protocol for WBAN with QoS Provisioning and Energy Efficient Design*

Time division multiple access based medium access control protocol was exploited to accomplish improved quality of service without rise in power depletion in wireless body area network [55]. At this point the communication demand was dynamically different in terms of network grade and application architecture of WBSN. In this technique the issue of collisions, idle listening, and overhearing were addressed by medium access control scheduling. Sleep scheduling also included in time division multiple access protocol according to medium access control protocol. A priority based adaptive medium access control (PA-MAC) algorithm was included in packet communication in wireless body area network [56]. In priority based adaptive medium access control technique, originally traffic was categorized into life-threatening, on-demand, ordinary, and non-health groups. Several channels were exploited for example beacon channel, and data channel. In the same way, binary dissimilar information communication processes were presented for dissimilar communication for example command message communication and uninterrupted message communication. Nevertheless, in two of the techniques life-threatening information also come with time division multiple access scheduling which rises communication delay.

3.2.4.10. *Priority consideration in inter-WBAN data scheduling and aggregation for monitoring systems*

In order to meet the quality of service requirements, two scheduling techniques for instance inter-WBAN scheduling and aggregation (IWSA) and inter wireless body area network scheduling (IWS) techniques were presented [57]. These binary techniques were concentrated on permitting compromise amongst delay and throughput. Therefore, life-threatening delay was taken as foremost metric in scheduling. The responsibility of scheduler was to calculate life-threatening delay for all information and to schedule the information in precise way in order that delay for all delay sensitive information was reduced. Taking into account of only single metric is not sufficient for scheduling method.

3.2.4.11. *Reducing Power Consumption in WBAN A novel data segregation and classification technique*

To be able to reduce the power depletion, health information created by wireless body area network was categorized into dissimilar groups [58]. In this method, health information was gathered using particular sensor positioned in wireless body area network. At that point collected information was categorized into crucial, less-crucial, and non-crucial packets. Information grouping at body sensor rises overhead at body sensor. Equally, this technique is not capable of managing various sensor nodes.

3.2.4.12. *A 4-tiers architecture for mobile WBAN based health remote monitoring system*

Three dissimilar processes for instance organization, scheduling, and vertical handover choice were included in wireless body area network based remote observing scheme [59]. Originally information was categorized and then information was scheduled by priority weighted round robin system. This technique was intended to decrease delay and to increase throughput in the network. However, waiting time for life-threatening information communication is improved as a result poor scheduling.

3.2.4.13. *iM-SIMPLE: iMproved stable increased-throughput multi-hop link efficient routing protocol for WBAN*

iM-SIMPLE routing algorithm was proposed to maintenance mobile sensor nodes in wireless body area network [60]. In this method, time division multiple access scheduling technique was utilized to decrease energy depletion. Selection of intermediate nod was accomplished by taking into account distance and residual energy metric. In iM-SIMPLE algorithm, participation of few metrics for intermediate node choosing rises amount of retransmissions which result to greater power depletion. This technique is not capable of distinguishing life-threatening packets so as to fulfil the quality of service requirements for life-threatening packets.

3.2.4.14. *Reliable ad hoc on-demand distance vector (RelAODV) routing protocol*

Power effective information communication was facilitated by reliable ad hoc on-demand distance vector (RelAODV) routing protocol [61]. At this point body nodes were permitted to monitor two dissimilar modes for example relay mode and single-hop transmission mode. Processing of on sensor processing was utilized before information communication to execute information grouping. In this technique, nodes in single-hop transmission mode undergo greater power depletion because single hop communication eats at of energy. Allowing on sensor processing is foremost goal behind power drop and overhead amongst nodes.

3.3. PATIENT MONITORING SYSTEMS

A considerable amount of patients monitoring systems have been proposed in literature. Some of the most important are as follows; CareNet [62], ALARM-NET [63], AID-N [64], and SMART [65].

3.3.1. CARENET

The CareNet patient monitoring system is a 2-tier system that sense, collect, route and forward the information to the coordinator. The coordinator then transmits the information to the medical record database, and then the users are able to access the data via patient portal service of the server as can be seen in figure 3.3 below. The use of a web portal with the patient's medical record system provides efficient access to the healthcare professionals [62].

3.3.2. SMART

Health care providers have reported cases in which the health of patients waiting at the emergency rooms deteriorate. If not given immediate medical attention, the patient's life can be put at risk. Hence, authors of [65] proposed a framework of patient monitoring in hospital emergency rooms named as the Scalable Medical Alert and Response Technology (SMART). Figure 3.4 shows the network architecture of the Scalable Medical Alert and Response Technology system.

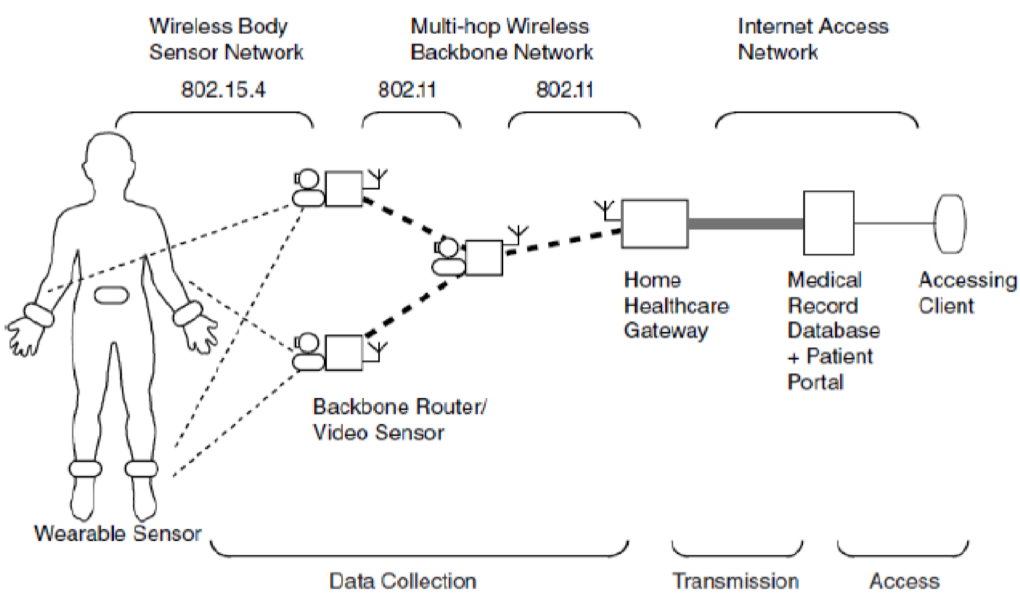

Figure 3.3:System architecture of CareNet

The goal of the scheme is to determine if the sick person waiting in the emergency room needs urgent support or not. This is achieved by placing the sensors in the sick person's body, then the sensors sense the sick person's information and transfer it wirelessly to a central computer for analysis. The central computer performs all the necessary computations to determine if the patient needs urgent attention and alert is sent to the caregiver so that patient gets medical attention before his health worsen.

3.3.3. AID-N

The aim of Advanced Health and Disaster Aid Network (AID-N) is to deal with mass casualty incidents. AID-N consists of 3 levels of devices as shown in figure 3.5. The first level is a network of body sensors.

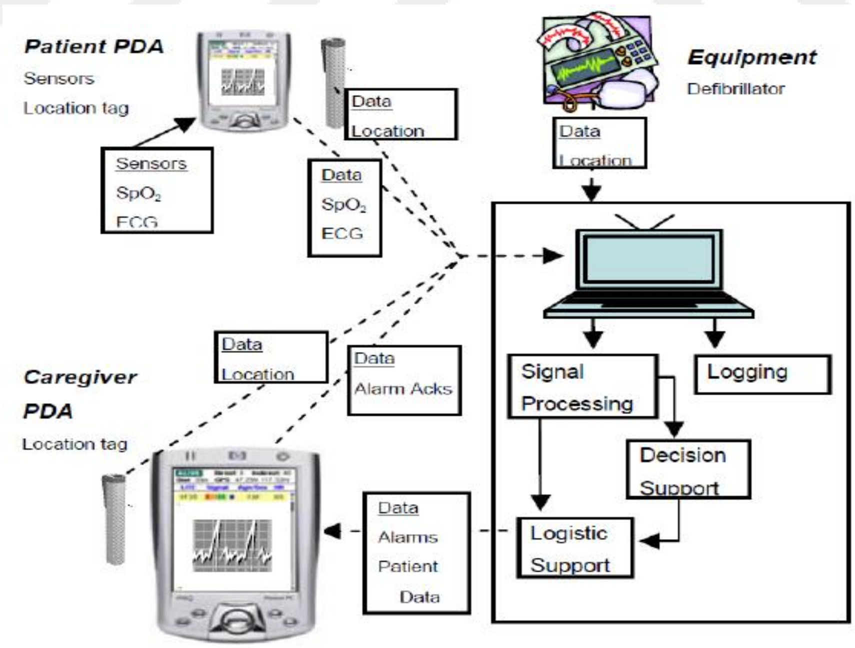

Figure 3.4: Architecture of SMART

Since these sensors are small and have stringent resource constraint such as memory, computational capabilities and communication rate, they are only able to collect and send these data to the level two devices (laptops and PDAs). These level two devices also known as servers transfer the data packet to level three devices (central servers) through the internet. The users who are authenticated can logon to the central servers and analyze critical information. However, Link or server failure can discontinue the observing development [64].

3.3.4. ALARM-NET

ALARM-NET system is a combination of heterogeneous sensors such as wearable and environmental to provide solution for assisted-living and residential monitoring. The goal assisted-living and residential monitoring is to accumulate and examine BAN data packet. However, reliability, link failure and lack of real-time display of data was not address.

Figure 3.5:Architecture of AID-N system

Hence, authors in [66] filled the gap by developing a peering framework emphasizes on the real-time display of body area network packet.

3.4. SUMMARY

While WBAN is operating and routing data packets, it faces many challenges such as limitation in hop count, temperature rise, heterogeneous environment, network life time and postural body movement. The reason for encountering these challenges is as a result of stringent resource contraint. Depending of the problem to be addressed and application of the body are network, routing protocol can be classified into cluster based, cross-layer, temperature and quality-of-service-based routing protocol. The chapter concludes by discussing brifely about the different types of patients monitoring systems. Such as CARENET, SMART, AID-N, and ALARM-NET patients monitoring systems. In general, all the systems framework work by sensing, analysing and transmitting the data to coordinator, then through the internet to the database server where the authorised doctor or person can access the data.

CHAPTER 4

Increasing network life time and throughput, whereas reducing energy depletion, delay, and dropped data are important performance parameters to be achieved in our proposed EQ-WBAN architecture. All the components that makes up our proposed EQ-WBAN architecture such as the modified MAC protocol IA-MAC, PWR routing protocol, GSS scheme based sleep scheduling, SMNN classifier and frame aggregation are discussed in great detail. Exhaustive simulations in the OMNeT++ based simulator Castalia 3.2 have been performed to demonstrate that the proposed EQ-WBAN outperforms other well-known energy and QoS algorithms. The remaining part of the chapter is structured shown in the sections and sub-sections: Section 4.1 explains and discusses the motivation and related work. Section 4.2 provides the proposed Energy aware and quality-of-service wireless body area network. Section 4.3 details the performance evaluation of the proposed EQ-WBAN. Section 4.4 concludes the chapter by summarizing what was presented.

4.1. MOTIVATION

In order to modify mobile body nodes in wireless body area network, iM-SIMPLE routing protocol was developed [60]. In this design, time division multiple access scheduling algorithm was exploited to extend network lifetime. The choosing of forwarder node was achieved by taking into account distance metric and residual energy metric. In an iMproved stable increased-throughput multi-hop link efficient protocol, participation of few number metrics for forwarder node choosing rises the amount of retransmissions which result to greater power depletion. This technique is not able to distinguish critical data packets so as to fulfill quality of service for critical data packets. Power management information communication was utilized by dependable ad hoc on-demand distance vector (RelAODV) routing technique [61]. At this point, body sensors were permitted to monitor dual dissimilar modes for instance multi-hop mode and direct mode. On sensor handling was utilized prior to information communication to achieve information grouping. In this technique, nodes in direct mode experiences greater power depletion because single hop communication depletes more energy. Supporting on sensor handling is the foremost purpose for power drop and overhead between body sensors.

Data scheduling and accumulation technique was presented for IEEE 802.15.6 and IEEE 802.11.e based wireless body area network [57]. At this point, scheduling was achieved according to critical delay which was calculated as seen in eq. (**4.1**):

$$\text{Critical Delay} = TLD - WD \qquad 4.1$$

TLD represents the accepted latency delay and WD was waiting delay. WD was given as shown below:

$$WD = t - T_{arri} \qquad 4.2$$

The packet arrival time was given as T_{arri} at time t. At this point, when subsequent rule is met, then arrived packet is dropped,

$$\text{Critical Delay} > WD \qquad 4.3$$

This technique drops data irrespective of kind of data which may serve emergency information. Therefore, in this technique data drops reduces entire performance of the network. Furthermore, emergency data are also combined into one particular frame by way of normal data which results to greater communication delay for critical data.

Super frame format of IEEE 802.15.4 based medium access control algorithm was improved to maintain power effectiveness, delay effectiveness, and via efficiency in wireless body area network [67]. The information packets were categorized into ordinary and critical data packet according to their body nodes. Then the data were given with importance level by taking into account packet type, packet size, and data generation rate. Sleep regulator scheme was maintained by discrete time finite state Markov model. Nevertheless, packet grouping by taking into account sensor node is not effective. At this point, great precedence is given to data with lesser size which rises communication delay for critical information with greater size of packet.

Consequently, in wireless body area network energy management and quality-of-service enhancement are concentrated on by numerous academics however, the outcomes are not satisfactory and convincing enough. As a result, we outline our major goals in wireless body area network as shown below:

- To optimize network lifetime
- To reduce energy depletion
- To develop quality-of-service metrics such as throughput and delay

4.2. Proposed Energy Aware QoS Guaranteed WBAN

This part of the thesis provides detail information on the proposed energy efficient and quality-of-service assured wireless body area network with novel schemes and protocols. Every critical scheme take part in different processes for example routing, scheduling, and grouping and are explained in depth in this section.

4.2.1. Network Overview

Energy aware QoS guaranteed wireless body area network architecture consist of 'n' amount of body sensor nodes (BSN), coordinator (CR), sink node (SN), and emergency sink node (E-SN). The complete architecture of our proposed work is showed in figure 4.1 and the brief explanation of the above abbreviation is given below:

BSN: This represent the body sensor nodes also known as biosensors particularly intended to observe human health conditions and it is extensively used in wireless body are network and electronic-healthcare systems. Foremost duty of body sensor node is to sense the patient vital signs and to reports the sensed information to sink node at regular intervals. Some examples of BSNs are as follows: electro encephala gram (EEG) sensor, Insulin sensor, Oxygen sensor, Electro cardio gram (ECG) sensors, motion sensor, CO_2 gas sensor, blood pressure sensor, temperature sensor, etc.

CR: Coordinator is a computationally more powerful device compared to the BSNs. The major duty of the coordinator is to collect all sensed information from body sensor nodes. Then the collected sick person's vital signs such as body temperature and pressure are communicated to sink node. In our proposed work, the coordinator's duty is also to categorize the arriving data into normal and emergency.

SN: This is known as the destination of the whole bio medical packet communicated from body sensor nodes. With the sink node, the entire biomedical information are moved to a server which is located in the cloud for additional actions such as illness diagnosis, recommendations generation etc. In our proposed work, normal data and near-emergency packet are grouped by coordinator and accepted by sink node.

E-SN: Just like the actions of SN, E-SN main duty is to receive all emergency data from CR. At this point, the sink node and emergency-sink node perform frame aggregation so as to decrease communication delay and energy depletion.

In EQ-WBAN, IA-MAC is developed so that it determines the criticality of the information which was sensed. In insistence aware medium access control protocol, the medium access control protocol header is improved to show the criticality stage of information minus rise in overhead. Accordance to criticality stage, routing through single-hop or multi-hop communication is selected. At this point, Prior-knowledge based weighted routing algorithm is integrated in multi-hop routing so as to choose the ideal route for information communication. In Prior-knowledge based weighted routing algorithm, energy management is major concern for choosing a path. Energy consumption is further reduced by developing another energy management scheme named as graph based sleep scheduling scheme.

In coordinator, split and map based neural network classifier which serves data classification minus time delay is integrated. According to the type of packet, the packet is communicated to sink node or emergency-sink node. Frame aggregation which decreases communication delay and maximize throughput is utilized in the two sink nodes. Every important algorithm included in EQ-WBAN is provided in detail in the section below.

4.2.2. IA-MAC

In our proposed work, medium access control header format is improved with added fields "data type and hop count". The conventional medium access control header frame consists of static length medium access control header, variable length frame body, and static length frame check sequence (FCS). At this point, the standard length of medium access control header is 7 octets in which several sub fields are comprised. Medium access control header comprises frame control field with 4 octets length, recipient ID with 1 octet length, sender ID with 1 octet length, and body area network ID with 1 octet length.

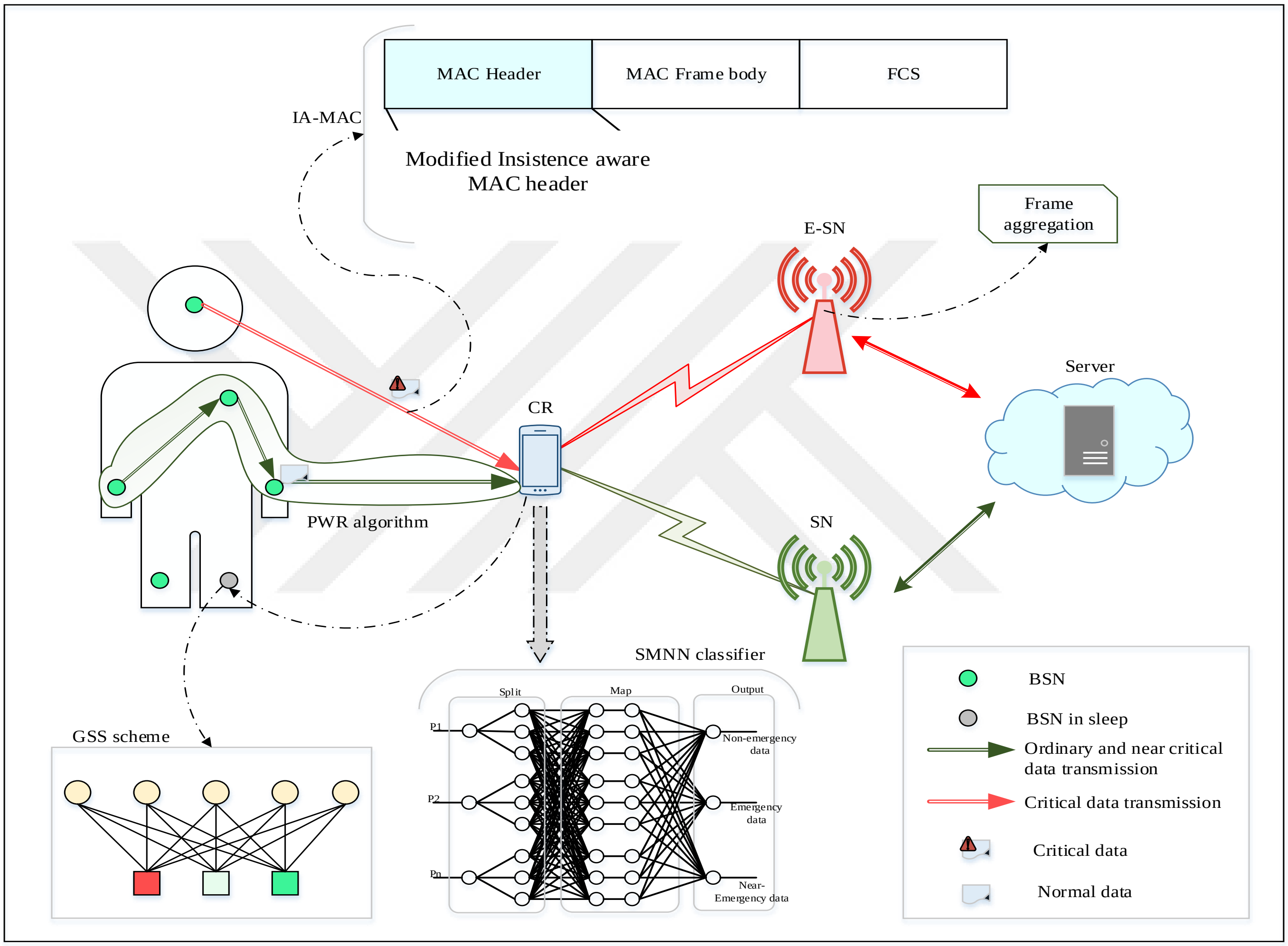

Figure 4.1: EQ-WBAN Architecture

At this point, we have exploited sender ID, recipient ID, and BAN ID bits to comprise added fields. The improved Insistence aware medium access control header is illustrated in figure 4.2.

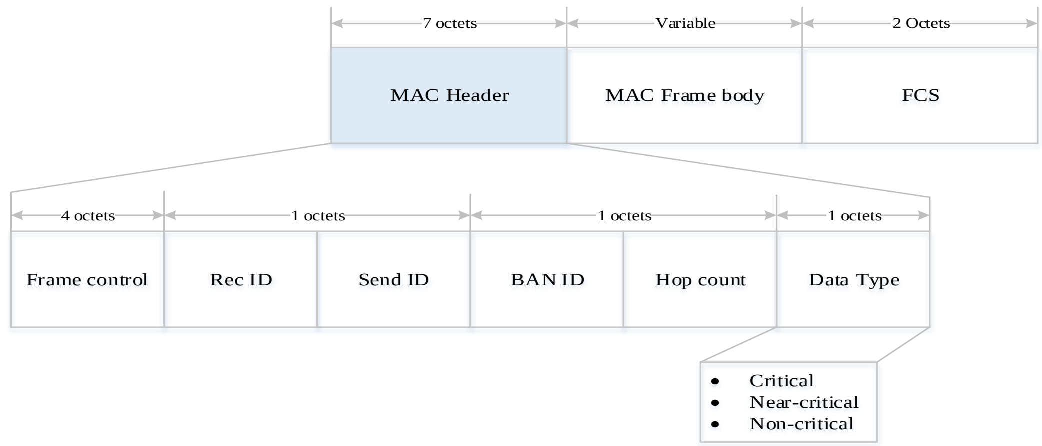

Figure 4.2: IA-MAC Format

As it can be seen in figure 4.2, IA-MAC header comprise of data type and hop count fields. At this point, recipient ID denotes ID of destination which is the coordinator. Send ID denotes as ID of body sensor nodes which is source of the packet. Body area network ID represents the ID of body area network in which the source node is present. Rec ID and Send ID shares 1 octet size whereas body area network ID and hopcount shares 1 octet. Remaining 1 octet is allocated for data type field. In this field data are represented as critical, near-critical, and non-critical. In order to decrease overhead this field is represented in binary values as shown in table 4.1.

Table 4-1:Binary representation of data type field

Data type	**Binary representation**
Critical (C)	00
Near-critical (NrC)	01
Non-critical(NoC)	11

The data type is decided by body sensor nodes according to the criticality level of every sensor. Overall, wireless body area network uses dissimilar wireless body area network s for different purpose.

For example, if the information that is sensed from temperature body node shows above 99^0, then this information is regarded as critical data. In the same way, every wireless body area network has critical, near-critical, and non-critical values. Then data type field is allocated with ideal value according to sensed information value. Accordingly, participation of Insistence Aware Medium Access Control protocol in our proposed work permits wireless body area network to decide critical level of information. According to emergency state of information, routing is executed in wireless body area network.

4.2.3. PWR based routing

The proposed work exploits Prior-knowledge based weighted routing algorithm to accomplish energy and quality-of-service efficient algorithm. In Prior-knowledge based weighted routing algorithm, both single hop and multi-hop communication are executed with regards to the type of data that was sensed. The choice on single hop or multi-hop transmission is made as can be seen in eq. (4.4) below:

$$Decision = \begin{cases} Single - hop & Datafield = 00, \\ Multi - hop & Other\ wise, \end{cases} \qquad 4.4$$

The data is transmitted directly to coordinator, when the decision to transmit the data using single-hop communication is made, it is important to note that the decision on selecting single-hop transmission is made only when the information is critical. The sensor node that holds critical information must be served without any time delay because the critical information has a lot of impact on the health of the patient. Consequently, the main reason for opting for single-hop transmission is the fact that it decreases delay in transmission with a price of little energy depletion. In the case of multi-hop communication, the most optimal next hop sensor node is chose according the weight value which is computed by taking into account several important metrics. Additionally, in order to rise throughput metric by permitting reliable communication, the PE with neighbor node also involved in Prior-knowledge based weighted routing. The amount of data successfully communicated through a particular body sensor node is used to compute the past experience (PE). To determine PE value for neighbor BSN, each and every node keeps a past experience table (PE table). So as to decrease the space complexity and overhead, the PE table only updates the amount of successful transmitted data. At this point, weight value for every neighbor sensor is calculated as show in eq. (4.5):

$$W_i = \sum(E_i, L_i, PE_i, SS_i) - \sum(D_i, \delta_i) \qquad 4.5$$

In equation (4.5) following metrics are considered,

W_i	-	Weight value of i^{th} BSN
E_i	-	Residual energy
L_i	-	Link stability
PE_i	-	Past experience
SS_i	-	Signal strength
D_i	-	Time delay
δ_i	-	Distance between i^{th} BSN and coordinator

The optimal next hop for data transmission is selected based on the BSN which has the highest weight value. In this way, every body sensor node sends the data to the optimal next hop node. Transmission delay and power depletion is minimized and throughput is increased as a result of participation of multiple significant metrics. At this point, a sensor node attains the highest weight value if it possesses high residual energy, link stability, PE, signal strength, lower delay, distance, and transmission power than every other node. Non-critical data are communicated in accordance with this process. Now, eq. (4.6) shows the computation of link stability between two nodes;

$$L_i = \frac{R}{dis(BSN_i, BSN_j)} \quad 4.6$$

The link stability between body sensor node$_i$ body sensor node$_j$ is calculated according to the coverage range of body sensor node$_j$ (R) and distance between two nodes (dis (BSN_i, BSN_j). On the other hand, this technique presents communication delay for near-critical data which are to be processed within time limit. This issue is solved by taking into account hop count in near-critical packet communication. In the proposed work, near-critical packet communication is supported by insistence aware medium access control. At this point, a predefined threshold value (Th) is taking into account or used for near-critical data communication. The whole forwarder nodes which receive packet increases hopcount value in the Insistence Aware Medium Access Control Protocol. Once the value is the same as the predefined threshold then the packet is communicated directly to coordinator. Therefore, taking into consideration that the hop-count is the most important metric for near-critical communication decreases the computational and time complexities.

Algorithm 1: PWR based routing	
1.	Begin
2.	For all $P_l \in P$
3.	If (Data field=00)
4.	Transmit $P_l \rightarrow CR$

```
     Else
       For all neighbor nodes
       Find W
         If Wi==High
            Select BSN_i → BF
            Transmit P_l → BSN_i
            BSNi inspect Pl
            If (Data field=01)
              Verify HC
              If (HC=Th)
                Transmit P_l → CR
              Else
            Else
              Find next hop neighbor
              End if
            End if
         Else
            Go to→step 6
         End if
       End for
   End for
   End
```

In algorithm.1, entire process that is in PWR algorithm is provided in detail. In Prior-knowledge based weighted routing, residual energy is regarded as most important metric so as to balance energy depletion whereas other important metrics contributes in reducing energy depletion and providing quality-of-service efficiency.

4.2.4. GSS based scheduling

WBAN operates by periodic monitoring, consequently, energy consumption because of idle listening leads to major energy consumption. By employing GSS scheme based on sleep scheduling, the problem of idle listening is resolved. In this scheme, during idle listening period, body sensor nodes are allowed to sleep. Duty cycle of body sensor nodes with M number of time slots are demonstrated in figure 4.3. Time slots are denoted as $\{T_1, T_2, T_3, \ldots\ldots, T_M\}$. In the assigned time slot each BSN, transmitting and sleeping is performed.

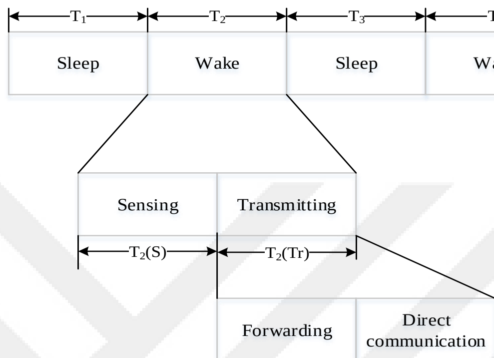

Figure 4.3:Duty cycle of BSN

Here, the two main states that each body sensor node follow are sleep and wakeup state. Sensing and transmitting are performed in the wakeup state by the nodes. Additionally, direct communication and forwarding communication are the two main actions performed in the transmission period. At this point, since direct communication consumes more energy, it is not always performed by sensor nodes. Direct communication is used only when the data that is sensed by the sensor node is an emergency data. Conversely, sleep scheduling in wireless body area should be conscious patient condition. This is because a patient may be sick and a have heart illness which necessitate uninterrupted observing of heart. In such patients, information from electrocardiogram sensor may involves with large number of critical and near critical data. At this point the electrocardiogram sensor should be in sleep state for a limited time period. Therefore, for each body sensor node, graph based sleep scheduling schedules the sleep and wake up time in an adaptive manner. At this point, the sleep time slots are allocated according to the amount of critical, near-critical, and non-critical information that are communicated.

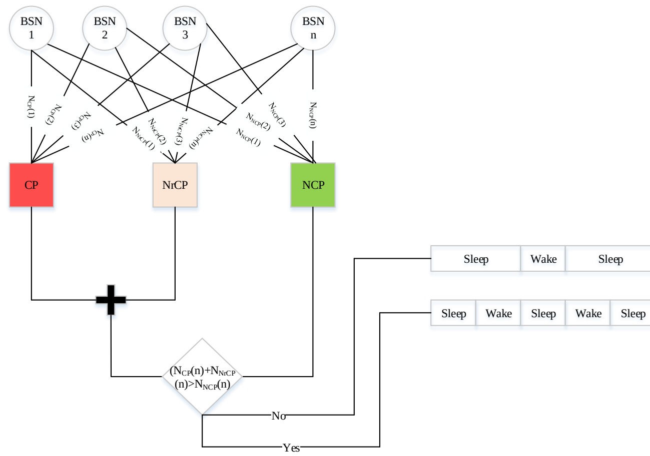

Figure 4.4:GSS scheme

Sleep wake-up slots are assigned for each body sensor node by the coordinator. Significant information of data type acquired from every body sensor node is held by CR. Then according to the amount of data in each type a weighted graph is constructed by the coordinator. The sleep and wake are given to every sensor by deducing from the graph. The weight graph depiction in graph based sleep scheduling scheme is demonstrated in figure 4.4. At this point, the weight value of body sensor node n with critical packet is represented by $N_{CP}(n)$, with near-critical packet is represented by $N_{NrCP}(n)$, and with non-critical packet is represented by $N_{NCP}(n)$. The body sensor network is regarded as critical body sensor network and allocated with least possible time slot for sleeping if overall amount of critical and near-critical packet is higher than amount of non-critical packet for body sensor nodes. Additionally, in order to avoid the node from being the forwarder node for all other nodes, the body sensor node ID is broadcasted in the network.

The sleep scheduling provided by CR are followed by the entire BSNs. Small sleep time is assigned to nodes with large amount of critical packets. However, due to the small sleep time, the node will consume large amount of energy in comparison to other nodes. In order to solve this problem, there should be decrease participation of the sensor from being forwarder node for other node's data communication. During the period of scheduling, coordinator broadcasts body sensor node ID which has high weight value compared to other body sensor nodes. After receiving that ID other body sensor nodes are not able to choose specific body sensor node as forwarder unless a different node ID is delivered by CR. Accordingly, power depletion for all body sensor nodes are balanced by graph based sleep scheduling algorithm.

Algorithm 2: GSS based scheduling

```
Begin
For each BSN_i∈BSN
    Compute N_CP(i)
    Compute N_NrCP(i)
    Compute N_NCP(i)
    Construct weighted graph
    N(i)= N_CP(i)+ N_NrCP(i)
    If N(i)<N_NCP(i)
        Assign sleep==T
        Goto sleep
    Else
        Assign sleep==T/2
        Broadcast ID(BSN_i)→other BSNs
    End if
    End for
    Update graph
End
```

Algorithm 2 above describes the scheduling process that is performed by critical data using GSS scheme. At this point the most important metric that increases the overall network performance is the criticality level of sensor node. Energy depletion because of idle listening is reduced by the use of GSS scheme.

4.2.5. Packet Classification by SMNN Classifier

Receiving all kinds of data packets from the whole BSN is the responsibility of CR. The CR is also responsible for classifying the aggregated data into normal and emergency data. The SMNN classifier carries out the classification process which speeds up the process of classification. In the beginning, the arriving data are separated and then mapped to conforming class in SMNN classifier. In order to decrease time waste for classification, the separating and mapping actions are accomplished over neural network. The parameters considered for classification are Packet size (PS), data type (DT), and time to live (TTL). At first all data are fed into input layer of neural network. After that, on each packet, the split and map phases are performed subsequently. All three features from each packet are split by the split phase. Data with similar features and fulfills specific requirements are mapped to same class in the map phase. The main reason for the participation of neural network is to decrease the time wasted during packet classification. Figure 4.5 shows the detail process of SMNN classifier. The extraction of all three features for classification of packets is performed by the split phase SMNN classifier. After that, in order to allocate data to conforming classes, the map phase apply the optimal conditions. According to the above requirements, data are divided into dual classes for example class 1 (emergency), and class 2 (Normal). Packet classification play important part in the proposed energy efficient and quality-of-service wireless body area network, because CR allocates data to conforming sink node according to the kind of packet.

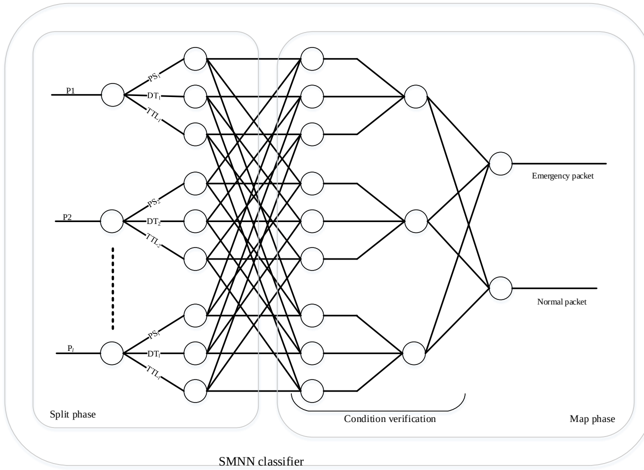

Figure 4.5:Packet classification by SMNN classifier

At this point, the algorithm steps below are performed to classify the arriving data into split and map based neural network classifier.

Steps involved in SMNN classifier	
Step 1:	Begin
Step 2:	Fed $P \rightarrow Input\ layer$
Step 3:	For each $P_l \in P$
Step 4:	Extract PS_l
Step 5:	Extract DT_l
Step 6:	Extract TTL_l
Step 7:	If (DT_l=00)
Step 8:	Assign $P_l \rightarrow Class$ 1
Step 9:	Else
Step10:	If (DT_l=01)
Step11:	If ($PS_l = High\&\&TTL_l = Low$)
Step 12:	Assign $PS_l \rightarrow Class$ 1
Step 13:	Else
Step 14:	Assign $P_l \rightarrow Class$ 2
Step 15:	End if
Step 16:	Else
Step 17:	Assign $P_l \rightarrow Class$ 2
Step 18:	End if
Step 19:	End if

Step 20:	End for
Step 21:	End

4.2.6. Frame aggregation

Frame aggregation can be referred to as the action of communicating two or more frames in a single transmission. Improving throughput by communicating multiple frames through single transmission is the most important objective of frame aggregation process. At this point medium access control service data unit (MSDU) aggregation scheme is exploited for frame aggregation. In order to improve throughput in EQ-WBAN, frame aggregation action is accomplished at both normal sink nodes and emergency. The gathered MSDU frame is made up of several Service Data Units. Each SDU's source and destination address are mapped to same transmitter and receiver address. Nevertheless, because all data packet has destination address which is named as monitoring server, this mapping action is not mandatory in our research. For further analysis and diagnosis, the accumulated frame is communicated to the monitoring server. Figure 4.5 illustrates the aggregated MSDU format.

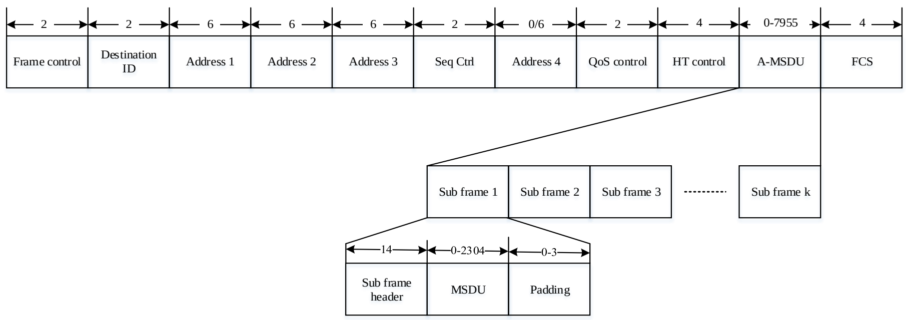

Figure 4.6:Aggregated MSDU format

The following fields: frame control, destination ID, address 1, address 2, address 3, Seq ctrl, address 4, QoS control, HT control, aggregates-MSDU (A-MSDU), and FCS are all included in the aggregated medium access control service data unit.

The aggregated medium access control service data unit consist of coming fields: frame control, destination ID, address 1 address 2, address 3, Seq ctrl, address 4, quality-of-service control, HT control, A-MSDU, and FCS. Then, for additional diagnosis, the aggregated medium access control service data unit frame is communicated to server. HT efficiency with minimum delay is as a result of the participation of frame aggregation procedure. Therefore, increase in the complete performance of the network is due to the participation of insistence aware medium access control, energy and quality-of-service efficient Prior-knowledge based weighted routing algorithm, criticality aware graph based sleep scheduling scheme, delay efficient packet classification, and throughput efficient frame aggregation scheme in energy and quality-of-service wireless body area network increases the whole performance of the network.

4.3. Performance Evaluation

In the performance evaluation part of this thesis, the performance of the proposed energy and quality of service wireless body area network architecture in terms of performance metrics such as energy consumption, packet drop, delay and throughput was evaluated. This part of the thesis is made up the following parts: simulation environment, and comparative analysis.

4.3.1. Simulation Environment

Simulation of the proposed work is carry out in Castalia 3.2 which is based on OMNeT++ environment. According to literature survey, NS-2 was found to be the most commonly used simulator for wireless sensor network; conversely, the best simulator for WSN, WBAN and other low-power devices was found to be OMNeT++ based Castalia environment, that is why it is used in to evaluate the performance of our work. Furthermore, since Castalia provides more routing models, network models, optimization algorithm, sensor network, supports high graphic user interface etc. we used it in our work. Therefore, we have implemented OMNeT++ based Castalia 3.2 in the simulation of EQ-WBAN. The experiment is made up of one coordinator as expected and 4 to 5 body sensors in simulation.

Table 4-2:Simulation parameters

Parameter	**Value**
Simulation area	1000*1000
WBAN Standard	IEEE802.15.6
Number of human	3
Number of BSN (For each human)	4-5
Number of coordinator	1
Number of sink nodes	2 (1 S, 1E-SN)
Number of end user	2
MAC header length	32
Packet size	2 kb
Pay load	Maximum 2000 byte
Bandwidth	20 MHz
Transmission rate	5 packets/second
Number of super frame slots	16
Slot duration	1 Sec
Data rate	1024

Transmission energy consumption	3.1 mW
Buffer capacity	32
Packet Interval	4s
Transmission power	10 mW
Simulation time	150 Sec

Table.2, listed outs the important simulation metrics involved in the proposed energy and quality-of-service wireless body area network implementation.

Table 4-3:Critical and non-critical data specifications

Sensor	**Critical**	**Near-critical**	**Non-critical**
Oxygen level	<60 (mm/Hg)	60-80 (mm/Hg)	80-100 (mm/Hg)
Respiratory	<15 bps	15-25 bps	25-40 bps
Heart rate	>100 bpm	80-100 bpm	60-80 bpm
Temperature	>100^{0}F	99^{0}F-100^{0}F	97.8^{0}F-99^{0}F
EEG	<7Hz	7-8Hz	>8 Hz

Table 4.3 depicts the criticality level of different sensor nodes. In the proposed EQ-WBAN, heart rate sensor, respiratory sensor, oxygen level sensor, and temperature sensor was used so as to gather the body's vital signs. After the data is collected, the level of criticality of each and every details determined in accordance to table 4.3.

Table 4-4:Obtained result for energy consumption

Process	Energy consumption
Sleep	0.02 mA
Reception	16.4 mA
Transmission	17 mA

Table 4.4 depicts, the result achieved for energy depletion throughout every process.

Table 4-5:Contention window for different data types

Data type	CW_{min}	CW_{max}
Critical	0	4
Near critical	4	16
Non-critical	6	30

The CW for dissimilar data types for example critical, near-critical, and non-critical are setup as shown in table 4.5. At this point, critical data is supplied with minimum CW period whereas non-critical information is supplied with maximum contention window period.

4.3.2. Comparative analysis

In the comparative analysis subsection, we analyzed the performance of our proposed EQ-WBAN with respect to the performance metrics. Comparisons are made with well-known researched for example [10], [68], and [57] according to energy consumption, network lifetime, dropped packets, throughput, and delay.

Table 4-6: Limitation in previous works

Previous work	**Limitations**
Co-LLEEBA[10]	• The choice of forwarder is made by sensor node itself is not efficient • Requires additional advanced nodes
QS-PS [68]	• Transmission delay is large as a result of participation of tree topology • Nodes presented in high-level in tree suffers from higher energy consumption
CD method [57]	• Large number of packets are dropped based on CD • Transmission delay is high for critical message
iM-Simple [60]	• Increases energy consumption due to number of retransmissions.

Table 4.6 tabulates the limitations of well-known similar works. These disadvantages have significant negative effect on performance metrics.

4.3.2.1. *Effectiveness of energy consumption*

Energy depletion in wireless body area network is referred as the overall quantity of energy expended by the network to execute sensing, transmitting, and receiving. Energy depletion (E_C) of network is given in eq. (4.7),

$$E_C = \sum_{i=1}^{l}(E_{Ti} + E_{Ri} + E_{si}) \quad 4.7$$

At this point, E_{ti} is referred to as the energy depleted by 'ith' body sensor node for transmission. E_{Ri} represents the energy expended by 'ith' body sensor node for data reception and E_{si} is referred to as the energy depleted by 'ith' body sensor node for sensing. Transmission energy increase with increase in distance to destination and vice versa.

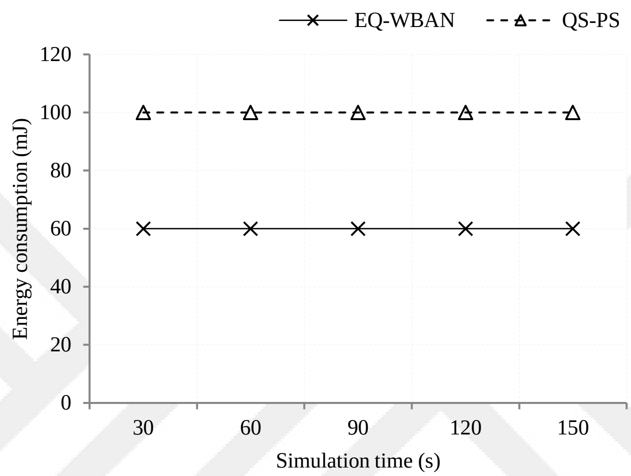

Figure 4.7:Analysis on energy consumption

In figure 4.7, the energy depletion in the proposed work is compare with energy with QS-PS method. It can be seen from the figure that the energy depletion in our proposed work is significantly lesser than QS-PS technique. The reason why greater energy depletion in QS-PS technique is experienced is as a result of the participation of tree topology which rises energy depletion of sensors available in top-level. Nevertheless, our proposed work solves this issue by utilizing efficient Prior-knowledge based weighted routing and graph based sleep scheduling. The proposed technique is 40% more efficient than related work (i.e.) it reduces 40% of energy depletion in the network. While the simulation time increase, our proposed EQ-WBAN consumes nearly 60mJ (i.e.) to accomplish same task.

4.3.2.2. *Effectiveness of network lifetime*

Network life time is referred to as the time duration from the beginning of the network operation till the death of a single node in the network. To put it differently, network lifetime is the time span where by the entire network is operational (i.e.) entire nodes are active. The network lifetime calculated as given in eq. (4.8),

$$NL = \frac{\varepsilon_0 - E[W]}{P_C + \lambda E[r]} \quad 4.8$$

NL is calculated with regards to the constant continuous power consumption (P_C), minus wasted energy (E[W]), average sensor reporting rate (λ), initial energy of network (ε_0), and expected energy for reporting (E[r]).

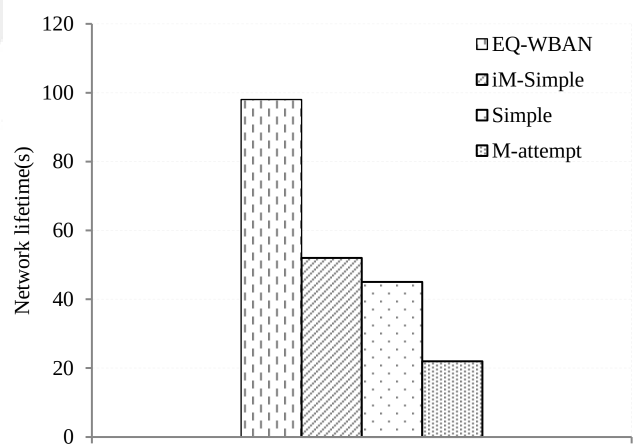

Figure 4.8:Analysis on network lifetime

In figure 4.8, network lifetime of the proposed works with other existing woks is analyze. At this point the time needed for initial node to die is taken as network lifetime. In M-attempt technique, first sensor dies within 22s although in Simple technique first sensor dies within 42s. In iM-simple technique the whole sensor alive for only 45s which is fairly lesser than energy and quality-of-service WBAN. Since, An iMproved stable increased-throughput multi-hop link efficient technique rises the amount of retransmission because of inefficient choosing of path, this results to early death of nodes in iM-simple technique. Proposed energy and quality-of-service wireless body area work remains alive for 98s which is considerably greater than other related works. At this point, energy depletion is reduced by Prior-knowledge based weighted routing algorithm and graph based sleep scheduling scheme which improve network lifetime. Furthermore, choosing the best route also assist to decrease energy depletion which results to maximization of network lifetime.

4.3.2.3. *Effectiveness on dropped packets*

In a network, data are dropped at any time the quality of the communication medium is less than accepted quality. Furthermore, packets are dropped whenever nodes in BSNs have a lesser energy than the accepted quality. Therefore, examining amount of dropped packets signifies the energy and quality-of-service efficiency of the EQ-WBAN.

Comparing the dropped packet with that of similar research can be is illustrated in figure 4.9. From the figure, it can be seen that the proposed technique reduces amount of packets dropped compared to CD technique. In the proposed technique, approximately 10% of packets are dropped whereas CD technique drops 40% of packets in the network. Conversely, in the proposed technique, the whole emergency packets are supplied with compulsory quality-of-service and reliable transmission with the provision of emergency sink node. However, CD technique drops packets devoid of understanding of packet type according to critical delay and waiting delay. As a result, amount of packet drops in CD technique is greater than the proposed EQ-WBAN. This investigation demonstrates the effectiveness of Prior-knowledge based weighted routing algorithm included in the proposed work. The limited number of packet drop take place as a result of involvement of graph based sleep scheduling scheme conversely emergency packets are not affected which increases complete performance of the network.

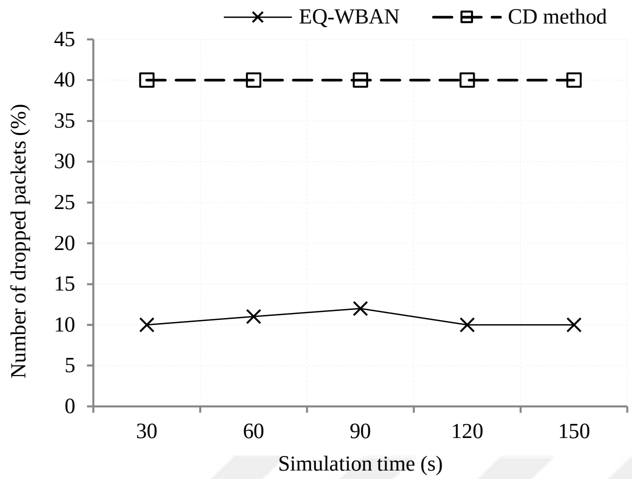

Figure 4.9:Analysis on dropped packets

4.3.2.4. ***Effectiveness on throughput***

Throughput can be referred to as the total amount of information sent to particular destination in specific time duration. Throughput can also be referred as the ratio between packet size and transmission times as seen in eq. (4.9);

$$Throughput = \frac{Packet\ size}{Transmission\ time} \qquad 4.9$$

Throughput efficiency of our proposed technique is illustrated in figure 4.10. At this point, CD technique achieves lesser throughput of approximately 35 kbps. Starting with the investigation on dropped data, it is understood that CD technique drops great amount of data. Therefore, the great amount of packets dropped in CD technique reduces throughput efficiency.

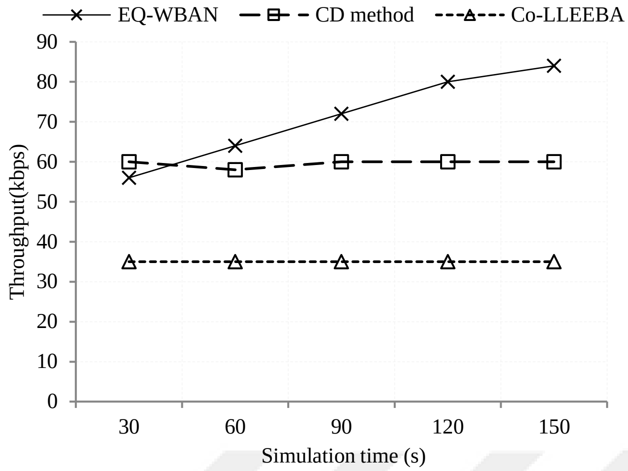

Figure 4.10:Analysis on throughput

In the same way, Co-LLEEBA technique produce throughput of approximately 60 kbps that is greater than CD technique but considerably lesser than the proposed technique. Participation of Prior-knowledge based weighted routing algorithm contribute to attain throughput up to 82 kbps. In the proposed technique, throughput is improved with increase in simulation time because of the amount of data that arrives to the destination rises over a time.

4.3.2.5. ***Effectiveness on delay***

The delay is referred to as the limited duration of time for a packet to move across the network to from source node to it destination node. Delay metric consist of the whole probable wait throughout data communication for example, queuing, processing, propagation, and transmission delay. It can be seen in eq. 4.10,

$$Delay = \sum_{P_l \epsilon P} t_r - \sum_{P_l \epsilon P} t_s \qquad 4.10$$

At this point, t_r represents to period required by a body sensor to obtain packets, and t_s refers to the period required to transmit a certain amount of data.

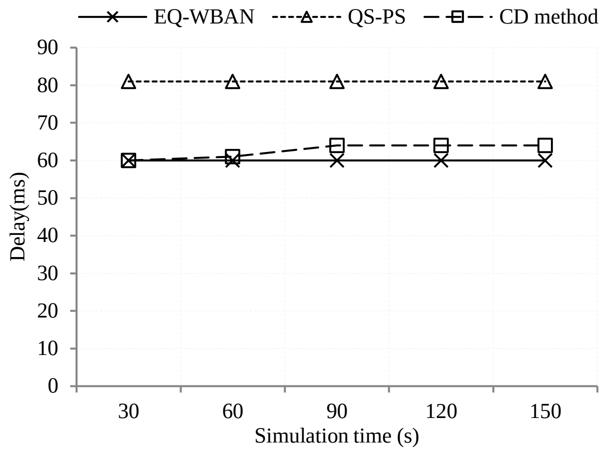

Figure 4.11:Analysis on delay

Figure 4.11 illustrates the delay efficiency of proposed work. Delay in QS-PS technique is greater than related techniques which approximately 20ms higher than related techniques. Greater delay in QS-PS technique is presented because of participation of tree topology (i.e.) the body sensor which are in the bottom-position of trees take great amount of time to arrive to the end. CD technique achieves 64 ms as an average delay which is to some degree greater than the proposed technique. Conversely, 64 ms delay is similarly experienced by emergency data which are to be processed within time. The proposed technique decreases average delay to 60 ms with the support of two sink nodes, frame accumulation, and Prior-knowledge based weighted routing.

The entire performance evaluation demonstrates that EQ-WBAN attains superior outcomes in terms of power depletion, lifetime of network, dropped packets, throughput, and delay. Consequently, the proposed novel insistence aware medium access control, Prior-knowledge based weighted routing algorithm, graph based sleep scheduling scheme, and split and map based neural network classifier are efficient which improves the entire performance. The proposed EQ-WBAN has significant effect on quality-of-service level in wireless body area network which occurs in real-world scenario. By implementing EQ-WBAN in the real-world, better quality-of-service and energy efficiency will still be achieved.

4.4. SUMMARY

This chapter started off by discussing some well-known energy and QoS aware algorithms and their limitations. Hence, our proposed energy and QoS-aware BAN architecture was used to fill that gap by developing five different algorithms and techniques as follows: Firstly, insistence aware medium access control was developed so as to determine the criticality of sensed data. Secondly, PWR algorithm was developed by incorporating in multi-hop routing so as to choose the best path for data communication. This algorithm increases the energy and QoS of the network. Thirdly, GSS scheme based sleep scheduling was employed to decrease energy depletion as a result of idle listening which is a major issue in wireless body area network because it requires only regular interval observing. Fourthly, Packet Classification by SMNN Classifier are achieved over neural network so as to decrease time depletion for packet grouping. Lastly, frame aggregation was used to send more than one frame in a single transmission. The goal is to increase throughput by communicating numerous frames over single transmission. Performance evaluation using OMNET based using Castalia 2.3 showed our proposed work outperformed our well-known similar works with regards to network lifetime, throughput, delay and packet drop.

CHAPTER 5

This chapter summarizes the key contributions of this dissertation and some vital directions for future work are recommended. The conclusion of this dissertation is summarized in section 5.1 and research direction for future work is presented in section 5.2.

5.1. THESIS SUMMARY

This thesis provides five significant contributions to WBAN. The main goal of this thesis is to solve the issue of poor QoS and energy efficiency due to stringent resource constraint in the sensor nodes by developing a novel efficient energy and quality-of-service wireless body area network architecture with two coordinators also known as sink. Quality-of-service demands for emergency packets communication is realized with the support of Insistence aware medium access control. According to criticality level of data, body sensor nodes perform route selection by exploiting Prior-knowledge based weighted routing algorithm. PWR algorithm make use of weight value which is calculated based on several important metrics in addition to previous experiences for the selection of the best path. To further decrease the power depletion, graph based sleep scheduling scheme was utilized amongst body sensor nodes. At this point criticality level of the sick is also taken in to account so as to advance network performance. CR categorizes the whole arriving data into critical and non-critical data so as to send the data to matching sink node. Split and map based neural network classifier is responsible for effective grouping of data in which data are grouped through split and map phases. At this point, packet size, data type, and time to live are taken into account for grouping. Frame accumulation procedure is commenced by the two sink nodes with the purpose of optimizing throughput metric in the network. Exhaustive simulation in OMNeT++ based Castalia 3.2 tool shows that proposed EQ-WABN outperforms other works in term of the following performance metrics: network life time, throughput, power depletion, delay, and dropped data.

5.2. FUTURE RESEARCH

A good number of stimulating future research directions are outlined in this section that will be the extension of this research.

In the future, we plan to in cooperate security in EQ-WBAN to protect the privacy of the patient's data against most important attacks such as spoofing, eavesdropping, and jamming because patient's data privacy is critical. Additionally, we plan to calculate the complexity of our research and compare it to that of similar works and report the result. Finally, postural movement might be added to our energy and QoS based algorithms and see how body movement will affect the algorithms.

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APPENDIX A

MODULES DEFINITION

Source codes of some important modules of our proposed EQ-WBAN are provided in appendix A. Section A.1 gives the code of Host.h function. Sections A.2 and A.3 contain the codes of TrainingData.cc and ehnHelloPacket_m.cc functions respectively.

A.1. Routing protocol module (Host.h)

```
/**********************************************************************
* Routing protocol module *
* OMNeT++ based simulator Castalia 3.2 is used for simulations *
* Castalia website: http://castalia.research.nicta.com.au/index.php/en/ *
* By Abdullahi Abdu Ibrahim */
/**********************************************************************
*// Host.h *
************************************************************************/

#include "Host.h"
#include<iostream>
#include<string.h>
#include <stdio.h>
using namespace std;



Define_Module(Host);


Host::Host()
{
   endTxEvent = NULL;
}
```

```
Host::~Host()
{
   cancelAndDelete(endTxEvent);
}


void Host::initialize()
{
   stateSignal = registerSignal("state");
    char co[8]="server[";
   const  char *dst="1";
 //  char*s= strcat(co,dst)

 //  char* s1=strcat("]",s);
 // ev<<"==================================="<<s<<"\n";

 //  getDisplayString().setTagArg("t",0,s1);

   server = simulation.getModuleByPath("server[0]");
   if (!server) error("server not found");

   txRate = par("txRate");
   radioDelay = par("radioDelay");
   iaTime = &par("iaTime");
   pkLenBits = &par("pkLenBits");

   slotTime = par("slotTime");
   isSlotted = slotTime>0;
   WATCH(slotTime);
   WATCH(isSlotted);

   endTxEvent = new cMessage("send/endTx");
   state = IDLE;
   emit(stateSignal, state);
   pkCounter = 0;
   WATCH((int&)state);
   WATCH(pkCounter);

   if (ev.isGUI())
      getDisplayString().setTagArg("t",2,"#808000");

   scheduleAt(getNextTransmissionTime (), endTxEvent);
}


void Host::handleMessage(cMessage *msg)
```

```
{
  ASSERT(msg==endTxEvent);

  if (state==IDLE)
  {
    // generate packet and schedule timer when it ends
    server = simulation.getModuleByPath("server[1]");
      if (!server) error("server not found");
    char pkname[40];
    sprintf(pkname,"pk-%d-#%d", getId(), pkCounter++);
    EV << "generating packet " << pkname << endl;

    state = TRANSMIT;
    emit(stateSignal, state);

    // update network graphics
    if (ev.isGUI())
    {
      getDisplayString().setTagArg("i",1,"yellow");
      getDisplayString().setTagArg("t",0,"TRANSMIT");
    }

    cPacket *pk = new cPacket(pkname);
    pk->setBitLength(pkLenBits->longValue());
    simtime_t duration = pk->getBitLength() / txRate;
    sendDirect(pk, radioDelay, duration, server->gate("in"));

    scheduleAt(simTime()+duration, endTxEvent);
  }
  else if (state==TRANSMIT)
  {
    // endTxEvent indicates end of transmission
    server = simulation.getModuleByPath("server[1]");
          if (!server) error("server not found");
    state = IDLE;
    emit(stateSignal, state);

    // schedule next sending
    scheduleAt(getNextTransmissionTime(), endTxEvent);

    // update network graphics
    if (ev.isGUI())
    {
      getDisplayString().setTagArg("i",1,"");
      getDisplayString().setTagArg("t",0,"");
    }
```

```
    }
    else
    {
        error("invalid state");
    }
}

simtime_t Host::getNextTransmissionTime()
{
    simtime_t t = simTime()+iaTime->doubleValue();

    if (!isSlotted)
        return t;
    else
        // align time of next transmission to a slot boundary
        return slotTime * ceil(t/slotTime);
}
```

A.2. Routing protocol module (TrainingData.cc)

```
/**********************************************************************
* Routing protocol module
* OMNeT++ based simulator Castalia 3.2 is used for simulations *
* Castalia website: http://castalia.research.nicta.com.au/index.php/en/ *
/**********************************************************************
*// TrainingData.cc h *
**********************************************************************/

#include <vector>
#include <iostream>
#include <cstdlib>
#include <cassert>
#include <cmath>
#include <fstream>
#include <sstream>
#include<TrainingData.h>

using namespace std;

void TrainingData::getTopology(vector<unsigned> &topology)
{
   string line;
   string label;

   getline(m_trainingDataFile, line);
   stringstream ss(line);
   ss >> label;
   if(this->isEof() || label.compare("topology:") != 0)
   {
      abort();
   }

   while(!ss.eof())
   {
      unsigned n;
      ss >> n;
      topology.push_back(n);
```

```
    }
    return;
}

TrainingData::TrainingData(const string filename)
{
    m_trainingDataFile.open(filename.c_str());
}
unsigned TrainingData::getNextInputs(vector<double> &inputVals)
{
    inputVals.clear();

    string line;
    getline(m_trainingDataFile, line);
    stringstream ss(line);

    string label;
    ss >> label;
    if (label.compare("in:") == 0) {
        double oneValue;
        while (ss >> oneValue) {
            inputVals.push_back(oneValue);
        }
    }

    return inputVals.size();
}

unsigned TrainingData::getTargetOutputs(vector<double> &targetOutputVals)
{
    targetOutputVals.clear();

    string line;
    getline(m_trainingDataFile, line);
    stringstream ss(line);

    string label;
    ss>> label;
    if (label.compare("out:") == 0) {
        double oneValue;
        while (ss >> oneValue) {
            targetOutputVals.push_back(oneValue);
        }
    }

    return targetOutputVals.size();
```

```
}


int smnntest()
{
   TrainingData trainData("trainingData.txt");
   //e.g., {3, 2, 1 }
   vector<unsigned> topology;
   //topology.push_back(3);
   //topology.push_back(2);
   //topology.push_back(1);

   trainData.getTopology(topology);
   Net myNet(topology);

   vector<double> inputVals, targetVals, resultVals;
   int trainingPass = 0;
   while(!trainData.isEof())
   {
      ++trainingPass;
      cout << endl << "Pass" << trainingPass;

      // Get new input data and feed it forward:
      if(trainData.getNextInputs(inputVals) != topology[0])
         break;
      showVectorVals(": Inputs :", inputVals);
      myNet.feedForward(inputVals);

      // Collect the net's actual results:
      myNet.getResults(resultVals);
      showVectorVals("Outputs:", resultVals);

      // Train the net what the outputs should have been:
      trainData.getTargetOutputs(targetVals);
      showVectorVals("Targets:", targetVals);
      assert(targetVals.size() == topology.back());

      myNet.backProp(targetVals);

      // Report how well the training is working, average over recnet
      cout << "Net recent average error: "
           << myNet.getRecentAverageError() << endl;
   }

   cout << endl << "Done" << endl;
```

```
}
*/
```

B.3. Routing protocol module (Neurofuzzy.h)

/*
* Routing protocol module
* OMNeT++ based simulator Castalia 3.2 is used for simulations *
* Castalia website: http://castalia.research.nicta.com.au/index.php/en/ *
/***
*// Neurofuzzy.h *
***/**

```
/* -*- Mode:C++; c-file-style:"gnu"; indent-tabs-mode:nil; -*- */

#include "Neurofuzzy.h"
#include <iostream>
#include <ctime>

using namespace std;

/* ... */

int fuzzy2rule:: fuzzylogic(double Oxygen ,double HearRate,double RR){

//output ==>0-low ,1-midium,2-High

int output=0;
 if(Oxygen==0 && HearRate==0 && RR==0   )
{
 output=0;
}

else if(Oxygen==0 && HearRate==0 && RR==1  )
{
 output=0;
}

else if(Oxygen==0 && HearRate==1 && RR==0  )
{
output=1;
}
```

```
else if(Oxygen==0 && HearRate==1 && RR==1  )
{
output=0;
}

else if(Oxygen==1 && HearRate==0 && RR==1 )
{
output=1;
}

else if(Oxygen==1 && HearRate==1 && RR==0  )
{
output=2;
}

else if(Oxygen==1 && HearRate==1 && RR==1  )
{
output=1;
}

return output;}
```