JADAVPUR UNIVERSITY

MASTER'S DEGREE THESIS PAPER

Power Aware Reliable Lightweight (PARL) Routing Protocol For Wireless Body Area Networks

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A thesis submitted in fulfilment of the requirements for the degree of Master of Technology in Computer Technology
in

Department of Computer Science & Engineering

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I, Piyali Maur, declare that this thesis titled, "Power Aware Reliable Lightweight (PARL) routing protocol for Wireless Body Area Networks" and the work presented in it are my own. I confirm that:

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Abstract

Faculty of Engineering and Technology, Jadavpur University Computer Science and Engineering

Master of Technology in Computer Technology

Power Aware Reliable Lightweight (PARL) routing protocol for Wireless Body Area Networks

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Wireless Body Area networks play a vital role in physiological, medical and non-medical applications. Advancement of medical science brings together new trend of proactive health care which gives rise to the era of Wireless Body Area Networks (WBAN). This thesis presents a lightweight power aware reliable routing algorithm for Wireless Body Area Networks (WBANs) for selecting reliable path. Protocol is simulated in Castalia simulator.

Acknowledgements

On the submission of “Power Aware Reliable Lightweight (PARL) routing protocol for Wireless Body Area Networks”, I wish to express gratitude to the Department of Computer Science & Engineering for sanctioning a thesis work under Jadavpur University under which this work has been completed.

I would like to convey my sincere gratitude to Dr. Chandreyee Chowdhury, Assistant Professor, Department of Computer Science & Engineering, Jadavpur University for her valuable suggestions throughout the project duration. I am grateful to her for her constant support which helped me a lot to fully involve myself in this project and develop new approaches in the field of Wireless Body Area Networks.

I would like to express my sincere, heartfelt gratitude to Mrs. Moumita Roy, Ph.D. Scholar, Department of Computer Science & Engineering, Jadavpur University, Kolkata, for suggestions and guidance.

I would also wish to thank Prof. Mahantapas Kundu, Head of the Department of Computer Science and Engineering, Jadavpur University and Prof. Chiranjib Bhattacharjee, Dean, Faculty of Engineering and Technology, Jadavpur University for providing me all the facilities and for their support to the activities of this research.

Lastly, I would like to thank all my teachers, classmates, guardians and well-wishers for encouraging and co-operating me throughout the development of this project. I would like to especially thank my parents whose blessings helped me to carry out my project in a dedicated way.

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Chapter-1

1. Introduction

Technologies are emerging day by day in order to improve the quality of life. Wireless Communication is a major factor that has made our life so much conducive than it was before. Healthcare and medical systems are also touched by this technological advancement. WBAN is such a wireless network developed mainly to look after the personal health. A WBAN is a special purpose sensor network. It is located inside and outside of a human body and designed to operate autonomously to connect various medical sensors and appliances.

Introduction of a WBAN for medical monitoring and other applications will offer flexibilities and cost saving options to both health care professionals and patients. A WBAN system can offer two significant advantages compared to current electronic patient monitoring systems. The first advantage is the mobility of patients due to use of portable monitoring devices. Second advantage is the location independent monitoring facility [1]. Each node in a WBAN is an independent node which is able to search and find a suitable path for transmitting data at a remote location. The WBAN node can also connect to internet for transmitting data. Using WPAN (Wireless Personal Area Network) as gateway, WBAN can be extended to a wider range and also the wearable devices on the human body can be connected to the internet.

WBAN provides many promising applications in different domains, such as healthcare, medicine, patient monitoring, sport and multimedia, to cite a few. The WBAN through its different tiny and smart sensors shown in table 1.1 can diagnose and treat several diseases. These sensors should have specific properties as low power consumption, light weight, and portability. It's monitoring one's physiological attributes such as blood pressure, heartbeat, and body temperature, Electrocardiography (ECG), Electromyography (EMG) etc., which provides large time intervals of data from a patient's natural environment. For which doctors will gave a cleaner view of the patient's status [2].

Table 1.1 Some Types of Sensors

Sensor	Role
Electrocardiogram sensor	Used for monitoring heart activity
Electromyography sensor	Used for monitoring muscle function activity
Electroencephalogram	Used for monitoring brain electrical activity
Breathing sensor	Used for monitoring respiration
Accelerometer	Motion capture
Pulse oximeter	Measures the oxygen saturation level in the blood
A capsule endoscope	Used for digestive disease monitoring
Tilt sensor	Monitor trunk position

In WBANs, nodes are placed in the clothes, on the body or under the skin. The node can be classified based on the way they are implemented [3] as:

Implant Node: This type of node is planted either underneath the skin or inside the body tissue.

Body Surface Node: It is either placed on the surface or 2 cm away from the human body.

External Node: It is not in contact with the human body and rather a few centimeters to 5 m away from the human body.

WBAN consists of multiple sensor nodes, each capable of sampling, processing, and communicating one or more vital signs (heart rate, blood pressure, oxygen saturation, activity) or environmental parameters (location, temperature, humidity, light). Sensor node collects information about the person and sends it through multi-hop wireless paths to the sink, in order to be processed or relayed to other networks. The sink is the common destination of all data collected by sensor nodes in the network. The sink is actually a gateway or interface between the sensor field and to the user. The relay node is a special device, added to WBAN, which reduces the transmission power of biosensors.

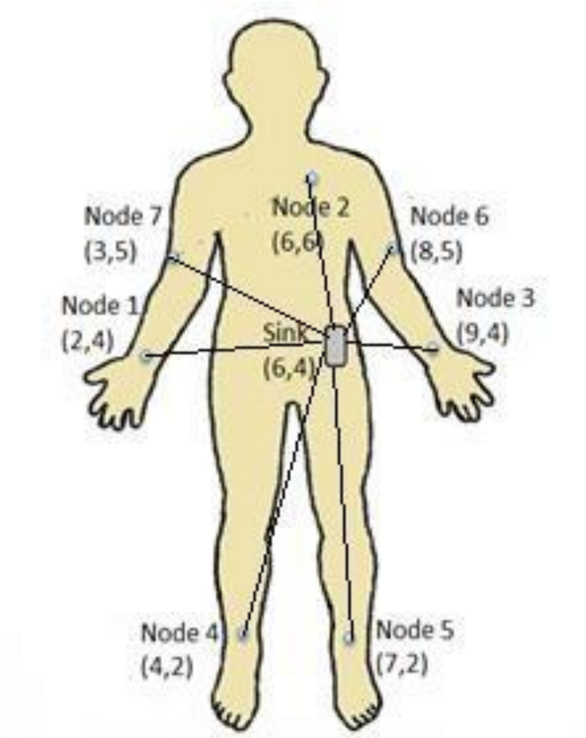


Figure 1.1 Structure of WBAN

In the WBAN we can distinguish 3 types of devices as shown in Figure 1.1:

Sensor node: It is a device that is able to gather sensory information, performing data processing and communicating with multiple nodes found in the network. The sensor nodes are small, lightweight, and consume low power. The values are taken from sensors are fed to the hardware device by wired or wireless devices like ZigBeeMAC (802.15.4) or Bluetooth (802.15.1) etc. The sensor node contains a processor, transceiver, power unit, memory, and sensor hardware. A sensor node undertakes three tasks: detecting signal via front end, digitizing/coding/controlling for a multi access communication.

Actuator: This device reacts according to the information received from the sensors. In the medical field, such node can pump insulin, stimulate the brain or pump the heart according to the application. The actuator node as the sensor node contains a processor, transceiver, power unit, and memory and actuator hardware.

The Personal Digital Assistant (PDA): is considered as a sink node. It transmits the data, received from the sensors and actuators to the server through the internet using WIMAX, GPRS or GSM. The PDA contains a processor, transceiver, power unit and memory [4].

1.1. Applications of WBAN

WBAN has introduced several numbers of innovative and effective applications due to capable of transmitting data through radio communication path. These applications can be characterized into two categories: medical and non-medical applications.

1.1.1. Medical Applications:

WBAN technology is improving the efficiency [5] of doctor-patient activities such as remote patient monitoring, health status, notification, emergency calling etc. [3] anytime and anywhere.

Remote Healthcare Monitoring

It is a homecare telehealth application that allows patients to use mobile medical device like sensors to gather patient body organ status such as body temperature, heart rate, blood pressure, ECG signal for monitoring heart activity, movement sensor to monitor patient movement and send it to healthcare professionals [4]. All the information can be monitored and stored from the control unit or remotely.

Telemedicine

It is an interesting application field of WBAN which provides health care services over a distance with the help of information and communication technology. It helps the patient to get treatment by online video consultation with doctors, transmission of medical reports and images, remote medical diagnosis etc. where doctors can provide e-prescription by monitoring patient's condition from anywhere [5].

Assisted Living

An assisted living is a long-term senior care option that provides personal care support services such as meals, medication management, bathing, dressing and transportation [3]. In WBAN application, wearable medical sensors can be used at home to measure the health condition of these people can be estimated from their heartbeat rate, blood pressure and accelerometer data from patient's body and transmit/store them into particular medical center server/control unit in a regular interval. It helps the patient to stay at home and get continuous support instead of staying at hospital. In case of any emergency sensors implanted on the body of patient at home can raise alarm of urgent notification to the nearby medical center.

Biofeedback

Biofeedback is the process of using precise instruments to measure physiological activity, and "feed" this biological information "back" to the user, thus allowing the individual to learn how to better control or change the physiological activity in order to improve health and performance [27].

1.1.2. Non-Medical Applications:

Non-medical applications are deployed for entertainment, security, or fitness monitoring applications and involve users as the target population.

Sports and Fitness

In WBAN wearable medical sensors monitor significant parameters like blood pressure, heartbeat, body temperature, respiration rate, blood oximetry and posture of any athlete in sports can be attained and collated through a single WBAN. It is possible for WBANs to provide motion capture aiding athletes [6] to improve their performance and prevent injury. They can also provide useful information relating to training schedules.

Entertainment and gaming

Entertainment and gaming are attractive fields for WBAN to play an important role. For examples, Streaming AV signal like wireless wearable music system, making video call using big screen TV, playback of audio and videos from portable devices to external big displays and audio system [28]. Body sensors enable game players to perform actual body movements, such as boxing and shooting, that can provide feedback to the corresponding gaming console, thereby enhancing their entertainment experiences.

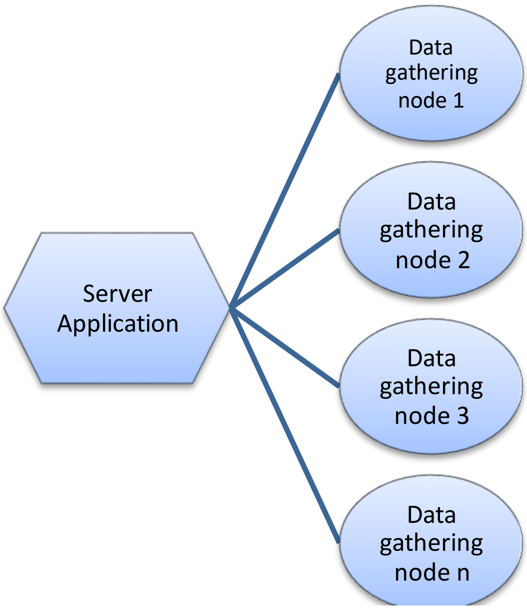
Military

There are many abundant opportunities to use WBAN in military and defense system. WBAN helps to monitoring a soldier activity as well as to provide information about surrounding environment in battlefield. It can also help to communicate between soldier, monitoring their health issue, location, location weather, and their attacking activities to their head commander [6] [28]. A battle dress uniform may include with a BAN may become a wearable electronics network that connects devices such as cameras, RF, life support sensors and transfer data to and from the soldier wearable computer.

1.2. Architecture of WBAN

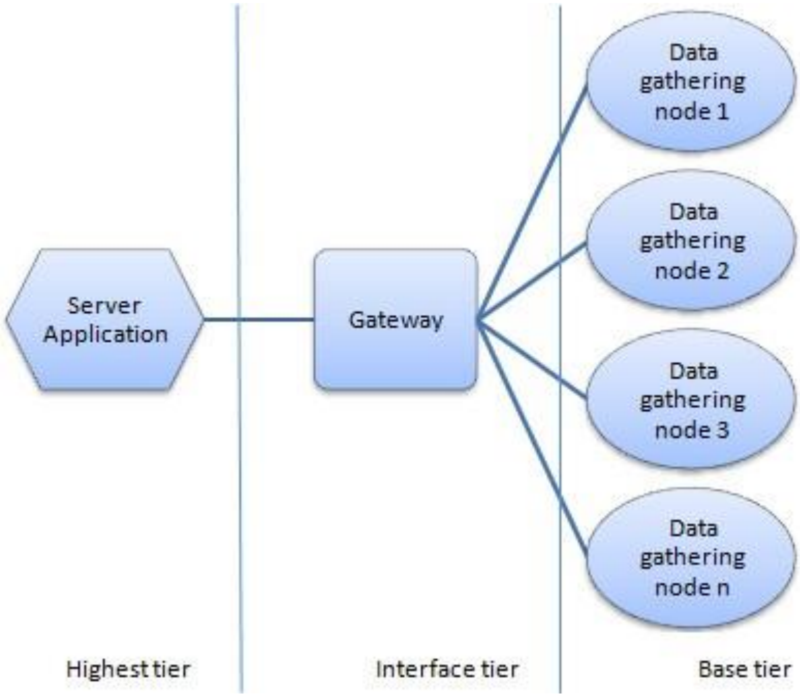
The network architecture of WBANs can be broadly classified into two major categories: flat architectures and multi-tier architectures [20].

Flat Architectures consist of a single data-gathering unit that sends its data to a personal computer or a personal server application running on a PDA shown in Figure 1.2.



$\boldsymbol{Figure}$ 1.2 **Flat Architecture**

Multi-Tier Architectures are used to achieve large data gathering of multiple physiological signals using multiple nodes in the base tier, a gateway at the second tier that acts as an interface between first tier and a server at the third tier shown in figure 1.3.



$\boldsymbol{Figure}$ 1.3 **Multi-tier Architecture**

1.2.1 Three tire architecture

The communication architecture of WBANs can be separated into three different tiers [2] shown in figure 1.4.
Tier-1: Intra-WBAN communication
Tier-2: Inter-WBAN communication
Tier-3: Beyond-WBAN communication

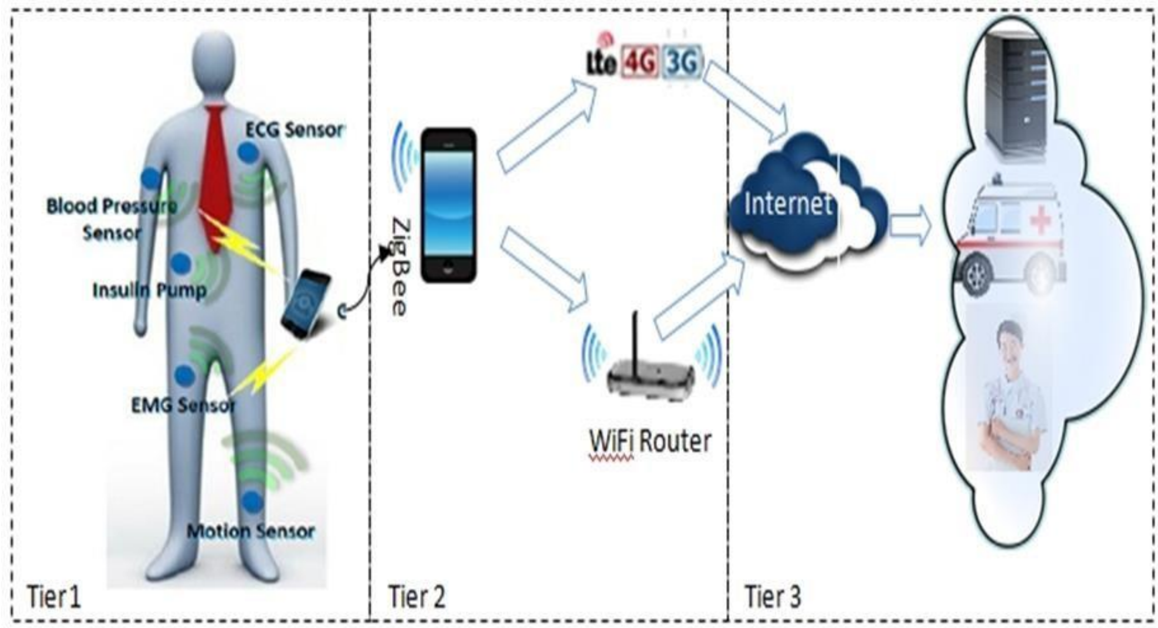


Figure 1. 4 Three - tier Architecture

Tier-1 is actually the lowest tier which represents the BSN (body sensor network). It depicts the network interaction of nodes and their respective transmission ranges (~ 2 meters) in and around the human body.

Tier-2 or the intermediate tier represents the PAN (Personal Area Network). This communication tier is between the PS and one or more access points (APs) like Zig-Bee, Wi-Fi router, Lte 4G,3G etc.

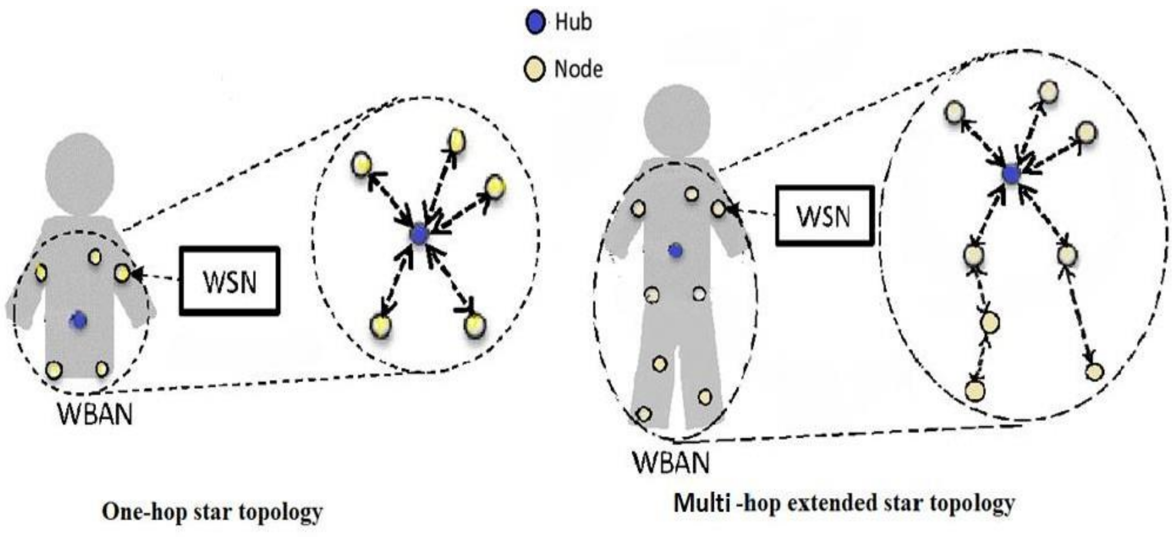
Tire-3 or highest tier represents the network server. The design of this communication tier is application-specific, for use in metropolitan areas. It allows restoring all necessary information as a database.

In tier-1 various sensors are used to forward body signals to Personal Server (PS). The PS sends physiological data to various APs in tier-2. A gateway such as a PDA (personal digital assistant) can be used to bridge the connection between Tier-2 and tier-3 [7]; in essence from the Internet to the Medical Server (MS) in a specific application. In a medical environment a database is one of the most important components of Tier-3 as it includes the medical history and profile of the user. Thus, doctors or patients can be notified of an emergency status through either the Internet or a Short Message Service (SMS).

1.3. Topology used in WBANs

There are a number of different topologies that may be used for wireless body area networks (WBAN), shown in figure 1.5. The topology itself depends on the requirements of the application and the unique application context. Factors that influence the choice of topology include sensor node costs, battery drain, robustness, scalability, mobility data routing and communication. These topologies are reliable and easy to implement.

In realistic WBAN scenarios, topology is specified commonly as a star topology and can be extended to a two-hop tree topology. This extension indicates that cooperative transmission of a sensor node through a relay is an alternative choice instead of direct one-hop transmission to the coordinator [22]. Cooperative transmission can effectively save energy and prolong the lifetime of sensor nodes that are relatively far away from the coordinator through mathematical analysis and numerical simulation. The combination of direct transmission and cooperative transmission to sensor nodes in WBANs can improve lifetime performance of the whole network. Hence, an appropriate relay selection is of great importance in cooperative transmission strategy to prolong the network lifetime of WBANs.



$Figure$ 1. 5 **Topology used in WBAN**

1.4. Routing Issues and Challenges

Design and development of efficient routing protocols for WBANs is a challenging job due to their unique requirements and specific characteristics. The issues and challenges are:

Network Topology - It describes the logical way in which the different communicating devices communicate with each other. Efficient routing protocol development requires a proper network topology as it effects the overall performance of the communication system. Proper network topology is very important for WBSNs because of the energy constraint, body postural movements, heterogeneous nature of the sensors and short transmission range. Some researchers use single hop communication, where each node communicates directly with the destination, while others use cluster based multi-hop routing.

Temperature Rise and Interference - When bio medical sensors are deployed in the human body and communicate each other using radio frequency transmission. Then creation of heat increases the local temperature, which does great harm to human bodies. These sensors generate electric and magnetic field due to radio signals. These electric and magnetic field cause of temperature rise because of antenna radiation absorption and power consumption of nodes. The transmission power of nodes needs to be extremely low to minimize interference and avoid tissue heating. The energy levels of nodes are considered for adjusting the available energy and computing power of nodes.

Energy efficiency - It covers both the local energy consumption of nodes and the overall network lifetime. For implanted bio-medical sensors, it is not possible to replace the power source, while for wearable bio-medical sensors replacing the batteries might lead to discomfort of patients. Therefore, both energy consumption and network lifetime are major challenges in wireless body sensor networks. Communication among the sensor nodes consumes more energy as compared to sensing and processing. Any proposed algorithm should be able to use different paths and/or nodes to send the data instead of depending on a single path and/or node preventing the consumption of total energy of that specific node(s). The time from which the network starts till the time when the first node of the network expires is known as network lifetime. The network life is very much important in WBANs because of energy constraints and the impossibility of replacing the energy source for implanted sensors.

Limited Resources - Along with limited energy source, WBANs also have short Radio Frequency (RF) transmission range, poor computation capabilities, limited storage capacity, as well as low bandwidth—which may keep on changing due to noise and other interferences. Researchers must be aware of the limited resources when designing routing protocols for WBSNs.

1.4.1. Issues related to topology optimization:

Mobility Management

Mobility scheme actually represents model and communication protocols for a person's movement. This means that movement is mostly dependent on posture, such as walking, standing, sitting, running and so on. As for this mobility, general mobility assumes movement according to a person's ordinary activity, while specific mobility does extraordinary movement with limitations in specific places such as hospitals. But in specific applications such as a hospital situation, sitting or even lying down can be thought of as mobile postures when some sort of carrier like a wheelchair or mobile bed is used.

Posture strongly influences the network topology and node connectivity. The sensor nodes adjust their connectivity according to change in posture. Therefore, it affects the connection between the nodes in the WBAN and the external network like other WBANs or the surrounding ambient sensor network. Experimental measurement results in [24] show how Packet Delivery Ratio (PDR) and link connectivity between different sensor nodes deployed on a human body vary over different postures. As the communication protocols are expected to support such changes in the network topology and link quality, the mobility model should model posture changes carefully to evaluate the protocol correctly.

Sink placement

Sink placement is a very important part in WBAN for mobility management. Node movement is done with the change of posture. It is difficult to choose the optimal transmission power which varies with link quality. If a sink node is installed in hand or in leg, then movement will be very high. If transmission power between sensors increases, then temperature also increases [25]. As a result, the human tissues will be damage. The sink node also has a radiation power. If the sink node installed in chest then it will be dangerous for health.

1.4. Motivation

In WBAN, power plays a vital role in WBANs to ensure communication reliability. The emitted electromagnetic waves go through human tissue and the waves' power is dissipated as heat for various body movement postures, which change link quality over time. For the change in posture, the interference between nodes increase and tissues are heated [18][19].

The existing research often focuses on developing routing solutions by addressing a single issue. For instance, the temperature aware protocols aim to avoid heated route in order to reduce thermal effect on human tissue although the obtained route may not be the optimal path to reach the sink. Cluster based protocols provides solution based on clustering approach which could be an overhead for such a small network (of 15 to 20 nodes max) like

WBAN. However, multiple issues have been addressed in few cost-based protocols which attempt to find least cost route to destination. Even few of them exploit adaptive transmission power selection approach both in single hop and multi-hop communications. How the energy resource and time varying channel parameters can be related in choosing optimal transmission power and finding reliable route is still unexplored.

1.5. Contribution

Here, in this paper our contribution is as follows. A lightweight routing protocol has been designed for WBAN, which can be implemented in such resource constraint framework without significant overhead. The protocol attempts to find a reliable route to destination with a combination of node reliability in terms of having energy resource and link reliability. Besides, it shows adaptive nature in selecting transmission power for each communication such that substantial output could be ensured with minimal energy draining.

1.6. Organization of the thesis

In section 2, we discuss various type of routing protocols and compare their advantages and disadvantages. In section 3, we describe our proposed routing protocol and algorithm and also analysis the complexity. Simulation parameters are described in section 4. The simulation results are described in section 5. Finally, the conclusion is drawn in section 6.

Chapter-2

2. Related Work

In WBAN, routing protocols are set of protocols which can identify and maintain the routes in the wireless body area network. The routing protocols are important for reliable communication where data can be exchanged between sensor nodes and sink efficiently. There are different kinds of routing protocols such as cluster-based, cross-layered based, postural movement based, quality of service (QoS) and temperature-aware based which are affected by different factor of nodes like energy, network topology, various QoS, temperature, transmission range of nodes, human posture etc.

2.1. Classification of Routing Protocols

The reliability and efficiency of WBAN depend on how the system responds quickly and accurately, to send and receive the data between the nodes, which eventually depends on the selected routing protocols or algorithms [8] [11] [9] [12]. Sending information from either an in-body or an on-body sensor node includes the radiation emitted from wireless transceivers which is similar to WSNs.

Cluster-based routing protocol: In WBAN limited energy sources is the main constraint to be resolved. The aim of this protocol is to decrease the power consumption and increase the lifetime. It tries to divide nodes into different cluster and employ a cluster head for individual cluster and route data from sensor to the sink that is base station through the cluster head.

Temperature routing protocol: There have multiple routing protocols in WBANs which is categorized about their purpose. When bio medical sensor deployed in human body and communicate each other using radio frequency transmission creation of heat and causes increase the local temperature, which does great harm to human bodies. For this the temperature routing protocols are specifically designed to diminish the local or complete system temperature rising. The reason behind this protocol is to route data from different routes to avoid a temperature rise in some sensor leading to human tissue damage and depletion of nodes.

Cross layer routing protocol [26] combines the challenges in routing with medium access issue. The efficiency between the protocols and optimization objective can be achieved by this protocol merging two or more layers within that protocol stack. Cross layer protocol gives many advantages to gain resource efficiency, improving the network performance, interaction with other layer.

Qos-based routing protocol: It plays an important role in any application technology, especially in resource constrained WBAN, which is a huge challenge. The Qos that need to be considered in the WBAN are—data priority, energy efficiency, link reliability and data transmission reliability, low transmission delay, node temperature, data security, etc.

Depending on some routing issues, declare above routing are classified into some group [13] shown in table 2.1:

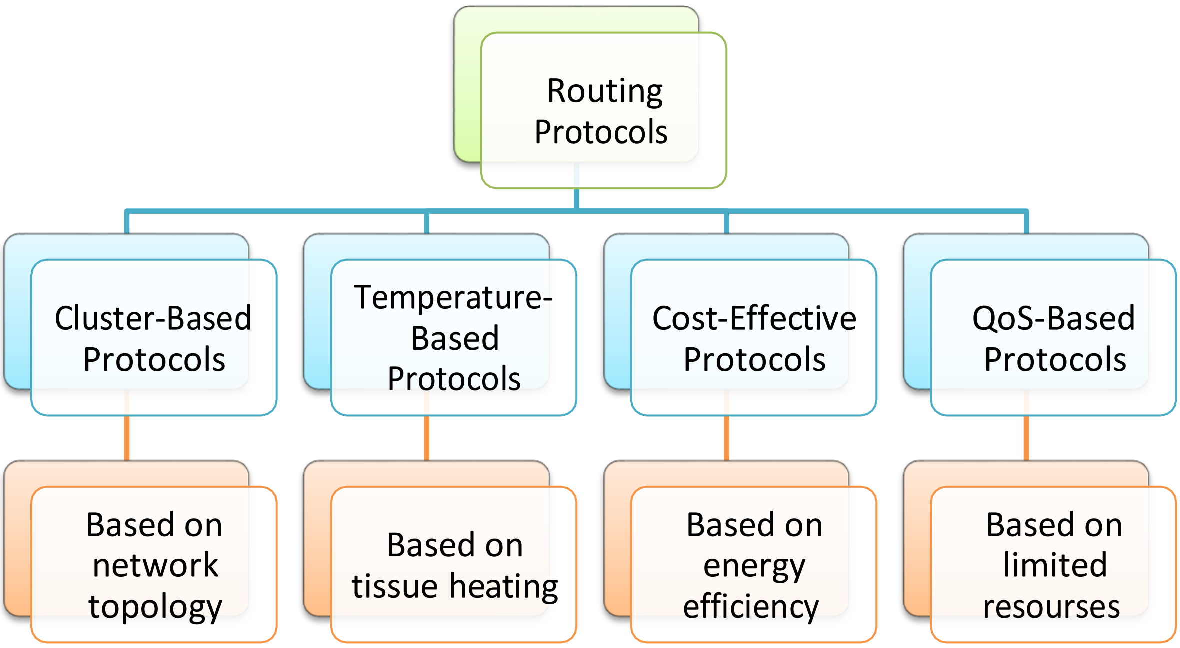


Table 2.1 **Types of routing protocols**

2.2. Existing Protocols

In this section, we discuss some existing routing protocols. Authors in [8] proposed a low-delay Protocol for Multi hop Wireless Body Area Networks (CICADA) which consists of a spanning tree structure and use TDMA protocol for communication of nodes. In this, nodes near the root act as relay or forwarder, collect data from child node and transmit it to sink. For the load from child nodes, parent nodes deplete their energy quickly.

In [9] authors proposed a Self-organization Protocol for Body Area Networks which has two phases: setup phase and steady state phase. It is actually a cluster-based protocol. At first in setup phase nodes are grouping into clusters then interconnection between these clusters identify the routing paths. Then in steady state phase data scheduling and data transmission are done. The objective of the protocol is to restrict the sensor nodes to transmit data directly to a sink. It improves efficiency of network by changing the selection criteria of cluster heads.

Table 2.2 Some existing works on WBAN routing protocols

Year	Protocol Name	Protocol Type	Problem
2007	CICADA [8]	Cross-layer based protocol	Deplete energy quickly
2007	Self-Organization Protocol [9]	Cluster based protocol	Restrict the sensor nodes to transmit data directly to sink
2010	Robust Protocol Stack for Multi-hop with Transmit Power Adaptation [21]	Multi-hop protocol	forward the data to links that works as hotspot
2013	M-ATTEMPT [10]	Thermal aware protocol	Select different route cause more energy consumption
2013	SIMPLE [11]	QoS based protocol	Not focus on achieving high throughput
2014	IM-SIMPLE [12]	Cost effective protocol	

In [10], an energy aware routing protocol named M-ATTEMPT is described, where each node selects a minimum hop route to the sink. When a parent node heated, the child nodes select another optimal route. Another full advantage of both single and multi-hop communication by choosing single hop for emergency data with minimum possible delay and multi hop for normal data. It selects different route where nodes acts like a hotspot. To minimize energy consumption and to avoid hotspots a Stable Increased-throughput multi-hop protocol for link efficiency is used in [11]. In SIMPLE protocol, author focus on network lifetime prolongation but not on the throughput.

In [12], an improved stable increased-throughput multi-hop link efficient routing protocol (IM-SIMPLE) for Wireless Body Area Networks is presented where beside network lifetime prolongation author focus on achieving high throughput. In this accost function is calculated by adding sensor node residual energy and its relative communication distance for select relay node or forwarder node. Sensor node with minimum distance and maximum residual energy selected as forwarder node. Wireless links between nodes may be disconnected due to body movements, which cause data loss. IM-SIMPLE protocol handles such mobility situation and assures maximum data delivery to sink.

In this chapter we discuss different types of routing protocols and some existing protocols related to those protocols. In next chapter, we discuss our proposed protocol and the algorithm and also discuss in which protocol class it belongs. A working example is also drawn to easily understand the proposed work. The best case and worst-case time and space complexity analysis for the proposed work are also presented.

Chapter-3

3. Proposed Routing Protocol

The proposed routing protocol is designed for sending data from sensor nodes to sink through a reliable communication path. Here different type of routing protocol like temperature aware protocol, cluster-based protocol is used for getting a uniform reliable routing protocol.

3.1. Description of the protocol

In this thesis paper, a lightweight routing protocol has been designed for WBAN which attempts to route data either to the sink directly or via some relay in reliable manner. The protocol is summarized as Algorithm1. Here n numbers of body sensor nodes are assumed to form a network where a smart handheld such as smart-phone acts as network coordinator or sink. The connectivity graph of these nodes may change over time due to posture change. The sensor nodes are assumed to be deployed all over the body including vital positions and could be implanted inside as well. Thus, the communication may take place through multiple mediums accordingly. At any time, t, each node quantifies its energy resource in terms of energy ratio E^t_{ratio} which is defined as the ratio between remaining energy E^t_{rem} at time t to the initial energy E_{ini} of each node.

$$E^t_{ratio} = \frac{E^t_{rem}}{E_{ini}} \tag{1}$$

Thus, a node with more remaining energy can participate more in network activities. Hence, E^t_{ratio} can be considered as node reliability at time instant t. Channel conditions can be measured in terms of received signal strength indicator (RSSI). Here link reliability at time t is measured as received signal strength with respect to transmission power (P_{tx}).

$$L^t_{rel} = \frac{RSSI}{P\text{tx}} \tag{2}$$

Sink S is assumed to broadcast periodic beacon. When a sensor node i receives such beacon from sink S, it estimates the reliability of the direct link between sensor i and sink S instead of just taking into account that it is connected with sink. The nodes connection can be measured in terms of communication reliability (Rel_{comm}).

$$Rel_{\text{comm}} = (w_1 * E^t_{ratio}) + (w_2 * L^t_{rel}) \quad \text{where } w_1 + w_2 = 1 \qquad (3)$$

Threshold value for comparing communication reliability of the direct connection to the sink is set as 0.5. This is obtained empirically. The weights w1 and w2 associated with energy ratio and link reliability are chosen as 0.5 each to provide equal importance to both the issues. Compare communication reliability with the threshold value. The nodes which are in upper layer of the threshold select as relay node and broadcasts its node id. Then the nodes which received broadcast added with RSSI in routing table. Sink received data directly from sensors in one or $multihop$. For that it set an optimal power level for reliable communication. We use the energy status and the link communication cost for calculation of the communication reliability, which considers the best reliable path for communication of sensor to sink directly.

Algorithm 1: Find Reliable Route To Sink(n_{source},n_{relay})

Input:
Periodic beacon packet from Sink
Output:
Reliable path {n_{source}, n_{relay}, Sink}
Repeat
1. **if** ($isSink$) **then**
    1.1. broadcast (beacon);
2. **end**
3. **if** receive (beacon) **then**
    3.1 compute (E_{ratio}) following equation 1;
        compute (L_{rel}) following equation 2;
        compute (Rel_{comm}) following equation 3;
        3.1.1 **if** ($Rel_{\text{comm}} >$ threshold) **then**
            3.1.1.1 set ($conn^{Sink}$ = true);
            3.1.1.2 broadcast ($selfNodeID$) as relay;
        3.1.2 end
4. **end**
5. **if** receive (broadcast)^j **then**
    5.1 add (j, RSSI) in RT
6. **end**
7. **if** (data) **then**

7.1 **if** $conn^{Sink}$ == true **then**
7.1.1 set (destination = Sink)
7.2 else
7.2.1 compute (Rel_{comm}) ∀ relay ∈ RT following equation 3;
7.2.2 set (destination = relay) $s.t.$ $Rel_{\text{comm}} = \max(Rel_{\text{comm}})$;
7.3 end
7.4 if ($E_{\text{ratio}} > 0.5$) **then**
7.4.1 if $L_{\text{rel}} > 0.8$ **then**
7.4.1.1 set ($P_{\text{tx}} = P_0$)
7.4.2 end
7.4.3 else if $0.6 < L_{\text{rel}} <= 0.8$ **then**
7.4.1.1 set ($P_{\text{tx}} = P_1$)
7.4.4 end
7.4.5 else if $0.5 < L_{\text{rel}} <= 0.6$ **then**
7.4.5.1 set ($P_{\text{tx}} = P_2$)
7.4.6 end
7.4.7 else
7.4.7.1 set ($P_{\text{tx}} = P_3$)
7.4.8 end
7.4.9 else
7.4.9.1 set ($P_{\text{tx}} = P_0$)
7.4.10 end
8. end
9. if receive (data) **then**
9.1 **if** ($isSink$) **then**
9.1.1 send (data) to upper layer
9.2 else
9.1.2 forward (data) to Sink
9.3 end
10. end
until every time period t;

3.2. A Working Example

In figure 3.1 an example of our proposed work is shown. Sink first sends beacon to all sensors in figure 3.1(a). If sensors received beacon then calculate energy ratio, link reliability, and communication reliability. Then the sensors whose communication reliability is greater than threshold will select as relay node and broadcast their node id shown in figure 3.1(b). Then sensors send data to sink in single or multi hop shown in figure 3.1(c).

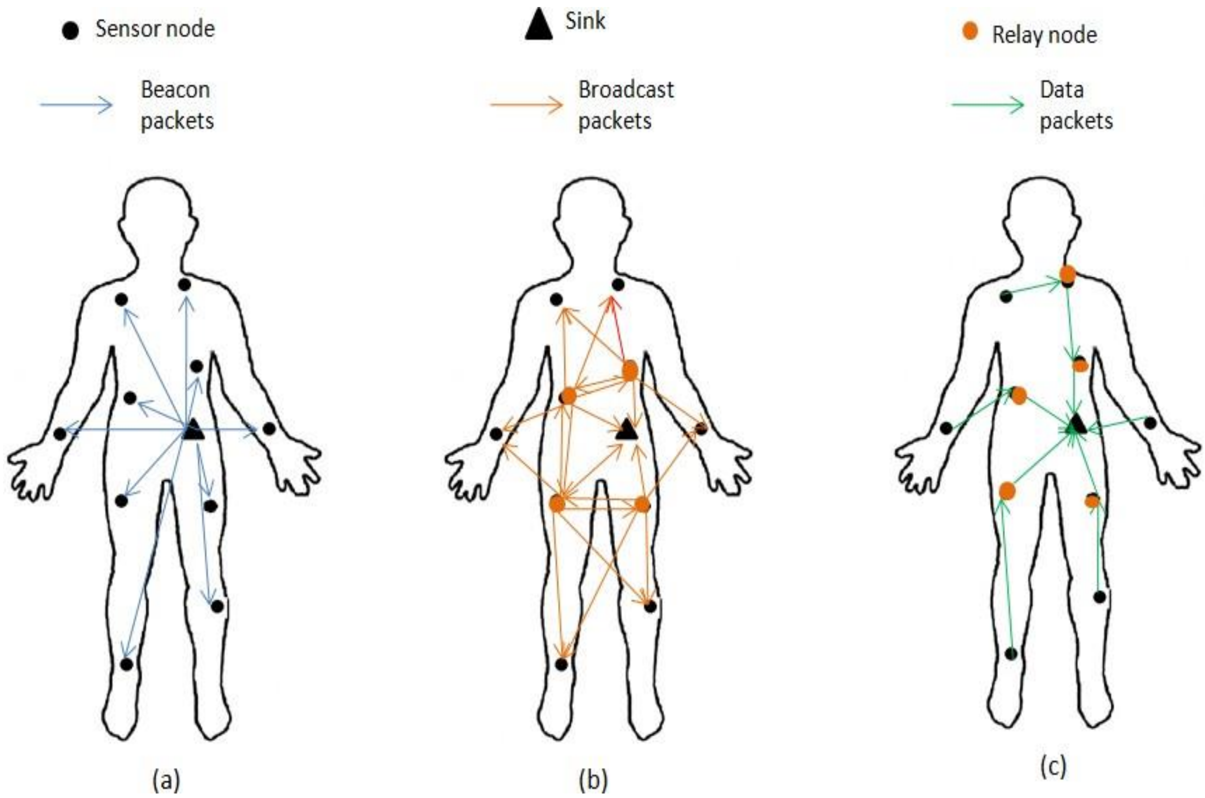


Figure 3.1 Proposed routing protocol diagram

3.3. Complexity Analysis

Algorithmic complexity is concerned about how fast or slow particular algorithm performs. An algorithm is said to run in constant time means complexity is $O(1)$, if it requires the same amount of time regardless of the input size. An algorithm is said to run in linear time means complexity is $O(n)$, if its time execution is directly proportional to the input size, i.e. time grows linearly as input size increases. The *best-case runtime complexity* of the algorithm is the function defined by the minimum number of steps taken on any instance of size n. The *worst-case runtime complexity* of the algorithm is the function defined by the maximum number of steps taken on any instance of size n.

Here the sink first sends periodic beacons to sensors to send a single data. When a single data packet is sent directly to the sink, only one control message is required from the sink and then the connection path is also reliable. So, message complexity is $O(1)$ in the best case. But in the worst case, when sensor fails to receive any beacon from sink then the connection path is poor, and so it waits for the broadcasts received from its neighbors. Then a forwarder is selected for sending n-1 control message. So, message complexity is $O(n)$ in worst case.

In this chapter, the proposed protocol and related algorithm is described briefly. Also, the complexity analysis and diagram for the work is described. In next chapter, we discussed about the simulation parameters and their value and also setup the experimental values for the proposed protocol.

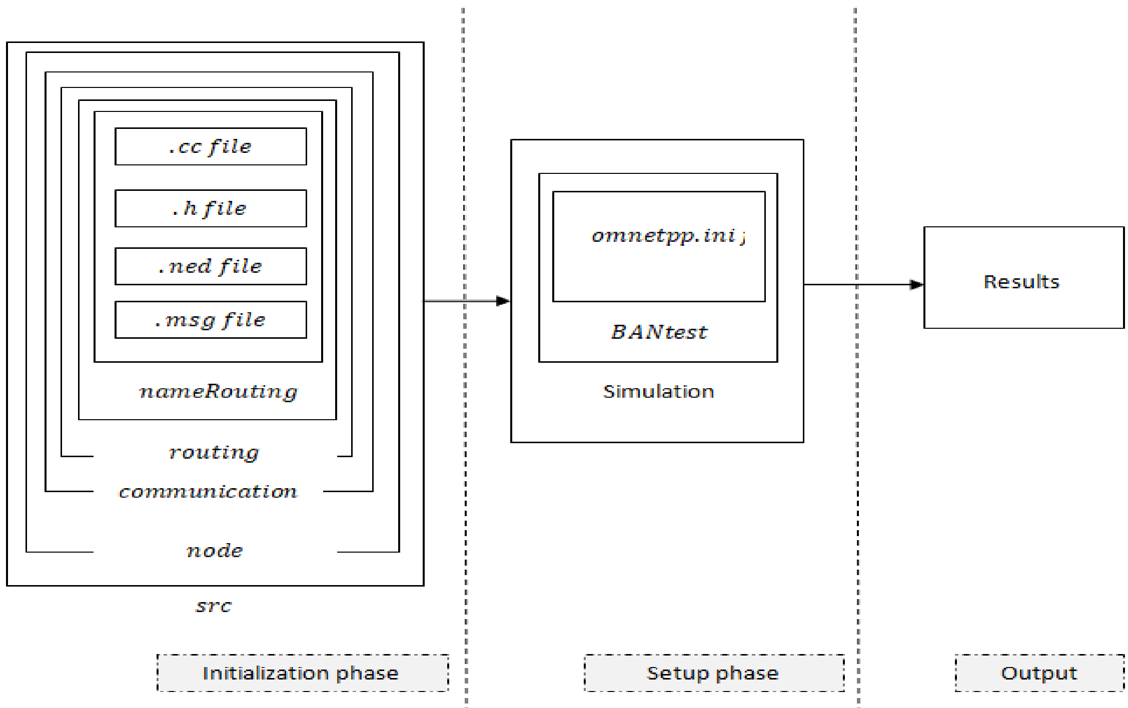
Chapter-4

4. Experimental Setup

The proposed protocol is implemented using Castalia-3.2 [15] simulator based on $OMNeT$++ [16] platform. $OMNeT$++, itself is an object oriented modular and a simulation framework without models for network protocols.

Castalia [15] is a simulator which is actually used for the networks of low-power embedded devices. Generally, the $OMNeT$++ platform-based simulator is used by researchers and developers to test their distributed algorithms and/or protocols in a realistic wireless channel and radio model, with a realistic node behavior especially relating to access of the radio for Wireless Sensor Networks (WSN), Body Area Networks. Few important files for implementing the algorithms proposed by the researchers are as follows files: -

- $.msg$ file which define various message types and various data fields also add to this file.
- $.ned$ file which define module structure with various parameters
- $.cc$ file and .h file which are actually C++ files with module sources



$\boldsymbol{Figure}\ \mathbf{4.1}$ Block diagram of the $OMNeT++$ implementation in Castalia

In $OMNeT$++, $.cc$ file include the $.h$ file and define various modules for the proposed protocol. In $.h$ file, the variable name and keyword and structure of routing table are declared and the type of the variable is also declared. It includes $VirtualRouting.\ h$ and $protocolPacket\_m.\ h$ file. In $.ned$ file different parameters and module types related to .cc file are declared. In $.msg$ file $RoutingPacket\_m.\ h$ and routing packet kind are declared. The block diagram is shown in figure 4.1.

We need to create an omnetpp.ini file to run the simulation. It tells the simulation program which network we want to simulate (as NED files may contain several networks), parameters are passed to the model, explicitly specify seeds for the random number generators, etc.

In the proposed model, 11 nodes are deployed over 1meter × 1.9meter area shown in figure 4.2, i.e. average body area of a human being out of which node 0 acts as sink node.

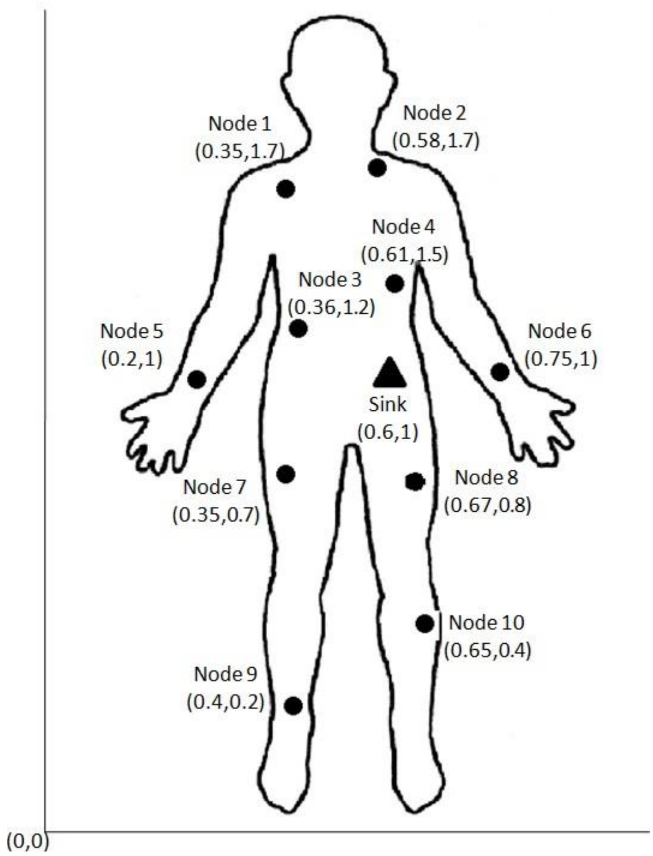


Figure 4.2 Initial node locations on human body

The network size is 11 in our simulation setup because according to existing literature [17], the number of nodes in WBAN is kept in the range 15 to 20 [23]. Sink is placed near the waist in such a way that initially all nodes get connected to the sink and form a star topology. The node coordinates are kept covering the major positions of human body such as legs, hands, arms etc. and these coordinates are scaled accordingly in our simulation set up. When body posture changes due to mobility it may take multi-hop communication. Mobility of each node is depicted with Line Mobility Model [15]. The sensor nodes as well as sink follow BAN radio model defined in Castalia-3.2. Each sensor node as well as the sink follows the radio model $BANRadio$ defined in Castalia-3.2 [15]. The transmission power levels (−25dBm, −20dBm, − 15dBm, −12dBm) and the corresponding transmission ranges are governed by $BANRadio$ [15]. All the sensors except the sink generate packets at the rate of 14 packets per second. Threshold value for comparing communication reliability of the direct connection to the sink is set as 0.5. This is obtained empirically. The weights w1 and w2 associated with energy ratio and link reliability are chosen as 0.5 each to provide equal importance to both the issues.

Various simulation parameters used in our experiments and their default values are listed in Table 4.1.

Table 4.1
SIMULATION PARAMETERS AND THEIR DEFAULT VALUES

Parameters	Value
Simulation area	1 m x 1.9m
Number of Nodes	11
Simulation time	10000sec
Mobility model	Line Mobility model
MAC protocol	ZigBeeMAC (IEEE 802.15.4)
Data generation rate	14 packets/sec
Threshold value	0.5
Weight1 (w1)	0.5
Weight2 (w2)	0.5

Few important parameters in . *ini* file are described as follows.

To obtain the traces of the routing protocol in a file, called Castalia-Trace.txt, the followings line is written:

```
SN.node[*].Communication.Routing.collectTraceInfo = true
```

For mobility of nodes in wireless channel switch as follows:

```
SN.wirelessChannel.onlyStaticNodes = false
SN.wirelessChannel.sigma = 0
SN.wirelessChannel.bidirectionalSigma = 0
```

A radio model and transmission power are chosen to a low value for better mobility. Here we use BAN radio model and a default transmission power for our proposed work.

```
SN.node[*].Communication.Radio.RadioParametersFile = "../Parameters/Radio/BANRadio.txt"
SN.node[*].Communication.Radio.TxOutputPower = "-15dBm"
```

To show interference clearly, big packets (2kb) are used and the maximum packet size is set to all communication layers as follows:

```
SN.node[*].Communication.Routing.maxNetFrameSize = 2500
SN.node[*].Communication.MAC.maxMACFrameSize = 2500
SN.node[*].Communication.Radio.maxPhyFrameSize = 2500
SN.node[*].Communication.Radio.collisionModel = 0
```

In our proposed model, 11 nodes are deployed all over the human body shown in **figure 4.2**. For that we have taken 1meter × 1.9meter area for deployment as follows:

```
SN.field_x = 1   # meters
SN.field_y = 1.9         # meters
SN.numNodes = 11
```

Sink and sensors position, and their node id shown in figure 4.1 are declared in .ini file as follows:

```
SN.node[0].Application.isSink = true
SN.node[0].Application.nodeID = 0
SN.node[1].Application.nodeID = 1
SN.node[2].Application.nodeID = 2
SN.node[3].Application.nodeID = 3
SN.node[4].Application.nodeID = 4
SN.node[5].Application.nodeID = 5
SN.node[6].Application.nodeID = 6
SN.node[7].Application.nodeID = 7
SN.node[8].Application.nodeID = 8
SN.node[9].Application.nodeID = 9
SN.node[10].Application.nodeID = 10
```

```
SN.node[0].xCoor = 0.6
SN.node[0].yCoor = 1
SN.node[1].xCoor = 0.35
SN.node[1].yCoor = 1.7
SN.node[2].xCoor = 0.58
SN.node[2].yCoor = 1.7
SN.node[3].xCoor = 0.36
SN.node[3].yCoor = 1.2
SN.node[4].xCoor = 0.61
SN.node[4].yCoor = 1.5
SN.node[5].xCoor = 0.2
SN.node[5].yCoor = 1
SN.node[6].xCoor = 0.75
SN.node[6].yCoor = 1
SN.node[7].xCoor = 0.35
SN.node[7].yCoor = 0.7
SN.node[8].xCoor = 0.67
SN.node[8].yCoor = 0.8
SN.node[9].xCoor = 0.4
SN.node[9].yCoor = 0.2
SN.node[10].xCoor = 0.65
SN.node[10].yCoor = 0.4
```

In our proposed work, sensor nodes send data to sink. So, the destination is declared as:

```
SN.node[*].Application.reportDestination = "SINK"
```

When body posture changes due to mobility it takes multi-hop for communication. For that we set Line mobility model [15].

```
SN.MobilityManagerName = " LineMobilityManager "
```

The transmission power levels are set in −25dBm, −20dBm, −15dBm, −12dBm as follows:

```
SN.node[*].Communication.Radio.TxOutputPower = ${Power ="-10dBm","-15dBm","-20dBm","-25dBm"}
```

To use ZigBeeMAC for the proposed work *omnetpp.ini* file is modified as follows:

```
SN.node[*].Communication.MACProtocolName = "Mac802154"
SN.node[0].Communication.MAC.isFFD = true
SN.node[0].Communication.MAC.isPANCoordinator = true
SN.node[*].Communication.MAC.phyDataRate = 250
SN.node[*].Communication.MAC.phyBitsPerSymbol = 2
```

Here we discuss the setup for the proposed work and how and where the value and parameters are taken to get result. In the next chapter we will see the result related to the proposed work and discuss how it works.

Chapter-5

5. Results and Discussions

5.1. Simulation Results

According to the proposed work, sensor nodes are sent data to sink in single and multi-hop. Every sensor node is situated in different position on human body, sent data to the sink through the reliable communication path. Here we take 10 sensor nodes for sending data to sink. Among 10 sensors few sensors are selected as forwarder or relay, which are forwarding data directly to sink in single hop. Here the data received by sink with varying time and their related consumed energy as time goes on is observed. Also forwarded data through relay as time goes on is measured.

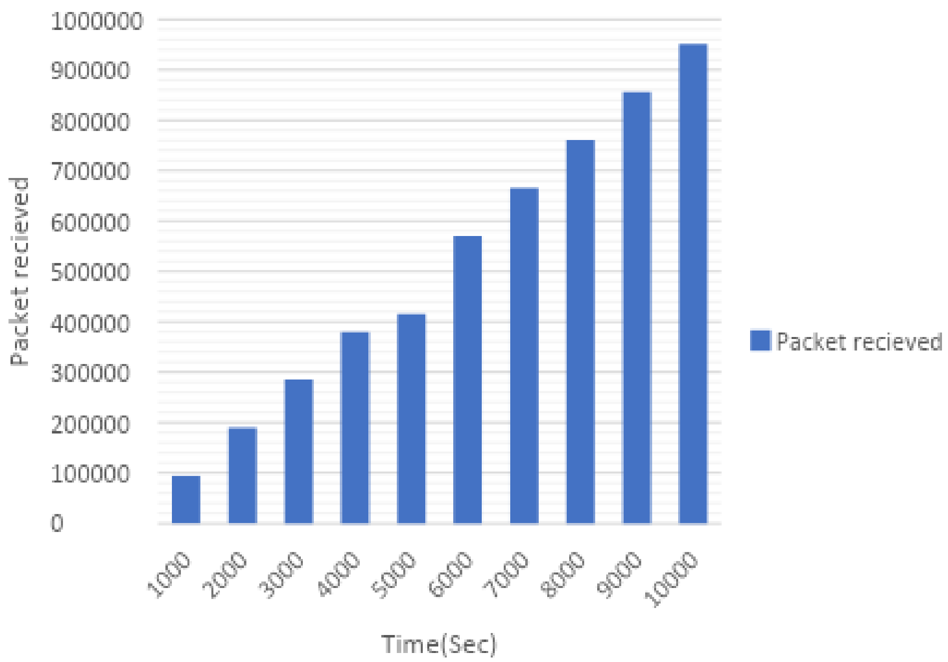


Figure 5.1 Variation of packets received at sink with time

Here we take maximum time of 10000sec to simulation. The number of packets are received at the sink with respect to time is depicted in figure 5.1. As obtained from the outcome, when nodes send data packets to the sink, number of packets increases as time increase.

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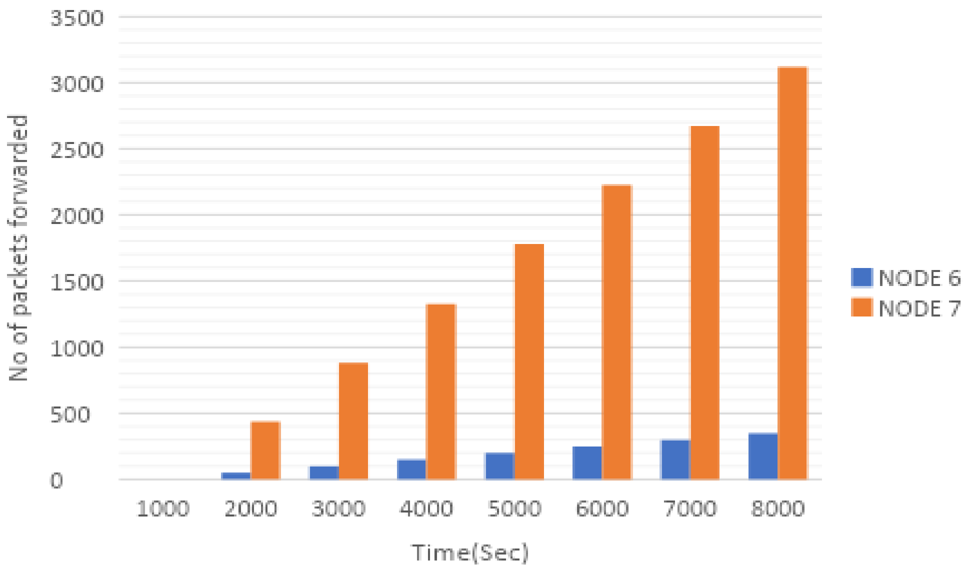

Figure 5.2 Variation of packets forwarded with time

The number of packets forwarded by relay node with respect to time is depicted in figure 5.2. When 10 sensor nodes want to send data through a reliable communication path, it selects some node as relay node. The relay node forward data to sink in single and multi-hop. Node1, node5, node 6 and node 7 are selected as relay node as changing simulation time. Here we show in graph, the forwarded packets received at sink as time goes on only for node 6 and node 7.

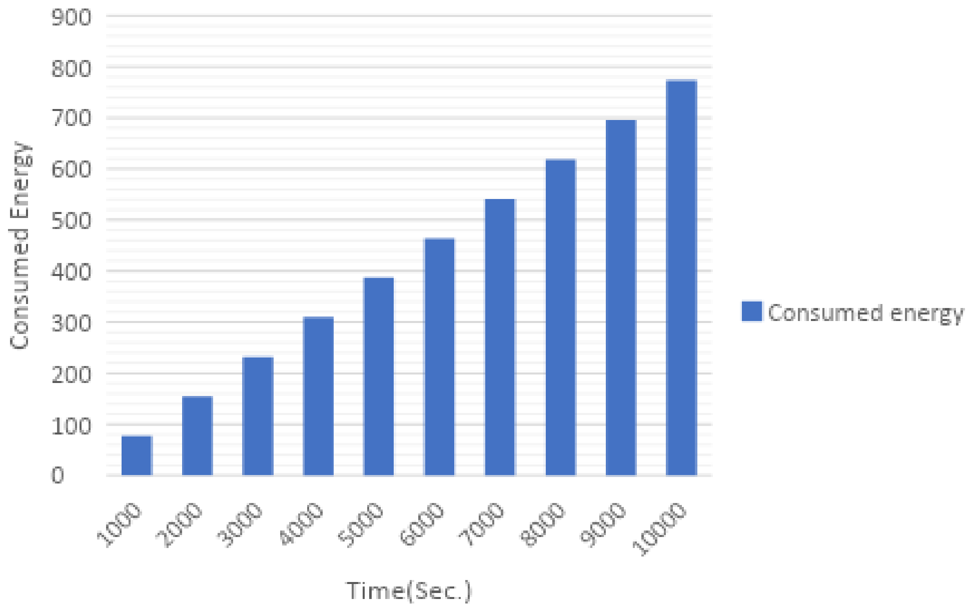

Figure 5.3 Variation of consumed energy with time

Total consumed energy by nodes with respect to time is depicted in figure 5.3. The energy consumption of nodes in the network as time increase is shown here. We get the energy consumption value from the resource manager in Castalia.

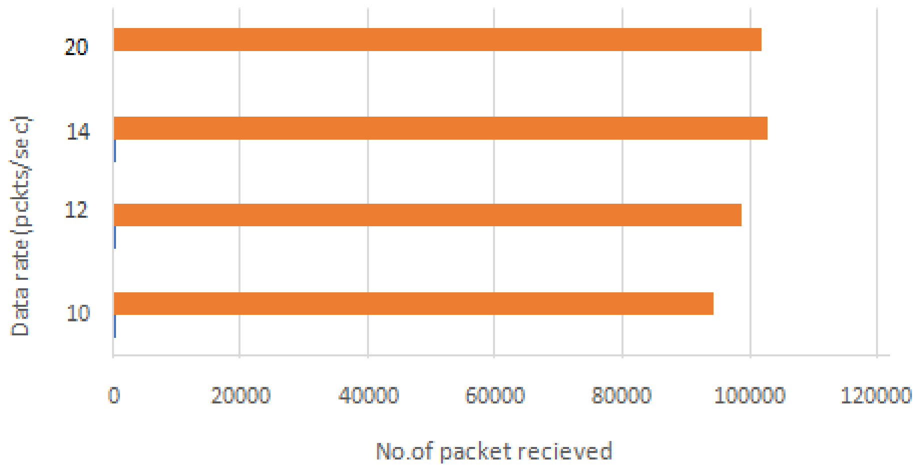

Figure 5.4 Variation of received data packets with varying data rate

In figure 5.4 data packets received at sink in different data rate and in 1000 second time is shown. Here number of data packets successfully delivered at the sink with corresponding data rate. Initially when data rate gradually increase, data traffic improves as more packets are sent. But once at a time channel is saturated with more sending data rate. Therefore, the numbers of received packets become less.

In this chapter, the experimental results for the proposed model are discussed. The related graph for various experiments and how they work that also mentioned. In the last chapter, the conclusion and future work is discussed.

Chapter-6

6. Conclusion and Future Work

6.1. Conclusion

In this thesis, a routing protocol for WBAN is formulated where sensor nodes get a reliable path to communicate with sink by selecting proper relay node. Sink received data directly from sensors in one or $multihop$. We use energy status and link communication for choosing a reliable communication path.

6.2. Future Work

The proposed protocol is developed for intra ban interference. In future, we can develop the protocol for inter ban interference. How the mechanism can handle the inter ban interference will be measured.

REFERENCES

1. Swati Gawand, Prof. Santosh Kumar “Wireless Sensor Network Based Healthcare Monitoring: A Review”, International Journal of Electronics, Communication & Soft Computing Science and Engineering ISSN: 2277-9477, Volume 3, Issue 7.

2. Samaneh Movassaghi, Student Member, IEEE, Mehran Abolhasan, Senior Member, IEEE, Justin Lipman, Member, IEEE, David Smith, Member, IEEE, and Abbas Jamalipour, Fellow, IEEE “Wireless Body Area Networks: A Survey” IEEE COMMUNICATIONS SURVEYS & TUTORIALS, 2013.

3. Samaher Al-Janabia, Ibrahim Al-Shourbajib,⇑, Mohammad Shojafarc, Shahaboddin Shamshirband “Survey of main challenges (security and privacy) in wireless body area networks for healthcare applications” Egyptian Informatics Journal 18 (2017), pp. 113–122.

4. A.G. Fragopoulos, J. Gialelis, D. Serpanos “Imposing holistic privacy and data security on person centric eHealth monitoring infrastructures” 12th IEEE international conference on E-health networking applications and services (Healthcom) (2010), pp. 127-134.

5. Rim Negraa, Imen Jemilia, Abdelfettah Belghitha “Wireless Body Area Networks: Applications and technologies” Procedia Computer Science 83 (2016), pp. 1274 –1281.

6. Jing Chen Wang, Mark Leach, Zhao Wang, Eng Gee Lim, Ka Lok Man, “Wireless Body Area Network and its Applications” ISOCC 2015.

7. M. Al Ameen, J. Liu, K. Kwak “Security and privacy issues in wireless sensor networks for healthcare applications” J Med Syst, 36 (1) (2012), pp. 93-101.

8. Benoit Latre ; Bart Braem ; Ingrid Moerman ; Chris Blondia ; Elisabeth Reusens ; Wout Joseph ; Piet Dem “A Low-delay Protocol for Multihop Wireless Body Area Networks” 2007 Fourth Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services (MobiQuitous).

9. Thomas Watteyne, Isabelle Augé-Blum, Mischa Dohler, Dominique Barthel “AnyBody: a Self-organization Protocol for Body Area Networks” in Proceedings of the ICST 2nd international conference on Body area networks. ICST (Institute for Computer Sciences, Social-Informatics and ..., 2007, p. 6.

10. N.Javaid, Z.Abbas, M.S.Fareed, Z.A.Khan, N.Alrajeh “M-ATTEMPT: A New Energy-Efficient Routing Protocol in Wireless Body Area Sensor Networks” 4th International Conference on Ambient Systems, Networks and Technologies (ANT), 2013.

11. Q. Nadeem, N. Javaid, S. N. Mohammad, M. Y. Khan, S. Sarfraz, M. Gull, “SIMPLE: Stable Increased-throughput Multi-hop Protocol for Link Efficiency in Wireless Body Area

Networks" IEEE 8th International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA'13), Compiegne, France, vol-1.

12. Nadeem Javaid, Ashfaq Ahmad, Qaisar Nadeem, Muhammad Imranc, Noman Haider "iM-SIMPLE: iMproved stable increased-throughput multi-hop link efficient routing protocol for Wireless Body Area Networks" Computers in Human Behavior 51 (2015), pp. 1003–1011.

13. Moumita Roy, Jadavpur University, Chandreyee Chowdhury, Jadavpur University, India, Nauman Aslam Northumbria University,Newcastle Upon Tyne, UK. "Designing an Energy Efficient WBAN Routing Protocol", (2017) 9th International Conference on Communication Systems and Networks (COMSNETS)

14. Majid Nabi, Twan Basten, Marc Geilen, Milos Blagojevic, Teun Hendriks, "A Robust Protocol Stack for Multi-hop Wireless Body Area Networks with Transmit Power Adaptation" BodyNets'(2010), pp. 10-12.

15. "Castalia Simulator", https://castalia.forge.nicta.com.au/index.php/en/.

16. "OMNeT++ website", http://www.omnetpp.org.

17. S. Movassaghi,M. Abolhasan,J. Lipman,D. Smith and A. Jamalipour, "Wireless Body Area Networks: A Survey" in IEEE Communications Surveys & Tutorials, vol. 16, no. 3,pp. 1658-1686, Third Quarter 2014.

18. S. Ullah, H. Higgins, B. Braem, B. Latre, C. Blondia, I. Moerman, S. Saleem, Z. Rahman, and K. Kwak, "A Comprehensive Survey of Wireless Body Area Networks," Journal of Medical Systems, pp. 1–30, Aug. 2010.

19. M. Quwaider and S. Biswas, "DTN routing in body sensor networks with dynamic postural partitioning," Ad Hoc Networks,vol. 8, no. 8, pp. 824–841, Nov. 2010.

20. Garth V. Crosby, Tirthankar Ghosh, Renita Murimi, Craig A. Chin"Wireless Body Area Networks for Healthcare: A Survey" International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC) Vol.3, No.3, June 2012

21. Majid Nabi,Twan Basten, Marc Geilen, Milos Blagojevic, Teun Hendriks "A Robust Protocol Stack for Multi-hop Wireless Body Area Networks with Transmit Power Adaptation" BodyNets'10 September 10-12, 2010, Corfu Island, Greece.

22. Jocelyne Elias and Ahmed Mehaoua "Energy-aware Topology Design for Wireless Body Area Networks" IEEE ICC 2012, pp. 3409 -3413.

23. Yu Zhang, Bing Zhang and Shi Zhang "A Lifetime Maximization Relay Selection Scheme in Wireless Body Area Networks", Sensors (2017).

24. M.Quwaider and S.Biswas. Probabilistic routing in on-body sensor networks with postural disconnections.In Proc. 7th ACM MobiWAC, pages 149–158. ACM, 2009

25. Muhannad Quwaider, Mahmud Taghizadeh and Subir Biswas. "Modelling On-Body DTN Packet Routing Delay in the Presence of Postural Disconnections", EURASIP Journal on Wireless Communications and Networking, 2011, Article ID 280324, pages: 1-19.

26. P.T. Sharavanan, R. Kumar, D. Sridharan "A Comparative Study of Cross Layer Protocols in WBAN" Australian Journal of Basic and Applied Sciences, 2015, Pages: 294-300.

27. Pereira, O., Caldeira, J. M., & Rodrigues, J. J. "Body sensor network mobile solutions for biofeedback monitoring" Mobile Networks and Applications, (2011), 16(6), pp. 713-732.

28. Md. Taslim Arefin, Mohammad Hanif Ali, A. K. M. Fazlul Haque "Wireless Body Area Network: An Overview and Various Applications" Journal of Computer and Communications, 2017, 5, pp. 53-64.