**Republic of Iraq**
**Ministry of Higher Education and Scientific Research**
**University of Babylon**
**College of Information Technology**
**Department of Information Networks**

# HYBRID ROUTING PROTOCOL TO ENHANCE THE WIRELESS BODY SENSOR NETWORK

A Thesis Submitted

to the Council of the College of Information Technology - University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Information Technology in Information Networks.

**By**

**Ali Samir Saleem Abbas**

**Supervised by**

**Prof. Dr. Saad Talib Hasson Aljebori**

**2022 A.D.** **1444 A.H**

بسم الله الرحمن الرحيم

**يرفع الله الذين آمنوا منكم والذين أوتوا العلم درجات والله بما تعملون خبير**

صدق الله العظيم

سورة المجادلة . آية 11

## Certification of the Examination Committee

We hereby certify that we have studied the thesis entitled (**HYBRID ROUTING PROTOCOL TO ENHANCE THE WIRELESS BODY SENSOR NETWORK**) presented by the student (**ALI SAMIR SALEEM ABBAS**) and examined her in its content and what is related to it, and that, in our opinion, it is adequate with (**Excellent**) standing as a thesis for the degree of Master in Information Technology-Information Networks.

Signature:
Name: Ali Kadhum Idrees
Title: Prof. Dr.
Date: / / 2022
(**Chairman**)

Signature:
Name: Ahmad Baheej Yaseen
Title: Asst. Prof. Dr.
Date: / / 2022
(**Member**)

Signature:
Name: Tariq Alwan Kadhum
Title: Lecturer
Date: / / 2022
(**Member**)

Signature:
Name: Saad Talib Hasson Aljebori
Title: Prof. Dr.
Date: / / 2022
(**Member and Supervisor**)

Approved by the Dean of the College of Information Technology, University of Babylon.

Signature:
Name: Hussein Atiyah. Lafta
Title: Professor
Date: / / 2022
(**Dean of Collage of Information Technology**)

# Supervisor Certification

I certify that the thesis entitled (**HYBRID ROUTING PROTOCOL TO ENHANCE THE WIRELESS BODY SENSOR NETWORK**) was prepared under my supervision at the department of Information Networks/ College of Information Technology / University of Babylon as partial fulfillment of the requirements of the degree of Master in Information Technology-Information Networks.

Signature:

Supervisor Name: **Prof. Dr. Saad Talib Hasson Aljebori**

Date: / /2022

## The Head of the Department Certification

In view of the available recommendations, I forward the thesis entitled "**HYBRID ROUTING PROTOCOL TO ENHANCE THE WIRELESS BODY SENSOR NETWORK"** for debate by the examination committee.

Signature:

Prof. Dr. **Saad Talib Hasson Aljebori**

Head of Information Networks Department

Date: / /2022

# Declaration

I hereby declare that this thesis, submitted to the University of Babylon in partial fulfillment of requirement for the degree of Master of Information Technology-Information Networks has not been submitted as an exercise for a similar degree at any other university. I also certify that this work described here is entirely my own except for experts and summaries whose sources are appropriately cited in the references.

Signature:

Name : **Ali Samir Saleem Abbas**

Date: **/ / 2022**

# Dedication

I dedicate this thesis

To the soul of my father

To the fountain of patience my mother

To my supervisor

To my family

To my friends

Researcher

# Acknowledgement

In the name of God, Most Gracious, Most Merciful, At first, Praise be to God and thanks to God and the satisfaction of parents and conciliation only from God greatest praise is to **Allah** for His assistance in facing the difficulty that I met in my study, and for always helping me to achieve my aims, also for His great graces and boons all the time.

I would like to express my deepest thanks to my supervisor **Prof. Dr. Saad Talib Hasson Aljebori** for their valuable advice, motivation, guidance, and for so many fruitful discussions throughout the preparation of this thesis.

I would like to extend my respect and deepest gratitude to the College of Information Technology.

Sincere appreciation and love go to my family, my father's soul who he was always be with me in my heart and my dear mother that whatever I did to her will not reward her they provide me with optimism and pure affection and they give me great hope, encouragement and they have stood with me in every step in this research. I dedicate this work and give special thanks to those who encouraged me to continue my scientific career, my wife, and my children.

Finally, Sincere thanks and appreciation to all friends, colleagues and loved ones

Researcher

# Abstract

The wireless body area network (WBAN) is a multi-disciplinary field that has the potential to revolutionize healthcare by enabling low-cost, continuous monitoring of patient health and real-time updates to medical records using data collected by sensors connected to the Internet of Things (IoT). In order to keep tabs on day-to-day happenings, it is crucial to construct a model that allows for control over sensor data with the least possible delay in order to construct a route among WBAN parts.

The proposed routing system based on the Hybrid Delay-based Routing Protocol (HDRP), which combines two delayed postural-aware routing protocols Probabilistic Routing with Postural Link Costs (PRPLC), and On Body Store and Flood Routing (OBSFR) to enhance network analysis for routing strategies that are equivalent for resource-constrained IoT sensors. Throughput, end-to-end delay, packet delivery, and goodput were used as the primary evaluation metrics in a simulation conducted with OMNET++ of (7, 13, and 23 IoT healthcare sensors; Electroencephalography (EEG), Electrocardiography (ECG), Temperature, Motion, and Blood Pressure).

The results showed that the proposed HDRP routing techniques have improved results in reducing the total minimal level average of each packet arrival delay as PRPLC as 22.3226 seconds, OBSFR as 21.672 seconds, HDRP as 18.855 seconds, packet delivery as 99.71 %, 99.91 %, and 99.93 %. for each PRPLC, OBSFR, and HDRP. Goodput is 3.2389 pkts/sec for PRPLC, 3.5118 pkts/sec for OBSFR, and 4.097 pkts/sec for HDRP, while the maximum average throughput for seven IoT sensors is 159.7544 Bps, 168.16833 Bps, and 176.5767 Bps. The proposed hybrid routing protocol enhanced evaluation metrics used as decreased delay, increased throughput, packet delivery ratio, and goodput respectively.

# Table of Contents

# Table of Contents

# Table of Contents

# List of Tables

## List of Figures

# List of Algorithms

# List of Abbreviations

| Abbreviation | Description |
|---|---|
| ALTR | Adaptive Least Temperature Routing |
| AODV | Ad Hoc On-Demand Distance Vector |
| AOMDV | Ad Hoc On-demand Multipath Distance Vector Routing protocol |
| M- ATTEMPT | Mobility- supporting Adaptive Threshold-based Thermal- aware Energy-efficient Multi-Hop Protocol |
| BBN | body-to-body network |
| BCU | Body Control Unit |
| BAP | Backhaul Adaptation Protocol |
| CICADA | Cascading Information retrieval by Controlling Access with Distributed slot Assignment Protocol |
| CRP | Cooperative Routing Protocol |
| CSMA/CA | Carrier Sense Multiple Access with Collision Avoidance |
| DMQoS | Data-Centric Multiobjective QoS-Aware |
| DSSS | Direct Sequence Spread Spectrum |
| DSDV | Destination-sequenced distance vector |
| DYMO | Hybrid Dynamic Manet On Demand Routing Protocol |
| ECG | Electrocardiography |
| EEG | Electroencephalography |
| EERP-DPM | Energy Efficient Routing Protocol using Dual Prediction Model |
| EMG | Electromyography Sensor |
| ER | Epidemic Routing |
| EPR | Energy-Proportional Routing |
| ETPA | Energy Efficient Thermal and Power Aware |
| ETE | End To End |
| IR | Infra-Red |
| ISM | Industrial Scientific Medical |
| GPSR | Greedy Perimeter Stateless Routing |
| HBC | Human Body Communication |
| HDRP | Hybrid Delay-based Routing Protocol |
| LBT | Listen-Before-Talk |
| LLF | Link likelihood Factor |
| LTE | Long-Term Evolution |
| LTE-A | Long-Term Evolution- Advanced |
| LTR | Least Temperature Routing |
| MICS | Medical Implant Communication Services |
| MS | Medical Server |
| M-DSDV-RMCP | Destination Sequenced Distance Vector (DSDV), Relayed Multicast Control Protocol |
| NB | Narrow Band |
| OBSFR | On Body Store and Flood Routing |

| | |
|---|---|
| OFDM | Orthogonal Frequency Division Multiplexing |
| OMNeT++ | Objective Modular Network Testbed in C++ |
| PD | Personal Device |
| PDA | Personal Digital Assistant |
| PDR | Packet Delivery Ratio |
| PHY | Physical Layer |
| PLCP | Physical Layer Convergence Procedure |
| PPDU | Physical Layer Protocol Data Unit |
| PQM | Path-Quality Monitoring |
| PRPLC | Probabilistic Routing with Postural Link Costs |
| PSR | Powerful Source Routing |
| PSDU | Physical Layer Service Data Unit |
| PSDU | Physical System Description Unit |
| QoS | Quality of Service |
| QPRR | QoS-Aware Peering Routing Protocol |
| QPRD | QoS-aware Peering Routing Protocol for Delay Sensitive Data |
| RAIN | Routing Algorithm for Network of Homogeneous and ID-less Biomedical Sensor Nodes |
| RL-QRP | Reinforcement Learning-based QoS-aware Routing Protocol |
| TARA | Thermal-Aware Routing Algorithm |
| TSHR | Thermal-aware Shortest Hop Routing |
| TTRP | Trust and Thermal Aware Routing Protocol |
| UWB | Ultra Wide Band |
| WASP | Wireless Autonomous Spanning Tree Protocol |
| WBAN | Wireless Body Area Network |
| WBSN | Wireless Body Sensor Network |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WLAN | Wireless Local-Area Network |

# List of Study Related Publications

**Name of Conferences: Fifth International Iraqi Conference on Engineering Technology (5th IICETA-2022), 2022 11th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS).**

- **1st Paper Title:** Modeling the Performance of Wireless Body Sensor Networks. DOI: 10.1109/IICETA54559.2022.9888538
- **2nd Paper Title:** Hybrid Delay-based Routing Protocol for Wireless Body Sensor Networks**. DOI: 10.1109/EECCIS54468.2022.9902939**
- **Authors:**
  - Ali Samir Saleem Abbas
  - Prof. Dr. Saad Talib Hasson Aljebori

Information Network Department, Information Technology College, Babylon University.

Email: ali.net.msc@student.uobabylon.edu.iq

Email: Saad_aljebori@itnet.uobabylon.edu.iq

# Modeling the Performance of Wireless Body Sensor Networks

Publisher: IEEE  Cite This  PDF

Ali Samir Saleem ; Saad Talib Hasson  All Authors



Abstract

Document Sections



Authors
Figures
References
Keywords

**Abstract:**
Wireless Body Area Network (WBAN) is a special purpose network of sensor nodes. Large number of patient's conditions could be continuously monitored, alarms the person who wears sensors about auto medication during emergency condition. Due to the advancement in technology which has led to a tremendous increase in the use of wireless devices, the wireless body area network sensors are becoming a necessity part of the human daily life. In this paper the proposed system is based on the on-body store and flood routing (OBSFR) routing techniques to control flooding packet in WBAN depending on the time required to build route among WBAN network elements. OBSFR decreased total elapsed time to build routing table for overall Internet of Things (IoTs) sensors, which showed enhancement during increased number of body sensors in the network. The results showed the proposed adaptive OBSFR routing techniques has better performance in reducing the total average of each packet delivery delay as 21.672 seconds, throughput as 35.877 Bps, and packet delivery ratio as 98.964 (%) of 23 IoT sensor nodes.

**Published in:** 2022 5th International Conference on Engineering Technology and its Applications (IICETA)

**Date of Conference:** 31 May 2022 - 01 June 2022
**DOI:** 10.1109/IICETA54559.2022.9888538
**Date Added to IEEE *Xplore*:** 27 September 2022
**Publisher:** IEEE
**ISBN Information:**
**Conference Location:** Al-Najaf, Iraq





**Modeling the Performance of Wireless Body Sensor Networks**
Ali Samir Saleem; Saad Talib Hasson
2022 5th International Conference on Engineering Technology and its Applications (IICETA)
Year: 2022 | Conference Paper | Publisher: IEEE

Abstract  HTML

# Hybrid Delay-based Routing Protocol (HDRP) for Wireless Body Sensor Networks

Publisher: IEEE



Ali Samir Saleem ; Saad Talib Hasson All Authors





**Abstract:**

Wireless Body Sensor Networks (WBSNs) are a subset of Wireless Sensor Networks (WSN s) that are responsible for monitoring vital sign-related data of patients and consequently routing this data towards a sink. WSNs are responsible for the monitoring of vital sign-related data of patients. WBSNs have some of the same routing issues that ordinary WSNs do when it comes to the routing of sensed data towards sinks. However, the specific needs of WBSNs impose certain additional limitations that need to be handled by the routing mechanisms in order for WBSNs to function properly. In this paper the proposed system is based on Hybrid Delay-based Routing Protocol (HDRP) routing techniques to control flooding packet in WBAN depending on the time required to build route among WBAN network elements. The results showed the proposed HDRP routing techniques has better performance in reducing the total minimum average of each packet delivery delay as Probabilistic routing with postural link costs (PRPLC) Routing Protocol as 22.3226 seconds, On Body Store and Flood Routing (OBSFR) Routing Protocol as 21.672 Seconds, HDRP Routing Protocol as 18.855 seconds, packet delivery ratio as 99.71 %, 99.91 %, and 99.93 %. for each PRPLC, OBSFR, and HDRP respectively.

**Published in:** 2022 11th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)

**Date of Conference:** 23-25 August 2022

**DOI:** 10.1109/EECCIS54468.2022.9902939

**Date Added to IEEE *Xplore*:** 04 October 2022

**Publisher:** IEEE

# *Chapter One*

# *Introduction*

## 1.1 Introduction

The Wireless Body Area Network (WBAN) is a multidisciplinary field that has the potential to make real-time, low-cost changes to medical data available online. Small, comfortable, and unobtrusive biosensors that may be placed on or inside the body are essential to the success of this field. The WBAN enables remote access to medical information and real-time monitoring of patient health [1].

Recent development and advancement of information systems and communication technologies facilitate people in different dimensions of life. Most notably, in the healthcare business, has grown more and more and integrated with the information and communication technology-based services[2]. Among the most crucial functions is remote patient monitoring, which allows doctors to check in on their patients and make diagnoses and prescriptions without ever having to leave their offices[3]. The benefit of sensor technology allows the flexibility of putting in, on or of the person of individuals, which is based on forwarding data wirelessly to remote servers. Such technology is named as Wireless Body Area Network (WBAN) [4].

The sensors will collect the different information in order to monitor the patient's health status regardless of the patient location; this information will be transmitted wirelessly to an external processing unit[5]. If an emergency is detected, an alert will be generated through the computer system to inform the patient and/or the medical staff [6].

Sensors in WBAN are connected by short-range (2-30m) wireless systems, such as ZigBee, Wireless Fidelity (WiFi), and Bluetooth[7]. A mobile phone, Personal Digital Assistant (PDA), and any other device may act as a gateway to gather sensor data and transmit it to a distant web server, where the data can be processed and analyzed using medical software[8]. Gateways may be connected with one another by a variety of telecommunication networks (Wireless Local-Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Long-Term Evolution (LTE), LTE-A, Satellite, etc.) [9].

WBAN is a collection of multiple sensors attached to or in the body, it used to generate different physical data, such as body temp, blood sugar, heart rate, pulse rate, respiration evaluation and even the number of calories, burned after activity etc [10]. WBAN is not only used in medical applications, but is also in multimedia and gaming applications. Sensor nodes can be placed in different topologies such as a star, mesh or tree [11].

The proposed system is focused on the main problems, which they are explained as follow:

- Precision of the sensor readings
- In what way should sensors be communicating with the central data repository?
- Dependability of real-time sensor data delivery.
- Interoperability of sensing devices
- Arrived data with minimum cost to the destination side of patient care.
- Sensor placement in the human body to be most effective for its intended therapeutic purpose.

## 1.2 Problem Statement

A WBAN is a network of sensors designed to be used inside the human body. With the proliferation of smartphones and other wireless devices, technology has supported the growth of WBANs. WBANs are rapidly gaining importance as it preventing widespread human mortality. Therefore, in order to get the best performance, it is necessary to pick a certain sort of the sensor network on the human body.

Since sensor have limited energy [11], it is also a difficult to increase their lifespan. A huge number of patients' states can automatically monitored in real time, with alerts sent to both medical professionals and patients who wear or carry sensors related to their medicine. Considerable challenges exist in determining the optimal placement and quantity of sensors for each individual user. The wireless collection and transmission of data from sensors, including the scheduling of those transmissions, and the use of a sink node and a specified base station, all need a modeling and simulation method to assure control and validity.

The motivation of the proposed system is simulated the healthcare sensors with optimal number of required sensors of WBAN and redirect packets with minimum delay from the source of packets to the final destination.

## 1.3 Thesis Contribution

The main contributions are represented by :

- Minimizing delay to build route among WBAN elements.

- Maximizing throughput by increasing the number of packets to transmit successfully to the end medical staff server, where higher throughput reflects improved quality of the network.

## 1.4 Aims of the Study

The aim of the proposed system is to create an efficient WBAN system, and it can be achieved by the following objectives:

- Studying and analyzing current WBANs.
- Proposing a WBAN approach for sensing and transmitting the data.
- Suggesting the optimal placement and number of required sensors that will be need.
- Proposing a technique for detecting and delivering the data.
- Improving the precision of transmit data between nodes in a network while decreasing latency.
- Improving the trustworthiness(reliability) of the collected information.

## 1.5 Related Work

Modeling the efficiency of WBANs to optimize resource allocation, processing power, data processing, channel use, and throughput, have been discussed and overviewed from 2019 to 2022 as follows:

In[12] at 2019 Energy efficiency increased network longevity and reduced the need for frequent battery recharges. There are two types of states in the Markov model that represent the subject's condition: normal and abnormal. Markov processes are used to forecast the change from normal to abnormal conditions. During normal conditions, the sensor nodes tracking the subject's status went into a sleep state, but during abnormal ones, they all woke up. They examined the sleep–wake approach and the priority queuing model and show how to implement both in MATLAB. The priority queuing model provides a novel solution for time-critical applications. As opposed to the Path-Quality Monitoring (PQM) routing protocol, the proposed TCEM-PQM has a shorter latency. Time delays is minimized for mission-critical programs, and the approach is well-suited to healthcare and monitoring settings. They used a Markov model simulation to test the validity of the suggested model.

In a quantitative analysis comparing the performance of WBAN routing protocols in [13] at 2019, they evaluated forth the results of detailed simulations that depict the relative performance of the three most recent routing protocols from the five existing routing categories for WBSN (M-ATTEMPT, CICADA, and PRPLC) to improve energy efficiency and other requirements. They briefly mention and explained the design of these protocols to help explain their effects on a network. The protocols are implemented according to their specifications published and based on the IEEE 802.15.6 standard. The comparison applied in OMNeT++ environment and the results of the simulations show that the M-ATTEMPT protocol provides the network stability period and high throughput.

A low-power routing protocol for WBASN is provided in [14] at 2020, which makes advantage of the network's sensor nodes to monitor key performance indicators. Forwarder nodes have made use of multi-hopping, an idea first developed for mobile networks. The forwarder node is the node that takes data from the sensor nodes that are remote from the sink. When a forwarder node receives data, it sends it on to a sink node. In addition different tools are remaining energy, network connectivity, lifetime, throughput, and route loss, are compared to one another. The results showed an efficient use of the path-cost estimation process, and it achieved efficient and effective multi-hop routing of data and improves the reliability and efficiency of data transmission over the network.

An effective routing protocol implemented using nRF24L01 in a Mobile Ad hoc Network (MANET) is used in [15] at 2020, to transport data such as temperature, pulse rate, blood oxygen level, and Electro Cardio Gram (ECG) to the command center. The most effective MANET protocol is found by contrasting the various MANET protocols simulated using OMNET++. Various bio-sensors measure physiological variables, and this information is sent to the command center through the route's mobile nodes. The results showed that Hybrid Dynamic MANET On Demand Routing Protocol (DYMO) was found to have a better performance for the application like health monitoring.

They offered a suitable concept for the optical Wireless Body Sensor Network (WBSN) channel in [16] at 2021 to follow the elderly as they go about. The authors compare and contrast senior and young models, considering the walk's temporal development through the sliding window - based approach, and then explain the resulting differences in body model, movement, and gait speed. They point out that, when considering a young body model, performance is either overestimated or underestimated, depending on which windowing parameter is fixed. It is, there-fore, important to consider the body model of the elderly in the design of the system.

In [17] at 2021, they study a body-to-body network (BBN) framework, which enables wireless body area network (WBAN) users located in close proximity to cooperate and share their network resources to improve the overall network performance. The main aim is to create a decentralized resource allocation system that fosters data sharing among all WBAN users. They suggested an auction-based approach to maximize data uploads and compensation for all users. The simulation results show that the proposed method consistently improves the individual performance of WBAN users and the overall performance of the BBN.

With the goal of lowering path loss, the authors of [18] at 2021 described a novel approach to on-body wearable sensors. The suggested method relies on swapping the positions of sensors already implanted in people. The Euclidean distance method is used to minimize path loss by taking into account the distance parameter.

They suggested a routing scheme to improve the energy efficiency, which then in turn increases the lifespan of the sensors, in [19] at 2021. It uses the Energy Efficient Routing Protocol using Dual Prediction Model (EERP-DPM) for Healthcare IoT to cut down on data transfer between sensor nodes and the medical server if estimations match the accurate reading or whether the data are considered important if they go above or below predetermined thresholds. The proposed EERP-DPM protocols has been shown to be very effective in comparison to other current routing protocols in both modeling and experimental settings, both in terms of power consumption and network lifespan, and in terms of assuring dependability, throughput, and end-to-end latency.

Optimizing WBAN performance is addressed in [20] at 2021, they focused on improving energy efficiency, network throughput, and reducing the end to end delay in multiple existence schemes. It is based on a cost function that uses the ratio of residual energy to node distance, the dependability of links, and the number of hops as its primary route selection parameters. The comparative analysis show that the efficiency, available bandwidth, and decreased end-to-end latency improved by 0.45%, 2.80%, and 13.7%, respectively, when compared to the standard protocol without MAC adjustments.

They used a cooperative routing protocol (CRP) to extend the life of the network and enhanced packet delivery via lower end-to-end latency in [21],at 2022. The end-to-end latency was used as a metric to determine the significance of CRP in WBAN routing protocols. The CRP speed up data transfer to the sinks and reduced the likelihood of packets being dropped. The proposed solution has shown that the end-to-end delay in the WBAN is considerably reduced by applying the cooperative routing protocol. The CRP technique attained a delivery ratio of 0.8176 compared to 0.8118 when transmitting packets in WBAN.

In [22] at 2022, the authors elaborated on why it's crucial for sensor nodes in the healthcare industry to communicate with one another in a way that conserves energy while yet maintaining a high level of accuracy and precision. The approach used relies on an energy-efficient architecture (the M-DSDV-RMCP routing algorithm) for WBAN. From layer 3, the communication infrastructure, packets were successfully sent to layer 4, the healthcare information system, where they could be analyzed and acted upon by clinicians and healthcare administrators.

The main gap of the related works are computation power as (Main memory, RAM, CPU) limitation, network mobility, resource allocation, traffic managements, delay required to build network performance. Table 1.1 showed the used methodology, goal , and results of the related works.

*Table 1.1: The used method, goal, and results of related works.*

| Ref. No, Year | The used Method | Goal | Results |
|---|---|---|---|
| 12, 2019 | Path-Quality Monitoring (PQM) routing protocol | Minimized Time delays to increase network lifetime. | Time delays are minimized for mission-critical programs. |
| 13, 2019 | M-ATTEMPT, CICADA, and PRPLC | Evaluated M-ATTEMPT, CICADA, and PRPLC routing protocols in WBSN | The results show that M-ATTEMPT protocol performs better than the other two protocols in terms of maximizing lifetime, throughput, and minimizing the energy consumption. |
| 14, 2020 | Energy harvested and cooperative enabled efficient routing protocol (EHCRP) | Efficient and effective multi-hop routing of data and improves the reliability and efficiency of data transmission over the network | Increasing network connectivity and lifetime, throughput, and route loss |
| 15, 2020 | Hybrid Dynamic MANET On Demand Routing Protocol (DYMO) | Designing a health monitoring system | The best transceiver module, the various parameters like the communication range, power consumption, and data rate |
| 16, 2021 | optical WBSN channel model | Tracking the elderly during a walking based on Wireless body sensor networks (WBSN) | Channel gain and delay spread statistics determined from the impulse responses |

| | | | |
|---|---|---|---|
| 17, 2021 | Cooperative routing protocol (CRP) | Created decentralized resource allocation system, decreasing end-to-end delay | The use of CRP in the WBAN for the mitigation of packet loss using the end-to-end delay is effective |
| 18, 2021 | Euclidean distance method | lowering path loss | High packet delivery ratio (PDR), average end-to-end delay |
| 19, 2021 | The Energy Efficient Routing Protocol using Dual Prediction Model (EERP-DPM) | Improving the energy efficiency, and improvement network evaluation metrics. | Increasing power consumption and network lifespan, and assuring dependability, throughput, and end-to-end latency. |
| 20, 2021 | Cross-layer mechanism for routing congestion control | Enhanced energy consumption, network throughput, and decrease end-to-end delay. | Decreased end-to-end latency may be improved by 0.45%, 2.80%, and 13.7%. |
| 21, 2022 | cooperative routing protocol (CRP) | lower end-to-end latency | CRP method improved the delivery ratio to 0.8176 % from 0.8118 %. |
| 22, 2022 | M-DSDV-RMCP routing protocol | Increasing packet delivery ratio, and energy efficient | Efficient routing between wireless sensor nodes, protocol delivers at least 90% of end-to-end packets, Robustness, and Efficiency. |

## 1.6 Thesis Outline

Furthermore, this thesis contains four chapters in addition to chapter one:

***Chapter Two:*** It described the theoretical background related to the proposed system, the explanation of routing protocols, WBAN topologies, architecture, popular wireless technologies, characteristics, and the IoT sensor types.

***Chapter Three***: It explained the major steps of the proposed system.

***Chapter Four:*** It described the results and evaluates the used system based on the used case studies for static, Probabilistic routing with postural link costs (PRPLC) Protocol, On Body Store and Flood Routing (OBSFR) Protocol , and Hybrid routing protocol approach.

***Chapter Five:*** It presented the results conclusion. Also, it described the future works suggestions.

# *Chapter Two*

# *Theoretical Background*

## 2.1 Introduction

Wireless sensor networks (WSNs) refer to networks of spatially dispersed and dedicated sensors that monitor and record the physical conditions of the environment and forward the collected data to a central location. Recent development and advancement of information and communication technologies facilitate people in different dimensions of life. Among the most crucial services is remote patient monitoring, which allows doctors to check their patients, make diagnoses and prescriptions without ever having to leave their offices. The advantage of miniaturization of sensor technologies gives the flexibility of installing in, on or of the body of patients, which is capable of forwarding physiological data wirelessly to remote servers. Such technology is named as Wireless Body Area Network (WBAN) [23].

## 2.2 Architecture of WBANs

The communication architecture of WBANs can be divided into three different tiers as follows [23]:

A- **Tier-1: Intra-WBAN communication**

Nodes communicate with each other and/or with coordinator in or around the human body. The data from nodes is managed and it is sent to Tier-2 [23].

**B- Tier-2: Inter-WBAN communication**

This communication tier is between the coordinator and access points (APs). Tier-2 connects WBANs with various networks including cellular networks and the Internet [24].

**C- Tier-3: Beyond-WBAN communication**

Data sent by Tier-2 is to be received by Medical Server (MS). Tier-3 makes possible this kind of connection. Personal Digital Assistant (PDA) can be used for connecting Tier-2 to Tier-3. A database for a user's medical history and profile is a crucial part of Tier-3, even if its architecture is application-dependent. Whether it's through the web, Short Messaging Service (SMS), or some other method, doctors or patients can be informed of emergency situation via various means including the Internet or Short Messaging Service (SMS) etc. Figure (2.1) showed the main three tires of WBANs.

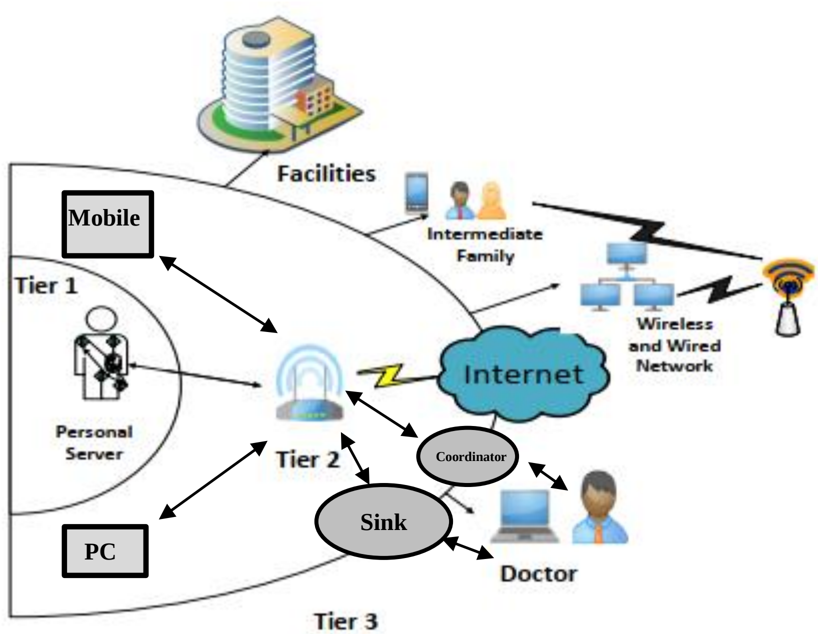



*Figure 2.1: Communication tiers in WBAN[24].*

## 2.3 Layers of WBANs

The IEEE 802.15.6 (WBAN) technical group has developed new Physical and MAC layers for WBANs, allowing for low-complexity, low-cost, high-reliability, ultra-low-power, and short-range wireless communication [25].

**A- Physical Layer**

The physical Layer (PHY) of IEEE 802.15.6 performs operations such as radio transceiver power on, power off, Clear channel assessment (CCA) for the active channel, and data transmission/reception. In order to communicate, the PHY layer is responsible for transforming a physical layer service data unit (PSDU) into a physical layer protocol data unit (PPDU). Human Body Communication (HBC), Narrow Band (NB), and UltraWide Band (UWB) are the three distinct physical layers established by IEEE 802.15.6. (UWB). According to the NB PHY requirements, PPDU is constructed by attaching a Physical Layer Convergence Procedure (PLCP) to a Physical System Description Unit (PSDU) [25].

**B- Medium Access Control (MAC) Layer**

The IEEE 802.15.6 set defines a MAC layer above the physical layer (PHY) to regulate channel access. The coordinator divides the whole channels and specifies beacon intervals of equal duration. In order to allocate resources more efficiently. The coordinator can also move the offsets of the beacon periods [25].

## 2.4 Difference between WSN and WBANs

A comparison of wireless sensor networks and wireless body area networks was presented in Table 2.1[26]

*Table 2.1: WBAN and WSN comparison[26].*

| Comparison | Wireless Body Area Networks | Wireless Sensor Network |
|---|---|---|
| Sensor Position | Sensors are either attached to human body or deployed very close to human body | Sensors are deployed over a large geographical area |

| | | |
|---|---|---|
| Topology | Usually star topology is adopted with a central node, usually termed as gateway while all communication of node is via gateway. | Mesh topology is adopted where each node can perform routing. |
| Nature of Data | Physiological signals are periodic. Hence periodic data is generated. | Aperiodic data is generated depending on the application. |
| Redundancy | Redundancy of node is null, no additional node is place-able for overcoming failure of a node | Redundancy is vital in WSN especially in scenarios where important data is to be recorded |
| Mobility | Channel condition changes with movement of body. Interference level increases whenever more than one users come closer to each other | WSN nodes have very little or no mobility at all making channel condition deterministic. |
| Data Collection | Many kinds of receivers can be used to collect data from sensors. | Data is collected only at the central database. |
| Node Size | Extremely small is required. | Small size is preferred. However, size is not a major issue in most cases. |
| Node Replacement | Hard in replacement of in-body nodes | Easy node replacement performed |
| Bio-compatibility | Vital for in-body and some on body sensors | Not a matter of concern in most cases |

In addition to these differences, WBAN also requires:

- Limited transmission range, often only 2 to 30 meters [27].
- Quite low consumption of power during sleep mode, in the order of no more than 0.5 milliWatt for conservation of battery life.
- Adaptable data rate, from 1 kbps to some Mbps.
- Extremely low latency in multi-hop network
- Nodes are lightweight and Small size.
- Improved Quality of Service (QoS) for handling vital physiological signals [28].

## 2.5 Popular Wireless Technologies Used in WBANs

Physical Layer Wireless Network and Local Area Network are the most widely deployed forms of wireless technology in WBAN [29].

**A- Physical Layer Wireless Technologies Used in WBAN**

The ZigBee standard, which is built on top of a IEEE 802.15.4 standard, defines the functionality of the network layer, application layer, and security layer. The MAC layer of the IEEE 802.15.4 standard uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for media access. Zigbee defines three kinds of nodes; end-device, router node and coordinator node. The coordinator node initiates the network manages network resources. Multihop communication between devices is made possible by router node. While the router make possible multi-hop communication between the devices in a network. ZigBee is often used in healthcare sector. Zigbee has several limitations. ZigBee sensor nodes consume high power. 2.4 GHz is very congested band of frequency which is used by Zigbee[30].

Within a Zigbee network, there are three distinct varieties of nodes: end devices, routers, and coordinators. It is the coordinator node's job to set up the network and oversee its administration. The router node facilitates device-to-device communication across several hops. A router, on the other hand, allows for communication between nodes in a network to occur across several hops. In the medical field, ZigBee is widely employed. There are a few drawbacks to using Zigbee. The energy needs of ZigBee sensor nodes are substantial. Zigbee operates in the overcrowded and often overloaded 2.4 GHz radio spectrum [30].

**B- Wireless Local Area Networks (WLANs)**

It is based on protocols for the physical and MAC layers by the IEEE 802.11 standard. IEEE 802.11 uses a variety of physical layer communication techniques, some more common than others. Different types of the IEEE 802.11 standards use different physical layer communication approaches e.g. IEEE 802.11 g standard uses Orthogonal Frequency Division Multiplexing (OFDM) while the IEEE 802.11b standard uses Direct Sequence Spread Spectrum (DSSS) for physical layer communication. WLAN standards provide high data rate to WBAN applications but because of high power consumptions, it is rarely used [31].

**C- Medical Implant Communication Services (MICS)**

The 401–406 MHz range is used for data transmission from an internal device to an external controller [32]. This band is used by the Federal Communications Commission (FCC) for transmitting data from an in-body device to an outside controller. 10 channels with 300 kHz bandwidth are allotted for communication within this band. The FCC requires that any device broadcasting in the MICS band have an average transmit power of around -16 dBm. Since the MICS band's transmission frequency is quite low, in-body communication environments have very modest propagation losses [33].

MICS gadgets employ the Listen-Before-Talk (LBT) approach to monitor the wireless channel before initiating a conversation. When channel is found busy, an MICS transceiver uses Adaptive Frequency Agile (AFA) technique for switching to another channel. The MICS band is only suitable for low-data-rate WBAN applications. Because of its low data transfer capacity, the MICS band is useless for applications that need a large data rate [33].

**D- Bluetooth**

Bluetooth operates in the 2.4 GHz Industrial Scientific Medical (ISM) band. Frequency Hopping Spread Spectrum (FHSS) is used for gaining access to the physical medium [34]. It has 79 channels, each with a bandwidth of 1 MHz, for a total bandwidth of 2402–2480 MHz. Communication is based on a piconet network architecture, in which one device may talk to up to seven others in the same network. In 2009, a low-power Bluetooth variant is created to address the issue of increasing power consumption by such gadgets. Interference is a problem for Bluetooth because of the overuse of the 2.4 GHz spectrum[35].

## 2.6 Topology used in WBANs

The IEEE 802.15.6 working group has defined WBANs to function in either a one-hop or two hop star topology having one node in the center [36, 37]. In the one-hop star topology, data transmission occur in two ways: from the nodes to the coordinator, and from the coordinator to the nodes.

In a star topology, there are two types of communication schemes: beacon modes and non-beacon mode. As the hub of the network, the coordinator of the beacon mode manages communication by frequently broadcasting beacons. To facilitate network association management and device synchronization, these beacons mark the beginning and conclusion of a data [38].

Non-beacon mode allows nodes to communicate with the coordinator through Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). In order to get information from the coordinator, the nodes need to power up and polling it. However, as shown in Table 2.2, the coordinator cannot do communication with the nodes all the times because the nodes need to wait to the time they are invited to partake in a communication [39].

*Table 2.2: Examining Star and Multi-hop Topologies in Wireless Body Area Networks[39].*

| **Comparison criteria** | **Star Networks** | **Multi-Hop Networks** |
|---|---|---|
| Energy Consumption | For nodes in close proximity to the PDA, the power used to transmit to the PDA will be low. The nodes further away, however, will consistently require more power to be able to transmit information. | The nodes that are closest to the PDA consume more energy as they will have to forward not only their own information but also information from other nodes. |
| Transmission Delay | The star network presents the least possible delay present in transmission from any | Dependent on how the network is configured. In terms of delay, the |

| | | |
|---|---|---|
| | sensor to the PDA, as there is only a single hop. | nodes closest to the PDA can get their information through quickly, without any intermediate relay. |
| Interference | Sensors that are farther away from the PDA require transmission with higher power, increasing the amount of interference. | Since each node is only transmitting to its neighbor nodes, the energy of transmission is kept low and hence mitigates the effects of interference. |
| Node Failure and Mobility | Only the failed node will be affected and the rest of the network can perform as needed. | The part of the network that involves the failed node has to be reconfigured. Overheads are involved. |

Most WBAN designs involve either a star topology (also called a single-hop/multi-hop topologies, with the former being the more common of the two [40].

- **A star network** : It is one in which all nodes are directly connected to the sink. In case of using PDA as a sink, all the nodes will transmit sensed data to the PDA directly without any intermediate. Nodes in a multi-hop network may link to the wireless router through a series of intermediate nodes. It's important to remember that the definition of a multi-hop network is rather broad and may even include a network architecture based on clusters [41]. The one-hop and multi-hop star topologies are shown in Figure 2.2.

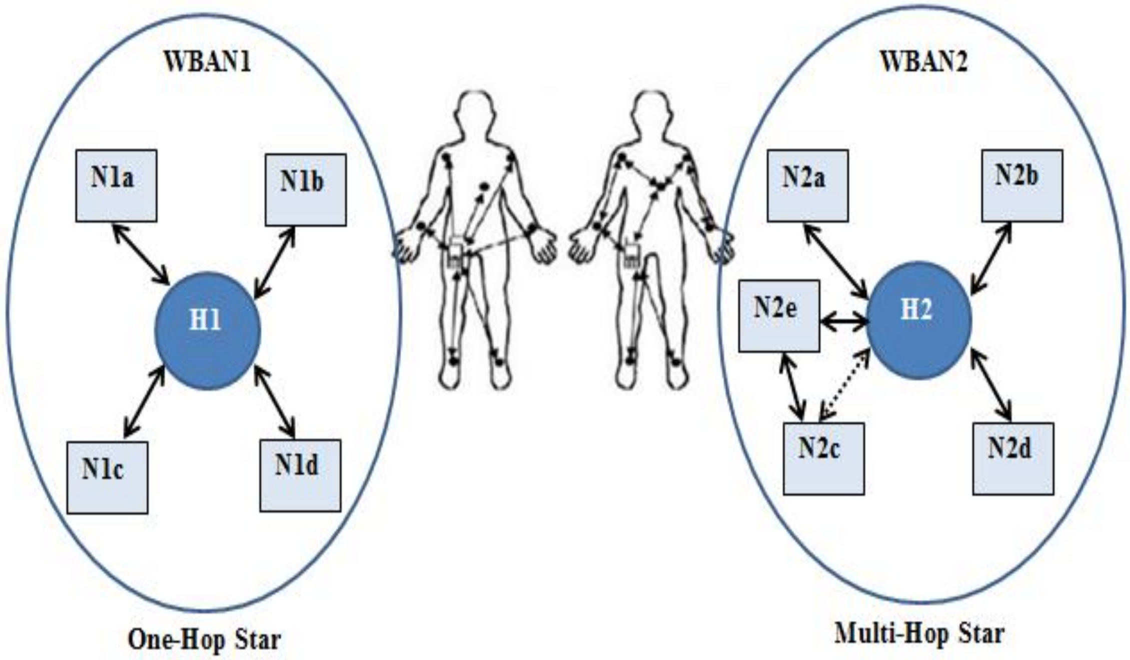



*Figure 2.2: A comparison between the WBAN star network (Single-hop topology) with the more common multi-hop topology[42].*

There are two channels of interaction in the star topology: The Beacon approach, Beacon-free approach [42].

Transmissions of beacons are used to synchronize devices and regulate how they are associated with one another in the beacon technique of network coordination. These beacons define the start and the end of the data to enable network association control and device synchronization. The duty ratio of the system, which is determined by the duration of the beacon period, is user-definable within specific bounds [43].

Using CSMA/CA, a network node may transmit data to the coordinators without the need of beacons. The node must turn on power and poll the coordinators for the data. By switching to non-beacon mode, the node's receiver doesn't have to be always on to pick up the beacon signal.

The coordinator cannot do communication with the nodes all the times because the nodes need to wait to the time they are invited to partake in a communication [44].

The proposed IEEE standard for WBANs only allows for a maximum of two hops[45].

## 2.7 Characteristics of Wireless Body Area Networks Nodes

WBAN nodes have several features that make them suitable for use in large number of emerging applications. Main features are [46]

- **Energy Saving**: It designed of sensors in a way that they use very low energy. Power management schemes are used to handle the power resources optimally so that nodes remain alive for a longer time and the network's lifetime increases.
- **Heterogeneous**: WBAN sensors in that different nodes perform different tasks (temperature sensing, blood pressure monitoring, etc.). It's important to note that the storage, processing, and power needs of these sensor nodes all vary widely [46].
- **Efficient**: Since the nodes use power optimally and are deployed over small area so they live longer and lesser number of nodes are required in network formation and replacement, when damaged. As a result, the overall cost of setting up a network is reduced.
- **Simple**: Lightweight, small sized of nodes are used which can be easily carried from one place to the other by wearing them or keeping them in a bag. Table 2.3 showed the main characteristics of WBAN sensor nodes [46].

*Table 2.3: WBAN sensor defining features[46].*

| WBAN Sensors | Characteristics |
|---|---|
| ECG Sensor | Gain: 1000<br>Range: ±1.5mV (with VCC = 3V)<br>Bandwidth: 0.5-100Hz<br>Consumption: ~1mA<br>Input Impedance: >100GOhm<br>CMRR: 100dB |
| Blood Pressure | Pressure range: 0 mmHg to 258 mmHg<br>Maximum pressure without permanent damage: 1550 mmHg<br>Typical accuracy: ±1 mmHg<br>Temperature compensated: -20°C to 85°C<br>Sensing element: SSCMRRN005PGAA5<br>Combined linearity and hysteresis: typical ±0.25%<br>Response time: 1 millisecond |
| EEG Sensor | Range: ±37.5µV (with VCC=3V)<br>Bandwidth: 0.80-48.23Hz<br>Input Impedance: >100GOhm<br>CMRR: 100dB<br>Cable Length: 100cm±0.5cm (customizable; extra costs may apply)<br>Connector Type: UC-E6 (male; must be connected to a biosignalsplux acquisition unit) |
| Temperature Sensor | Range: 0°...100°C<br>Accuracy: < 0,1°C + NTC-spread over 0°...70°C<br>Resolution : 2 m°C@30°C and 25 m°C@100°C<br>Amb.temp : 0°...60°<br>Control : Micro-WireTM 5 (Di, Do, Clk en CS)<br>Levels : 0 and 5 Volt<br>Power : +12 Volt 3,5 mAmp (+5,5 .... +20 Volt)<br>-5 Volt 1 mAmp (-4,5 ....-8 Volt) |

| | |
|---|---|
| Motion Sensor | Voltage : 4.8 V – 20 V<br>Current (idle) : <50 µA<br>Logic output : 3.3 V / 0 V<br>Delay time : 0.3 s – 200 s, custom up to 10 min<br>Lock time : 2.5 s (default)<br>Trigger : repeat : L = disable , H = enable<br>Sensing range : <120 °, within 7 m<br>Temperature : – 15 ~ +70 °C |

## 2.8 Types of WBANs Nodes

Using a wireless body area network, it is possible to track a person's whereabouts and actions in real time. Based on the operating environments the monitoring sensors can be classified into two types: [47].

A- Wearable sensor devices worked on the human body surface.

B- Implantable devices operated inside human body.

Sensors that a person may wear would allow for close monitoring of her or his own functions and the surroundings, as well as quick feedback for optimum and constant state. In order to keep tabs on a patient in critical condition, one could use an ECG, EEG, or Blood Pressure sensor; using a GPS sensor to pinpoint a specific location; and using a variety of other sensors to measure things like distance, temperature, motion, etc[47].

Implantable sensors are placed in close proximity to the skin or even deeper into the human body to monitor vital signs and other health indicators. The capacity of implantable bio-sensors to continue monitor metabolite levels, independent of the patient's physiological condition, makes them a significant subset of biosensors (sleep, rest, etc.) [48]. Diabetes patients, those in need of emergency treatment after a trauma, and active duty troops may all benefit greatly from the use of implanted biosensors (military). In addition, there are three distinct types of WBAN traffic, as shown in [49]:

**A- Regular Traffic**

Normal traffic is the data traffic which is used to monitor the normal condition of a person without any criticality and on demand events.

**B- Emergencies Traffic**

The nodes themselves launch emergency traffic when they reach a certain critical mass or when an unexpected event occurs. Such traffic is entirely unexpected.

**C- High-Demand Traffic**

On-demand traffic is initiated by the authorized personnel like doctor or consultant to acquire certain information for diagnostic purpose. [49].

### 2.8.1 WBAN sensor device

The WBAN sensor gadget detects various parameters in human either in or out of. Sensors can be employed either on upper surface of the human body or can be implanted inside the skin of human body for real-time monitoring of desired activity of specific organ or tissue. These nodes take data, process it for adjusting to transmission and send it to concerned devices for further communications transmission to server or doctor node [49].

Many kinds of such sensors exist for specific applications and may be attached to specific body locations for monitoring an individual anywhere and anytime. Some currently offered and applied sensor nodes are: EMG, EEG, ECG, Temperature, Moisture content, Blood pressure, Sugar levels, SpO2, CO2 Gas sensor, Spirometer, Plethysmogram, DNA Sensor, etc [50].

#### 2.8.1.1 Electrocardiography (ECG)

To diagnose heart problems and monitor the efficacy of treatment, doctors utilize ECGs, which are graph representations of the heart's electrical activity. Humans have electrodes attached to their chests, arms, etc. Electrode potential difference is the source of the ECG signal[51].

#### 2.8.1.2 Electroencephalography (EEG)

This sensor is used for measuring the electrical activity that occurs inside the brain. Humans do this by inserting electrodes into certain spots on their heads. Electrodes pick up data on the brain's electrical activity and transmit it to an amplifier, which in turn generates tracing patterns. When brain areas' electrical activity are coordinated, it shows that they serve related purposes [52].

#### 2.8.1.3 Blood pressure

This sensor uses an oscillometric method for calculating systolic and diastolic readings of blood pressure [53].

#### 2.8.1.4 Motion

It is designed to detect and measure movement. Motion sensors are typically embedded systems. Motion sensors may turn on lights, sound alarms, flip switches, and even call the police if necessary [54].

#### 2.8.1.5 Temperature

These sensors can detect both the ambient humidity and an individual's core temperature. If there are some changes in the readings which are above threshold value then alarm signal is issued [55].

### 2.8.2 Personal Device (PD)

This device is used to do constant and accurate measurement of the body in real time, and it gathers data from the sensors and actuators as it becomes available. When PD needs new information, it will initially begin talking to the sensor nodes. At times of crisis, nodes may reach out to PD on their own. The PD then communicates with the user via an intermediary system. This class includes terms like body gateway, Body Control Unit (BCU), and personal digital assistant [56].

### 2.8.3 Actuator

The actuator receives data from the sensors [57] and provides feedback in the network in the form of acting on sensor data. For example, in several medical applications, it injects precisely the prescribed dose of medication after receiving instructions [58]. The healthcare industry today makes use of a wide variety of actuator types. Surgical procedures involving the insertion of an actuator into a patient's heart are increasingly commonplace. It is used in a variety of fields, including endoscopy, to gain insight into the inner workings of the human body and the precise dosage of medication that must be manage to each organ and tissue [59].

## 2.9 WBANs Applications

The WBAN system should ensure the safety of mobile workers (e.g., firefighters and first responders) in presence of hazardous and unhealthy conditions. Second, effective communication between WBAN users in the operation field and real-time transmission of the collected information (i.e., especially sensitive and real-time) to their remote command center should be provided for appropriate decisions making and proper management and scheduling of workforces [60].

Furthermore, in a dangerous environment, network infrastructures (such as WiFi, LTE, 3G generation, and 4G) may not be available, as is the case in rural areas, be damaged by the controlled disaster (such as a major fire), or even be overloaded in the event of an emergency or in areas with a high population density. Fourth, there are a several of potential dangers and unknowns that employees may encounter, such as the presence and emission of hazardous and combustible compounds, high temperatures, highly restricted vision conditions, and the lack of a priori understanding of the environment design (i.e., they do not have at their disposal real-time maps to identify damaged and changed areas). Finally, the limitations shown in Table 2.4 highlight the need of scalability and inter-technologies collaboration for a successful end-to-end monitoring solution when deploying WBANs in highly dynamic and dangerous contexts [61].

*Table 2.4: Critical Application Design Considerations for WBANs[61]*

| **Comparison Criteria** | **WBAN Applications** | |
|---|---|---|
| | **Traditional WBAN Applications** | **Critical WBAN Applications** |

| | | |
|---|---|---|
| Deployment Environment | Controlled and Static | Hazardous and Dynamic |
| Operation Conditions | Controlled and healthy | Presence of hazards and uncertainties |
| Communication Infrastructure | Present | Damaged, Absent, or Overloaded |
| Intra-WBAN Communications | High | Low |
| Inter-WBAN Communications | N/A | High |
| Extra-WBAN Communications | High | High |
| WBAN Mobility | Low/Static | High |
| Coexistence | Non-collaborative (mostly) | Hybrid (collaborative/non collaborative) |

## 2.10 Routing Protocols in WBAN

The routing protocols that are used in WSNs have been under study for the past few years, these protocols cannot used for WBANs because of its stringent requirements. For WSNs, the primary focus is on minimal routing overhead and maximal throughput than reduced energy consumption. Also, WSNs are mostly homogenous networks, the WBANs are heterogeneous [68]. Network topology, posture body motions, restricted resource, level of service measures, radiation and interfering, global network lifespan, diverse environment, node temperatures, etc. are all examples of the problems and obstacles that might arise throughout the routing process [69]. Because of the varied nature of the WBANs environment, designing effective routing protocols is a complex task. The main aspects are summarized as following [70]:

### 2.10.1 Limited Energy Capacity

Although biosensors can be removed from their operation site to be recharged (hard task and not always applicable), or recharged by external IR radiation, energy consumption is an important constraint for WBANS. WBAN routing methods should take energy consumption into account, since charging batteries often is inconvenient and radiation may harm patients [71].

### 2.10.2 Limited Hardware Resources

Biosensor nodes have other limitations besides their high power consumption, such as low data storage and processing speeds. If a lot of data is being sent via tiny small sensor devices, for instance, the network's lifespan would diminish quickly [72].

### 2.10.3 Operating Environment

Humans may become a high-loss medium for transmitted waves because of the widespread use of implanted and wearable biosensors [73].

### 2.10.4 Dynamic Network Topology

The topology of the WBAN so dependent on the patient's mobility, network protocols should account for mobility while creating them[74].

### 2.10.5 Quality of Service (QoS) Requirements

Due to the wide variety of devices that make up WBANS, it is essential that routing algorithms be able to handle both types of traffic and dynamic changes in QoS requirements [75].

### 2.10.6 Security and Privacy

Medical information is included in the forwarded data, making it more important that routing procedures protect patient privacy. To improve the lifespan of the WBAN system and to fulfill QoS requirements for various WBAN applications, the most tough challenge is how to integrate low duty cycle management with the minimal energy route [76].

## 2.11 Routing Protocols Classification

The classification of routing protocols can be done in different categories that correlate with the routing challenges of WBAN. Existing protocols may be classified into many types, including those that are cluster-based, cross-layer, postural, QoS-aware, temperature-aware, and so on. The Figure 2.3 gives a classification of a number of routing protocols developed for WBAN [77].

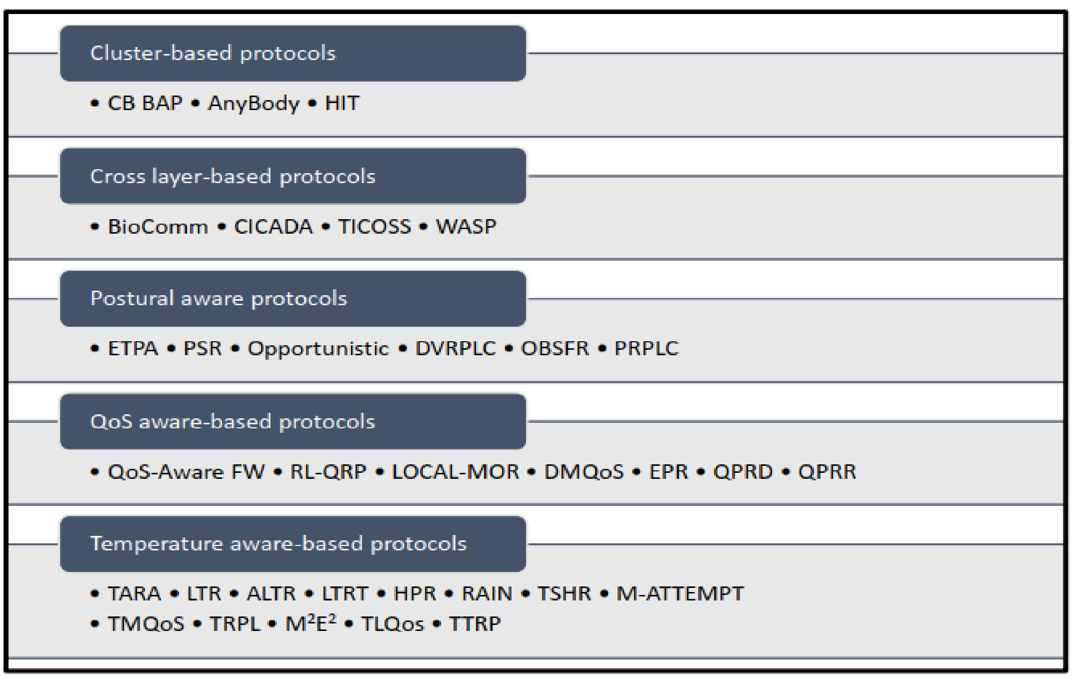



*Figure 2.3: WBAN Routing Protocol Classification[78].*

### 2.11.1 Cluster-based Protocols

The first limitation to examine in WSNs and WBANs is the availability of a sufficient energy supply. To reduce the amount of energy used by the networks and extend their useful life, numerous effective cluster-based techniques have been developed. To lessen the need for direct connection between the perception layer and the sink (base station), the bio-medical sensor network are clustered using various approaches to determine which node within each cluster will serve as the Cluster Head (CH) for that cluster [79].

The number of clusters may remain the same if some nodes are added to the network, as in the instance of AnyBody, or it may rise, as with the case of the LEACH protocol, which may end up establishing new cluster in this situation [80].

### 2.11.2 Cross layer-based Protocols

When the levels of the protocol stack (adjacent and non-adjacent) communicate their information with one another, as opposed to the rigid tiered model, thereby it can optimize the overall network performance. This is the case with protocols like WASP, TICOSS, and many more. This is a new field of study in WBAN, but it has already attracted the interest of WSNs researchers [81].

### 2.11.3 Postural Aware Protocols

The network topology of WBSNs or the link between two nodes often faces the problem of partitioning or disconnection because of the body postural movements. Opportunistic, OBSFR, and PRPLC are all examples of routing protocols in this category of WBSNs that attempt to address link termination by establishing a cost function that is updated periodically. These protocols choose the least expensive paths for transmitting data packets from biomedical sensor base station [82].

### 2.11.3.1 Probabilistic routing with postural link costs (PRPLC) Protocol

The on-body delay values are the primary focus of its design. This method of decreasing blackout occurrences is based on monitoring the quality of connections in the past and choosing those with a higher quality rating[83].

An on-body node I can build and keep the Likelihood Factor $\boldsymbol{P_{i,j}^{t}}$ , for all $j \in N$, $j \neq i$ , by combining Eqns. (2.1), (2.2), and (2.3).

$$\boldsymbol{P_{i,j}^{t}} = P_{i,j}^{t-1} + (1 - P_{i,j}^{t-1}).\ \omega_{i,j}^{t} \text{ if link } L_{i,j} \text{ is connected} \quad (2.1)$$

$$\boldsymbol{P_{i,j}^{t}} = P_{i,j}^{t-1}.\ \omega \text{ if link } L_{i,j} \text{ is disconnected} \quad (2.2)$$

$$\omega_{\boldsymbol{i,j}}^{\boldsymbol{t}} = \sum_{r=tit}^{t} L_{i,j}^{r} \,/\, T_{window} \quad (2.3)$$

Where :

$\boldsymbol{P_{i,j}^{t}}$ **=** The probability for a link (link likelihood).

$\boldsymbol{L_{i,j}}$ **=** Link between nodes i and node j to be connected.

T = Discrete time slot.

ω = Tuning factor over a time window, it is a constant.

$T_{window}$= It is measurement window (in number of slots) over which the connectivity quality.

$\omega_{i,j}^{t}$= Rate determined by the constant

When the connection is made, the value of $\boldsymbol{P_{i,j}^{t}}$ will rise at a rate given by the constant $R_{i,j}^{t}$ $is$ ω ($0 \leq \omega \leq 1$) and the difference between of present value of $\boldsymbol{P_{i,j}^{t}}$ and its max number, which is 1.

Therefore, if the connection is maintained for a very long period, the value of the number $\boldsymbol{P_{i,j}^{t}}$ will asymptotically converge to 1. When the connection is severed, $\boldsymbol{P_{i,j}^{t}}$ will asymptotically become 0 at a rate equal to the constant (ω). In conclusion, for a fixed, the Likelihood Factor (LLF), $\boldsymbol{P_{i,j}^{t}}$ adapts to the current connectivity state of the link $L_{i,j}$.

$L_{i-j}^{r}$, which is not shown in equation (2.3), is 1 if the connection is connected during time slot r and 0 otherwise. The constant $T_{window}$ stands for the number of slots across which the connection quality is averaged during the measurement window. Historical link quality $L_{i-j}$is represented as a percentage of the time the connection was connected over the course of the previous $T_{window}$ by the parameter $\omega_{\boldsymbol{i,j}}^{-}$ ($0 \leq \omega_{\boldsymbol{i,j}}^{-} \leq 1$). Time constants for human postural mobility should be used to determine the value of $T_{window}$ [84].

This routing logic expects that every on-body node will eventually be within two hops of the final destination. Simply put, node I has spotty visibility of other nodes since node d comes into touch with them at random. This hypothesis held true over all of our experimental topologies. In a WBAN architecture, all nodes sometimes make direct linkages with other nodes in a network, however this does rely on the precise postural patterns.

Because of this fact, the assumption may be safely applied to WBANs in general, which often have a narrow network diameter. This is a multipoint-to-multipoint implementation of the distributed routing method. The technique described here must be run on every on-body sensor node. Each node-i in the network eventually builds the $P_{i,j}^{t}$ values with other nodes using the periodic Hello process.

All other nodes linked to node-i get the node's LLF, the value $P_{i,d}^{t}$ , in the same Hello messages. This ensures that all nodes know the LLFs of their neighbors on the path to the final destination, node-d. Whether packets (originating from node-i or another node) exist in node-buffer i's at any given moment, node-i will see if any of its directly connected neighbors has a lower LLF to node-d than it does.

If LLF at node-i is the greatest, then it will hold the packet in its own buffer. In any other case, packets are sent to the directly linked node with the greatest LLF to node-d. This reduces the projected end-to-end delivery latency by having node-i send a packet to the node most likely to reach the target node.

Therefore, it is important for every node to keep track of its Likelihood Factors (LLFs) to every destination, not just the one it shares. Figure 2.4 showed the main concept of PRPLC routing protocol in WBAN architecture. It showed how packets rerouted from the source node to the neighbors, the sink node, and then to the server out of body network element[85].

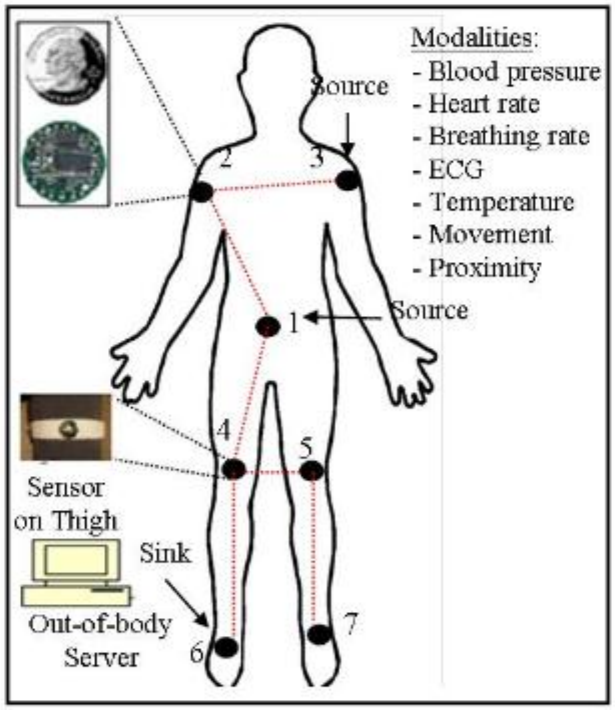



*Figure 2.4: PRPLC routing protocol in WBAN architecture[85].*

In addition, Figure 2.5 shows the main steps of the capturing link connectivity locality in PRPLC routing protocol in WBAN architecture.

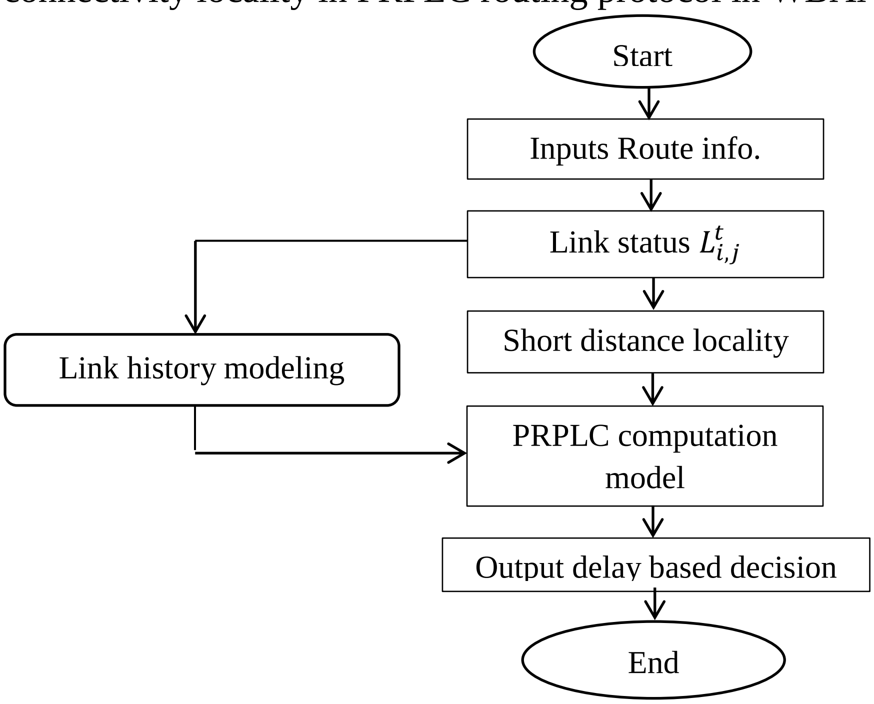



*Figure 2.5: The link likelihood connectivity locality in PRPLC routing protocol.*

#### 2.11.3.2 On Body Store and Flood Routing (OBSFR) Protocol

When comparing to the other flooding techniques, the OBSFR approach produces far better delay and packet times (i.e. the real lower limit) than the other ways, and this is mostly because of the multi-forwarding characteristic that it possesses. A specialized flood protocol for segment networks called On-body Store and Flood Routing (OBSFR) is applied in order to determine the approach that provides the best case delayed performance. With flooding, multiple copies of a packet from a source node can reach to the destination through multiple routes, and the first arrived copy at the destination shows the minimum possible end-to end storage/buffering delay resulted from PRPLC protocol [86].

Although a traditional technique for flooding packets might be used to this situation, a few additional routing syntaxes are necessary in order to reduce the number of packets that are lost in certain circumstances, particularly those that occur because of network split. A packet contains, besides its singular identity, referred to as the "source id., seq No.", a packet also carries a list of node-ids indicating its path so far from the source node. When a node-i receives a packet for the first time (which can be determined by its one-of-a-kind identification), it slows it down the packet until it encounters at least one position that is not included in the list of a base station that are recognized in the packet. Upon encountering at least one such node, the packet is handed over from i to such nodes using broadcast, and then deleted from i’s buffer. Like in regular flooding, upon any subsequent reception of the same packet, node-i will ignore it. [87].

When there is network partitioning present, using this changed flooding method helps reduce the number of packets because of the partitioning. Take into consideration the following scenario. Using the standard flooding method (that is, not to use the list of node-ids), when node-i communicate the packet to a node-j, it is possible that node-j has already broadcast transferred the same message and, as a result, it simply discards this after receiving it from node-i. This is because the standard flooding method does not use the list of node-ids. If node-i and node-j are currently forming a network partition that does not contain the packet's destination, then the packet is dropped from this partition and will never be forwarded to its final destination [88].

However, since the updated flooding uses the lists of base station, the subtree will not distribute the message to node j. This is because in order for node j to receive the packet, it has to be included in the list the base stations that the packet contains. Because of this, , node-i will buffer the packet till it encounters a node that is not already traversed trough by the packet in question. This improves the chance for the packet to be forwarded out of the current partition (formed by nodes i and j), thereby reducing the overall packet loss probability. This modification only applies to relatively small networks that have a few nodes; it is not suitable for large sensor networks that contain tens or hundreds of nodes and must have their node identifiers included in the packets [88].

However, despite improvements made to flooding, there is still a circumstance known as partition message saturation, in which it is possible for a package to be dropped. Take into consideration the scenario in which node-i gets the packet for the first time when it comes into a partition that also contains node links p and q in such a way that all 3 nodes are connected inside the partition. Now, since nodes p and q do not appear on the ballot of base stations in the payloads, node-i will broadcast the packet both to node p and q and then delete it itself from buffer. This is because node p and q do not appear in the listing of base stations. Because q doesn't really appear with in list of p's copy of a packet and p doesn't really show up in the list of q's copy of the packet, at this point nodes p & q will neither forward the information to each other. Following the completion of this cycle of packet forwarding, p and q will each delete the message from the buffers associated with themselves. This cause the packet being discarded from this partition, and will never be redirect to its final destination as a result. Figure 2.6 showed the main concept of OBSFR routing protocol in WBAN architecture[89].

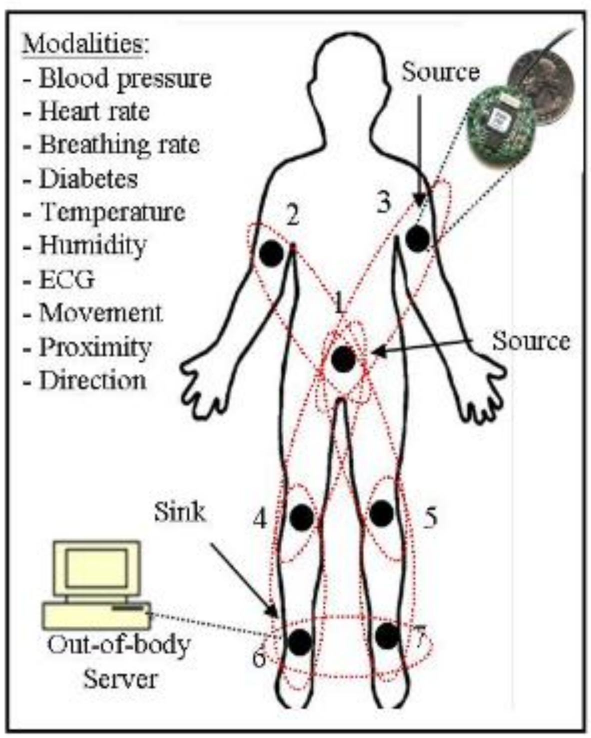



*Figure 2.6: OBSFR routing protocol in WBAN architecture.*

In addition, packet capture and broadcasting in OBSFR routing algorithm are shown in Figure 2.7. Each sensor node stores the identifier and position of the next sink or next hop in its local memory and broadcasts a short information packet including this information together with its own identifier and location to all other connected sensors.

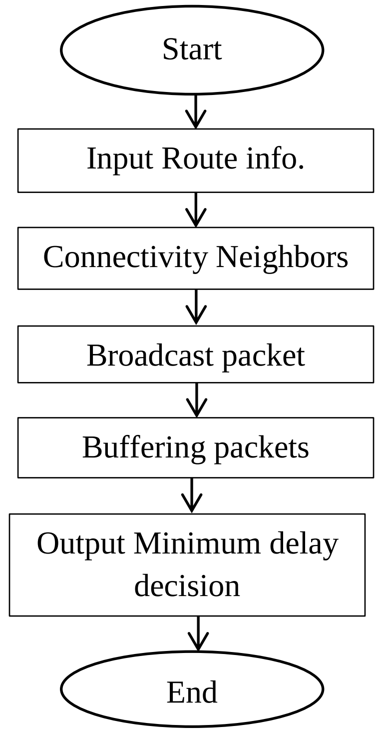



*Figure 2.7: The OBSFR routing protocol behavior.*

### 2.11.4 QoS Aware Protocols

Presently, there are a number of diverse QoS aware protocols available in WSNs, including as QoS-Aware Peering Routing Protocol (QPRR), Data-Centric Multi-objective QoS-Aware Routing Protocol (DMQoS), etc. Although WBANs can't use them directly, they are possible to use after their special constraints are considered. Common factors considered attaining QoS include the health of the wireless channel, the volume of network traffic, the efficiency of each node in terms of data transmission and reception, the priority of the data being transmitted, and many more. End-to-end latency, the percentage of packets delivered, and the total energy used by the routing process are all considered when determining a protocol's efficacy [90].

### 2.11.5 Temperature Aware Protocols

Both the greater issue merely on the body and the absorption of light are important considerations to bear in mind while working with transmitters and receivers around and on human bodies. The antenna radiation, its absorption and interference are the major challenges to be considered while designing a body sensor network, because electric and magnetic fields are generated due to the radio signals used in wireless communication, such as reducing blood circulation, halting the growth of certain body tissue, halting enzyme action, and potentially harming the healthy cells if it is in place for long durations[90].

In order to achieve this goal, several of protocols have been established such as Thermal-Aware Routing Algorithm (TARA), Least Temperature Routing (LTR), Adaptive Least Temperature Routing (ALTR), and Routing Algorithm for Network of Homogeneous and ID-less Biomedical Sensor Nodes (RAIN) [90].

### 2.11.6 Other classification

It is possible to classify the routing protocols used in WBAN applications as Energy-aware, Connection, Movement, Delay-tolerant aware, and Medium-access-control-aware due to the wide variety of criteria that must be considered when designing and implementing such networks in highly sensitive environments as the human body [90].

## 2.12 Performance Metrics

### 2.12.1 Throughput

Throughput is described as the ratio of the number of packets sent and received to the total required time. With the corresponding equation being [91] :

$$\text{Throughput} = \frac{\text{Total Number of sent and received packets}}{\text{Time}} \quad (2.4)$$

### 2.12.2 End To End (ETE) Delay

The time taken for a packet to travel from its origination point to its destination point is known as the "end-to-end" (ETE) delay [92].

ETE= Src packet time- Dest packet time (2.5)

Where : Src: Source node, and Des: Destination node.

### 2.12.3 Packet Delivery Ratio (PDR)

It measures how many data packets were successfully delivered from the source to the sink relative to the total number network data packets sent. The formula is as follows: [93]:

$$PDR = \frac{\text{Number of packets received at sink}}{\text{Total number of packets sent}} \quad (2.6)$$

### 2.13.4 Goodput

It refers to the number of packets that have been successfully received at the sink during a certain period of time[94].

$$Goodput = \frac{\text{Total Number of received packets at sink}}{\text{Time}} \quad (2.7)$$

# Chapter Three

# The Proposed Approach

## 3.1 Overview

This chapter explains the main steps of the proposed system implementation, configuration and installation. The proposed routing protocols are explained as probabilistic routing with postural link costs (PRPLC), On Body Store and Flood Routing (OBSFR), and Hybrid Delay-based Routing Protocol (HDRP).

## 3.2 The proposed methodology

The proposed solution relies on sink nodes receiving data from WBAN sensors and processing it for its primary purpose. However, collisions, delays, and a high lose rate are all possibilities while transferring data from sensor nodes to the sink node. Neglecting to take precautions to optimize resources in such an IoT setting, WBAN employs Hybrid Delay-based Routing Protocol (HDRP) approaches to reduce these parameters. To avoid data collisions and conquer the partitioning issue, it is necessary to transfer data to the sink node in a certain way.

In the proposed healthcare applications, data on a patient's vital signs is continually collected and sent to a server station managed by a remote monitoring crew. Myocardial infarction may be avoided and other illnesses like cancer, asthmatic, and neurological disorders treated using the information included in this massive database.

People with impairments may have their IoT sensor behavior replicated using the suggested simulated WBAN. A retina prosthesis chip, for instance, may be inserted in a person's eye to improve their vision, and the network's behavior could then be assessed in terms of how sensitively data was routed from the patient's device to the staff server.

The proposed Hybrid Delay-based Routing Protocol (HDRP) protocol improved channel utilization, decrease path cost (delay) through redirect packets delivery over the minimum cost path from source to the sink. The proposed method aims to achieve high network performance for all the types of IoT sensor nodes in the WBAN environment. Figure 3.1 showed the forwarding strategy within the proposed system.

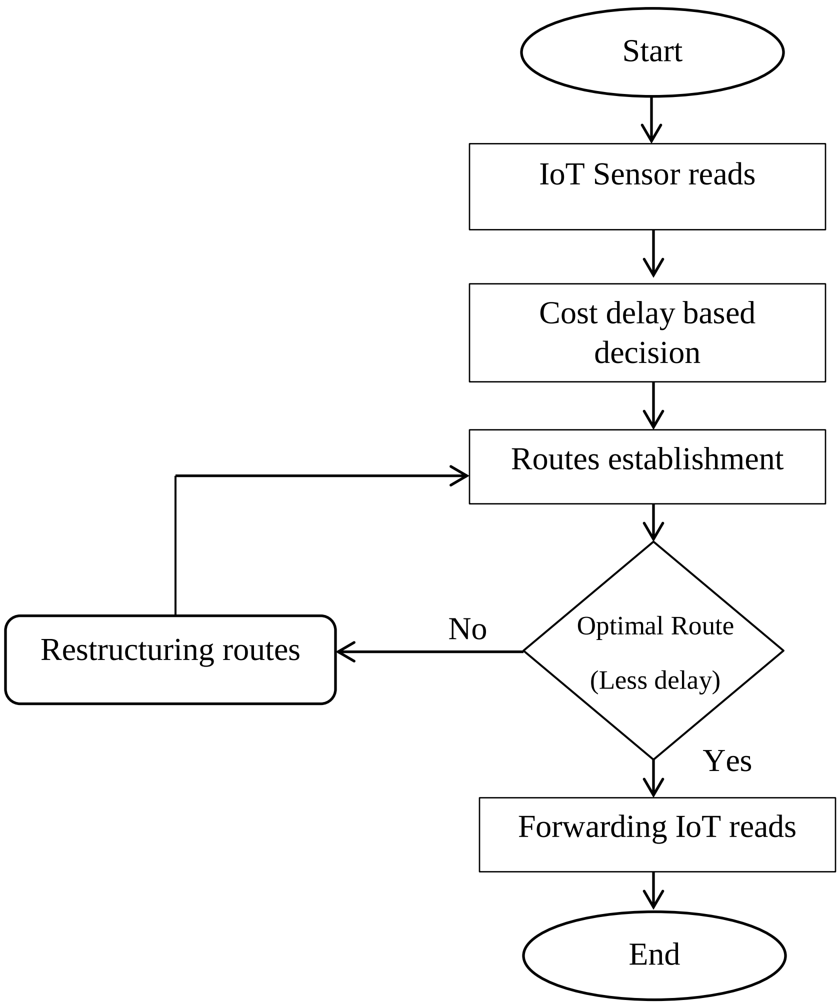



*Figure 3.1: The forwarding strategy of the proposed system.*

In addition, the main steps of modeling the performance of wireless body sensor networks are explained by the following representation steps in Figure 3.2.

In the used WBAN architecture generally, all the collected data is being transmitted to a Sink, where it aggregates and treats this data to come up with useful information then manage them in an accessible staff server. Data transmission is ensured by routing protocols that are facing different hitches to be handled like the absence of infrastructure, extremely limited resources such as delay. It is the main obstacle must put in consideration while using a routing protocol.

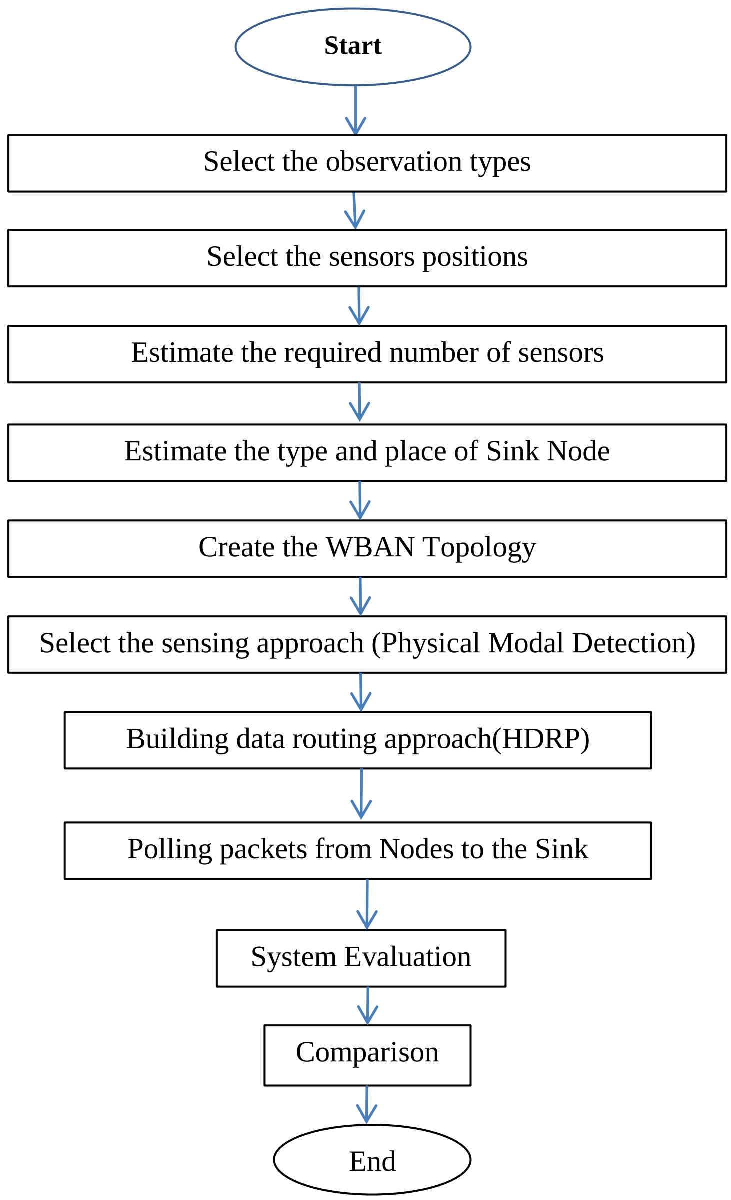



*Figure 3.2: The proposed system steps.*

The main explanation of the proposed system steps are as follow:

1. Select the observation types : the initial state of the proposed system is select the priority sensors to pass the emergency reads from specific sensors as the first and then others so the sink build the best path with minimum delay value for these sensors.
2. Select the sensors positions : the proposed framework build the devices positions and features to create known devices for all node neighbors in the network.
3. Estimate the required number of sensors : sink node estimate the optimal number of sensors to pass sensor reads to the staff server.
4. Estimate the type and place of Sink Node : sink node broad cast messages as beacon message to build route with all connected sensors in the network.
5. Create the WBAN Topology : building the network topology with setting and configuration frames among network elements.
6. Select the sensing approach (Physical Modal Detection) : the proposed framework applied the sensing approach among WBAN devices based on the physical modal detection.
7. Building data routing approach(HDRP) : the proposed methodology approach in the sink node build the routing information with all requirements from the connected devices to reroute two main packets : route packets with delayed approach, and data packets with sensor reads.
8. Polling packets from Nodes to the Sink : the sink is polled the packets for store and forwarding purpose.

9. System Evaluation : it explained the evaluation state of the system with evaluation metrics.
10. Comparison : the proposed system is compared with sub-cases system and other related works in the same research direction.

In addition, WBAN stores several distinct types of data, all of which have varying quality of service needs. Some information must be supplied immediately, while other pieces of data may be sent a little later. Critical information (EEG, ECG, etc.), delay-sensitive data (PH monitoring, vital signaling monitoring, breathing track), and ordinary data are proposed in the system (temperature) using the proposed hybrid technique. The proposed procedure includes :

### 3.2.1 Probabilistic Routing with Postural Link Costs (PRPLC) Protocol

The primary objective of (PRPLC) routing is to minimize the time it takes for packets to travel from one end of a network to the other by selecting high likelihood links and avoiding intermediate storage at nodes on low probability links, such as when a node keeps track of its likelihood of being in direct (one-hop) touch with every other the network's nodes.

The chance that node-j will connect to node d is greater than the probability that it will connect with the other nodes. For this reason, it is reasonable to move packets from node-i to node-j in an effort to reduce the total time it takes to route a packet from beginning to finish routing procedure.

For each connection Link likelihood Factor (LLF), among nodes i and j, PRPLC calculates a LF), denoted by $P_{i,j}^{t}$ t, that describes the probability that this link will be established within the given time interval t time slot.

Besides, $L_{i,j}$is set to 1 if and only if the link in question is connected throughout the time slot t, and to 0 otherwise. So, after (t) the time slot. The PRPLC routing protocol is shown in Algorithm 3.1

| **Algorithm 3.1: The Probabilistic routing with postural link costs (PRPLC)** |
|---|
| **Input** : Route information from IoT healthcare WBAN sensors.<br><br>**Output** : Less delay route based on likelihood factor. |
| **Begin**<br><br>- Routing logic for node-I to forward packets to sink-d time slot-t<br>**While** (true)<br><br>**For** (all node j [ j ∈ N, j ≠ i])<br><br>$\boldsymbol{R_{i,j}^{t}}=\sum_{r=tit}^{t} L_{i,j}^{r}$ / $T_{window}$<br><br>If ($L_{i,j}^{t}$ = 1)<br><br>$P_{i,j}^{t}= P_{i,j}^{t-1}+(1- P_{i,j}^{t-1}).\ \omega_{i,j}^{t}$<br><br>**Else**<br><br>$\boldsymbol{P_{i,j}^{t}}= P_{i,j}^{t-1}.\ \omega_{i,j}^{t}$<br><br>**If** ($L_{i,j}^{t}$= 1) {<br><br>**Send**<br><br>$P_{i,d\ to\ node-j}^{t}$<br><br>- find node-k so that $P_{i,d}^{t}$ is maximum for [k ∈ N, k ≠ i, d, $L_{i,k}^{t}$ = 1]<br>**For** (all buffered packets to be forwarded to sink node-d){<br><br>**If** ($L_{i,d}^{t}$ = 1) // node-I has direct link to node-d<br><br>- Deliver the packet to the sink node-d. |

**else**

**id** ($P_{k,d}^{t}$ > $P_{i,d}^{t}$) // node-k has better link likelihood with sink-d

- Forward the packets to node-k:

**else**

- continue buffering the packet in node-i

**End algorithm**

The proposed PRPLC based on the analysis incoming rout information from IoT sensor nodes to the sink, building links state based on the likelihood distance as delay time to deliver packets from sensor to the sink, link history model used to determine the rate at which the likelihood Factor increases and decreases when the link is connected and disconnected, and then delayed based modeling is implemented to calculate delay time and redirect packets to the minimum delay response sensor until the packets arrived to the sink node.

### 3.2.2 On Body Store and Flood Routing (OBSFR) Protocol

With OBSFR, it can be certain that the transmission packets will arrive at their destination with the least amount of delay possible. The core of the process is flooding; several copies of a packets sent from a source address might eventually arrive at the destination node through different paths, and the first copy to arrive at the destination represents the least amount of time that the whole transmission took.

To determine if it has previously seen a certain packet, a sensor node checks its local storage. If the packet has not been received previously, the sensor node will store it in a buffer. If a sensor node discovers a new sensor network that is not included in its database of sensor node IDs, it will retransmit the packet it has been buffering. The packet is removed from the buffer by the sensor node after transmission. The key issues addressed by the proposed system are as follows:

- Error rate used in the proposed system as an accuracy evaluation of gathered data from sensors to the staff element.
- How to transmit sensor readings to sink node
- Reducing network latency so that sensor data may be sent reliably and in real time without latency.
- Coordination of sensing devices to optimal transfer rate.
- Information has arrived at its destination with minimum delay to the healthcare patient care.
- Meaningful mapping between sensor types and healthcare functions, as well as the anatomical sites where those sensors will be most useful in human body.

Challenges with the OBSFR algorithm include its inability to handle single forwarding packet delivery, its high transmission energy and cost (computation procedures), and its high cost. The nodes' transmission technique was shown in Algorithm 3.2; once a message was received, it was transmitted to the base station and, after being processed, sent on to the staff server.

| **Algorithm 3.2: The used On Body Store and Flood Routing (OBSFR) algorithm** |
| --- |
| **Input** : Route information from IoT sensor nodes<br>**Output** : Minimum delay route decision |
| **Begin** |

```
while True do
    for all forward all packets do
    for all nodes [ j ∈ N, j ≠ i]) do
      Li,j ← links between node i and node j
      if (Li,j = 1 & j neighbor of (i) ) then
          PL ← Parent List
          nj PL of node i
          Broadcast packet
      else
          Continue buffering at node i
      end if
    end for
  end for
 end while
if Packet is Received then
  if Destination = 1 then
     Received Packet
  else
     Modifying message
  end if
  if neighbor= 1 then
        Forward it
  else
        Discard it
  end if
end if
```

**End algorithm**

In OBSFR, the attributes of a packet, including its source ID, identifier seq-number, and a table containing the complete IDs of a sensor nodes along the path, are stored in each packet (sink). A sink node, upon receiving a packet, checks its internal state to see whether it has previously seen the message. If the packet has not been received previously, the sink node will store it in a buffer.

When a sink node discovers a new sensor network that is not in its sensor node ID database, it will retransmit the buffered packet. Once the packet has been sent, the sink node will un-buffer it (it removes the packets). In comparison to PRPLC, and OBSFR, the main difference is in its transmission method. The packet buffer is routed to a different sensor node in PRPLC, one with a better chance of connecting to the sink.

By sending a packet to a single sensor node instead of all of them, PRPLC is able to maximize the use of available network resources more effectively than OBSFR. A Link Likelihood Factor is used by PRPLC to determine the likelihood of a connection to the sink (LLF). The sink nodes send out a greeting message using their LLF format as the sink node. The delayed packet is sent when a sensor network has a direct connection to the sink.

If no nearby sensor nodes have a higher LLF value, it may be forwarded to the next sensor or delayed at the current sensor node. Table 3.1 showed the main comparisons between PRPLC and OBSFR routing protocols in WBAN.

*Table 3.1: comparisons between PRPLC and OBSFR.*

| Parameters | PRPLC | OBSFR |
|---|---|---|
| Basic Principle | Store and forward | Store and forward |
| Network metric / Architecture | Link likelihood factor | Distance to the sink |
| Target performance parameter | Delay | Delay |

### 3.2.3 Hybrid Delay-based Routing Protocol (HDRP)

In order to reduce latency and the loss rate at which IoT sensor readings are sent, as well as to boost goodput and throughput network evaluators, the proposed hybrid method combine On Body Store and Flood Routing (OBSFR) and Probabilistic routing with postural link costs (PRPLC) postural protocols. HDRP is more efficient in several ways, including its capacity (routing overhead) to scale and its method of optimal selecting a forwarder node. To regulate packet traffic in WBAN, the proposed protocol makes use of adaptive forwarding method that adjusts its priorities based on the end-to-end packet latency, the number of packet per transmission, and the packet delivery ratio.

In order to decrease the temporary storage delay caused by packets blocked at nodes on low probability connections of the same linked job healthcare set, for example the ECG, EEG IoT sensor set, the primary objective is to create an adaptive method for routing packets by choosing a high likelihood end-to-end path. The necessary time for packets to reach the destination starting from the source. This time is calculated in the routing layer to determine minimum required time to pass sensor reads from the different healthcare sensor to the staff server. When sink select less path route to the final destination, it redirects the sensor read through this path. In a broad sense, data integrity issues might arise during network transmission owing to dropped packets or broken defective connections. As a result, the internal server receives erroneous information. Such information from the proposed system might lead to inaccurate readings in medical applications. This necessitates that each incoming packet be checked for accuracy by having the relevant data certified by the receiving personnel. Algorithm 3.3 proved the described state.

**Algorithm 3.3: The used Hybrid Delay-based Routing Protocol (HDRP) algorithm**

**Input:** Route information

**Output:** Optimal delay-based route

**Begin**

- **Node-i** to forward packets to **sink-d**

**While** (true){

  **For** (all buffered packets to be forwarded to sink node-d){

    **for (all** node j [ j ∈ Nk, k=1(EEG), k=2(ECG), k=3 (Temperature), k=4(motion), k=5(blood pressure)]) {

      **If** ($L_{i,j}^{t}$= 1 and j ∈ list of node-id in packet) {

        **j**// is a neighbor of i, and the packet did visit node-j before

        **Broadcast** the packet;

        **Remove** it from node-i's buffer

        **Break**; //done with this packet forwarding

      } **else**

        Continue buffering the packet at node-i;

      }

    }

  }

- **Sink-d** after receiving a packet

  **If** (the packet was not received before)

```
        Buffer the routing packets in for future forwarding;
        Calculating delay value and buffered.
    If (this is not the destination)
    Buffer the packet in for future forwarding;
    else if (this is the destination; staff){
        Match delayed value.
        Select minimum delay value as the best route. }
    else
    Discard the packet;// it was received before }
End algorithm
```

The information included in the "Packet Type, Node ID, lag duration as the proximity distance to Sink, near sensor broadcasts from each IoT sensor node at regular intervals to the likelylihod nodes. The IoT sensor multiforwarded the packets among its neighbors, and when the newly produced packets reached the sink, the sensor buffered them and calculated the least delay.

Iteratively adding the optimum delay packet's path to the forwarding table and sending it to the personnel server is done until all packets have been redirected. As a result, the hybrid strategy reduced overall packet delays by proactively selecting paths with minimal delays in packet storage and buffering owing to topological breaks.

It decreased the time it took for data to be delivered by cutting down on the time packets spent in intermediate likelihood nodes' buffers. As shown in Figure 3.3, the HDRP routing system calculates packet delays optimally.

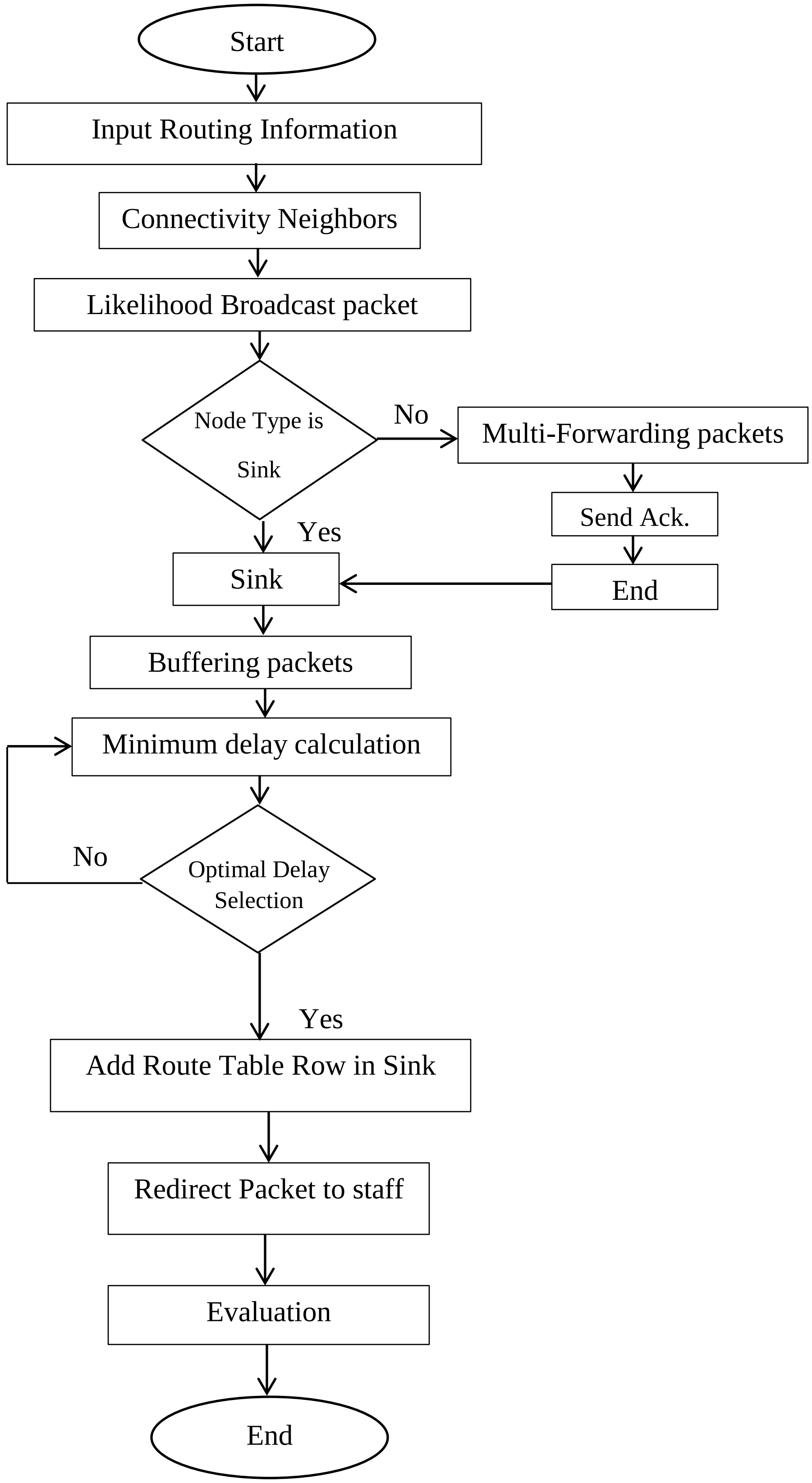



*Figure 3.3: The proposed HDRP routing protocol behavior.*

## 3.3 The proposed system implementation steps

The suggested system is built in Castalia library inside OMNeT++ simulator to conduct the simulation and verify the performance of proposed routing protocols. The suggested system makes use of the OMNeT++ framework, which is a C++ object-oriented flexible discrete event simulation tool framework that is both expandable and modular. Its general design allows it to be used to a wide variety of WBAN use cases, such as: - Modeling wired and wireless transmission WBAN networks

- Modeling a wireless body area network's routing system.

- Queueing, latency, and network performance simulations.

The used Body Area Networks are simulated using the Castalia library, a project under the OMNeT++ platform of Body Area Networks (BAN). Because it is extremely parametric and capable of simulating a variety of platforms, it is used to assess the merits of various platform structure for usage in a variety of contexts.

Therefore, the proposed method is based on an evaluation of the performance of a wireless Body Area System for health monitoring using an HDRP method of routing protocol such as the OBSFR algorithm and the PRPLC to enhance the evaluation of networks and their routing strategies so that they are equivalent for sensors with resource constraints. The suggested system has a three layers design.

A- The first layer consists of IoT-WBAN sensors that transmit sensing data such as (electroencephalogram (EEG) readings for tracking brain electrical activity, electrocardiogram (ECG) readings for tracking heart activity, body temperature readings for tracking body temperature, motion readings for identifying the user's status and estimating his or her level of activity readings for tracking blood pressure.

B- The Sink node layer, which regulates the transmission of collected sensing data via the WBAN network, is the second layer.

C- The staff server layer is used to process and received sensor reads which redirected by sink node.

Furthermore, the WBAN maintenance and setting may be done using the interface. Registration of sensor nodes (type and number of components), activation (sampling frequency and operation mode specified), customization (Accreditation or signal processing methods uploaded according to user preferences), also secure establishment connection are all part of network configuration (key exchange).

How fast and precisely the system replies to transmit and receive data between nodes is ultimately determined by the routing or algorithms used, and is crucial to the efficient operation of WBAN.

Figure 3.4 depicts the Sink node's role in managing the WBAN network once it has been setup. This includes coordinating channel sharing, end-to-end delay, synchronization, data retrieval and process, and analysis.

Through initial state the sink node build the characteristics of network transmission as node-ID, interfaces, exchange packets to build route delay and direction among all sensor nodes and when all network elements are connected and associated with sink. The healthcare IoT sensor nodes generate data reads, and they send reads to the sink node , which then chooses the most efficient path in the network to forward the data to the final destination as staff server. Staff server will reply to each data request and store the sensor reads for evaluation and next step preprocessing.

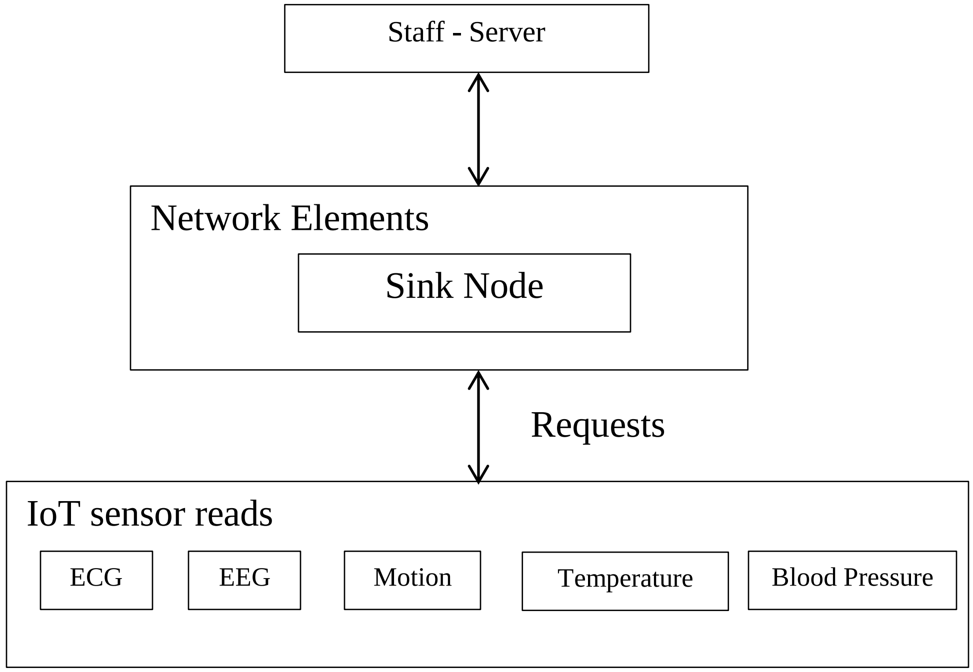



*Figure 3.4: The proposed system architecture in WBAN environment.*

# Chapter Four

## Results and Discussion

## 4.1 Introduction

This chapter discusses the results for the proposed system that are described in chapter three. The proposed system implemented in OMNET++, it is based on the fourth case studies. The 1st case study based on the static routing packet delivery for WBAN Internet of Things sensors. The 2nd case study is based on Probabilistic routing with postural link costs (PRPLC) Packet Delivery Scenario. The 3rd is implemented with On Body Store and Flood Routing (OBSFR) Packet Delivery Scenario. The 4th case study is the Hybrid Delay-based Routing Protocol (HDRP) Packet Delivery Scenario.

## 4.2 Implementation Environment

The proposed system has been implemented in an environment with the following specifications showed in Table 4.1. Besides, The code of proposed the system has been written in C++ of OMNET++ 4.6 simulation tool.

*Table 4.1: Environment specifications for the proposed system.*

| | |
|---|---|
| **Operating Systems** | Windows 10, 64-Bit |
| **CPU** | Core (TM) I 7-4210U |
| **RAM** | 8.00 GB |
| **Implementation Tools** | OMNET++ 4.6, INET 3.3.0, and Castalia ++ |

## 4.3 The proposed system Results

The results are evaluated with different evaluation measures such as throughput measured in bits per second (bps), end-to-end packet delay measured in milliseconds (ms), PDR measured in percentage, and goodput measured in packets per second (pkts/sec).

### 4.3.1 The 1st Scenario of Static Packet Delivery

The 1st is the static packet delivery, which depends on static route for pass and redirect packets in the WBAN network elements. The routing information is built in sink node to direct packets to the destination node. A static route is a pre-determined pathway that a packet must travel to reach a specific node without take into consideration the link delay to deliver packets. In addition, the proposed system is simulated with (7, 13,and 23) IoT healthcare sensors.

Table 4.2 presents the main specifications of network elements which effected on the network architecture, with network configuration ID-node identifier, and network interfaces.

*Table 4.2: The Specification of the WBAN environment.*

| **Node-ID** | **Node Type** | **Network interface** |
|---|---|---|
| **10.0.0.2/30** | IoT sensor 1 | eth0-eth0 |
| **10.0.0.6/30** | IoT sensor 2 | eth0-eth1 |
| **10.0.0.22/30** | IoT sensor 3 | eth0-eth5 |
| **10.0.0.30/30** | IoT sensor 4 | eth0-eth7 |
| **10.0.0.14/30** | IoT sensor 5 | eth0-eth3 |
| **10.0.0.18/30** | IoT sensor 6 | eth0-eth4 |
| **10.0.0.1/30** | Sink Node | eth0-to-eth8 |
| **10.0.0.10/30** | Staff | eth0-eth2 |

Table 4.3 shows the evaluation metrics of the proposed system based on 7 sensor IoT nodes, as the ECG sensors, EEG sensors, Motion sensor Blood pressure sensor, and Temperature sensor.

*Table 4.3: The static route packet delivery with 7 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To- Sink | Sink-To- Staff | | |
| ECG sensor | 104.98 | 104.98 | 53753.06 | 61752.03 | 99.93 | 1.9530 |
| ECG 2 sensor | 102.96 | 101.35 | 53702.04 | 50789.23 | 99.02 | 1.8872 |
| EEG sensor | 103.92 | 99.71 | 53712.22 | 58792.10 | 99.27 | 1.8563 |
| EEG 2 sensor | 104.09 | 102.99 | 52560.27 | 51471.90 | 99.80 | 1.9594 |
| Motion sensor | 14.99 | 14.98 | 7679.01 | 8478.90 | 99.99 | 1.9507 |
| Blood pressure sensor | 104.20 | 98.90 | 13734.02 | 5879.45 | 98.01 | 7.2010 |
| Temperature sensor | 104.30 | 99.98 | 16219.41 | 58792.41 | 99.12 | 6.1642 |
| Sink (Avg) | 154.625 | 153.125 | 54993.375 | 50349.106 | 99.58 | 1.4535 |
| Staff-server | 599.902 | 598.922 | 487577.102 | 351794.610 | 99.47 | 0.7135 |
| Packet Size | 1024 Byte | | | | | |

Table 4.4 showed the evaluation metrics as Throughput in Bps, End to End Packet Delay in ms, Packet Delivery Ratio in precentage (%)Goodput in packets per seconds of the proposed system based on 13 IoT healthcare sensor nodes.

*Table 4.4: The static route packet delivery with 13 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To- Sink | Sink-To-Staff | | |
| ECG sensor | 49.23 | 48.24 | 19335.38 | 19142.02 | 98.93 | 2.4949 |
| ECG 2 sensor | 47.12 | 46.17 | 18948.67 | 18759.18 | 98.04 | 2.4365 |
| ECG 3 sensor | 49.02 | 48.03 | 18755.31 | 18567.75 | 99.30 | 2.5608 |
| ECG 4 sensor | 48.71 | 47.73 | 19722.08 | 19327.63 | 98.56 | 2.4201 |
| ECG 5 sensor | 54.80 | 53.70 | 20108.79 | 19706.61 | 98.92 | 2.6704 |
| EEG sensor | 42.22 | 41.39 | 19528.73 | 18942.86 | 98.00 | 2.1194 |
| EEG 2 sensor | 44.03 | 43.14 | 18755.31 | 18192.65 | 99.10 | 2.3001 |
| EEG 3 sensor | 39.27 | 38.48 | 17401.84 | 16879.78 | 98.02 | 2.2112 |
| EEG 4 sensor | 43.86 | 42.98 | 18561.96 | 18005.10 | 98.70 | 2.3154 |
| EEG 5 sensor | 49.27 | 47.28 | 20495.50 | 19265.77 | 98.20 | 2.3068 |
| Motion sensor | 37.48 | 36.73 | 17227.82 | 16194.15 | 98.90 | 2.1320 |
| Blood pressure sensor | 60.45 | 58.24 | 21315.31 | 19610.08 | 98.58 | 2.7323 |
| Temperature sensor | 24.98 | 22.48 | 14299.09 | 13155.16 | 98.39 | 1.5721 |
| Sink (Avg) | 67.30 | 62.92 | 22807.38 | 22123.15 | 97.90 | 1.4003 |
| Staff-server | 489.70 | 478.59 | 463198.24 | 449302.29 | 96.84 | 5.2448 |
| Packet Size | 1024 Byte | | | | | |

Table 4.5 showed the evaluation metrics of the proposed system that depends on 23 nodes, it showed the decreased number of packets and increased end to end delay between IoT sensor to sink and sink to the staff

server, due to the increased number of active connections from the nodes which effected with the increased number of nodes. The results of static route packet delivery with 23 IoT sensors as the total sum of PDR is 2447.57 %, Total sum of goodput is 40.2673 packets in seconds.

*Table 4.5: The static route packet delivery with 23 IoT sensors.*

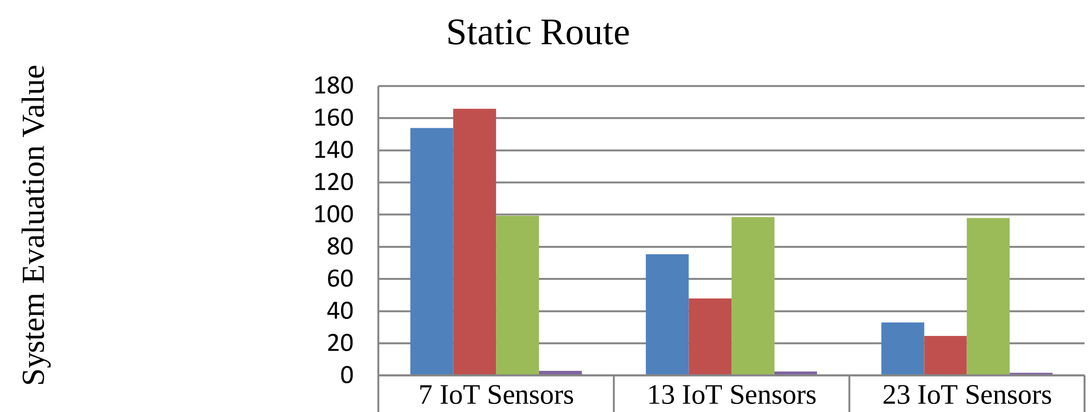
| Sensor Reads | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To- Staff | | |
| ECG sensor | 25.59 | 25.33 | 13148.05 | 13016.56 | 97.94 | 1.9265 |
| ECG 2 sensor | 24.50 | 24.25 | 12885.09 | 12756.23 | 97.05 | 1.8820 |
| ECG 3 sensor | 25.49 | 24.98 | 12753.61 | 12498.53 | 98.30 | 1.9586 |
| ECG 4 sensor | 25.32 | 24.81 | 13411.01 | 13142.78 | 97.57 | 1.8499 |
| ECG 5 sensor | 28.49 | 27.63 | 13673.97 | 13263.75 | 97.93 | 2.0206 |
| ECG 6 sensor | 21.95 | 21.29 | 13279.53 | 12881.14 | 97.02 | 1.6032 |
| ECG 7 sensor | 22.89 | 22.20 | 14753.61 | 14311.00 | 98.60 | 1.5047 |
| ECG 8 sensor | 20.42 | 19.60 | 11833.25 | 11478.25 | 97.52 | 1.6563 |
| ECG 9 sensor | 22.80 | 21.88 | 13622.13 | 12941.02 | 98.20 | 1.6062 |
| ECG 10 sensor | 25.62 | 24.33 | 13936.94 | 13240.09 | 97.70 | 1.7457 |
| EEG sensor | 19.48 | 18.50 | 11714.91 | 13240.09 | 98.40 | 1.5791 |
| EEG 2 sensor | 31.43 | 29.22 | 14494.41 | 13769.68 | 98.08 | 2.0159 |
| EEG 3 sensor | 12.98 | 12.07 | 9723.38 | 9237.211 | 97.89 | 1.2413 |
| EEG 4 sensor | 25.59 | 23.79 | 13148.05 | 11833.24 | 97.41 | 1.8093 |
| EEG 5 sensor | 24.50 | 22.54 | 12885.09 | 11596.58 | 96.35 | 1.7493 |
| EEG 6 sensor | 25.49 | 22.94 | 12753.61 | 11478.24 | 96.35 | 1.7987 |
| EEG 7 sensor | 25.81 | 23.22 | 13411.01 | 12069.90 | 98.43 | 1.7314 |
| EEG 8 sensor | 26.30 | 23.67 | 13673.97 | 12306.57 | 97.54 | 1.7310 |

| | | | | | | |
|---|---|---|---|---|---|---|
| EEG 9 sensor | 20.26 | 18.23 | 13279.53 | 11951.57 | 98.30 | 1.3727 |
| EEG 10 sensor | 21.13 | 19.01 | 12753.61 | 11478.24 | 98.56 | 1.4905 |
| Motion sensor | 18.84 | 16.95 | 11833.25 | 10649.92 | 98.42 | 1.4324 |
| Blood pressure sensor | 21.05 | 18.94 | 12622.13 | 11359.91 | 98.30 | 1.5005 |
| Temperature sensor | 23.64 | 21.27 | 13936.94 | 12543.24 | 97.60 | 1.5261 |
| Sink (Avg) | 36.85 | 35.03 | 16509.01 | 14858.10 | 99.19 | 1.1167 |
| Staff-server | 269.33 | 258.55 | 324974.80 | 292477.32 | 98.92 | 0.4187 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.1 showed the comparisons among three states of the static route depending on the increased number of IoT sensor nodes. It showed that with increased number of nodes lead to decrease throughput, increase total delay per nodes, decreased total average packet delivery ratio, and decreased total goodput delivery ratio.

The results of static route compression as total average throughput of 7 IoT Sensors 153.828 Bps, 75.4513 Bps of 13 IoT Sensors, and 32.9196 Bps of 23 IoT Sensors. Total Average Delay (s) is decreased from 165.7811 seconds to 24.6278 seconds. Total average PDR is decreased from 99.3544 % to 97.9028 %. Total average goodput (pkts/sec) is decreased from 2.7932 to 1.6107 packets in seconds.

The results of static route showed that the throughput is decreased due to the increased number of active nodes which leads to the decreased number of generated packets by each node, Delay is decreased by node due to the node job is completed in less time manner, while the PDR is decreased due to the decreased number of successful packets to the final destination, and Goodput is decreased due to the decreased acknowledged packets arrived in time period.




| | 7 IoT Sensors | 13 IoT Sensors | 23 IoT Sensors |
|---|---|---|---|
| Total Avg Throughput / Bps | 153.828 | 75.4513 | 32.9196 |
| Total Avg Delay (s) | 165.7811 | 47.9211 | 24.6278 |
| Total Avg PDR (%) | 99.3544 | 98.4253 | 97.9028 |
| Total Avg Goodput (pkts/sec) | 2.7932 | 2.4611 | 1.6107 |

*Figure 4.1: The comparison of the static route case study.*

### 4.3.2 The 2nd Scenario of PRPLC Routing Protocol

The proposed 2nd case study based on the system Probabilistic routing with postural link costs (PRPLC) that minimizes end-to-end packets delay by dynamically choosing routes having low storage/buffering delays. It is determined by the likelihood that any linked for a discrete slot 't' This likelihood is referred to as the LLF, and it is denoted by $P_{i,j}^{t}(0 \leq P_{i,j}^{t} \leq 1)$. The LLF is supposed to be updated dynamically at regular interval ‘t’. In this scenario, all of the nodes always send hello messages to their neighbors, in which they communicate their local link function (LLF) towards their neighbors in addition to towards the sink node.

Every node will only forward a packets to its neighbor if the distance between their own LLF towards to the end nodes and their neighbor's LLF towards to the destination is either below than or equal to one another. If this is not the case, the packet is stored in the buffer while it waits for a suitable next-hop node.

Table 4.6 showed the evaluation metrics of the proposed adaptive routing system based on 7 IoT sensor nodes. The packet delivery ratio (%) of PRPLC routing protocol packet delivery with 7 IoT sensors as 897.41 %. Total sum of goodput is 29.1499 packets in seconds. End To End delay sensor-to-sink is 720725.896 ms, and sink-to-staff is 632757.54 ms.

*Table 4.6: The PRPLC routing protocol packet delivery with 7 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To-Staff | | |
| ECG sensor | 108.72 | 108.69 | 49829.08 | 55972.03 | 99.75 | 2.1812 |
| ECG 2 sensor | 106.60 | 105.89 | 48675.52 | 46035.36 | 99.66 | 2.1754 |
| EEG sensor | 107.60 | 104.19 | 48684.75 | 53289.15 | 99.69 | 2.1400 |
| EEG 2 sensor | 107.77 | 106.63 | 47640.62 | 46654.13 | 99.69 | 2.2382 |
| Motion sensor | 15.51 | 15.50 | 6960.246 | 7685.273 | 99.79 | 2.2269 |
| Blood pressure sensor | 107.89 | 106.21 | 12448.51 | 5329.127 | 99.71 | 8.5319 |
| Temperature sensor | 107.99 | 105.42 | 14701.27 | 53289.44 | 99.65 | 7.1708 |
| Sink (Avg) | 160.11 | 159.50 | 49846 | 45636.43 | 99.78 | 1.6704 |
| Staff-server | 621.19 | 620.17 | 441939.9 | 318866.6 | 99.69 | 0.8151 |
| Packet Size | 1024 Byte | | | | | |

Table 4.7 showed the evaluation metrics of the proposed PRPLC system based on 13 sensor nodes.

The PRPLC route packet delivery with 13 IoT sensors is 1481.20302 %, and goodput is 36.7796 packets in sec. End to End Packet Delay Sensor-to-sink is (662090.16) ms, while it is (640982.63) ms from sink-to-staff. In addition, Throughput sent is (1188.1175) frames in seconds, besides received is (1155.6655) Frames/sec.

*Table 4.7: The PRPLC route packet delivery with 13 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To- Sink | Sink-To-Staff | | |
| ECG sensor | 50.977 | 49.951 | 17525.58 | 17350.32 | 99.64018 | 2.8501 |
| ECG 2 sensor | 48.792 | 47.804 | 17175.06 | 17003.31 | 98.74288 | 2.7833 |
| ECG 3 sensor | 50.7585 | 49.7325 | 16999.81 | 16829.81 | 99.0021 | 2.9254 |
| ECG 4 sensor | 50.4355 | 49.419 | 17876.09 | 17518.56 | 99.26132 | 2.7645 |
| ECG 5 sensor | 56.7435 | 55.6035 | 18226.6 | 17862.06 | 99.62024 | 3.0506 |
| EEG sensor | 43.7095 | 42.8545 | 17700.84 | 17169.8 | 97.71597 | 2.4210 |
| EEG 2 sensor | 45.5905 | 44.669 | 16999.81 | 16489.82 | 98.8027 | 2.6276 |
| EEG 3 sensor | 40.66 | 39.843 | 15773.02 | 15299.83 | 97.72594 | 2.5260 |
| EEG 4 sensor | 45.41 | 44.498 | 16824.56 | 16319.81 | 98.4039 | 2.6448 |
| EEG 5 sensor | 51.015 | 48.9535 | 18577.12 | 17462.49 | 97.9054 | 2.6351 |
| Motion sensor | 38.8075 | 38.0285 | 15615.29 | 14678.38 | 98.6033 | 2.4353 |
| Blood pressure sensor | 62.5955 | 60.306 | 19320.19 | 17774.58 | 98.28426 | 3.1213 |
| Temperature sensor | 25.859 | 23.275 | 12960.69 | 11923.84 | 98.19453 | 1.7958 |
| Sink (Avg) | 69.6825 | 65.151 | 20672.6 | 20052.42 | 99.62024 | 1.5997 |
| Staff-server | 507.0815 | 495.577 | 419842.9 | 407247.6 | 99.68006 | 0.5991 |

| Packet Size | 1024 Byte | |
|---|---|---|

Table 4.8 is showed the main goal of the adaptive route delivery system by minimizing end-to-end packet delays by dynamically choosing routes on which the less buffering delays caused due to topological disconnections are low among WBAN nodes based on the maximum number of nodes as 23 IoT sensors.

In addition, the PRPLC route packet delivery with 23 IoT sensors Total sum PDR(%) of the PRPLC route packet delivery with 23 IoT sensors is 2448.89 %, while total sum of goodput is 45.992 packets in seconds.

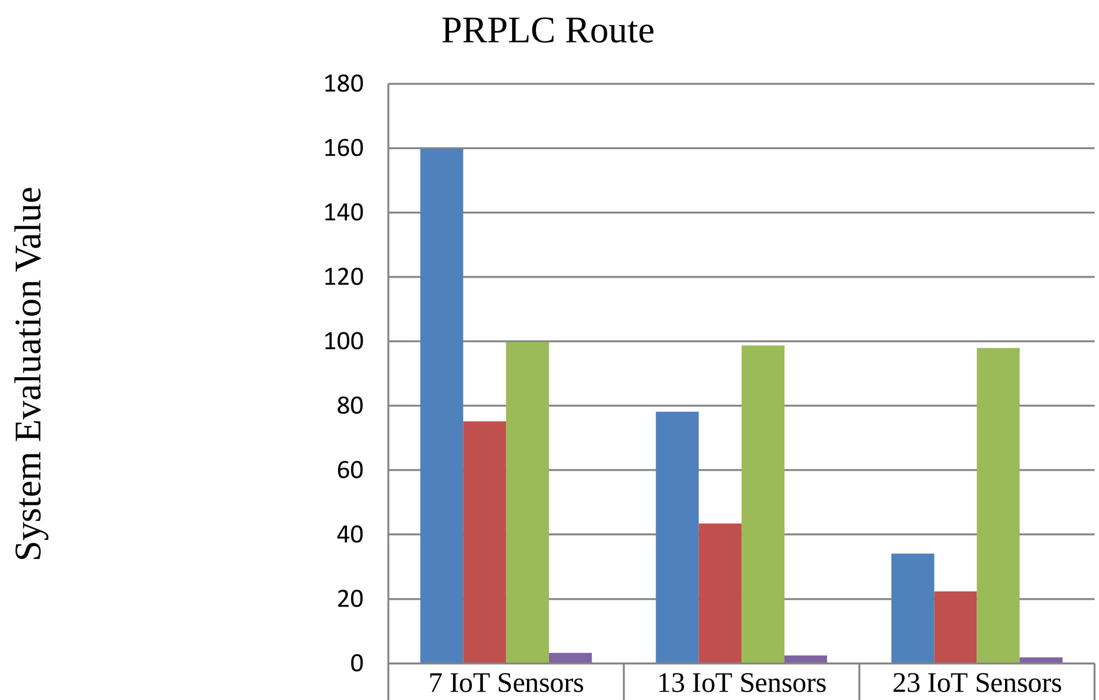
*Table 4.8: The PRPLC route packet delivery with 23 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput (pkts/sec) |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To-Staff | | |
| ECG sensor | 26.4955 | 26.22 | 11917.39 | 11798.21 | 98.73 | 2.2001 |
| ECG 2 sensor | 25.365 | 25.1085 | 11679.04 | 11562.24 | 98.82 | 2.1498 |
| ECG 3 sensor | 26.391 | 25.859 | 11559.87 | 11328.66 | 97.68 | 2.2369 |
| ECG 4 sensor | 26.2105 | 25.688 | 12155.73 | 11912.61 | 97.53 | 2.1132 |
| ECG 5 sensor | 29.4975 | 28.6045 | 12394.08 | 12022.26 | 97.30 | 2.3079 |
| ECG 6 sensor | 22.724 | 22.04 | 12036.56 | 11675.46 | 97.78 | 1.8310 |
| ECG 7 sensor | 23.7025 | 22.9805 | 13372.67 | 12971.49 | 97.49 | 1.7184 |
| ECG 8 sensor | 21.1375 | 20.292 | 10725.66 | 10403.89 | 97.79 | 1.8919 |
| ECG 9 sensor | 23.6075 | 22.648 | 12347.09 | 11729.73 | 97.80 | 1.8342 |
| ECG 10 sensor | 26.524 | 25.1845 | 12632.44 | 12000.81 | 97.52 | 1.9936 |
| EEG sensor | 20.1685 | 19.152 | 10618.39 | 12000.81 | 97.96 | 1.8036 |
| EEG 2 sensor | 32.5375 | 30.248 | 13137.73 | 12480.83 | 97.86 | 2.3023 |

| | | | | | | |
|---|---|---|---|---|---|---|
| EEG 3 sensor | 13.433 | 12.4925 | 8813.267 | 8372.602 | 97.49 | 1.4174 |
| EEG 4 sensor | 26.4955 | 24.6335 | 11917.39 | 10725.65 | 98.54 | 2.0670 |
| EEG 5 sensor | 25.365 | 23.332 | 11679.04 | 10511.14 | 97.31 | 1.9977 |
| EEG 6 sensor | 26.391 | 23.75 | 11559.87 | 10403.88 | 97.57 | 2.0545 |
| EEG 7 sensor | 26.7235 | 24.035 | 12155.73 | 10940.16 | 97.43 | 1.9772 |
| EEG 8 sensor | 27.227 | 24.51 | 12394.08 | 11154.67 | 98.30 | 1.9775 |
| EEG 9 sensor | 20.976 | 18.8765 | 12036.56 | 10832.9 | 97.61 | 1.5682 |
| EEG 10 sensor | 21.8785 | 19.684 | 11559.87 | 10403.88 | 98.79 | 1.7027 |
| Motion sensor | 19.5035 | 17.5465 | 10725.66 | 9653.078 | 98.83 | 1.6359 |
| Blood pressure sensor | 21.793 | 19.608 | 11440.69 | 10296.62 | 98.73 | 1.7138 |
| Temperature sensor | 24.472 | 22.021 | 12632.44 | 11369.19 | 98.82 | 1.7432 |
| Sink | 38.1577 | 36.271 | 14963.76 | 13467.37 | 97.68 | 1.2757 |
| Staff-server | 278.882 | 267.7195 | 294557.2 | 265101.4 | 97.53 | 0.4783 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.2 showed the system comparisons among three states of the PRPLC system. The results of PRPLC route compression enhanced compared with the static route due to the optimization route and it managed with PRPLC. The results of PRPLC as the total average throughput of 7 IoT Sensors (159.7544) Bps, (78.1261) Bps of 13 IoT Sensors, and (34.0832) Bps of 23 IoT Sensors. Total Average Delay (s) is decreased from (75.1935) seconds to (22.3226) seconds. Total average PDR is decreased from (99.7123) % to (97.9593) % due to the decreased number of successful arrived data packets from the sensors to the final destination. Total average

goodput (pkts/sec) is decreased from (3.2389) to (1.8397) packets in seconds due to decreased number of acknowledgment packets from the receiver node.




| | 7 IoT Sensors | 13 IoT Sensors | 23 IoT Sensors |
|---|---|---|---|
| Total Avg Throughput / Bps | 159.7544 | 78.1261 | 34.0832 |
| Total Avg Delay (s) | 75.1935 | 43.4357 | 22.3226 |
| Total Avg PDR (%) | 99.7123 | 98.7468 | 97.9593 |
| Total Avg Goodput (pkts/sec) | 3.2389 | 2.462 | 1.8397 |

*Figure 4.2: The comparison of the PRPLC route case study.*

### 4.3.3 The 3rd Scenario of OBSFR Routing Protocol

The proposed 3rd case study based on the system as on-body packet flooding mechanism as (OBSFR) that serves as a performance benchmark with delay lower-bound, it decreased the time required to build route between IoT sensors to the sink and sink to the staff-server to provide better routing performance compared to the static technique. In this scenario, it is the responsibility of the sink node for collecting the original data from the other Internet of things medical sensor nodes and forward the processed results to the staff server that is situated outside of the body, resulting in multi-point-to-point routing.

In other words, each packet carries a list of the node-IDs showing its path from the source node along with a unique identifier (source_ID, seq_No.). This information is also included in the packet's sequence number. When a node receives a packet, it stores the packet in its buffer before beginning the search for other nodes as the node starts search for the nodes whose IDs are not listed in the received packet’s IDs list. Once it has discovered one or more of these nodes, it will then forward the packets via a method known as broadcasting. Figure 4.3 showed the proposed network structure, which included the connected 7 IoT sensors nodes.

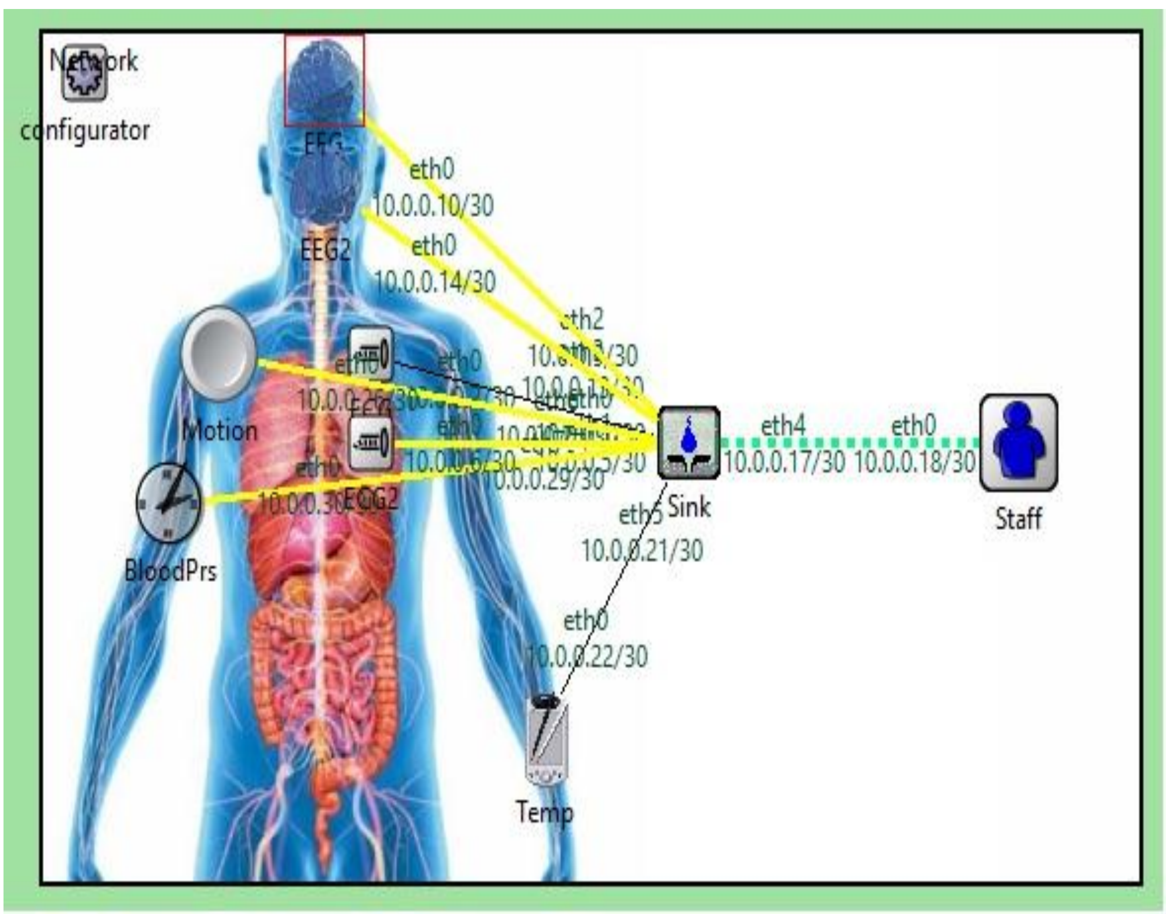



*Figure 4.3: The proposed topology with 7 IoT sensors.*

Table 4.9 showed the evaluation metrics of the proposed adaptive routing system based on 7 IoT sensor nodes.

The results showed enhancement compared with PRPLC due to the behavior of this protocol to deal with delay, so the packet delivery ratio (%) of OBSFR route packet delivery with 7 IoT sensors as (899.21%). Total sum of goodput is (31.606) packets in seconds. End to end packet delay sensor-to-sink is (699733.86) ms, and sink-to-staff is (614327.73) ms.

*Table 4.9: The OBSFR route packet delivery with 7 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To-Staff | | |
| ECG sensor | 114.45 | 114.42 | 48377.75 | 54341.78 | 99.95 | 2.3651 |
| ECG 2 sensor | 112.22 | 111.47 | 47257.79 | 44694.52 | 99.86 | 2.3587 |
| EEG sensor | 113.27 | 109.68 | 47266.75 | 51737.04 | 99.89 | 2.3204 |
| EEG 2 sensor | 113.45 | 112.25 | 46253.03 | 45295.27 | 99.89 | 2.4268 |
| Motion sensor | 16.33 | 16.32 | 6757.52 | 7461.43 | 99.99 | 2.4150 |
| Blood pressure sensor | 113.57 | 111.80 | 12085.93 | 5173.91 | 99.91 | 9.2504 |
| Temperature sensor | 113.68 | 110.97 | 14273.08 | 51737.32 | 99.85 | 7.7747 |
| Sink (Avg) | 168.54 | 167.90 | 48394.17 | 44307.21 | 99.98 | 1.8111 |
| Staff-server | 653.89 | 652.82 | 429067.84 | 309579.25 | 99.89 | 0.8838 |
| Packet Size | 1024 Byte | | | | | |

In addition, Figure 4.4 showed the proposed adaptive OBSFR system with 13 IoT sensors.

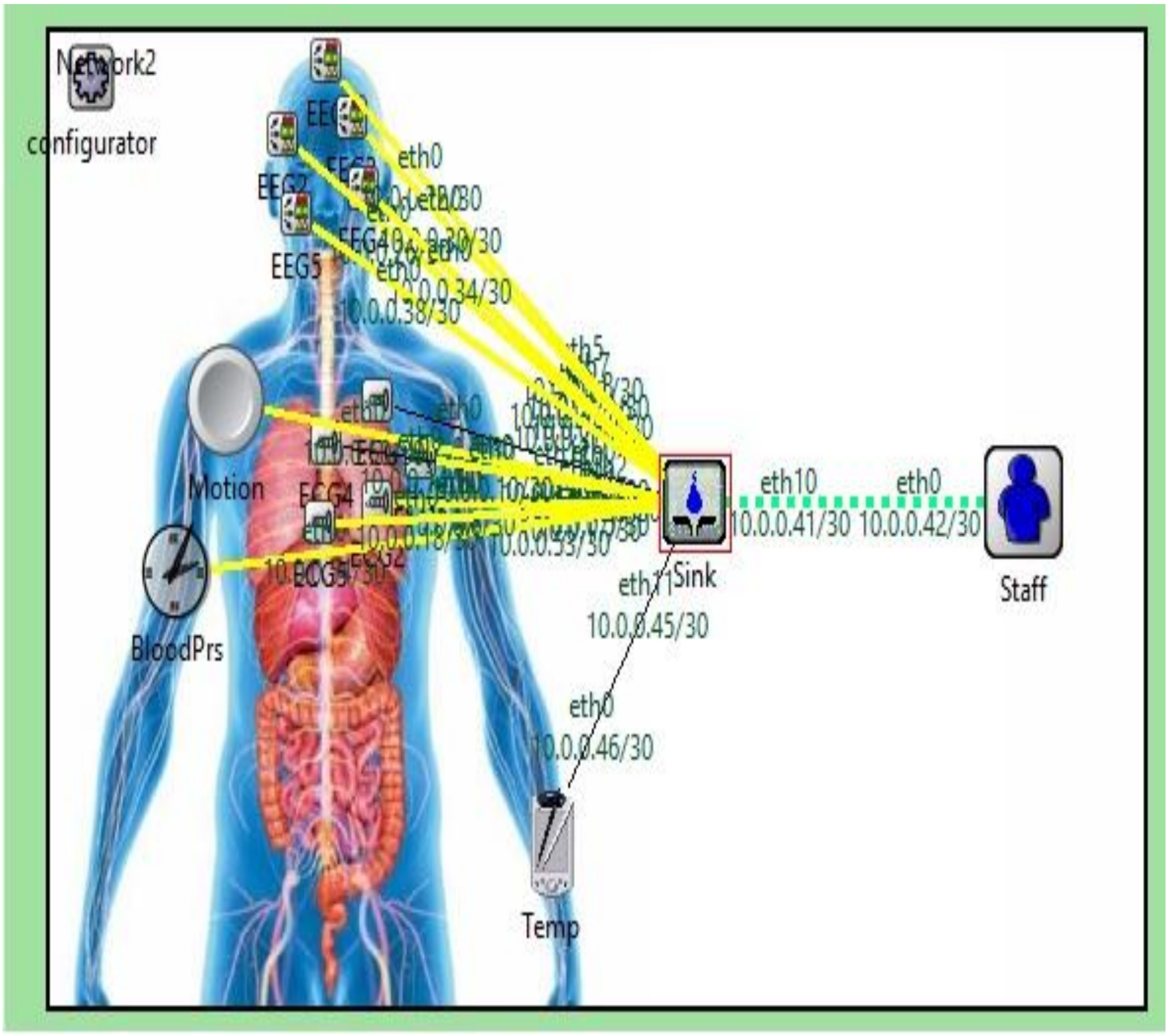



*Figure 4.4: The proposed topology with 13 IoT sensors.*

Table 4.10 showed the evaluation metrics of the proposed OBSFR system based on 13 sensor nodes. The OBSFR route packet delivery with 13 IoT sensors is (1485.66 %) is enhanced with PRPLC, and goodput is (39.8769) packets in sec.

Besides, end to end packet delay sensor-to-sink is (642805.98) ms, while it is (622313.21) ms from sink-to-staff. In addition, Throughput sent is (1250.65) frames in seconds, besides received is (1216.49) Frames/sec.

*Table 4.10: The OBSFR route packet delivery with 13 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To- Sink | Sink-To-Staff | | |
| ECG sensor | 53.66 | 52.58 | 17015.13 | 16844.97 | 99.94 | 3.0901 |
| ECG 2 sensor | 51.36 | 50.32 | 16674.82 | 16508.07 | 99.04 | 3.0177 |
| ECG 3 sensor | 53.43 | 52.35 | 16504.67 | 16339.62 | 99.3 | 3.1718 |
| ECG 4 sensor | 53.09 | 52.02 | 17355.43 | 17008.31 | 99.56 | 2.9973 |
| ECG 5 sensor | 59.73 | 58.53 | 17695.73 | 17341.81 | 99.92 | 3.3075 |
| EEG sensor | 46.01 | 45.11 | 17185.28 | 16669.71 | 98.01 | 2.6249 |
| EEG 2 sensor | 47.99 | 47.02 | 16504.67 | 16009.53 | 99.1 | 2.8488 |
| EEG 3 sensor | 42.80 | 41.94 | 15313.61 | 14854.20 | 98.02 | 2.7387 |
| EEG 4 sensor | 47.80 | 46.84 | 16334.52 | 15844.48 | 98.7 | 2.8675 |
| EEG 5 sensor | 53.70 | 51.53 | 18036.04 | 16953.87 | 98.2 | 2.8570 |
| Motion sensor | 40.85 | 40.03 | 15160.48 | 14250.85 | 98.9 | 2.6404 |
| Blood pressure sensor | 65.89 | 63.48 | 18757.47 | 17256.87 | 98.58 | 3.3842 |
| Temperature sensor | 27.22 | 24.50 | 12583.19 | 11576.54 | 98.49 | 1.9470 |
| Sink (Avg) | 73.35 | 68.58 | 20070.49 | 19468.37 | 99.92 | 1.7344 |
| Staff-server | 533.77 | 521.66 | 407614.45 | 395386.01 | 99.98 | 0.6496 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.5 showed the proposed system with 23 IoT sensors data transmission, in addition, it showed how nodes connected with sink to send sensor reads to the staff server through sink node after determine the best route to the staff server.

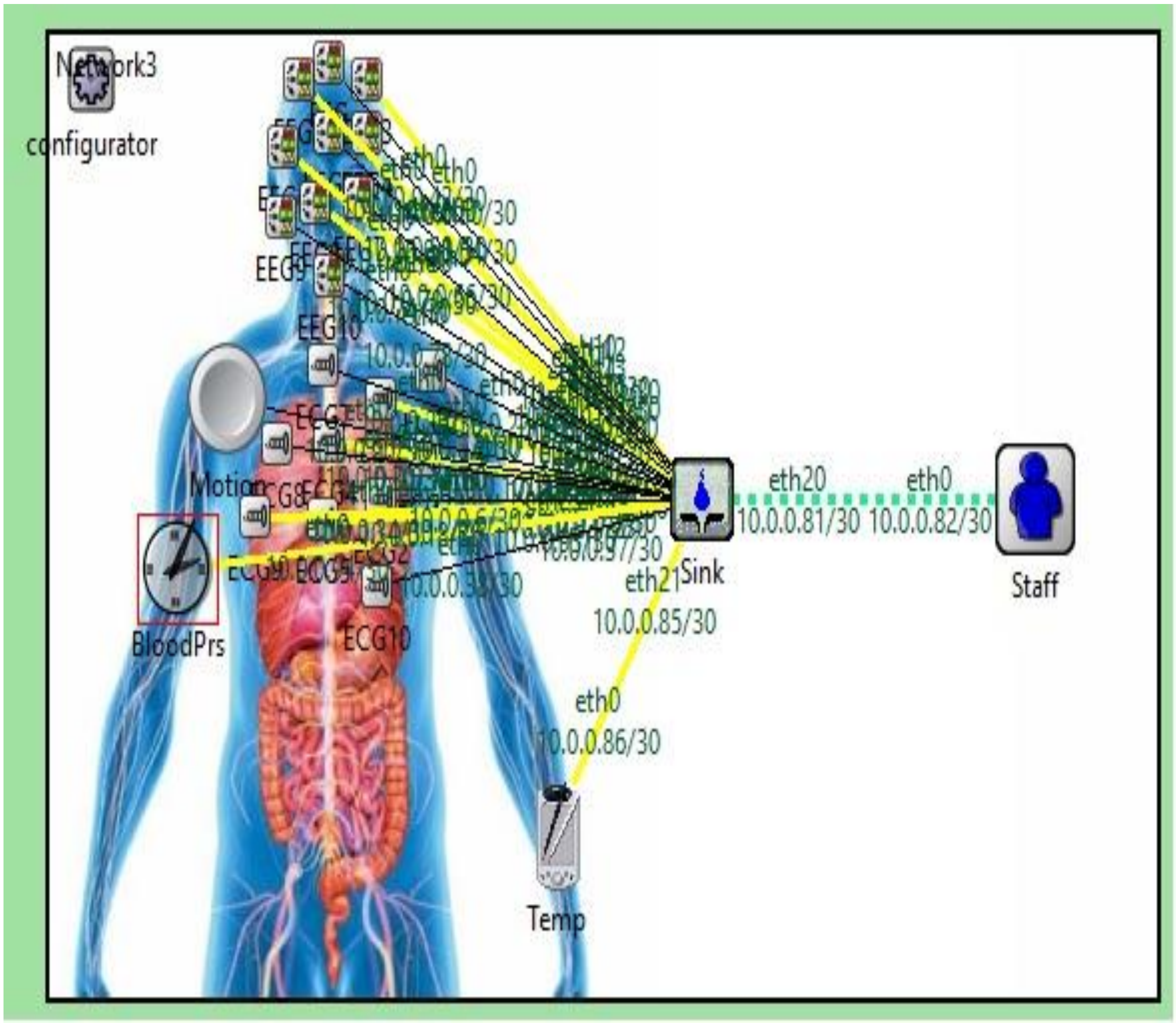



*Figure 4.5 : The proposed topology with 23 IoT sensors.*

The main objective of the OBSFR approach delivery platform is shown in Table 4.11. The goal is to decrease total message transit times by selecting routes with the lowest latency owing to geography problems are low between many WBAN nodes. The maximum the number of nodes supported by this system is 23 IoT sensors.

In addition, the OBSFR route packet delivery with 23 IoT sensors the total sum PDR is (2473.72) % of the OBSFR route packet delivery with 23 IoT sensors is (2448.89 %), while total sum of goodput is (49.8653) packets in seconds.

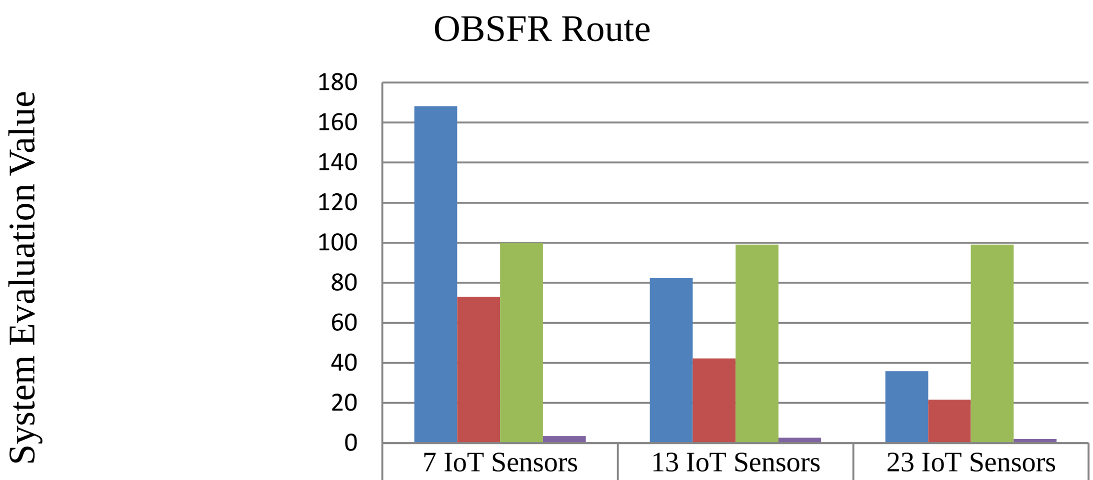
*Table 4.11: The OBSFR route packet delivery with 23 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To- Staff | | |
| ECG sensor | 27.89 | 27.60 | 11570.28 | 11454.57 | 99.73 | 2.3854 |
| ECG 2 sensor | 26.70 | 26.43 | 11338.87 | 11225.48 | 99.82 | 2.3309 |
| ECG 3 sensor | 27.78 | 27.22 | 11223.17 | 10998.70 | 98.67 | 2.4253 |
| ECG 4 sensor | 27.59 | 27.04 | 11801.68 | 11565.64 | 98.52 | 2.2911 |
| ECG 5 sensor | 31.05 | 30.11 | 12033.09 | 11672.1 | 98.29 | 2.5022 |
| ECG 6 sensor | 23.92 | 23.20 | 11685.98 | 11335.40 | 98.77 | 1.9852 |
| ECG 7 sensor | 24.95 | 24.19 | 12983.17 | 12593.68 | 98.48 | 1.8631 |
| ECG 8 sensor | 22.25 | 21.36 | 10413.26 | 10100.86 | 98.78 | 2.0512 |
| ECG 9 sensor | 24.85 | 23.84 | 11987.47 | 11388.09 | 98.79 | 1.9887 |
| ECG 10 sensor | 27.92 | 26.51 | 12264.50 | 11651.27 | 98.51 | 2.1615 |
| EEG sensor | 21.23 | 20.16 | 10309.12 | 11651.27 | 98.95 | 1.9555 |
| EEG 2 sensor | 34.25 | 31.84 | 12755.08 | 12117.31 | 98.85 | 2.4962 |
| EEG 3 sensor | 14.14 | 13.15 | 8556.57 | 8128.74 | 98.48 | 1.5368 |
| EEG 4 sensor | 27.89 | 25.93 | 11570.28 | 10413.25 | 99.54 | 2.2410 |
| EEG 5 sensor | 26.70 | 24.56 | 11338.87 | 10204.99 | 98.3 | 2.1660 |
| EEG 6 sensor | 27.78 | 25.00 | 11223.17 | 10100.85 | 98.56 | 2.2275 |
| EEG 7 sensor | 28.13 | 25.30 | 11801.68 | 10621.51 | 98.42 | 2.1437 |
| EEG 8 sensor | 28.66 | 25.80 | 12033.09 | 10829.78 | 99.3 | 2.1440 |
| EEG 9 sensor | 22.08 | 19.87 | 11685.98 | 10517.38 | 98.6 | 1.7003 |
| EEG 10 sensor | 23.03 | 20.72 | 11223.17 | 10100.85 | 99.79 | 1.8461 |
| Motion sensor | 20.53 | 18.47 | 10413.26 | 9371.92 | 99.83 | 1.7737 |
| Blood pressure | 22.94 | 20.64 | 11107.47 | 9996.72 | 99.73 | 1.8582 |

| | | | | | | |
|---|---|---|---|---|---|---|
| sensor | | | | | | |
| Temperature sensor | 25.76 | 23.18 | 12264.50 | 11038.05 | 99.82 | 1.8900 |
| Sink | 40.166 | 38.18 | 14527.92 | 13075.12 | 98.67 | 1.3831 |
| Staff-server | 293.56 | 281.81 | 285977.82 | 257380.04 | 98.52 | 0.5186 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.6 showed the system comparisons among three states of the OBSFR adaptive system. The results of OBSFR route compression enhanced compared with the PRPLC route due to the delay function used as the minimum value to build route table. The results of OBSFR as the total average throughput of 7 IoT Sensors (168.16833) Bps, (782.238) Bps of 13 IoT Sensors, and (35.8771) Bps of 23 IoT Sensors, it decreased due to the increased number of sensor nodes which effects on the total generated packets from sensors.

Total Average Delay in second is decreased from (73.0034) seconds to 21.6724 seconds due to the active sensor take the connection to transmit data and wait reply from dedicated servers. Total average PDR is decreased from (99.9122) % to (98.9648) % due to decreased number of arrived packets because of increased number of sensors. Total average goodput (pkts/sec) is decreased from (3.5118) to (1.9946) packets in seconds in state of increased number of sensors.




| | 7 IoT Sensors | 13 IoT Sensors | 23 IoT Sensors |
|---|---|---|---|
| Total Avg Throughput / Bps | 168.16833 | 82.238 | 35.8771 |
| Total Avg Delay (s) | 73.0034 | 42.1706 | 21.6724 |
| Total Avg PDR (%) | 99.9122 | 99.044 | 98.9648 |
| Total Avg Goodput (pkts/sec) | 3.5118 | 2.6585 | 1.9946 |

*Figure 4.6: The comparison of the OBSFR route case study.*

### 4.3.4 The 4th Scenario of HDRP Routing Protocol

The proposed 4th adaptive case study based on Hybrid Delay-based Routing Protocol (HDRP) that works as an adaptive forwarding routing strategy for broadcast packets from IoT sensor nodes to the sink node and vice versa. The hybrid approach enhanced the better delayed protocol OBSFR in case of routing overhead and required time, prevents wasting network capacity due to repeated IoT sensors which solved by depending on likelihood strategy from another delayed protocol as PRPLC by using the same required minimum delayed for the same type of IoT sensors for example ECG sensors in case of 7 IoT sensors was two ECG sensors and the selecting minimum delayed for the incoming packet route (by request).

The proposed hybrid will select the best delayed based on the combined PRPLC and OBSFR protocol at the same time. So, the used hybrid approach integrated both protocols mixed in the same system. Figure 4.7 showed the case study topology of 7 IoT sensors node.

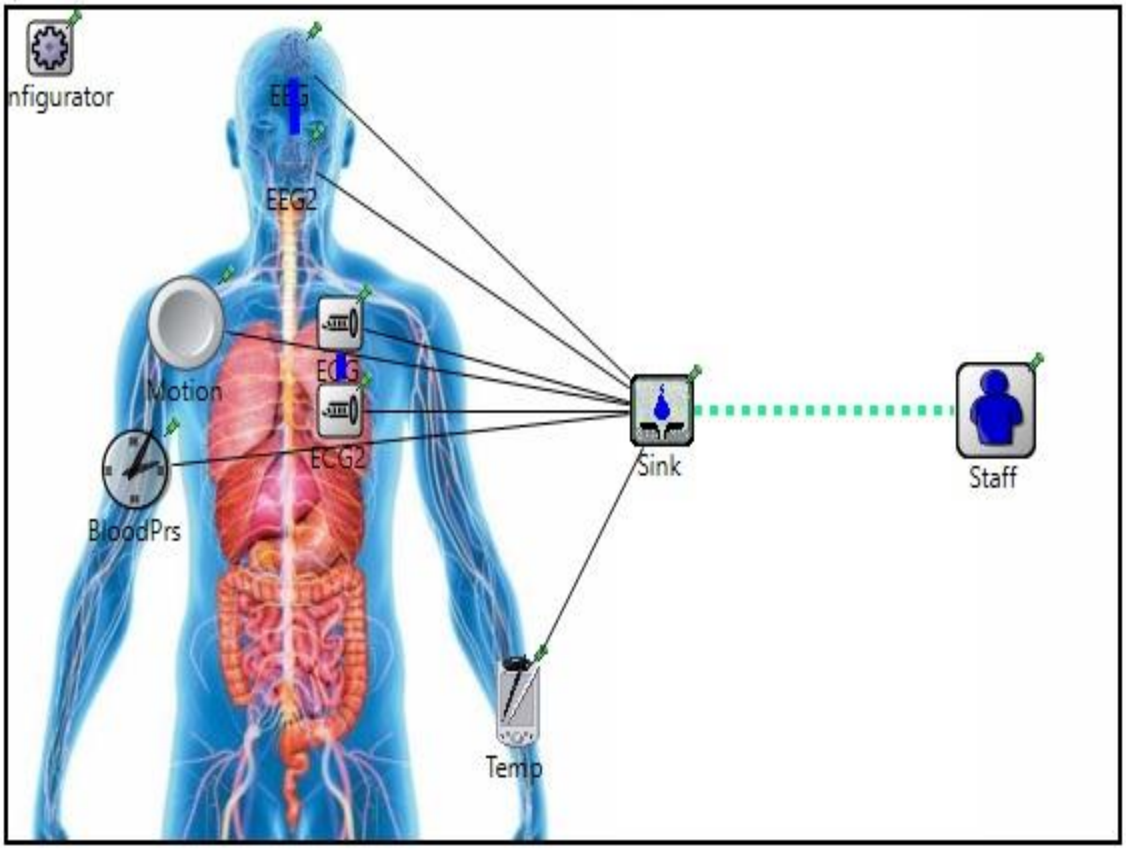



*Figure 4.7: the case study of 7 IoT sensor topology of HDRP routing protocol.*

Table 4.12 showed the evaluation metrics of the proposed HDRP routing system based on 7 IoT sensor nodes. The results of Hybrid routing approach showed enhancement compared with PRPLC and OBSFR due to the technique of this protocol to deal with minimum delay used as the best path route of the likelihood IoT sensor identifier , so the packet delivery ratio (PDR)(%) of OBSFR route packet delivery with 7 IoT sensors as (899.31 %). Total sum of goodput is (36.8738) packets in seconds. End to end packet delay sensor-to-sink is (629760.528) ms, and sink-to-staff is (552894.936) ms.

*Table 4.12: The HDRP route packet delivery with 7 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To-Staff | | |
| ECG sensor | 120.1725 | 120.141 | 43539.98 | 48907.6 | 99.96 | 2.7593 |
| ECG 2 sensor | 117.831 | 117.043 | 42532.01 | 40225.07 | 99.87 | 2.7518 |
| EEG sensor | 118.9335 | 115.164 | 42540.08 | 46563.34 | 99.90 | 2.7071 |
| EEG 2 sensor | 119.1225 | 117.862 | 41627.73 | 40765.74 | 99.90 | 2.8313 |
| Motion sensor | 17.1465 | 17.136 | 6081.768 | 6715.287 | 100 | 2.8176 |
| Blood pressure sensor | 119.2485 | 117.39 | 10877.34 | 4656.519 | 99.92 | 10.7921 |
| Temperature sensor | 119.364 | 116.518 | 12845.77 | 46563.59 | 99.86 | 9.0705 |
| Sink (Avg) | 176.967 | 176.295 | 43554.75 | 39876.49 | 100 | 2.1130 |
| Staff-server | 686.5845 | 685.461 | 386161.1 | 278621.3 | 99.90 | 1.0311 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.8 showed the 13 IoT sensor nodes of HDRP routing protocol.

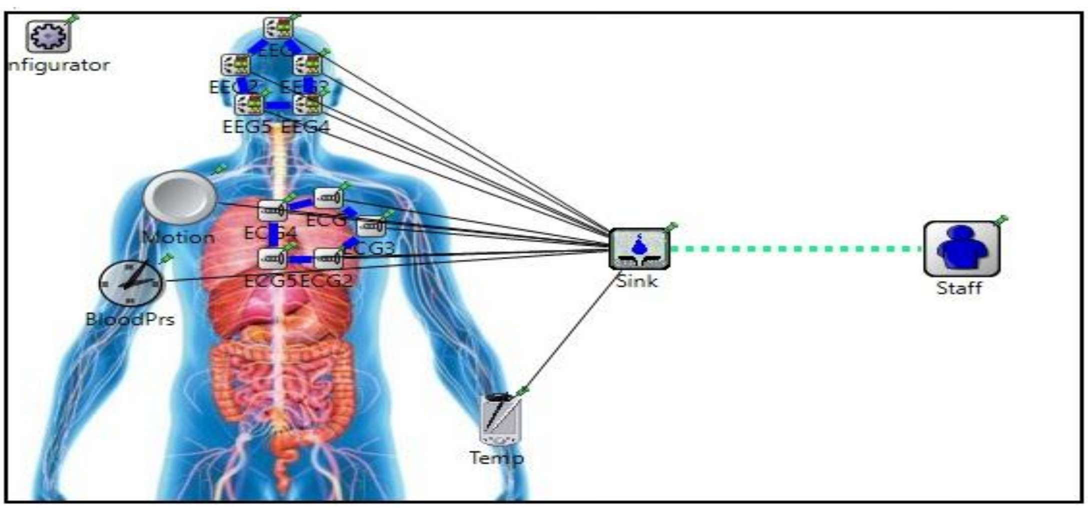



*Figure 4.8: the case study of 7 IoT sensor topology of HDRP routing protocol.*

Table 4.13 showed the evaluation metrics of the proposed adaptive Hybrid routing protocol system based on 13 sensor nodes. In addition the results affected with increasing number of IoT sensor nodes.

The Hybrid (HDRP) route packet delivery with 13 IoT sensors is (1486.5114 %), and goodput is (46.3018) packets in sec. Besides, end to end packet delay sensor-to-sink is (565669.25) ms, while it is (547635.65) ms from sink-to-staff. In addition, Throughput sent is (1325.689) frames in seconds, besides received is (1232.39) Frames/sec.

*Table 4.13: The HDRP route packet delivery with 13 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To- Sink | Sink-To-Staff | | |
| ECG sensor | 56.8796 | 53.64 | 14973.31 | 14823.57 | 99.99996 | 3.5823 |
| ECG 2 sensor | 54.4416 | 51.38 | 14673.84 | 14527.1 | 99.09942 | 3.5014 |
| ECG 3 sensor | 56.6358 | 53.41 | 14524.11 | 14378.87 | 99.35958 | 3.6773 |
| ECG 4 sensor | 56.2754 | 53.08 | 15272.78 | 14967.31 | 99.61974 | 3.4754 |
| ECG 5 sensor | 63.3138 | 59.59 | 15572.24 | 15260.79 | 99.97995 | 3.8266 |
| EEG sensor | 48.7706 | 46.17 | 15123.05 | 14669.34 | 98.06881 | 3.0529 |
| EEG 2 sensor | 50.8694 | 48.08 | 14524.11 | 14088.39 | 99.15946 | 3.3103 |
| EEG 3 sensor | 45.368 | 43 | 13475.98 | 13071.7 | 98.07881 | 3.1908 |
| EEG 4 sensor | 50.668 | 47.9 | 14374.38 | 13943.14 | 98.75922 | 3.3323 |
| EEG 5 sensor | 56.922 | 52.59 | 15871.72 | 14919.41 | 98.25892 | 3.3134 |
| Motion sensor | 43.301 | 41.09 | 13341.22 | 12540.75 | 98.95934 | 3.0799 |
| Blood pressure sensor | 69.8434 | 64.54 | 16506.57 | 15186.05 | 98.63915 | 3.9099 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Temperature sensor | 28.8532 | 25.56 | 11073.21 | 10187.36 | 98.54909 | 2.3082 |
| Sink (Avg) | 77.751 | 69.64 | 17662.03 | 17132.17 | 99.97995 | 2.0014 |
| Staff-server | 565.7962 | 522.72 | 358700.7 | 347939.7 | 100 | 0.7397 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.9 showed the case of 23 IoT sensor node of HDRP routing protocol case study and it explained the ring connection among sensors and making likelihood among neighbor nodes to redirect packet to the sink. This model can provide flexibility in route determination due to the behavior used by the hybrid approach as it based on the benefits from the PRPLC and OBSFR routing protocol.

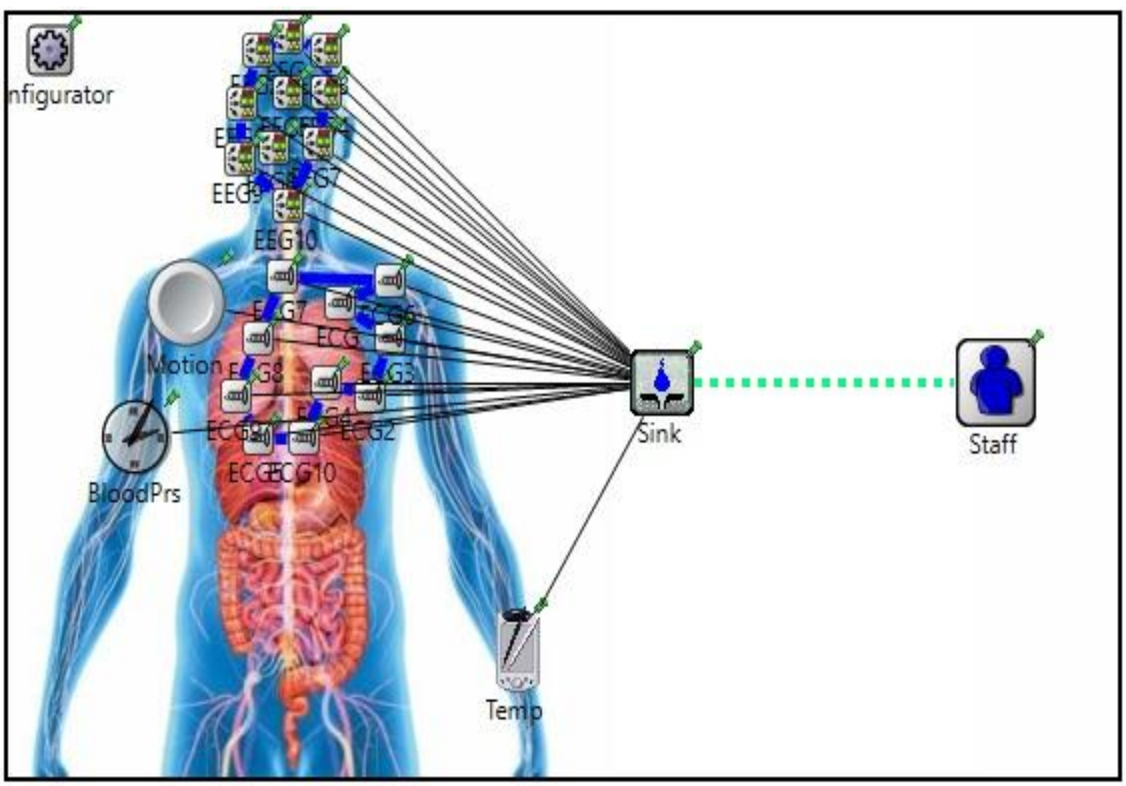



*Figure 4.9: the case study of 7 IoT sensor topology of HDRP routing protocol.*

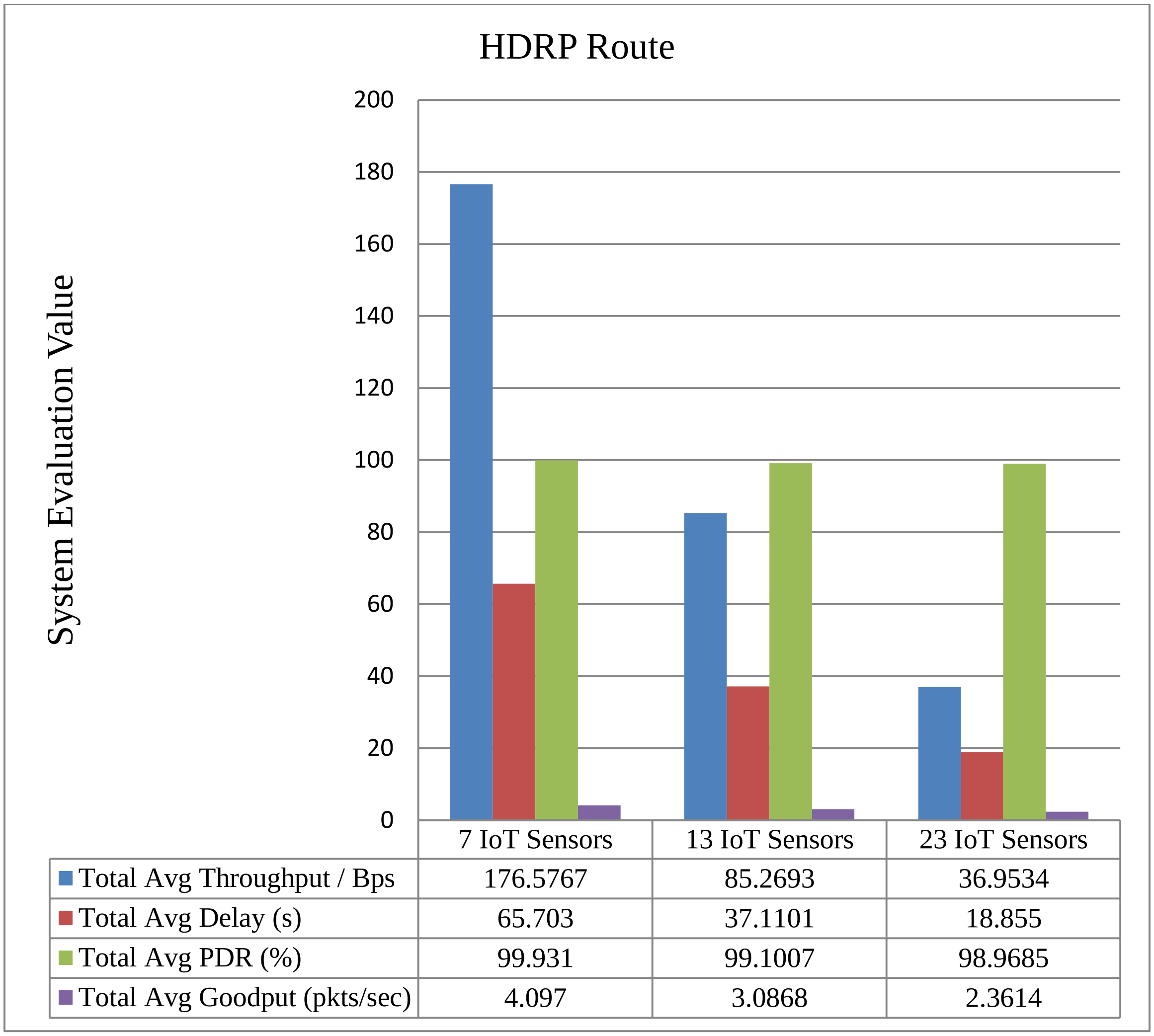
Table 4.14 is showed the main goal of the HDRP route delivery system based on the maximum number of nodes as 23 IoT sensors. In addition, the hybrid route packet delivery with 23 IoT sensors the total sum packet delivery ratio is (2474.195 %), total sum of throughput sent is (949.39838) frames/sec and received is (898.2733) frames/sec, while total sum of goodput is (59.0359) packets in seconds.

*Table 4.14: The HDRP route packet delivery with 23 IoT sensors.*

| Network Elements | Throughput / Bps | | End to End Packet Delay (ms) | | Packet Delivery Ratio (%) | Goodput pkts/sec |
|---|---|---|---|---|---|---|
| | Frames/sec Sent | Frames/sec Received | Sensor-To-Sink | Sink-To- Staff | | |
| ECG sensor | 28.7267 | 28.428 | 10066.14 | 9965.476 | 99.749 | 2.8241 |
| ECG 2 sensor | 27.501 | 27.2229 | 9864.817 | 9766.168 | 99.839 | 2.7595 |
| ECG 3 sensor | 28.6134 | 28.0366 | 9764.158 | 9568.869 | 98.689 | 2.8713 |
| ECG 4 sensor | 28.4177 | 27.8512 | 10267.46 | 10062.11 | 98.539 | 2.7125 |
| ECG 5 sensor | 31.9815 | 31.0133 | 10468.79 | 10154.73 | 98.309 | 2.9624 |
| ECG 6 sensor | 24.6376 | 23.896 | 10166.8 | 9861.798 | 98.789 | 2.3503 |
| ECG 7 sensor | 25.6985 | 24.9157 | 11295.36 | 10956.5 | 98.499 | 2.2058 |
| ECG 8 sensor | 22.9175 | 22.0008 | 9059.536 | 8787.748 | 98.799 | 2.4284 |
| ECG 9 sensor | 25.5955 | 24.5552 | 10429.1 | 9907.638 | 98.809 | 2.3544 |
| ECG 10 sensor | 28.7576 | 27.3053 | 10670.12 | 10136.6 | 98.529 | 2.5590 |
| EEG sensor | 21.8669 | 20.7648 | 8968.934 | 10136.6 | 98.969 | 2.3151 |
| EEG 2 sensor | 35.2775 | 32.7952 | 11096.92 | 10542.06 | 98.869 | 2.9553 |
| EEG 3 sensor | 14.5642 | 13.5445 | 7444.216 | 7072.004 | 98.499 | 1.8194 |
| EEG 4 sensor | 28.7267 | 26.7079 | 10066.14 | 9059.528 | 99.559 | 2.6532 |
| EEG 5 sensor | 27.501 | 25.2968 | 9864.817 | 8878.341 | 98.319 | 2.5643 |
| EEG 6 sensor | 28.6134 | 25.75 | 9764.158 | 8787.74 | 98.579 | 2.6371 |
| EEG 7 sensor | 28.9739 | 26.059 | 10267.46 | 9240.714 | 98.439 | 2.5380 |
| EEG 8 sensor | 29.5198 | 26.574 | 10468.79 | 9421.909 | 99.319 | 2.5384 |

| | | | | | | |
|---|---|---|---|---|---|---|
| EEG 9 sensor | 22.7424 | 20.4661 | 10166.8 | 9150.121 | 98.619 | 2.0130 |
| EEG 10 sensor | 23.7209 | 21.3416 | 9764.158 | 8787.74 | 99.809 | 2.1857 |
| Motion sensor | 21.1459 | 19.0241 | 9059.536 | 8153.57 | 99.849 | 2.0998 |
| Blood pressure sensor | 23.6282 | 21.2592 | 9663.499 | 8697.146 | 99.749 | 2.1999 |
| Temperature sensor | 26.5328 | 23.8754 | 10670.12 | 9603.104 | 99.839 | 2.2375 |
| Sink | 41.37098 | 39.3254 | 12639.29 | 11375.35 | 98.689 | 1.6375 |
| Staff-server | 302.3668 | 290.2643 | 248800.7 | 223920.6 | 98.539 | 0.6140 |
| Packet Size | 1024 Byte | | | | | |

Figure 4.10 showed the system comparisons among three states of the HDRP routing system. It showed the maximum total average throughput is 176.5767 Bps of 7 IoT sensor node case study due to the increased number of generated read healthcare packets from IoT sensor nodes with less delay from these sensors. Minimum total average delay is 18.855 seconds of 23 IoT sensor nodes due to the required time of each node to transmit data packets is decreased so the total average will be also decrease. Maximum total average goodput is 4.097 pkts/sec of 7 IoT sensor node case study due to the decreased number of successful data read packets from sensors to the final destination staff in case of number of sensor increased. The proposed Hybrid routing protocol enhanced delay to build route among sensor route to the final destination and with decreased delay it enhanced throughput, packet delivery ratio, and goodput, so it improved modeling network performance by increasing number of successful data packets generated from IoT healthcare sensors to the staff server.




| | 7 IoT Sensors | 13 IoT Sensors | 23 IoT Sensors |
|---|---|---|---|
| Total Avg Throughput / Bps | 176.5767 | 85.2693 | 36.9534 |
| Total Avg Delay (s) | 65.703 | 37.1101 | 18.855 |
| Total Avg PDR (%) | 99.931 | 99.1007 | 98.9685 |
| Total Avg Goodput (pkts/sec) | 4.097 | 3.0868 | 2.3614 |

*Figure 4.10: The comparison of the HDRP route case study.*

## 4.4 System Comparisons

The comparisons of the used case studies in Table 4.15 which showed the total throughput of transmit and received data increased in hybrid approach due to the increased number of packets send and received without errors and the delay time is decreased by recognize shared node healthcare application type, node details in the network to build route table and eliminate repeated route in the routing table pool which effects on the routing packets process in the network overall and specially the sink device.

*Table 4.15: The proposed system comparison.*

| Routing Protocol | Evaluation metrics | Number of IoT sensor nodes in WBAN | | | |
|---|---|---|---|---|---|
| | | TotlAvg Throughput / Bps | TotlAvg Delay (s) | TotlAvg PDR (%) | TotlAvgGoodput (pkts/sec) |
| Fixed Route | 7 IoT sensors | 153.828 | 165.7811 | 99.3544 | 2.7932 |
| | 13 IoT sensors | 75.4513 | 47.9211 | 98.4253 | 2.4611 |
| | 23 IoT sensors | 32.9196 | 24.6278 | 97.9028 | 1.6107 |
| PRPLC | 7 IoT sensors | 159.7544 | 75.1935 | 99.7123 | 3.2389 |
| | 13 IoT sensors | 78.1261 | 43.4357 | 98.7468 | 2.462 |
| | 23 IoT sensors | 34.0832 | 22.3226 | 97.9593 | 1.8397 |
| OBSFR | 7 IoT sensors | 168.16833 | 73.0034 | 99.9122 | 3.5118 |
| | 13 IoT sensors | 82.238 | 42.1706 | 99.044 | 2.6585 |
| | 23 IoT sensors | 35.8771 | 21.6724 | 98.9648 | 1.9946 |
| HDRP | 7 IoT sensors | 176.5767 | 65.703 | 99.931 | 4.097 |
| | 13 IoT sensors | 85.2693 | 37.1101 | 99.1007 | 3.0868 |
| | 23 IoT sensors | 36.9534 | 18.855 | 98.9685 | 2.3614 |

In addition, the proposed system has been compared with other related works concerned with route delivery packets in different types of Internet of things devices that measure different health parameters of WBAN environment. It showed the enhancement simulated results of hybrid routing approach. Table 4.16 showed the better performance of proposed system with the used evaluated parameters.

*Table 4.16 :The results of proposed system with the compared systems.*

| Ref.No | Year | Environment | Routing Protocol Techniques | PDR | goodput |
|---|---|---|---|---|---|
| [14] | 2020 | OMNET ++ | Destination-sequenced distance vector (DSDV) | 29 % | / |
| | | | Ad Hoc On-Demand Distance Vector (AODV) | 58.7% | / |
| | | | Greedy Perimeter Stateless Routing (GPSR) | 95 % | / |
| | | | Hybrid Dynamic Manet On Demand Routing Protocol (DYMO) | 99.8 % | / |
| [17] | 2022 | NS2 | Destination-sequenced distance vector (DSDV) | 81.13% | 1.28 |
| | | | Ad Hoc On-Demand Distance Vector (AODV) | 86.41% | 1.56 |
| | | | Ad Hoc On-demand Multipath Distance Vector Routing protocol (AOMDV) | 84.46% | 1.58 |
| [20] | 2022 | MATLAB | Cooperative Routing Protocol (CRP) | 84.46% | / |
| Proposed- system Min-PDR Min-goodput | | OMNET ++ | PRPLC Routing Protocol | 97.95 % | 1.8397 |
| | | | OBSFR Routing Protocol | 98.96 % | 1.9946 |
| | | | HDRP Routing Protocol | 98.96 % | 2.361 |
| Proposed- system Max-PDR Max- goodput | | OMNET ++ | PRPLC Routing Protocol | 99.71 % | 3.2389 |
| | | | OBSFR Routing Protocol | 99.91 % | 3.5118 |
| | | | HDRP Routing Protocol | 99.93 % | 4.097 |

## 4.5 Summary

The performance analysis for packet delivery is carried out in a simulation environment for the WBAN. Results are produced in the simulation for both static and dynamic routing strategies using Probabilistic routing with postural link costs (PRPLC), On Body Store and Flood Routing (OBSFR), and Hybrid Delay-based Routing Protocol (HDRP). These techniques are used. The simulation is run for three different states, each with a different total number of Internet of Things (IoT) sensor nodes (7, 13, or 23 IoT sensors), and each of these states is evaluated using the primary metrics of throughput, end-to-end delay, packet delivery ratio, and goodput. After doing research on the relationship between packet rate and throughput, the researchers came to the conclusion that increasing the packet rate to greater levels would result in an increase in the network's overall throughput. It has been shown that the improvement in the transmission rate that is caused by an increase in the number of node has only a negligible influence on the delay. The proposed Hybrid Delay-based Routing Protocol (HDRP) gives a greater throughput, lower latency, a higher packet delivery ratio, and goodput.

# Chapter Five

## Conclusions and Suggestions for Future Works

## 5.1 Conclusions

This chapter explains the proposed system conclusions and the main suggestions for future works they can be summarized as:

1- The proposed system is Delay-based Routing Protocol in WBAN, and the used routing protocols are :

   A- Hybrid Delay-based Routing Protocol (HDRP) routing

   B- Probabilistic routing with postural link costs (PRPLC)

   C- On Body Store and Flood Routing (OBSFR).

2- The Hybrid routing protocol is implemented efficiently to manage the routing delay to redirect IoT sensor reads to the final destination as staff server.

3- Throughput, end-to-end delay, PDR, and goodput are evaluated by simulation for (7,13, and 23 IoT sensors) respectively, and the results of the Hybrid routing protocol showed that the throughput is increased, end to end delay is decreased, and goodput is increased.

4- The increase in the packet rate due to the increased number of nodes has a marginal effect on delay. The proposed Hybrid Delay-based Routing Protocol (HDRP) technique gives higher throughput, less delay, high packet delivery ratio, and goodput.

5- The results showed that the Max Packet Delivery Ratio (PDR) for PRPLC Routing Protocol was 99.71 %, for OBSFR it was 99.91 %, and for HDRP it was 99.93 %, while the Max goodput was 3.2389 packets per second (pkts/sec) for PRPLC, 3.5118 (pkts/sec)for OBSFR, and 4.097 (pkts/sec) for HDRP.

6- The total average PRPLC Delay of 23 IoT sensors is 22.3226 sec, OBSFR is 21.6724 sec, and HDRP is 18.855 sec of the 23 IoT sensors.

## 5.2 Suggestions for Future Works

There are numerous considerations can be realized for future expansion of present research through utilizing the following propositions:

1- Sink mobility will be added, and tested for all routing protocol variants. Additionally, the movement patterns for individual IoT sensor nodes in clusters.

2- Building a model to decrease the power consumption of the sensing ecosystem. However, optimizing the transformation of collected data with lightweight power consumption method.

3- Developing a classification model with machine learning to classify communication anomalies and increase its trustworthiness.

4- Protecting the confidentiality of patients' vital statistics, extending the useful life of networks, and evaluating their performance via actual deployment of a test bed(real-world implementation).

5- Improving network speed by only allowing approved IoT devices to participate in secure transactions by increasing the degree of security to identify and reconfigure authorized nodes.

6- Developing cluster-based routing protocols, therefore, a more comprehensive, intelligent, and energy-efficient cluster-based protocol is required for inter-cluster routing.

# REFERENCES


[1] Abidi, B., Jilbab, A., & Mohamed, E. H. (2020). Wireless body area networks: a comprehensive survey. *Journal of Medical Engineering & Technology*, *44*(3), 97-107.

[2] Haddad, O., Khalighi, M. A., Zvanovec, S., & Adel, M. (2020). Channel characterization and modeling for optical wireless body-area networks. *IEEE Open Journal of the Communications Society*, *1*, 760-776.

[3] Mehmood, G., Khan, M. Z., Waheed, A., Zareei, M., & Mohamed, E. M. (2020). A trust-based energy-efficient and reliable communication scheme (trust-based ERCS) for remote patient monitoring in wireless body area networks. *IEEE Access*, *8*, 131397-131413.

[4] Al-Sabti, S. M. B., Abdulateef, A. A., Atilla, C., & Mohammed, A. H. (2020, October). Wireless body region networks abnormality identification and energy saving a study. In *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)* (pp. 1-5). IEEE.

[5] Tavera, C. A., Ortiz, J. H., Khalaf, O. I., Saavedra, D. F., & Aldhyani, T. H. (2021). Wearable wireless body area networks for medical applications. *Computational and Mathematical Methods in Medicine*, *2021*.

[6] Taleb, H., Nasser, A., Andrieux, G., Charara, N., & Motta Cruz, E. (2021). Wireless technologies, medical applications and future challenges in WBAN: a survey. *Wireless Networks*, *27*(8), 5271-5295.

[7] Liu, Q., Mkongwa, K. G., & Zhang, C. (2021). Performance issues in wireless body area networks for the healthcare application: A survey and future prospects. *SN Applied Sciences*, *3*(2), 1-19.

[8] Shawqi Jaber, A., & Kadhum Idrees, A. (2020). Adaptive rate energy-saving data collecting technique for health monitoring in wireless body sensor networks. *International Journal of Communication Systems*, *33*(17), e4589.

[9] Mehdi, H., Zarrabi, H., Zadeh, A. K., & Rahmani, A. (2020). Self-Adaptive sampling rate to improve network lifetime using watchdog sensor and context

recognition in wireless body sensor networks. *Majlesi Journal of Electrical Engineering*, *14*(3), 11-22.

[10] Bilandi, N., Verma, H. K., & Dhir, R. (2020). Performance and evaluation of energy optimization techniques for wireless body area networks. *Beni-Suef University Journal of Basic and Applied Sciences*, *9*(1), 1-11.

[11] Ibrahim, A. A., Bayat, O., Ucan, O. N., & Salisu, S. (2020, February). Weighted energy and QoS based multi-hop transmission routing algorithm for WBAN. In *2020 6th International Engineering Conference "Sustainable Technology and Development"(IEC)* (pp. 191-195). IEEE.

[12] Thirumoorthy, P., Kalyanasundaram, P., Maheswar, R., Jayarajan, P., Kanagachidambaresan, G. R., & Amiri, I. S. (2020). Time-critical energy minimization protocol using PQM (TCEM-PQM) for wireless body sensor network. *The Journal of Supercomputing*, *76*(8), 5862-5872.

[13] Alzahrani, A. S., & Almotairi, K. (2019, May). Performance comparison of WBAN routing protocols. In *2019 2nd International Conference on Computer Applications & Information Security (ICCAIS)* (pp. 1-5). IEEE.

[14] Khan, M. D., Ullah, Z., Ahmad, A., Hayat, B., Almogren, A., Kim, K. H., Ali, M. (2020). Energy harvested and cooperative enabled efficient routing protocol (EHCRP) for IoT-WBAN. *Sensors*, *20*(21), 6267.

[15] Santhanamari, G., Premi, J., Rahavi, S., & Vijay, S. (2020, December). Health Monitoring of Soldiers Using Efficient Manet Protocol. In *2020 IEEE Recent Advances in Intelligent Computational Systems (RAICS)* (pp. 57-62). IEEE.

[16] Kaba, A., Sahuguede, S., & Julien-Vergonjanne, A. (2021). Channel Modeling of an Optical Wireless Body Sensor Network for Walk Monitoring of Elderly. *Sensors*, *21*(9), 2904.

[17] Oleiwi, S. S., Mohammed, G. N., & Al_barazanchi, I. (2022). Mitigation of packet loss with end-to-end delay in wireless body area network applications. *International Journal of Electrical and Computer Engineering*, *12*(1), 460.

[18] Singh, S., Prasad, D., Rani, S., Singh, A., Alharithi, F. S., & Almotiri, J. (2022). Wireless Body Area Routing Protocols Impact Analysis on Entity Mobility Models with Static Sink Node. *Applied Sciences*, *12*(11), 5655

[19] Almalki, F. A., Ben Othman, S., A Almalki, F., & Sakli, H. (2021). EERP-DPM: energy efficient routing protocol using dual prediction model for healthcare using IoT. *Journal of Healthcare Engineering*, *2021*.

[20] Liu, Q., Mkongwa, K. G., Zhang, C., & Wang, S. (2021). A simple cross-layer mechanism for congestion control and performance enhancement in a localized multiple wireless body area networks. *Journal of Ambient Intelligence and Humanized Computing*, 1-18.

[21] Oleiwi, S. S., Mohammed, G. N., & Al_barazanchi, I. (2022). Mitigation of packet loss with end-to-end delay in wireless body area network applications. *International Journal of Electrical and Computer Engineering*, *12*(1), 460.

[22] Ahmad, N., Shahzad, B., Arif, M., Izdrui, D., Ungurean, I., & Geman, O. (2022). An Energy-Efficient Framework for WBAN in Health Care Domain. *Journal of Sensors*, *2022*.

[23] Taha, M. S., Rahim, M. S. M., Hashim, M. M., & Johi, F. A. (2018). Wireless body area network revisited. *International Journal of Engineering & Technology*, *7*(4), 3494-3504.

[24] Le, T. T. T., & Moh, S. (2018). Hybrid multi-channel MAC protocol for WBANs with inter-WBAN interference mitigation. *Sensors*, *18*(5), 1373.

[25] Mu, J., Stewart, R., Han, L., & Crawford, D. (2018). A self-organized dynamic clustering method and its multiple access mechanism for multiple WBANs. *IEEE Internet of Things Journal*, *6*(4), 6042-6051.

[26] Yuan, X., Li, C., Ye, Q., Zhang, K., Cheng, N., Zhang, N., & Shen, X. (2018). Performance analysis of IEEE 802.15. 6-based coexisting mobile WBANs with prioritized traffic and dynamic interference. *IEEE Transactions on Wireless Communications*, *17*(8), 5637-5652.

[27] Kim, S. (2021). A New Two-Stage Bargaining Game Approach for Intra-and Inter-WBAN Management. *Mobile Information Systems*, *2021*.

[28] Shen, J., Chang, S., Shen, J., Liu, Q., & Sun, X. (2018). A lightweight multi-layer authentication protocol for wireless body area networks. *Future generation computer systems*, *78*, 956-963.

[29] Saboor, A., Ahmad, R., Ahmed, W., Kiani, A. K., Le Moullec, Y., & Alam, M. M. (2018). On research challenges in hybrid medium-access control protocols for IEEE 802.15. 6 WBANs. *IEEE Sensors Journal*, *19*(19), 8543-8555.

[30] Hammood, D. A., Rahim, H. A., Ahmad, R. B., Alkhayyat, A., Salleh, M. E. M., Abdulmalek, M., ... & Abbasi, Q. H. (2018). Enhancement of the duty cycle cooperative medium access control for wireless body area networks. *IEEE Access*, *7*, 3348-3359.

[31] de Jesus Oliveira, S. R., & Soares, A. B. (2018). A new priority-based dynamic protocol for multiple access control improves data transfer rates in WBANs. *Biomedical Signal Processing and Control*, *41*, 100-108.

[32] Bouani, A., Maissa, Y. B., Saadane, R., Hammouch, A., & Tamtaoui, A. (2021). A comprehensive survey of medium access control protocols for wireless body area networks. *Wireless Communications and Mobile Computing*, *2021*.

[33] Zia, Y., Bashir, F., & Qureshi, K. N. (2020). Dynamic superframe adaptation using group-based media access control for handling traffic heterogeneity in wireless body area networks. *International Journal of Distributed Sensor Networks*, *16*(8), 1550147720949140.

[34] Chen, C. M., Xiang, B., Wu, T. Y., & Wang, K. H. (2018). An anonymous mutual authenticated key agreement scheme for wearable sensors in wireless body area networks. *Applied Sciences*, *8*(7), 1074.

[35] Yessad, N., Omar, M., Tari, A., & Bouabdallah, A. (2018). QoS-based routing in Wireless Body Area Networks: A survey and taxonomy. *Computing*, *100*(3), 245-275.

[36] Yan, S., Soh, P. J., & Vandenbosch, G. A. (2018). Wearable ultrawideband technology—A review of ultrawideband antennas, propagation channels, and applications in wireless body area networks. *Ieee Access*, *6*, 42177-42185.

[37] Hasan, K., Biswas, K., Ahmed, K., Nafi, N. S., & Islam, M. S. (2019). A comprehensive review of wireless body area network. *Journal of Network and Computer Applications*, *143*, 178-198.

[38] Liu, Q., Mkongwa, K. G., & Zhang, C. (2021). Performance issues in wireless body area networks for the healthcare application: a survey and future prospects. *SN Applied Sciences*, *3*(2), 1-19.

[39] Wang, S., Yin, Z., Li, Z., & He, T. (2018, September). Networking support for physical-layer cross-technology communication. In *2018 IEEE 26th International Conference on Network Protocols (ICNP)* (pp. 259-269). IEEE.

[40] Takabayashi, K., Tanaka, H., & Sakakibara, K. (2018). Integrated performance evaluation of the smart body area networks physical layer for future medical and healthcare IoT. *Sensors*, *19*(1), 30.

[41] Takabayashi, K., Tanaka, H., & Sakakibara, K. (2018). Integrated performance evaluation of the smart body area networks physical layer for future medical and healthcare IoT. *Sensors*, *19*(1), 30.

[42] Basir, A., Bouazizi, A., Zada, M., Iqbal, A., Ullah, S., & Naeem, U. (2018). A dual-band implantable antenna with wide-band characteristics at MICS and ISM bands. *Microwave and Optical Technology Letters*, *60*(12), 2944-2949.

[43] Garcia-Pardo, C., Andreu, C., Fornes-Leal, A., Castelló-Palacios, S., Perez-Simbor, S., Barbi, M., ... & Cardona, N. (2018). Ultrawideband technology for medical in-body sensor networks: An overview of the human body as a propagation medium, phantoms, and approaches for propagation analysis. *IEEE Antennas and Propagation Magazine*, *60*(3), 19-33.

[44] Mu, J., Liu, X., & Yi, X. (2019). Simplified energy-balanced alternative-aware routing algorithm for wireless body area networks. *IEEE Access*, *7*, 108295-108303.

[45] Rabby, M. K. M., Alam, M. S., & Shawkat, M. S. A. (2019). A priority based energy harvesting scheme for charging embedded sensor nodes in wireless body area networks. *PloS one*, *14*(4), e0214716.

[46] Asam, M., Jamal, T., Adeel, M., Hassan, A., Butt, S. A., Ajaz, A., & Gulzar, M. (2019). Challenges in wireless body area network. *International Journal of Advanced Computer Science and Applications*, *10*(11).

[47] Rismanian Yazdi, F., Hosseinzadeh, M., & Jabbehdari, S. (2019). A priority-based MAC protocol for energy consumption and delay guaranteed in wireless body area networks. *Wireless Personal Communications*, *108*(3), 1677-1696.

[48] Yuan, D., Zheng, G., Ma, H., Shang, J., & Li, J. (2019). An adaptive MAC protocol based on IEEE802. 15.6 for wireless body area networks. *Wireless Communications and Mobile Computing*, *2019*.

[49] Mu, J., Yi, X., Liu, X., & Han, L. (2019). An efficient and reliable directed diffusion routing protocol in wireless body area networks. *IEEE Access*, *7*, 58883-58892.

[50] Qu, Y., Zheng, G., Wu, H., Ji, B., & Ma, H. (2019). An energy-efficient routing protocol for reliable data transmission in wireless body area networks. *Sensors*, *19*(19), 4238.

[51] Nahali, A., Hamdi, A., Gautier, M., Courtay, A., & Braham, R. (2019, June). Energy modeling of wireless body area networks with on-body communication channel characterization. In *2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC)* (pp. 220-225). IEEE.

[52] Ren, Y., Leng, Y., Zhu, F., Wang, J., & Kim, H. J. (2019). Data storage mechanism based on blockchain with privacy protection in wireless body area network. *Sensors*, *19*(10), 2395.

[53] Yuan, D., Zheng, G., Ma, H., Shang, J., & Li, J. (2019). An adaptive MAC protocol based on IEEE802. 15.6 for wireless body area networks. *Wireless Communications and Mobile Computing*, *2019*.

[54] Cicioğlu, M., & Çalhan, A. (2019). SDN-based wireless body area network routing algorithm for healthcare architecture. *Etri Journal*, *41*(4), 452-464.

[55] Asam, Muhammad, Tauseef Jamal, Muhammad Adeel, Areeb Hassan, Shariq Aziz Butt, Aleena Ajaz, and Maryam Gulzar. "Challenges in wireless body area network." *International Journal of Advanced Computer Science and Applications* 10, no. 11 (2019).

[56] Haider, Z., Jamal, T., Asam, M., Butt, S., & Ajaz, A. (2020). Mitigation of wireless body area networks challenges using cooperation. *International Journal of Security and Its Applications*, *14*(1), 15-30.

[57] Mehmood, G., Khan, M. Z., Abbas, S., Faisal, M., & Rahman, H. U. (2020). An energy-efficient and cooperative fault-tolerant communication approach for wireless body area network. *IEEE Access*, *8*, 69134-69147.

[58] Mehmood, G., Khan, M. Z., Waheed, A., Zareei, M., & Mohamed, E. M. (2020). A trust-based energy-efficient and reliable communication scheme (trust-based ERCS) for remote patient monitoring in wireless body area networks. *IEEE Access*, *8*, 131397-131413.

[59] Raj, A. S., & Chinnadurai, M. (2020). Energy efficient routing algorithm in wireless body area networks for smart wearable patches. *Computer Communications*, *153*, 85-94.

[60] Ben Ammar, M., Ben Dhaou, I., El Houssaini, D., Sahnoun, S., Fakhfakh, A., & Kanoun, O. (2022). Requirements for Energy-Harvesting-Driven Edge Devices Using Task-Offloading Approaches. *Electronics*, *11*(3), 383.

[61] Dhinakaran, M., Phasinam, K., Alanya-Beltran, J., Srivastava, K., Babu, D. V., & Singh, S. K. (2022). A System of Remote Patients' Monitoring and Alerting Using the Machine Learning Technique. *Journal of Food Quality*, *2022*.

[62] Iqbal, J., Adnan, M., Khan, Y., AlSalman, H., Hussain, S., Ullah, S. S., & Gumaei, A. (2022). Designing a healthcare-enabled software-defined wireless body area network architecture for secure medical data and efficient diagnosis. *Journal of Healthcare Engineering*, *2022*.

[63] Bhatti, D. M. S., Khalil, R. A., Saeed, N., & Nam, H. (2022). Detection and Spatial Correlation Analysis of Infectious Diseases Using Wireless Body Area Network under Imperfect Wireless Channel. *Big Data*, *10*(1), 54-64.

[64] Khatami, N., & Majidi, M. (2021). Resource Allocation for Full-Duplex Wireless Information and Power Transfer in Wireless Body Area Network. *Journal of Electrical and Computer Engineering Innovations (JECEI)*, *10*(2), 329-340.

[65] Zenieh, C., Al-Mahairi, M. M., & Haddad, M. (2022). A High-Throughput Random Binary Sequence Generator Based on ECG. *IEEE Access*, *10*, 67117-67127.

[66] Hussain, S., Ullah, S. S., Uddin, M., Iqbal, J., & Chen, C. L. (2022). A comprehensive survey on signcryption security mechanisms in wireless body area networks. *Sensors*, *22*(3), 1072.

[67] Kanwal, Samira, Junaid Rashid, Jungeun Kim, Sapna Juneja, Gaurav Dhiman, and Amir Hussain. "Mitigating the coexistence technique in wireless body area networks by using superframe interleaving." *IETE Journal of Research* (2022): 1-15.

[68] Zhong, L., He, S., Lin, J., Wu, J., Li, X., Pang, Y., & Li, Z. (2022). Technological Requirements and Challenges in Wireless Body Area Networks for Health Monitoring: A Comprehensive Survey. *Sensors*, *22*(9), 3539.

[69] Bhatti, D. M. S., Khalil, R. A., Saeed, N., & Nam, H. (2022). Detection and Spatial Correlation Analysis of Infectious Diseases Using Wireless Body Area Network under Imperfect Wireless Channel. *Big Data*, *10*(1), 54-64.

[70] Al_Barazanchi, I., Niu, Y., Abdulshaheed, H. R., Hashim, W., Alkahtani, A. A., Daghighi, E., ... & Rauf, H. T. (2022). Proposed a new framework scheme for the path loss in wireless body area network. *Iraqi Journal For Computer Science and Mathematics*, *3*(1), 11-21.

[71] Kim, B. S., Shah, B., He, T., & Kim, K. I. (2022). A survey on analytical models for dynamic resource management in wireless body area networks. *Ad Hoc Networks*, *135*, 102936.

[72] Ullah, S., Higgins, H., Braem, B., Latre, B., Blondia, C., Moerman, I., ... & Kwak, K. S. (2012). A comprehensive survey of wireless body area networks. *Journal of medical systems*, *36*(3), 1065-1094.

[73] Hajar, M. S., Al-Kadri, M. O., & Kalutarage, H. K. (2021). A survey on wireless body area networks: Architecture, security challenges and research opportunities. *Computers & Security*, *104*, 102211.

[74] Arefin, T., Ali, M. H., & Haque, A. F. (2021). Scenario Based Transmission Power Control (TPC) Analysis over Wireless Body Area Network (WBAN). *Communications and Network*, *13*(3), 93-110.

[75] Latré, B., Braem, B., Moerman, I., Blondia, C., & Demeester, P. (2011). A survey on wireless body area networks. *Wireless networks*, *17*(1), 1-18.

[76] Saleem, F., Majeed, M. N., Iqbal, J., Waheed, A., Rauf, A., Zareei, M., & Mohamed, E. M. (2021). Ant Lion Optimizer Based Clustering Algorithm for

Wireless Body Area Networks in Livestock Industry. *IEEE Access*, *9*, 114495-114513.

[77] Singla, R., Kaur, N., Koundal, D., & Bharadwaj, A. (2022). Challenges and developments in secure routing protocols for healthcare in WBAN: A comparative analysis. *Wireless Personal Communications*, *122*(2), 1767-1806.

[78] Khan, M. D., Ullah, Z., Ahmad, A., Hayat, B., Almogren, A., Kim, K. H., ... & Ali, M. (2020). Energy harvested and cooperative enabled efficient routing protocol (EHCRP) for IoT-WBAN. *Sensors*, *20*(21), 6267.

[79] Khan, R. A., Mohammadani, K. H., Soomro, A. A., Hussain, J., Khan, S., Arain, T. H., & Zafar, H. (2018). An energy efficient routing protocol for wireless body area sensor networks. *Wireless Personal Communications*, *99*(4), 1443-1454.

[80] Anand, J., & Sethi, D. (2017, February). Comparative analysis of energy efficient routing in WBAN. In *2017 3rd International Conference on Computational Intelligence & Communication Technology (CICT)* (pp. 1-6). IEEE.

[81] Roy, M., Chowdhury, C., & Aslam, N. (2020). Security and privacy issues in wireless sensor and body area networks. In *Handbook of computer networks and cyber security* (pp. 173-200). Springer, Cham.

[82] Chander, D., & Kumar, R. (2018). QoS enabled cross-layer multicast routing over mobile ad hoc networks. *Procedia Computer Science*, *125*, 215-227.

[83] Nekooei, S. (2017). *Cross-Layer Media Access Control in Wireless Body Area Networks Using Fuzzy Logic and Evolutionary Computation* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington).

[84] Sethi, D., Bhattacharya, P. P., Kumar, R., Chauhan, N., Chand, N., Xiao, S., ... & Zhou, Z. (2017). A Comparative Analysis of Single-Hop and Multi-hop transmission using EERDT Protocol in Mobile and Critical Scenario for WBAN. *International Journal of Multimedia and Ubiquitous Engineering*, *12*(9), 1-14.

[85] Jijesh, J. J. (2017, January). A survey on Wireless Body Sensor Network routing protocol classification. In *2017 11th International Conference on Intelligent Systems and Control (ISCO)* (pp. 489-494). IEEE.

[86] Saha, R., Biswas, S., & Pradhan, G. (2017, March). A priority based routing protocol with extensive survey and comparison of related works for healthcare

applications using WBAN. In *2017 International conference on wireless communications, signal processing and networking (WiSPNET)* (pp. 1424-1430). IEEE.

[87] Rashid, T., Kumar, S., Verma, A., Gautam, P. R., & Kumar, A. (2018). Pm-EEMRP: postural movement based energy efficient multi-hop routing protocol for intra wireless body sensor network (Intra-WBSN). *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, *16*(1), 166-173.

[88] Anand, J., & Sethi, D. (2017, February). Comparative analysis of energy efficient routing in WBAN. In *2017 3rd International Conference on Computational Intelligence & Communication Technology (CICT)* (pp. 1-6). IEEE.

[89] Ayatollahitafti, V., Ngadi, M. A., & Sharif, J. B. M. (2015). REQUIREMENTS AND CHALLENGES IN BODY SENSOR NETWORKS: A SURVEY. *Journal of Theoretical & Applied Information Technology*, *72*(2).

[90] Ventura, J. M., Fajardo, A., & Medina, R. (2019). Priority based data transmission for WBAN. *International Journal of Electrical and Computer Engineering*, *9*(5), 3671.

[91] Cai, G., Fang, Y., Wen, J., Han, G., & Yang, X. (2019). QoS-aware buffer-aided relaying implant WBAN for healthcare IoT: Opportunities and challenges. *IEEE Network*, *33*(4), 96-103.

[92] Jiang, W., Wang, Z., Feng, M., & Miao, T. (2017, July). A survey of thermal-aware routing protocols in wireless body area networks. In *2017 IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC)* (Vol. 2, pp. 17-21). IEEE.

[93] Khairnar, M., Vaishali, D., & Kotecha, D. (2013). Simulation-based performance evaluation of routing protocols in vehicular ad-hoc network. *arXiv preprint arXiv:1311.1378*.

[94] Khan, M. K. U., & Ramesh, K. S. (2019). Effect on Packet Delivery Ratio (PDR) & Throughput in Wireless Sensor Networks Due to Black Hole Attack. *Int. J. Innov. Technol. Explor. Eng*, *8*(12S), 428-432.

# الخلاصة


شبكة منطقة الجسم اللاسلكية (WBAN) هي مجال متعدد التخصصات لديه القدرة على إحداث ثورة في الرعاية الصحية من خلال تمكين المراقبة المستمرة منخفضة التكلفة لصحة المريض والتحديثات في الوقت الفعلي للسجلات الطبية باستخدام البيانات التي تم جمعها بواسطة أجهزة الاستشعار المتصلة بإنترنت أشياء (IoT). من أجل مراقبة الأحداث اليومية ، من الضروري إنشاء نموذج يسمح بالتحكم في بيانات المستشعر بأقل تأخير ممكن من أجل إنشاء مسار بين أجزاء شبكة WBAN.

نظام التوجيه المقترح الذي يعتمد على بروتوكول التوجيه المعتمد على التأخير الهجين (HDRP) ، والذي يجمع بين بروتوكولي التوجيه المتأخرين المدركين للوضعيات ، التوجيه الاحتمالي مع تكاليف الارتباط الوضعي (PRPLC) ، والتخزين على الجسم وتوجيه الفيضانات (OBSFR) لتعزيز تحليل الشبكة لاستراتيجيات التوجيه المتكافئة لأجهزة استشعار إنترنت الأشياء ذات الموارد المحدودة. تم استخدام الإنتاجية ، والتأخير من طرف إلى طرف ، وتسليم الحزم ، والمُدخلات كمقاييس تقييم أولية في محاكاة أجريت باستخدام OMNET ++ من (٧ ، ١٣ و ٢٣) من مستشعرات الرعاية الصحية لإنترنت الأشياء ؛ تخطيط كهربائية الدماغ (EEG) ، تخطيط القلب الكهربائي (ECG) ، درجة الحرارة والحركة وضغط الدم).

أظهرت النتائج أن تقنيات توجيه HDRP المقترحة قد حسّنت النتائج في تقليل متوسط المستوى الأدنى الإجمالي لكل تأخير وصول حزمة مثل PRPLC كـ ٢٢.٣٢٢٦ ثانية ، OBSFR كـ ٢١.٦٧٢ ثانية ، HDRP كـ ١٨.٨٥٥ ثانية ، تسليم الحزمة كـ ٩٩.٧١٪ ، ٩٩.٩١٪ ، و ٩٩.٩٣٪. لكل PRPLC و OBSFR و HDRP. Goodput هو ٣.٢٣٨٩ حزم بالثانية لـ PRPLC ، و ٣.٥١١٨ حزم بالثانية لـ OBSFR ، و ٤.٠٩٧ حزم بالثانية لـ HDRP ، في حين أن الحد الأقصى لمتوسط الإنتاجية لسبعة مستشعرات IoT هو ١٥٩.٧٥٤٤ بايت بالثانية ، ١٦٨.١٦٨٣٣بايت بالثانية و ١٧٦.٥٧٦٧ بايت بالثانية.

يحسن بروتوكول التوجيه المقترح من تقويم النتائج حيث يساهم بتقليل التأخير وزيادة الطاقة الإنتاجية للبيانات وتسليم الحزم وكذلك مدى نجاح تسليم الحزم الى العقدة النهائية على الترتيب.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية تكنولوجيا المعلومات
قسم شبكات المعلومات

# بروتوكول التوجيه الهجين لتعزيز شبكة مستشعر الجسم اللاسلكية

رسالة مقدمة

إلى مجلس كلية تكنولوجيا المعلومات في جامعة بابل والتي هي جزء من متطلبات

الحصول على درجة الماجستير في تكنولوجيا المعلومات / شبكات المعلومات

**من قبل الطالب**

**علي سامر سليم عباس**

**باشراف**

**أ.د سعد طالب حسون الجبوري**

٢٠٢٢ م ١٤٤٤ هـ