DESIGN AND DEVELOPMENT OF ROUTING PROTOCOLS FOR THE IMPROVEMENT OF QOS IN WIRELESS BODY AREA NETWORK

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Electronics and Communication Engineering

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2024

DECLARATION

I, Anil Kumar Rawat hereby declare that the presented work in the thesis entitled "**Design and Development of Routing Protocols for The Improvement of QoS in Wireless Body Area Network"** in fulfilment of the degree of **Doctor of Philosophy (Ph. D.)** is the outcome of research work carried out by me under the supervision of Dr. Amandeep Singh, working as Associate Professor, in the School of Electronics and Electrical Engineering of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgments have been made whenever the work described here has been based on the findings of other investigators. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled **Design and Development of Routing Protocols for The Improvement of QoS in Wireless Body Area Network**” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Wireless Communication/ School of Electronics and Electrical Engineering is a research work carried out by Anil Kumar Rawat, 41700222, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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High achievement always takes place in the framework of high expectations. The expectation was there and I began with a determined resolve and put in sustained hard work. It has been rightly said that every successful individual knows that his or her achievement depends on a community of persons working together but the satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible. This is to acknowledge with gratitude the guidance and ameliorating suggestions from my supervisor, Dr. Amandeep Singh, and co-supervisor Dr. Manwinder Singh for their support and motivation throughout the thesis work. I am indeed thankful to all anonymous reviewers of my research papers submitted to various International Journal and International conferences, due to which I was able to improve upon the work contained herein.

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Anil Kumar Rawat

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Abstract

Sensor technology advancements have provided the platform to implement wireless body area networks, thanks to the nanosized sensor units capable of sensing, aggregating, and forwarding physiological information. The collected information is routed to the desired destination unit for data analysis and decision-making in remote healthcare. However, improving energy utilization remains a brain-teasing problem for the research community, especially considering imbalanced energy consumption and postural movements. Mobility contributes to disconnectivity issues, high energy drainage, and retransmission delays. In addition, the sensor node's thermal level also poses a challenge in maintaining safer and reliable data transmission. To overcome these issues, a novel Mobility and Temperature Sensitive Energy-Efficient Routing ¬(MTS-EER) protocol has been proposed that includes a two-step process. In step 1, an Intelligent Path Estimation Function (IPEF) is designed considering the sensor's mobility, temperature, and energy level. IPEF depends on crucial parameters i.e.: - residual energy, signal-to-noise ratio (SNR), distance, total energy, and most importantly temperature of the sensor unit. The sensor node with the least IPEF is selected as the Cluster Head (CH). In step 2, an optimized and sustainable energy conservation model (OSECM) is implemented based on the Adaptive Transmission Power (ATP) and the Power Management Module (PMM). The ATP conserves the energy via intelligently varying the transmission power and PMM manages the sleep pattern of sensor nodes to yield a high network lifetime and efficient energy utilization. The algorithm includes a clustering approach with dual sink nodes to conserve energy and improve reliability. Finally, the results are compared with the recent state-of-the-art research work. The proposed algorithm provides better results considering residual energy, throughput, network lifetime, and end-to-end delay.

Energy conservation is the most common method used to fulfil energy requirements. Therefore, an advanced model is presented for energy conservation in WBAN. A Novel Robust, and Adaptive Energy-Efficient Model (NR-AEEM) for energy conservation is presented in the research work. It is an amalgamation of four techniques for resolving the energy drainage problem at multiple levels. It includes an intelligent coded system developed to reduce transmission-related issues. The noble model is proposed to provide balanced energy drainage, prolonged network performance, and efficient data transmission for dynamic nodes. The results are compared with the latest state-of-the-art research papers that confirm the supremacy of the presented work.

Chapter 1
Introduction

1. Overview

Aging is a natural process affecting the lifestyle of individuals. Recent advances in technology have magically improved the life expectancy of humankind, however, in the same breath, it has also increased the possibilities of diseases unheard of in the past century. An unhealthy lifestyle and stressful living environment have aggravated the manifestation of diseases at an alarming rate. The worst part of the scenario is that people don't even have time to visit the medical care and follow the prescription even in case of a medical diagnosis. This new generation or the 21st-century population is on the verge of self-destruction and is looking for a magic lamp or a genie to guide and change their way of living. Chronic diseases are the centre of the majority of the suffering of society. It is like a parasite feeding on its prey and growing stronger without even the knowledge of the patient. It sometimes takes years for a disease to manifest and become life-threatening and the sad part is that the host is not even aware of it. Dementia is a disease related to the loss of memory and not being able to do the daily routine due to the life-threatening condition. Cancer, diabetes, asthma, and many more such chronic diseases could be cured at the early stages of diagnosis [1]–[3].

There have been attempts in the past and still going on in this direction to early diagnose or to provide any emergency response based on the patient history. The latest technology has fast-tracked how we think and respond in the medical healthcare industry. Patients are monitored in a hospital and immediate medical care is given, improving the patient's recovery rate. However, in certain cases, it hinders the patient's mobility as it restricts the patient from being plugged into the sensitive body information vis ECG, EEG, etc. It also restricts monitoring of the individual's behavior in the natural environment. The latest advancement in technology has the potential of being the new e-revolution in medical healthcare, the centre focus or the priceless aspect would be the vital information about the human body organs. It poses immense possibilities of a blissful healthy society at the same time, a weapon of destruction as a breach of privacy, or secrecy could lead to disaster. Therefore, it is a significant possibility to provide a real-time monitoring system that could change human life in a better way.

1.1 Scope of Research

The idea of monitoring patients remotely has the potential of immense possibilities for advancement to achieve a reliable, low-cost, energy-efficient body area network. However, the miniature sensors can acquire limited energy demands optimized energy utilization. Energy consumption is a major challenge in realizing such a system. It demands the sensors on the body to be comfortable to be worn by the user, low weight, and long-lasting with the ability to sense, store, analyze, and transmit the information to the central unit for further processing. All this will require energy and it is not desired to change the pacemaker implanted regularly after short intervals due to energy constraints. The same applies to sensors on the body and around it. The source of energy consumption of a WBAN on, in, and around the body includes (i) tans-receiver (ii) sensing unit (iii) processing unit [4]. A significant amount of energy is dissipated during the packet transfer between the sensor nodes.

It is a challenge in wireless body area networks (WBANs) to achieve minimal energy consumption considering postural movement. The body movements affect the reliable data transmission leading to retransmissions and energy wastage. Another aspect is the temperature level of the sensor nodes. As the sensor nodes are utilized, their temperature level increases. It not only affects the human tissue but also adversely affects the transmission. Regular monitoring of the patient is the key interest of the medical staff. Sometimes, medical staff require situation-dependent biological data collection for more reliable transmission.

WBAN demands low energy requirements and reliable data transmission with minimal latency to implement in a real-time environment. Energy demands depend on various aspects including the location of sensors on the body, sensor nodes distance based on sensor coordinates, the frequency of consumption, and most importantly the routing algorithm used to identify the reliable communication route.

Reliability is of utmost importance while dealing with human physiological data transfer. It requires precise data to be transmitted in a critical health situation with the least latency. Packet drops or corrupt data could be life-threatening as they could delay the treatment process or lead to misinterpretation. Researchers have addressed these issues but considering a holistic approach with multiple factors like path loss, postural movement, and sensor temperature is still a challenge in WBANs equally for medical and the research community.

As the sensor nodes are utilized in the WBAN, it will increase the thermal level of the sensor units. The temperature increase beyond a point could affect the transmission efficiency. It could also affect the human skin or internal organs in the case of implanted sensors. Therefore, it is important to restrict the usage of the sensor node within the stipulated temperature range. The natural environment provides freedom of movement to the user. However, it burdens the network to ensure reliable transmission of packets in a mobility-constraint scenario. Therefore, a robust WBAN network is desired to address the thermal constraint in a mobility and energy-constraint network.

1.2 Wireless Body Area Network

WBAN provides a solution to the problems of the healthcare industry. It can remotely gather the vital signs of the patient. It includes multiple sensor nodes placed on the human skin or on wearable devices or implanted inside the body to monitor the physiological parameters of patients [5]-[6]. The sensor nodes placed on the body are miniature with limited energy capacity. Therefore, the energy consumption rate, mobility, interference, and resource availability are critical in a reliable WBAN. A detailed review of WBAN has been thoroughly done in [7]–[10]. Out of many applications like re-habitation, assisted living, and sports, one such application of WBAN is a personal healthcare management system wherein it is possible to remotely monitor an individual's vital body organ data for a normal daily healthy lifestyle and in emergencies.

WBAN is a sensor technology that has the potential for exponential growth considering the outreach in varied areas of applications, specifically the healthcare industry. It involves the integration of sensors connected and communicating with each other, thereby providing an ecosystem for critical human-sensitive data to be available on an online platform that remote medical representatives can interpret. It can ease the monitoring process of the aging population suffering from chronic disease in their natural environment, diagnosing chronic diseases in the initial phase and significantly helping move from ‘cure to personalized healthcare’. In simple terms, this can change the healthcare approach and add quality to the lives of the sufferers. It eases the extensive workload and hence improves the quality of medical caregivers. It has the potential to provide the quality of medical care required by patients living in remote areas. Moreover, quality medical care is a challenge in an emergency where the accessibility to remote locations becomes a hindrance. A shortage of quality health workers in the medical field leads to work overload. Hence, WBAN can fill this gap to overcome the shortage of quality health workers. As technology is improving day by day, personalized health care could play a crucial role in it.

However, the technology faces challenges in implementation aspects catering to the healthcare industry. The primary constraint is the restricted energy storage due to the miniaturized sensors. It can only be stored in millijoules. Sensors are connected to the skin or implanted inside the human body in a WBAN. The fundamental aspect of WBAN is to transfer sensitive data from the data-originating sensor node to the desired sink node. However, it depends on multiple factors that decide the QoS of the network which can never be compromised as it will destroy the sole purpose of assistance. In an emergency, faster and more reliable precise data transmission is important. Some applications demand longevity and reliability compromising on delay aspects. For example, regular monitoring of diabetic patients for sugar levels in the blood sample or a person suffering from chronic disease. Therefore, the disease of a person has a significant role in deciding the QoS parameter and may vary accordingly. A Heart patient demands a different set of QoS than a Diabetic patient. A patient suffering from Alzheimer's or Schizophrenia may have different data types and data rate requirements.

In short, WBAN in healthcare needs an optimized approach based on the QoS desired by the patient. Unfortunately, QoS has not been discussed effectively in the past research works. Ideally, all the approaches discussed related to WBAN lie under the umbrella of "QoS" catering to specific situations. Additionally, the WBAN has even extended areas beyond healthcare like military, sports, and rescue operations, the individual's vitals are key to the mission's success rate and planning the strategies. Group WBAN has also emerged as an extended research area for such applications. These areas need to be addressed for improvements and further research.

WBAN is a sub-domain of the WSN, however, the dynamics between them change significantly due to the low power constraints, nano-sensors, and replacement issues. Its key role is to monitor the vital signs of the patient continually as mentioned in Figure 1.3. Its larger aim is to move from a perspective of curing to the idea of personalized health. It is a three-layer architecture approach wherein the first layer collects the vital physiological signs using sensors connected in, on, or around the body. The second layer consists of the Internet collecting data from smartphones, computers, or PDAs. The third layer comprises the doctor, expert group, hospital, and other data mining to assist the layer 1 user in availing the services based on the data interpretation.

1.3 WBAN Architecture

The architecture of WBAN can be divided into three different layers, as mentioned in the Figure 1.1 [7]. The realm of wireless networks is presented in Figure 1.2.

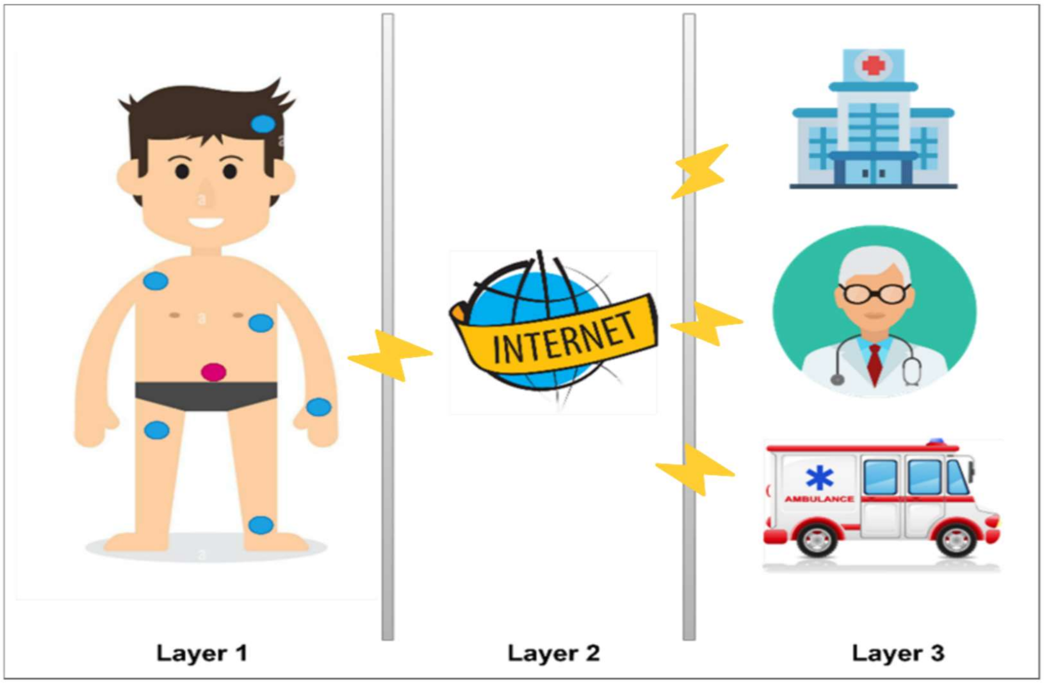

Figure 1-1 The Basic Architecture of WBAN as a Three-tier Network

Layer 1: This layer consists of sensor nodes deployed inside, on, or around the human body. The sensors collect the data, aggregate it, and send it to the sink node or the base station.

Layer 2: It ensures the data availability to the internet through the PDA or personal computers.

Layer 3: It deals with the vital information required by medical experts like medical health providers, researchers, ambulances, doctors, expert groups, etc.

The paper [11] discusses the in-body implants in a WBAN. Switching and transmission aspects are thoroughly discussed in [12] & [13]. The researchers in [14] discuss the multi-hop technique to enhance the network lifetime of WBAN. Thermal-aware routing deals with the solutions to the temperature rise in the sensor units leading to life-threatening situations[15]. Security threats and attacks can compromise the critical physiological data of the patient. Various countermeasures related to this have been discussed in [16]. Data management-related WBAN issues were discussed in [17]–[19] which deals with data compression, aggregation, and segregation. Communication protocols considering energy efficiency-oriented papers are discussed [20]–[23]. Energy Harvesting is an emerging field providing solutions to the energy constraints discussed in [24]–[27].

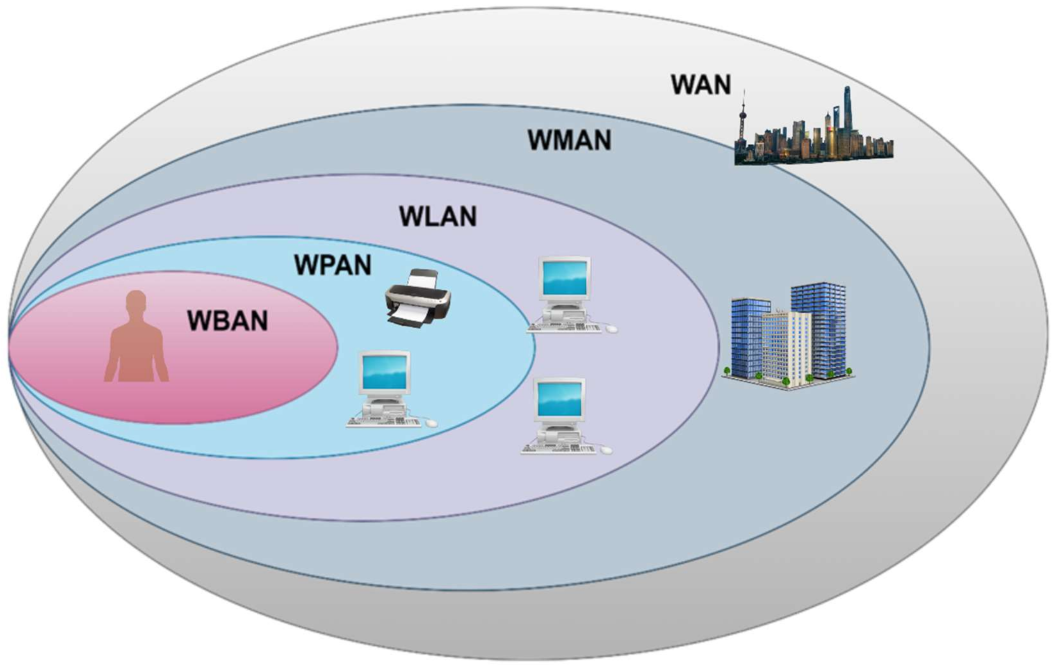

Figure 1-2 WBAN in a Broader Wireless Network Realm

Interference is a big challenge addressed in the papers [28]–[32] ranging from WBAN, U-WBAN, WSN, and VANET. WBAN originates from Wireless Sensor Networks (WSN), hence the DNA to an extent will match and therefore papers related to WSN are discussed here [33]–[43]. Energy-efficient clustering techniques/protocols are discussed in [44]–[49]. QoS-enabled protocols for the Internet of Multimedia are discussed in [50]. Other papers relevant to the routing protocols are [51]–[54]. The paper related to WBAN associated with applications is discussed in [55]–[68]. WBAN antenna-related papers are discussed in [69]–[72]. Network longevity in e-health is discussed in[73]. The model model-driven architecture of WBAN is discussed in [74], cloud-assisted reliability [75], and content-aware scheduling [76].

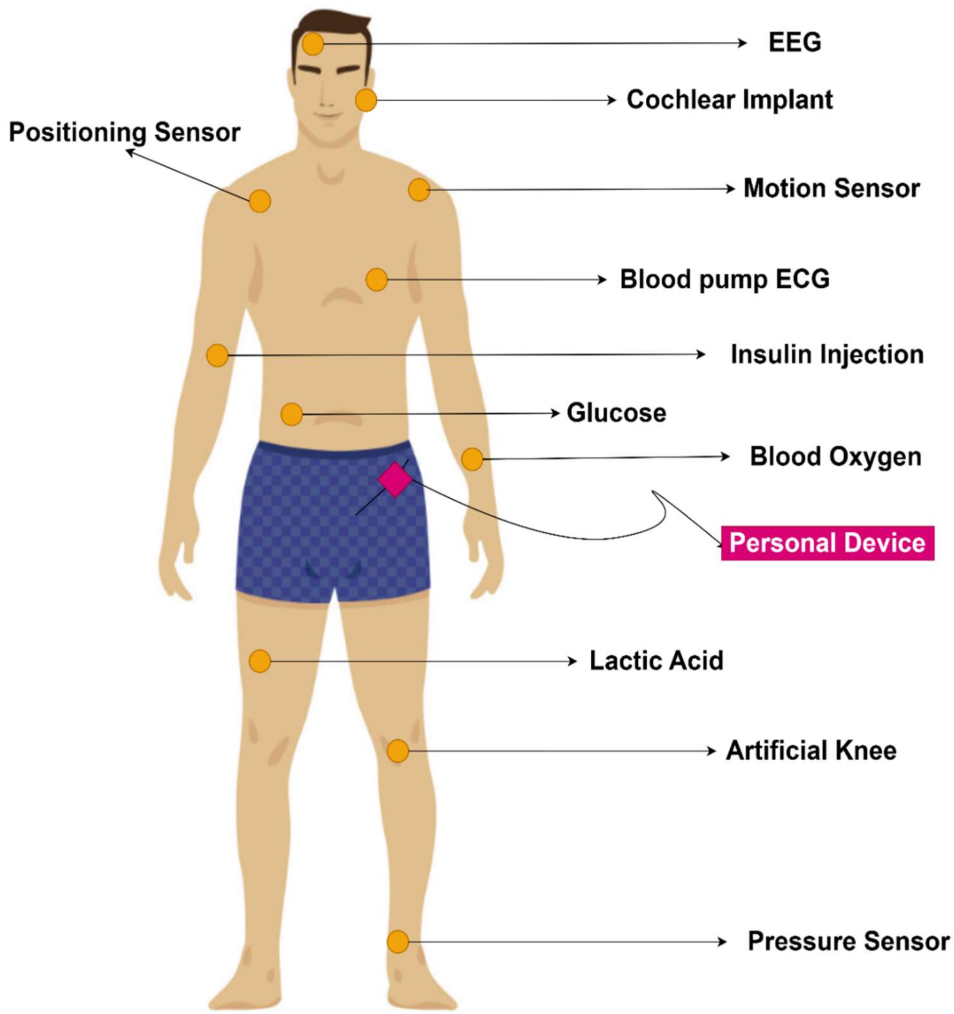

Figure 1-3 Examples of Patient Monitoring in WBAN

1.4 Wearables in WBAN

Medical healthcare has shown exponential growth in the past decade and the emergence of advanced technologies has a major role to play in it.Miniaturization of sensors, energy-efficient batteries,and GPU-enabled processors are redefining data processing. The patient monitoring is presented in Figure 1.3. Remote monitoring has become the buzz word coining a term called the Wearables. Freedom of mobility without restriction has been the core of human evolution in that context, humans have always desired to be in control of situations and always improvised to enhance the quality of life. Wearable devices are becoming apart of our daily lives, helping us make decisions and providing a better lifestyle. Better healthcare decisions play a significant role in addressing these issues, not randomly but in sequences of decisions taken over time.

Wearables have come a long way in terms of their impact on the lifestyle of an individual as various health monitoring devices are easily available in the market however, the major trend and hype is its usage in medical applications. Wearable devices ranging from vital sign monitoring, ambient environment monitoring, and home environment monitoring to drug delivery systems and early diagnosis of chronic diseases like asthma, sleep apnea, dementia, and other aging-related diseases, have accelerated the acceptance of remote monitoring systems in our daily requirements.

To achieve continuous monitoring, digestion of enormous data into useful information, data storage & transmission, security, and privacy are the key areas. The healthcare industry at large is facing challenges in dealing with chronic diseases, the increased percentage of aging populations in many countries, and medical treatment costs. In this context, remote monitoring & medication of patients using wearable devices is discussed in [77]. Internet of Things-enabled healthcare monitoring using medical wearables is a new concept that has revolutionized the medical industry offering mobility. Medical Wearables can be defined as devices worn by the individual for continuous monitoring of individual activities without restricting the natural activities or movements of the user. Considering the need for wearables in healthcare and its possible contributions, so much research has been done in this area. Wearable technology in medicine [78] ranges from head-mounted wearables simulation in medical education and other applications. The medical industry has to intervene, collaborate with scientists, engineers, and doctors, and provide proper guidelines to ensure that the wearables can be streamlined in medical healthcare with credibility, accuracy, and validation.

1.5 Wearables: An Unconventional Approach

Wearable technology deals with all those devices that in one way or another are worn by an individual and are capable of extracting meaningful data that could lead to a healthy lifestyle, early diagnosis, or provide better care to the individual. One of the simplest methods is adopted in [79]. It uses an A-Z approach to highlight and explain the key terminologies. An exhaustive review detailing the applications, architecture, design goals, and emerging trends is contributed by [80] in which the sensor-based system is discussed. In [81], wearable in the medical revolution is discussed in detail.

Unobtrusive sensing envisions the approach in which various methods and technology blend into the natural environment contributing to health informatics. An overview of four unobtrusive technologies highlighting the significance of smart textiles with properties like flexibility, printability, and stretching ability of electronic devices. The ground rule for such technology is the blend of day-to-day devices like mirrors, sleeping beds, and walking sticks to act as a sensing device thereby creating an ambient environment for an individual's speedy recovery.

Another term that explores another variant of application of wearable technology is the Ambient Intelligence (AmI) in healthcare[82].The involvement of artificial intelligence to create an environment that could understand the emotional behavior of the subject and change its environment to improve the individual's response. In short, AmI is a context-aware anticipatory personalized system that is adaptive to the needs of the used ensuring ubiquity and transparency.

Data sharing is a very critical concern in the future of wearables. Without a safe and secure platform, the faith of the common man toward adopting this technology will be under question.Addressing these issues, a safe sharing method is discussed in [83]. A gene fusion technology for robust security provides scalability and versatility which are elementary for wireless sensor networks

(WSN). Another in-depth survey on wearables is covered in [84] highly recommended which details wireless body area network (WBAN) classifying wearable devices into three types namely:-

(i) Accessories (ii) E-Textiles (iii) E-patches. Another Wearable technology variant is discussed in [84] , re-enforcing the role of games and environment in the behavioral aspect of the patients suffering from medical illness. The study shows significant improvement in physical activity and cognitive ability encouraging the incorporation of serious games, especially for older adults in ambient environments. A comprehensive review is done in [85] in which details of the type of sensors, the communication protocols, and challenges are addressed considering the critical approach.

Medical healthcare for adults is a challenging concern that needs immediate interventionas with the improvement in healthcare, the average life expectancy has improved significantly. On the one hand, this is satisfactory, but on the other hand, it has given rise to diseases related to the elderly population. Market prospects and the ambient environment, of wearable textiles are discussed in [86].

Medical accreditations are the key for wearable devices as they validate the data used for the clinical trial. Clinical trials take an average of 10 years for validation of a drug hence a major reason for the financial burden for the society. After clinical validation, it still requires another 5 years of on-field trials for the drug to be introduced in the market. The safety of the individual cannot be compromised at any cost; hence such an exhaustive process needs to be followed. Clinical trials aim to collect data for drug validation. Wearable devices can significantly contribute to this area by providing remote monitoring access between the subjects and the expert. Thousands of subjects consuming the drug can be evaluated continuously thereby speeding the process of drug availability in the market. A detailed survey on clinical trials for wearable technology has been done in [8 6] including ethical and legal concerns. In short, wearables play a significant role in reducing healthcare costs and improving clinical trial efficiency. However, these devices strictly require FDA approval to penetrate the medical industry. Clinical trials of these wearables need to be done to utilize the potential of wearables in healthcare.

1.6 Wearables for Chronic Diseases

Various chronic diseases need medical attention. Wearables can change the way the vital signs are monitored in such scenarios. Some of the diseases are presented here that need attention in this regard.

i. Respiratory Diseases

Respiratory sound spectra can provide a lot of information capable of helping diagnosing asthma. Otherwise, it generally takes a long-term diagnosis time and is costly. In [87], a new method is discussed wherein 94.91% of accuracy with 96.28% of specificity and 89.34% of the sensitivity is achieved. Sleep Apnea is a sleep disorder in which the breathing is obstructed multiple times which could have severe consequences ranging from increased blood pressure or even heart failure. Continuous monitoring by the expert in a controlled environment is expensive and tedious. Hence an automated detection method is discussed in [88] which has improved the diagnosis accuracy with the relaxed job requirement of continuous monitoring. Another way of dealing with the problem is using a wearable sensor which will keep track of the respiratory rate and in case of any abnormal variations can alert the system.

ii. Cardiovascular Disease

Heart rate monitoring using motion-based sensing has emerged rapidly due to low cost and low energy requirement thereby contributing to the growth of wearable sensors for medical applications. A survey on heart rate monitoring in [89] is conducted with a successful demonstration. It supports the growth of medical wearable technology. A similar study is undertaken in [90] which aim at improving the quality of analysis related to chronic respiratory diseases.

An optical measurement method named Photoplethysmography (PPG) is used in [91] for heart rate monitoring and recent studies have shown that the same method can provide a range of other useful information however it requires continuous and real-time monitoring which opens doors for wearable sensors detailed in the research work.Motion artifacts introduce noise in wearable sensors and restrict the precise monitoring ability of the sensor. To solve this problem, a concept related to particle filters is used in [92] providing noise-suppressed data. Impedance cardiography (ICG) is another noninvasive technique for cardiac monitoring for educational and research purposesdemonstrated in [93] hence providing future ground for wearable technology.

iii. Dementia

Dementia requires critical healthcare intervention at the emotional, physical, and psychological levels. It is difficult to provide care to people with dementia. Wearable technology in healthcare can provide efficient, analytics-driven interventions, to support this labor-intensive method of care aptly discussed in [94].Improved life expectancy has prolonged the lifetime of an individual, however on the other hand a new type of neurodegenerative disease, Alzheimer's Disease (AD) is manifested. Aged people suffering from AD require continuous monitoring and healthcare,hence a smart home-based prediction of the symptoms is analyzed wherein the role of medical healthcare through smart devices or wearables has a significant role to play.

Parkinson's Disease is a neurodegenerativedisorder that affects the part of the brain dealing with the motor senses, hence resulting in an involuntary movement of body parts. In [95], a studyon such patients includes a wearable device worn on the wrist to indicate and analyze the motor state forthe therapy individualization for the patients.

1.7 Wearables for Movement Monitoring

The quality and quantity of subject movement in the natural environment can provideuseful information to avoid injury and enhance the performance of a sportsperson. The physics behind the body movement in action provides vital information, resulting in a game changer in a crunch situation. In addition to that, people born with restricted limb movement or due to other reasons can now diagnose the problem while in action using wearable sensors as discussed in [95]. Physical activity monitoring for performance enhancement has also been discussed in [96] comparing two algorithms and highlighting the limitations. Health & well-being monitoring is another area in case of the passive subject to understand the lifestyle behavior and provide better personal health management using wearables.

Self-health monitoring and preventive medicine reduced costs for prevention and monitoring. Activity monitoring is an area of great concern specifically for aged people or people suffering from dementia wherein their daily routine does not include activity, further worsening theirmedical condition. In [97], activity recognition for the aged society is discussed highlighting the need for continuous monitoring and wearables are the potential solutions.

1.8 Wearable Sensors & Nanomaterials

With the advent of wearable devices, the race to provide miniature, low-power, durable, and harmless materials is in the spotlight to the research community accelerating the growth of the wearable healthcare industry. The same has been discussed in [98] details with nanomaterials and nanocomposites' role in wearable devices. Medical IoT is a field of study that deals with all the medical information generated on the body using the sensors to be stored and analyzed for better and faster decision-making. Implantable is a wearable medical device inside the human body primarily used to monitor vital signs, symptoms of disease, and other parameters like stress or depression. In [99], a detailed review of wearable and implantable Sensors is done on the biomedical applications. Wearables are significant in creating smart environments using the Brain Computer Interface (BCI) [100] which is a new branch of study for controlling the electronic device using brain activity including applications in medicine, biometrics, and neuro-gaming.

1.9 Challenges in Medical Wearables

i. Power Constraint

Power availability in wearable devices is critical as the requirement for advanced functionalities within the device is increasing. Data storage processing and transmission consumes a lot of energy forcing frequent recharging of these devices. Hence, prolonged energy is critical for wearable device usability and effectiveness in the natural environment. To improve the life span of a battery, efficient use of power is done either by reducing the size of the wearable or extending battery life using technological advancements. Low power and real-time design objectives toward wearable Quality-on-Demand (QoD) ECG applications are achieved in [101]. Higher energy density and the ability to efficiently harness the energy while converting it to electricity will contribute to a long-lasting battery life. It is clear from the discussion that the advancement in power management and energy conservation willdefine the fate of wearable devices and their evolution.

ii. Big Data

Data management is one more concerning factor surrounding the growth of wearable medical devices. Big data is a term that corresponds to a large amount of data to be analyzed, searched or queried to extract useful information for decision making and a fuzzy rule-based classifier is used to make efficient decision-making [102]. In [103], the methods involving this play an important role in better decision-making. Big data on the cloud proposed by [103] highlights the challenges inwearable technology listed as network bandwidth, data security, datavisualization, data complexity, computational complexity, data transmissionrate, and data synchronization.

The uniqueness of an individual has a key role in designing a device. Specifically, person-centric calibration considers factors contributing to the person's individuality. Genetics aspect, daily routine, family history, diet, and so many other factors make an individual uniquely different. Disturbances due to environmental noise, changes in sensor location, and sudden movement of individuals can significantly alter the outcome and contribute to inaccurate reading. Although various filtration and noise suppression techniques are discussed, a lot needs to be done to improve the system to be acceptable for medical accreditations. Therefore, a tailor-made device could be the ultimate solution to early diagnosis and assistive guidance for perfect health solutions. Thus, wearable devices should address this issue to accurately harness and interpret the biological chain of signals,thereby ensuring a preventive approach toward a healthy society.

iii. **Standardization of Wearables**

Standardization [103] is a major concern generally as a whole in the medical industry. The quality of data varies as it is collected from varied sources. Different protocols or machines don't have globally acceptable standards. This problem can easily extend to wearables, therefore, there is a need for global standard protocols ensuring a common data platform, hence providing a larger pool of data on the cloud being used for better decision-making.

iv. **Security & Privacy**

Sharing medical data on the cloud can accelerate advances in medical wearable technology. Data Security is another area that needs the global community to collaborate and create standards for secured storage on the cloud and create confidence leading to medical experts making better faster decisions. In the same space, [103] has addressed this issue by introducing homomorphic encryption which computes data without decryption and on the same grounds, has proposed another technique addressing the security concern. Integrated Circuit Metric (ICMetric) technology is introduced in [104] as a provision for security in wearable devices. At large issues related to confidentiality, authentication, hostile environment, and device network security in future research. An in-depth analysis of existing security and privacy concerns including future challenges covered in [105] emphasizing requirements for lightweight protocols for wearables.

v. Sensor Accuracy

The sensor accuracy is affected by various factors including the type of sensor, the environmental conditions, and the positioning of the sensors in a WBAN network. Different types of sensors have varying degrees of accuracy depending on their purpose, mechanism, and design considerations. The environment conditions like temperature, humidity, noise, distortion, electro-magnetic interference also impact the sensor accuracy. Sensor positioning is also critical in terms of extracting the accurate reading. Sensor sensitivity indicates the ability of the sensor to detect small variations in signal which get affected by the environmental conditions. The tiny processor attached to the sensors to eliminate redundant or similar data has the potential to exponentially improve the WBAN performance and drastically shift the use of real-life WBAN networks. However, the processor size, processing power, and energy requirements are the critical factors require balancing between comfort and performance in a WBAN network ensuring accuracy.

1.10 Applications of WBAN

WBAN has potential in diverse areas apart from healthcare to non-healthcare applications. WBAN networks are combined to form the Group WBAN network helpful in a team environment, whether a military operation or sports-oriented performance. The prospect of personalized health can be visualized with self-energized nano-sensors deployed inside the human body and providing manifestation-level information about the disease. Several review articles are discussed by the research community providing the recent work. Energy-specific applications are covered in [106], QoS-based applications are covered in [107], and detailed applications are covered in [108].

1.11 Challenges in WBAN Architecture

WBAN has the potential to cater to the health industry, however, it demands a high level of precision, real-time data delivery for critical situations, and reliability.

It poses various challenges in designing such a WBAN architecture. The different physiological parameters may vary in data rates, security level, and resource requirements such as channel occupancy, amount of data, priority, and data type. Moreover, noisy or crowded environments and body postural movements also restrict the quality of service in the WBAN. All these factors converge to the requirement of ample energy at its disposal. WBAN therefore, being energy starved demands an energy-efficient routing protocol to meet all the desired outcomes. Hence it becomes important to study and analyze various routing protocols in WBAN.

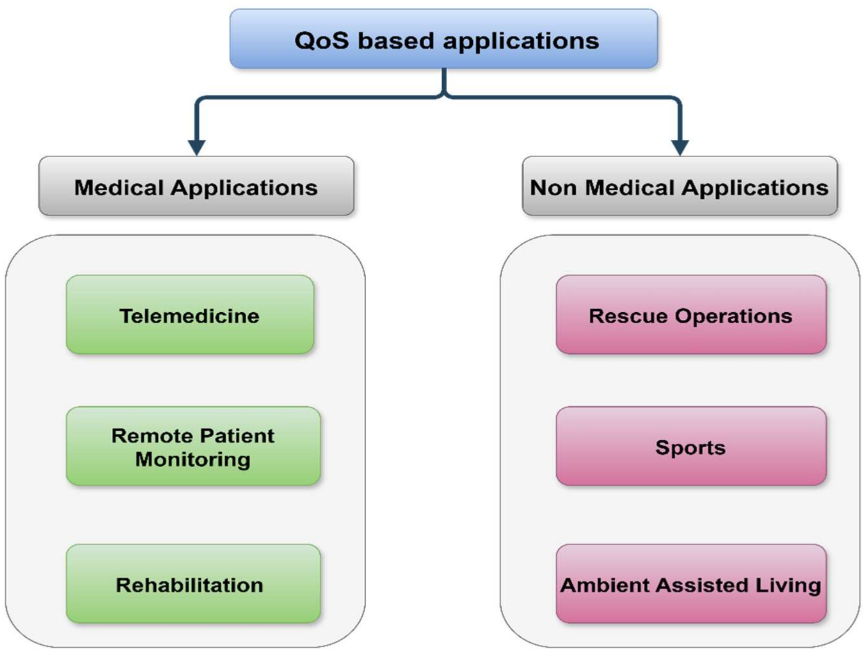

Figure 1-4 Quality-of-Service-Based Applications

The Routing protocol can be divided mainly into four different types namely: 1) “Clustered routing protocol” 2) “Cross-layered routing protocol” 3) “Temperature-based routing protocol” 4) QoS aware routing protocol. To report the latest research trends, the relevant research work considering the exception of significant research papers still compared to recent research work.

However, WBAN with Quality-of-Services in healthcare applications demands certain conditions to be fulfilled before it's implemented in real-life scenarios. Quality-of-Services applications are presented in Figure 1.4 and the challenges related to WBAN are highlighted in Figure 1.5. The fundamental and foremost important condition is minimal or no risk to the quality of human life. Therefore, heat dissipation in sensors can't be compromised. It could lead to damage to the internal organs or the skin of the patient. Unfortunately, temperature-sensitive routings are studied in isolation by the majority of the researchers. However, this parameter can be neglected or its weightage reduced in case of sensors deployed around the body. Applications considering wearable devices or sensors on apparel can be seen as potential applications.

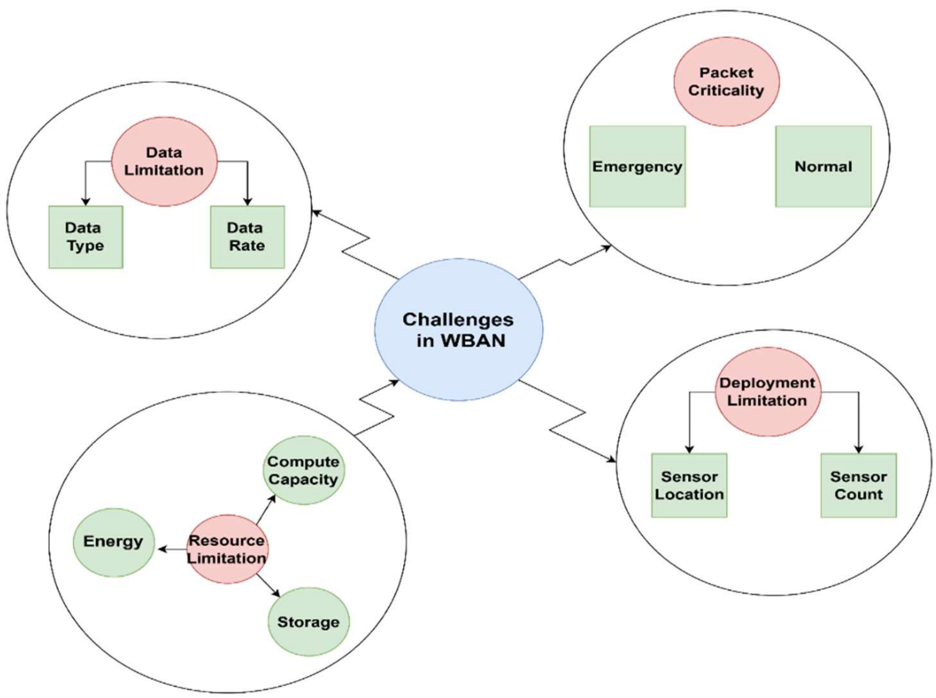

Figure 1-5 Challenges in WBAN

Secondly, high data rate transmission demands high frequency. High-frequency radiation can damage the tissue or the organ inside the body as it penetrates the body and therefore be avoided. In the case of on or around the body, the condition may be relaxed and hence can have an improved network. Sensor heat dissipation can't be compromised in this case for a realistic WBAN technology contributing to healthcare. The energy constraint is an important parameter that defines multiple aspects of the network. In this, the energy conservation methods will purely depend on the application. Therefore, optimizing the desired parameters and maintaining the energy level is required. Hence direct data transfer is preferred without bothering about the network lifetime. However, in a routine data transfer, redundancy, longevity, and multi-hop routing mechanisms are preferred compromising on the latency. However, the energy parameter can't override the heat dissipation aspect in both the cases discussed.

Applications demanding a mix of normal data monitoring and emergency data require prioritization of data and a smooth and efficient coordination between the different layers of the OSI model. It also caters to the varied data types demanding different levels of services. In such scenarios, mobility and energy aspects may have implications considering the application. In a nutshell, the observation is that the academicians and research community come together and look at the problem in a "QoS application-driven mindset". Solving one part of the puzzle, and neglecting the other may lead to directionless efforts.

1.12 Thesis Organization

The thesis is presented in five chapters as follows:

Chapter 1 deals with the introduction to wireless body area networks. It elaborates on the architecture of WBAN, the role of wearables in WBAN, applications, and challenges of WBAN in real-time applications. It further discusses the role of routing protocols in providing solutions concerning the WBAN. The research gaps are presented leading to the research objective identification and formation of the research methodology.

Chapter 2 extensively explores the literature review on WBAN related to the proposed research work. The review provides significant insights related to current state-of-the-art research concerning the role of routing protocols. The challenges in the routing protocols are also presented in the current work providing scope for improvement in the form of research gaps.

Chapter 3 presents significant state-of-the-art research work like the EHCRP [108], EHRCB [109] , EHARP [110], mobTHE[111], IMQRP[112], and RBDT[113]. The proposed algorithm introduces a two-step process. Step 1 includes a path estimation function that provides an optimized route selection and step 2 present the energy conservation model with enhanced network lifetime. Moreover, the proposed algorithm is subjected to the mobility and temperature constraint environment to handle extreme network situations. The proposed work provides better results as compared with the recent state-of-the-art work.

Chapter 4 focuses on the enhanced energy conservation techniques to improve network sustainability in a mobile and temperature-sensitive environment. An extensive literature survey related to energy conservation techniques has been presented. It proposes a novel robust and adaptive energy-efficient model for energy conservation. It focuses on energy harvesting, data compression using the coded system, energy efficient wakeup mechanism, adaptive sampling, and sensing.

Chapter 5 presents the major contributions, conclusion, and future scope of the research work. The thesis work has enhanced the network lifetime owing to the energy utilization due to the presented improved routing algorithm. The performance is significant as it performs in temperature-restricted, and mobility-sensitive environment that causes pathloss, and fading concerns demanding high energy consumption.

Chapter 2
Literature Survey

2. Introduction

Wireless body area networks deal with miniature sensor units with restricted energy deployed on the human body to monitor vital human parameters. The sensors are interconnected to ensure data acquisition, aggregation, and forwarding to the destination unit. Data transmission through the reliable and low-latency route is critical in a remote monitoring environment. As the desired route may change due to the dynamic sensor nodes, it becomes important to identify the best route for each round the data packet is routed to the destination unit. Hence designing routing protocols in a WBAN network has been a significant area of research for the past decades. The routing protocols depend on multiple parameters that define the path estimation function to identify the suitable route. The sensor position, relative distances, real-time energy level, sensor temperature, signal-to-noise ratio, dynamic nature of sensor nodes, and many more contribute to selecting the best route.

The present section highlights the significant contributions of the researchers concerning the selection and improvement of routing protocols. The major types of routing protocols are presented in Figure 2.1.

2.1 Routing Protocols

The QoS-aware routing includes well-known routing protocols like SIMPLE [113], LAEEBA[114], CO-LEEBA[115], MLAEEBA [116], and M2E2[117]. QoS-based routing focuses on a specific set of metrics significant in an environment. For example, a hospital environment is different from a real-time home environment. If the WBAN is surrounded by other similar WBAN networks also known as group WBANs, the approach and QoS metrics will change significantly. These areas demand frequent mobility and different QoS metrics to sustain the network. An ambulance service demand, high-speed transmission, reduced latency, and real-time vital parameter sensing as the patient's life is at stake. Compromising with the energy is acceptable in such an environment however latency and real-time data transfer aren't. Therefore, this type of routing protocol keeps in mind the WBAN. The types of routing protocols are presented in Figure 2.1.

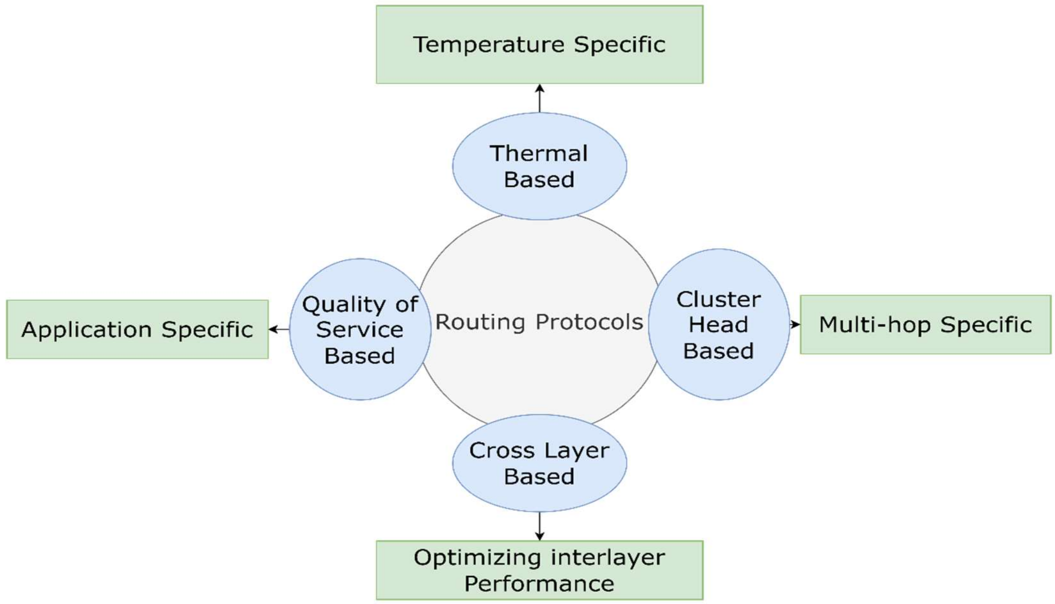

Figure 2-1 Types of Routing Protocol

WBAN can be deployed in varied environmental conditions demanding QoS based on the environment viz the hospital, home, office, etc. Hence while catering to such areas of applications, it is important to prioritize the demands of the network for such an environment. For example, in a hospital, studying the real-time physiological parameter changes in an emergency ward is of utmost priority. Hence latency, link reliability, and high-speed data transmission will define the QoS. Compromise on energy demands can be considered in this case. Mobility of the patient can be excluded. However, a WBAN system deployed on a patient suffering from diabetes may need a different QoS. Patients in the hospital and the real environment have varied QoS challenges. In rescue operations, sports, or missions, the QoS may change, thereby the treatment.

The protocol AMCRP (Adaptive muti-cost routing protocol [118] focuses on traffic prioritization to improve the lifetime of the nodes critical to sustaining the reliability and usability of the network. It considers multi-cost routing considering four parameters viz residual energy, distance, temperature, and priority of data sensed. It includes 19 bio-sensors and 5 relay sensors with the sink node at the centre. The proposed protocol has significant improvement in the network lifetime and network stability. Its application lies in patient monitoring and enhancing the network's lifetime and reliability. It utilizes a priority-based enhanced TDMA approach wherein the forwarding and aggregation are done in the specified time slot. In case of no traffic, the node goes idle mode, saving node energy. The data event is mathematically modeled for the normal and prioritized data. The protocol is compared with SIMPLE and M-ATTEMPT and shows better results. However, mobility and interference issues are not addressed in the work.

Researchers in [119] presented a "Dual Forwarder Selection Technique" DFST to reduce energy drainage and improve the throughput, stability, and reliability of the network. The result reduces the number of dead nodes by 50%. The average throughput is 51% and 8% higher respectively. The residual energy has a drastic improvement as compared with iM-SIMPLE [120] and RE-ATTEMPT. The methodology includes the division of the forwarder nodes into two groups catering to the upper and lower regions. However, it also ensures that the emergency data is allowed to transfer directly to the sink node without the forwarder node. The authors aim to introduce energy harvesting techniques and add security to the network. The application is smart healthcare for the patient.

The issue of fading resulting from postural movements in the patient results in the bit error rate BER. The higher the BER, the higher the power dissipation, and therefore the authors in [121] introduces "Game Theory" using two master nodes to reduce the bit error rate.

ERQTM [122] is a software-driven scheme to deal with the traffic management problem to improve the network lifetime and reliability ensuring QoS. It utilizes the clustering approach with the NP-Hard problem to solve the problem. It addresses the problem of energy balancing in the energy nodes and achieves higher packet delivery rates. It considers multiple QoS metrics to ensure balanced energy consumption using the generic algorithm objective function. The system utilizes cognitive radio-based software driven with a spectrum sensing approach to avoid collision. Comparing the results with EHARP [110] shows significant improvements.

The research work in [112] focuses on real-time Healthcare monitoring systems. It proposes iM-QRP wherein the patient can be monitored while living their normal life in a hospital or home environment. This could be a real boon to the aging society dealing with chronic diseases.

2.2 Literature Survey

The literature survey presented in Table 2.1 considers the year of publication, the protocol, the goals of the respective article, the performance metric used, and the respective research gap in the article.

Table 2-1 Literature Survey

S. No	Pub. Yr.	Protocol	Goal	Performance metrics	Research Gap
1	2023	PLQE-RP[123]	➢ Faster data transmission ➢ Improved reliability	➢ PDR ➢ E2E Delay ➢ Throughput	➢ Temperature Issues not addressed
2	2022	IM-QRP[112]	➢ Improved energy ➢ Path loss reduction ➢ Improved SNR	➢ Residual energy ➢ Path loss ratio ➢ Link reliability	➢ Mobility and Temperature Issues not addressed
3	2021	TLD-RP[124]	➢ Link reliability ➢ Path delay reduction	➢ Throughput ➢ PDR ➢ Stability	➢ Postural movement is not considered
4	2021	ERQTM [122]	➢ Traffic Management ➢ Improved network stability ➢ reliability	➢ Throughput ➢ Residual Energy ➢ E2E delay ➢ Network Lifetime	➢ Mobility and Temperature Issues not addressed

S. N	Pub. Yr	Protocol	➢ Goal	➢ Performance metrics	➢ Research Gap
5	2020	EHCRP [125]	➢ Improve energy ➢ Improved Lifetime ➢ Reduce redundancy	➢ Network Lifetime ➢ Throughput ➢ E2E Delay	➢ Mobility and Temperature Issues not
6	2019	E-HARP [126]	➢ Distributed Network ➢ Energy Harvesting ➢ Remove Redundant Data ➢ Path Loss Issues	➢ Network Lifetime ➢ Throughput ➢ PDR, Stability	➢ Mobility Issue not addressed
7	2019	EH-RCB [109]	➢ Network stability	➢ Throughput ➢ E2E Delay ➢ Stability	➢ Temperature Issues not addressed
8	2019	mobTHE [111]	➢ Mobility issue ➢ Temperature issue	➢ Throughput ➢ Residual Energy	-
9	2019	WET-RP[127]	➢ Improves end-to-end delay ➢ Reduces packet Network Stability drop	➢ Network Lifetime ➢ Throughput	➢ Postural body movement to be considered in future work
10	2019	EEP [2]	➢ Improve energy efficiency	➢ Data reduction and aggregation	-
11	2019	LBEE [128]	➢ Improves Load Sharing	➢ Network Lifetime ➢ Throughput	➢ Node instance traffic load
12	2019	EE-RP [5]	➢ Improved Network Lifetime ➢ Multiple network	➢ Network lifetime ➢ Path loss	-
13	2019	EEFDRS [128]	➢ Improve Network lifetime, ➢ Improve Throughput	➢ Throughput ➢ Latency ➢ Residual Energy	➢ Cost effective energy efficient data Tx
14	2018	ELR-W [129]	➢ Improved Energy Efficiency	➢ Network Lifetime ➢ Throughput	➢ Integration of WBANs with the IoT

S. N	Pub. Yr	Protocol	➢ Goal	➢ Performance metrics	Research Gap
15	2018	Rahat et. al.[8]	➢ Improved Network Stability ➢ Improved Network Lifetime	➢ Network Lifetime ➢ Network Stability	-
16	2018	E-SIMPLE [130]	➢ Improved Throughput	➢ Residual Energy ➢ Distance	-
17	2017	OCER [131]	➢ Improved Network Lifetime	➢ Residual Energy ➢ Throughput	➢ Inter-BAN
18	2016	ENSA-BAN [132]	➢ Improved QoS ➢ Optimized link cost function	➢ Residual Energy ➢ end-to-end delay ➢ PDR	➢ Body movement and packet prioritization
19	2015	Energy efficient routing [12]	➢ Improved Network Lifetime	➢ Residual Energy ➢ Distance	-
20	2015	Multi-hop cost function [13]	➢ Improve Network Lifetime	➢ Dead Nodes ➢ Residual Energy ➢ e2e delay ➢ Throughput	-
21	2015	ARBA [133]	➢ Enhanced bandwidth utilization ➢ Improved Network Lifetime ➢ Improved Routing	➢ Residual Energy ➢ Throughput	-
22	2015	Co-LAEEBA [115]	➢ Improved Routing ➢ Path-loss	➢ Network Stability ➢ Residual Energy ➢ Path Loss	➢ Adaptive learning-based load-forecast

S. N	Pub. Yr	Protocol	➢ Goal	➢ Performance metrics	➢ Research Gap
23	2015	QPRD[134]	➢ Improved Network Lifetime	➢ Residual energy ➢ PDR ➢ Throughput	-
24	2014	Two-hop transmission scheme [18]	➢ Improved Network Lifetime ➢ Improved Network Stability	➢ Residual Energy ➢ Total energy ➢ Dead Nodes	-
25	2014	Relay-based Routing protocol [19]	➢ Improved Network Lifetime ➢ Reduced end-to-end Delay	➢ Residual Energy ➢ Dead Nodes ➢ Network lifetime	-
26	2014	LAEEBA[114]	➢ Minimal Pathloss	➢ Network Stability ➢ Residual Energy ➢ Network Lifetime, ➢ Throughput	➢ Expected Transmission Count and delay spread link metrics
27	2014	Modified LAEEBA [135]	➢ Improved Throughput ➢ Reduced end-to-end Delay	➢ PDR ➢ E2E Delay ➢ Throughput	➢ Not capable of handling the faulty node
28	2014	ZEQoS [136]	➢ To provide better QoS by selecting the best routing paths	➢ Residual Energy ➢ Throughput,	-
29	2015	CDR [137]	➢ Improved Reliability ➢ Reduced delay	➢ PDR ➢ Residual Energy	➢ Poor performance average temperature rise
30	2013	SIMPLE [138]	➢ Improved Network Stability ➢ Improved Throughput	➢ Network lifetime ➢ Network Stability ➢ Throughput, ➢	➢ Implement Expected Transmission Count (ETX) link metrics

S. N	Pub. Yr	Protocol	➢ Goal	➢ Performance metrics	➢ Research Gap
31	2012	QRP [139]	➢ Improve energy efficiency	➢ Residual energy ➢ Hop Count	➢ Improved moderately balanced energy consumption
32	2012	EPR [140]	➢ Improve Reliability ➢ Reduce network traffic ➢ Improve energy efficiency	➢ Traffic load ➢ Energy consumed ➢ Throughput	➢ Reliability and network lifetime
33	2012	EERS [31]	➢ Adaptive power transmission ➢ Improving energy efficiency	➢ Throughput ➢ End-to-End Delay	-
34	2012	Modified Dijkstra's Global Algorithm [141]	➢ Improved Network Lifetime	➢ Network lifetime	-
35	2011	QPRD [134]	➢ Reduce end-to-end delay	➢ Traffic load, Transmission rate, number of packets timeout	-
36	2011	DMQoS [142]	➢ To achieve best QoS services for different data types	➢ End-to-End delay ➢ PDR,Residual Energy	-
37	2010	EAR [143]	➢ Improved Network Lifetime ➢ Improved Network Reliability	➢ Network Stability Data aggregation	-
38	2008	RL-QRP [144]	➢ Improved Throughput ➢ Reduced end-to-end Delay	➢ E2E delay ➢ PDR ➢ Residual Energy ➢ overhead	➢ Multi-agent reinforcement learning framework

2.3 Research Gaps

After a detailed literature review, the following research gaps are listed: -

- The energy constraint is critical in ensuring the longevity of usage of the WBAN. Specifically dealing with real-time WBAN applications related to human life.
- The mobility concern demands a robust network to handle reliable packet transmission. So, an intelligent routing mechanism can be implemented to provide reliable, low-latency packet transfer specifically in a critical or emergency.
- The WBAN sensors may get heated due to usage or other factors that could be harmful or life-threatening as the sensors may be implanted or mounted on the human skin. Although the sensor temperature aspect has been discussed in the existing research, the holistic approach involving other critical aspects needs attention.
- Energy conservation methods can be modified to enhance the energy efficiency of the WBAN.

2.4 Research Objective

Considering the research gaps discussed in the previous section, it is clear that an energy-efficient routing protocol is required to identify the optimal route in a mobility and temperature-sensitive environment. Observing the requirements concluded with an extensive literature review, the research objectives of the proposed research work are outlined as:

1. Investigation of routing protocols and propose routing algorithms for Quality of Service (QoS) provisioning in WBAN.
2. Development of mathematical models considering the Cost Function (CF) for proposed protocols.
3. Design the routing protocols for QoS in static and dynamic sensor nodes.
4. Performance evaluation of proposed algorithms using standard benchmark.

2.5 Research Methodology

The set of steps required to achieve the objectives defined in the research work is presented in Figure 2.2 comprising the research methodology adopted in the thesis.

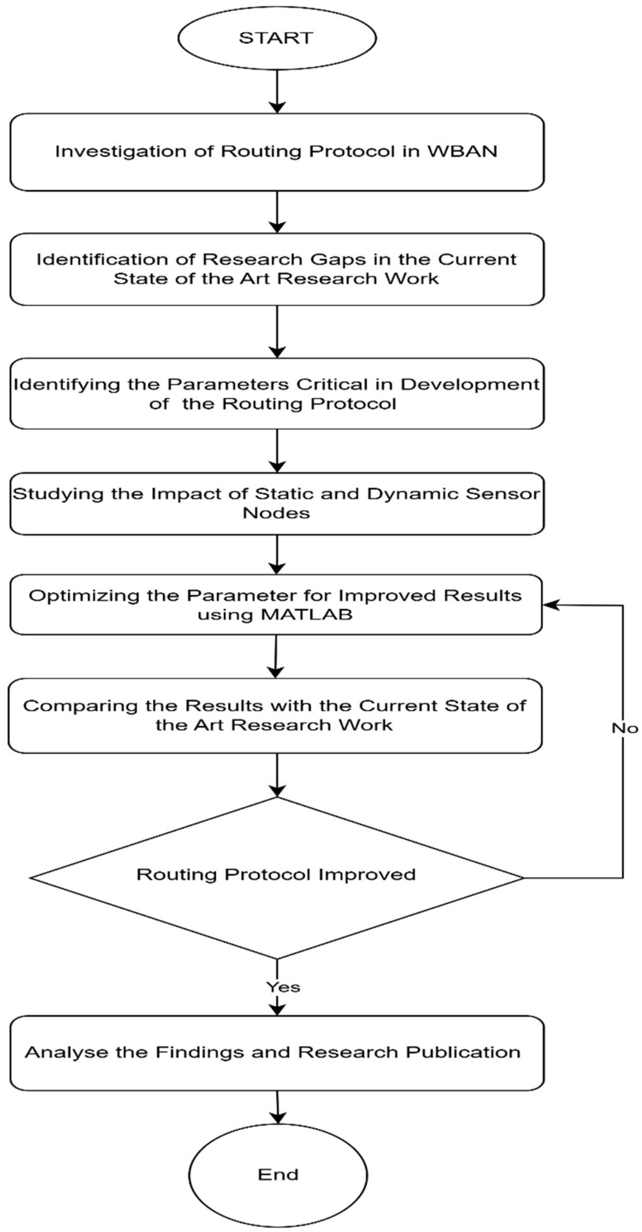

Figure 2-2 Research Methodology

The proposed research presents a novel Mobility and Temperature Sensitive Energy-Efficient Routing (MTS- EER) algorithm that involves a two-step process. In step 1, an Intelligent Path Estimation Function (IPEF) is designed considering the sensor's mobility, temperature, and energy level. IPEF depends on crucial parameters i.e.: -residual energy, distance, signal-to-noise ratio (SNR), total energy, and most importantly temperature of the sensor unit. The lowest IPEF value sensor is selected as the Cluster Head (CH). In step 2, an optimized and sustainable energy conservation model (OSECM) is implemented using the Adaptive Transmission Power (ATP) and the Power Management Module (PMM). The ATP conserves the energy via intelligently varying the transmission power and PMM manages the sleep pattern of sensor nodes to yield a high network lifetime and efficient energy utilization. The algorithm includes a clustering approach with dual sink nodes to conserve energy and improve reliability. Finally, the results are observed with the recent state-of-the-art research work. The proposed algorithm provides better results considering residual energy, throughput, network lifetime, and end-to-end delay.

2.6 Summary

The chapter presents an extensive literature review presenting the role of WBAN network in healthcare to quality of health services to the individual. It also presents the challenges of the WBAN network including the transmission through the reliable and low-latency route. The routing protocols and their major types are presented. The literature survey incorporates exhaustive study of more than 15 years of research highlighting the research gaps. The major issues that still need further attention are the energy constraints in temperature-sensitive environment and the mobility concerns for a robust network. The research objective presents the study of routing protocol for the static and dynamic environment to improve the energy constraints in a mobility-driven temperature-sensitive environment is presented. Finally, the research methodology and the thesis organisation is presented to highlight the overview of the research work.

Chapter 3
Mobility and Temperature Sensitive Energy Efficient Routing Protocol in Wireless Body Area Network

3. Overview

This chapter presents two algorithms MTS-EER and OSECM to address the energy concerns of the network in a dynamic environment. The MTS-EER algorithm mainly focuses on the mobility and temperature aspects with dynamic sensor nodes. It depends on the cost function that guides the packet transfer to the destination in an energy-efficient manner. The OSECM model conserves energy by implementing adaptive power transmission and management modules.

Sensor technology advancements have provided the platform to implement wireless body area networks, thanks to the nanosized sensor units capable of sensing, aggregating, and forwarding physiological information. The collected information is routed to the desired destination unit for data analysis and decision-making in remote healthcare. However, improving energy utilization remains a brain-teasing problem for the research community, especially considering imbalanced energy consumption and postural movements. Mobility contributes to disconnectivity issues, high energy drainage, and retransmission delays. In addition, the sensor node's thermal level also poses a challenge in maintaining safer and reliable data transmission. To overcome these issues, a novel Mobility and Temperature Sensitive Energy-Efficient Routing ¬(MTS-EER) protocol has been proposed that includes a two-step process. In step 1, an Intelligent Path Estimation Function (IPEF) is designed considering the sensor's mobility, temperature, and energy level. IPEF depends on crucial parameters i.e.: - residual energy, signal-to-noise ratio (SNR), distance, total energy, and most importantly temperature of the sensor unit. The sensor node with the least IPEF is selected as the Cluster Head (CH). In step 2, an optimized and sustainable energy conservation model (OSECM) is implemented based on the Adaptive Transmission Power (ATP) and the Power

Management Module (PMM). The ATP conserves the energy via intelligently varying the transmission power and PMM manages the sleep pattern of sensor nodes to yield a high network lifetime and efficient energy utilization. The algorithm includes a clustering approach with dual sink nodes to conserve energy and improve reliability. Finally, the results are compared with the recent state-of-the-art research work. The proposed algorithm provides better results considering residual energy, throughput, network lifetime, and end-to-end delay.

3.1 Introduction

WBAN have emerged as a boon in the healthcare system as the world suffers from chronic diseases. The WBAN architecture in presented in Figure 3.1. In a normal scenario, the affected population has no other option than to visit the medical healthcare services frequently, which increases the ratio of patients compared to available medical staff. It not only adds a financial burden to the patient but also restricts the medical staff to monitor the patient frequently. WBAN provides a remote monitoring facility wherein the sensors collect and provide vital information to the medical health care for critical diagnosis and decision-making. The collected data is stored in the central database that can be accessed by medical experts, medical institutions, scientists, and the research community. Hence an ecosystem is created that benefits the patient, researchers, medical practitioner, and the medical industry. It finds application in various areas including telemedicine, remote monitoring, sports, and personalized healthcare. This ecosystem's foundation lies in collecting sensitive data from the sensor units. These sensors are expected to work efficiently to provide reliable, real-time data critical for decision-making. These sensor units can be deployed inside or on the human body which can be a part of the Internet of Things[123]. The sensors deployed inside the body generally require complex procedures with higher expenses and expertise. Therefore, the sensor is required to be operational for a very long duration and must be hazard-free. Sensors deployed on or around the human body are miniature with limited power storage. It therefore demands efficient energy utilization in a resource-constrained environment [1], [85], [107], [145]–[150].

Researchers have explored various techniques to optimize the energy requirements in a network. The most common approaches include using dual sink nodes[151]–[154], relay nodes[155], [156], multi-hop[123], [157], [158], clustering approach[159]–[161], cross-layer approach, temperature-based approach, quality of service approach[112], [122], [123], [162]–[164], and many more. All these approaches focus on identifying the optimal route to the destination unit i.e., the Sink Node (SN) also known as the Central Co-ordinator Node (CCN). The sensed data is collected and sent directly to the CCN.

The sensor placement in or on the human body defines the network topology which is critical in designing an efficient WBAN network. Once the sensors are deployed, the initialization process is initiated. The CCN is capable of higher storage and processing capabilities as compared with other sensor nodes also labeled as Normal Nodes (NN). The CCN doesn't sense the data but only stores and processes it before forwarding it to the other external networks as mentioned in Figure 3.1. The miniature size of the sensor node has limited resources. Hence the battery level of the sensor node depletes faster owing to multiple operations. The nodes farther from the CCN deplete faster as the distance between them is high. It results in unbalanced energy consumption in the network leading to network failure. It causes network failure even when other sensor nodes have ample sensor energy to sustain the network.

Therefore, the concept of Cluster Head (CH) has been introduced by the researchers. It is used to balance the network load by selecting the best sensor node as the cluster head considering multiple significant parameters. Redundant data transmission also affects the network performance. Therefore, the identification and elimination of duplicate data becomes critical in ensuring network longevity. Retransmissions due to packet loss also drain the network energy resources. Packet loss can be attributed to path loss due to postural movements, signal-to-noise ratio

SNR, or inefficient route selection. Another major constraint is the thermal level of the sensor node which may increase beyond a safe zone leading to harm to the human skin. It restricts the usage of that sensor node further till it achieves the safer limits.

Hence a well-designed routing algorithm is required to provide quality of service QoS driven resource management. This demands the creation of an intelligent route cost function that could handle such a scenario. It must consider single-hop transmission for emergencies and situations where the sensor node is closer to the CCN than the CH. In such a situation, real-time and reliable delivery of information is of utmost importance. In the case of normal data transfer, dual or multiple-hop transmission can be considered. It will provide an optimized route that provides balanced energy utilization and ensures robust link identification. It will lead to better network stability, longevity, and throughput with a slight compromise with the end-to-end delay which is acceptable in the case of normal data transmission. However, it demands a robust route selection function to provide the benefits discussed. Also, it has been observed that better link quality can help reduce the retransmission issue. These issues are due to path loss, path noise, and postural motion resulting in network disconnectivity issues. Better link quality will contribute to high reliability, low latency, and lesser retransmissions. Sensor units that are designed to compare and eradicate duplicate data need to be incorporated to avoid redundant transmissions. As the nominated CHs are continuously aggregating and processing the data, the high heat dissipation problem also needs deliberation.

Given the various points discussed above, critical issues that need immediate attention are the network lifetime, network stability, and throughput in a mobility-constrained temperature-sensitive environment. To overcome these issues, a novel Mobility and Temperature Sensitive Energy Efficient Routing (MTS-EER) protocol is presented in this research work. The present work relies on clustering the body sensor nodes into two clusters. Each cluster is designated with a CH depending on the individual value of the IPEF of the cluster members. It enables network partitioning enabling optimized energy utility. It provides better reachability by reducing the distance between the CH and the sensor node in a cluster. It thereby reduces the energy consumption in data transferring to the selected CH improving the reliability and longevity of the network. The CH's role is to evenly balance the energy consumption thereby enhancing the network lifetime which is a critical aspect of a wireless body area network. The nominated CH is responsible for data aggregation from all the cluster member nodes and transmits it to the CCN in the respective time slot. In addition to this, to avoid network disconnectivity issues, two CCNs are used to balance the network load and provide better network stability. Due to the postural movements, the distance between the dynamic sensor unit changes. Therefore, the path loss issue and interference issues increase leading to packet drop. By introducing two CCNs on the left and right sides, these issues are resolved with reduced packet drops and reduced energy consumption between the CHs and the respective CCNs. It also contributes to balancing the network load improving network lifetime and reducing end-to-end delay. The CCN's role is to collect the data from the sensor nodes deployed in/on different parts of the body and send it to the layer 2 network for further processing. The CH is selected based on the cost function which considers varied parameters to optimize the route. The aggregation and forwarding of data may lead to relatively higher energy consumption. Therefore, dynamic CH selection is proposed to ensure energy balance in the network leading to network longevity. The proposed protocol is depicted and presented in the flowchart as mentioned in Figure 3.3.

The proposed work optimizes the network resources to achieve the following:

- We propose a novel Intelligent Path Estimation Function (IPEF) to select the CH that handles the problem of mobility and thermal sensitivity of the sensor. The proposed novel IPEF method helps in routing and maintaining the energy level of the sensor node and avoids spikes in temperature among the sensor node.

- We propose an Optimized and Sustainable Energy Conservation Model (OSECM) to improve energy distribution and enhance energy conservation using the Adaptive Transmission Module (ATP) and the Power Management Module (PMM). The ATP module varies the transmission power considering the sensor node location and contributes to the energy conservation of the sensor node. PMM regulates the sleep cycle of the sensor node till the immediate next time slot and thereby conserves node energy.
- Further an Effective Redundant Data Cancellation (ERDC) mechanism is introduced. All the sensor nodes shall be capable of storing and comparing the consecutive data packets for similarity. In case of a similarity match, the packet is discarded otherwise it is considered for forwarding to the CCN.

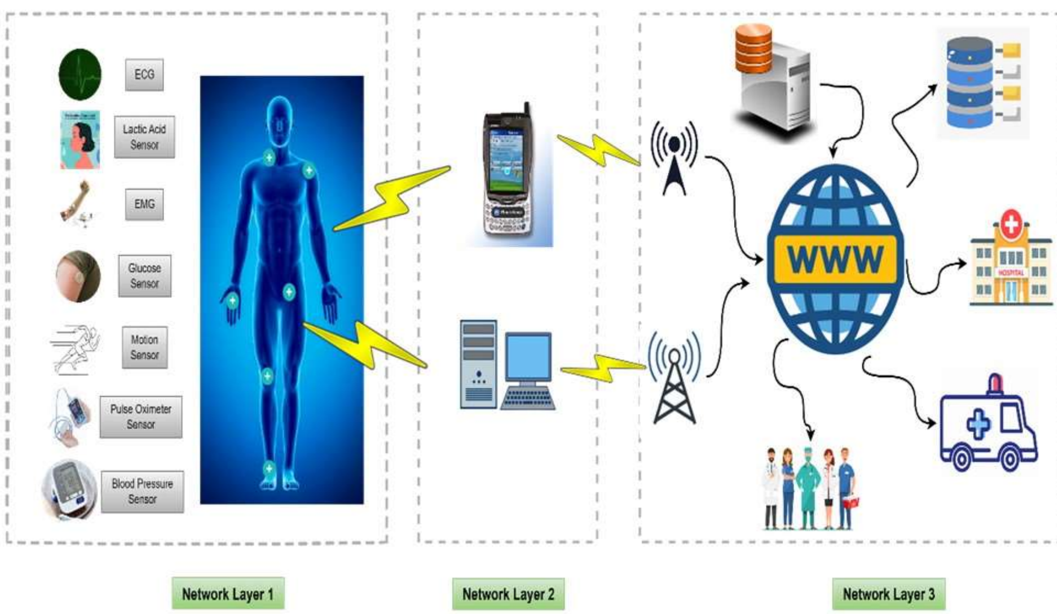

Figure 3-1 Wireless Body Area Network Architecture

The recent state-of-the-art research in the field is presented as the "Related Work" in section 3.2. "System Model" is presented in section 3.3. The proposed algorithm is explained in section 3.4. Section 3.5 presents the results and provides insight into it. The conclusion encapsulates the significant highlights and presents future directions of research.

3.2 Related Work

The researchers in [125] introduced EHCRP having ten sensors to achieve energy-efficient routing in the WBAN network. It utilized two sink nodes acting as co-ordinators. It proposed the integration of Internet-of-Things with WBAN to promote remote health monitoring. It addresses the issues of duplicate data transmission in a heterogeneous sensor network. It considers multiple parameters like Residual Energy, Network Congestion Level, SNR, etc. These parameters collectively contribute to selecting the forwarding node using the path function. The paper claims efficient and reliable data transmission using PCEF. It utilizes energy harvesting techniques that help improve the network stability and lifetime. The single-hop or multi-hop transmission depends on the type of data. Direct packet transfer is preferred in critical or emergency data transmission to ensure low latency and real-time data delivery. The energy-efficient techniques are utilized in normal data transfer to absorb latency concerns. However, the temperature aspect is not considered in this work. It governs performance and human safety.

The authors in [165] focus on stabilizing the WBAN network. The routing technology with two sink nodes is connected in the front and back. It considers an energy harvesting technique EH-RCB which utilizes a clustering approach considering four parameters: SNR, required transmission power, total available energy, and distance between nodes. The cost function is derived from these parameters to select the forwarding node which also acts as the cluster head for that transmission round. The CH is nominated in every round to identify and update the best forwarding node. The paper indicates better results for E2E delay, PDR, network throughput, and network stability. However, it does not consider the temperature aspects in calculating the cost function.

EHARP [110] utilizes an energy harvesting technique with a clustering approach to improve the routing mechanism. It restricts the duplicate data at the sensor unit only to retain and conserve energy critical for effective routing. It utilizes two Coordinator Nodes to avoid path loss and improve network energy balancing. It utilizes a dynamic cluster head approach wherein the CH is nominated on rotation. The route calculation function helps identify the suitable CH, which depends on four parameters. Mobility concerns are considered in terms of network disconnectivity issues. However, the algorithm ignores the sensor heating impact on the human skin which could harm the patient utilizing the technology.

Mobility-assistive temperature-sensitive algorithm for heterogeneous sensor nodes is addressed in mobTHE [111]. It focuses on sustaining the network based on node lifetime, throughput, and temperature. It uses two co-ordinator nodes acting as the sink node for continuous data reception from different sensor nodes simultaneously. Hence it also focuses on dropping the duplicate data received by the two co-ordinating nodes. It synchronizes the two Coordinator Nodes to optimize network resources and improve the packet drop rate. Dual hop transmission is adopted in case the sensor node is not in direct contact with any of the coordinator nodes. In such a case, the node looks for the nearest possible sensor node as the forwarder node to the Coordinator Node. It considers the temperature parameter considering the mobility issues however energy and link reliability aspects can be further improved.

The leveraging of the network management flexibility of Software-defined Networking (SDN) and cognitive radio is considered in ERQTM [122] to provide QoS in heterogeneous WBAN. It considers network lifetime, minimum delay, and throughput to achieve desired QoS. It thereby improves network reliability and stability. It focuses on routing mechanisms and traffic management using clustering techniques. It considers parameters: RE, energy consumption rates in consecutive intervals, SNR, path loss, and distance to SDN. However, issues related to duplicate re-transmissions are not addressed in this paper.

A QoS-based RBDT scheme [113], is introduced to handle the redundant data transfer and its overloading effects in a WBAN network. It includes node behavior identification, relay selection, and data compression techniques to optimize energy consumption and improve network lifetime and overall performance. However, the RBDT scheme can further be enhanced considering temperature and mobility constraints in a dynamic WBAN.

The literature review discussed above has presented the research achievements and research gaps. To overcome the addressed problem, the MTS-EER protocol is proposed and presented in the paper. Section 3.3 will explore the system model considered for the WBAN network.

3.3 System Model

The system model includes the network model, the path loss model, and the energy model which has been discussed below.

i. Network Model

The network model consists of two Central Coordinator Nodes CCN1 and CCN2 deployed on the left and right side of the body (Figure 3.2). The sensor nodes are positioned on the body considering the physiological parameter to be measured. Considering the human body's dynamics, fourteen sensor nodes and two CCNs are deployed on the various parts of the body as depicted in Figure 3.2. The model considers single-hop communication in case of emergency data or the sensor node is a hop distance from the NNs. To optimize the network performance, dual-hop communication is considered in normal data transfer via a selected CH. In such a scenario, IPEF is evoked to identify the suitable CH. All the sensor nodes calculate the IPEF shared with the CCNs. The CCNs select the node with the least IPEF as the CH. Time slots are periodically allocated to the CH by each CCN during the initialization stage related to the sensing and transmission of data using the TDMA approach.

The proposed research work considers the following assumptions related to the network: -

1. The position of the dynamic nodes may change due to the postural body movement.

2. The power consumption for the data acquisition and processing by the sensor nodes is negligible concerning the transmission power and therefore neglected.
3. The Energy Harvesting (EH) technique is introduced in the network to cater to the limited availability of energy resources. The factors that can replenish the depleting energy resource are the rate of charging and the availability of consistent energy harvesting sources.
4. The network includes 14 NN and 2 CCNs measuring vital signs.

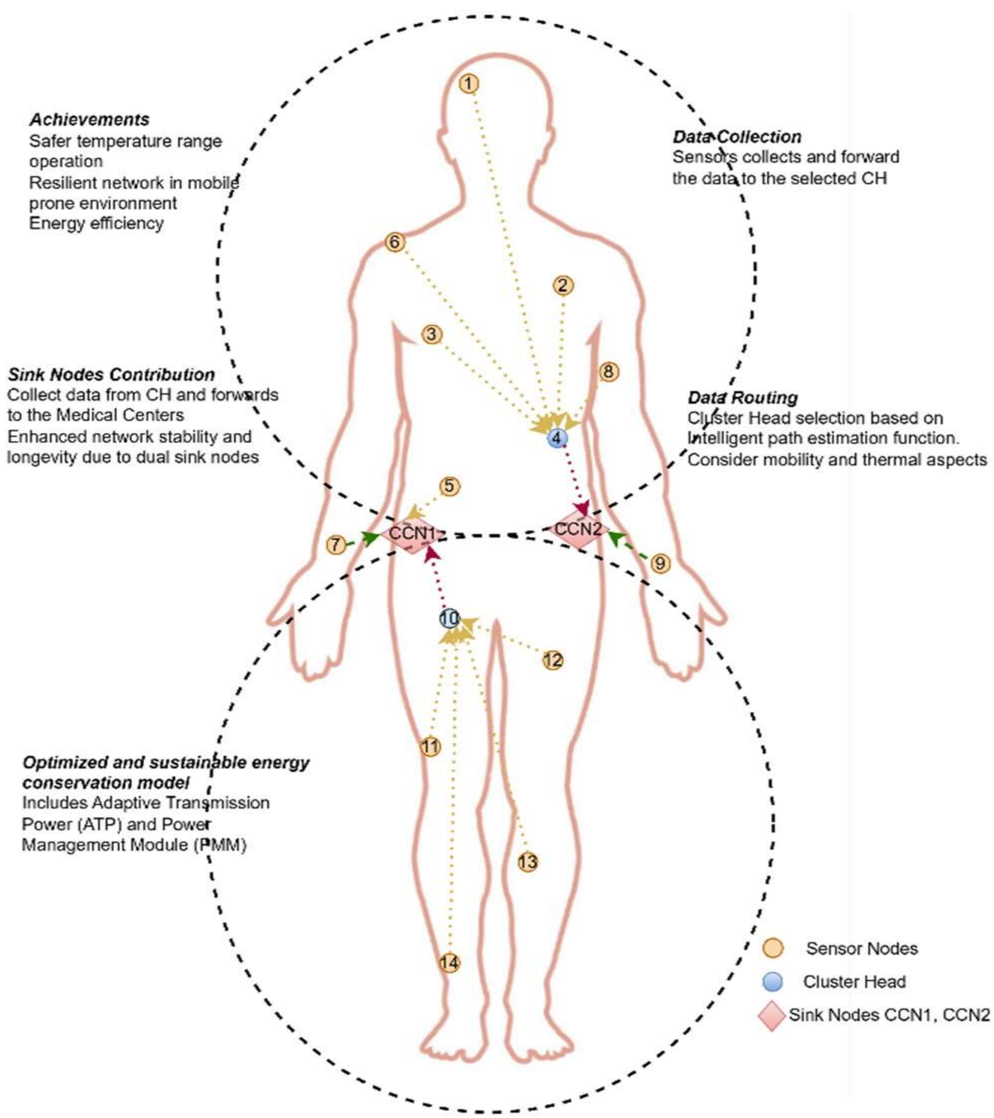

Figure 3-2 Node Deployment on Human Body

ii. Path Loss Model

The path loss model is followed based on the frequency and distance as mentioned in the equation:

$$PL_{(d)} = PL_{(d0)} + 10\eta \, log_{10} \frac{d}{d0} + \sigma_s \quad \textbf{(1)}$$

Wherein $PL_{(d0)}$ *is given by*

$$PL_{(d_0)} = 20 \, log_{10} \frac{4d}{\lambda} \quad \textbf{(2)}$$

Here λ is the wavelength, d is the distance between the transmission unit and the receiver unit. Also $\lambda = \frac{f}{c}$, therefore equation 2 is represented by

$$PL_{(d_0)} = 20 \, log_{10} \frac{4\pi df}{c} \quad \textbf{(3)}$$

Here c is the speed of light and f is the frequency.

iii. Energy Consumption Model

The energy consumption in the network is presented into four types:

- The energy consumption due to the transmission of K bits depend on the distance d and due to the electric circuit to sustain the transmission is expressed by

  $$ETx(K, d) = K * (Energy_{Tx} + \eta * Energy_{Amp} * d^2) \quad \textbf{(4)}$$

  Here $E_{Tx(K,d)}$ represents total transmission energy consumed by the sensor node considering the distance between two nodes, K is the bits/data packet sent, $Energy_{Tx}$is the energy consumed to send one bit of data and $Energy_{Amp}$is the energy consumed by the electrical circuit to transmit one bit of data. The expression is derived from the first-order ratio model.
- The energy consumed during the reception of K bits depend on the bits received and the energy of the electric circuit as expressed by: -

$$E_{Rx(K,d)} = K * (Energy_{Rx}) \quad \textbf{(5)}$$

Here $E_{Rx(K,d)}$ is the energy required by the electrical circuit to receive the K -bit data packet.

- The energy consumed in the accumulation of K bit data packet is presented as:

$$E_{Ag(K)} = K * \left(Energy_{Ag}\right) \quad \textbf{(6)}$$

- The energy consumed by the node to sense the vital sign is given by: -

$$E_{Sense(K)} = K * (Energy_{Sense}) \quad \textbf{(7)}$$

Therefore, the total energy consumed during the process of sensing, aggregation, transmission, and reception of K bit packets is given by: -

$$E_{Total(K,d)} = E_{Tx(K,d)} + E_{Rx(K,d)} + E_{Ag(K)} + E_{Sense(K)} \quad \textbf{(8)}$$

iv. MTS-EER Protocol

The proposed algorithm majorly considers the following issues concerning the WBAN network: -

- Imbalanced energy utilization restricting the network lifetime and compromising the network reliability. Intelligent path estimation function ensures balanced energy utilization in the network.
- Postural movements causing network discontinuity due to non-line of sight NLOS issues leading to network failure. Therefore, two CCNs are introduced to overcome this issue.
- Overheating of implanted and wearable sensor nodes affects the efficient utilization of the route. It also has the potential to harm the human skin. Considering the safer threshold value and adaptive temperature function in the IPEF calculation overcomes this issue by considering multiple parameters for network route tuning. Duplicate data transmission causes unnecessary energy expenditure. The issue became severe when the duplicate transmitted packet also got rejected. Hence ERDC mechanism is introduced to overcome this issue.

- Sensor nodes sending data at full power capacity even when lower power transmission is sufficient to do the same leading to energy wastage. This issue is resolved by using the OSECM model.
- Sensor nodes remain active throughout the network lifetime leading to energy wastage. Therefore, the sensors need to be kept idle while not in use by providing sleep mode till the next time slot for transmission.

v. Experimental Setting and Parameter Selection

The MTS-EER protocol is implemented using the MATLAB simulation tool to validate and compare with the recent protocols. The sensor nodes and their positional coordinates are tabulated in Table 3.2. It includes 14 normal sensor nodes NN and two CCNs on the left and right sides of the body as presented in Figure 3.2. The simulation environment is presented in Table 3.1. It indicates the simulation dimension of 2x2 m^2 and the energy consumption pattern. The payload and node temperature T at different points in the simulation phase are presented in Table 3.1.

The Received Signal Strength Indicator (RSSI) calculates distance and location coordinates. The sensor nodes calculate the distance between the neighboring and central coordinator nodes. The next step includes a BEACON message transmission providing the node identification, neighbor distance d, destination node identification, residual energy RE, temperature T of the sensor node, and the location of the node. The dynamic nodes share the updated location after a fixed interval. In this manner, the CCNs and the sensor nodes are well-informed about their locations at any time. Therefore, a well-tuned WBAN network simulation environment has been created to address the issues with the current state-of-the-art research articles focusing on enhancing network performance. The next section deals with the calculation of the cost function.

vi. Intelligent Path Estimation Function Calculation

The best route identification is critical in optimal data transmission. It not only improves the energy utility in the networks but also enhances various other factors associated with it. It improves the packet delivery ratio, avoids retransmissions, balances energy consumption, and ensures reliable data transmissions. The existing state-of-the-art protocols generally consider the distance between nodes and the residual energy of the nodes to optimize the network performance. This paper presents a multi-parameter selection approach that depends on the weight factor contribution. Apart from the standard distance and residual energy, the present work considers the temperature of the sensor node as a critical parameter.

Apart from the standard distance and residual energy, the present work considers the temperature of the sensor node as a critical parameter. It affects the real-time application of the network owing to the health concerns associated with it. The mobility issue arising due to the postural movements of the human body also challenges and affects the network topology. Mobility is linked with the path loss factor which increases with an increase in distance between the mobile node and the coordinator nodes. To address the mobility issue, the path loss factor and the link efficacy are considered. The link efficacy indicates the health of the network. Hence all the above points are considered in the paper to optimize the route of the packet transmission.

To summarize, the factors involved in the calculation of the Intelligent Path Estimation Function (IPEF) are residual energy RE, distance d, link efficacy (LE, and temperature T while observing SNR.

The expression of IPEF is given by:

$$IPEF = \frac{\alpha * RE + \beta * LE + \delta * d + \tau * T}{SNR} \quad \textbf{(9)}$$

Here, α,β, δ, and τ are the weighting factors of RE, LE, d, and T

As the BEACON message is shared in the network, the path loss is calculated. The value of path loss defines the quality of the network. If the value is greater than 0.5 then it is considered good otherwise not fit for transmission.

Table 3-1 Simulation Environment

Environment Details	**Value**
Simulation Dimension	2x2 m2
Sensor Nodes	14
Sink Nodes	2
Network nodes positions	As per Table 3.2
Sensor energy, **E**	0.5 J
Energy consumed for transmission	16.7nJ/bit
Energy consumed for reception	36.1nJ/bit
Energy consumed by the amplifier	1.98nJ/bit
Initial node temperature, **T**	37^o C
Node Sleeping temperature, $\mathbf{T_s}$	42^o C
Node Wakeup temperature, $\mathbf{T_w}$	40.3^o C
Node temperature rise, $\mathbf{T_{inc}}$	0.01^o C/transmission
Node temperature decrease, $\mathbf{T_{dec}}$	0.02^o C/sleeping round
Wavelength	0.138m
Frequency	2.4 GHz
Payload	3000

The present network considers the energy-centric approach and employs a simple path loss function. The distance d between two sensor nodes is calculated by using the Euclidean Distance equation given as

$$d(i,j) = \sqrt{(X1 - X0)^2 - (Y1 - Y0)^2} \quad \textbf{(10)}$$

Link Efficacy (LE) between two nodes (i , j) is an indicator of end-to-end transmission which can be given by:

$$LE = \frac{T_{PR}}{T_{TX}} \quad \textbf{(11)}$$

Here T_{PR} is the total packets received and T_{TX} is the total packets transmitted.

Table 3-2 Sensor Node Co-ordinates

Node	***Sensor***	***X-coordinate***	***Y-coordinate***
1	*EEG*	*0.32*	*1.77*
2	*ECG*	*0.35*	*1.37*
3	*ECG*	*0.22*	*1.35*
4	*Glucose*	*0.36*	*1.01*
5	*Glucose*	*0.35*	*0.01*
6	*Motion*	*0.08*	*1.45*
7	*EMG*	*0.06*	*0.98*
8	*Blood Pressure*	*0.37*	*1.27*
9	*Pulse Oximeter*	*0.4*	*1.01*
10	*Lactic Acid*	*0.22*	*0.91*
11	*Accelerometer*	*0.45*	*0.45*
12	*Respiration*	*0.15*	*0.5*
13	*Pressure*	*0.15*	*0.45*
14	*Pressure*	*0.25*	*0.17*
CCN1	*Central Coordinator Node (Right)*	*0.3*	*1.03*
CCN2	*Central Coordinator Node (Left)*	*0.09*	*1.05*

The signal strength is also affected by the noise produced by the surrounding electronic devices using communication technologies. In the present work, Higher noise level leads to higher packet drop rates. Therefore, its value must remain within the safer limits for effective packet transmission. The SNR expression is given by:

$$SNR_{RX} = P_T + P_{pl} + P_N \quad \textbf{(12)}$$

Here SNR_{RX} is the SNR of the receiver, P_T is the power of the transmitter, P_{pl} is the power of the path loss + P_N is the power of the noise.

vii. Cluster Head Formation

The cluster head formation and data transmission are presented in Figure 3.3 and Figure 3.4. respectively. It is identified by calculating the IPEF values of all the cluster sensor nodes based on equation (9). These values are then shared with the neighboring nodes and the respective CCNs. The sensor node with the least value of IPEF is selected as the cluster head by the respective CCN. All the sensor nodes are informed about the selected CH. All the sensor nodes in a cluster shall forward the data to the CH which aggregates and forwards it to the respective CCN. A new CH is nominated in every round based on the updated $IPEF$ values of the sensor nodes.

The distance $d(i, CH)$ indicates the distance between the present sensor node i and the cluster head CH of the specific cluster. The distance $d(i, CCN)$ indicates the distance between the present sensor node and the sink node. Hence, if the sensor node is nearest to the CCN, it will directly send the data to the respective CCN. It reduces end-to-end delay and improves energy consumption and packet delivery ratio. However, if $d(i, CCN) > d(i, CH)$ then the data packet is transmitted to CCN through CH to facilitate balanced energy consumption thereby improving network stability and network lifetime. The cluster head is nominated in every round to ensure the sensor node with the help of the cost function value $IPEF$ value calculated using the critical parameters. Tuning these parameters effectively can be revolutionary in providing real-life health monitoring devices.

3.4 Optimized and Sustainable Energy Conservation Model

It has been observed that unbalanced energy usage remains a major concern that the research community is still grappling with in recent times. Therefore, in the proposed work, an "Optimized and Sustainable Energy Conservation" OSECM model is presented. It considers the adaptive transmission power (ATP) module to conserve the sensor node energy. The coordinates of the network for extreme distance communication are identified between the sensor node 14 with coordinates (0.25, 0.17) and the $CCN1$ coordinates (0.3, 1.03). The Euclidian distance is identified to be 86.1 cm.

Table 3-3 Notations Used in Algorithms

Abbreviation	Description
H.P.	Hello Packet with source and destination details
RE	Residual Energy left with the neighbor nodes
LE	Link efficiency in terms of packets received for packets sent by a node
D	distance within sensor nodes including CCNs
T	sensor temperature level
N.T.	Neighboring Table with all updated parameter
N_i	Source Node
N_x	Immediate Node for N_i
CCN1	Central Co-ordinator Node 1
CCN2	Central Co-ordinator Node 2
SNR	Signal-to-Noise Ratio
IPEF	Intelligent Path Estimation Function
RT	Routing Table
ND	Normal Data
ED	Emergency Data
RD	Redundant Data

The safer maximum power transmission required in communicating at a distance of 90 cm is considered. The per cm power factor comes out to be 1.11.

Here b is the additional 4% power buffer to ensure the reliability of data packet transfer. Now once the distance between the sender and receiver node is identified, it is multiplied by the power factor (PF) of 1.11 to get the Percentage Power Transmission Requirement $PPTR$ as mentioned:

$$PPTR = d(i,j) * PF + b \quad \textbf{(13)}$$

In OSECM, all sensors forwards data to the CH or CCN in a specific time slot only except in critical data. Therefore, the power management module (PMM) ensures that the sensor node shall remain in sleep mode for the respective time slot.

The same applies when a redundant data packet is dropped and the sensor node shifts to sleep mode. It contributes to effective energy conservation by switching the sensor node to the Sleep Mode during idle time.

Algorithm 1 Topology Discovery and Packet Sensing

Step1: Hello Packet (H.P.) received from neighboring nodes 'i' and 'j'

1. *Start*
2. *For every hello packet*
3. *If* $H.P.(RE, LE, d, T) = N.T.(RE, LE, d, T)$

Packet information of neighbor table is recorded

4. *Update the details in the neighboring table*
5. *Else*
6. *The details are already updated, discard the Hello packet*
7. *If* $H.P.(\,) = empty\ then$
8. *Update the details in the neighboring table*
9. *Else go to* ***line 8***
10. *End if*
11. *End if*
12. *End for*
13. *End*

Algorithm 2: Cluster Head Identification

Input: Records available in the Neighbour Table

1. *Start*
2. *If Ni is in direct reach to the CCN1 or CCN2*
3. *Send the packet directly to CCN1 or CCN2*
4. *Update the link efficiency*
5. *Else*
6. *for each record of the N.T.*
7. *Calculate IPEF*

$$IPEF = (\alpha * RE + \beta * LE + \delta * d + \tau * T)/SNR$$

Select another neighbor node of the current node from the NT

8. *Else*
9. *Compute SNR and ensure SNR>1*
10. *Compute all other parameters*
11. $RE = RE + EH$
12. *If (current node RE < TH)*

    Select from NT

13. *Else*
14. *Calculate the IPEF of the current node*
15. *Record and update IPEF in NT*
16. *Ensure all neighbor nodes are checked*
17. *Else send data directly*
18. *Else skip and initiate the sleep mode*
19. *End if*
20. *End if*
21. *End if*
22. *End*

<u>Algorithm 3: Effective Redundant Data Cancellation Technique</u>

Input: Data Packets from any node 'i'

1. *Start*
2. *If DP is ED, then*
3. *Sent it directly to CCNs*
4. *Else if the data packet is ND*
5. *Send it through the Cluster Head selected based on IPEF in each round*
6. *Else if the data packet is RD*
7. *Discard the data packet*
8. *Initiate sleep mode till next time slot*
9. *End if*
10. *End*

The **three algorithms'** description is presented:

The **"Algorithm 1"** is used for topology discovery and packet sensing. The first step is the Hello Packet sent by the sensor which includes parameters like *RE, LE, d, and T* to update the routing table. The routing table is updated after every round. The topology change due to the dynamic nature of the network is recorded to provide real-time information on the position and other associated parameters. This is the primary and critical step in network discovery.

"Algorithm 2" is designed to identify the cluster head of the specific cluster. It selects the sensor node with the least IPEF as presented. The IPEF value is updated in the neighboring table in each round. All the sensor nodes eligible for participation in the network are calculated. The cluster head is nominated in every round. The data transmission is done in a fixed time slot only. In case of emergency or critical data transfer, direct data transfer is done bypassing the regular time slot implications. During the idle time, the sensor node shifts to the sleep mode.

"Algorithm 3" deals with packet transfer and ensures that any redundant data sent in the previous timeslot is dropped. This is done by comparing the packet with the consecutive data packet. It ensures the availability of routes for effective traffic management. It also conserves network energy used in the transmission of redundant data. Hence it conserves the sensor energy thereby enhancing the network lifetime.

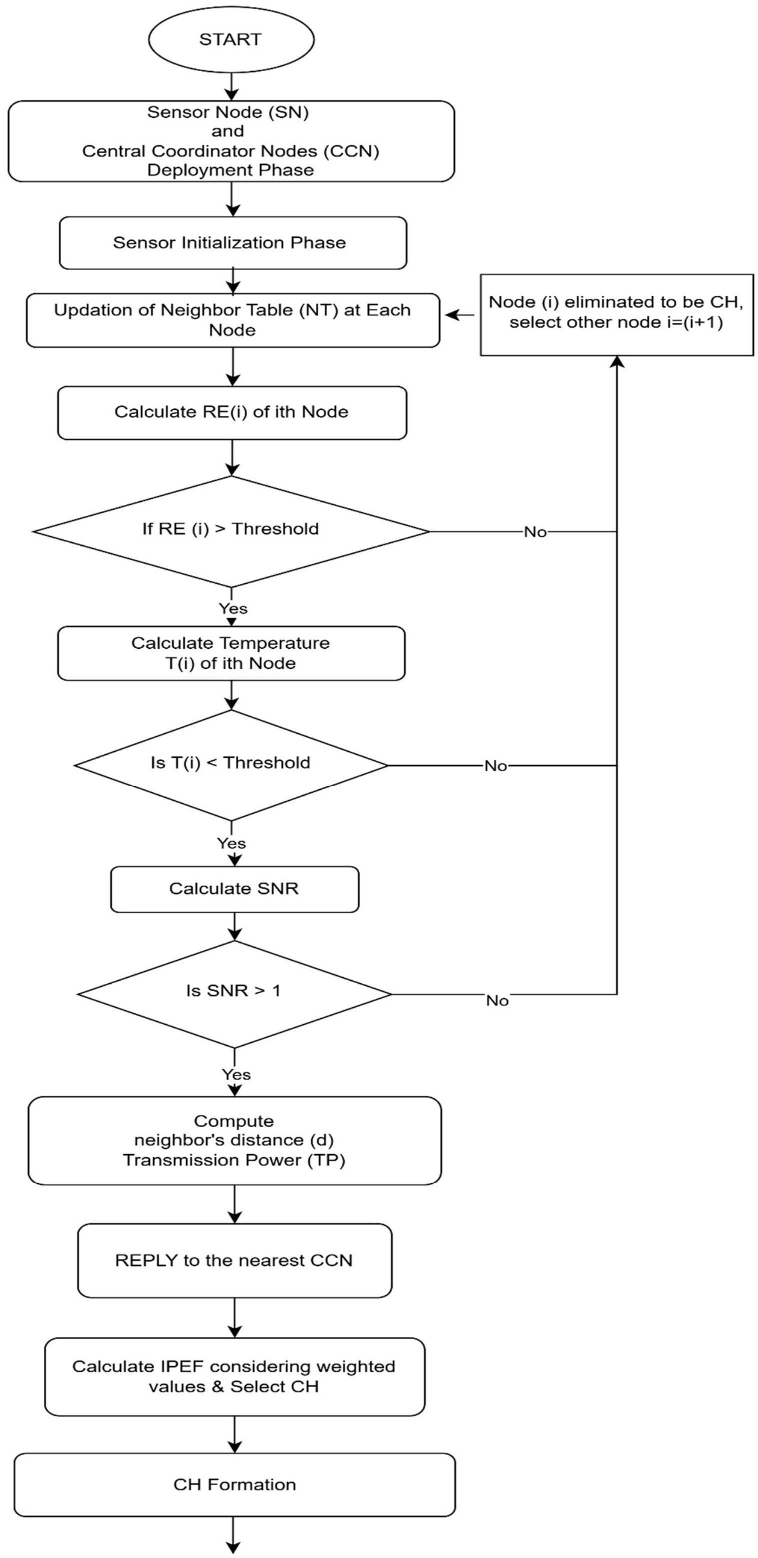

Figure 3-3 Flowchart of Cluster Head Formation in MTS-EER Protocol

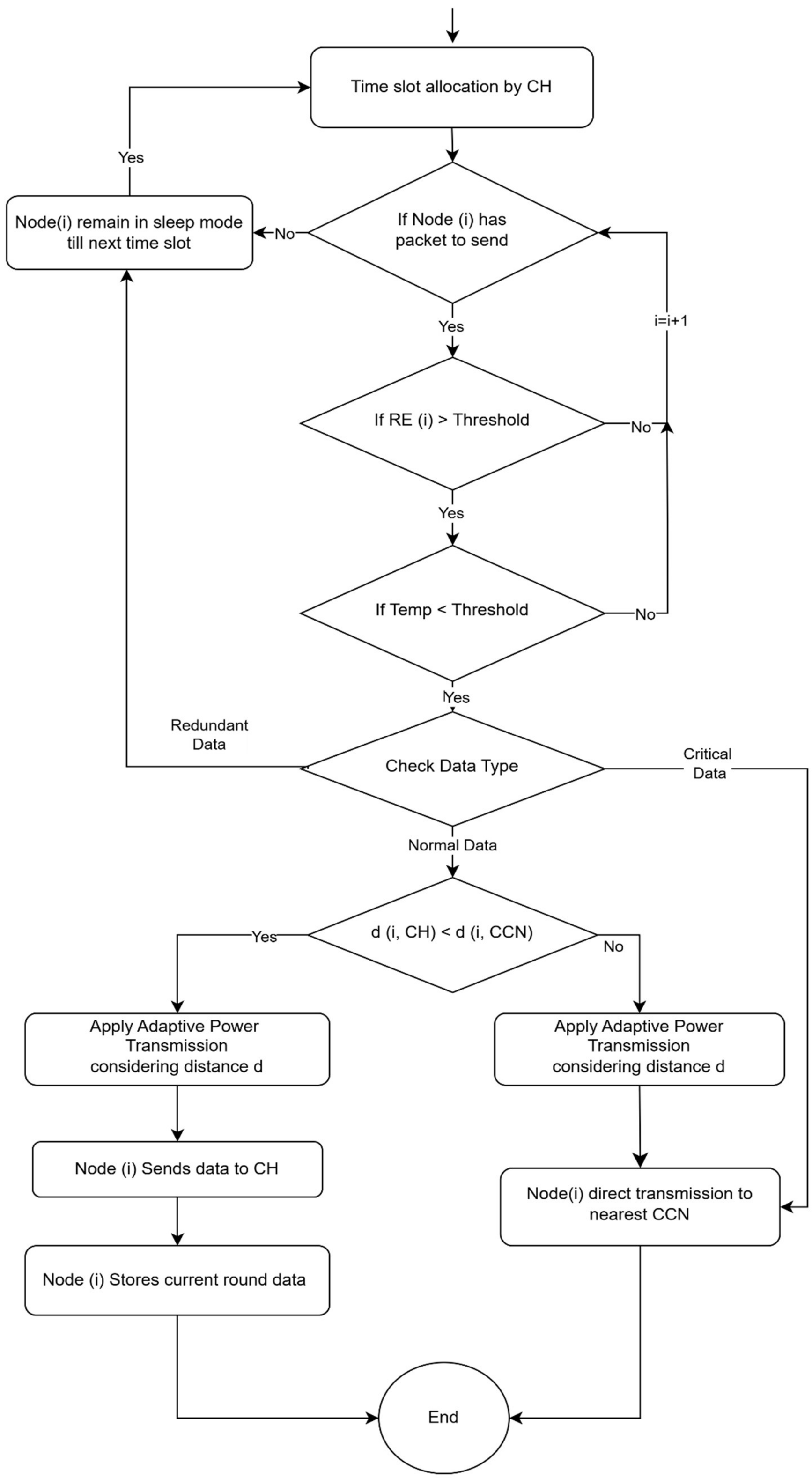

Figure 3-4 Data Transmission in MTS-EER Based on Time Slot Allocation

3.5 Proposed Protocol Operation

All sensor nodes and CCNs are deployed in the initial stage in WBAN. As illustrated in Figure 3.2. and described in Table 3.2, there are fourteen nodes throughout the human body. The sensor nodes start figuring out where they are about their neighbor and the coordination node.

The routing part of the MTSEER algorithm includes three steps. Step 1 deals with data initialization and sensing of packets. Step 2 is the critical part that nominates the CH. Step 3 represents the ERDC mechanism as elaborated in the flowchart mentioned in Figure 3.3. The flowchart initializes with the deployment of sensor nodes on the different parts of the human body. The CCN then allocates time slots for packet transmission. If the sensor node has a data packet to send, it checks for the hop count. If no data packet is available for transmission, then it will check the data in the next time slot for data transmission. If the packet is closer to the sink node, it is sent directly to the CCN. In case the packet is closer to the CH, it is routed through the CH to the CCN. The IPEF with the least value is selected CH. The selected CH acts as the forwarder node which checks for the data from all its member nodes, aggregates it, and forwards it to the respective CCN. The process is repeated concerning the time slot allocation for efficient performance of the network.

3.6 Result and Performance Evaluation

The proposed algorithm MTS-EER is evaluated using the MATLAB Simulation tool based on extensive experiments. The network topology includes 14 sensor nodes and 2 CCNs connected to the human body as shown in Figure 3.2 and Table 3.2 respectively. The proposed MTS-EER algorithm is compared with the recent algorithms namely EHCRP[166], EHRCP[125], EHARP[110], mobTHE[111], IM-QRP[112] and RBDT[113]. The comparison includes residual energy, network stability, throughput, network lifetime, and end-to-end delay. The simulation environment is mentioned in Table 3.1.

i. Network Stability

The period wherein all the sensor nodes are active defines the stable network. Hence it is desired to have a longer stable period. In the proposed algorithm MTS-EER, the first node dies after 9400 rounds compared to 9200 rounds in the case of RBDT. The other algorithms comparably are less stable with the first node die at 8500 rounds, 7500 rounds, 6800 rounds, and 5000 rounds for EHCRP, EHARP, mobTHE, and EHRCP respectively as in Figure 3.5. Hence MTS-EER is far better network stability, providing better connectivity with the sensor nodes due to the two CCNs. Adaptive transmission power further stabilizes the network, thereby improving the network's energy balance.

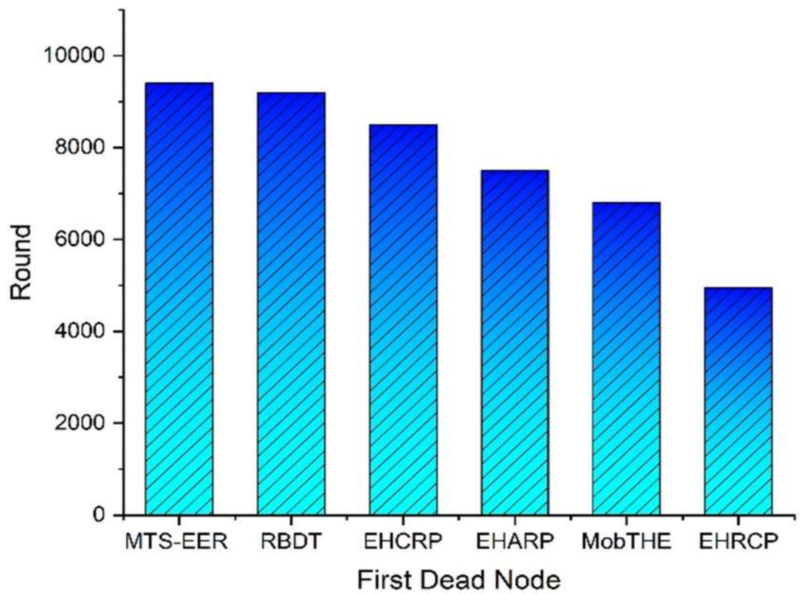

Figure 3-5 Network Stability Analysis

ii. Network Lifetime

It is the duration till the last sensor node dies. A longer network lifetime is a critical aspect of a resource-constrained network.

Table 3-4 Network Lifetime vs Time (s)

Protocol	Number of Alive Nodes vs Time (s)										
	0	**2000**	**4000**	**6000**	**8000**	**10000**	**12000**	**14000**	**16000**	**18000**	**20000**
MTS-EER	14	14	14	14	14	13	10	8	4	1	0
EHCRP	10	10	10	10	10	9	7	5	2	1	-
EHRCP	14	14	14	13	12	10	8	0	-	-	-
EHARP	14	14	14	14	13	11	9	4	0	-	-
mobTHE	8	8	8	8	5	3	0	-	-	-	-
IM-QRP	8	8	8	8	8	4	4	0	-	-	-
RBDT	14	8	5	0	4	-	0	-	-	-	-

The proposed algorithm MTS-EER is compared with the other algorithms considering the graph between the dead nodes vs rounds as in Figure 3.6. The detailed tabular representation has been presented in Table 3.4. The first node dies at 9400th round which is comparatively better than other algorithms. The last node dies at around the 19000th round compared to the 18000th round in the case of EHCRP which is the sole algorithm nearer to the proposed work. The other algorithms EHARP, RBDT, and EHRCP die at the 16000th round, 14000th round, and 12000th round respectively.

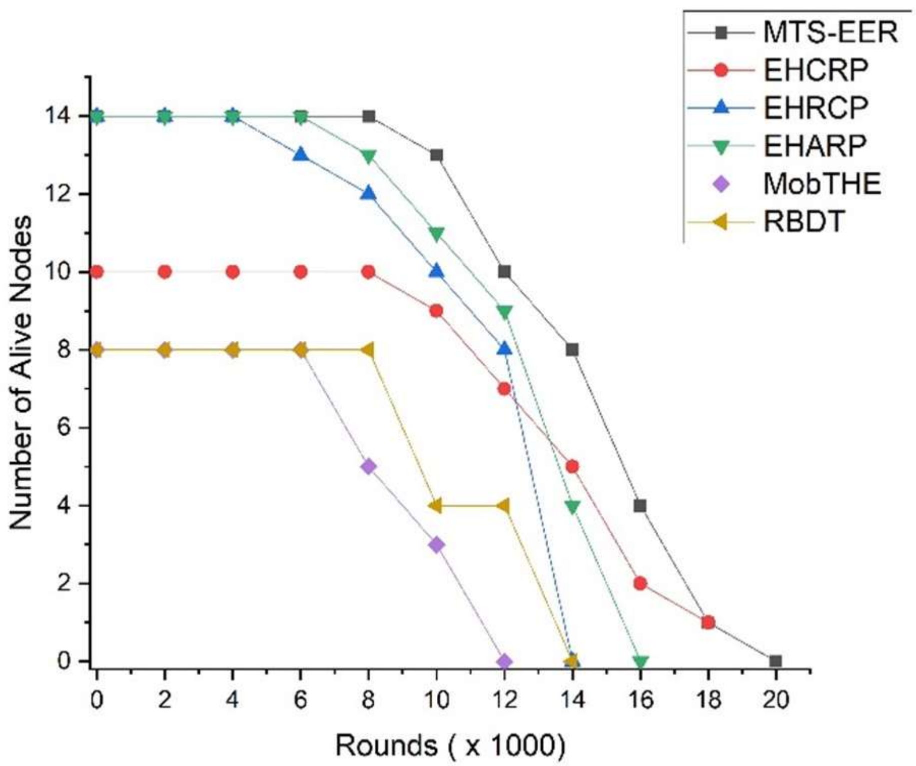

Figure 3-6 Network Lifetime Analysis

iii. Throughput

The network performance can be evaluated by observing the number of successful packet deliveries concerning the packets sent. It is highly desired to have minimal packet drop. In the current work, deploying a dual sink and dual clustering approach ensures easier and better reachability even a mobility-prone network due to postural movements. The proposed algorithm maintained higher throughput than other algorithms. EHCRP has shown close throughput initially and beyond 12000 rounds as in Figure 3.7. However, the proposed algorithm has consistently better throughput throughout all rounds. The tabular representation of the network throughput has been presented in Table 3.5.

Table 3-5 Network Throughput vs Time (s)

Protocol	Packets Received to Time (s)							
	2500	**5000**	**7500**	**10000**	**12500**	**15000**	**17500**	**20000**
MTS-EER	2.3	3.2	6.6	7.5	8.4	9.7	10.5	10.9
EHCRP	2.5	3	6.7	7.2	8.1	9.5	10.2	10.7
EHRCP	0.8	1.8	2.9	3.5	4	4.4	-	-
EHARP	2	4.23	6	6.8	7.95	8.56	9.6	0
mobTHE	2.5	4.2	6.4	7.8	7.9	-	-	-
RBDT	1.5	2.5	3.5	5	5.5	5.9	-	-

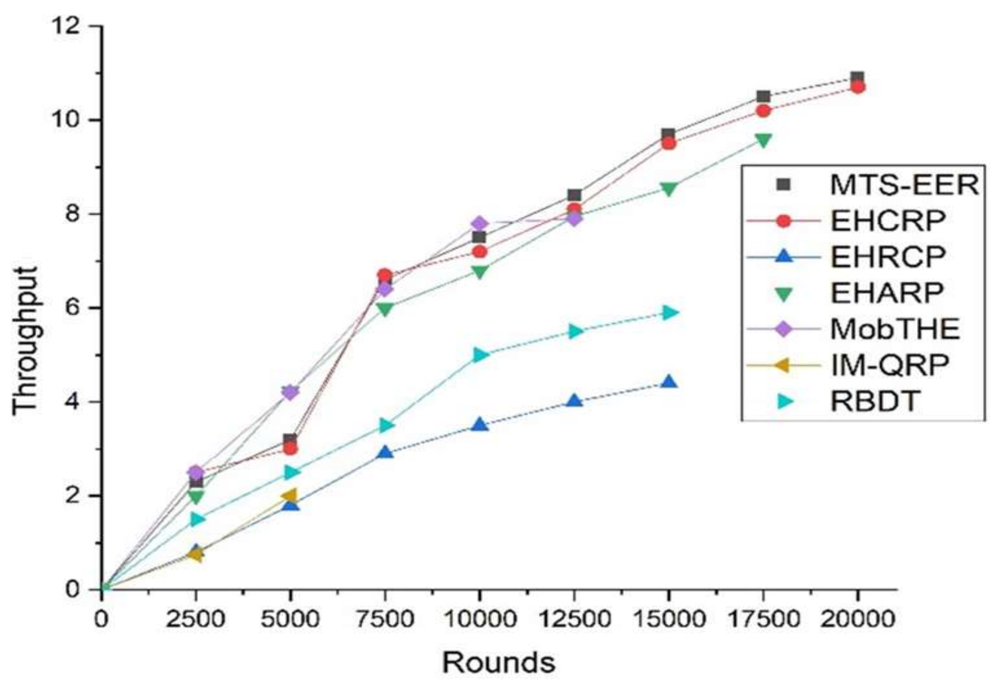

Figure 3-7 Network Throughput Analysis

iv. Residual Energy

It is the real-time energy present with the sensor node after every round. Since the sensor nodes have limited resources, utilizing and retaining the energy during network usage is critical. Initially, all the sensor nodes are provided with 0.5J of energy. Therefore, the total energy contribution depends on the number of sensor nodes deployed as evident from Figure 3.8. and Table 3.6. As the network is utilized, the residual energy is reduced. The proposed algorithm has higher residual energy from 5000 to 20000 rounds as compared with other algorithms as in Figure 3.8.

Table 3-6 Network Residual Energy vs Time (s)

Protocol	Network Residual Energy vs Time (s)										
	1000	**2000**	**4000**	**6000**	**8000**	**10000**	**12000**	**14000**	**16000**	**18000**	**20000**
MTS-EER	6.9	6.8	6.5	5.8	5.2	4.5	3.5	2.8	2.2	1.5	0.8
EHCRP	6.8	6.6	6.2	5.6	4.8	4.2	3.2	2.4	2	1.3	0.5
EHRCP	7.2	6.7	5.7	5	4.3	3.2	3	2.1	1	0.2	0
EHARP	6.6	6.3	5.3	4.6	4	3.2	2.7	1.7	1	0.2	0
mobTHE	3.6	3.2	2.56	1.92	1.2	0.4	0	0	0	0	0
IM-QRP	3.3	2.6	1.2	0.2	0	0	0	0	0	0	0
RBDT	3.5	3.1	2.1	1.2	0.8	0.3	0.1	0	0	0	0

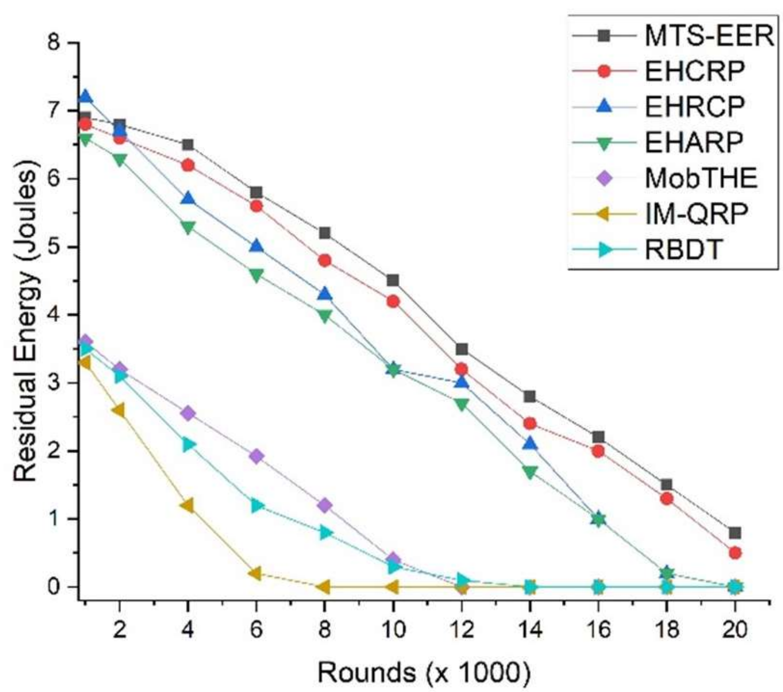

Figure 3-8 Network Residual Energy Analysis

There is higher energy consumption in the network owing to computational requirements at the initial stage. However, as the network routing table is updated, the consumption gets stable. The better performance of the proposed algorithm is due to the energy harvesting capability of the sensor nodes, the ATP, and the PMM modules.

v. End-to-End Delay

The time the packet takes to reach its destination from the source is known as the end-to-end delay.

Table 3-7 End to End Delay vs Time (s)

Protocol	**End to End Delay vs Time (s)**							
	2000	**4000**	**6000**	**8000**	**10000**	**12000**	**14000**	**16000**
MTS-EER	515	485	410	325	245	235	197	150
EHCRP	515	470	390	300	210	185	130	120
EHRCP	510	460	335	250	240	225	193	142
EHARP	515	482	410	321	205	160	160	137

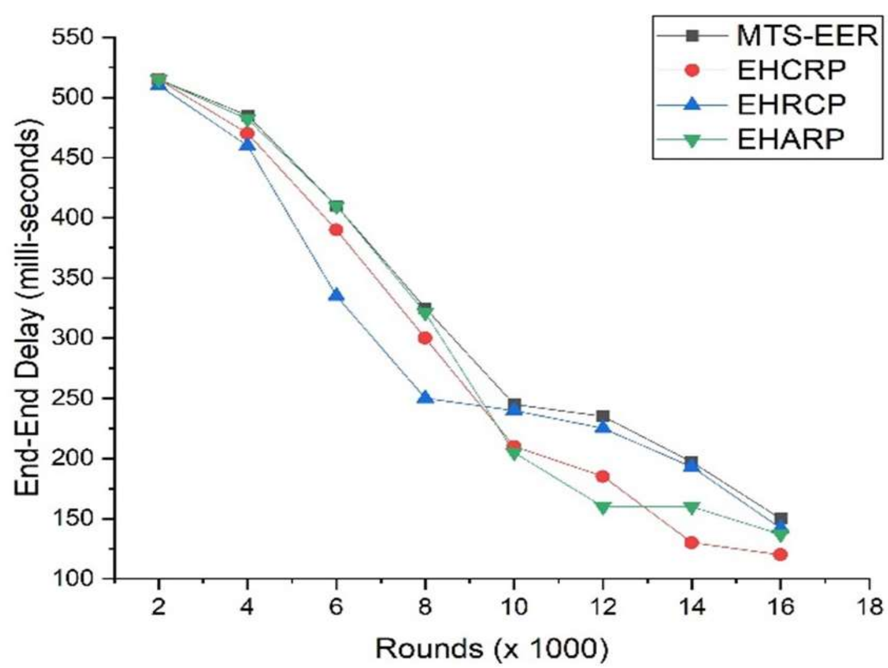

Figure 3-9 Network End-to-End Delay Analysis

It is desired to have a minimum end-to-end delay in a network. The results illustrate that MST-EER performs significantly better than another algorithm as in Figure 3.9. and Table 3.7. Initially, owing to the aggressive calculations to update the neighboring tables for the selection of CH, the end-to-end delay behaved at par with other algorithms. However, the delay was reduced to 110 ms compared with the other algorithms.

3.7 Conclusion and Future Prospects

In this chapter, a Mobility and Temperature Sensitive Energy Efficient Routing - (MTS-EER) scheme is presented. The chapter proposes two mechanisms to optimize the WBAN performance in a mobility-prone and temperature-sensitive environment. The elimination of redundant data transfer along with adaptive transmission power improves network lifetime. Intelligent path estimation function ensures balanced energy utilization in the network. The main achievement of this research work is the improved network lifetime and energy efficiency in a mobility and temperature-constraint environment. The algorithm also adds stability to the network by employing energy harvesting. In addition, two sink nodes are used to balance the network load and address the path-loss problem. MTS-EER employs an ERDC technique which restricts the duplicate data transfer to improve network performance; under this mechanism, redundant or similar data is ignored and is not sent to the sink or CH. This decreases the burden on the CH and sink, conserves network bandwidth, and eventually enhances network performance in general. The latest research protocols namely EH-RCP, E-HARP, and EHCRP are considered for comparison in terms of end-to-end delay, throughput, network stability, and network lifetime, according to the comparison results. The proposed algorithm outperforms the current state-of-the-art algorithms. In the future, the suggested protocol will be implemented on the actual WBAN platform to collect performance statistics in real-time.

Chapter 4
A Novel Robust and Adaptive Energy-Efficient Model for Energy Conservation in a Wireless Body Area Network

4. Overview

A Wireless Body Area Network is a web of sensor units capable of extracting and transferring critical data for remote medical services. However, the limited energy storage in a tiny sensor unit compels the network to utilize the energy efficiently. Further, mobility triggers another challenge network connectivity and poor communication leading to high retransmissions that cause excessive energy drainage. It demands a robust link and efficient route management thereby eradicating retransmission issues arising from the postural movements and surrounding interference. Hence the requirement is to improve the network lifetime ensuring reliability and reduced latency. Researchers have explored various techniques to overcome these issues yet further improvement is required. Energy conservation is the most common method used to fulfil energy requirements. However, the amount of energy generation rate by such techniques is low. Therefore, it can't be relied upon. Hence, a novel and advanced model is required for energy conservation. A Novel Robust, and Adaptive Energy-Efficient Model (NR-AEEM) for energy conservation is presented in the research work. It is an amalgamation of four techniques for resolving the energy drainage problem at multiple levels. It includes an intelligent coded system developed to reduce transmission-related issues. The noble model is proposed to provide balanced energy drainage, prolonged network performance, and efficient data transmission for dynamic nodes. The results are compared with the latest state-of-the-art research papers that confirm the supremacy of the proposed model.

4.1 Introduction

In a world with an increasing elderly population and restricted medical healthcare services, patient monitoring has become a challenging task. Therefore, dedicated technological intervention is required in healthcare applications to provide personalized healthcare to the needy. Sensor developments and their size miniaturization have created the possibility of monitoring the patient for remote applications. Sensor units deployed on the human body constitute the wireless body area network. It provides connectivity between the sensor nodes sharing and forwarding vital human signals to the online platform. The medical and research community utilizes the raw data to analyze and create predictive models for medical decision-making. The limited energy drains faster impacting the network performance and durability. The research community has presented various methods and techniques to address this critical problem. However, the network demands further improvements to make the technology more adaptive to real-time applications.

However, WBAN is energy-starved due to the restricted energy storage ability of the sensor nodes. Other challenges of WBAN include finding the optimal route to improve the energy efficiency of the network. In noise-prone surroundings, the required transmission power level also increases resulting in faster energy drainage and consequently reducing the network lifetime. Add mobility into it due to the postural movements and the situation of sustaining the reliable network worsens. Human skin and internal organs are susceptible to abrupt temperature fluctuation thereby restricting the sensor node from being utilized within the permissible safety limits. Researchers have been working on these issues and proposed various methods to overcome the problems discussed.

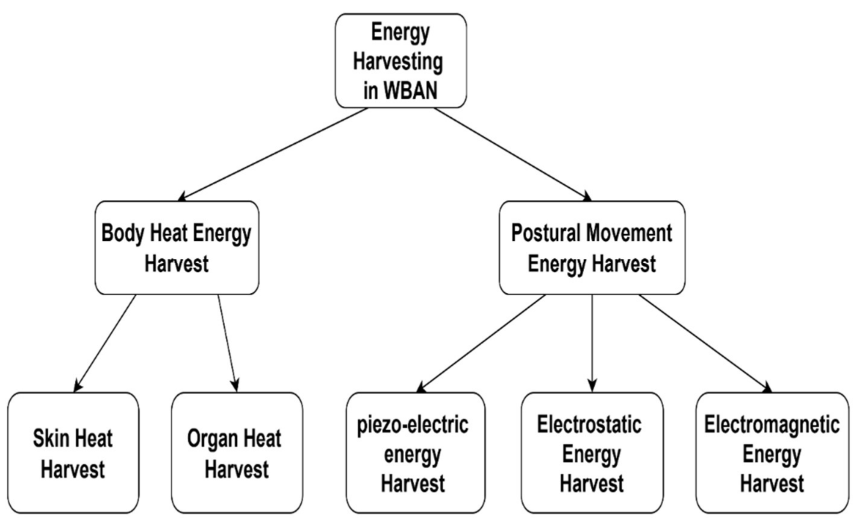

Figure 4-1 Energy Harvesting in WBAN

The basic compression techniques are divided into two types. The first type is Lossless compression techniques. It has the potential to recover the complete data without any loss of information. The healthcare industry demands precise and complete data to be received as any decision based on it could be critical for human life. The lossy compression techniques are not able to reverse the process of complete recovery of compressed data. Figure 4.1 presents other energy harvesting techniques useful in providing energy energy-efficient networks.

Most of the research work in the recent past is linked with designing a sensor unit capable of harvesting energy majorly in the form of thermal heat of the body and the kinetic energy generated during the postural movements of the body. The significance of energy harvesting in WBAN has been presented in Figure 4.2.

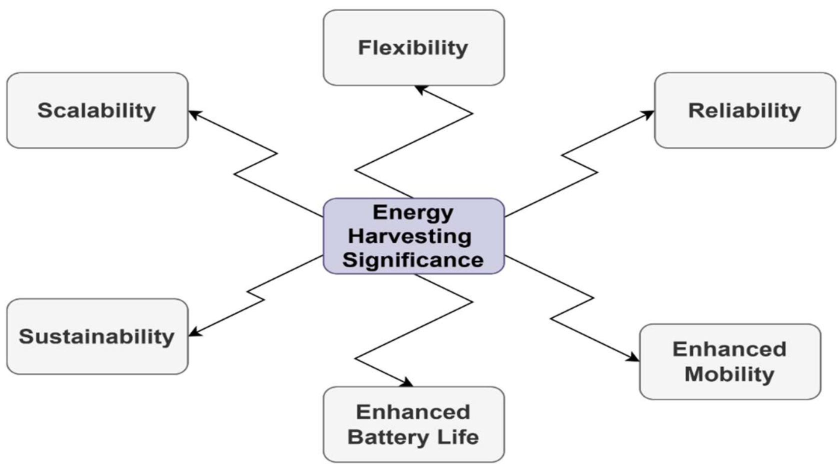

Figure 4-2 Significance of Energy Harvesting in WBAN

4.2 The Proposed Energy Conservation Approach

However, the holistic approach to applying the solutions in a real-world scenario needs further attention. Improving the network performance with the multiple constraints discussed above demands robust energy management capable of handling extreme energy requirements with network reliability.

To ensure the desired level of Energy harvesting techniques (Figure 4.2) have been proposed and are most commonly being used in the latest research work. Although the possibility of energy harvesting can be explored as a viable solution, the technology is not yet advanced enough to cater to network energy demands. Hence, a novel and advanced model is required for energy conservation with utmost efficiency. In this paper, a novel robust, and Adaptive energy-efficient Model for Energy Conservation is proposed which is an amalgamation of four techniques resolving the energy drainage problem at multiple levels.

The proposed work addresses the following issues: -

1. Sensor nodes remain active all the time leading to energy wastage during the idle period.
2. The high traffic rate adds a burden to the network leading to packet drop, retransmissions, transmission delays, and energy wastage.
3. Similar data transfer burdens the network leading to congestion, energy wastage, and at times unnecessary retransmission.
4. Lack of effective and reliable energy harvesting mechanism for real-time WBAN applications.

4.3 Literature Survey Considering the Energy Conservation

The researchers in EHCRP [125] introduced the integration of IoT along with an energy harvesting approach in a dual sink node deployed on the left and right side of a heterogeneous sensor network. Redundant data is screened and dropped at the sensor level only to conserve transmission energy. The multi-hop approach is considered to conserve the overall energy level of the network in a balanced manner ensuring a reliable, stable, and durable network. Path Cost Estimation function developed using multiple parameters contributes to the selection of optimal path with higher reliability, and link quality ensuring higher Packet Delivery Ratio. Thus, the paper utilized multiple energy conservation techniques to improve the network lifetime.

EH-RCB [165] also utilized energy harvesting techniques in dual sinks deployed on the front and back sides of the WBAN network. To conserve and balance the energy of the network it used the clustering approach wherein a Cluster Head is selected in each round based on parameters: SNR, required transmission power, total available energy, and distance between nodes.

EHARP [110] focused on mobility concerns leading to the energy drainage in the network. Energy conservation techniques include removing duplicate data at the sensor node only, utilizing two CN to avoid path loss, and improving network energy balancing. In addition, it considers dynamic cluster head selection to balance energy in the network. However, the algorithm ignores the sensor heating impact on the human skin which could harm the patient utilizing the technology.

mobTHE [111] is a mobility assistive algorithm that also considers the temperature variations in a heterogenous with dual sink node. It removes the duplicate data by synchronizing the two coordinator nodes used in the network.

ERQTM [122] uses cognitive radio in a Software-defined Networking SDN for network management to deal with energy drainage problems. The clustering approach is utilized in the network focusing on the identification of priority data based on high data rate, need-related power, and routing.

Researcher in the review [167] summarized the role of wireless power transfer (WPT) and SWIPT that can handle and provide power as well as information transfer. It presented both battery-assisted and battery-free designs in a varied WBAN architecture.

Data compression techniques have been presented in [168] catering to wireless sensor networks. It elaborates on three types of compression including communication-oriented, sampling oriented, and data-oriented. However, data transmission in healthcare should avoid any losses due to compression and therefore demands care in this concern. The papers present research gaps and prospects involving IoT-based WBAN applications in healthcare. Some critical factors that affect energy consumption are compression ratio, complexity, minimized transmission, energy consumption, and scalability are discussed and compared with recent research.

Energy harvesting in wireless sensor networks has been presented in [169] that considers various methods of generating and conserving energy to sustain or prolong the usage of a device.

Data freshness has been observed in[170] dealing with the age of information (AOI) perspective. The proposed research work has shown improved results in terms of energy conservation.

SpWBAN also known as Self-powered WBAN [171] deals with designing nanosensors capable of powering themselves and performing the task of acquiring and transmitting the vital information in real time. It presents the role of renewable sources, supercapacitors, and body kinetic energy.

The wearable device's energy harvesting mechanism has been discussed in [172][173].

4.4 The Proposed NR-AEEM Scheme

The proposed NR-AEEM Scheme is presented here to address the issue of energy conservation.

- An energy-efficient wakeup mechanism is presented to avoid the sensor node active all the time.
- In case of the high traffic situation, considering the priority of data, an adaptive sampling and sensing model will be implemented resulting in energy conservation.
- Data compression using the pseudocode mechanism ensuring lossless compression.
- Removing redundancy suppression to reduce energy consumption, traffic load management.
- The proposed algorithm also includes energy harvesting techniques to further enrich the network with energy.

The detailed energy conservation techniques have been presented in the flowchart-shown in Figure 4.3.

The NR-AEEM scheme is also implemented using the MATLAB simulation tool to validate and compare with the other state-of-the-art protocols. The sensor nodes and their positional coordinates are tabulated in Table *3*.2. It includes 14 normal sensor nodes NN and two CCNs on the left and right sides of the body as presented in Figure *3*.2. The simulation environment is presented in Table *3*.1 indicating the simulation dimension of 2x2 m^2, and energy consumption pattern during the transmission, amplification, and reception of the data packet. The flowchart in Figure 4.1 elaborates on the process of energy conservation. The sensor nodes are in sleep mode till the time slot is allocated for data transmission. It then checks for data redundancy and if in case there is duplicate data in consecutive transmissions, the packet is dropped. The data traffic load of the network is analysed. If the traffic load is beyond a specific threshold, the data compression pseudocode is used as per the algorithm. Finally, observing the energy harvesting ability of the sensor, if the sensor energy still goes below a threshold, the specific sensor is not utilized till the sensor regains its minimum energy level.

4.5 Results and Discussion

The proposed algorithm NR-AEEM presented a novel robust and adaptive scheme to improve the energy utilization in a wireless body area network. As presented in Figure 4.3, the proposed algorithm has shown significantly better results in terms of residual energy. Initially both the protocols have similar trends till around 4000. The improvement in residual energy is visible drastically at 12000 rounds.

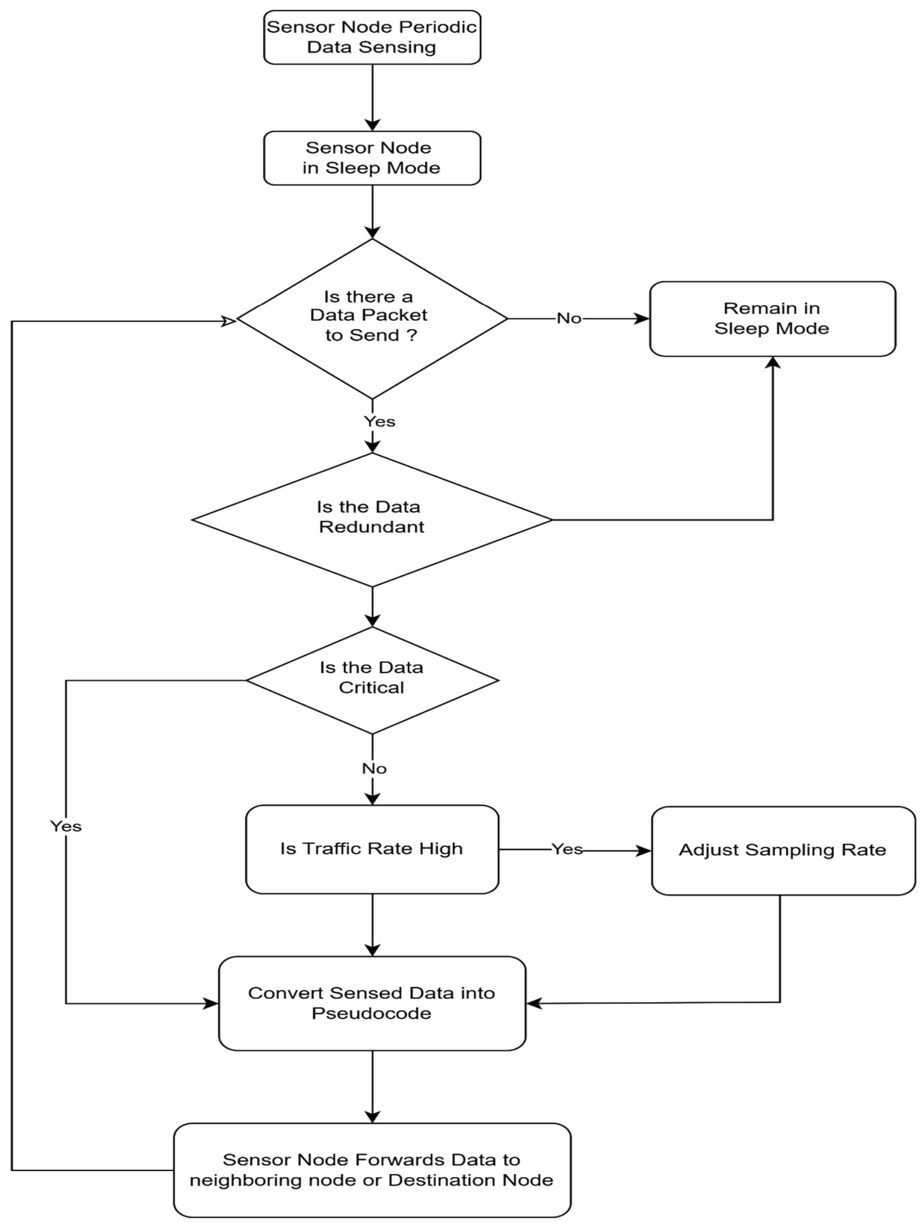

Figure 4-3 Flowchart of Energy Conservation Model

It can be attributed to the data compression employed during the high-traffic load, duplicate data removal, and energy harvesting of the sensor.

The impact of the proposed scheme on the various accountable parameters is presented below:

i. Residual Energy

The residual energy defines the longevity, reliability, and robust network. Figure 4.2 indicates that the NR-AEEM algorithm which is an extension of MTS-EER deals with redundancy reduction, data compression, and employing an efficient wakeup mechanism. Initially, NR-AEEM showed similar trends but with the increase in rounds, the proposed energy conservation model outperformed all other models convincingly. The trend visible in Figure 4.2 is majorly attributed to the pseudocode method incorporated in the model.

Table 4-1 Network Residual Energy vs Rounds

Protocol	Network Residual Energy vs Rounds										
	1000	**2000**	**4000**	**6000**	**8000**	**10000**	**12000**	**14000**	**16000**	**18000**	**20000**
NR-AEEM(P)	6.9	6.8	6.5	6.1	5.5	4.9	4.1	3.1	2.7	1.8	1.5
MTS-EER(P)	6.9	6.8	6.5	5.8	5.2	4.5	3.5	2.8	2.2	1.5	0.8
EHCRP	6.8	6.6	6.2	5.6	4.8	4.2	3.2	2.4	2	1.3	0.5
EHRCP	7.2	6.7	5.7	5	4.3	3.2	3	2.1	1	0.2	0
EHARP	6.6	6.3	5.3	4.6	4	3.2	2.7	1.7	1	0.2	0
mobTHE	3.6	3.2	2.56	1.92	1.2	0.4	0	0	0	0	0
IM-QRP	3.3	2.6	1.2	0.2	0	0	0	0	0	0	0
RBDT	3.5	3.1	2.1	1.2	0.8	0.3	0.1	0	0	0	0

ii. Throughput

The throughput indicates the successful packets received compared to the total packets transmitted. Higher throughput indicates a better network in terms of timely packet delivery, reduced latency, lesser re-transmissions, and consequently higher energy efficiency. The data compression introduced in the energy conservation model reduces network congestion. It thereby reduces the burden of the individual sensor nodes. It results in reduced energy consumption and faster packet transmission. Figure 4.4 indicates that the proposed model outperforms all other models.

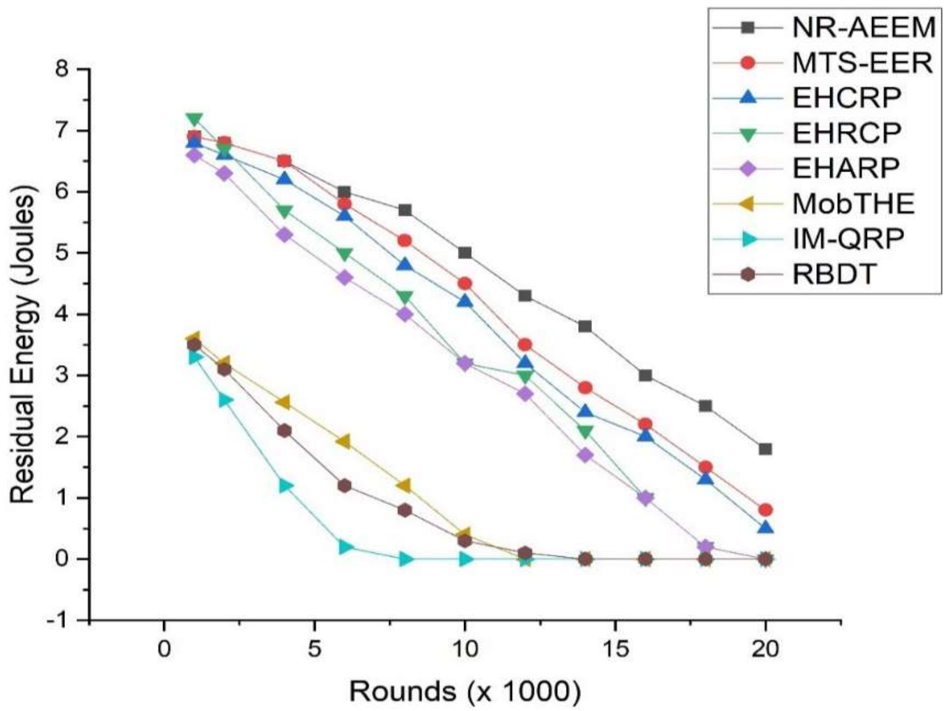

Figure 4-4 Residual Energy Vs Rounds for Energy Conservation Model

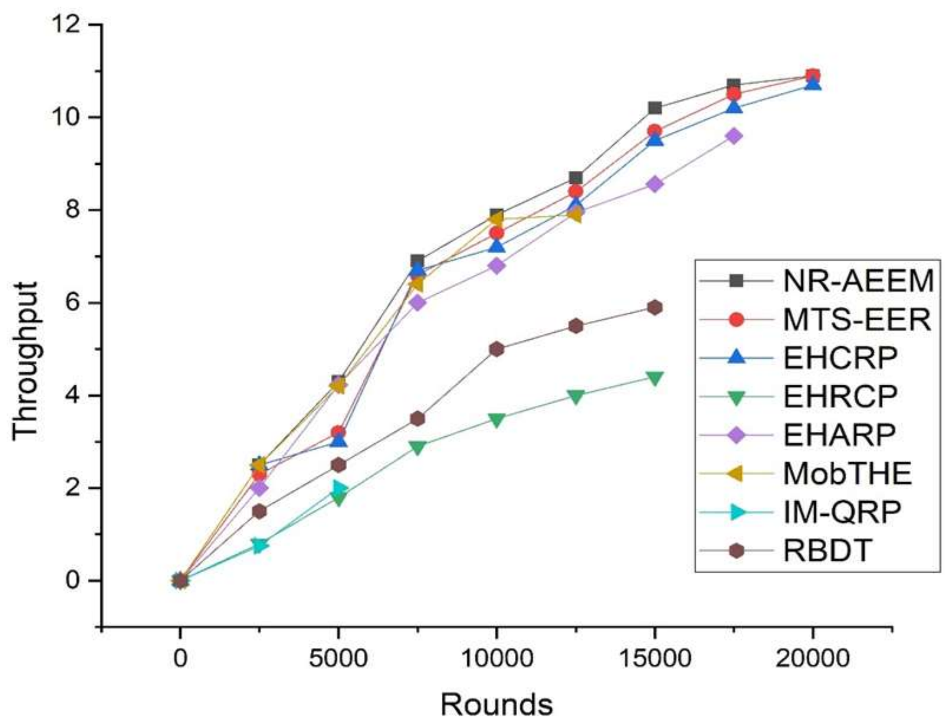

Figure 4-5 Throughput Vs Rounds for Energy Conservation Model

Data compression also helps the sensor nodes maintain an ambient temperature range which is crucial in ensuring active participation in the network for an extended duration. Temperature increases beyond a certain value reduce the sensor performance. It also poses threat to the human body specifically in the case of implanted sensor units.

iii. End-to-End Delay

End-to-end delay is a significant parameter in case of critical or emergency packet transfer. The time required for a packet to reach the destination from the source sensor node is known as the end-to-end delay. Chapter 3 provides the MTS-EER algorithm that provides the routing algorithm to route the packet optimally to the destination unit. In the proposed algorithm, by ensuring reduced traffic and improved energy levels, the end-to-end delay is reduced drastically making the algorithm suitable for emergencies. Observing Figure 4.7, it is clear that the research community has not explored the parameter effectively. The latency of the proposed model is significantly low as compared to other algorithms. The detailed literature survey also indicates the least emphasis on it. However, this is one of the significant and critical for real-time healthcare applications and could define the future of WBAN in healthcare.

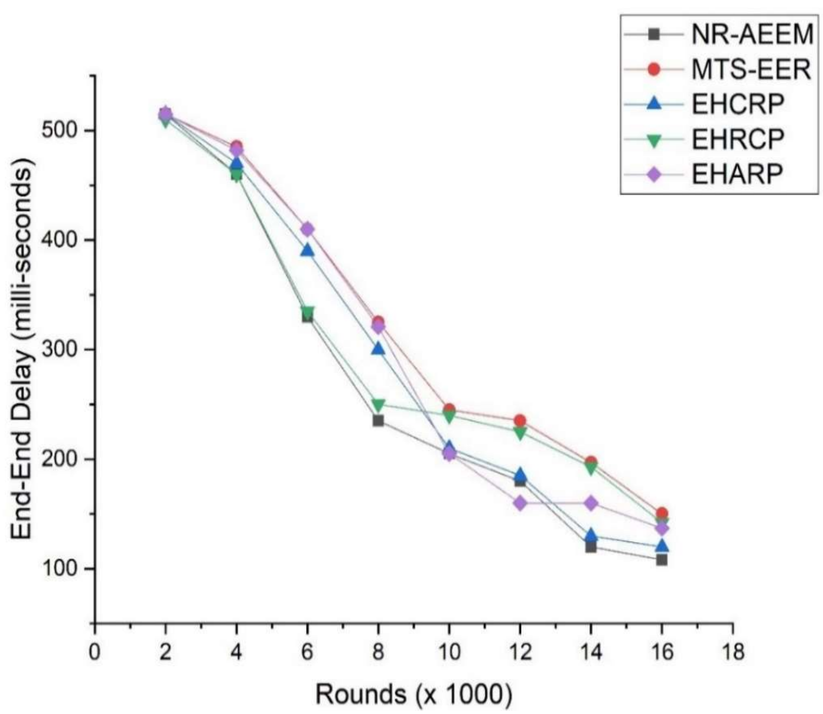

Figure 4-6 End-to-End Delay Vs Round for Energy Conservation Model

iv. Network Lifetime

Network performance till the last node dies indicates the lifetime of the network. It is desired to have the longevity of the network. It depends on multiple factors such as the initial energy of the sensor nodes, congestion level, postural movements, path loss, and routing protocol. In Chapter 3, MTS-EER has been presented which provided better results than the state-of-the-art work.

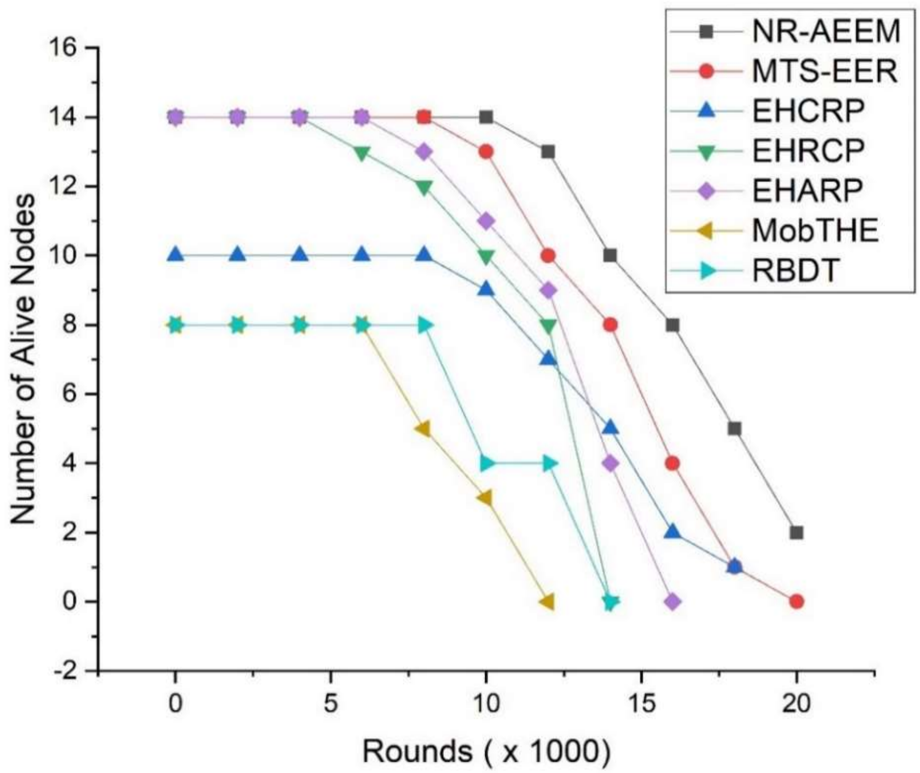

Figure 4-7 Alive Nodes Vs Rounds for Energy Conservation Model

The proposed energy conservation model enhances the network lifetime by using pseudocode, thereby reducing congestion, and load on individual sensor nodes and enhancing the reliability (Figure 4.7). Prolonged network lifetime is critical in ensuring the comfort level of the user. Specifically, in the case of implanted sensors, it also reduces the financial burden of the patient.

v. Network Stability

Network stability is one of the critical parameters of network robustness, reliability, and longevity. It is indicated by the duration wherein all the sensor nodes are alive contributing at their best to provide the best suitable route. It is therefore desired to have prolonged network stability. As it deals with the first dead node, the energy level and utility of energy in the sensor node are critical in ensuring network stability. Keeping in mind, the proposed model presents a multi-layer approach to conserve the energy level and reduce sensor overusage. Figure 4.9 presents the bar chart of state-of-the-art algorithms with the first dead node round. It outperforms the other algorithms with the first dead node 10250 round as compared to 9400, 7500and 4950 in the case of MTS-EER, EHARP, and EHRCP respectively.

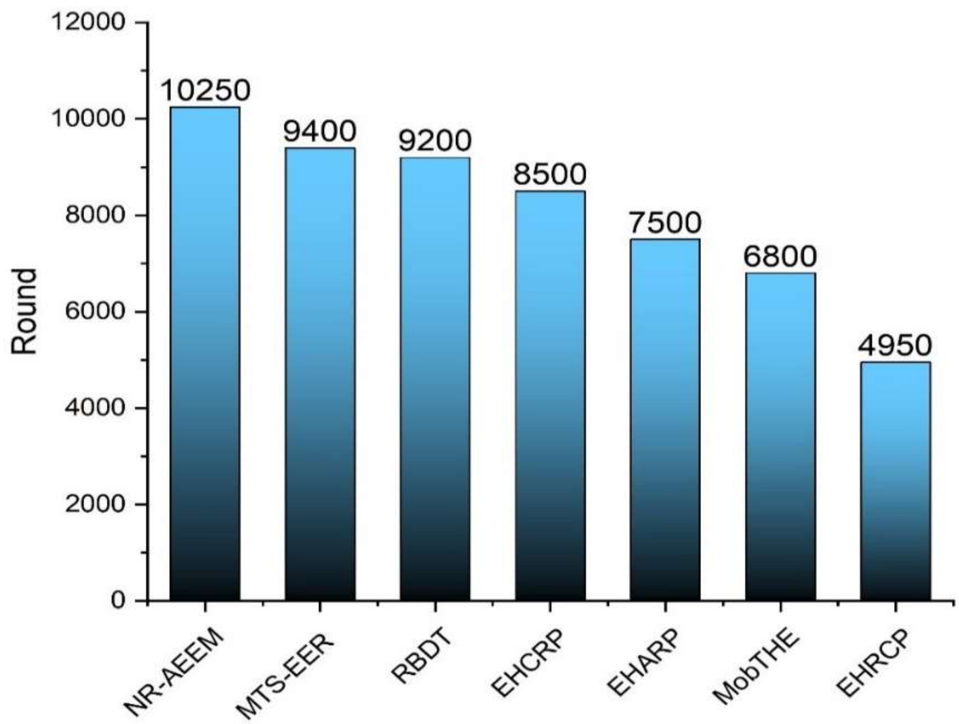

Figure 4-8 Network Stability for Energy Conservation Model

4.6 Summary

This Chapter presented the conservation techniques to enhance the sensor units' energy availability, thereby enhancing the network's performance across multiple aspects. The chapter presented a novel robust and adaptive energy-efficient model work with a multi-level approach. Firstly, the redundant packets are identified and dropped to avoid retransmissions. The sensor nodes are intelligently utilized in their respective time slots only or in case of emergencies. Otherwise, the sensors remain in the sleep mode. This is done using an energy-efficient wakeup mechanism. Moreover, the scheme keeps track of the traffic load on the network. In case it increases beyond a point, the adaptive sampling mechanism is activated which reduces the sampling rate of normal data packets leading to better traffic management and energy conservation. Finally, a pseudocode is designed that observes the daily range of physiological data and encodes the range of data into pseudocodes leading to lossless data compression and reduced energy consumption due to less data transmission through the sensor nodes to the destination.

Chapter 5

5. Conclusions and Future Scope

5.1 Overview

The role of wireless body area networks has been explored in the thesis work. A thorough literature review of the routing protocols has been done to identify the existing research gaps. Wireless body area network is the future of mankind with enormous potential to disrupt the current medical healthcare system. With advancements in nanotechnology, high-speed internet connectivity, the evolution of artificial intelligence along with data mining, and the role of big data, WBAN can evolve and contribute to humanity. Considering the research gaps, a new routing protocol has been presented to improve the quality of service in a wireless body area network.

5.2 Conclusions

In this thesis, the role of WBAN in healthcare has been presented. The research gap has been summarized and the major issues concerning the WBAN are highlighted. Energy utilization is a major concern in a miniature sensor network with limited energy resources at its disposal. Other factors like temperature constraints, postural movement, and the environment conditions further present concern in-term of reliable data transmission and energy utilization for extended network lifetime. The solutions to these issues are presented in this thesis.

A Mobility and Temperature Sensitive Energy Efficient Routing (MTS-EER) scheme is presented to optimize the WBAN performance in a mobility-prone and temperature-sensitive environment. The latest research protocols namely EH-RCP, E-HARP, and EHCRP are considered for comparison in terms of end-to-end delay, throughput, network stability, and network lifetime, according to the comparison results. The proposed algorithm outperforms the current state-of-the-art algorithms.

The WBAN network is evaluated on five parameters viz network stability, network lifetime, residual energy, throughput and end-to-end delay. The presented algorithms have outperformed in terms of residual energy, network lifetime and throughput.

The present work has also focussed on energy conservation via redundancy removal, sleep mode utilization and traffic load identification. It incorporates the adaptive sampling mechanism which reduces the sampling rate of normal data packets leading to better traffic management and energy conservation. Pseudocode is designed that observes the daily range of physiological data and encodes the range of data into pseudocodes leading to lossless data compression and reduced energy consumption due to less data transmission through the sensor nodes to the destination.

The chapter-wise contribution is presented as under:

In Chapter 1, WBAN architecture has been presented. The various applications, and advantages of WBAN have also been discussed. The importance of WBAN and its impact on society has been evaluated. The healthcare industry can drastically change the approach to delivering medical care through remote monitoring. Based on the detailed literature review highlighting the recent research in the field, the research gaps have been identified in Chapter 2.

In Chapter 3, a mobility and temperature-sensitive energy-efficient routing protocol has been presented. It highlighted the recent state-of-the-art research work done in the field of study. It presented a novel path estimation function to handle the problem of mobility and thermal sensitivity of the sensor. In addition, an optimized and sustainable energy conservation model is presented to enhance the energy distribution in the network.

Lastly, Chapter 4 presents a novel robust, and adaptive energy-efficient model for energy conservation specifically dealing with energy harvesting and conservation techniques.

The contributions of the thesis work are presented as:

- The comparative analysis and investigation of routing protocols for improved energy efficiency in mobility and temperature-sensitive WBAN.
- Development of mathematical models considering the Intelligent Path Estimation Function (IPEF).
- Design and simulation of improved routing protocol in a dynamic WBAN.
- Performance evaluation of proposed algorithms with the existing state of the art.

5.3 Future Works

The thesis presents the solution to the research gaps identified in the literature survey. The design and simulation of routing protocol in a WBAN for improved energy efficiency in a constrained environment has been presented. However, the research community still needs to implement a real-time remote monitoring system to be useful for the society. Hence, the issues that can be addressed in the future work are presented as:

- Design and performance evaluation of presented routing protocol with real-time applications.
- Exploring the energy harvesting and energy conservation techniques with real-time applications.
- Integrating other technologies like artificial intelligence, IoT, Big data, and machine learning to provide healthcare services through digital platforms with real-time implications

As WBANs become more prevalent, ensuring the security and privacy of sensitive health data will be crucial. Advanced encryption methods and secure communication protocols are required to ensure data security. Compliance with healthcare regulations and standards will be necessary to ensure that WBAN technologies protect user privacy and adhere to legal requirements. In short, the robust WBAN health application needs other technological support to build a pool of resources providing seamless connectivity around the globe for personalized healthcare.

5.4 List of Publications

Journal

[1] A. K. Rawat, A. Singh, and M. Singh, "Mobility and Temperature Sensitive Energy Efficient Routing (MTS-EER) protocol in a wireless body area network," *Eng. Res. Express*, vol. 6, no. 3, 2024, doi: 10.1088/2631-8695/ad62b6.

[2] Anil Kumar Rawat, Amandeep Singh, and Manwinder Singh, "A Novel Robust and Adaptive Energy-Efficient Model for Energy Conservation in a Wireless Body Area Network". **(Communicated)**

International Conferences

[1] Anil Kumar Rawat, Amandeep Singh, and Manwinder Singh, "Investigation of Routing Protocols for Quality-Of-Service Provisioning in Wireless Body Area Network", in 7th International Joint Conference on Computing Sciences (ICCS-2023) "KILBY100". **(Published)**

[2] Anil Kumar Rawat, Amandeep Singh, and Manwinder Singh, "Routing Protocols for Wireless Body Area Network: Futuristic Scope in the 7th International Joint Conference on Computing Sciences (ICCS-2023) "KILBY100" **(Published)**

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