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Three-Tier WBAN Communication: Design and Performance Evaluation

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Abstract: *Recent technological advancement in wireless communication has led to the invention of wireless body area networks (WBANs), a cutting-edge technology in healthcare applications.*

WBANs interconnect with intelligent and miniaturized biomedical sensor nodes placed on human body to an unattended monitoring of physiological parameters of the patient. These sensors are equipped with limited resources in terms of computation, storage, and battery power. The data communication in WBANs is a resource hungry process, especially in terms of energy. One of the most significant challenges in this network is to design energy efficient next-hop node selection framework. Therefore, this paper presents a green communication framework focusing on an energy aware link efficient routing approach for WBANs (ELR-W). Firstly, a link efficiency- oriented network model is presented considering beaconing information and network initialization process. Secondly, a path cost calculation model is derived focusing on energy aware link efficiency. A complete operational framework ELR-W is developed considering energy aware

next-hop link selection by utilizing the network and path cost model. The comparative performance evaluation attests the energy-oriented benefit of the proposed framework as compared to the state- of-the-art techniques. It reveals a significant enhancement in body area networking in terms of various energy-oriented metrics under medical environments.

Keywords: Wireless Body Area Networks (WBANs), health care applications, Energy aware link efficient routing approach (ELR-W), Next-hop node selection framework ,wearable sensors, routing protocol

I. INTRODUCTION

The technological advancement has brought a revolution in today's human life. It has changed the way of human's working in every field of life such as home automation, smart cities, environment Sensors 2018, 18, x 2 of 17 monitoring, and prediction [1–5]. Despite all these advancements, humans still face many challenges. The current forefront challenge in healthcare is fast growing of world population and decreasing number of healthcare facilities in proportion to the population ratio. According to the US Census Bureau, it is predicted that the population of aged people in the world will be doubled up to 761 million in 2025 from 375 million in 1990 [6]. Generally, the elderly suffer from various chronic diseases, thus they require continuous medical care. Most of them have to stay in hospitals or remain under constant supervision of a medical professionals, otherwise their lives may be at risk. Every year, thousands of the current forefront challenge in healthcare is fast growing of world population and decreasing number of healthcare facilities in proportion to the population ratio. According to the US Census Bureau, it is predicted that the population of aged people in the world will be doubled up to 761 million in 2025 from 375 million in 1990 [6]. Generally, the elderly suffer from various chronic diseases, thus they require continuous medical care. Most of them have to stay in hospitals or remain under constant supervision of a medical professionals, otherwise their lives may be at risk. Every year, thousands of people die due to fatal or chronic diseases. The most common reason for such fatal diseases is lack of timely diagnoses. Research has revealed that most of these diseases may be controlled if identified at their initial stages [7]. Therefore, there is a pressing need to develop proactive and affordable healthcare systems for continuous health monitoring without any attendants and

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to diagnose the diseases at their early stages. people die due to fatal or chronic diseases. The most common reason for such fatal diseases is lack of timely diagnoses. Research has revealed that most of these diseases may be controlled if identified at their initial stages [7]. Therefore, there is a pressing need to develop proactive and affordable healthcare systems for continuous health monitoring without any attendants and to diagnose the diseases at their early stages. In order to address the healthcare challenges, researchers from academics and medical sciences have introduced wireless body area networks (WBANs). This is a promising technology in healthcare which consists of smart biomedical sensor nodes (BSNs) that can be implanted or worn on human body. The BSNs are equipped with limited computational resources including sensing and collecting In order to address the healthcare challenges, researchers from academics and medical sciences have introduced wireless body area networks (WBANs). This is a promising technology in healthcare which consists of smart biomedical sensor nodes (BSNs) that can be implanted or worn on human body. The BSNs are equipped with limited computational resources including sensing and collecting data from human body and sending it to medical center for further processing [8,9]. WBAN is an economical healthcare system for medical professionals and patients. It gives the advantage of mobility to patients, allowing them to be engaged in their routine activities instead of staying in hospital or under constant supervision of a medical professional [10]. data from human body and sending it to medical center for further processing [8,9]. WBAN is an economical healthcare system for medical professionals and patients. It gives the advantage of mobility to patients, allowing them to be engaged in their routine activities instead of staying in hospital or under constant supervision of a medical professional [10]. WBANs emerged from wireless sensor networks (WSNs) [11]. However, they are somehow diverse due to some intrinsic challenges. WBAN three tiers communication architecture is shown in Figure 1. Tier-1 (Intra-WBAN) refers to communications among BSNs and body node coordinator (BNC) where nodes send their sensory data to BNC. Tier-2 (inter-WBAN) denotes the communication WBANs emerged from wireless sensor networks (WSNs) [11]. However, they are somehow diverse due to some intrinsic challenges. WBAN three tiers communication architecture is shown in Figure 1. Tier-1 (Intra-WBAN) refers to communications among BSNs and body node coordinator (BNC) where nodes send their sensory data to BNC. Tier-2 (inter-WBAN) denotes the communication of BNC with remote medical site. Tier-3 (Beyond-WBAN) consists of medical servers for real-time diagnosis, history of patients record keeping and generating alert to the emergency services, medical professionals, and immediate caretakers of the patients [12].

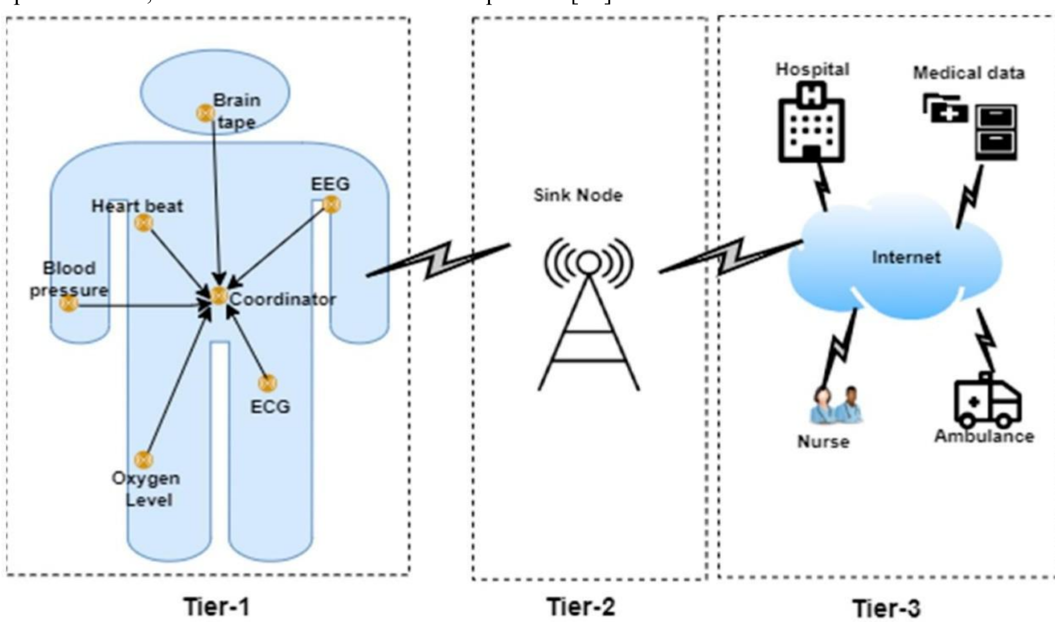

Figure 1. WBAN communications

In intra-WBAN communication, reliable data transmission is a critical challenge due to dynamic and impulsive behaviour of BSNs [13]. Sensor nodes have short battery life, the optimal energy consumption is the major problem in

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WBANs[14,15]. If a sensor node runs out of battery and is unable to transmit physiological signals, it will be life threatening to the patient. Hence, the sensor nodes should survive longer. Almost 80% of the sensor energy in WBANs is utilized by communication processes [16,17]. The network lifetime of BSNs can be enhanced by optimizing the communication process. Due to the resource limitations and short communication range of BSNs, direct communication between BSNs and BNC is not suitable because of path loss issues [18,19]. Direct communication consumes more energy. Therefore, multi-hop communication is comparatively more appropriate for WBANs because it balances out the energy more efficiently [20]. BSNs in multi-hop communication, in which sensor nodes send data to their neighbouring nodes instead of sending directly to the BNC [21,22]. In multi-hop communication, the selection of next-hop as a forwarder node is the most critical part of routing protocols. The existing routing protocols in WBANs present several trade-offs for selecting the next-hop. However, these protocols attempt to choose the route with shorter path instead of route with best quality path. Hence, these protocols lead to high power consumption in WBANs. Towards this end, this paper presents a green computing framework focusing on an energy aware link efficient routing approach for WBANs (ELR-W). Here it is noteworthy that literature did not consider multipath oriented path loss-oriented impacts while calculating link efficiency. However, our major novelty is on incorporating multipath path loss-oriented packet reception rate, and interference effect on link quality calculation along with distance and residual energy considerations. Our overall contribution in this paper can be summarized as follows:

- Firstly, a link efficiency-oriented network model is presented considering beaconing information and network initialization process.
- Secondly, a path cost calculation model is derived focusing on energy aware link efficiency.
- A complete operational framework ELR-W is developed considering energy aware next-hop link selection by utilizing the network and path cost model.
- The comparative performance evaluation has been carried out focusing on energy-oriented metrics under WBANs medical environments.

Furthermore, the related previous work is presented in Section 2 of this paper, modelling detail of the proposed ELR-W framework is discussed in Section 3. Section 4 discusses simulation results and analysis, followed by Section 5 where the conclusion of this study and future direction are presented.

II. WBAN ARCHITECTURE

The sensor tier in WBAN architecture is responsible for collecting physiological data from the human body. This tier typically consists of small, low-power sensor nodes that are implanted in or worn on the body. These sensor nodes can measure various physiological parameters, such as heart rate, blood pressure, oxygen saturation, and body temperature.

The relay tier in WBAN architecture acts as an intermediary between the sensor tier and the application tier. This tier is typically a personal server or a smartphone that collects data from the sensor nodes and transmits it to the application tier for further processing and analysis. The relay tier can also perform some basic processing and filtering of the data before transmitting it.

The application tier in WBAN architecture is responsible for processing, analysing, and storing the physiological data collected by the sensor nodes. This tier can be a remote server or a cloud-based platform that provides a centralized repository for storing and managing the data. The application tier can also provide various services, such as data analytics, decision support, and alerts and notifications.

In addition to the three tiers, WBAN architecture also includes various communication protocols and standards that enable wireless communication between the sensor nodes, relay tier, and application tier. Some of the commonly used communication protocols in WBANs include Bluetooth, Zigbee, and IEEE 802.15.6.

Overall, WBAN architecture provides a flexible and scalable framework for designing and implementing wireless body area networks. By enabling wireless communication between sensor nodes, relay tier, and application tier, WBAN architecture provides a powerful tool for monitoring and managing physiological data in real-time.

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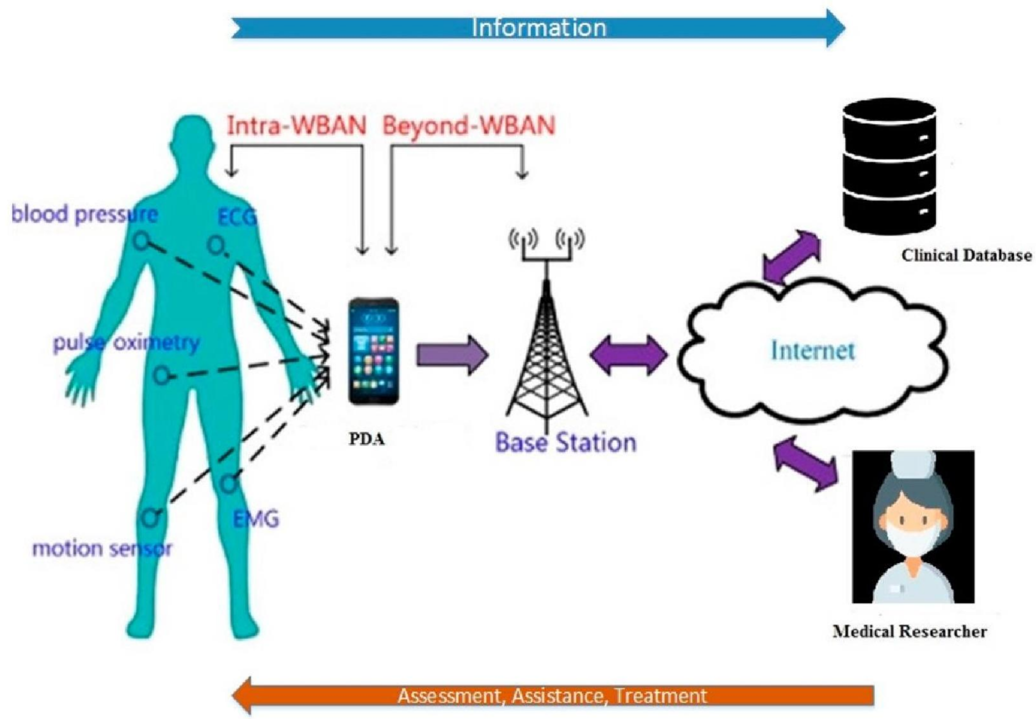

Figure 2: Architecture of WBAN communication

III. PREVIOUS WORK AND MOTIVATION

Wireless Body Area Networks (WBANs) have emerged as a crucial technology for remote health monitoring, sports, and military applications, enabling continuous monitoring of physiological signals and providing real-time feedback to users. However, the unique characteristics of WBANs, such as node mobility, dynamic network topology, and limited energy resources, pose significant challenges for designing efficient routing protocols. Previous research has focused on developing various routing protocols, including temperature-based, QoS-based, cluster-based, and cross-layer-based approaches, to address these challenges. These protocols aim to minimize energy consumption, reduce temperature rise in sensor nodes, ensure quality of service, and handle node mobility. Recent studies have explored adaptive multi-cost routing protocols, energy-aware routing protocols, and fuzzy-based routing protocols, which have shown promising results in improving network lifetime, reliability, and QoS. Despite these advancements, there is still a need for more efficient and reliable routing protocols that can efficiently handle the complex and dynamic nature of WBANs, while meeting the requirements of various applications. Furthermore, the integration of emerging technologies, such as artificial intelligence and machine learning, into WBAN routing protocols has the potential to further enhance their performance and efficiency. Overall, the development of efficient routing protocols for WBANs is crucial for realizing the full potential of this technology and enabling its widespread adoption in various domains

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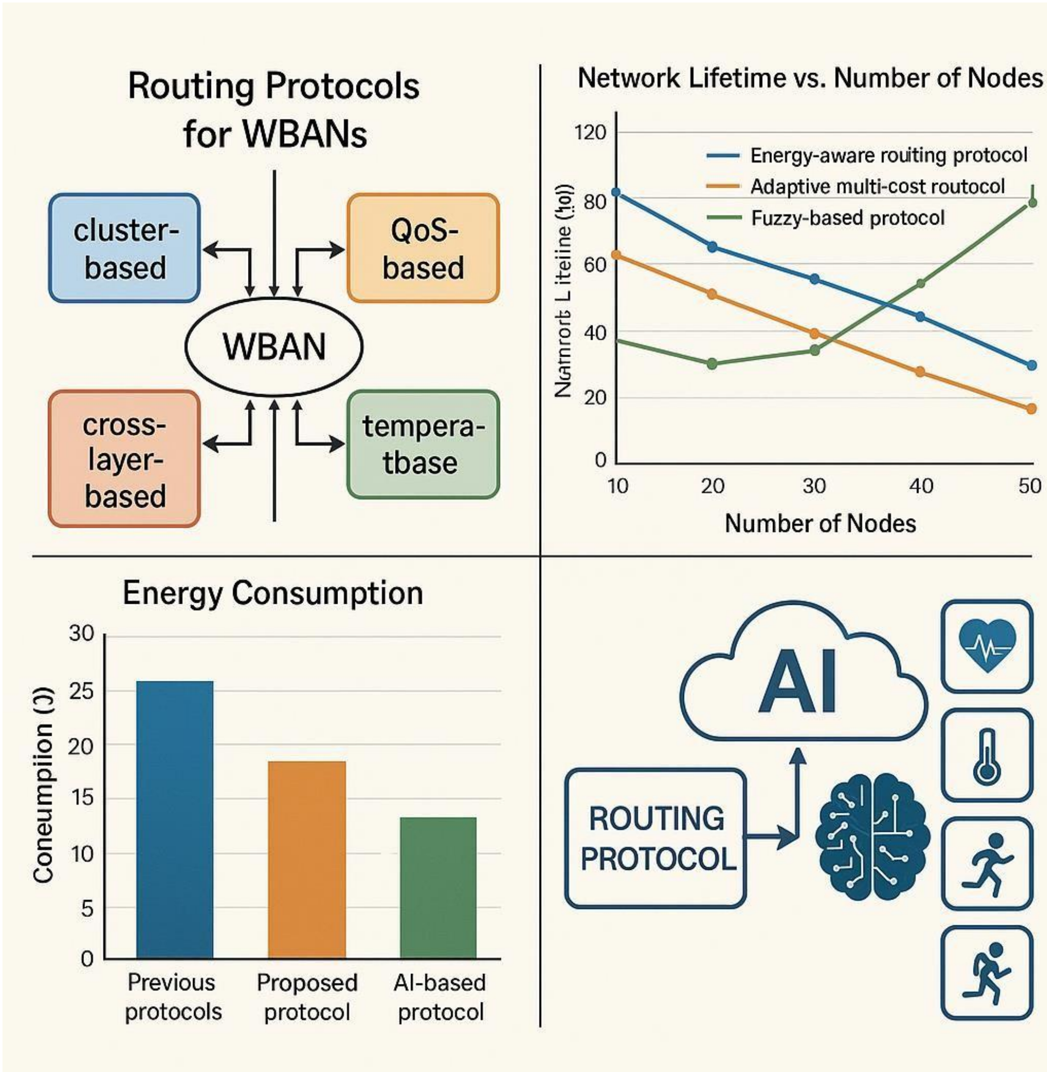

Figure 3: Previous work and motivation for WBANs communication

IV. HUMAN BODY POSTURES

Human body postures play a crucial role in determining the performance and reliability of Wireless Body Area Networks (WBANs), which are designed to monitor various physiological signals and provide real-time feedback to users. The dynamic nature of human body movements, such as walking, running, or even simple gestures, can cause sensor nodes to shift, leading to changes in network topology and potential link failures. Furthermore, the human body's unique characteristics, including tissue absorption and scattering of radio signals, can significantly impact signal strength and quality, making it challenging to maintain reliable communication between sensor nodes. To address these challenges, researchers have developed posture-aware routing protocols that take into account the dynamic nature of human body movements and adapt to changing network conditions. These protocols aim to minimize energy consumption, reduce latency, and ensure reliable data delivery, thereby improving the overall performance and efficiency of WBANs. Examples of such protocols include DVRPLC, M-ATTEMPT, and LOCALMOR, which consider postural movements, link connectivity patterns, and QoS requirements to optimize network performance. Moreover, the development of more advanced posture-aware routing protocols that can learn and adapt to individual

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users' movement patterns and habits could further enhance the performance and reliability of WBANs. Additionally, integrating machine learning and artificial intelligence into WBAN routing protocols could enable them to make more informed decisions and optimize network performance in real-time. Overall, the development of efficient posture-aware routing protocols is essential for realizing the full potential of WBANs and enabling their widespread adoption in various applications, including healthcare, sports, and entertainment. By addressing the challenges posed by human body postures, researchers can create more reliable, efficient, and scalable WBANs that can provide accurate and timely feedback to users, ultimately improving their overall experience and well-being.

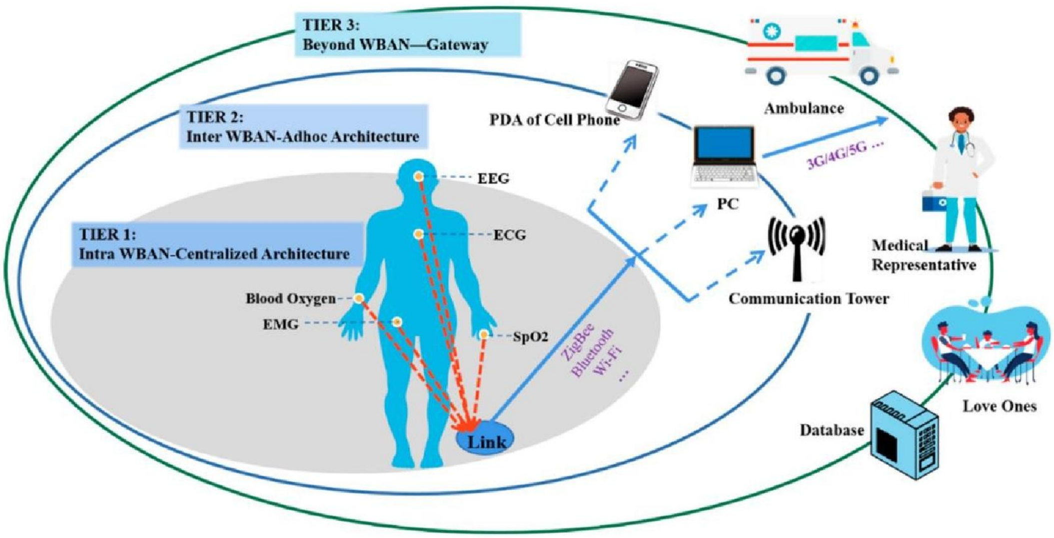

Figure 4: Human Body Postures in WBANs communication

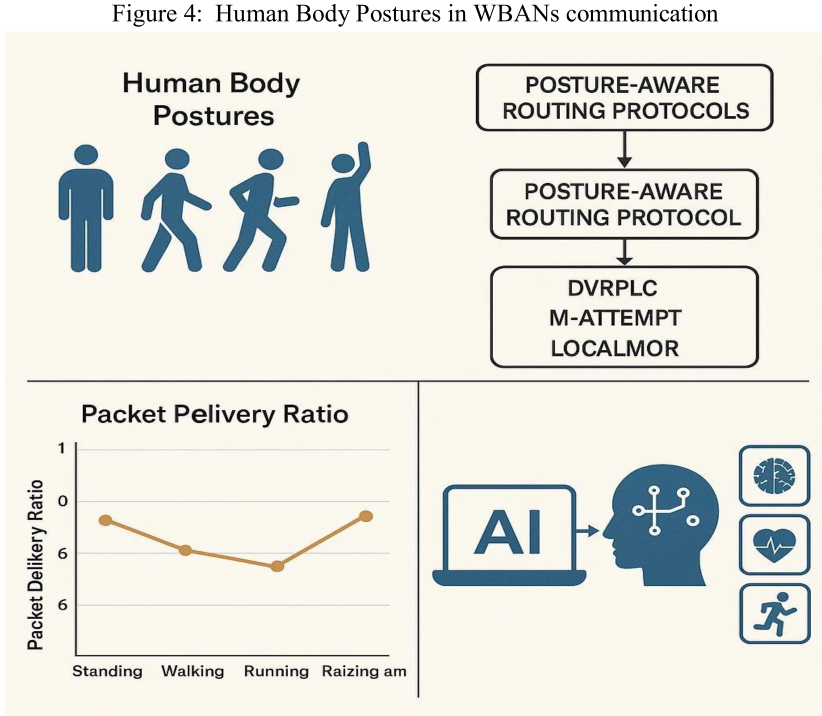

Figure 5: Flowchart and Graph of Human Body Postures

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V. ENERGY EFFICIENT ROUTING SCHEME FOR WBAN

Authors	WBAN Protocol / Standard used	Strengths	Limitations
Z. Khan et al. [11]	Energy-aware Peer Routing protocol (EPR) is designed for WBAN.	Limitation in network traffic load. Minimum energy consumption factor.	Mathematical model / algorithm is not designed.
M. Sahndhu et al. [40]	Balanced Energy Consumption (BEC) protocol is designed.	Stability in network lifetime.	Maximum path loss ratio.
L. Liang et al. [41]	Energy Efficient Routing Scheme (EERS) is not designed. Collection Tree Protocol (CTP) is used for data collection among wireless sensor nodes.	EERS is used for route selection, link quality estimation and data forwarding.	Scheduling schemes for data transmission in WBAN is not proposed.
N. Javaid et al. [39]	Mobility supporting Adaptive Threshold-based Thermal-aware Energy-Efficient Multi-hop routing Protocol (M-ATTEMPT) is designed.	Proposed algorithm is capable to sense the thermal heat of hotspot during routing process and thus possibly explore maximum number of routes.	Selects maximum number of cluster heads in each round by using multi-hop communication.
A. Ahmad et al. [24]	Energy-aware routing protocol for WBAN is designed (RE-ATTEMPT).	Reduction in temp rise, energy consumption, delay and select route with min hop count.	Average number of packet drop ratio of sensor nodes is high in each round.
C. Abreu et al. [29]	IP version 6 based routing scheme for low power WBAN (6WLoWBAN) is designed	Energy Aware routing protocol for WBAN is designed. Low power sensor nodes are used to calculate blood pressure, temperature, heartbeat and pulse rate	Maximum power consumption factor is an important issue to consider.
S. Ahmed et al. [43]	Cooperative Low Energy Efficient Body area network routing protocol (CO-LEEBA) is proposed for a single hop & multi-hop communication.	Co-LEEBA protocol is used to select the most suitable route with minimum path loss.	Maximum energy utilization of sensor node in single hop in emergency circumstances.
Chen et al. [44]	Harmony Search-based Energy Efficient QoS based Routing protocol (HSBEER) is designed for Medical WSN.	HSBEER routing algorithm is designed for maximizing the network lifetime. Improvement in convergence speed & accuracy of routing.	Multi-hop routing in case of cluster head selection increases the power consumption overhead.
N. Javaid et al. [45]	Improved stable increased throughput multi-hop link efficient routing protocol (IM-SIMPLE) for WBAN is designed.	Energy consumption-based model, linear programming based mathematical model is designed for maximum throughput.	Greater path loss ratio as compared to M-ATTEMPT.
Ha et al. [46]	Addresses the limitations in M-ATTEMPT routing protocol.	Routing algorithm for sensor node deployment in case of back and the front side of the human body is designed.	Integration with Medical Emergency server is not available.
N. Javaid et al. [47]	Distance-Aware Relaying Energy Efficient (DARE) Routing protocol is designed. Heterogeneous network is deployed in case of body sensors and body relays.	MI-DARE does not transmit redundant packets as M-ATTEMPT, which leads to prolonged network lifetime. Intelligent routing for data messages using swarm optimization technique.	Energy-aware QoS routing is under consideration.
Z. A. Khan et al. [48]	Energy-aware routing protocol for indoor hospital BAN communication is designed.	The protocol ensures end to end network link reliability. Reduces network traffic load and energy consumption.	The protocol is most suitable for moving patients as compared with stationary.

VI. PROPOSED ALGORITHM

1. Energy-Efficient Optimized Routing Protocol using Particle Swarm Optimization (PSO)

1. Initialize network topology and node positions.
2. Calculate the distance between each node and the sink node.
3. Assign weights to each node based on residual energy and distance
4. Select the node with the highest weight as the next hop.
5. Repeat steps 3-4 until the data reaches the sink node.

2. Dynamic Interference Avoidance Algorithm (DIAMA)

1. Detect interference in the current channel.

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2. Switch to a different channel to avoid interference.
3. Monitor the new channel for interference.
4. Adjust the channel switching strategy based on interference patterns.

3. Cross-Layer Design Optimal (CLDO)

1. Initialize network parameters and node positions.
2. Calculate the optimal transmission power and lifetime.
3. Adjust the transmission power and lifetime based on network conditions.
4. Monitor network performance and adjust parameters as needed.

4. Fuzzy-Based Dynamic Time Slot Allocation

1. Determine the energy ratio and packet arrival rate for each node.
2. Use fuzzy logic to allocate time slots based on energy ratio and packet arrival rate.
3. Monitor network performance and adjust time slot allocation as needed.

5. Genetic Algorithm-Based Routing Protocol

1. Initialize population of candidate solutions.
2. Evaluate fitness of each solution based on energy efficiency and network lifetime.
3. Select parents for crossover and mutation.
4. Generate new offspring and repeat evaluation and selection process until optimal solution is found.

6. MMPQoS-Aware Routing Protocol

1. Determine QoS requirements for each application.
2. Calculate QoS metrics for each possible route.
3. Select the route that meets QoS requirements.
4. Monitor network performance and adjust routing as needed

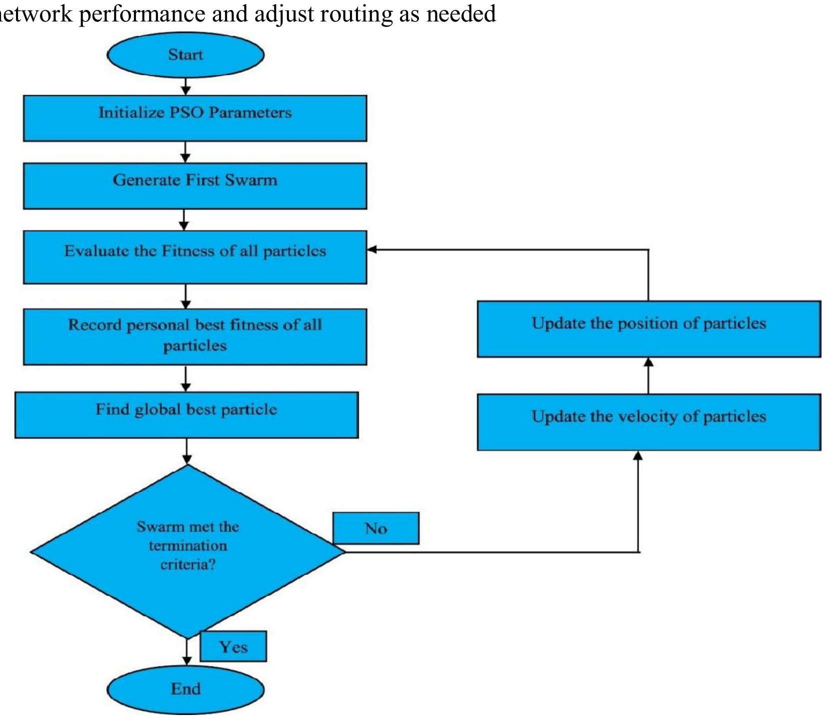

Figure 6: Flowchart of WBANs proposed algorithms

VII. ROUTING PROTOCOLS IN WBAN

1. M-ATTEMPT (Mobile Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol)

Full Form:
Mobile Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol

Key Features:

- **Thermal-aware**: Prevents hot-spot creation by avoiding routes that can overheat the human body.
- **Mobility Support**: Designed to function efficiently in mobile scenarios.
- **Energy Efficient**: Minimizes energy consumption by optimizing the number of hops and selecting reliable paths.
- **Multi-hop Communication**: Uses intermediate nodes to forward data when the direct path to the sink isn't feasible.

Working:
It maintains **threshold temperature levels** for each node.
Routes are **dynamically changed** when node temperature crosses a limit to avoid tissue damage.
Direct communication is preferred when nodes are near the sink; otherwise, **multi-hop** is used.

Advantages:

- Reduces thermal effects on the human body.
- Supports body mobility.
- Increases network lifetime by balancing energy consumption.

2. RE-ATTEMPT (Reliable Energy-efficient Adaptive Thermal-aware Threshold-based Energy-efficient Multi-hop Protocol)

Full Form:

- Reliable Energy-efficient Adaptive Thermal-aware Threshold-based Energy-efficient Multi-hop Protocol

Key Features:

- Improved version of M-ATTEMPT.
- **More Reliable**: Focuses on link stability and packet delivery ratio.
- **Adaptive Thresholding**: Dynamically adjusts threshold values based on current network conditions.
- **Enhanced Fault Tolerance**: Supports route reconfiguration when links fail.

Working:

- Uses **resilient path selection** based on thermal readings and energy levels.
- Introduces **feedback mechanisms** to detect and replace failing nodes.
- Balances **load and temperature** more efficiently than M-ATTEMPT.

Advantages:

- Greater reliability and packet delivery.
- Improved fault tolerance.
- Adaptive to both temperature and mobility.

3. QPRD (QoS-based Power and Residual energy-aware Dynamic routing protocol)

Full Form: Quality of Service-based Power and Residual energy-aware Dynamic routing protocol

Key Features:

- Focuses on **QoS** (delay, throughput, reliability) for healthcare monitoring.
- Considers **residual energy**, link quality, and **path reliability** during routing.
- Aims for **real-time data delivery** with minimal packet loss.

Working:

- Classifies data as **critical** and **non-critical**.
- Critical data is routed via **minimum delay** paths; non-critical data via **energy-efficient** paths.
- Nodes are ranked based on **residual energy and link quality** to determine optimal paths.

Advantages:

- Ensures timely delivery of vital health data.
- Balances network lifetime with service quality.
- Minimizes packet loss and delays.

4. CO-LAEEBA (Cooperative Link Aware and Energy Efficient Protocol for Body Area Networks)

Full Form: Cooperative Link Aware and Energy Efficient Protocol for Body Area Networks

Key Features:

- **Cooperative communication**: Uses helper nodes for better transmission quality.
- **Link-aware**: Considers link quality metrics like RSSI (Received Signal Strength Indicator).
- **Energy-efficient**: Minimizes retransmissions by using high-quality links.

Working:

- Selects **cooperative relay nodes** based on link quality and residual energy.
- Aims to reduce **transmission errors** and **packet retransmissions**.
- Routes are established to maximize **packet delivery success rate**.

Advantages:

- Reduces energy usage due to fewer retransmissions.
- Improved communication reliability in dynamic conditions.
- Better suited for **on-body and in-body** communication.

5. IM-QRP (Improved QoS-based Routing Protocol)

Full Form: Improved Quality of Service-based Routing Protocol

Key Features:

- Enhances QoS by considering **delay, energy, and reliability**.
- Targets **mission-critical healthcare applications** where timely and accurate data delivery is crucial.
- Uses **priority scheduling** for emergency data.

Working:

- Applies **weighted cost function** that includes delay, energy, and link stability.
- Routes with **minimum delay and high energy** are prioritized for **real-time** data.
- Non-critical data follows energy-optimized routes.

Advantages:

- Enhances **timeliness and reliability** of health monitoring.
- Reduces network congestion by segregating traffic based on urgency.
- Better supports **heterogeneous WBAN applications**

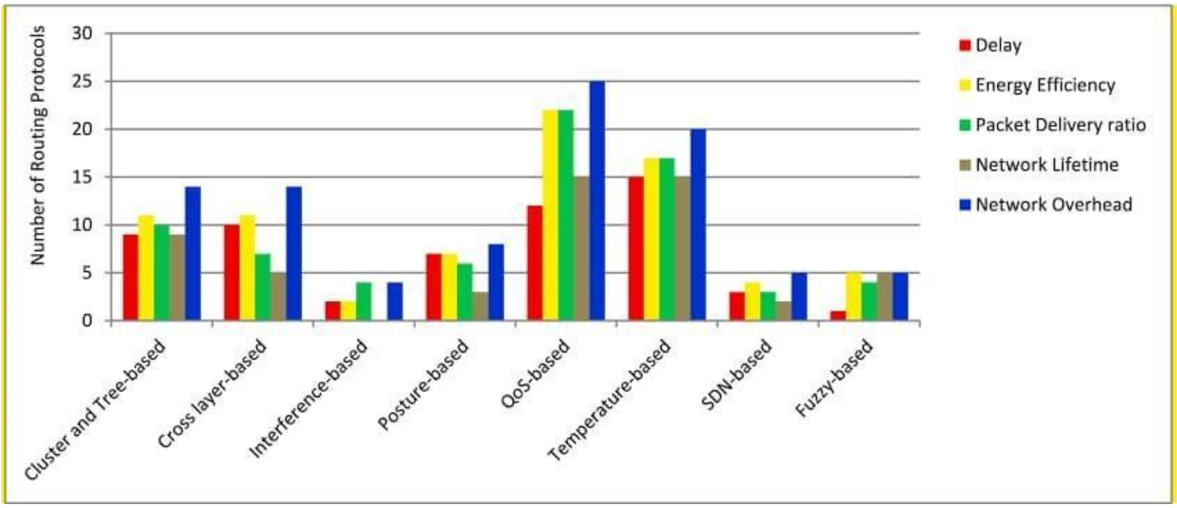

Figure 7: Graph of Routing protocols in WBAN

VIII. COMPARATIVE ANALYSIS OF COMPLEXITY OF ROUTING PROTOCOLS IN WBAN

Sr No	Algorithms	Contributions	Limitations	Time Complexity
1.	M-ATTEMPT [39]	• Select thermal heat of hot spot during Routing Mechanism. • Temperature Aware Routing Protocol for WBAN	• Maximum power Transmissions is utilized by sending maximum number of packets directly towards the sink Node.	$O(n^2)$
2.	RE-ATTEMPT [24]	• Selects the Route for data transmission with minimum hop count and lesser delay as compared with M-ATTEMPT. • Routing Path quality is better than simple M-ATTEMPT	• Minimization in Network Life time due to increased energy consumption. • Short range transmission using IEEE 802.15.6 Standard	$O(n)$
3.	QPRD [67]	• QoS Aware Routing Protocol in WBAN. • Ensures Higher data transmission rate (maximum throughput) and limited packet drop with stable Network Traffic	• Less coverage rate and exploration • Transmission link failure can occur. •	$O(n \log n)$
4.	CO-LAEEBA [43]	• QoS Aware Routing Protocol for WBAN having minimum path Loss. • Having Low Energy Consumption and High packet delivery ratio	• Minimized Network life time, i.e. limited number of alive nodes for maximum amount of time	$O(n*m)$
5.	IM-QRP [proposed]	• Improved QoS Aware Routing protocol for WBAN. • Higher SNR, Maximum throughput, maximum residual energy of sensor nodes, Maximum number of packets transmissions, Enhanced Network life time	• Integration with 6G wireless framework is future research challenge.	$O(n)$

IX. CONCLUSION

In this research project, we have proposed Improved QoS Aware Routing Protocol (IM-QRP) for WBAN. The proposed protocol is capable to select the most feasible route and significantly improves the network lifetime by introducing arrangement of sensor nodes and relay nodes mounted on the human body based on the postural movement

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of patients. The major Contribution of this research work is based on improvement in QoS provision. Improvement in residual energy of sensor nodes and High SNR results in strong link reliability of the overall network. The strong link reliability improves the RSSI which enables the maximum number of packets to receive at receiver side (sink node). Validation of the proposed protocol is performed by simulations, using MATLAB. QRP proto col is compared with the QPRD and CO-LEEBA protocols. IM-QRP protocol shows significant improvement in residual energy, QoS, minimization of path loss and improvement in SNR. The future works are focused on integrating the proposed WBAN framework with smart homes by deploying Internet of Things (IoT) based framework. We propose an energy efficient model for deploying WBAN using multi hop topology. Use of a relay between the sensor nodes and the coordinator optimally placed is suggested. The model uses an optimum distance to place a relay for retransmitting signals from nodes beyond the specified distance. The simulation showed that the nodes use lower energy to send signals through a relay. The energy consumption graph showed that the relay can be placed at a distance of between 50cm and 75 cm to achieve energy efficiency. Path loss was used as a performance metric and it showed that the further the nodes from the coordinator, the higher the path loss. Use of the relay reduces path loss. However, the relay also adds to the cost of system design since it will require higher hardware specifications to be able to transmit signal from the nodes. This challenge can be solved by replacing relay batteries periodically when they get depleted. The transmitter energy required also was shown to increase with distance. This implies that when a relay is used, lower energy will be dissipated during signal transmission.

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