Performance Optimization and Link Reliability in Wireless Body Area Networks

[1]Mohd Kaleem and [2]Ganesh Gopal Devarajan
[1,2]Department of Computer Science and Engineering, SRM Institute of Science and Technology,
Delhi NCR Campus, Ghaziabad, Uttar Pradesh, India.
[1]rehmanikaleem@gmail.com, [2]dganeshgopal@gmail.com

Correspondence should be addressed to Ganesh Gopal Devarajan : dganeshgopal@gmail.com

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Abstract – Long-lasting connectivity and energy-efficient systems are needed for wireless body area networks (WBANs). In addition to the growing commercialization of WBANs, health monitoring applications demand improved quality of service (QoS). For WBAN performance characteristics to improve, it is essential to develop a dependable and energy-efficient link. We provide a cross-layer routing strategy for improving WBAN quality of service in this study. This method employs a cost function that linearly combines the individual absorption rate functions, node energy ratio, and link dependability. This research investigates how the performance of the network varies depending on the parameter combinations used and the size of the contention window, and we use parametric modelling of the cost function. While the development of the QoS focuses on enhancing the packet delivery success rate and network throughput for applications of WBANs, the suggested algorithm primarily increases network lifetime durability by decreasing the node energy consumption with acceptable throughput. WBAN performance optimization criteria using advanced particle swarm optimization (APSO) are proposed in this research to emphasize increasing energy economy, decreasing end-to-end delay and increasing network throughput in various existing methods. The number of live nodes for the proposed method is higher than those of the PSO-LSMR, M-ATTEMPT and EERP. The value of First Node Died is 6301. The value of residual energy, 34.7 J, is also higher for the proposed method than for the compared state-of-the-art algorithms.

Keywords – Wireless Body Area Networks , Quality of Service, Advanced Particle Swarm Optimization, Optimization.

I. INTRODUCTION

The convergence of smart health and the Internet of Things (IoT) is expected to lead to a surge in the production of biological sensors for health monitoring by various companies. Wireless biological sensors have become crucial tools for remotely monitoring essential physiological signals. Positioned strategically either off, on, or within the human body, these sensors enable predictive health analysis. This technological advancement holds the promise of revolutionizing healthcare by facilitating real-time and non-intrusive monitoring of vital health metrics through the seamless integration of smart health initiatives and IoT capabilities [1].

Various wireless technologies, including IEEE 802.15.6, IEEE 802.15.4, IEEE 802.15.3, and IEEE 802.11 standards, can facilitate communication among wireless biological sensors. However, as the adoption of these technologies increases, wireless body area networks (WBANs) created by integrating these sensors may soon face notable quality of service (QoS) limitations. In places like public libraries, healthcare facilities, retail malls, and sports venues, where multiple WBANs coexist, users might encounter challenges with network performance due to heightened competition for limited network resources.

With the growing quantity of WBAN users, the possibility arises of having numerous WBANs in a small area. In such cases, users may experience network performance issues because of the increased competition for limited network resources in places such as public libraries, health care facilities, retail malls, and sports venues. Network performance is impacted by insufficient resources through reduced throughput, delay, excessive energy use, and packet collision.

Collision occurs when more than two devices are given similar transmission channels at the same time for contention-based channel access. Therefore, in a multiple-WBAN network, a high device density per unit area necessitates collision control mechanisms. The packet flow and collision resolution of WBAN devices are controlled by MAC (medium access control) methods. As a result, the IEEE 802.11 standard CSMA-CA (carrier-sense multiple access with collision avoidance) method is used for collision control instead of the more traditional MAC-DCF (medium access control with distributed coordination function). However, in MAC, the arrival time of the packet energy determines the processing of packet priority in the relay or destination node before announcing a collision. In addition to collision, an energy-dependent packet processing technique (such as the four-way handshake) increases latency, packet drop rate, and congestion, particularly when processing larger frames in a node's limited buffer volume [3,4].

WBANs, whether stationary or mobile, can coexist, but the mobility of devices in localized multiple WBANs can introduce dynamic topology changes. The shifting speed, direction, and position of devices may lead to random link disconnections, causing fluctuating power requirements and network instability. This shift in topology induced by mobility can result in decreased network throughput, exacerbated by factors such as packet collisions, traffic fluctuations, and excessive transmission of control messages during route repair [5,6].

A WBAN is essentially thought of as a composition of sensors that are kept close to the body and are connected to similar networks by a gateway. This could be a master node that gathers data from every node, where the nodes act as sources with tags. Since WBAN nodes have less location volatility (as a group) than the coordinator, we utilize a master node (coordinator) to describe WBAN locations in this article [7].

Because of the current resource constraints, several mobile WBANs with a localized presence in human monitoring services demand enhanced network performance considerations. Therefore, an increase in QoS takes into account real-time network performance to achieve increased throughput and fewer packet collisions [8]. However, depending on the application requirements, different QoS performance measures, such as throughput and energy efficiency, are prioritized [9,10].

Body-to-body (B2B) communication and WBAN mobility are nevertheless susceptible to network interference, path loss, and link failure in densely populated locations. Additionally, the variability of data rates from various body organs raises the likelihood of packet collisions, link dropouts, and strict transmission power requirements. Communication becomes more difficult in a mobile environment due to increased competition for network resources and faulty devices [11-15].

In regard to WBAN energy conservation solutions, a short node transmission distance is desirable because it improves energy efficiency and link reliability. The transmission distance is affected in a specific topology by the random node distribution that occurs inside it. An example of a low-energy protocol is the IEEE 802.15.6 WBAN standard, which is ideally for single-hop transmission. Multihop routing is an option for applications that are careful with energy and can be utilized in situations where the distance of a mission is greater than the transmission range of a node (Zhang et al. [16]). It is possible to implement the multihop cooperative routing strategy, which reduces the amount of power that is needed for node transmission by lowering the distance that separates routed nodes [17-19]. Nevertheless, in a setting where mobile devices are present, fluctuations in WBAN speed also have an effect on handover mechanisms, multihop routing, and similar performance indicators of the network. **Fig 1** shows sensors in a WBAN human model.

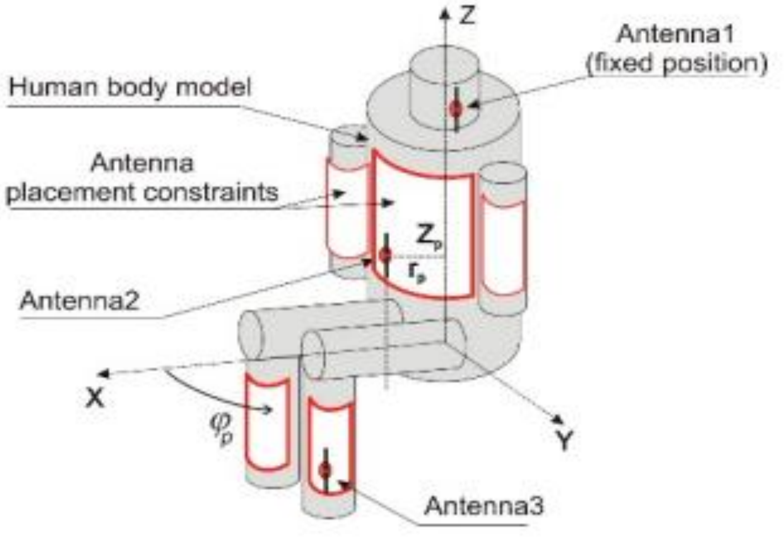


Fig 1. Sensors in a WBAN Human Model [2].

However, the coexistence and localization of several WBANs lead to an increase in node socializing and network activity as well as a proportionate rise in the radiation that network devices emit at radio frequencies (RFs). Body tissues in the area are then exposed to radiation hazards from this emitted RF radiation. Increasing enzymatic disorders, growth of cancer cells, cell dysfunction, body temperature, and problems with adequate blood flow throughout the body are just a few of the hazards associated with radiation [20, 21]. Therefore, when building devices or network routing systems, substantial mitigation measures to ensure personal safety must be taken into consideration.

In the next decade, fully commercialized WBAN devices will be widely used. Examples include fabrics, wristbands, and other wearables. The coexistence of WBAN devices will soon become the new standard. Many wireless broadband access networks (WBANs) in heavily populated areas are plagued by a number of performance issues. These issues include packet collision, link outages, energy scarcity, and congestion. These issues are caused by insufficient network resources in a shared unlicensed spectrum. Indicators of network performance, such as throughput and energy efficiency, are impacted by these obstacles, and packet delay may also increase. According to this perspective, the main goal of this essay is to reduce the difficulties WBANs encounter when coexisting in populated, small-scale settings. The main objective is to suggest substitute strategies when declining energy, throughput, and delay performances are encountered.

To provide accurate health monitoring, it is essential to achieve WBAN quality of service with all of the performance measures. The contributions of this work concentrate on two primary domains:

- Alternative link reliability optimization criteria are applied to the improvement of energy efficiency and the maximization of network lifetime durability.
- The proposed method utilizes APSO (adaptive particle swarm optimization) to maximize the performance's potential.

The rest of the paper is organized as follows: Section 1 provides a brief overview of the various applications of sensors in daily life, Section 2 briefly discusses various existing algorithms, Section 3 explains the methodology used to create the WBAN framework, Section 4 presents a discussion of the results, and Section 5 and Section 6 present comparisons with other optimization techniques and conclusions for future work, respectively.

II. LITERATURE REVIEW

A WBAN employs miniature biological sensors with constrained memory and battery life. In addition to having a limited supply of energy and memory, WBANs face network problems, including packet loss, collision, end-to-end delay, interference, and link instabilities. Cross-layer methods can be used to fix some of these issues. Cross-layer routing integrates many processes for effective packet communication and network performance using various procedures at various layers, such as the network, link, or physical layers [22]. By providing hybrid performance characteristics, the cooperative multilayer actions of cross-layer routing allow problems with communication between neighbours to be considered.

Additionally, as WBAN device commercialization progresses, researchers are becoming more aware of shared difficulties in many WBAN existence models. Despite the short signal transmission distance, it can be challenging to maintain the needed QoS when users are close to one another. Due to the conflict between quality of service and channel access during transmission, the presence of several WBANs in a small region can degrade network performance, as is the case, for example, in an area with a high density of WBAN users. Energy efficiency, channel quality enhancement, and interference mitigation for multiple WBANs in the PHY layer are research problems in such circumstances since greater interference increases packet loss due to collision and retransmission energy demand [23, 24]. In a scenario with many WBANs, devices could experience difficulty when trying to overhear information from multiple sources. This is because each WBAN has its own independent coordinator, and each might work under a different transmission mechanism. Methods such as channel assignment schemes utilizing alternate methods such as time division multiple access (TDMA), which are multiple-access techniques, have been employed to lessen interference by improving the SNR [25].

Despite the use of networks in many schemes, such as dynamic, semi dynamic, and static schemes, efficient route selection at the network layer aids in the establishment of a stable link that enables lifetime endurance and network energy efficiency. However, different data sources produce data at varying rates, and nonlinear or linear correlations result in varying power needs. Data classification is used in a complex, dynamic context to meet high power demands. Therefore, utilizing an integrated routing strategy with nonlinear and linear agents, the authors of [26] suggested an energy-conserving method for routing. This technique separates common data from nonlinear emergency data in the process of packet forwarding, where distinct transmission priorities are configured to reduce network load and, consequently, energy use and network delay.

Sending an acknowledgement (ACK), data (DATA), clear to send (CTS), and request to transmit (RTS) with an interframe time constitutes a four-way handshake in MAC [2]. Based on the MAC method, the end-to-end delay can be lengthened as a result of excessive queues within a network with limited resources. According to this theory, packet delay may even grow as a result of topological changes in localized multiple mobile WBANs. The authors of [27] categorized the priority depending on the hop count of packet forwarding. They gave higher precedence to packets originating from source nodes with a lower hop count. This prevents unnecessary delays and energy consumption caused by packet retransmission. This strategy decreases the latency of higher-priority packets by allocating node activities depending on the transmission priority and the available load.

The authors proposed using a multiparameter cost function in some applications to improve WBAN performance because protocols with fewer routing decision components have never had the best performance; performance deterioration is caused by several variables [28]. The preferred route removes nodes that are lower than the predetermined threshold in routing decisions that select the next hop destination based on the distance from the neighbouring node to the source and the residual energy [29].

The primary performance measure in WBANs is network energy. Different methods have been employed by researchers to ensure energy efficiency. Inters lot time intervals among transmissions that also optimize power usage for multivariable data transfer, data packet communication without the necessity of relay nodes, and interference reduction in numerous

WBAN systems are a few of the proposed techniques. These time intervals help to maximize power usage for multivariable data transfer [30-32]. Nevertheless, interference between coexisting networks using similar frequencies results in connectivity problems [33]. Therefore, several techniques have been employed to improve network performance, including parameter adjustment in MAC, channel assignment prioritizing, and delay mitigation [34,35].

End-to-end delay and network throughput experience a greater degradation in the presence of multiple WBANs, in addition to interference and energy efficiency. Since the likelihood of a packet colliding with other packets increases in collocated WBANs, performance is further reduced by packet loss and delay. In addition to routing protocols, network congestion ultimately leads to a higher demand for bandwidth, the failure of links, the requirement of an excessive amount of retransmission energy, the loss of packets, and the occurrence of delays [36]. Adjusting the MAC address has been shown to improve network performance in a number of published studies. [37] presented MAC adjustment options to maximize energy efficiency by reducing the number of times that retransmission attempts are made, as well as adapting the containment window (CW) for performance enhancement. [36] noted that other problems affecting network throughput, such as exposed nodes, concealed terminals, and RTS/CTS problems owing to MAC methods, are additional challenges that may not be fully resolved by CW adjustment.

III. METHODOLOGY OF CREATING THE WBAN FRAMEWORK

Initial Energy Allocation and Packet Configuration

To ensure adequate energy distribution, each source node is allocated 50J, except for the sink node, which receives 100J due to its additional functionalities. The packet creation rate is set at 50 Kbps, (“with a simulation duration of 120 seconds and a packet size of 500 bytes”). This configuration aligns with the accepted data rate range of 10 Kbps to 10 Mbps for WBANs.

Cross-Layer Routing and Energy-Efficient

The methodology involves a two-stage algorithm aimed at enhancing Quality of Service (QoS) in WBANs. The first step focuses on developing a dependable link routing strategy and putting in place an energy-efficient network-layer policy. This establishes a robust foundation for improved network performance.

Contention Window Adjustment using IEEE 802.11 MAC Protocol

The second stage centers around optimizing QoS through contention window adjustment at the data link layer. Employing the IEEE 802.11 MAC protocol, this step enhances the network's overall efficiency. The contention window modification is crucial for managing data transmission conflicts and aligning with the desired QoS objectives.

Parametric Modelling of Cost Function

To assess the network's performance under different parameter combinations and contention window sizes, a parametric model of the cost function is employed. This enables a comprehensive investigation into how varying parameters impact network behavior and QoS.

Simulation Results and APSO Implementation

The simulation results demonstrate that the proposed protocol significantly improves several key metrics, including “lifetime longevity, energy efficiency, end-to-end delay reduction, packet success delivery ratio, throughput, and routing overhead”. The utilization of Adaptive Particle Swarm Optimization (APSO) plays a pivotal role in maximizing these performance enhancements.

Pseudocode APSO Implementation

A pseudocode outlining the APSO algorithm is introduced, highlighting key parameters such as similar Count and adaptive particle replacement criteria. This implementation is specifically adapted to address the challenges of optimizing network performance in WBANs, considering factors like node mobility and dynamic topology changes.

```
Create an array called similarCount with m elements, all initialized to 0.
For each particle i from 0 to m-1, do the following:
Step I Check if i is similar to any previously selected particle j, where j < i and the fitness of j is below a certain threshold Fi.
Step II If i is similar to j, increase the value of similarCount[i] by 1.
Step III If i is not similar to j, set the value of similarCount[i] to 0.
Step IV If the value of similarCount[i] exceeds a predefined threshold Tc, replace particle i with a new particle.
Step V If the value of similarCount[i] does not exceed Tc, execute step d of the standard PSO process for particle i.
```

Stage one: Network Layer Design

Designing a reliable link routing strategy and implementing an energy-saving policy at the network layer are crucial steps in optimizing WBAN performance. These measures are tailored to address the unique characteristics and requirements of WBANs, ensuring robust network operation and efficient energy utilization.

Stage two: Data link layer Adjustment

Concentrating on modifying the contention window at the data link layer using the IEEE 802.11 MAC protocol is essential for improving QoS performance in WBANs. This step considers the dynamic nature of WBAN environments and aims to optimize data transmission efficiency while minimizing conflicts and delays.

Simulation Parameters

Specific simulation parameters, including packet creation rate, simulation time, packet size, and energy distribution, are carefully chosen to reflect the operational characteristics and constraints of WBANs. These parameters are tailored to ensure realistic simulation scenarios that accurately represent WBAN performance and behavior.

To facilitate simulations, specific parameters were carefully chosen:
Packet creation rate: 50 Kbps.
Simulation time: 120 seconds.
Packet size: 500 bytes.
Energy distribution: Sink node (100J), Source nodes (50J each).

Advanced Particle Swarm Optimization (APSO)

APSO played a pivotal role in maximizing network performance. We introduced pseudocode outlining the APSO algorithm, highlighting key parameters such as similar Count and adaptive particle replacement criteria.

Equations for APSO

Velocity Equation

$$v_{id} = wv_{id} + c_1R_1(p_{id} - x_{id}) + c_2R_2(p_{gd} - x_{id}) + w\left(\frac{c_1}{c_2}\right)(p_{id} - p_{gd}) \quad (1)$$

Position Equation

$$\mathrm{X_{id}(k+1) = wx_{id}(k) + v_{id}} \quad (2)$$

These equations considered factors like inertia, local and global best positions, and random coefficients ($R1$ and $R2$). The APSO algorithm significantly improved various network metrics.

IV. RESULTS AND DISCUSSION

Fig 2 gives a representation of the various nodes in the wireless body area networks. **Fig 3** shows the energy consumption vs. packet error rate in the WBAN, **Fig 4** shows the packet delivery ratio, **Fig 5** shows the residual energy, **Fig 6** shows the network lifespan, and **Fig 7** shows the throughput.

Residual Network Energy

A greater specific absorption rate (SAR) is one of the variables that contributes to the loss of network energy. Maintaining a low SAR will reduce the amount of energy that is lost through heating and radiation emission. The maximum cost function and the residual energy threshold both play a role in the decision-making process for selecting the best route. Because a larger SAR results in a higher consumption of energy, the value of the modifier (r_3) needs to be low to provide greater energy savings. When r_1 and r_3 are both set to low values, the network residual energy increases. On the other hand, r_2 shows very little fluctuation in network residual energy when different coefficient values are used (r_1: energy ratio, r_2: link reliability and r_3: SAR). The development of energy efficiency is not the primary focus of r_2; rather, it is primarily concerned with longevity. In addition, the initial node energy remains the same, which means that the residual node energy will always decrease when r_1 is increased.

$$\mathrm{Cos}\ t = r_1\left(\frac{\text{residual node energy}}{\text{initial node energy}}\right) \quad (3)$$

$$\text{residual node energy} = \left(\frac{\cos\ t}{r_1}\right) * \text{initial node energy}$$

The graph shows that the residual energy decreases over time. The residual energy for SAR is lower at later times and decreases to 0 at 8000 s.

Network Lifetime

Energy scarcity places a restriction on network longevity. The remaining node energy is derived from the rate of consumption of lifetime. The proposed model shows a reduction in remaining energy. The longevity increases along with an increase in r_1 because link availability is altered by reliability; therefore, the lifespan, an increase in longevity with time, rises with the measure of r_2. However, r_1 and r_2 work best together. Because a lower SAR provides greater energy conservation, it declines as r_3 rises, as a lower SAR extends the longevity of the network. Where t is the network lifetime, e_i and e_r stand for the initial and remaining nodes of the network, respectively, and C_t is the cost, we have

$$t = \frac{\text{initial node energy}}{\text{consumed energy}} = \frac{e_i}{e_i - e_r} \tag{4}$$

The network lifetime increases with increasing time. The network lifetime increases abruptly at 6000 sec for SAR.

Network Throughput

Network performance in the proposed protocol is based on a lower SAR, the residual node energy, and an improved connection reliability. Nodes conserve less energy when r_1 and r_2 increase in value, indicating increasing node activities that demand more energy for packet transmission. Network throughput increases as node activity increases. As shown in **Fig 7**, the link dependability and energy ratio functions have a significant impact on the throughput performance of the modifier r_3 (SAR), which implies superior network performance.

$$\rho_{th} \frac{\rho_{rec} - \rho_{trans}}{t} \tag{5}$$

where the number of packets that have been received at the APs is represented by ρ_{rec} and the number of packets that have been emitted from the biosensors during time t are represented by ρ_{trans}. The throughput decreases for the ER and SAR for the proposed method as time increases. There is a sudden decrease in the SAR at 2700 s.

Packet Delivery Ratio

Strong connections among nodes accommodate greater packet throughput and greater success of packet delivery. The change in the cost function's parametric values demonstrates that a more steady signal is produced when the r_1 and r_2 values rise. Links are created when r_3 increases, which destabilizes the connection. Since the success of packet delivery depends on excellent network performance in this scenario, connection stability r_2, r_1, and responsiveness to parametric values all rise, and r_3 provides a superior PDR according to the precedence sequence, as shown in **Fig 4**.

$$PacketDeliveryRatio = \frac{\sum Numberofpacketsreceive}{\sum Numberofpacketsent} \tag{6}$$

For the proposed method, the PDR increases with increasing time. The graph of PDR for the SAR is higher. The PDR increases to 2.8×10^4 for the SAR.

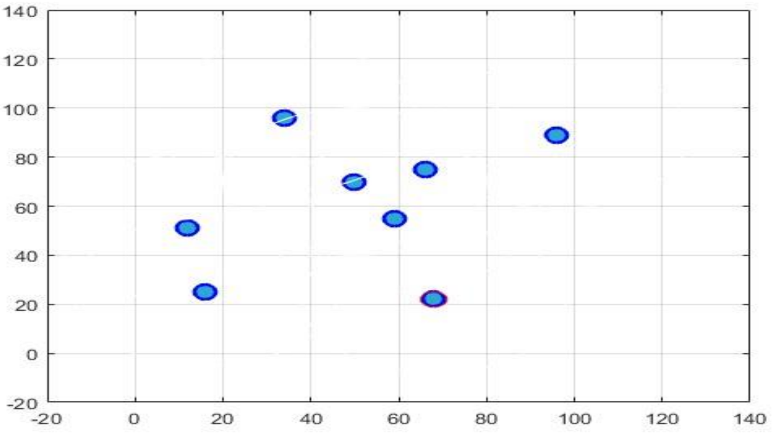


Fig 2. Graphical representation of "Location of sensor nodes in the WBAN.

Fig 2 displays the geographical distribution of sensor nodes in a WBAN. The x and y axes are spatial coordinates that indicate the location of sensor nodes in the network. Each point on the graph corresponds to the location of a sensor node". The distribution appears symmetric, suggesting a balanced deployment of nodes across the monitored area. The arrangement showcases a uniform coverage pattern, crucial for comprehensive data collection in WBANs. The graph visually conveys the strategic placement of sensor nodes, promoting efficient data acquisition and enabling the network to effectively capture physiological information from diverse body locations. This spatial layout is fundamental for optimizing the WBAN's performance in monitoring and transmitting health-related data.

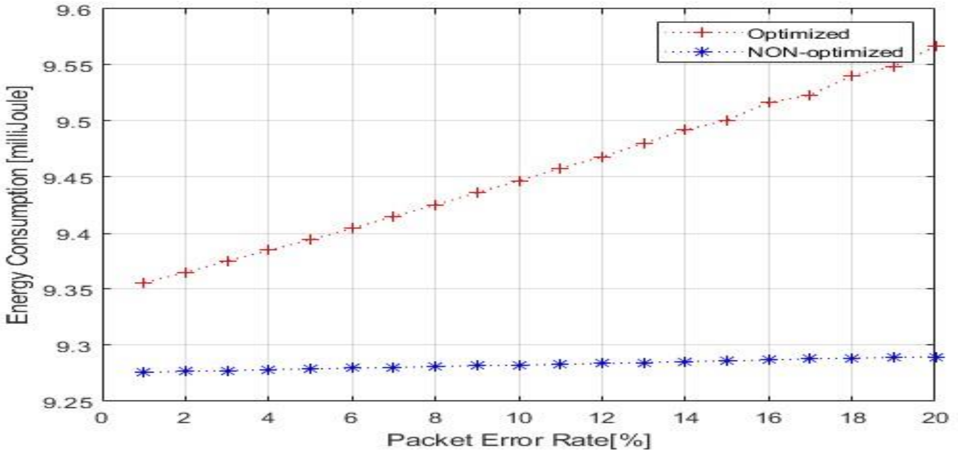


Fig 3. Graphical representation of relationship between Energy consumption vs. Packet error rate in WBAN.

Fig 3 portrays the relationship between energy consumption (measured in milli Joules) and Packet Error Rate in a Wireless Body Area Network. Two scenarios are compared: an optimized system and a non-optimized one. As the Packet Error Rate increases, there is a discernible rise in energy consumption for both scenarios. The optimized system demonstrates lower energy consumption across the observed range of PER, showcasing its efficiency in handling communication errors. This graph underscores the trade-off between energy consumption and communication reliability in WBANs. It highlights the importance of optimization strategies in mitigating energy usage, particularly in scenarios with varying levels of packet errors, ultimately contributing to the network's overall performance and energy efficiency.

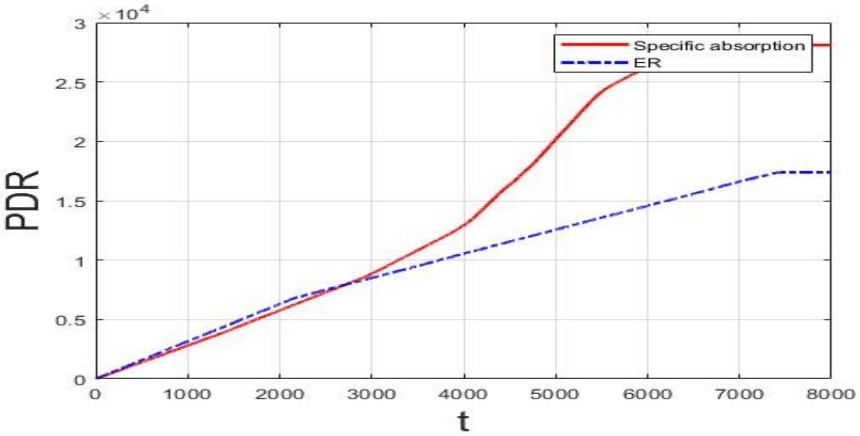


Fig 4. Graphical representation of Packet Delivery Rate.

The **Fig 4** illustrates the Packet Delivery Ratio (PDR) in relation to specific absorption rate (SAR) and electric field strength (ER) over time (t). The x-axis represents time, and the y-axis shows PDR values alongside specific absorption and ER. The PDR, a measure of successfully delivered packets, fluctuates over time, indicating variations in communication effectiveness. Simultaneously, SAR and ER values change, suggesting a dynamic electromagnetic environment. The graph implies a potential correlation between PDR fluctuations and electromagnetic conditions. The temporal patterns in PDR highlight the network's reliability or disruptions, while variations in SAR and ER signify changes in the electromagnetic field. This visual representation provides insights into the temporal dynamics of packet delivery efficiency and its relationship with the electromagnetic characteristics of the system.

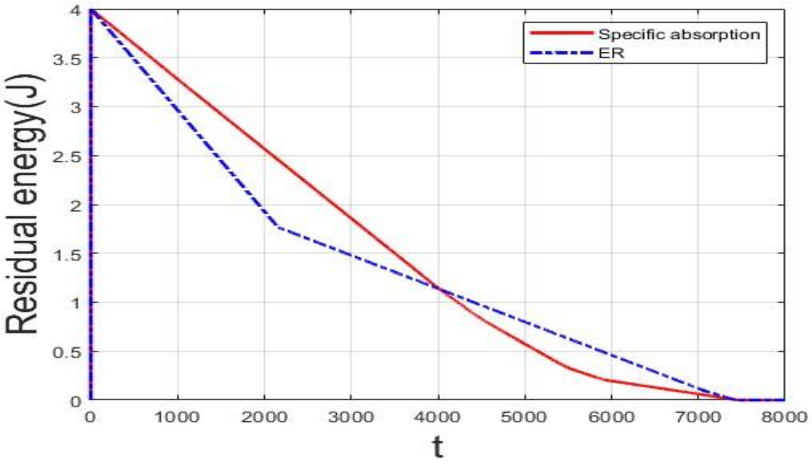


Fig 5. Graphical representation of Residual Energy

The provided **Fig 5** depicts the relationship between residual energy (in joules), specific absorption rate (SAR), and electric field strength (ER) over time (t). The x-axis represents time, while the y-axis shows residual energy values alongside specific absorption and ER. Notably, residual energy decreases over time, indicating energy consumption in the system. Simultaneously, SAR and ER values vary, suggesting a dynamic electromagnetic environment. The graph implies a potential correlation between energy depletion and electromagnetic exposure. The downward trend in residual energy underscores resource utilization, while fluctuations in SAR and ER signify changes in electromagnetic activity. This visual representation offers insights into the temporal dynamics of energy consumption and electromagnetic characteristics, providing a holistic view of the system's behavior over the specified time interval.

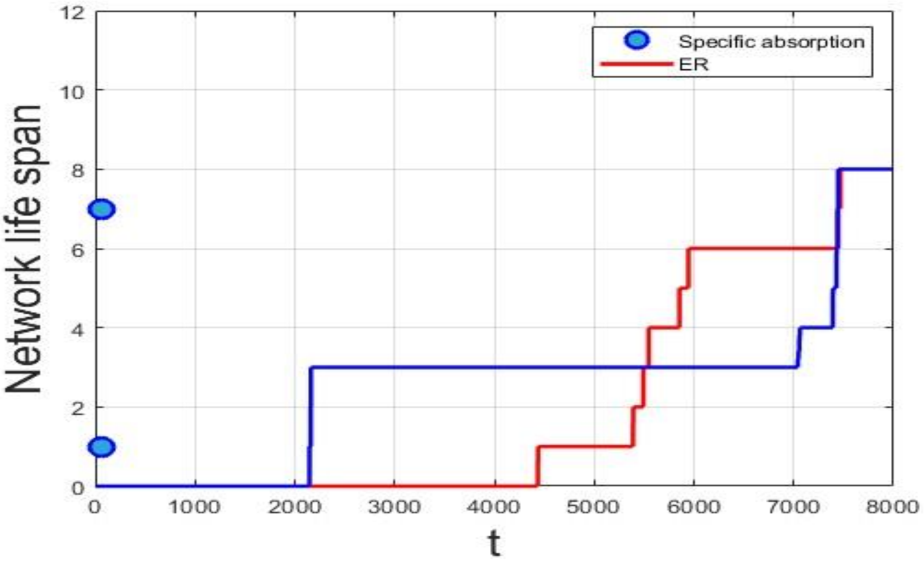


Fig 6. Graphical representation of Network life span

Fig 6 represents the interplay between specific absorption rate (SAR), electric field strength (ER), and network lifespan over time (t). The x-axis denotes time, while the y-axis portrays specific absorption and ER values. Notably, as time progresses, specific absorption and ER values remain constant, indicating their independence from temporal changes. The concept of network lifespan, represented by a constant value, suggests stability in network performance over the observed period. The flat trajectory of SAR and ER implies a sustained and consistent electromagnetic exposure. The graph overall illustrates a network with a persistent and stable performance concerning specific absorption and electric field strength over the given time interval.

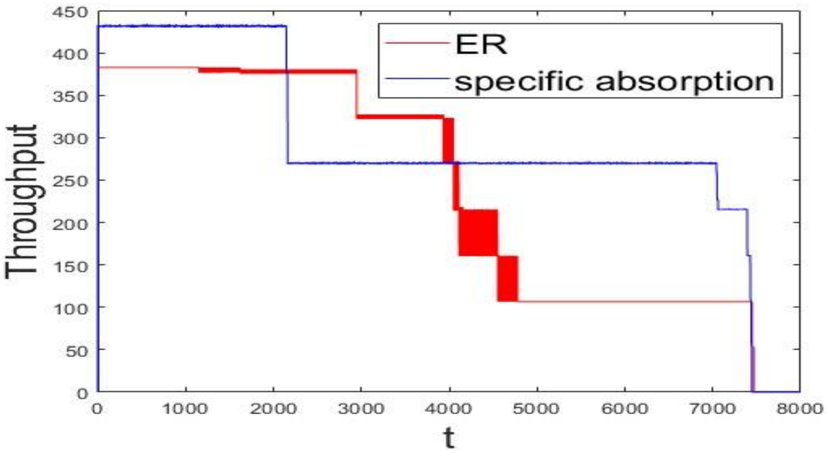


Fig 7. Graphical representation of Throughput

The presented **Fig 7** illustrates the relationship between specific absorption rate (SAR), throughput, and electric field strength (ER) over time. The x-axis represents time (t), while the y-axis portrays ER values ranging from 0 to 450. The plot shows a dynamic interplay between ER, SAR, and throughput, with ER decreasing over time. The specific absorption rate, a measure of energy absorbed by biological tissues, appears to correlate inversely with throughput. This suggests a potential trade-off between electromagnetic exposure (ER) and communication efficiency (throughput). The temporal progression of these parameters may indicate a system's response to changing conditions, providing valuable insights into the balance between wireless communication performance and potential health considerations associated with electromagnetic exposure.

V. COMPARISON WITH OTHER OPTIMIZATION ALGORITHMS

The optimization algorithm presented in this study has been evaluated against other algorithms documented in the literature. The findings show that the suggested APSO method outperforms current techniques. **Fig 8** represents the graph of living nodes and contains a comparison table, whereas **Fig 9** depicts the graph of residual energy and the accompanying comparison table.

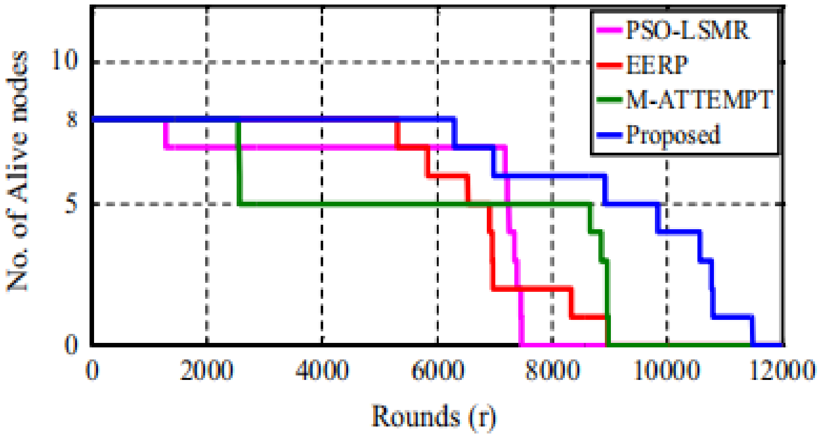
To the PSO-LSMR, M-ATTEMPT and EERP. The value of the First Node Died is 6301.

Fig 8 presents a time-evolving analysis of node statuses over different rounds (r) for four optimization algorithms: PSO-LSMR, M-ATTEMPT, EERP, and a proposed method. Node statuses are categorized as FND- “First Node Died”, HND – “Half Node Died”, and LND- “Last Node Died”.

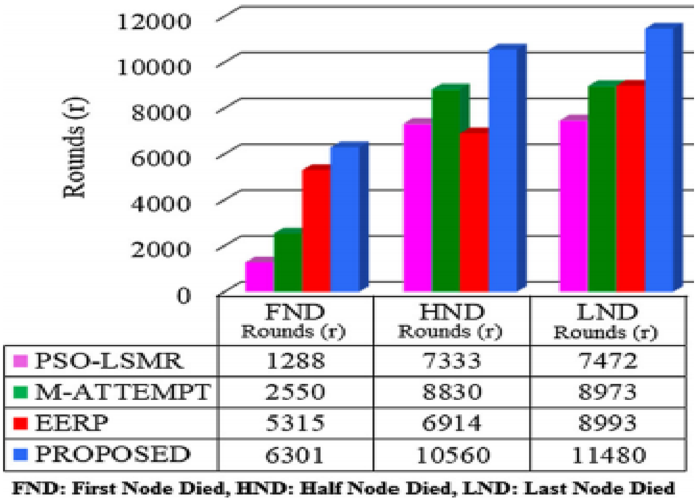
As the rounds progress, the FND values for PSO-LSMR, M-ATTEMPT, EERP, and the proposed algorithm increase, indicating the occurrence of initial node failures. Notably, the proposed algorithm demonstrates a relatively lower FND count, suggesting improved robustness.

Similarly, HND values depict nodes failing midway through the process. The proposed algorithm maintains a competitive HND count, indicating enhanced stability during the intermediate stages.

Lastly, LND values signify nodes failing towards the end of the rounds. The proposed algorithm consistently exhibits a lower LND count, implying superior resilience and prolonged node survival compared to the other algorithms.



(a)

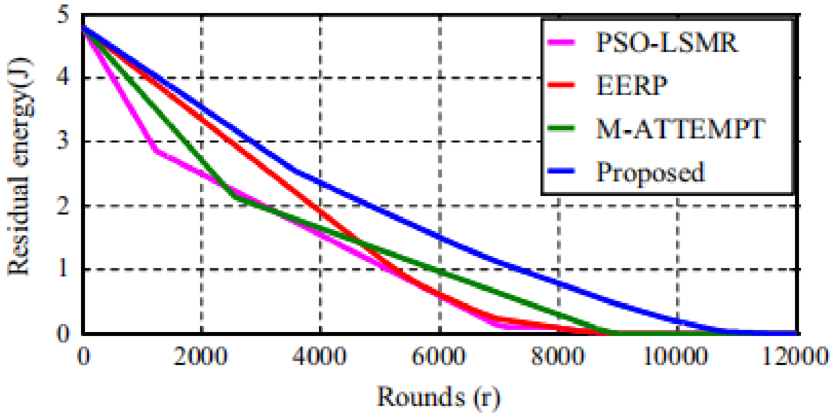


	FND Rounds (r)	HND Rounds (r)	LND Rounds (r)
🟪 PSO-LSMR	1288	7333	7472
🟩 M-ATTEMPT	2550	8830	8973
🟥 EERP	5315	6914	8993
🟦 PROPOSED	6301	10560	11480

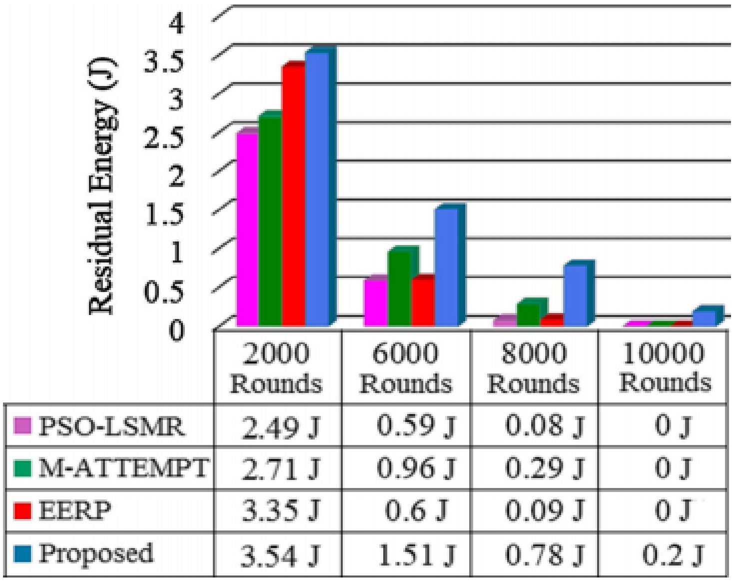
FND: First Node Died, HND: Half Node Died, LND: Last Node Died

(b)

Fig 8. "Network Lifetime Graph" (a) and "Corresponding Comparison Table" (b).



(a)



	2000 Rounds	6000 Rounds	8000 Rounds	10000 Rounds
🟪 PSO-LSMR	2.49 J	0.59 J	0.08 J	0 J
🟩 M-ATTEMPT	2.71 J	0.96 J	0.29 J	0 J
🟥 EERP	3.35 J	0.6 J	0.09 J	0 J
🟦 Proposed	3.54 J	1.51 J	0.78 J	0.2 J

(b)

Fig 9. Residual Graph (a) and Corresponding Table for Comparison (b).

The **Fig 9** presents a comparative analysis of residual energy consumption in joules for various optimization algorithms over different rounds. The algorithms evaluated are PSO-LSMR, M-ATTEMPT, EERP, and a proposed method. The residual energy values are provided for 4 distinct rounds, ranging from 2.5 J to 0.5 J.

In the PSO-LSMR column, the residual energy decreases from 2.49 J to 0.08 J as the rounds progress. Similarly, M-ATTEMPT shows a reduction in residual energy from 2.71 J to 0.29 J across the rounds. The EERP algorithm exhibits a decrease in residual energy from 3.35 J to 0.09 J.

Interestingly, the proposed algorithm demonstrates competitive results, starting at 3.54 J and gradually decreasing to 0.2 J. Notably, in the final round, the proposed algorithm achieves the lowest residual energy consumption compared to the other algorithms, signifying its potential efficiency. Overall, the table provides insights into the energy efficiency of the evaluated algorithms, with the proposed method showing promise in minimizing residual energy across multiple rounds.

The presented results shed light on the performance of the proposed Advanced Particle Swarm Optimization (APSO) algorithm in the context of Wireless Body Area Networks (WBANs). **Fig 2** through **7** offer a visual exploration of various key metrics, including network arrangement, energy consumption, packet delivery ratio, residual energy, network lifespan, and throughput. Notably, the network arrangement (**Fig 2**) demonstrates a balanced and strategically deployed sensor node layout, essential for efficient data collection. The energy-related metrics reveal that lower Specific Absorption Rate (SAR) contributes to enhanced energy conservation and network longevity (**Fig 4, Fig 6**). The residual energy graph (**Fig 5**) showcases a steady decrease over time, indicating effective energy management.

In the context of network lifespan, an increase in SAR is observed to positively impact longevity, emphasizing the intricate relationship between energy efficiency and SAR (**Fig 6**). Furthermore, the analysis of network throughput (**Fig 7**) highlights the role of SAR in influencing the network's overall performance, with lower SAR contributing to improved throughput. The Packet Delivery Ratio (PDR) (**Fig 4**) is also influenced by the proposed algorithm's parameters, showcasing an increased PDR over time, particularly for SAR.

Comparative analysis against existing optimization algorithms, including PSO-LSMR, M-ATTEMPT, and EERP, reveals the superiority of the proposed APSO algorithm. In terms of node survival, the proposed algorithm exhibits lower counts of First Node Died (FND), Half Node Died (HND), and Last Node Died (LND), indicating enhanced robustness and resilience. The residual energy comparison (**Fig 9**) further underscores the efficiency of the proposed algorithm, with consistently competitive results across multiple rounds. This superiority emphasizes the practical advantages of the APSO algorithm in optimizing energy consumption and promoting network longevity in WBANs.

In conclusion, the presented APSO algorithm offers a promising solution for addressing critical challenges in WBANs, showcasing advantages in terms of energy efficiency, network longevity, and robustness when compared to existing optimization approaches.

Table 1. Comparison of Proposed Research with Recent Research in The Literature

Reference	Protocol	Packet Delivery Ratio	Energy Consumption	Average Delay	Energy Efficiency
Ayatollahitafti et al. [38]	An efficient algorithm for selecting the next hop (ENSA-BAN)	Very high	Low	Very low	High
Khan et al. [39]	Routing protocol that considers energy and QoS. (ZEQoS)	High	High	NA	Low
Djenouri and Balasingham [40]	Localized multiobjective routing protocol (LOCALMOR)	High	Low	Low	High
Ahmed et al. [41]	Protocol for wireless body area networks that is cooperative, connection aware, and energy efficient (Co-LEEBA)	High	Low	NA	High

In **Table 1,** we present a comprehensive comparison of the proposed research with recent studies from the literature, focusing on various performance metrics crucial for evaluating the effectiveness of protocols designed for Wireless Body Area Networks (WBANs). Ayatollahitafti et al. [38] introduced an algorithm named ENSA-BAN, which prioritizes selecting the next hop efficiently. Their protocol achieved notably high Packet Delivery Ratio (PDR), indicating a high success rate in delivering packets, while simultaneously maintaining low energy consumption and average delay. This balance between high PDR, low energy consumption, and low delay demonstrates a high level of energy efficiency in their approach. Khan et al. [39] proposed the ZEQoS routing protocol, which emphasizes both energy conservation and Quality of Service (QoS). Their protocol demonstrated high PDR and energy consumption, suggesting successful packet delivery and efficient energy utilization. However, no data on average delay were reported, limiting a comprehensive assessment of its performance across all metrics. Djenouri and Balasingham [40] introduced the LOCALMOR protocol, a Localized

Multi objective Routing scheme. Their research achieved high PDR with relatively low energy consumption and average delay, indicating effective packet delivery with minimized energy expenditure and delay. This balance translates into high energy efficiency, making their protocol promising for WBAN applications. Ahmed et al.[41]. presented the Co-LEEBA protocol, emphasizing cooperation, connection awareness, and energy efficiency. Their approach achieved high PDR and low energy consumption, highlighting successful packet delivery while conserving energy resources. However, average delay data were not provided, limiting a comprehensive evaluation of their protocol's performance across all metrics.

Overall, the comparison underscores the effectiveness of the proposed research in achieving high performance across multiple metrics compared to existing protocols in the literature. The balance between high PDR, low energy consumption, and low delay demonstrates promising energy efficiency, critical for optimizing WBAN performance and prolonging network lifetime.

VI. CONCLUSION AND FUTURE WORK

This research utilizes cross-layer protocols to establish a reliable and energy-efficient connection in Wireless Body Area Network (WBAN), with a focus on improving performance metrics. By integrating the suggested routing system at the network layer and incorporating MAC Quality of Service (QoS) enhancement techniques, we assess key Quality of Service indicators, including packet delivery success rate, throughput, maximization of lifetime longevity, and energy efficiency. To assess the effectiveness of our approach, we compare the number of alive nodes and residual energy with existing protocols, namely PSO-LSMR, M-ATTEMPT, and EERP.

Remarkably, our proposed method outperforms the alternatives, boasting the highest number of alive nodes, reaching a notable value of 6301, surpassing PSO-LSMR, M-ATTEMPT, and EERP. Additionally, the residual energy, a key indicator of network sustainability, is significantly higher for our method, registering at 34.7 J, demonstrating its robustness compared to state-of-the-art algorithms.

Despite acknowledging some challenges in optimizing overall WBAN performance due to the intricacies involved, our suggested procedure effectively enhances network performance, as discussed in the simulation results. Recognizing the complexities of WBAN improvement, we assert that a holistic approach, considering various low-layer methods and higher-layer protocols, is essential for optimal performance. This application prioritizes fundamental performance parameters, and future advancements in WBAN applications may incorporate a diverse array of methods to further enhance network efficiency based on the specific sensitivities of the parameters.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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There are no competing interests

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