Extending WBAN Lifetime through Adaptive Sink and Sensor Node Positioning Strategies

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ABSTRACT

Wireless Body Area Networks (WBANs) stand out as a key technology advancing the field of healthcare monitoring. Sensor devices in this network help continuously monitor health parameters that are sent using a specific methodology to specialists for diagnosis. The most important challenge in WBANs is to save energy and maximize the lifetime of sensors as much as possible, since they are powered by replaceable or rechargeable batteries. This work investigates ways to reduce the energy consumption of WBANs and increase their lifetime. The work provides an efficient routing framework that optimizes relay node selection to reduce energy consumption. The proposed method relies on changing the position of the coordinator/sink node and the positions of all sensor nodes, in addition to the threshold energy value. Simulation results indicate that the proposed WBAN outperforms traditional WBANs in terms of energy efficiency, network stability, and data reliability.

Keywords- Wireless Body Area Network (WBAN); relay selection; cost-effective; lifetime; energy efficiency

I. INTRODUCTION

Wireless body area networks (WBANs) have emerged as a transformative technique in modern healthcare and human-focused applications, offering a skilled and real-time method for monitoring important health parameters. WBANs are designed to operate in close proximity to the human body [1]. These networks include several short, low-power sensor nodes that can be either wearable or implanted, allowing them to continuously collect physical and environmental data. The collected data are transmitted through interconnected wireless devices such as mobile phones, individual digital assistants (PDAs), or dedicated monitoring systems, which act as intermediate processing and communication hubs. Finally, this information is sent to a remote medical facility, hospital, or cloud-based healthcare platform, where medical professionals process and analyze it to support real-time diagnosis and long-term patient care [2].

In the past few years, WBAN technology has received particular attention due to its potential uses in medical diagnostics and management, monitoring chronic diseases, caring for the aged, tracking performance with the aid of sports gadgets, rehabilitation practices, and even military applications [3]. Among these areas, the integration of WBANs in medical fields is of utmost importance because of their capability to provide uninterrupted, non-invasive, and remote health monitoring, which results in improved quality of life, timely disease identification, and preventive healthcare. The strong point of WBANs is their ability to advance patient care while reducing the need for hospital visits and providing targeted treatment, making them a building block in the global smart healthcare system [4].

Even though WBANs have an array of benefits, they still face certain obstacles which, if not dealt with, could prove damaging to their utility and efficiency in the future. Energy in WBAN design has a big bearing on the network lifespan of these systems. Since the sensor nodes in WBANs are mostly implantable, they are usually powered by small, portable, single-use batteries, which are hard, if not impossible, to replace [5]. What makes things worse is that these sensors are needed to constantly collect health data and send it for processing, so if any of the sensors run out of power, network performance will plummet and can lead to total system failure. Energy consumption in WBANs includes the following [1-3]:

- Health monitoring applications need to transmit data on a regular basis, which requires large amounts of energy.
- Sensor nodes have to communicate with a gateway device or a medical center, which consumes a lot of power.
- The energy generation is limited in the majority of WBAN sensors, and for implanted sensors, the battery replacement is intrusive and needs surgical access, so energy conservation is very important.
- Because of the natural dynamism of human movement, signal crosstalk, and variable channel conditions, additional energy is required to sustain robust connectivity.
- Most physiological parameters vary over time in small amounts; however, conventional WBANs send data at every point in time, irrespective of the reporting frequency, which wastes energy.

Because of these challenges, the extension of the service life of WBAN sensors has emerged as an important research direction. Designing an energy-conscious WBAN networking architecture that reduces wasteful power consumption yet preserves high data reliability is a critical factor for the sustainable and efficient operation of WBAN. A promising solution for the energy issues of WBANs is the adoption of relay selection algorithms [6]. A relay node, intermediate between sensor nodes and the main communication medium, provides data transmission to minimize direct communication energy. Instead of requiring each sensor to transmit data directly to the destination, a relay selection protocol enables sensors to transfer data through optimized relay nodes, reducing overall energy consumption and enhancing network longevity [7]. Table I introduces the main benefits of applying relay selection techniques to WBANs [7-9].

TABLE I. MAIN BENEFITS OF DEPLOYING RELAY SELECTION APPROACHES TO WBANS

Benefit	Discussion
Load balancing	By distributing the transmission load among multiple relays, the depletion of energy of a single node can be avoided
Energy conservation	Optimal relaying saves the combined power consumption needed to transmit the data by choosing the relay nodes with maximum residual energy
Improved network reliability	By tuning data transmission channels, relay selection mitigates the risk of network outages caused by sensor failures
Minimized interference	Human body movements can lead to dynamic changes in the channels, and smart relay selection is beneficial to ensure reliable and steady connectivity

To reduce energy consumption in WBANs, various mechanisms, such as relaying and cooperative communication, have been proposed [7-13]. In the relaying approach, certain nodes do not actively participate in sensing data but are utilized solely as relay nodes, forwarding traffic within the network. Tactical placement of such relay nodes enhances network efficiency significantly by optimizing energy consumption and transmission overhead [9]. In cooperative communication, as opposed to employing dedicated relay nodes, the sensor nodes collaborate by exploiting the residual energy of neighboring nodes to forward data. This approach circumvents the need for additional relay infrastructure while leveraging the collective energy reserves of the network to provide efficient communication.

Another approach in [14] uses a dedicated relay network to forward data. In this setup, all sensor nodes are connected to a relay network via a single-hop connection using a relay node within its line of sight. While this approach employs an energy-efficient protocol for channel access and routing, additional relay nodes are introduced progressively to ensure that all the sensors have a line-of-sight connection with at least one relay node. However, the increased number of relay nodes involves higher overall deployment costs, making this solution less viable, particularly in scenarios where patient comfort and mobility are paramount. WBAN communication protocols can be categorized into three main types: direct, one-relay, and two-relay communication.

Authors in [15] proposed SIMPLE-DRR, which is a low-energy multi-hop routing protocol, specifically designed for WBANs in medical monitoring. The authors introduced a significant extension of the cost function used for relay node selection by improving its decision-making parameters. Unlike traditional approaches based on merely reducing the distance to the sink and maximizing residual energy, SIMPLE-DRR considers additional parameters like the number of alive nodes per round and Received Signal Strength Indicator (RSSI). By including these parameters, the protocol maximizes the relay node selection operation in favor of nodes that promote network stability as well as energy efficiency.

This enhanced selection process significantly improves network lifetime and stability compared to earlier protocols such as SIMPLE [16] and M-ATTEMPT [17]. By preventing premature node depletion and maintaining energy distribution evenly, SIMPLE-DRR extends the operation time of the WBAN, which is an acceptable solution for extended health monitoring applications where reliability is the top priority. Furthermore, optimization algorithms have been researched to further improve WBAN routing efficiency [18, 19]. One such protocol, SIMPLE, was introduced in [16] with the primary objective of maximizing network lifetime. The performance of SIMPLE was compared with that of other routing protocols under various network conditions to measure key parameters such as energy spent and system life. Simulation tests indicated that SIMPLE can efficiently extend network lifetime, making it an excellent candidate to be used as an energy-conserving WBAN communication protocol. The proposed work is a modified version of the SIMPLE model.

This research aims to build an optimal relay selection algorithm to save energy and promote the stability period of WBAN sensors. The proposed strategy concentrates on developing a dynamic relay selection policy conditioned on real-time network state changes, thereby guaranteeing that the most energy-efficient transmission paths are always employed. The proposed relay selection algorithm considers the following main factors:

- Residual energy levels of candidate relay nodes for fair energy usage.
- Link quality and signal strength are essential for providing reliable data transmission.
- Minimization of transmission power without compromising data accuracy.
- Adaptive adaptation to changing network topology for better performance in real-world situations.

Through optimization of relay selection in WBANs, this work contributes to building next-generation medical healthcare monitoring systems by achieving the following.

- High reliability for long-term health tracking.
- Energy efficiency, ensuring continuous operation without frequent sensor replacements.
- Cost-effectiveness, reducing the need for invasive interventions and maintenance.
- Scalability, applicable to a growing number of wearable and implanted sensors.

II. WIRELESS BODY AREA NETWORK ARCHITECTURE

The architecture of a WBAN can be divided into three hierarchical levels, each playing a critical role in ensuring efficient data collection, transmission, and processing. The lower-level layer includes biomedical sensor nodes that can be either implanted, wearable, or attached to garments. These nodes continuously monitor various physiological signals. Implantable sensors offer high fidelity, chronic surveillance, whereas wearables and clothing-based sensors can be used to collect non-intrusive data streams for patient-focused applications. After the data are acquired, they are sent to a coordinator/sink node for processing. The coordinator (e.g., embedded in a smartphone, smartwatch, or microcontroller) combines sensor data, filters spurious data, and formats them for forwarding to a higher level. Energy efficiency is a key consideration in this layer, as sensor nodes operate on limited battery power and must balance continuous data acquisition with minimal energy consumption.

To be useful in healthcare applications, sensors must deliver reliable, real-time information without interrupting patient movements. High-performance signal-processing algorithms and low-power computing are essential to reducing battery power requirements and providing continuous monitoring. In addition, the coupling of AI and machine learning further optimizes the performance of the sensor system through the identification of anomalies, prediction of health risks, and patient-to-individual personalization [20]. Sensors are the heart of WBANs, translating physical parameters into electronic signals to be processed and transmitted. These sensors can be classified according to their functionality and positioning in the human body as follows [21-23]:

- Physiological sensors: Physiological sensors quantify biological parameters and are used extensively in continuous health monitoring and medical diagnosis. These sensors monitor body temperature, glucose levels, ambulatory Blood Pressure (BP), Electroencephalography (EEG), Electrocardiogram (ECG), Electromyography (EMG), and blood oxygenation (SpO_2). The information collected helps in the early diagnosis of health deviations, the individualized preparation of therapy plans, and the management of chronic diseases.
- Biokinetic sensors: Biokinetic sensors assess human body movement, posture, and acceleration. These types of sensors are widely applied in rehabilitation, fall detection in elderly patients, and sports analytics at an individual level. Quantifying rotational speed and acceleration allows for real-time gait analysis and motion tracking, which is essential for physiotherapy, injury prevention, and activity recognition.
- Ambient sensors: Ambient sensors provide information about conditions that could affect patients' health. Such sensors can measure sound levels, ambient pressure, light intensity, temperature, and humidity. Their potential applications in managing patients suffering from respiratory diseases, allergies, or environmental sensitivities are of special interest due to the contextual awareness of health management and adaptation to external stimuli.

Also, WBAN sensors can be categorized into non-invasive (external) and invasive (implantable) sensors according to their positioning within the body. Non-invasive (external) sensors are wearable or attachable and provide external parameters (e.g., heart rate, motion, and temperature). They offer convenient and unobtrusive continuous health monitoring. However, invasive (implantable) sensors are surgically implanted and used for long-term health surveillance of critical metrics such as intracranial pressure, cardiac function, and neural activity. They also guarantee high accuracy and nonstop functioning, especially for medical applications providing life-sustaining support.

The second layer acts as a wireless mesh center and allows protected data dissemination from sensor nodes to the outside links. Various wireless communication standards facilitate this process, including the following [21]:

- Bluetooth Low Energy (BLE) for short-range, energy-efficient communication.
- Wi-Fi and Wireless Local Area Networks (WLANs) for bandwidth-intensive applications.
- ZigBee and 6LoWPAN for low-power, low-data-rate communication.
- Cellular networks (3G, 4G, 5G) for telehealth.

This level incorporates a Decision Control Unit (DCU), which is also engaged in sensor data analysis and preliminary diagnosis of patient health. The DCU can also identify abnormalities, activate alerts, and communicate with healthcare professionals regarding the most urgent health information. Furthermore, encryption and authentication measures are implemented at this point to protect confidential patient data from cyber-attacks and open access.

The highest layer at the end of the multitier system links WBAN systems with each other and with loads in the cloud, hospital networks, and remote healthcare providers, allowing for real-time patient monitoring as well as medical actions. This tier consists of the following three main components:

- Cloud computing platforms offer scalable storage and data chunking.
- Electronic Health Records (EHRs) and hospital databases contain patient histories.
- AI-enabled analytics with the ability to recognize patterns, forecast potential health risks, and provide preferred treatment approaches.

All these components allow healthcare professionals to access live patient data and make informed clinical decisions. Direct access to patient data facilitates telemedicine appointments, predictive diagnosis, and tailored health planning. By leveraging machine learning algorithms, WBAN systems in this tier can automate disease detection, monitor chronic conditions, and optimize patient care workflows.

WBANs utilize two primary communication types to facilitate seamless data exchange and real-time monitoring: on-body and in-body communication. On-body communication occurs between wearable sensor nodes placed on the skin, integrated into clothing, or attached externally to the body. To enable efficient data transmission, Ultra-Wideband (UWB) and Industrial, Scientific, and Medical (ISM) bands are commonly used. UWB provides high data rates and energy efficiency, making it suitable for short-range wireless transmission between wearables. Meanwhile, the ISM band supports low-power, interference-resistant communication, ensuring that WBAN devices function reliably even in noisy environments. These communication technologies allow real-time health monitoring, fitness tracking, and wearable medical diagnostics, ensuring that collected data are efficiently transmitted to a central processing unit or a gateway device [21].

In-body communication involves data exchange between implanted sensor nodes located inside the human body. These implants monitor critical health parameters such as blood glucose levels, intracranial pressure, neural activity, and cardiac performance. Unlike on-body sensors, implanted devices require specialized communication techniques due to signal attenuation, biological tissue interference, and strict power consumption limitations. For in-body communication, the Medical Implant Communication System (MICS) band is the most widely adopted frequency range. MICS operates within 402–405 MHz, providing low-power, interference-free, and biocompatible communication specifically designed for implanted medical devices [22]. This ensures seamless interaction between pacemakers, neurostimulators, insulin pumps, and other critical medical implants, facilitating real-time data transfer to external monitoring systems.

To achieve a fully integrated healthcare monitoring system, both on-body and in-body communications must function cohesively. Implantable medical devices rely on gateway nodes positioned externally on the body (e.g., a wearable hub or smartphone) to relay critical health information to hospital networks, cloud platforms, or remote healthcare providers. This enables efficient data collection, storage, and analysis, allowing healthcare professionals to monitor patient conditions remotely and respond to medical emergencies in real-time.

III. SYSTEM MODEL

This section provides the network model for the proposed WBAN. The network deploys N medical sensor nodes placed on the human body in different locations. These locations can be calculated using the proposed model introduced in [9]. Data transmission to the sink node can be done using direct or multi-hop transmission using a relay/forwarding node. Two sensor nodes, ECG and glucose use only direct transmission and do not participate in relaying other data, as their data are critical and should not be delayed. Other sensor nodes can be selected as relay nodes depending on their condition.

A. Energy Model

Energy efficiency is one of the most important issues for WBANs because of the restricted power availability of sensor nodes. WBAN devices operate in a constrained battery world; therefore low-power communication, optimized signal processing, and effective data transmission are crucial for long-term operation. Energy consumption in WBANs is affected by sensor activation, communication distance, data processing, and environmental parameters (attenuation of human body signal). The proposed WBAN is energy-aware and considers transmission energy, reception energy, amplification energy, and path loss effects due to the human body. The transmission energy ($\mathrm{E_{tx}}$) is modeled as follows:

$$\mathrm{E_{tx}(b,d) = E_{tx-ele} \times b + E_a \times n \times b \times d^n} \quad (1)$$

where $\mathrm{E_{tx-ele}}$ is the energy required for signal processing in the transmitter circuit, b is the packet size in bits, $\mathrm{E_a}$ is the energy required by the amplifier circuit, and n is the path loss exponent, which is set to 3.38 for human body tissues. The path loss exponent accounts for signal attenuation caused by body tissues, with different values depending on whether the signal propagates through muscle, fat, or skin. Receiving data also consumes energy, primarily for processing and decoding the incoming signals. The energy required for reception (E_{rx}) is given by the following equation:

$$E_{rx}(b) = E_{rx-ele} \times b \quad (2)$$

where E_{rx-ele} is the energy required for signal processing in the receiver circuit, and b is the packet size in bits. Since no amplification is required at the receiver, circuit power consumption primarily governs the reception energy. The energy parameters defined in these equations are of the Nordic nRF 2401A transceiver. The proposed framework considers the following approaches to further enhance energy efficiency in WBANs:

- Adaptive transmission power control scheme: Nodes dynamically adjust their transmission power based on distance, signal quality, and network congestion. Also, lower power levels are used for close-range communication to conserve battery life.
- Data aggregation and compression: Redundant sensor readings should be eliminated before transmission. Furthermore, efficient compression techniques reduce packet size and transmission overhead.
- Energy harvesting for sustainable WBANs: Bio-energy harvesting (e.g., body heat, motion energy) schemes may be used to extend battery life. Wireless energy transfer, such as RF energy harvesting, has been investigated for use with power implantable sensors.
- Machine learning for predictive energy optimization: AI-based models predict network conditions and optimize duty cycles, reducing unnecessary transmissions. Smart algorithms balance energy consumption across all nodes, preventing early node failures.

B. *Path Loss Model*

Path loss significantly impacts the energy consumption and signal reliability of WBANs. In energy-limited scenarios, like WBANs, signal attenuation due to the presence of body tissues and external factors can greatly influence transmission efficacy. The presented path loss model includes, when needed, physically representative characteristics of human body propagation. It is specifically designed to maximize energy efficiency and reliable sensor node communication. The following equation defines the considered path loss model:

$$PL(f, d) = PL_o + 10n\log_{10}\frac{d}{d_o} + X_\sigma \quad (3)$$

where PL is the path loss at frequency f and distance d, PL_o is the free-space path loss at reference distance d_o, n is the path loss exponent, dependent on Line-Of-Sight (LOS) or Non-LOS (NLOS) conditions, X_σ is the Gaussian random variable accounting for environmental variations, d_o is the reference distance (10 cm), and σ is the standard deviation of the shadowing effect. The free-space reference path loss is computed as follows:

$$PL_o = 10\log_{10}\frac{(4\pi \times d \times f)^2}{c} \quad (4)$$

where f is the transmission frequency (Hz), d is the distance between the transmitter and receiver, and c is the speed of light (3×10^8 m/s). The human body significantly impacts the propagation of signals, with different path loss exponents for LOS and NLOS conditions. This includes the following two main conditions:

- LOS communications (e.g., between wearable sensors on the same body side): $n = 3 - 4$.
- NLOS communications (e.g., communication between sensors on different body sides, obstructed by body mass): $n = 5 - 7.4$.

To improve energy efficiency in WBANs, the path loss model is enhanced with adaptive power control and energy-efficient routing. The transmission power (P_{tx}) is dynamically adjusted based on path loss and energy constraints as follows:

$$P_{tx} = P_{min} + \alpha(PL(f, d) - PL_{threshold}) \quad (5)$$

where P_{min} is the minimum required power for maintaining communication, α is the adaptive scaling factor for power adjustment, and $PL_{threshold}$ is the threshold path loss value for reliable transmission. The total energy consumption (E_{Total}) is computed by considering transmission, reception, and amplifier energy as follows:

$$E_{Total} = E_{tx}(b, d) + E_{rx}(b) + E_{amp}(b, d) \quad (6)$$

where $E_{tx}(b, d)$ is the transmission energy per bit over distance d, $E_{rx}(b)$ is the reception energy per bit, and $E_{amp}(b, d)$ is the amplifier energy, dependent on signal attenuation and required gain. Directional antennas and beamforming techniques are employed to mitigate excessive path loss, particularly for NLOS communication scenarios. The effective gain of the antenna is calculated as follows:

$$G_{eff} = G_{tx} + G_{rx} - PL(f, d) \quad (7)$$

where G_{eff} is the effective gain after compensation and G_{tx}, G_{rx} are the transmitter and receiver antenna gains.

IV. PROPOSED METHOD

In the considered experiments, we employed eight sensor nodes, varying the coordinator location using the same cost function used to choose the relay node. The proposed framework tried to prolong the network's stability period by optimizing energy usage and making a judicious choice of the relay node. The cost function, as provided in (8), is computed from two parameters: the residual energy of a sensor node and its distance to the sink. The relay node is chosen based on priority, with the node with the least cost function value being chosen. This means that the node with maximum residual energy and minimum distance from the sink is prioritized as the relay node.

$$\text{Cost function}(i) = \frac{d(i)}{R.E(i)} \quad (8)$$

Once selected, the relay node remains active for this role until it is no longer operational as a result of the exhaustion of its energy supply. This iteration continues until the last sensor node of the network fails. The sensor nodes' coordinates are positioned spatially according to the range and inequalities specified in [23], to allow proper comparison with existing methodologies. Our experimental results are compared with well-known methods, including SIMPLE [19] and M-ATTEMPT [20], to verify the performance of the proposed approach in improving network stability and energy efficiency. Table II provides the range values specified for placing sensor nodes, and Table III introduces the real distribution of sensor nodes in the network.

TABLE II. SENSOR NODE PLACEMENT RANGES

Number of sensor node	Range
1: Calf 3: Lactic acid (thigh)	$x \in [-20, -5]$ $y \in -105, -24]$
2: Knee 4: Temperature (thigh)	$x \in [5, 20]$ $y \in -105, -24]$
5: Left palm	$x < -20, y < 42$ $0.91x + y + 38.2 > 0$
6: Right palm	$x > 20, y < 42$ $0.91x - y - 38.2 > 0$
7: Glucose 8: ECG	$x \in [-20, 20]$ $y \in [-25, 45]$
Coordinator/sink	$(0.25, 0)$

TABLE III. SENSOR NODE DISTRIBUTION

Number of sensor node	Position (m)
1: Calf	(-0.15, -1)
2: Knee	(0.15, -0.85)
3: Lactic acid (thigh)	(-0.05, -0.4)
4: Temperature (thigh)	(0.2, -0.5)
5: Left palm	(-0.6, 0.35)
6: Right palm	(0.6, 0.35)
7: Glucose	(-0.1, -0.1)
8: ECG	(0.2, 0.4)
Coordinator/sink	(0.25, 0)

Figure 1 presents the flow chart of the proposed framework. First, the system parameters are defined: number of sensor nodes (N=8), the new positions of sink and sensor nodes, initial energy, threshold energy, transceiver parameters, and path loss coefficients. Then, the distance between each sensor node and the sink is calculated. Before data transmission, the proposed model checks the status of the sensor node. If its energy (E) is less than zero, the first dead sensor node is recorded; otherwise, we check the priority (P). If $P = 1$, calculate the cost function of the sensor nodes, then select the node with the minimum cost function value as the relay node.

After that, the model calculates the distance between the sensor node and its relay node. If it is less than its distance to the sink node, the sensor node will transmit data to the relay node; otherwise, data will be transmitted to the sink node. In each case, the number of data packets sent to the destination and energy and path loss values are updated after transmission. If the energy level decreases below a threshold value (0.2) during transmission, data will be transmitted directly to the sink node without relaying.

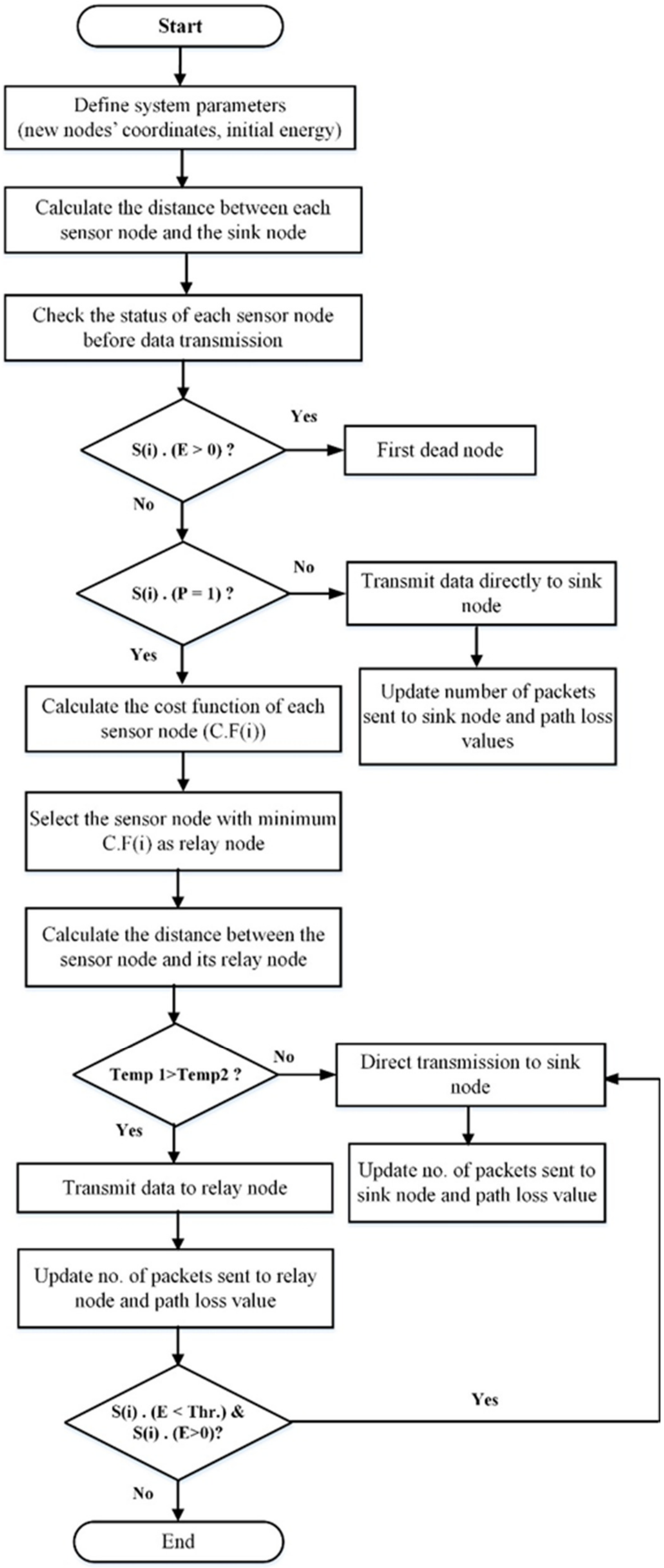

Fig. 1. Flowchart of the proposed method.

V. RESULTS AND DISCUSSION

The proposed WBAN network was simulated using MATLAB R2017a to test its energy efficiency. According to the SIMPLE protocol, network lifetime is defined as the time taken from the WBAN initialization/restart until the last node in the network dies. In the simulation, we apply the proposed method when the initial energy of each sensor node in the network is constant (0.5 J) by changing the coordinator's position to (0.25, 0) instead of being at the origin. The threshold energy value is 0.2 J instead of 0.1 J. The number of sensor nodes is also N=8 to compare the results with relevant protocols such as SIMPLE and M-ATTEMPT. The performance efficiency of our proposal is evaluated using different metrics, such as network lifetime, throughput, path loss, and residual energy.

A. Network Lifetime

The time that the network takes from the initialization till the first node dies is the network stability period [19]. Table IV clarifies the network stability of the different protocols. Figure 2 presents the number of dead nodes in each round. The first node dies after 5,298 rounds in our proposed protocol. In contrast, it dies after 4,437 and 2,109 rounds in SIMPLE and M-ATTEMPT, respectively. Thus, as shown in Figure 2, our proposed method improves network stability period by 19.4% compared to SIMPLE and by 151.2% compared to M-ATTEMPT. Additionally, the network lifetime, which is the time taken from the initialization of the network until the last sensor node dies, is reduced by 1% compared to SIMPLE. As a result, changing the sensor nodes' distribution, including the coordinator, and setting a suitable value for the energy threshold contributes to improving the network stability period, which is a good chance for network lifetime improvement. Also, we use the positive and negative (x, y) coordinates, not only the positive axis as in SIMPLE.

B. Throughput

Throughput refers to the number of packets received successfully at the sink node. This metric is important in WBANs because the patient's data are critical. Figure 3 shows our proposed protocol achieving higher network throughput. It achieves a Packet Delivery Ratio (PDR) of 42.14% and 128.7% higher than SIMPLE and M-ATTEMPT, respectively. As the number of alive nodes improves, higher throughput can be achieved. The number of received packets at the sink for each protocol is shown in Table V.

TABLE IV. NUMBER OF DEAD NODES VERSUS ROUNDS

Protocol	No. of dead nodes at different no. of rounds							
	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000
Proposed	0	0	0	0	0	5	6	8
SIMPLE	0	0	0	0	1	6	6	8
M-ATTEMPT	0	0	3	3	3	3	3	8

TABLE V. NUMBER OF RECEIVED PACKETS AT THE SINK

No. of rounds	Proposed	SIMPLE	M-ATTEMPT
2000	$8.42*10^{3}$	$5.76*10^{3}$	$6.30*10^{3}$
4000	$2.17*10^{4}$	$1.29*10^{4}$	$1.06*10^{4}$
6000	$3.78*10^{4}$	$2.597*10^{4}$	$1.46*10^{4}$
8000	$3.98*10^{4}$	$2.80*10^{4}$	$1.74*10^{4}$

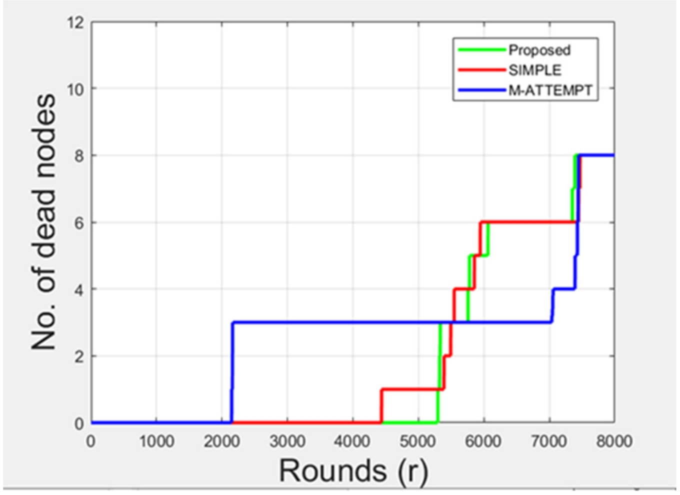

Fig. 2. Number of dead nodes versus rounds.

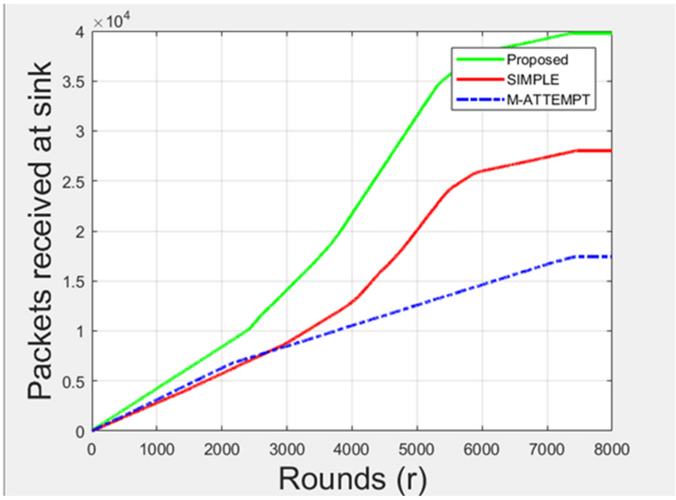

Fig. 3. Number of received packets at the sink.

C. Path Loss

Figure 4 shows the path loss of the network. Path loss refers to the difference between the average number of packets sent to the sink and the average number of packets received at the sink [15]. In network topology, path loss is the nodes' distance function from the sink, with a constant frequency factor of 2.4 GHZ [24]. The path loss coefficient used for calculation is 3.38, and the standard deviation is 4.1. As in the SIMPLE protocol, the proposed model has an efficient selection of forwarder nodes with a minimum cost function value that depends on the minimum distance to the sink node. Minimal path loss is achieved by involving the minimum distance to initialize multi-hop and direct communication with the sink [24]. When compared to SIMPLE, our proposed protocol achieves nearly the maximum path loss factor: 389.3 dB and 382.7 dB, respectively. M-ATTEMPT's maximum path loss factor is 430.8 dB, which is higher than our proposal and SIMPLE. Thus, our protocol performed well in terms of path loss.

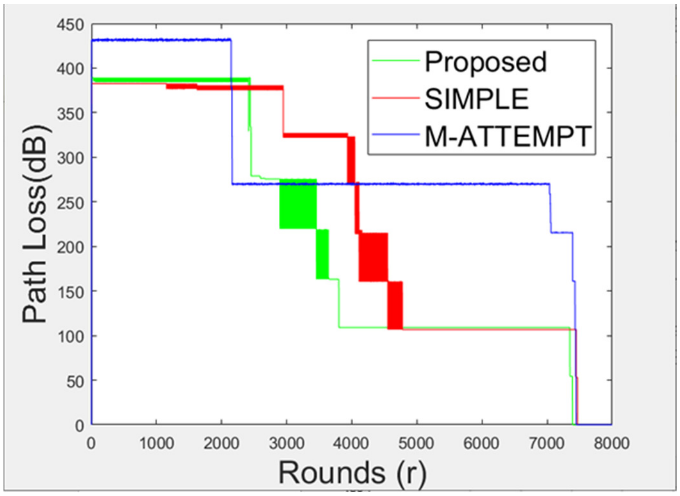

Fig. 4. Path loss in dB.

D. Residual Energy

Residual energy represents a network or node's current energy level [25]. Figure 5 shows the nodes' residual energy of each protocol with regard to the number of rounds. The mean residual energy value for both our proposed and SIMPLE protocols is 1.4520 J, which is higher than M-ATTEMPT's value of 1.3506 J. The increased number of alive nodes in the network and the suitable threshold energy value in our proposal contribute to improving average residual energy.

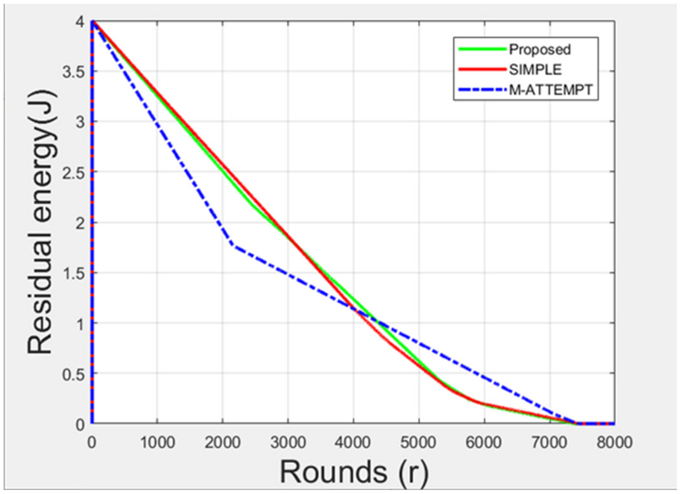

Fig. 5. Residual energy of different protocols over rounds.

VI. CONCLUSION AND FUTURE WORK

Wireless Body Area Networks (WBANs) play an important role in the field of human health care. The most significant challenge these networks face is achieving energy efficiency. This work addressed one of the most prominent issues regarding WBANs: the optimization of energy to increase the lifetime of the network.

Much research has been done to enhance to enhance WBANs energy because their sensor nodes are powered by small batteries related to their small size. The proposed method depends on changing the position of the coordinator/sink node as well as the positions of all sensor nodes, in addition to the value of the threshold energy, which impacts the network performance metrics such as stability period and throughput, resulting in improvements compared to SIMPLE and M-ATTEMPT protocols. The proposed method outperformed traditional WBAN setups, achieving greater energy efficiency, improved network stability, and enhanced data reliability. These results highlight the efficacy of adaptive node relocation techniques in addressing the energy challenges posed by WBANs, making WBANs more practical for long-term healthcare monitoring.

In future work, we intend to apply a machine learning algorithm as an optimization technique or utilize different cost function techniques for relay node selection to achieve more efficient energy usage.

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