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Original Article

Improvement of a Cluster-based Energy-Efficient Algorithm for Wireless Body Area Network

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Abstract *- The increasing prevalence of terminal diseases has heightened the need for reliable, efficient, and intelligent monitoring systems to ensure timely medical intervention. Wireless Body Area Networks (WBANs) have gained attention as a critical technology for addressing this challenge. Leveraging mobile phones and Personal Digital Assistants (PDAs), WBANs offer advanced, energy-efficient data transmission with high packet rates, enabling rapid health data delivery. This research proposes an enhanced cluster-based energy-efficient routing algorithm (iRK) for WBANs, incorporating a two-sink head architecture for improved reliability. One sink head is positioned at the front of the body, while a backup sink head is placed at the back to ensure uninterrupted communication in case of energy depletion at the primary sink. Additionally, a forwarder node selection mechanism is introduced to mitigate high end-to-end delays and path loss, optimizing the packet delivery process. Compared to the existing RK algorithm, the iRK demonstrates a 15.43% improvement in packet delivery rate, a 40% reduction in path loss, a 4.24% increase in network lifetime, and a 2.83% boost in node residual energy. These advancements contribute to a more robust and energy-efficient WBAN, enabling real-time health monitoring with enhanced reliability. The proposed system offers a promising solution for managing terminal diseases, improving patient care through continuous monitoring, and advancing the practical applications of WBANs in healthcare systems.*

Keywords *- Personal Digital Assistants (PDAs), Improved Rahat Khan(iRK), residual energy, Rahat Khan (RK), Wireless Body Area Network (WBAN).*

1. Introduction

Wireless Body Area Networks (WBANs) have emerged as a critical technology for improving patient monitoring and reducing early mortality, particularly in situations requiring immediate medical attention. WBANs enable the monitoring of a patient's health by leveraging small sensor nodes positioned on or inside the body. These sensors track vital signs like heart rate, body temperature, blood pressure, and other key indicators, transmitting this data remotely to healthcare professionals for continuous monitoring and timely intervention [1, 2]. Despite their advantages, WBANs face significant challenges related to communication complexity within the human body, which involves varying physiological factors such as skin conductivity, tissue composition, and body movement [3]. These factors make communication from sensor nodes inside or near the human body more difficult than typical network communications. Signal transmission often suffers from interference and attenuation, reducing the reliability of the network and impacting patient safety [4]. One of the main advantages of WBANs is the ability to reduce the cost of patient care by enabling remote monitoring, reducing the need for hospitalization. However, improving the performance of WBANs requires addressing key challenges such as energy consumption, network reliability, and packet delivery efficiency. Sensor nodes are limited by their battery power, and their failure or energy depletion can lead to critical issues like transmission delays, node failure, or missed health alerts. Efficient energy management, high data rates, and robust communication protocols are essential to enhance the network's reliability. Existing research in WBANs has largely focused on route selection based on metrics such as residual energy, hop count, signal-to-noise ratio (SNR), and communication range. However, many of these studies have overlooked factors like buffer traffic conditions and

Processing Capacity (PC), which significantly reduce transmission delays and improve packet delivery efficiency. Furthermore, while low-power sensor nodes are a priority, higher data rate communication is essential to support applications that require real-time health monitoring, such as critical care systems.

Quality of Service (QoS) is a critical consideration in WBANs, as reliable and timely data transmission is paramount in medical applications. Ultra-wideband (UWB) radio technology, with its ability to transmit high-power signals over a wider bandwidth, has gained attention as an efficient method for overcoming the challenges posed by body tissue and obstructions. UWB's ability to transmit signals in challenging environments reduces interference and enhances signal reliability, which is crucial for WBAN applications [5]. However, the high demand for data packets in WBANs can lead to energy wastage, as excessive power consumption during communication results in the increased temperature of sensor nodes, further draining their battery life. To ensure optimal QoS in WBANs, routing management strategies must focus on reducing energy consumption while improving data throughput. An effective routing strategy can prevent excessive retransmissions, which typically increase energy consumption and decrease the battery life of nodes [6]. Researchers have recently emphasized the need to focus on QoS parameters, including node energy, packet delivery rate, and end-to-end delay, to ensure efficient operation and performance of WBANs.

Routing algorithms play a crucial role in WBANs, with cluster-based protocols being one of the most commonly employed techniques. Cluster-based routing divides the network into multiple clusters, where sensor nodes within each cluster communicate with a designated cluster head [7, 8]. These protocols are designed to optimize energy efficiency, throughput, and network lifetime. However, most current cluster-based algorithms in WBANs focus on line-of-sight (LoS) communication and fail to account for non-line-of-sight (NLoS) conditions or the processing capacity of forwarder nodes. This limitation can lead to reduced network performance, especially in environments where obstacles or interference affect communication reliability [9-11]. One of the main drawbacks of current WBAN routing algorithms is using a single sink node for data collection, which can lead to congestion and poor network performance. The single-sink approach increases packet delay, reduces network lifetime, and accelerates energy consumption.

In contrast, using multiple sink nodes could improve data transmission, reduce delays, and enhance network lifetime by balancing the load across multiple routes. However, many existing algorithms do not incorporate the concept of multiple sinks or the processing power of forwarder nodes in their routing protocols. Additionally, the classical route distance computation is used by the current cluster-based WBAN algorithms as a metric for packet forwarding. These route distance measures still need to be modified further to ensure effective use of the limited node energy. This study intends to improve the RK cluster-based routing algorithm to improve the WBAN performance for the healthcare system. Some of the problems associated with using a single sink node are shown in Figure 1.

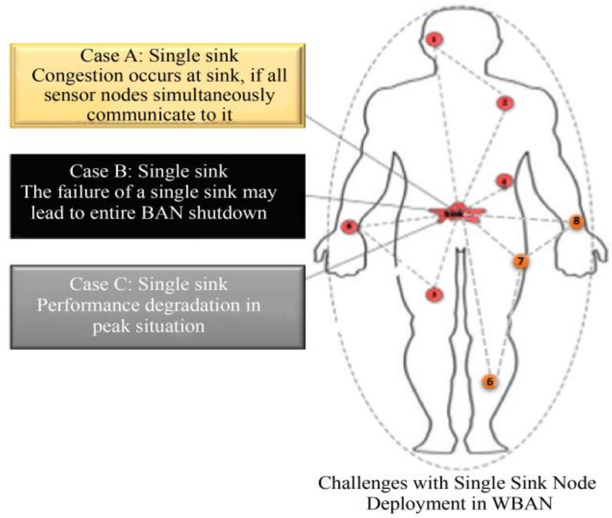

Fig. 1 Challenges with the use of Single Sink Node in WBAN [8]

2. Literature Review

This sub-section reviews similar works that have been done in this area of study. This review is done in order to provide us with current technological knowledge in the area of this study. Thus, the following are the reviews carried out: [3] Presented a Path-loss and Energy Efficient Model (PLEEM) approach to minimize path-loss for both off-body and on-body communications. Two off-body relays were used to minimize path loss when the body was moving. The PLEEM scheme's performance measures included minimal distance to sink and node residual energy. Twelve patients were placed in the ward with two meters between each of their bodies, and two off-body relays were set up on the opposite side of the wall. Based on the simulation results, the PLEEM model fared better than more recent systems like iM-SIMPLE in terms of network life, path loss, stability period, residual energy, and throughput. The computing cost of the PLEEM scheme was significantly increased by the extensive mathematical computations required to evaluate system path loss and hop selection. Due to the computational complexity, these nodes underwent a great deal of processing activity, which raised their temperature and resulted in packet loss because the WBAN routing algorithm did not permit high-temperature nodes.

[8] Proposed an RK-energy-efficient routing method was presented for wireless body area sensor networks. The effort is focused on extending the limited capacity batteries of the wireless body area network sensor. They demonstrated how

ongoing processes, including parameter sensing, transmitting sensed data to the base station, and processing seen data, cause the rapid energy loss of the WBN sensors. It should be mentioned that because these tiny sensors and batteries are found inside the human body, they are rarely updated. To limit the energy consumption of the WBAN network, an energy-efficient protocol needs to be created. In light of this, the authors suggested an energy-efficient routing system to lower network energy use. The transmission concept from classical LEACH was used in the work to transfer data over a number of hops via a forwarder node. However, there is a fixed sink node here. The results showed that the multi-hop energy transmission technique increased residual energy, network lifetime, and stability. However, because of the network's heavy reliance on a single sink node, the node's excessive processing activity ultimately caused the battery to run out of power. The considerable network latency further decreased the anticipated network throughput. This results from the forwarder nodes' close proximity to the patient's sink node, especially the nodes.

[13] Created a thermal-unaware reliability Enhanced Adaptive Threshold Energy-efficient Multi-hop Protocol (RE-ATTEMPT) Nodes were placed within or on top of the body based on energy levels or data speeds. Both single-hop and multi-hop routing techniques were available. A longer network lifetime and consistent energy consumption at each round resulted in the load being uniformly distributed across the nodes. It selected a route that required the fewest hops. It was created to steer clear of M-ATTEMPT's problems. Reducing packet loss and increasing network lifespan were the protocol's main advantages. The RE-ATTEMPT ensured that energy consumption and load distribution remained constant throughout each loop. Nonetheless, the fact that a node was placed in or on the body in accordance with data rates implied that there would be constant node replacement whenever the demand for data changed, which usually resulted in a loss in data throughput and an increase in end-to-end latency. WBAN performance declined as a result.

In [14], A more energy-efficient BAN routing technique was further developed. The network's lifespan was extended by the work's consideration of energy minimization. A strategy was developed to address the many limits encountered during the article's routing process. The technique used the gateway body sensor, responsible for transmitting information to the base station. While some biosensors employed a clustering technique, others communicated data directly. The type of information transmitted has an impact on this process. Simulation experiments showed that the clustering-based routing protocol for wireless body area networks (CRPBA) extended the stability window and reduced energy consumption, thus improving the network quality. However, the algorithm took into account the body network's use of a single cluster head, which resulted in poor network performance since the cluster head experienced heavy transmission activity, which decreased system throughput and, as a result, resulted in subpar network performance.

[15] Suggested frame structure model for the Self-Adaptive Guard Band (SAGB) protocol to reduce BAN energy consumption. In this work, the SAGB introduced a Guard Band (GB) in each time slot according to the maximum time drift allowed by the crystal, adaptively adjusting the GB's value based on the actual time drift and making sure that the node simultaneously synchronized with the coordinator during beacon transmission and maintained its sleeping state. Simulation results showed that the SAGB protocol's frame structure model modified the GB and extended the nodes' sleeping periods compared to the traditional GB MAC protocol, decreasing energy consumption and extending the network's lifespan. However, because the algorithm only considered one sink node, there was a higher chance that congestion would arise at the sink node, which decreased network throughput.

[16] Developed a medium access control system with great performance for wireless body area networks based on priorities. The endeavor aimed to tackle the concerns raised by the WBAN regarding energy efficiency and service quality. To do this, the authors determine a sensor priority based on the degree of relevance, sampling rate, timeout situation, and energy left. The value of a node transmitting data frames during a given time window was then represented by a utility function that included the channel's properties and the node's priority. In order to maximize the overall utility of data transmission for all nodes over a predefined period of time, the authors then created a model for the time slot allocation problem. To do this, they must change each node's time and length of transmission. Lastly, a greedy strategy-based time slot allocation method is proposed by the authors, which successfully lowers the temporal complexity of the direct solution to the problem. Higher priority nodes were set up to send data frames at the best timeslots for channel conditions by employing this technique. The experimental results showed that the proposed scheme greatly increased QoS and energy efficiency compared to the comparator schemes. The drawback of the work was that other sensor nodes might have delivered data that was essential in preventing a major health issue for a human user, even if it wasn't immediately required. However, the priority selection of nodes prevented that from happening.

In [11], a routing coordinator was proposed as a substitute for a relay node in WBAN to boost energy efficiency and dependability. It was noted that the study compared the energy of the sensor nodes in two different scenarios. One sink was taken into consideration in the first, while two sinks were taken into consideration in the second. The WBAN design for scenario 1 consisted of six stationary nodes connected to a single sink around the thigh. But in scenario 2, the lower body was monitored by the first sink, positioned near the thigh, and the chest was covered by the second sink, positioned near the shoulder. The energy usage for each scenario was calculated based on distance. The second redundant coordinator on the shoulder increased the energy usage and allowed the nodes to perform more rounds of the operation. Compared to scenario 1, scenario 2 had a longer stability time at which the first node perished. Although the information was sent to the sink using multipath-oriented transmission to consider a shorter path to save energy, multipath-oriented interference due to the shorter distance could result in higher path loss, which could increase energy consumption and make the link less reliable.

In [17], a useful network architecture that combines WBAN and Cloud for sharing legal data was presented based on the LEACH principle. The application, network, cloud computing, and perception layers formed the basis for creating the proposed network architecture. The proposed network's high user mobility is made possible by WBAN coordinators' compatibility with several local networks, including WiFi and LTE. The proposed network architecture included Content-Centric Networking (CCN) to increase the effectiveness of WBAN coordinators. This enabled the continual delivery of media healthcare material.

The adaptive streaming technique was also applied to reduce packet loss. The simulation showed that the proposed method improved real-time data transmission via the network compared to a traditional IP-based network. However, the BAN system's four-network topology increased the amount of control packets the energy-constrained sensor nodes had to process and added computational complexity. Ultimately, the high processing energy needs caused sensor nodes to exhaust their energy, resulting in packet losses. Furthermore, the extra processing work that the sensor nodes performed resulted in energy loss, raising the sensor node's temperature and increasing the possibility that it would harm body tissues.

[18] Introduced an energy-aware and stable routing protocol (ESR) for WBAN networks that selects the best path for data packet transmission by utilizing the stability and remaining energy of nodes. The cost coefficient establishes the stability of a path at a given time, and the cost function energetically depicts a path at a certain moment. According to the simulation's findings, the ESR protocol enhanced network longevity and overhead. However, because the ESR protocol only uses one coordinator node, it is susceptible to congestion events at the sink node when all sensor nodes send data simultaneously, particularly when sending critical data. This led to an increase in network overhead. Because the criteria for route selection were energy-based, intermediary nodes were at risk of processing more packets based on their energy instead of their current buffer capacity, which made the network slow and short-lived.

[19] Introduced a wireless, energy-efficient, body area network-based health monitoring system. The study provided a novel approach to energy conservation and the detection of potentially dangerous medical conditions. To cut down on energy usage, a two-tier approach was employed. The first tier eliminated "uninteresting" health parameter readings from the location of a sensing node and stopped them from being sent to the LPU through the WBAN. The proposed anomaly detection system at the LPU, which could recognize abnormalities from streaming health parameter information and signal a significant medical condition, was also part of the second layer of examination.

[20] Proposed the development of a Distributed Energy-Efficient Clustering and Routing for Wearable IoT-Enabled Wireless Body Area Networks. Each node obtained information about its neighboring nodes within a two-hop range in the cluster formation phase. The modified grey-wolf optimization algorithm was utilized for cluster head (CH) selection and routing optimization. Node connectivity and residual energy were jointly considered to determine the CH in each cluster. An analytical model was developed to determine the optimal number of clusters by accounting for intra- and inter-cluster transmission distances, reducing the overall transmission distance and number of transmissions. A routing algorithm was designed to ensure energy-efficient packet delivery from CHs to the sink. Simulation results demonstrated that the proposed DECR significantly outperformed existing clustering and routing protocols across various performance metrics.

In [21], a comparative evaluation of two technologies was carried out to assess their suitability for various WBAN healthcare applications. Using the NS3 simulator, six key performance metrics were measured: throughput, arrival rate, delay, energy consumption, packet delivery ratio (PDR), and network lifetime. The performance of each technology was analyzed under different node densities. At a density of 50 nodes, IEEE 802.15.6 exhibited superior throughput, achieving 45 kbps and a higher PDR of 30% compared to LoRaWAN. It also demonstrated a higher arrival rate of 0.33%. Conversely, LoRaWAN excelled in energy efficiency, consuming only 42J, and had a significantly lower delay, with just 7 seconds. Furthermore, LoRaWAN achieved an extended network lifetime of 18 hours, surpassing IEEE 802.15.6.

[22] Proposed the use of adaptive algorithms for enhancing wireless body area networks. The research introduced adaptive algorithms that combined Convolutional Neural Networks (CNNs) with dynamic threshold mechanisms to enhance the performance and energy efficiency of Wireless Body Area Networks. The study utilized the MIB-BIH Arrhythmias dataset to improve arrhythmia detection. The results demonstrated a 10.53% improvement in battery life and a 5.62-fold enhancement in temperature management when sleep mode technology was applied. The model achieved an average ECG classification accuracy of 98%, along with high selectivity and sensitivity for normal heartbeats and satisfactory performance in classifying arrhythmia heartbeats.

In [23], To send dependable data packets in a WBAN, a straightforward, innovative routing system called the Simple Energy-Aware and Reliable (SEAR) routing protocol is suggested. In order to dynamically choose the optimal forwarder node, the suggested routing system considers important variables such as priority data, hop count to the sink node, and the remaining energy of sensor nodes. Additionally, the suggested protocol chooses the best path between the source sensor node and the sink node out of all feasible routes by using the Route Reliability Factor (RRF). RRF chooses the path with the fewest hops and the highest route residual energy. Consequently, SEAR can offer efficient single-hop and multi-hop routing data transmission to increase data transmission reliability, reduce sensor node energy consumption, and extend network lifetime. According to the simulation results, the SEAR routing protocol performs better than the current routing protocols in terms of the following metrics: energy consumption, network lifetime, normalized routing load, packet loss ratio, throughput, and end-to-end delay. The findings show that, compared to EERR-RLFL and AMCRP, the suggested protocol improves overall energy consumption by 18.76% and 10.89%, respectively. In the meantime, SEAR lowers the normalized routing load by 31.17% and 20.91%, the packet loss ratio by 29.48% and 17.69%, and the average end-to-end delay by 17% and 9%. Furthermore, SEAR outperforms the EERR-RLFL and AMCRP routing protocols regarding throughput by up to 16% and 9.71%, respectively.

[24] Proposed a novel metaheuristic algorithm to optimize cluster selection, aiming to develop an energy-efficient protocol for healthcare monitoring. The research focused on minimizing the energy consumption of WBANs by selecting the most suitable Cluster Heads (CHs) using the Black Widow Optimization (BWO) algorithm. The proposed BWO-based routing protocol demonstrated superior performance in terms of energy consumption, packet loss, packet delivery ratio, network lifetime, end-to-end delay, and throughput. It optimized energy usage by efficiently selecting CHs and routing paths, resulting in balanced energy utilization and extended network operation.

The BWO model significantly reduced end-to-end delay by directing data packets through the shortest and least congested routes, critical for real-time health monitoring. It achieved a high packet delivery ratio, typically ranging from 95% to 98%, ensuring reliable data transmission while maintaining a low packet loss rate of 1% to 5%. Furthermore, the BWO-based routing protocol extended the network lifetime by preventing early node depletion and enhanced throughput by reducing congestion and packet collisions, enabling continuous and reliable health data monitoring.

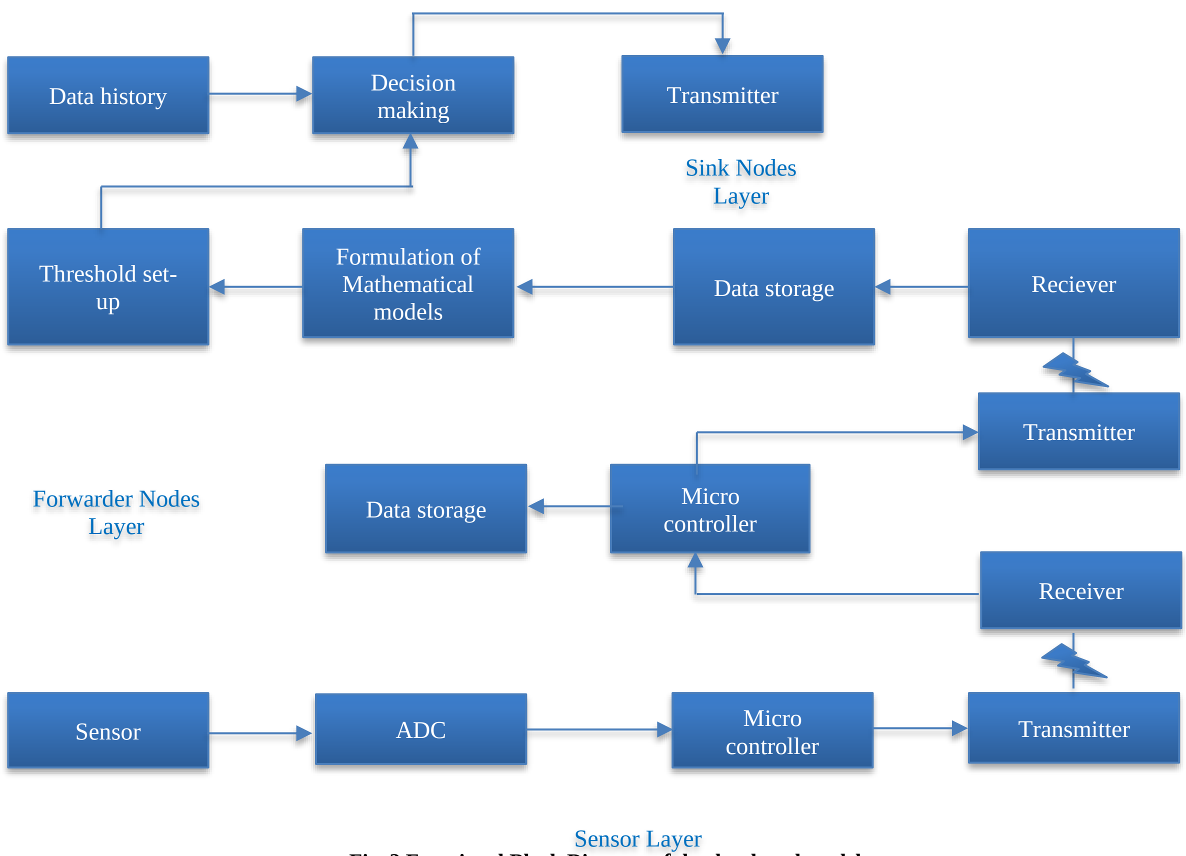

Fig. 2 Functional Block Diagram of the developed model

3. Methodology

This section outlines the procedures for developing an improved cluster-based energy-efficient algorithm for wireless body area networks.

3.1. The Block Diagram

The sink node, the forwarder node, and the sensor nodes form the key components of the network. These three different nodes perform various unique functions in the network, which can easily be visualized using a function block diagram. Hence, the functional block diagram of the developed energy-efficient body area network is presented in Figure 1.

The block diagram presents the various layers in developing an energy-efficient wireless body area network system: the sensor layer, forwarder node layer, and sink node layer.

3.1.1. The Sensor Layer

This layer defines how the human body's sensors work within the WBAN system. Every node in the sensor network can execute particular activities, gather sensor data, and communicate with other connected nodes.

3.1.2. The Forwarder Nodes Layer

This layer presents the specific sensor chosen to relay other sensor nodes' information based on their higher energy level and proximity to the sink node. The forwarder node receives the information from potential transmitting nodes in the WBAN system to avoid depleting the energy of other transmitting nodes.

At the same time, they wait for the sink nodes to accept their data. The forwarder node becomes the only node that waits for the sink node to accept its package from its transmitter to the sink node receiver, thereby enabling energy efficiency.

3.1.3. The Sink Nodes Layer

In this paper, two sink nodes were introduced into the WBAN model as an improvement on the RK WBAN model to increase the delivery rate of packet transmissions and to reduce time travel from each sensor to the sink nodes.

This layer is the end of the algorithm model; all information gathered at the sink is then forwarded to the PDA, which has the medical interpretation for the body signals.

3.1.4. The Wireless Body Area Network Setup

This research has developed the usage of two sink nodes, one placed in the front of the human body and the backup sink placed at the back.

To determine the distance of each sensor node to the sink head, the highlighted coordinates in Table 1 were used.

Table 1. Sensor Coordinate Value (m)

Node	Horizontal axis(m)	Vertical axis(m)
Sink 1(Front)	0.45	0.40
Sink 2 (Back)	0.47	0.70
Sensor 1	0.27	0.10
Sensor 2	0.45	0.15
Sensor 3	0.27	0.55
Sensor 4	0.45	0.60
Sensor 5	0.24	0.70
Sensor 6	0.40	0.80
Sensor 7	0.65	0.60
Sensor 8	0.70	0.60

For ease of identification during the simulation, Sink 1 (Front) and Sink 2 (Back) were labeled S1 and S2, respectively, in the developed system. At the same time, all the sensor nodes were numbered from 1 to 8.

3.2. Development of an Improved RK Double Sink Cluster-Based Routing Algorithm For WBAN

Recall that the conventional RK algorithm assumed that the sink node was placed on the body with the forwarder node communicating every node's data directly to the sink. The forwarded node expires after every round of observation communicated to the sink node, and a new forwarder node is selected for a new communication using equation (1).

$$\boldsymbol{f_i = \frac{d}{E_i}} \tag{1}$$

Where: d represents the distance of the i^{th} sensor node
E represents the residual energy of the i^{th} sensor node
i represent the sensor number

To avoid traffic congestion between the sensor nodes and the forwarder node, Time Division Multiple Access (TDMA) was used. Nevertheless, the re-election of a new forwarder node for every communication with the sink nodes adds extra energy overhead on the sensor nodes. This allows the sensor nodes to deplete energy faster while performing voting for the next forwarder node. Equally, there is the possibility of missing valuable data readings from the human body during the forwarder selection period. Hence, a need to modify the RK algorithm as energy is a critical factor in wireless body area networks. Hence, the proposed improved RK algorithm performs ranking of forwarder nodes based on their energy level and proximity to the sink node during the initial voting processes. Thus, the sensor nodes during the initial condition have the same energy level of 0.0005 Joules, and the node with the shortest distance becomes the forwarder node. The rest of the nodes are ranked according to their distances. To mitigate against any sensor node from reaching zero directly, the threshold of 0.0001 joules was used. Thus, the forwarder sensor node selection is performed using equation (2).

$$F_{Si} = \sum_{i}^{n} \frac{d}{E_{i-1}} \tag{2}$$

Where: Fs is the forwarder sensor node
n is the total number of sensor nodes deployed on the human body
d is determined using the equation (3)

$$d(s, Dst) = \sqrt{(X_s - X_{Dst})^2 + (Y_s - Y_{Dst})^2} \quad (3)$$

From equation (2), the deployed sensor nodes deployed on the human body energy level and distance are evaluated on deployment. The node with the least distance from the sink node and the highest energy level is selected as the forwarder node. In contrast, the other nodes are ranked according to their respective energy level and proximity. Since the forwarder nodes transmit more data than the remaining nodes, there is a need to reduce path loss due to the sudden death of the forwarder node. Therefore, a threshold of 0.0002 joules was set as the handing-over energy level for all forwarder sensor nodes. Once a forwarder node's energy level reaches the set handing over energy level threshold, the next sensor node with the second least distance and highest energy level becomes the next forwarder node. This process continues until the last node becomes the forwarder node. The path loss analysis is evaluated using equation (4) to sustain good network stability.

$$L_{(f,D)} = R_o + 10n\, log_{10} \frac{D}{D_o} + S \quad (4)$$

Where the Ro is the reference distance path loss and mathematically expressed using equation (5)

$$R_o = 10n\, log_{10} \left[\frac{4\pi D f}{c}\right]^2 \quad (5)$$

The reference distance path loss given in equation (5) can be substituted into equation (4) for path loss evaluation. Therefore, equation (4) can be rewritten as given in equation (6)

$$L_{(f,D)} = 10n\, log_{10} \left[\frac{4\pi D f}{c}\right]^2 + 10n\, log_{10} \frac{D}{D_o} + S \quad (6)$$

Since the sensor nodes communicate with the sink node through the forwarder node, single-hopping and multi-hopping scenarios were deployed in the network. The energy required for single hopping is equivalent to the transmitted energy and is given by equation (7).

$$SH_E = (E_{Amplication} + E_{Elect}) \times s \times D^2 \quad (7)$$

Where: SH represents the Single Hopping and is the same as the transmitted energy (TX_E)
S represents the packet size
Equation (7) can be written as expressed in equation (8).

$$SH_E = TX_E \quad (8)$$

The Energy consumed in a multi-hopping communication is mathematically expressed by equation (9).

$$MH_E = \left[TX_E + (DA_E + RX_E) \times \frac{(n-1)}{n}\right] \times s \times n \quad (9)$$

Where: RX_E is the receiver energy
DA_E is the consumed energy during data aggregation
And n represents the number of rounds.

Since both the single hopping and the multi hopping must occur in a network lifetime, as the multi hopping communication will be used once the nodes are more than two and the single hopping will be used once it is just a node and the sink, the total energy consumed in the network can be summarized mathematically as expressed in equation (10)

$$N_E = (E_{Amplication} + E_{Elect}) \times s \times D^2 + \left[TX_E + (DA_E + RX_E) \times \frac{(n-1)}{n}\right] \times s \times n \quad (10)$$

Where: N_E is the energy consumed

Equation (9) is the sum of energy consumed using single-hopping and multi-hopping in the network.

To further conserve energy in the network, a second sink node was designed to act as a backup for the first sink node. While the first node is placed at the front of the human body, the backup sink node is placed at the back of the body. The front sink node exchanges its energy level with the backup sink node at the introduction of every new forwarder node in the network. This helps the backup node update its current forwarder node information. A threshold of 0.0002 joules was assigned as the sink handover threshold. Once the energy level of the front sink reaches 0.0002 joules, it sends all its acquired sensor data and ranked lists of the remaining forwarder nodes to the backup node. Once information is acquired, the backup node notifies the front sink node of its location and energy level. Updated with the backup sink node's current location by the front sink node, the forwarder node is informed. The forwarder node's original sink position is overridden by this location data. Communications between the front and back sink nodes are switched by the forwarder nodes. The double sink node algorithm that was developed is described as follows.

Table 2. Pseudocode for Improved RK Double Sink Cluster-Based Routing Algorithm

Algorithm
Input: *SensorNode(S_1,…,S_n)*,where 1<n<8, Sin *k* (*k1,…,Ki*), where 1 < i < 2, residual energy (RE), path loss parameters Output: $L_{(f,D)}$, N_E, Pkts Ensure: Forwarder node selection, energy consumption analysis 1: Initiate Parameters 2: for each sensor node, *i* do 3: Calculate cost function *CFi* 4: $CF_{i\text{-source}} = d \div RE_{i\text{-source}}$

5: Rank forwarder nodes from the least to the greatest cost function
6: for *k* from 1 to *i* do
if (Sin k_i energy >0.0002j) then
7: Send the ranked forwarder node list to Sin K_i
8: Select forwarder node with the least cost function
9: Receive forwarder node sensed data
10: Receive critical sensor node from *SensorNode(S1,…,Sn),*
11: end if
12: Send ranked forwarder node list from Sin k_i to Sin K_{i-1}
13: Send Sin K_{i-1} location to current forwarder node
14: Forwarder node replaces Sin K_i location with Sin K_{i-1} location
15: Receive forwarder node sensed data
16: Receive critical sensor node data from *SensorNode(S_1,…,S_n),*
17: end for
18: Use Time Division Multiple Access (TDMA) for data transmission
19: Calculate Distance $d(s, Dst) = \sqrt{(X_s - X_{Dst})^2 + (Y_s - Y_{Dst})^2}$
20: Calculate path loss $L_{(f,D)} = 10n\, log_{10}\left[\frac{4\pi Df}{c}\right]^2 + 10n\, log_{10}\frac{D}{D_o} + S$
21: Calculate energy consumption in single hopping $SH_E = TX_E$
22: Calculate energy consumption in multi-hopping

$$MH_E = \left[TX_E + (DA_E + RX_E) \times \frac{(n-1)}{n}\right] \times s \times n$$

23: Calculate the total energy consumed in the network

$$N_E = (E_{Amplication} + E_{Elect}) \times s \times D^2 + \left[TX_E + (DA_E + RX_E) \times \frac{(n-1)}{n}\right] \times s \times n$$

4. Results and Discussion

4.1. Evaluation of the Developed Improved RK Double Sink Cluster-Based Routing Algorithm for WBAN

The developed double sink for the wireless body area network became necessary owing to the need to improve the existing system's performance for effective adoption. To evaluate the performance of the developed improved RK double sink cluster-based routing algorithm, the full network of 8 sensor nodes was deployed for effective monitoring. The observations are shown in Figures 3a and 3b, respectively.

Upon full network node deployment, the packets from the eight sensor nodes were sent to sink 1 (front sink node), as seen in Figure 3a. However, after the death of the seventh sensor node, the sink 1 energy was depleted, and the sink 2 (back node) took over the reception of the packets, as shown in Figure 3b. This shows that the sink 1 energy depleted below the 0.0002 J as discussed in subsection 3.2. Therefore, all packets of sink 1 were successfully handed over to sink 2.

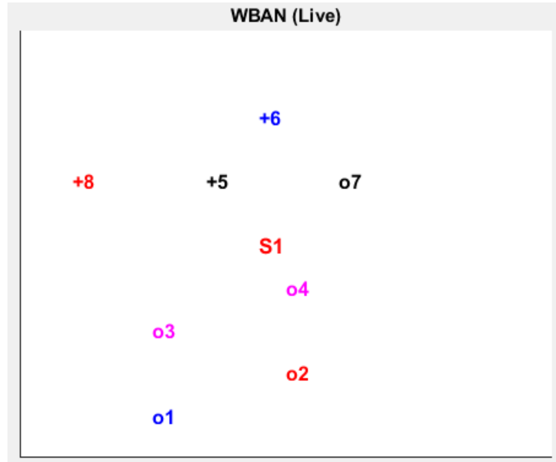

Fig. 3a Packets all sent to Sink 1 (Front)

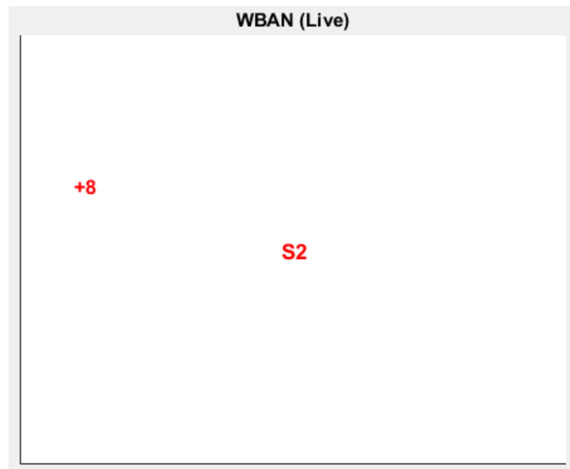

Fig. 3b Packets sent to Sink 2 (Back)

4.2. Evaluation of the Improved-RK algorithm Using Network Lifetime, Packets Received, Path Loss, and Residual energy as performance indicators

The developed improved RK algorithm simulator allows the monitoring of patients remotely through the wireless body area sensor node from the graphical user interface. The patients to be monitored are assigned a patient ID and their respective total sensor node to be monitored. Once the patient ID and the total number of sensor nodes are selected through the graphical user interface, the improved RK system is selected, and the run simulation button invokes the submodule to monitor the patient ID. For this simulation, 10 patients with labelled IDs 1 to 10 were used. Each patient has a maximum body area sensor of 8. The entire sensor can be monitored, or the selected total sensor numbers can be monitored, depending on the user's preference. The monitoring allows the users to visualize the sensor nodes in communications in real time until their energy level drops to 0.0001 joules, as shown in Figures 4a, 4b, 4c, and 4d, respectively.

From Figure 4a and Figure 4c, the sensor nodes in communication are 3 and 6, respectively. In each of these communications, a forwarder node relays the sensed data to the sink until the forwarder node's energy drops to the minimum energy level of 0.0002 joules. Thus, multi-hopping communication is used with more than three sensor nodes. Single hopping is used when there are no forwarder nodes to relay the sensed data to the sink. The sensing node is relayed directly to the sink in such a scenario. Thus, the nodes in communication are just two: the sink node and the sensing node. For the network lifetime of the two scenarios (3 nodes and 6 nodes) in Figures 4b and 4d., the network lifetime is 3000 and 6000, respectively. The sensor node with 6 nodes in Figure 4c. had a longer network lifetime than the sensor node with 3 nodes. The reason for this hinges on the usage of more multi-hopping communication due to the higher number of nodes that act as forwarder nodes. Thus, less energy is dissipated for the sensor nodes when relaying their sensed data.

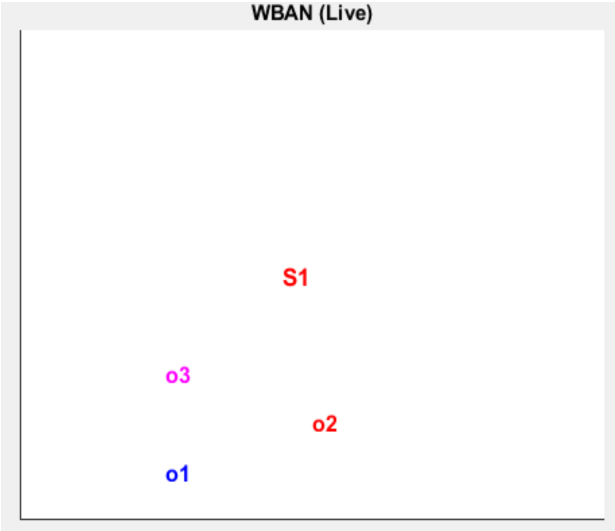

Fig. 4a 3 Sensor nodes

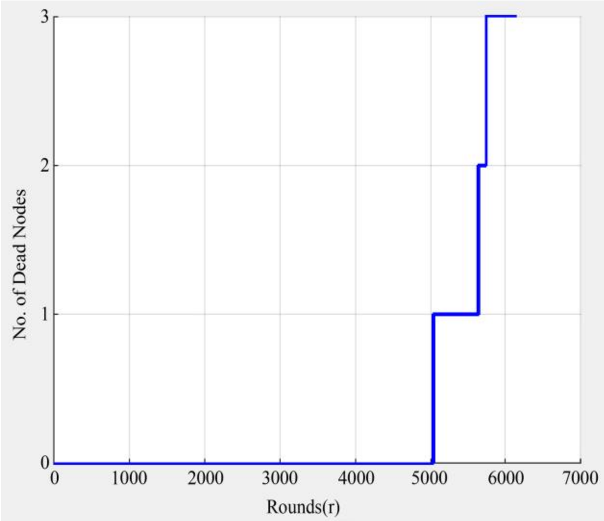

Fig. 4b Network lifetime for 3 nodes

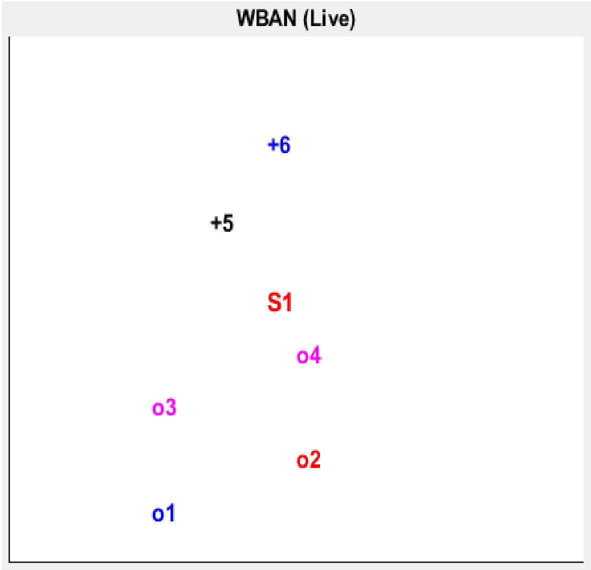

Fig. 4c 6 Sensor nodes

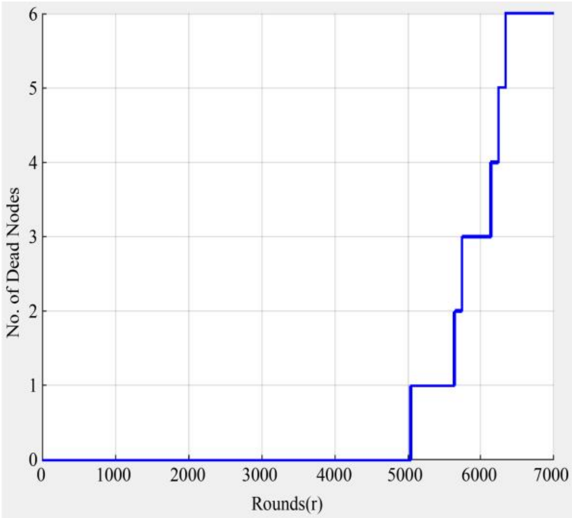

Fig. 4d Network life time of 6 nodes

4.2.1. Packets Received and Path Loss

The sensor node's transceivers go into sleep mode whenever the sensor node is not receiving any data, thereby conserving energy. Since the wireless body area network monitors human health conditions, the network's throughput becomes crucial. Thus, any sensed data from each node is expected to be delivered to the sink node, and then the information is transferred to the PDA for effective monitoring and decision-making.

Furthermore, network instability results after the first forwarder node dies and a new forwarder node emerges. Hence, the path loss and total packets received at the sink node were evaluated from the deployed 3 and 6 sensor nodes. The results obtained are presented in Figures 5a, 5b, 5c, and 5d.

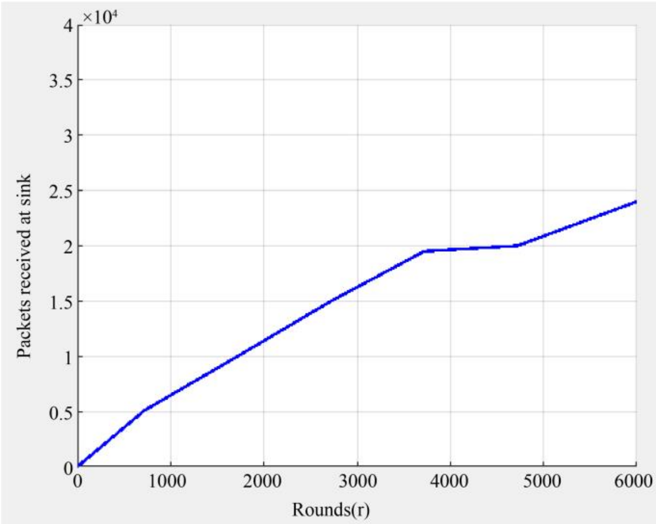

Fig. 5a Packets Received for 3 Nodes

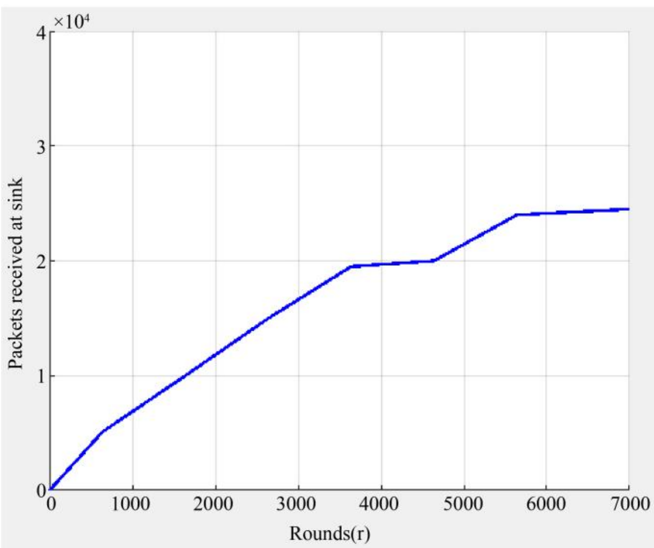

Fig. 5b Packets Received for 6 Nodes

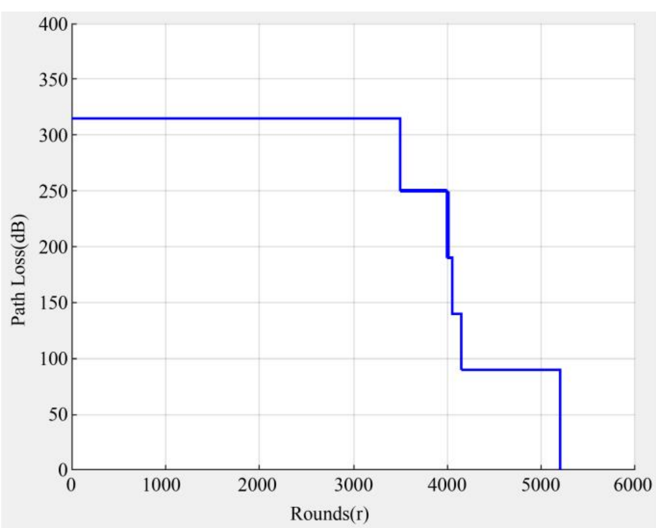

Fig. 5c Path Loss for 3 Nodes

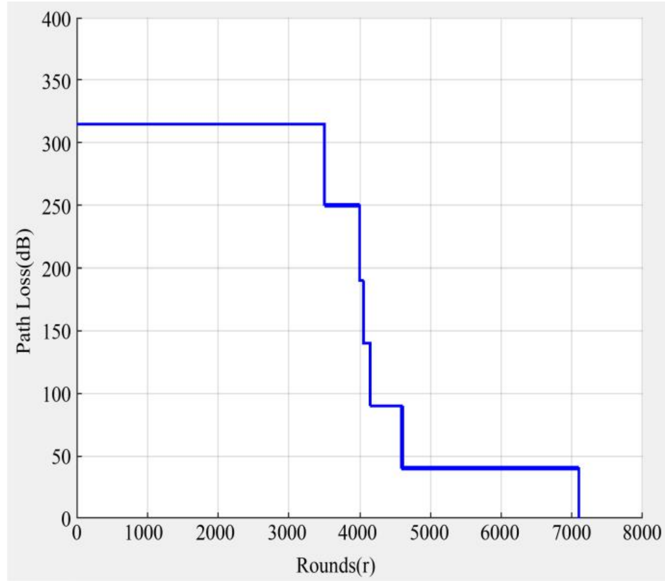

Fig. 5d Path Loss for 6 Nodes

From Figures 5a and 5b, it is seen that the network with six (6) nodes sent more packets, which were equally received at the sink nodes, compared to the network with just three (3) nodes.

The sink received 2.62 x 104 packets and 2.47 x 104 at around 6000 and 7000 rounds for the six nodes and three nodes in the network, respectively.

Furthermore, there is more path loss for the network with 3 nodes compared to the network with 6 nodes, as the network has fewer nodes, which dies faster, as evident in their residual energy shown in Figures 6a and 6b, respectively.

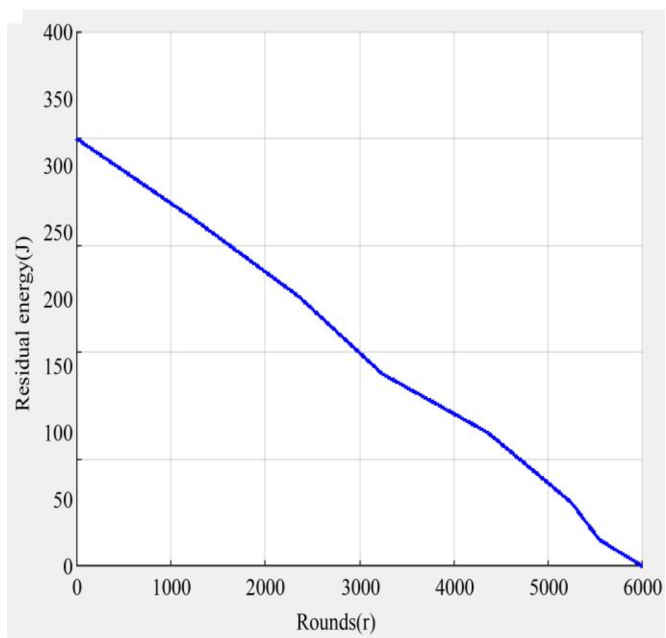

Fig. 6a Path Loss for 3 Nodes

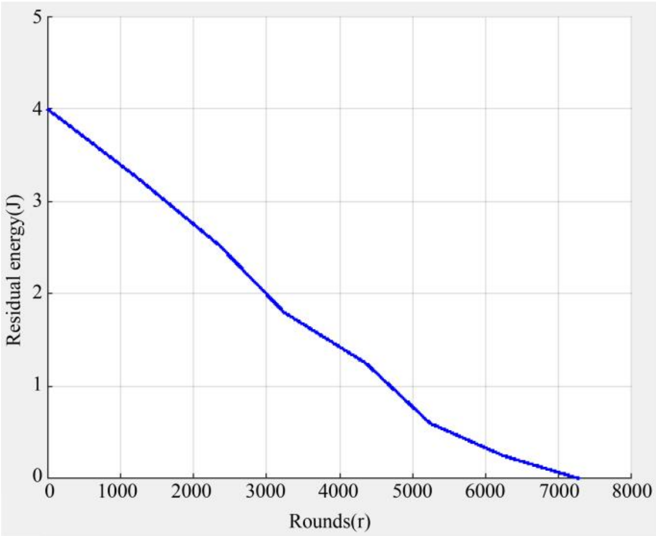

Fig. 6b Path Loss for 6 Nodes

From Figure 6a, the residual energy drops to 0 at around 6000 rounds, whereas Figure 6b depicts the residual energy reaching 0 at over 7000 rounds. This shows that the network with 3 nodes has less residual energy than the network with 6 nodes. Furthermore, several simulations were carried out on the developed and improved RK simulator to see the effect of sensor nodes on the performances of the network. The simulation was carried out, varying the total number of nodes to be monitored. The results obtained from the simulations are presented in Table 3.

Table 3. Effects of sensor nodes on network performances

Total Nodes	Network Life (rounds)	Path Loss(rounds)	Packet Delivered To Sink	Residual Energy (rounds)
1	5122	4600	2.370×10^4	5322
2	5718	5000	2.482×10^4	5718
3	5822	5200	2.512×10^4	6000
4	6180	6000	2.528×10^4	6250
5	6360	7000	2.686×10^4	7000
6	6380	7100	2.794×10^4	7330
7	7659	7600	2.832×10^4	7878
8	8000	7890	3.228×10^4	8000

From Table 3, the network lifetime, path loss, packet delivery, and residual energy increase with an increase in the number of sensor nodes in the network. The reason for this hinges on more nodes lessening the energy required for transmitting sensed data from the body to the sink. Hence, multi-hopping communication, double sink nodes, and forwarder nodes improve the network lifetime of the wireless body area network.

Since the maximum number of nodes in the network is eight, which is the full deployment, the average network lifetime, packets received at the sink, path loss, and residual energy were.

4.3. Comparative Analysis of Network Lifetime

Table 4. Comparative analysis of network life time for different nodes

Total Nodes	Developed System	[8] System
1	5118	4800
2	5718	5400
3	5780	5500
4	6180	5900
5	6318	6000
6	6422	6100
7	7661	7492
8	7818	7500

Table 4 and Figure 7 show that the developed improved RK algorithm had a higher network lifetime as it takes more rounds for the sensor nodes' energy to reach 0.0001 joules compared to the RK algorithm.

Since the maximum number of nodes in the network is eight, evaluating the improvement of the developed model when subjected to full deployment is essential. The average percentage improvement of the developed system can be evaluated using equation (11).

$$\%\,Improvement = \frac{Developed - Existing}{Existing} \times \frac{100}{1} \quad (11)$$

From the comparative analysis of the developed system and results obtained from [8] in Table 4, 7818 and 7500 rounds were what it took the last node from the 8th sensor nodes deployed to reach an energy level of 0.0001 joules for the improved RK system and RK system respectively.

Therefore, the network lifetime % improvement can be evaluated using equation (11)

$$Network\ Lifetime = \frac{7818 - 7500}{7500} \times \frac{100}{1}$$
$$Network\ Lifetime = 4.24\%$$

From the evaluated results, the network lifetime percentage improvement of 4.24% was achieved from the comparative analysis of the improved RK algorithm against the RK algorithm. Therefore, the developed system has improved by 4.24% over the state of the art.

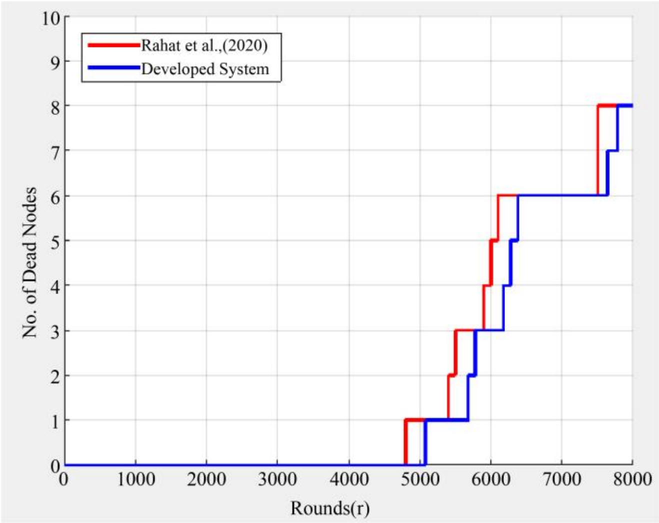

Fig. 7 Network Lifetime for Improved-RK and RK Algorithm

Table 5. Comparative analysis of the total packets delivered to the sink by various nodes

Total Nodes	Developed System	[8] System
1	2.372×10^4	2.340×10^4
2	2.478×10^4	2.250×10^4
3	2.516×10^4	2.400×10^4
4	2.528×10^4	2.450×10^4
5	2.682×10^4	2.600×10^4
6	2.712×10^4	2.500×10^4
7	2.832×10^4	2.780×10^4
8	3.232×10^4	2.800×10^4

From Table 5 and Figure 8, it is seen that an increase in the number of nodes led to an increase in the total packets received by the sink for the developed improved RK system and the RK system of [8]. Thus, the more nodes there are, the human body will monitor the more data. Nonetheless, the developed system had more packets received by the sink compared to [8]. The comparative analysis of the improved-RK and RK algorithm network throughput shows that the improved-RK algorithm obtained a throughput of 3.232 x 10^4, and the RK algorithm successfully transmitted 2.800 x 10^4 packets to the sink for a full network deployment of eight sensor nodes. Therefore, the network throughput improvement can be evaluated using equation (11).

$$Network\ Throughput = \frac{3.232 \times 10^4 - 2.8 \times 10^4}{2.8 \times 10^4} \times \frac{100}{1}$$
$$Network\ Throughput = 15.43\ \%$$

From the evaluated results, the network throughput percentage improvement of 15.43% was achieved from the comparative analysis of the improved RK algorithm against the RK algorithm. Therefore, the developed system has a 15.43% improvement over the state of the art.

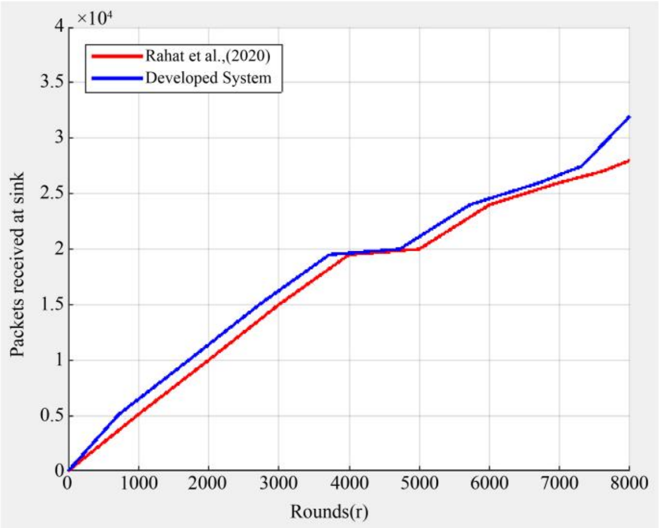

Fig. 8 Packets received at the sink for the Improved-RK and RK algorithm

Table 6. Comparative analysis of the network path loss for various sensor nodes deployed

Total Nodes	Developed system (dB)	[8] System (dB)
1	70.5	150
2	30	100
3	80	150
4	10	100
5	20.5	100
6	19.5	100
7	30	100
8	30	50

From Table 6 and Figure 9, the developed system had a lower path loss compared to the RK system. The path loss for the full deployment of eight sensor nodes is 30 dB and 50 dB for the developed system [8].

The average percentage improvement of the developed system can be evaluated using equation (11).

$$Path\ Loss = \frac{50 - 30}{50} \times \frac{100}{1}$$
$$Path\ Loss = 40\ \%$$

From the evaluated results, the path loss percentage improvement of 40% was achieved from the comparative analysis of the improved RK algorithm against the RK algorithm.

Therefore, the developed system has a 40% improvement over the state of the art.

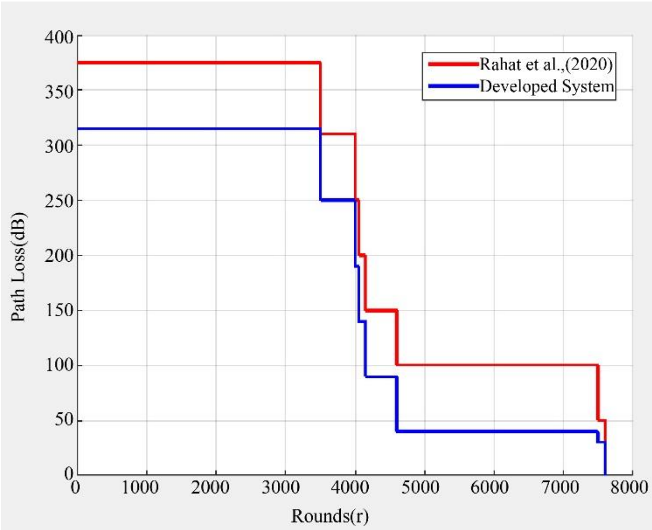

Fig. 9 Path loss comparative analysis

Table 7. Comparative analysis of residual energy for varying sensor nodes

Total Nodes	Developed System	[8] System
1	5318	5000
2	5680	5400
3	6360	6000
4	6610	6250
5	7000	6920
6	7372	7000
7	7882	7822
8	8000	7780

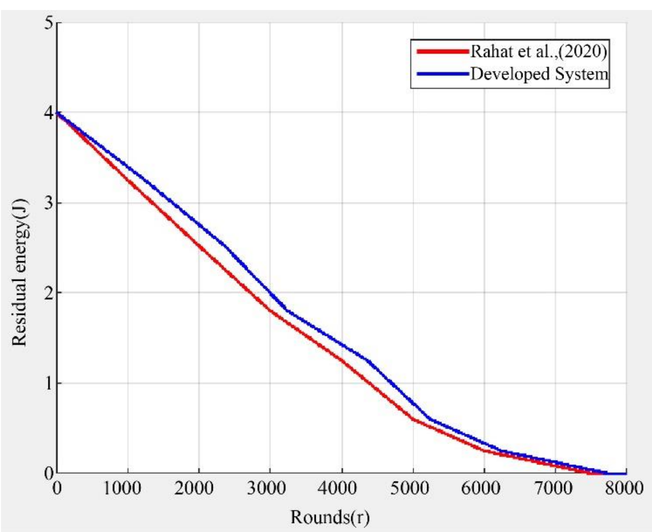

Fig. 10 Residual energy for the Improved-RK and RK algorithm

From the results presented in Table 7 and Figure 10, the sensor nodes' residual energy reaches the 0.0001 joules state at various rounds. The developed system showed higher rounds compared to the RK system, as it takes a longer time for the last node to lose its final energy. From Table 6, it takes 8000 rounds and 7780 rounds for the last node in the fully deployed eight sensor nodes to reach its death stage. Therefore, the residual energy percentage improvement can be evaluated using equation (11).

$$Residual\ Energy = \frac{8000 - 7780}{7780} \times \frac{100}{1}$$
$$Residual\ Energy = 2.83\ \%$$

From the evaluated results, the residual energy percentage improvement of 2.83% was achieved from the comparative analysis of the improved RK algorithm against the RK algorithm. Therefore, the developed system has a 2.83% improvement over the state of the art. From the comparative results shown in Figure 7, Figure 8, Figure 9, Figure 10, Table 4, Table 5, Table 6, and Table 7, it is seen that the developed improved RK algorithm holds great potential in improving the existing wireless body area network performances. The higher network life, lower path loss, improved residual energy, and increase in packet reception are critical factors that can curb the surge in terminal diseases through an effective remote monitoring system that is constant, steady, dependable, efficient, and intelligent for easier expert attention.

5. Conclusion

The use of forwarder nodes has proven to be an effective strategy for enhancing the performance of cluster-based energy-efficient algorithms in Wireless Body Area Networks (WBANs). By selecting forwarder nodes judiciously, the network lifetime is extended, energy consumption is reduced, throughput is increased, and path loss is minimized. The developed improved forwarder node selection strategy, which ranks all nodes during the initial forwarder node election, has significantly reduced the need for frequent reselection of forwarder nodes.

This approach resulted in improved performance during network simulations, where a network of eight sensor nodes on a patient exhibited a throughput of 3.2 x 10^4 and a network lifetime of 7850 rounds. Additionally, the Improved Rahat Khan (iRK) algorithm outperformed the existing RK algorithm, showing a 15.43% improvement in packet delivery rate, a 40% reduction in path loss, a 4.24% increase in network lifetime, and a 2.83% increase in node residual energy. This advancement in energy-efficient clustering algorithms contributes to addressing the rising need for continuous and reliable health monitoring, particularly in scenarios where medical staff is scarce.

The integration of intelligent selection mechanisms for forwarder nodes significantly optimizes WBAN performance, ensuring stable and efficient data transmission in critical healthcare applications. Future studies should focus on incorporating machine learning techniques into cluster-based energy-efficient algorithms to further optimize the selection of forwarder nodes and predict network behavior with higher accuracy. Implementing machine learning models with lower computational costs could allow for real-time prediction of critical parameters such as network lifetime, path loss, residual energy, and packet loss. This would enhance the overall sustainability and adaptability of WBANs in dynamic healthcare environments. Moreover, research could explore hybrid approaches combining deep learning with optimization algorithms to improve network efficiency and reliability in large-scale WBAN deployments.

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