



An Energy-Efficient Cluster-Based Routing Protocol for WBAN in Elk Herd Optimizer

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Abstract

A wireless body area network (WBAN) is a wireless sensor network (WSN) that is essential to monitor patient health. Sensor nodes (SNs) are commonly positioned either inside or outside the patient's body within this network. These nodes have the ability to send data to the sink node if any functional modifications in the patient are observed. Delivering efficient routing and energy management of network nodes is a complex effort in WBAN. The energy efficiency of SNs is a primary challenge to the effective deployment of WBAN. To handle this problem, a new metaheuristic optimization algorithm called Elk Herd Optimizer (EHO) is proposed in this research. This research aims to focus on energy-efficient routing methods in WBAN sensors that are connected to the human body to enhance health monitoring efficiency. The proposed WBAN model includes the deployment of eight biosensor nodes on the human body. The primary objective is to minimize the energy utilization of WBANs by selecting the most appropriate cluster heads (CHs) based on the EHO. The EHO-based routing protocol showed higher performance in WBANs in terms of energy consumption, End-to-End (E2E) delay, packet delivery rate (PDR), network lifetime (NLT), packet loss rate (PLR), and throughput. The research model was validated by comparing its findings with the existing routing protocols. The research model surpassed all the comparable models in terms of energy consumption, latency, NLT, PDR, PLR, and throughput. The routing protocol based on the EHO algorithm improves energy efficiency by effectively selecting CHs and routing paths. The EHO model efficiently reduces the total time delay, which is essential for monitoring health in real time. It achieves a high PDR while maintaining a low packet loss rate. Furthermore, the EHO-based routing extends the longevity of the network. Additionally, it enhances network performance, hence facilitating uninterrupted and dependable monitoring of health data.

Keywords: WBAN; WBSN; WSN; Healthcare Monitoring; Elk Herd Optimization; Cluster-based Routing

1. Introduction

Remote healthcare systems have gained popularity in recent times because of the emergence of pandemics. Therefore, there is a requirement for a medical professional who can identify and examine the underlying reasons for life-threatening illnesses and provide suitable treatments and preventive measures based on their findings. In 2017, the mortality rate attributed to chronic illnesses, such as heart disease and cancer, was reported to be 70%. The mortality rate among the elderly was recorded at 9.62% in 2017. In the year 2050, there will be a steady increase to 21.1% in the death rate, and by the year 2100, it is projected to rise to 31.1%. Given the exponential growth of the population, it is anticipated that the demand for healthcare will likewise escalate significantly, leading to a significant financial shortage in the future, as indicated by the data. Developing an appropriate and progressive healthcare system is essential for the advancement of future generations [1]. Over the years, the advancement of information and communication technology (ICT) has greatly contributed to the progress in detecting diseases and monitoring the medical condition of patients. This has been made possible via the use of wireless sensor devices that collect and analyse data. Consequently, the patient's lifespan will extend as they gain relief from various chronic illnesses. A robust healthcare

system must include key attributes such as efficient communication networks, flexibility, and user-friendly interfaces to effectively achieve the life expectancy objectives of patients. These circumstances can be attained using a WBAN. WBAN is a wireless network composed of small bio-medical nodes that are placed on the body, either on the surface, beneath the skin, inside the body, or near it [2]. WBAN, or Wireless Body Sensor Network (WBSN), is a specific form of WSN as described by IEEE 802.15.6. The IEEE 802.15.6 standard, issued in 2012, is currently the sole standard for WBAN. IEEE 802.15.6 offers dependable, limited-distance communication and a diverse range of data speeds suitable for many application types. The SNs, which operate at an exceptionally low power level, can effectively monitor the essential physiological indicators of the human body. Additionally, certain nodes possess the capability to handle medication effectively in the body [3]. Currently, WBAN is a widely utilized multipurpose framework inside the IEEE 802.15.6 standard that is mostly employed for monitoring human health and activities. Within the domain of implanted medical devices, WSN technologies and methodologies have replicated the advancement of distinct biological networks known as body sensor networks (BSNs) and body area networks (BANs) [4]. BSNs are a kind of WSNs where the nodes are attached or implanted to the patient’s body, resembling electrodes or wearable patches. The SNs are strategically positioned within BSNs to extract and transmit data wirelessly within the human body [5]. Some of the essential physiological indicators are proximity, temperature, galvanic skin reaction (GSR), breathing rate, Electroencephalogram (EEG) readings, electrocardiogram (ECG), electromyogram (EMG), heart rate, and diastolic and systolic blood pressure. These indicators could be tracked using BSN [6]. Figure 1 represents the typical architecture of WBAN.

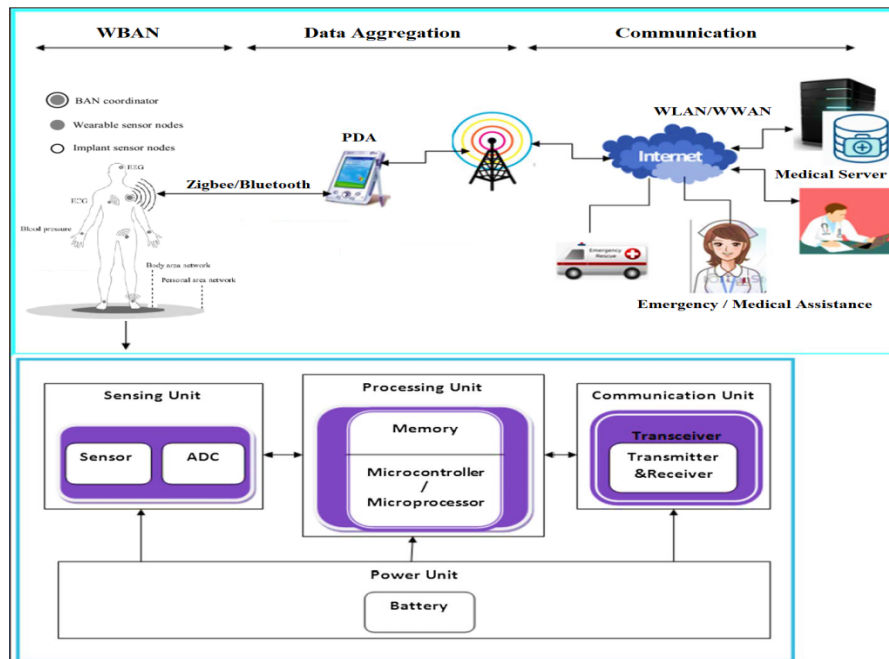


Figure 1. Common Architecture of WBAN

A routing protocol determines the best route for data transfer and network communication between all network components. It uses routing algorithms to find the most efficient route. The utilization of various routing protocols is based on the capability of all the nodes and the specific demands of all applications. Various routing strategies were suggested in various studies for the WBAN to address various issues like network size, energy efficiency, quality of service (QoS), network topology, heterogeneous environment, security, resource limitation, data rate, mobility, path loss. Routing-based on clustering is an energy-efficient approach where clusters are created, and nodes with higher energy handle data processing and transmission, while nodes with limited energy were tasked with detecting and relaying information to the CHs. The utilization of cluster formation in the routing protocol enhances scalability, reduces energy consumption, and maximizes the network lifespan [7].

1.1. Problem Statement

Designing effective routing protocols in WBANs is a complex undertaking because of the many attributes of the WBAN environment. Therefore, while developing a routing protocol for WBAN, it is crucial to consider key factors such as the limited energy capacity, limited hardware resources, dynamic network topology, operating environment, secure communication, and QoS requirements [8]. The human body's rapid mobility presents a challenge due to the dynamic nature of the network. The

restricted deployment of nodes and lack of redundancy necessitate the use of routing methods that have minimal failure rates. Energy efficiency is a crucial factor in determining the routes. Maximizing energy efficiency is crucial in the design and structure of WBAN architecture. Most of the existing modelling approaches focus on routing models, particularly on offering energy-efficient routes [9]. Cluster-based routing methods include partitioning the network into groups of nodes called clusters. Each cluster is led by a CH, which is responsible for gathering the data sensed from its cluster and transmitting it to the base station (BS). The primary objective of this protocol is to reduce direct connections between SNs and BSs [10]. Hence in this research, a cluster-based routing protocol is developed using the EHO algorithm.

1.2. Research Contributions

To provide a consistent transmission of collected data to the BS, an efficient clustering method is necessary. This technique should minimize energy usage and meet the network's limitations. There are different clustering methods available to address this issue, however, these strategies produce many CHs, which results in increased energy consumption. Increased energy use reduces the lifespan of sensors and raises the expenses associated with monitoring. This research introduces a metaheuristic method for choosing the optimal clusters in WBANs to implement an energy-efficient cluster-based routing protocol for monitoring the health condition of the patients. The research methodology utilizes the EHO algorithm to choose the optimal clusters by considering cluster-based routing. This proposed research's primary contributions are presented as follows:

- The research introduces an effective clustering approach for implementing the energy-saving protocol of WBANs used for monitoring health.
- The difficulty of selecting the optimal CH is transformed into a mathematical model, as discussed in the following sections.
- The optimum clustering issue is solved using the EHO metaheuristic approach, which offers advantages such as a reduced number of parameters, increased reliability in convergence, and improved capabilities in exploring the search space.
- By choosing the optimal CHs to minimize energy utilization and prolong the lifespan of WBANs, various performance metrics are considered for simulation purposes.
- The proposed EHO-based clustering routing protocol for the WBAN model's results is compared with the current models for validation.

The following sections of the article are ordered in the following order. Section 2 presents an existing literature overview on WBANs, with a specific emphasis on existing models and a brief discussion of earlier research on routing protocols in WBANs. Section 3 provides a detailed description of the mathematical model used to create a routing protocol with energy efficiency for WBANs, as well as the mathematical representation of EHO. Section 4 encompasses the results of the simulation and the subsequent analysis, while Section 5 presents the final summary and conclusion of the research.

2. Related Works

An IEEE 802.15.6 WBAN routing protocol must be developed to fulfil the demanding QoS criteria of healthcare applications. A clustering strategy for data routing in WBANs, which was based on fuzzy logic was proposed in [11]. Clusters were formed by grouping nodes, and CH nodes were chosen using a Fuzzy-Genetic Algorithm (FGA). The FGA evaluated the two characteristics of all the cluster nodes, namely the node's remaining energy and the cost of selecting it as a CH. The selection of CH cost of the nodes refer to the predicted amount of energy that would be used by the network if the node were to function as a CH. The FGA employed a fuzzy-TOPSIS function to quantitatively compare cluster nodes and choose the CH node that has qualities closest to their ideal values. The optimization technique utilized a GA to adjust the feature weights for selecting CHs. The FGA improved the longevity of the network by evenly distributing the routing load. A clustering and routing technique for multi-WBANs that utilized fuzzy logic and temperature-aware routing was developed in [12]. The technique groups comparable sensors together and makes use of data aggregation. The technique utilized a Fuzzy Logic Controller (FLC) to include variables, including the temperature of CH, the count of comparable neighbours, the count of neighbours, residual energy, and route loss. To enhance the efficiency of these FLCs, a novel hybrid Aquila optimizer algorithm (HAOA) was introduced. HAOA was designed to optimize the parameters and rules of the FLCs. The HAOA was developed through enhancing and merging the exploitation and exploration stages of the AOA to alleviate the issue of local optima in AOA and boost its convergence speed. The findings demonstrated that the approach effectively mitigated hotspot issues in WBAN, hence enhancing its stability and longevity. A routing protocol called Simple Energy-Aware and Reliable (SEAR) was developed in [13]. The protocol was to ensure the transmission of reliable data packets in a WBAN. The protocol considered the priority data, remaining energy of SNs, and hop count to the BS as important factors for choosing the most suitable forwarder nodes.

The protocol used the route reliability factor (RRF) to choose the most efficient route within every available path among the source SNs and the BS. The factor chooses the path that has the highest remaining energy and the fewest number of hops. SEAR has the capability to offer efficient multi-hop and single-hop routing for data transfer, enhancing the data transmission reliability, reducing energy utilization of SNs, and extending the network's longevity. The research [14] concentrated on energy-efficient routing methods in WBANs that were connected to the human body, with the aim of enhancing health monitoring efficiency. An assessment was conducted to evaluate the performance of the routing algorithms for transmitting health data from the source to the destination. The results obtained using MATLAB indicated that routing from the source to the sink using incremental distance yielded superior performance in terms of network lifespan, route loss, and energy consumption compared to both direct single-hop routing and the fixed threshold-based in-between distance technique when considering the same network design. Incremental distance-based routing minimized the Specific Absorption Rate (SAR) by utilizing low transmission power, hence reducing the risk of health concerns. An energy optimization routing (EOR) utilizing an improved artificial bee colony (iABC) was developed for cluster-based WSN [15]. The method utilized an iABC to choose energy-efficient CH at regular intervals by using mutation and crossover techniques. By including the onlooker and employee-bee phases, the delay convergence was eradicated, hence enhancing the effectiveness of local search. A path with the highest efficiency of energy consumption, from the CH to the BS, was identified to enhance the efficiency of network data collecting. The Cauchy operator and Grenade Explosion Method (GEM) were utilized to dynamically expand search strategies from one location to another to accommodate large-scale WSN. The routing method optimized energy usage and extended the lifespan of the network. The WBAN must carry out physiological measures while minimizing energy consumption of the nodes, to sustain a long-lasting health monitoring procedure. The study [16] used the meta-heuristic GA to determine the optimal routing path by computing distances between nodes across various circumstances, as opposed to the existing direct distance optimization approach. The network based on GA has been determined to conserve energy and enhance the network's lifespan.

Table 1: Comparison Analysis of Reviewed Works [17] – [22]

Ref	Approach	Application Scenario	Advantages	Disadvantages
[11]	FGA	WBAN Clustering	Improved network longevity by evenly distributing load.	Complexity in the CH selection process.
[12]	FLC + HAOA	Multi-WBAN Clustering	Enhanced stability and longevity by mitigating hotspots.	Complexity in parameter optimization.
[13]	SEAR Protocol	Reliable Data Transmission	Efficient multi-hop and single-hop routing, reduced energy consumption, and extended network lifespan.	Not handle dynamic changes efficiently.
[14]	Incremental Distance-Based Routing	Health Monitoring	Superior performance in network lifespan, route loss, and energy consumption.	Not applicable to all network designs.
[15]	iABC Algorithm	Cluster-Based WSN	Optimized energy usage, and extended network lifespan.	Computational complexity due to mutation and crossover techniques.
[16]	GA	Optimal Routing in WBAN	Conserved energy, and enhanced network lifespan.	High computational requirements.
[17]	OCER and E-OCER Protocols	Energy Efficient Routing in WBAN	Enhanced performance in energy efficiency.	Complexity in GA optimization.
[18]	OEESR Protocol	Secure Data Transfer in WBAN	Secure data transfer, and reduced network congestion.	Additional overhead for security implementation.
[19]	FSKH Algorithm + HS Algorithm	Relay Node Placement	Enhanced network lifespan and throughput.	Laborious procedure to identify efficient configurations.
[20]	MGCSMO Algorithm	SDN-based WBAN	Optimization of energy consumption, and congestion control.	Complexity in considering multiple factors (energy, delay, temperature).

[21]	GWO, PSO, ALO Algorithms	Relay Node Selection	GWO outperforms in throughput, residual energy, path loss, and network lifespan.	Complexity in implementing GWO.
[22]	TSFIS-GWO Model	Multi-Hop Routing in WBAN	Real-time solutions, optimized routing tree.	Complexity in fuzzy rules fine-tuning.

3. Proposed Methodology

Energy efficiency and network lifetime are the primary challenges in the advancement of WBAN technology. This is because, in a WBAN, the process of recharging or replacing the batteries of biosensors that are linked to the human body might cause uneasiness or discomfort. Therefore, the conservation of energy is a significant factor to consider in WBAN. Deployed nodes must efficiently utilize the battery to prolong the lifespan of the network. The SNs transmit data to the sink via a relay node. SNs prioritize selecting a path that minimizes the distance to the sink node and minimizes energy consumption. To establish an efficient communication system, it is necessary to determine a suitable network architecture since it directly influences the communication between devices. This is of utmost importance, especially for WBAN, due to two primary factors: the restricted distance over which data may be sent, and the rapid and unexpected motion of bodies or nodes. Consequently, it exhibits a higher level of complexity and requires optimization. Node clustering is a strategy used to address these challenges, alongside other techniques. The restricted transmission spectrum of WBAN nodes adds complexity to their routing. The limited transmission range greatly restricts the selection of the next node in routing. Thus, an appropriately optimized protocol was necessary to ensure the effective transportation of packets within the networks. WBAN enables the placement of smart and low-power sensors on the body of an individual for monitoring bodily processes and the surrounding environment. The human body generates many physiological changes that could be measured by these sensors such as EMG, ECG, EEG, etc. Once these nodes (sensors) capture physiological data from the human body, it is sent directly to the cloud server for health analysis. The proposed WBAN model includes the deployment of eight SNs (S1, S2, S3, ..., S8) on the human body. Every SN possesses similar power and computing capabilities. The BS was located at the midpoint of the human body. Each SN in this model performs unique tasks. S1 was utilized for EEG, S2 was utilized for respiration sensor, S3 was utilized for ECG, S4 was utilized for temperature rate, S5 was utilized for BP monitoring, S6 was utilized for galvanic skin response, S7 was utilized for SPO2 monitoring, and S8 was utilized for motion sensing, as represented in Figure 2.

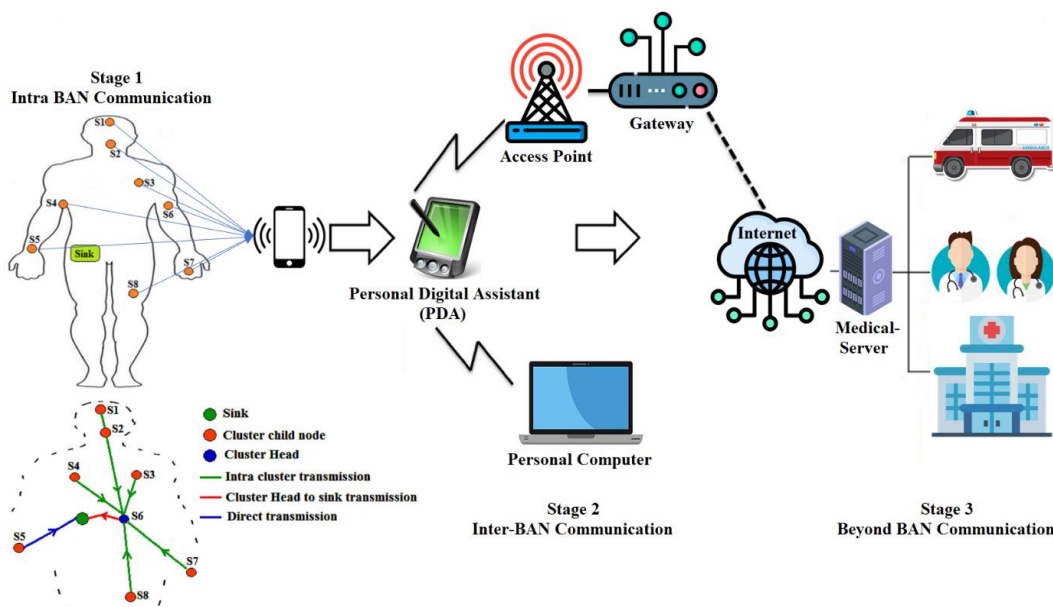


Figure 2. Architecture of the Proposed WBAN Model

3.1. Energy Modelling

To make effective use of the transmission bandwidth, the patient data in the radio model are digitally sent to WBSN. The protocol model utilizes a first-order radio model to estimate energy usage. The key components of the model are T_E (energy transmission), D_s (distance transmission), and P_l (packet length). The equation (1) is utilized for data transmission in a resource-limited environment.

$$T_E(D_s, P_l) = \begin{cases} P_l E_e + P_{l_{fs}} D_s^2, & D_s < D_{s_0} \\ P_l E_e + P_{l_{mp}} D_s^4, & D_s \geq D_{s_0} \end{cases} \quad (1)$$

The consumption of energy is directly proportional to the P_l and the distance D_s^2 . The ratio $T_E(D_s, P_l)$ represents the amount of power utilized by a biosensor during communication. The energy consumption is directly influenced by the distance of communication; longer distances result in higher energy consumption, whilst shorter distances result in lower energy consumption.

$$Rec_E(P_l) = P_l E_e \quad (2)$$

Equation (2) is utilized to compute the quantity of energy expended during the reception of patient data. In the $R_E(P_l)$ equation, P_l and E_e represents the energy required for an SN to receive data. The energy consumption per bit is determined using the following equation.

$$E_e = 50nJ/bit \quad (3)$$

$$D_{s_0} = 100m \quad (4)$$

Since the distance, D_s is less than D_{s_0} , the free space model is implemented in the proposed model, which is represented by $\epsilon = f_s = 10PJ/bit/m^2$. The variable f_s represents the amplifier power utilized in the model to ensure effective and dependable transmission of data from the source to the target nodes.

A computation is made to calculate the number of network nodes as N , and the projected count of cluster heads is obtained for a certain iteration as k . After N/k iterations, the method guarantees that every node turns out as a CH, an equivalent count of times and that the energy of every SN was nearly similar. $P(t)$ was a probability task that estimates the likelihood of the node t becoming a cluster head while performing iteration r .

$$P(t) = \begin{cases} \frac{k}{N - k * (r \bmod \frac{N}{k})}: & CH_{Ind}(t) = 1 \\ 0: & CH_{Ind}(t) = 0 \end{cases} \quad (5)$$

Simulation findings demonstrate that the proposed protocol improves both the lifetime and performance of the network, while also reducing the number of individual nodes [23].

3.2. Mathematical Modelling

The primary aim of this research is to reduce the energy consumption of WBANs by selecting the most efficient CHs. Given that all nodes were dynamic and shift randomly, it was presumed that every node has an equivalent probability of occupying any location in the search region and being chosen as a header node under common circumstances. This theory posits that every node typically possesses an equal quantity of remaining energy. Let $Cl = [Cl_1, Cl_2, \dots, Cl_{N_c}]$ denote the collection of clusters including N_c clusters in WBANs. Let $Cl_i \in Cl$ is defined as cluster i in the search space, where $Cl_i = [n_{1,Cl_i}, n_{2,Cl_i}, \dots, n_{M_i,Cl_i}, n_{h,Cl_i}]$. The variable M_i indicates the total count of nodes with CH, n_{j,Cl_i} signifies node j in Cl_i , while n_{h,Cl_i} indicates the CH in Cl_i . The variables x_{j,Cl_i} and x_{h,Cl_i} represent the coordinates of node j and CH in Cl_i .

To represent the most efficient grouping of nodes in WBANs, the process is formulated as an optimization issue with multiple objectives, which involves the definition of two objective functions. The initial objective function, Obf_1 , is referred to as the cluster density metric, which considers the total members in the cluster. The delta difference objective was precisely described in Equation (6) as follows.

$$Obf_1 = \sum_{i=1}^{N_c} |U_{dn} - (M_i - 1)| \quad (6)$$

In the equation, M_i represents the total members in the cluster i , including the cluster head. U_{dn} was a parameter that quantifies the user's preference of network for the cluster density. The clusters created are denser when the user assigns a greater value to U_{dn} , and less dense when a lower value is supplied. A smaller number objective function Obf_1 value indicates that the total clusters align more closely with the user's preference. The condition $Obf_1 = 0$ signifies the optimal situation where cluster creation aligns precisely with the user's specifications. The second objective function, Obf_2 , referred to as the energy consumption measure, is formulated to optimize the energy usage in WBANs. Let $WBAN_E$ be the total energy used by every

cluster in network for communication of data, and let Cl_{i_E} represent the energy used with Cl_i , here i ranges from 1 to N_C . The energy consumption in WBANs is directly influenced by the energy consumption in every cluster. Therefore, the Obf_2 could be precisely calculated using equations (7) and (8).

$$Obf_2 = WBAN_E \tag{7}$$

$$Obf_2 = Cl_{1_E} + Cl_{2_E} + \dots + Cl_{N_{CE}} = \sum_{i=1}^{N_C} Cl_{i_E} \tag{8}$$

Since the amount of energy used in a cluster is determined by the distance between the CH and the related member nodes, Obf_2 could be expressed as the aggregate of all these distances across all clusters. The distance among cluster head and its members directly affects the energy spent in that cluster. As the distance decreases, the energy consumption also decreases, and increases. The energy expended in a cluster Cl_i could be represented as the total distances among its cluster head and member nodes, as seen in Equation (9).

$$Cl_{i_E} = \sum_{j=1}^{M_i-1} |x_j, Cl_i - x_h, Cl_i| \tag{9}$$

The task of finding the best clustering could be seen as a minimization problem, where the objective function is described by Equation (10).

$$\min f = w_1 \times f_1 + w_2 \times f_2 \tag{10}$$

The objective function may be minimized by satisfying the restrictions described in equations (11) to (13), leading to the identification of optimum clusters that can be used to implement an energy-efficient protocol for WBANs. Reducing energy usage leads to a longer lifespan for the network, hence decreasing monitoring expenses.

$$s. t. |x_j, Cl_i - x_h, Cl_i| \leq 2x_\tau \forall n_{j,Cl_i} \in Cl_i \wedge \forall Cl_i \in Cl \tag{11}$$

$$M_i \leq N_{NC,max} \tag{12}$$

$$R_{E,hi} \geq R_{E,th} \forall n_{h,Cl_i} \in Cl_i \wedge \forall Cl_i \in Cl \tag{13}$$

The variable x_τ represents the transmission range of the WBSN, whereas $N_{NC,max}$ represents the highest count of nodes inside the clusters. The variables $R_{E,hi}$ and $R_{E,th}$ represent the header node's residual energy in the i th clusters and the residual energy of any node's threshold value, correspondingly. The modulus operator was utilized to calculate the absolute value of the difference among two nodes. The limitation specified in Equation (11) guarantees that the distances among cluster head and remaining nodes stays inside the communication area. Equation (12) restricts to limit of the total nodes inside the cluster, hence guaranteeing safe transmission and stable functioning of WBANs. Equation (13) sets a limitation to guarantee that the residual energy in selected CHs exceeds the threshold value required for secure communication [24].

3.3. EHO-Based Protocol

This research employed a novel optimization technique called EHO, which is inspired by the nature and swarm behaviour of the elk herd (EH). It draws inspiration from the reproductive process of the EH. The EHO is theoretically formulated within the framework of optimization as seen below. Elks have two primary seasons for breeding: rutting and calving. At first, the population of the EH is categorized into different groups of families, which is determined by the number of male elks. During the rutting season, the leadership of all the families is assumed by a bull elk, whose total harems or cows was chosen based on its strength. The strength of the bull is assessed by engaging in dominance challenges. During the calving season, every family produces offspring in quantities that correspond to the count of members in family. Eventually, during the chosen season, the individuals from every family were combined, and the most exceptional members will allow to take part in the rutting season one more time. This procedure was iterated to guarantee that the developed EH was proficient in coping with the problems in the external environment. The EHO model proposes six stages to integrate the breeding process of EHs into the optimization model.

Step 1: Set the initial values for the EHO algorithm's parameters and the optimization problems. To include problem-specific information in the algorithm, two essential elements must be supplied: an objective function, which assesses the solutions, and the representation of solutions, which defines the kind of search region. Typically, optimization issues refer to straightforward scenarios with continuous search spaces, where all the decision variables are assigned a fixed range of values. The objective function could be expressed in the generic form as shown in Equation (14).

$$\min_x fO(x) \quad x \in [LB, UB] \tag{14}$$

The objective function, denoted as $fO(x)$, is utilized to assess the fitness of all the elks or solutions $x = (x_1, x_2, \dots, x_n)$. The term x_i in all the elks represent a specific property of the elks, indexed with 'i'. The value of x_i falls within the range $[LB_i, UB_i]$, where LB_i was the lower limit and UB_i was the upper limit for a feature x_i . The variable 'n' represents the total characteristics in all elk solutions or the dimensionality of the solutions. The EHO was specifically developed to incorporate a single parameter, known as the bull rate B_r , which directly influences the bull's initial rate within the EH. The last two typical factors were the size of the elk herd (EHS), also known as the size of population, and the maximum count of iteration M_{itr} .

Step 2: Create an initial population of elk An EH is originally formed, consisting of a population of elk that includes both males and harems. The matrix of EH has dimensions of $n \times EHS$, as defined in Equation (15).

$$EH = \begin{bmatrix} x_1^1 & x_2^2 & \dots & x_n^1 \\ x_1^2 & x_2^2 & \dots & x_n^2 \\ \vdots & \vdots & \dots & \vdots \\ x_1^{EHS} & x_2^{EHS} & \dots & x_n^{EHS} \end{bmatrix} \tag{15}$$

In the context of the continuous domain, every solution x^j could be obtained as $x_i^j = LB_i + (UB_i - LB_i) \times U(0,1)$, $\forall i = 1, 2, \dots, n$. The value of fitness for all the elk solutions was computed utilizing Equation (2). In the end, the elks in EH were arranged in ascending order according to its fitness levels, denoted as $f(x^1) \leq f(x^2) \leq \dots \leq f(x^{EHS})$.

Step 3: Season of Rutting During the season of rutting, the EHO algorithm was designed to form families depending on the B_r . The initial calculation for the total families was determined by $B = \lfloor B_r \times EHS \rfloor$. Next, the bulls were chosen from EH according to its value of fitness. The elks in group B with the highest values of fitness at the highest level of EH were selected as bulls, as indicated by Equation (16). This is to illustrate the competition among elks, where the most powerful ones are selected and given a larger number of harems.

$$B = \arg \min_{j \in \{1, 2, \dots, B\}} f(x^j) \tag{16}$$

The bulls in the B set are engaging in combat to establish familial units. To allocate the harems to every bull in B , a method called roulette-wheel selection is employed. This method assigns the harems to its respective bulls according to its value of fitness, proportionate to the overall value of fitness. Initially, all the bulls were labelled as x^j in the set B will be allocated a selection probability denoted as p_j . This probability was defined by splitting the bull's absolute fitness value, $f(x^i)$, by the values of total absolute fitness of every bull, as calculated in Equation (17).

$$p_j = \frac{f(x^j)}{\sum_{k=1}^B f(x^k)} \tag{17}$$

Furthermore, the allocation of harems to the bulls will be determined by their respective selection probability p_j . The vector $H = (h_1, h_2, \dots, h_k)$, where $k = EHS - B$, represents the harems. Every harem is allocated a bull index chosen using roulette-wheel selection.

Step 4: Season of Calving During the season of calving, the calf $(x_i^j(t + 1))$ of all the families are generated using mostly the characteristics inherited from its mother harem $(x_i^j(t))$ and father bull (x^{h_j}) . If the calf shares an identical index i as its bull father in the group, the calf was replicated according to Equation (18).

$$x_i^j(t + 1) = x_i^j(t) + \alpha \cdot (x_i^k(t) - x_i^j(t)) \tag{18}$$

The value of α is a randomly generated number between 0 and 1. This value controls the rate at which inherited traits are passed on from randomly picked elk in the herd $x^k(t)$, where k ranges from 1 to EHS. It is important to understand that increasing the value of α increases the probability of random factors being involved in the creation of the new calf, which ultimately leads to a larger level of diversification. If the calf has an identical index as its mother, it will inherit the traits of its mother's harem x^j and its bull father x^{h_j} as defined in Equation (19).

$$x_i^j(t + 1) = x_i^j(t) + \beta (x_i^{h_j}(t) - x_i^j(t)) + \gamma (x_i^r(t) - x_i^j(t)) \tag{19}$$

The variable $x_i^j(t + 1)$ represents the feature 'i' of the calf 'j' at t+1 iteration, and it is kept in EH' . The term h_j refers to the dominant bull in the 'j' harem, while 'r' represents the position of the randomly selected bulls from the present collection of bulls, denoted as B , where 'r' is an element of B . In certain instances, by nature, the female harem may engage in mating with different males if her current partner fails to adequately protect the female. The parameters β and γ are randomly selected from

the scale of [0, 2] to identify the proportions of traits transmitted from previously created calves. Equation (19) highlights that the coefficients β and γ in the proposed EHO are important factors since they bear similarities to the 'cognitive' and 'social' models in the PSO.

Step 5: Season of selection

All the male and female bulls, harems, and calves, from different families have come together as one group. The EH matrix that previously contained the bulls and harem solutions, as well as the EH' matrix that stored the solutions of the calves were combined into a single matrix called EH_{temp} . Elks in EH_{temp} population was arranged in ascending order according to their values of fitness. At last, the highest-ranking elks in the total EHS in EH_{temp} will be retained for the next generation, replacing the elks in EH. This means that $EH^j = EH_{temp}^j, j = (1, \dots, EHS)$. In the field of evolution scheme, this selection form was referred to as $\mu + \lambda$ selection, with μ representing the population of parents and λ representing the population of offspring.

Step 6: Termination criterion

The process of steps 3 to 5 will continue to be continued till the termination requirement was satisfied. Typically, the termination condition could be defined as reaching the maximum iterations. These options include the maximum ideal iterations, the maximum computing time, or the capacity to obtain the best answer. The EHO's parameter settings consist of the following values: $EHS = 10, n = 10, B_r = 30\%, t_{max} = 500, LB = -100,$ and $UB = 100$ [25].

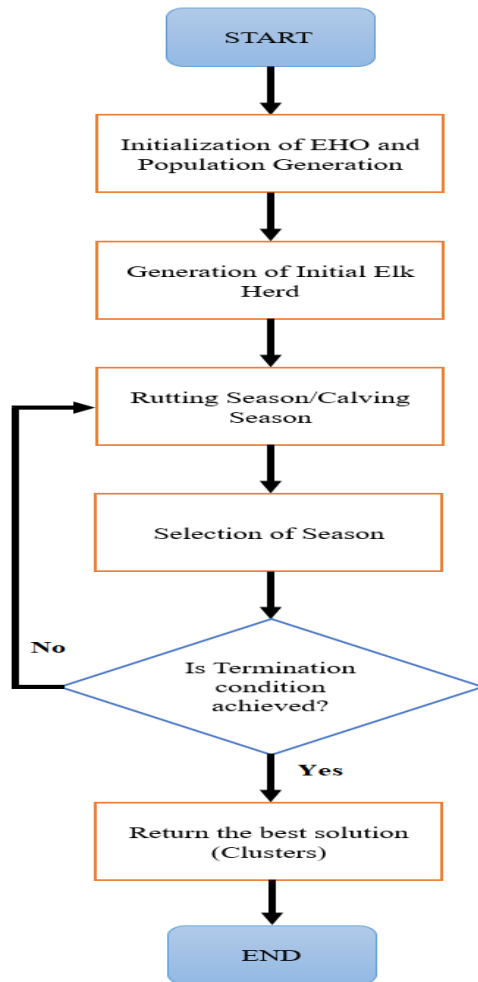


Figure 3. Flowchart of the EHO

Initialize the parameters of EHO

population size (n)
 elk herd size (EHS)
 Bull rate (B_r)
 Maximum iterations (t_{max})
 Dimensionality of the search space (dim)
 Generate initial elk herd (EH) of size $n \times EHS$
 Calculate the fitness of each elk
 Set iteration counter $T = 1$
 While ($T \leq t_{max}$) do
 Sort the elks in EH based on their fitness.
 Select the Bulls B , where $|B| = EHS \times B_r$
 Rutting Season
 Distribute harems to their Bulls and create $H = (h_{B+1}, \dots, h_{EHS})$ using roulette wheel selection.
 Calving Season
 For each Bull i in B do:
 For each family member j in the bull family i do:
 If j index is a bull, then:
 Select a random $k \in (1, \dots, EHS)$
 Select a random $\alpha \in [0, 1]$
 Update the position of j using bull- k and α
 Else
 Select a random r , where $r \in B$
 For each dimension k in dim do:
 Generate random $\gamma \in [-2, 2]$
 Update the position of j using bull- r and γ
 End For
 End If
 End For
 End For
 Selection of Season
 Perform $\mu + \lambda$ selection: Merge bulls, harems, and calves of the current and new generations
 Select the top EHS elks for the next generation
 $T = T + 1$
 End While
 Return the best elk from EH (Optimal CHs)

4. Experimental Results and Discussion

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The simulation plays a vital role in completely assessing the performances of WBANs. Simulation provides a controlled and repeatable setting for evaluating a research model, allowing researchers to examine its impact on various network features. The research model was assessed by simulation, considering several aspects. The performance of the model was evaluated to determine its overall efficiency. The tests are conducted with the MATLAB 2018A simulation tool on a computer that is equipped with a 64-bit Central Processing Unit (CPU), an Intel i5 processor, and 12 gigabytes of Random Access Memory (RAM). The simulation parameters used are presented in Table 2.

Table 2: Parameters for Simulation

Parameters	Values
Simulator	NS-2.34
Simulation Area	100x100m
No. of Nodes	250
Initial Energy	0.5 J
Transmitter Energy	16.7 nJ/bit
Receiver Energy	36.1 nJ/bit
Packet Size	512 bytes
No. of Rounds	6000

4.1. Performance Parameters

This research specifically examines the effectiveness of the suggested innovative routing protocols in WBANs, considering many parameters like energy consumption, PDR, PLR, E2E Delay, Throughput, and NLT.

Energy Consumption: This metric estimates the amount of energy consumed by SNs when the WSN is in operation. Reducing energy usage is desirable since it leads to longer NLT and decreased environmental impact.

E2E Delay: This parameter estimates the duration required for data to be transmitted from the originating node to the receiving node. Reducing end-to-end latency is essential for applications that require fast transmission of data.

PDR: This metric quantifies the proportion of packets that have been successfully delivered out of the total number of packets transmitted. A greater PDR signifies a more dependable network.

PLR: This metric measures the percentage of packets that were not successfully delivered to their intended destination, indicating the level of dependability and resilience of the routing protocols. A smaller ratio of dropped or lost packets is more desirable.

NLT: This metric refers to the period during which a WSN can function efficiently before a considerable number of nodes exhaust their energy. Expanding the use of NLT is crucial for ensuring the continued and lasting use of this technology.

Throughput: This metric refers to the speed at which data is effectively transferred over a network. Increased throughput is a sign of enhanced network efficiency and the ability to distribute data more effectively [11-13].

4.2. Performance Evaluation

A comprehensive examination and discussion on the assessed performances of the research model, focusing on energy consumption, end-to-end latency, PDR, PLR, NLT, and throughput was presented in this section. Table 3 displays a comparison of energy usage between the BWO-based approach and other models presented in the literature review section. The findings of the EHO were compared with several models including TSFIS-GWO, MGCSMO, FSKH, OEESR, and SEAR. The energy consumption in WBAN is a crucial statistic that has a direct impact on the lifespan of the networks and the overall performance of the model. In WBAN, energy consumption often encompasses elements such as the energy used for communication and sustaining the network's operational condition. The table presents the evaluation of outcomes based on nodes ranging from 50 to 250. The BWO model has achieved superior energy efficiency across all node ranges, while still delivering optimal performance. The EHO model attained 0.080J at 50 nodes, which is 0.011J to 0.029J minimum than the compared models. The maximum difference in energy consumption varies from 0.036J at 100 nodes, 0.038J at 150 nodes, 0.047J at 200 nodes, and 0.088J at 500 nodes. Figure 4 depicts a graphical representation of the comparison of energy consumption.

Table 3: Comparison of Energy Consumption

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OESR	SEAR
50	0.080	0.091	0.095	0.098	0.102	0.109
100	0.155	0.167	0.173	0.180	0.186	0.191
150	0.224	0.236	0.244	0.250	0.258	0.262
200	0.289	0.305	0.317	0.319	0.328	0.336
250	0.317	0.369	0.378	0.390	0.395	0.405

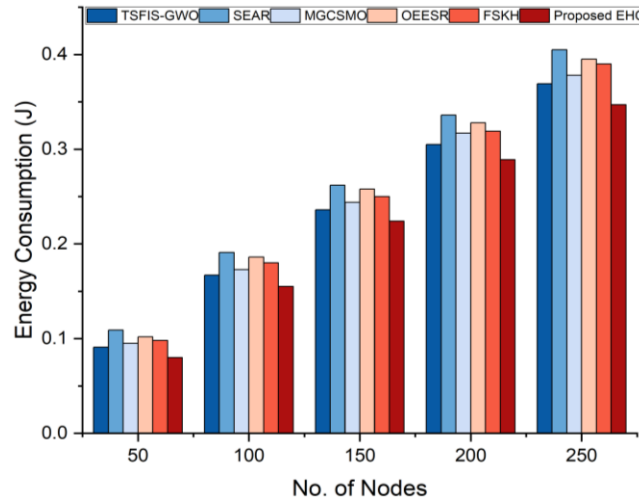


Figure 4. Graphical Plot of Energy Consumption Comparison

Table 4: Comparison of PDR

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OESR	SEAR
50	98.4%	96.8%	94.6%	92.5%	91.4%	89.9%
100	97.6%	95.7%	93.3%	91.2%	90.3%	88.7%
150	96.9%	94.4%	92.1%	90.4%	89.5%	87.5%
200	95.8%	93.6%	91.3%	89.2%	88.2%	86.9%
250	94.7%	93.3%	90.2%	88.4%	87.3%	86.2%

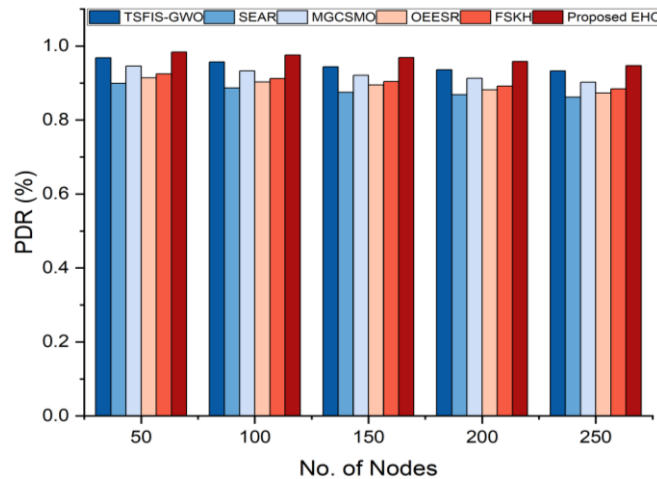


Figure 5. Graphical Plot of PDR Comparison

Table 4 displays the comparative findings of PDR utilizing the EHO-based protocol in relation to other existing models. The PDR in WBAN quantifies the level of dependability and effectiveness of communication inside the network. The EHO model

enhances the PDR by optimizing the selection of CHs and the routing pathways, ensuring efficient delivery of packets from SNs to the BS. The EHO model optimizes the reduction of packet loss and energy usage, resulting in improved PDR performance. The results are assessed according to the total number of nodes, which varies from 50 to 250, as indicated in the table. The EHO model has achieved superior PDR across all node ranges, demonstrating the highest level of performance. The EHO model attained 98.40% PDR at 50 nodes, which is 1.6% to 8.5% higher than the compared models. The maximum difference in PDR varies from 8.9% at 100 nodes, 9.4% at 150 nodes, 8.9% at 200 nodes, and 8.5% at 500 nodes. Figure 5 depicts a graphical representation illustrating the comparison of PDR performance.

Table 5: Comparison of PLR

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OESR	SEAR
50	1.6%	3.4%	5.6%	7.8%	8.9%	10.4%
100	2.4%	4.6%	6.9%	9.2%	9.11%	11.6%
150	3.1%	5.9%	8.2%	9.9%	10.9%	12.4%
200	4.1%	6.7%	8.8%	11.1%	12.3%	13.8%
250	5.2%	7.9%	10.1%	11.6%	12.8%	14.7%

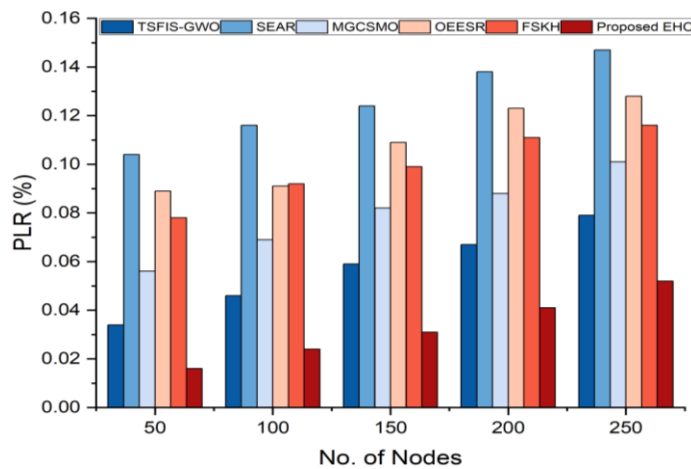


Figure 6. Graphical Plot of PLR Comparison

A comparison of the outcomes of PLR employing the EHO-based protocol with other existing models is presented in Table 5. PLR in WBAN is a critical metric that indicates the dependability and effectiveness of data transmission inside the network. The EHO model decreases the PLR by optimizing the CH selection, which reduces congestion and minimizes energy depletion among the nodes. Consequently, the PLR of the research model is significantly lower than that of the other models being compared. The results are assessed according to the total number of nodes, which varies from 50 to 250, as indicated in the table. The EHO model attained 1.6% PLR at 50 nodes, which is 1.8% to 8.8% lower than the compared models. The maximum difference in PLR varies from 9.2% at 100 nodes, 9.3% at 150 nodes, 9.7% at 200 nodes, and 9.5% at 500 nodes. Figure 6 depicts the graphical representation of the comparison of PLR performance.

Table 6: Comparison of End-to-End Delay

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OESR	SEAR
50	0.16	0.21	0.26	0.30	0.33	0.36
100	0.20	0.24	0.32	0.35	0.41	0.43
150	0.25	0.31	0.38	0.40	0.45	0.48
200	0.29	0.36	0.44	0.46	0.49	0.52
250	0.33	0.42	0.49	0.52	0.54	0.56

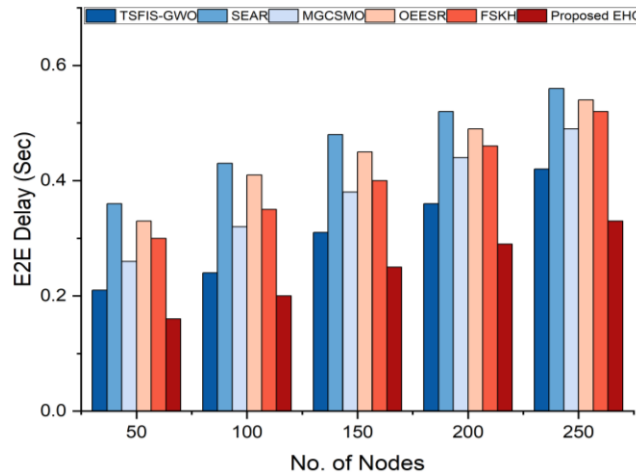


Figure 7. Graphical Plot of E2E Delay Comparison

Table 6 displays a comparison of the E2E delay findings between the EHO-based protocol and other existing models. The E2E delay in WBAN refers to the overall duration taken for the data packet to move from the source to the destination node. The EHO model minimizes the end-to-end delay by efficiently selecting CHs and optimizing the routing pathways. This results in reducing the distance and the number of hops that a packet needs to travel. The suggested EHO-based protocol ensures expedited delivery of data packets, which is crucial for time-critical applications such as healthcare. The results are assessed according to the total number of nodes, which ranges from 50 to 250, as indicated in the table. The EHO model has achieved a reduction in E2E latency across all node ranges, demonstrating superior performance. The EHO model attained a 0.16 sec delay at 50 nodes, which is 0.05 sec to 0.20 sec minimum than the compared models. The maximum difference in delay varies from 0.04 sec at 100 nodes, 0.23 sec at 150 nodes, 0.23 sec at 200 nodes, and 0.22 sec at 500 nodes. Figure 7 depicts a graphical representation illustrating the comparison of E2E delay performance.

Table 7: Comparison of Network Lifetime

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OEESR	SEAR
50	5885	5815	5674	5550	5481	5395
100	5840	5768	5596	5475	5412	5334
150	5814	5726	5559	5433	5360	5271
200	5722	5647	5472	5351	5286	5205
250	5636	5518	5418	5304	5201	5149

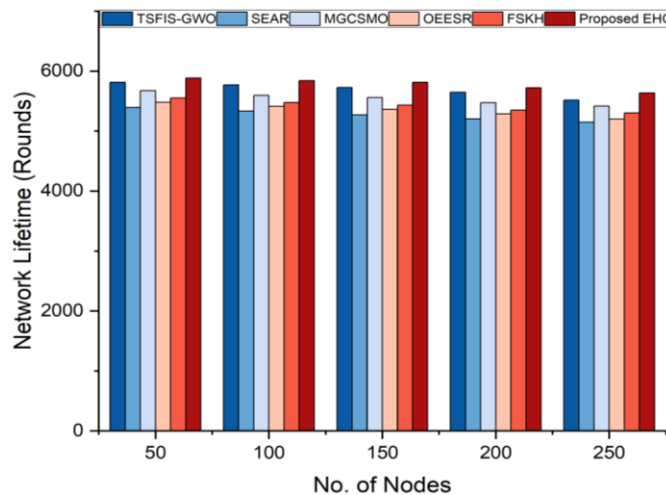


Figure 8. Graphical Plot of NLT Comparison

A comparison of the network lifetime findings comparing the EHO-based protocol with other existing models is presented in Table 7. The network lifespan in WBAN is a metric used to quantify the duration during which the network may function effectively before the first node exhausts its energy. The EHO-based protocol enhances the network's lifespan by optimizing the selection of CHs and routing pathways. This optimization ensures a balanced energy consumption among nodes and minimizes the energy cost. This leads to an efficient allocation of energy usage, preventing nodes from running out of energy prematurely. The table presents the evaluation of outcomes, which is according to the total nodes, varying from 50 to 250. The EHO model has shown superior network longevity across all node ranges, demonstrating optimal performance. The EHO model attained 5885 rounds at 50 nodes, which is 70 to 490 rounds higher than the compared models. The maximum difference in NLT varies from 506 rounds at 100 nodes, 543 rounds at 150 nodes, 517 rounds at 200 nodes, and 487 rounds at 500 nodes. Figure 8 depicts a graphical representation of the comparison of network lifetime performance.

Table 8: Comparison of Network Throughput

No. of Nodes	Proposed EHO	TSFIS-GWO	MGCSMO	FSKH	OESR	SEAR
50	0.96	0.92	0.90	0.90	0.87	0.85
100	0.94	0.89	0.88	0.87	0.85	0.82
150	0.91	0.87	0.85	0.82	0.80	0.76
200	0.90	0.85	0.80	0.78	0.76	0.74
250	0.88	0.83	0.79	0.75	0.74	0.71

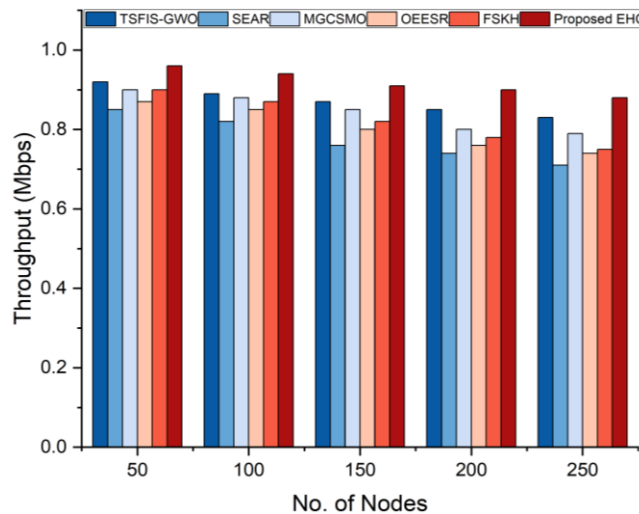


Figure 9. Graphical Plot of NLT Comparison

Table 8 displays a comparison of network performance between the EHO-based protocol and other existing methods. Network throughput is the pace at which packets of data are successfully sent from the source to the target within a given time. The EHO-based protocol model enhances network throughput by optimizing the selection of CHs and routing channels, hence decreasing packet collision and congestion, and ensuring efficient data transmission and aggregation. This results in increased throughput, ensuring the research model's reliability and the timely transmission of health data in healthcare applications. The results are assessed according to the total number of nodes, which varies from 50 to 250, as indicated in the table. The EHO model has achieved superior network throughput across all node ranges, demonstrating optimal performance. The EHO model attained 0.96% throughput at 50 nodes, which is 0.04% to 0.11% higher than the compared models. The maximum difference in throughput varies from 0.12% at 100 nodes, 0.15% at 150 nodes, 0.16% at 200 nodes, and 0.19% at 500 nodes. Figure 9 depicts a graphical figure illustrating the comparison of network throughput performance. Additionally, it enhances network performance, hence facilitating uninterrupted and dependable monitoring of health data.

5. Conclusion

Bio-sensor nodes require a significant percentage of allocated node energy to transfer data to other nodes, hence a routing protocol with energy efficiency is essential to WBAN. A clustering-based protocol offers a cost-effective data routing system that minimizes energy consumption while maintaining acceptable levels of data loss and network delay. Several WBAN

systems have been developed for health monitoring applications, specifically designed to overcome issues such as limited lifetime, difficulty in recharging, and restricted energy constraints. Cluster-based routing algorithms improve network lifespan, optimize network capacity, and reduce network load to boost overall network performance for improved analysis and efficiency. This work introduced a novel metaheuristic algorithm for the purpose of selecting the most optimum clusters in WBANs. The aim was to enhance the energy efficiency of the healthcare monitoring routing protocol. The primary objective was to minimize the energy utilization of WBANs by selecting the most appropriate CHs based on the EHO. The EHO-based routing protocol showed higher performance in WBANs in terms of energy consumption, E2E latency, PDR, NLT, PLR, and throughput. The research model was validated by comparing its findings with the existing routing protocols. The research model surpassed all the comparable models in terms of energy consumption, latency, NLT, PDR, PLR, and throughput. In future, the proposed model can be integrated with the Internet of Things (IoT) to extend the proposed research to the next level of healthcare monitoring with the Smart Home application. Furthermore, the privacy and security of healthcare data can be protected and secured by implementing a cryptography application.

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