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Enhanced network lifetime in WBAN using hybrid meta-heuristic-enabled mobile and multiple sink nodes-connected routing

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Abstract: Wireless body area networks (WBANs) contain many miniature sensor devices. These frameworks are constructed to transfer the sensed physiological signals continuously. It is highly complex to design a WBAN protocol with mobile and multiple sink nodes. The conventional algorithms did not fulfil the requirements of the application completely. Focusing on lower energy consumption, this paper aimed to propose an energy-aware routing protocol in WBAN by employing the mobile and multiple sink nodes. The hybridised forms of the well-efficient heuristic algorithm are developed as hybrid barnacle mating dingo optimisation (HBMDO) for optimal cluster head selection. Here, the optimal cluster heads are chosen with multi-objective constraints like distance, energy, delay, transmission load, path loss, node trust, and packet delivery ratio. The designed routing methods in WBAN thus secured efficient performance when correlated with the existing routing approaches regarding energy consumption and network lifetime.

Keywords: wireless body area networks; hybrid barnacles mating dingo optimisation; optimal cluster head selection; energy aware routing protocol; multi-objective constrains; energy consumption; network lifetime; mobile and multiple sink node.

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1 Introduction

Nowadays, WBAN and wearable computing have enormous growth in healthcare diagnosis and monitoring applications. These types of WBAN and wearable communication applications provide the services such as secure, rapid, and safe access to healthcare providers and patients from anywhere (Ahmed et al., 2020). Wireless Sensor Networks (WSN) became the backbone for healthcare applications based on WBAN. WSNs are formulated with the help of a number of small sensors, and they can be self-organised in all types of environments like homes, battlefields, volcanic areas, hospitals, and oceans (Mkongwa et al., 2019). These sensors are mostly utilised to collect information from various backgrounds and transfer it to the new powerful node named the sink node. WBAN is a WSN variant that has a huge range of applications in different domains like healthcare, military, sports, and wildlife applications (Otal et al., 2009). But, the smart computing concept and arrival of IoT in the building block of WSN have become highly essential in recent times and have reached a new height in the WBAN research community (Samarji and Salamah, 2021). As WBAN concentrated on monitoring different areas like space, sports, hospitals, and the army and it became a challenging task to create a new effective framework with sensible power sources for enhancing the lifetime of the network (Kim and Eom, 2014).

WBAN model comprises a huge amount of tiny sensor nodes with it, and they are utilised in transmitting real-time health data, receiving work commands from Personal Stations (PS), and monitoring the background condition (Liao et al., 2018). Body Sensor Nodes (BSNs) it has only a finite number of battery storage but requires a long lifetime, so expanding the network lifetime as well as energy saving in the nodes creates high complexity in Medium Access Control (MAC) protocols for WBANs (Mkongwa et al., 2019). The initial contribution of the model includes a basic scheme to find out the landmark nodes, which is highly essential at the time of allocating efficient data aggregation and mobile sink in sensor node (Samarji and Salamah, 2021). The random walk concept is not utilised to identify landmark nodes in the network (Liao et al., 2018). The mobile sink scheduling and conventional clustering approaches use the location information of the sensor node (Hung et al., 2010). In addition, the existing information related to optimal clusters is not required, so a new model is developed to tune mobile sink movement towards non-localised landmark nodes (Goudar and Potkonjak, 2013). The kalman filter structure is interoperated over online trilateration to allocate the mobile sink and to upgrade the location of the landmark node. The computation performed in the enhanced location of the landmark node for mobile sink allocation is explained (Agyei-Ntim and Newman, 2013). This new model attained more effective enhancement in network lifetime than other approaches.

The tuned communication approaches are widely utilised in routing, sink mobility, and network clustering (Rismanian Yazdi et al., 2021). The global application normally utilises a mobile sink to enhance the network's lifetime (Cai et al., 2015; Loganathan and Arumugam, 2020). Different enhancements performed in data aggregation and load balancing schemes are analysed with the help of multiple and single mobile sinks in the network. But, it is complex to perform scheduling in the mobile sink (Shunmugapriya and Paramasivan, 2022). The mobile sink didn't have any capability to perform operations in the network without using any extra information about the network. The network's lifetime is enhanced by utilising a trajectory-bounded mobile sink (Rajendra Prasad and Bojja, 2020). Different meeting point presented in the network helps to tune the scheduling in the mobile sink. Most of the WBAN network needs superior data transmission rates, continuous monitoring, and sensor sampling (Yang et al., 2018). WBAN commonly uses the star network topology when the WSN act as a multi-hop signal. Then, the communication of WBAN is performed in various modes, such as short-range, wireless, and real-time. Similarly, the characterisations and outdoor or indoor ultra-wide-band (UWB) radio broadcasting methods are utilised in WBAN. Some widely used wireless technologies like Bluetooth and ZigBee are employed for WBAN. The ZigBee model consumes very low power, and they are widely implemented in small-sized sensor nodes. Thus, to overcome all the above limitations, a new routing approach based on energy efficiency in WBAN with mobile and multiple sink nodes is essential.

Some of the major contributions of the developed routing protocol in WBAN with mobile and multiple sink nodes are listed below.

- To build a new energy-efficient routing protocol with mobile and multiple sink nodes for WBAN over hybrid optimisation approaches to ensure the long lifetime of the network.
- To explore the developed hybrid approach named HBMDO to recognise the optimal short path between sensor nodes to minimise the transmission load and distance and maximise packet delivery ratio and throughput in WBAN with mobile and multiple sink nodes.
- To prove the efficiency of the proposed HBMDO-based routing protocol with mobile and multiple sink nodes by performing different simulation observations with various cost functions.

The remaining parts of the developed routing protocol in WBAN are explained. The challenges attained in existing conventional approaches are elaborated in part II. The WBAN system models, along with developed hybrid approaches with mobile and multiple sink nodes, are given in part III. The energy-efficient routing performed by WBAN is described in part IV. Various parameters utilised to perform energy-efficient routing in WBAN with mobile and multiple sink nodes are explained in part V. The achieved outcomes over the developed model in WBAN with mobile and multiple sink nodes are elaborated in part

VI. The conclusion of the developed protocol for WBAN with mobile and multiple sink nodes is presented in part VII.

2 Literature survey

2.1 Related works

In 2018, Yang et al. (2018) have recommended a novel MAC layer protocol to improve the efficacy of energy as well as to enlarge the BSN lifetime in WBAN. The developed protocol has used hybrid approaches based on time division and collision avoidance methods. The transmission overheads were allocated to the personal stations, and designed a waiting order phase for sensor nodes was to enhance the efficacy of the energy. Thus, the developed protocol attained better simulation outcomes, and also it has reduced energy consumption than other existing approaches. In 2019, Mu et al. (2019) have suggested a simplified energy-balanced alternative-aware routing algorithm (SEAR) for WBAN. The current loads, as well as residual energy in upcoming hop destinations, were observed at the time of redirecting the request procedures. The essential data were transferred at the time of enhancing the routing request. The robustness as well as compatibility of the network was enhanced by including an interchanging path. The outcome of the SEAR has attained relatively superior regarding residual network energy, end-to-end delay and throughput, and also in network lifetime.

In 2022, Amutha et al. (2022) have designed the hybrid butterfly and ant colony optimisation algorithm along with static sink node (HBACS). Butterfly optimisation (BOA) was utilised to decide the optimal cluster heads, and also ant colony optimisation (ACO) was employed to achieve efficient routing by maximising the lifetime of the network and also reducing energy usage. The multi-hop communication has been achieved between the sink nodes and cluster nodes that were eliminated by employing mobility. The developed HBACM and HBACS approaches were accomplished in a simulator named NS2. The developed model attained improved performance rate in throughput, residual energy, and alive nodes-based analysis.

In 2019, Redhu and Hegde (2019) have implemented a landmark-based scheduling scheme according to data aggregation. The landmark node and network clustering recognisation was improved with the help of network graphs. A mobile sink scheduling approach was enhanced to perform data aggregation with the Kalman filtering structure. The major work of the filtering framework was to improve the information robustness in landmark nodes. The simulations were performed by utilising the dataset in a real WSN test bed and also achieved improved network lifetime in different configurations and further utilised in the application of cyber-physical systems. In 2021, Durga Rao and Sridevi (2021) have initiated a reliable trust management system by assuring the stability and security in WSN with the help of WBAN. The nodes were not considered cooperative when different attacks were performed. According to fuzzy logic, the selfish nodes are observed by using the residual power as the essential factor in declined nodes, and they were not suitable for memberships and defuzzification. The developed model has achieved a better outcome than conventional protocols.

In 2022, Guo et al. (2022) have developed an optimised routing protocol energy efficient and reliable routing, based on reinforcement learning and fuzzy logic (EERR-RLFL). WBAN node heterogeneity was considered in EERR-RLFL, and then the node rank division method was developed by sensor nodes with three aspects. Here, all the ranks were termed as one factor, and they have affected the quality of the link. So, a new approach was proposed named the “fuzzy-logic-based link quality evaluation (FLLQE)” algorithm. This method utilised the fuzzy evaluation approach by considering various factors to perform link quality validation between two nodes. The validation outcomes of the developed model achieved effective performance with respect to packet loss ratio, energy efficiency, and network lifetime. In 2022, Rahman et al. (2022) have initiated a new dual forwarder selection technique (DFST) to enhance the lifetime of the network by minimising the consumption of energy and maximising the throughput and stability time of the network. DFST was performed by grouping the sensor nodes. The developed model was validated with respect to throughput, lifetime, and network stability. The network energy usage got reduced by enhancing the energy of the residual network.

In 2019, Choudhary et al. (2019) have proposed a novel “energy budget based multiple attributes decision making algorithm (EB-MADM)” to perform dynamic cluster head selection. The developed model selected the optimum nodes as cluster heads, and they have effective residual energy levels, and. also they performed data routing with reduced energy. The EB-MADM chose an updated CH in several transition round and supplied an equal amount of cluster head to all nodes, leading to improved network lifetime. The validation was performed over the MATLAB tool and achieved a better performance rate with respect to throughput, propagation delay, network lifetime, and stability period.

2.2 Problem statement

WBAN is the branch of WSN still attains differences in the network. The WSN scales are usually larger and hold a large number of nodes which leads the system to be complex. The WSN has widely utilised the redundant nodes, leading to low priority for robustness rate. The WBANs are requested to utilise a minimal number of nodes to ensure a high packet loss rate. Various challenges attained in the existing approaches for the enhancement of network lifetime in WBAN using hybrid meta-heuristic approaches enabled with mobile and multiple sink nodes in connected routing are listed in Table 1. MAC layer protocol (Mu et al., 2019) utilises the sensor node to enhance the efficacy of energy. But, it uses awaiting orders state to lower the energy usage in BSN, and also, it has very low scalability and creates complexity in the system. SEAR (Amutha et al., 2022) achieved superior throughput and residual energy to enhance the network's lifetime. Still, it needs a high focus on enhancing the performance rate of routing approaches to achieve an accurate efficacy rate in practical applications. HBACS and HBACM (Redhu and Hegde, 2019) utilised the sink node to remove the multi-hop communication in-between dink nodes and cluster head. At the same time, it may suffer when the local minimum gets trapped, and the tendency of population diversity is low. Kalman filtering (Durga Rao and Sridevi, 2021) has a high robustness rate when continuous updating is achieved in the landmark node. But, it requires a cooperative, mobile sink scheduling scheme in a huge WSN network. Fuzzy logic (Guo et al., 2022) computes the performance rate of the trust factor concerning cost function based on traffic and energy. But, it always requires residual power in the nodes, and sometimes they don't provide good coordination to the membership function. EERR-RLFL (Rahman et al., 2022) offers effective reference when routing selection in path is performed. Yet, it faces packet loss issues due to unstable network topology, leading to inaccurate data collection. DFST (Choudhary et al., 2019) rapidly minimises the consumption of energy in the network, and also it enhances the throughput as well as stability rate in the network. But, it always needs a high concentration on energy harvesting mechanisms to maximise the network lifespan. EB-MADM (Sulaiman et al., 2020) and DAP-DS (Bairwa et al., 2021) choose the optimal node as cluster head, and they attain a high level of residual energy in the network and. also achieve data routing with minimal cost and also with less residual energy. Still, it couldn't utilise in real time WBAN platform due to the low efficacy rate. These challenges are considered and motivated to design a new enhancing network lifetime in WBAN with hybrid approaches.

Table 1 Features and challenges of existing WBAN model with routing approaches

Author (citation)	*Methodology*	*Features*	*Challenges*
Yang et al. (2018)	MAC layer protocol	• It utilises the sensor node to enhance the efficacy of energy. • It uses awaiting orders state to lower the energy usage in BSN.	• It has very low scalability and creates complexity in the system.
Mu et al. (2019)	SEAR	• It achieved superior throughput and residual energy to enhance the network's lifetime.	• It needs a high focus on enhancing the performance rate of routing approaches to achieve an accurate efficacy rate in practical applications.
Amutha et al. (2022)	HBACS and HBACM	• It utilised the sink node to remove the multi-hop communication in-between dink nodes and cluster head.	• It may suffer when the local minimum gets trapped and the tendency of population diversity is low.
Redhu and Hegde (2019)	Kalman filtering	• It has a high robustness rate during continuous updating achieved in the landmark node.	• It requires a cooperative, mobile sink scheduling scheme in a huge WSN network.
Durga Rao and Sridevi (2021)	Fuzzy logic	• It computes the performance rate of the trust factor concerning cost function based on traffic and energy.	• It always requires residual power in the nodes, and sometimes they don't provide good coordination to the membership function.
Guo et al. (2022)	EERR-RLFL	• It offers effective reference when routing selection in the path is performed.	• It faces packet loss issues due to unstable network topology, leading to inaccurate data collection.
Rahman et al. (2022)	DFST	• It rapidly minimises the consumption of energy in the network. • It enhances the throughput as well as the stability rate in the network.	• It always needs a high concentration on energy harvesting mechanisms to maximise network lifespan.
Choudhary et al. (2019)	EB-MADM	• It chooses the optimal node as cluster head, and they attain high level residual energy in the network. • It achieves data routing with minimal cost and also with less residual energy.	• It couldn't utilise in real time WBAN platform due to a low efficacy rate.

3 System model of WBAN with the new hybrid meta-heuristic algorithm for routing

3.1 WBAN system model

Because of the huge development in wireless communication and sensor technology, a new WSN approach has been developed to monitor the health of individuals based on EMG and ECG signals in humans, and it is said to be a WBAN system. These WBAN systems with mobile and multiple sink nodes provide real time updates about individual health and gained huge recognition in the research field. WBAN with mobile and multiple sink nodes is widely utilised in many applications such as entertainment, sports, medical fields, and social welfare. The major use of WBAN is to gather complex data from individuals and provide it to the medical server to monitor the activity of the patient and also to perform a diagnosis for the disease. The structure of WBAN consists of 3 stages, so it is named a three-tier body network structure. Initially, in the tier 1 stage, entire sensors are associated with the human body. The major aim of this process is to collect and transfer the patient physical information. The tier 2 utilised smartphones, smart devices, and personal computers. The acquired data are transferred to the terminal center over the wireless medium. Finally, in tier 3, the WBAN utilised a terminal data centre, bounded by the remote server, which provides a huge range of advantages to the applications. In this phase, the receiver data are computed and evaluated to offer a dynamic response. At the time of providing abnormal information to the sensor node, the system suddenly alerts the individuals and their families to take immediate safety measures and precautions to save the life of the individual. The general structural view of WBAN is given in Figure 1.

Figure 1 Structural view of the WBAN system (see online version for colours)

3.2 Developed hybrid HBMDO algorithm

HBMDO algorithm is developed to select the shortest path in the sensor nodes to enhance the network lifetime with mobile and multiple sink nodes. BMO (Bairwa et al., 2021) approach is selected to offer superior classification outcomes, but it doesn't offer an effective convergence rate and may cause a premature convergence rate in a few cases. So, it is essential to utilise DOX in the developed approach, and this fusing is referred to as HBMDO. DOX (Cao et al., 2020) requires a very minimal amount of mathematical effort and also needs low computational time to discover the available best optima value. But, it is a challenging task to select an accurate search in real time system because it use number of local optima solution in search space. The suggested HBMDO approach is used to update the first position with BMO and also to update the second position with DOX. These two positions are represented by y_1 and y_2, respectively. The positions y_1 and y_2 are utilised to update the final position based on the new concept with equation (1).

$$q_{final} = mn(q_1, q_2) + \left(\frac{std(q_1, q_2)}{2} \right) \tag{1}$$

Here, the term q_1 indicates the updated position of BMO and q_2 denote the updated position of DOX, respectively. The term $mn(q_1, q_2)$ denotes the mean positions of BMO and DOX, and also the term $std(q_1, q_2)$ represents the standard position of BMO and DOX. The final update is performed based on equation (1).

The BMO algorithm utilises three processes such as initialisation, choice process, and reproduction, and these three processes are discussed below.

Process 1-Initialisation: The barnacles utilised for the basic population are indicated in equation (2).

$$B = \begin{bmatrix} b_1^1 & b_1^E \\ b_e^1 & b_e^E \end{bmatrix} \tag{2}$$

The decision parameters are given E, and the individual number is represented e respectively. The lower and upper ranges are presented in equations (3) and (4).

$$A_s = \left[A_s^1, \ldots, A_s^v \right] \tag{3}$$

$$D_s = \left[D_s^1, \ldots, D_s^v \right] \tag{4}$$

The lower limit is indicated A_s, and the upper limit is termed D_s vth the parameter. The outcomes achieved in the first execution are stored in Kth the solution matrix.

Process 2-Choice method: The barnacle's reproduction is performed according to the penis length K_z. The preferences are performed according to the factors explained below:

- the option for random approaches is getting fixed according to penis length
- the entire barnacle gets the sperms from an alternate barnacle due to the fertilisation of the entire barnacle achieved only one time by other barnacles
- the paired barnacles are chosen according to a fixed point, referred to as off-spring production
- the cast sperm policy is achieved by choosing the repetition when selecting the weight K_z.

In this approach, the exploration process and the exploring process take place. The off-spring process is performed over the sperm cast process in the exploring phase, and they are validated by utilising equations (5) and (6).

$$T_q = rnd\left(h\right) \tag{5}$$

$$T_c = rnd\left(h\right) \tag{6}$$

The mated parents are indicated by T_c and T_q, respectively.

Process 3-Reproduction: The systematic approach utilised for individual protection is not obtainable. So, the optimisers mainly aimed to attain the inheritance frequency in offspring production with the help of "The Hardy-Weinberg" principle. The attained off-spring parameters are achieved by equation (7).

$$J_g^{w_{km}} = MB_{g_c}^a + NB_{g_p}^a \tag{7}$$

The pseudo-random distribution at the range of $\left(0,1\right)$ denoted as E. The mother individual is denoted by $K_{s_d}^t$, and the dad individual is indicated by $K_{s_B}^t$. The process of exploration is presented in equation (8).

$$J_g^{w_{km}} = rnd \times B_{g_p}^a \tag{8}$$

The term rnd refers to the accidental amount in the limit $\left(0,1\right)$. Finally, the offspring is produced by the mother individual. The evaluation of off-spring is achieved, and they are fused through parents to improve the solution matrix in the dimension variant. The selection of 50% of the best outcomes and the assembling process are performed in the spices dimension, so it becomes simple to eliminate the unnecessary outcome.

DOA is an organic model which is highly utilised to perform optimisation in globally and to imitate dingo hunting schemes. Dingoes performed various steps like scavenging behaviour, grouping tactics, and persecution, which are explained below.

Step 1- Group attack: The dingoes chose a group activity to perform hunting. Dingoes have the capability to detect the food easily, and the remaining dingo begins to cover the quarry. The features of dingoes are represented in equation (9).

$$\vec{Q}_g(r+1) = \beta_1 \sum_{u=1}^{ab} \frac{\left[\overrightarrow{\phi j(r)} - q\vec{g}(r)\right]}{ab} - \vec{j}*(r) \tag{9}$$

Here, the term $\vec{q}\left(r+1\right)$ represents the new search agent position, $\vec{q}_g\left(r\right)$ indicate the current search agent, $\phi q\left(r\right)$ denote the search agent of the subset, ab refer to the integer random number, and $\vec{q}*\left(r\right)$ refers to the best search agent achieved from the existing iteration, respectively. The random numbers developed uniformly in $\left[-2,2\right]$ intervals are given as β_1, respectively.

Step 2-Persecution: The main goal of the dingo is to get a small amount of prey, and so it starts to follow the prey to get it alone, and this character is given in equation (10).

$$\vec{q}_g(r+1) = \vec{q}*(r) + \beta_1 * e^{\beta_2} * \left(\vec{q}_{b_1}(r) - \vec{q}_g(r)\right) \tag{10}$$

Here, the term $\vec{q}\left(r+1\right)$ denotes the motion of the dingo, the random variable achieved in $\left[-1,1\right]$ the interval that is indicated as β_2, b_1 be the random variable, $\vec{q}_g\left(r\right)$ refer to the current search agent, and $\vec{q}_{b_1}\left(r\right)$ is the search agent of rth the interval, respectively.

Step 3-Scavenger: The scavenger characteristics are indicated as an attack at the time of finding food, and the behaviour of the dingo is given in equation (11).

$$\vec{q}_g(r+1) = \frac{1}{2}\left[e^{\beta_2} * \vec{q}_{g_1}(r) - (-1)^{\sigma} * \vec{q}_g(r)\right] \tag{11}$$

Here, the term σ denoted the binary number and was created randomly.

Step 4-Survival rate: The dingo survival rate is given in equation (12).

$$sr(l) = \frac{Ft_x - Ft\left(l\right)}{Ft_x - Ft_w} \tag{12}$$

The best fitness function is denoted as Ft_x, and the worst fitness function is given as Ft_w of the following generation and $Ft(l)$ indicates the fitness function of lth the search agent, and the survival rate is presented in equation (13).

$$\vec{q}_g(r+1) = \vec{q}*(r) + \frac{1}{2}\left[\vec{h}_{b_1}(r) - (-1)^{\sigma} * \vec{h}_{b_2}(r)\right] \tag{13}$$

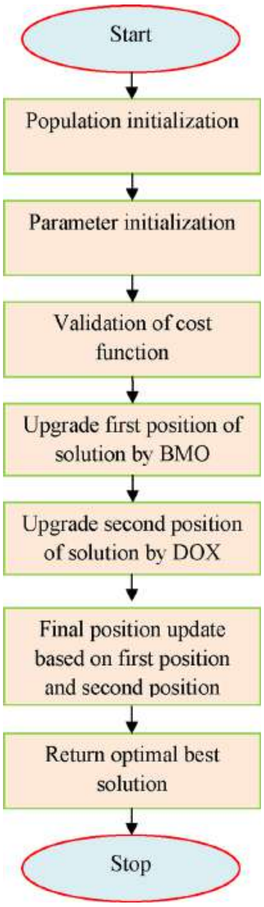
Here, the term b_1 and b_2 the random number $\vec{q}_g\left(r\right)$ denote the low survival rate, $\vec{h}_{b_1}(r)$ search agent b_1, and $\vec{h}_{b_2}(r)$ search agent b_2, respectively. The pseudo-code for the developed HBMDO is given in Algorithm 1.

Algorithm 1 Developed HBMDO

```
Initialize the population of Barnacles and Dingo
Determination of algorithm parameters
For all solution
Validate fitness for the entire solution
  Upgrade the first position of the solution using the BMO procedure by equation (8)
  Upgrade the position two of the solution by DOX procedure by equation (13)
  The final update is performed by equation (1)
End for
Find the optimal best solution
End
```

The flowchart for the developed HBMDO is presented in Figure 2.

Figure 2 Flowchart of the developed HDMDO (see online version for colours)

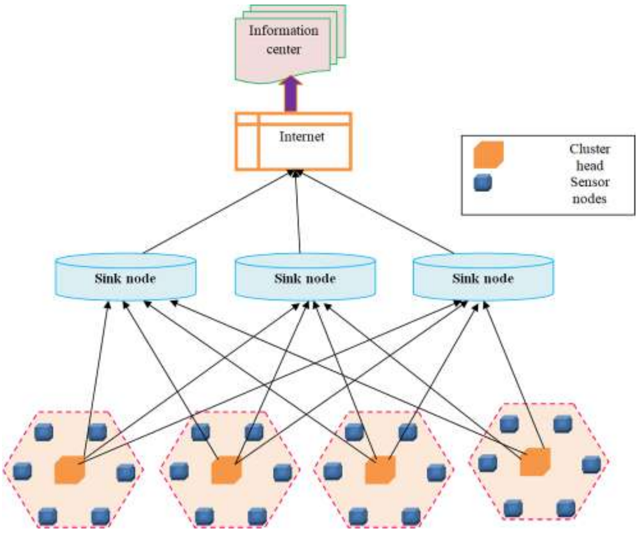


4 An energy-efficient routing with mobile and multiple sink nodes for WBAN

4.1 WBAN routing

Routing is essential to better communication in WBAN with mobile and multiple sink nodes. The routing process is mainly used to choose the optimal route over multiple routes to send the packets to the target node without performing any variation in the packet. The routing protocols are utilised in WBAN to enhance the effectiveness of the network according to minimising latency and path loss, long network lifetime, and low energy expenditure. Designing a WBAN system with mobile and multiple sink nodes faces a lot of complexities at the time of achieving a superior life in the network and consistent data delivery in finite power supply constrain. So, a well-designed routing approach is essential to offer high-quality service to extend the network's lifetime over effective management techniques. The common procedure for clustering in the sensor node of WBAN with mobile and multiple sink nodes is to conserve the sensor node energy. At the time of clustering, the minimum energy consumption needs to be achieved while using the multiple sink nodes, and the selected cluster head (CH) is utilised to acquire the data from sensor node and transfer it to various sink nodes. The routing structure in WBAN with mobile and multiple sink nodes is represented in Figure 3.

Figure 3 Diagrammatic representation of routing in WBAN with multiple sink nodes (see online version for colours)



4.2 Parameter description

A new HBMDO-based routing protocol is developed in the WBAN with mobile and multiple sink nodes to enhance the life as well as routing efficiency of the network. Various simulation parameters are used for the energy-efficient routing in WBAN protocols, such as simulation area, number of sensor nodes, number of sink nodes, packet length, size of the population, maximum number of iterations, network lifetime, initial energy, wavelength, frequency range, number of rounds, minimum supply voltage and data generation rounds that are listed in Table 2.

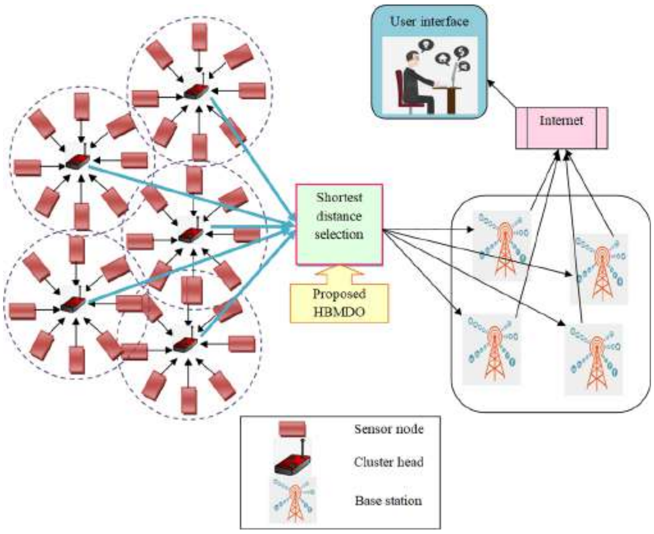
Table 2 parameters utilised for simulation in WBAN routing

Parameters	*Specifications*
Simulation area	2×2 m^2
Sensor node count	14
Sink node count	5
Length of the packet	4000 bits
Population size	10
Number of iterations	10
Initial energy	0.5 J
A lifetime of the network	High
Wavelength	0.125 m
Frequency	2.4 GHz
Minimum supply voltage	1.9 v
Number of rounds	2000
Data generation round	4000 bits /round

4.3 Developed routing model

Routing algorithms are highly dynamic with programming languages, and they are enhanced with the help of graph theoretic theory. The network analysis in a data communication system is performed using maximal flow, minimum span issues, and shortest route. With the help of the short routing path protocol, it simply identifies the short path in the destination node. Routing is termed as a complex in WSN. The routing scheme selects the network path and transfers the information through the host in the network. Routing became challenging owing to the huge variation achieved in the network, so flexible approaches are highly essential to continue routing. In small networks, flat routing works effectively, and at the same time, they are inappropriate for the large-scale network with limited resources. The hierarchical topology in WSN performs a different task in the entire nodes, and they are arranged in the form of a number of clusters according to their needs. Generally, all the clusters hold a leader as CH, and member nodes and the rest of the CH are approved for extra phases. These nodes hold more effective energy than CH and process the data task to telecast the data. The node that holds the reduced energy act as member nodes, and also, they sense the task data effectively. So, clustering became more efficient in routing schemes in WSN with superior features like high robustness rate, minimal load, maximum scalability, and very low energy consumption. The diagrammatic representation of developed energy-efficient routing in WBAN with mobile and multiple sink nodes is shown in Figure 4.

Figure 4 Diagramatic view of developed routing model in WBAN (see online version for colours)



5 Constraints used for proposed energy-efficient routing in WBAN

5.1 Recorded Constraints

Various constrain attained in the developed energy-efficient routing schemes with mobile and multiple sink nodes are listed below.

Energy Egy is "acquired through the average energy contained in the alive node", and is given in equation (14).

$$Egy = Egy_m - \left(egy_m^{fd} + egy_m^{kr}\right) \tag{14}$$

Here, the term egy_m^{fd} denotes the energy used to acquire the data, Egy_m indicate the energy in the node m, and the term En_m^{kr} refers to the energy utilised at the time of transmitting data.

The distance Dst in-between the destination and source nodes are given in equation (15).

$$Dst = \sqrt{\sum_{p=1}^{P}\left(Bi_t - Bj_t\right)^2} \tag{15}$$

Here, the source nodes are given as $nde_1 = \left(Bi_1, Bi_2, \ldots Bi_t\right)$, and the destination node is presented as $nde_2 = \left(Bj_1, Bj_2, \ldots, Bj_t\right)$. The packet delivery ratio is "the ratio of the number of lost packets to the total number of sent packets in the cloud network". It is presented $PTls$ and formulated in equation (16).

$$PTls = \frac{p_{ls}}{Ps_{gn}} \tag{16}$$

Here, the term p_{ls} indicates the packet loss count and ps_{gn} refers to the considered sensor node.

Delay Dly "computed by conducting the transmission and propagation delay over the packets" and elaborated in equation (17).

$$Dly = \frac{\max \sum_{z=1}^{Z} PS_z}{m} \tag{17}$$

The data transmission among the base station and sensor node is given $\max \sum_{z=1}^{Z} PS_z$, and the term m indicates the node count in the network.

Transmission load Ts is "computed by counting the transmitted packets through the node". Path loss $PTls$ is "determined through computing the energy loss when wave propagation between the receiver and transmitter".

5.2 Derived multi-objective function

The developed HBMDO approach selects the shortest path between the target node and the source node considering the multi-objective function such as transmission load, delay, packet delivery ratio, energy, and path loss. The attained multi-objective function is given in equation (18).

$$Obf = \underset{\{Sp_t\}}{\arg\min}\left(MF_6\right) \tag{18}$$

The term Sp_t indicates the shortest path selected between WBAN with mobile and multiple sink nodes over-developed HBMDO. The multi-objective function Mf_6 is derived from the below equations.

$$Mf_1 = \alpha * Dst + \left(\left(1-\alpha\right) * \left(\frac{1}{Egy}\right)\right) \tag{19}$$

$$Mf_2 = \beta * Mf_1 + \left(\left(1-\beta\right) * Dly\right) \tag{20}$$

$$Mf_3 = \gamma * Mf_2 + \left((1-\gamma) * \left(\frac{1}{Ts} \right) \right) \tag{21}$$

$$Mf_4 = \omega * Mf_3 + \left((1-\omega) * \left(\frac{1}{PTls} \right) \right) \tag{22}$$

$$Mf_5 = \varepsilon * Mf_4 + \left((1-\varepsilon) * \left(\frac{1}{Tst} \right) \right) \tag{23}$$

$$Mf_6 = \delta * Mf_5 + \left((1-\delta) * \left(\frac{1}{PDr} \right) \right) \tag{24}$$

The multi-objective function has utilised six different constraints with some specific value. The utilised parameters for performing multi-objective functions are $\alpha = 0.2$, $\beta = 0.2$, $\gamma = o.2$, $\omega = 0.2$, $\varepsilon = 0.1$ and, respectively.

6 Results analysis

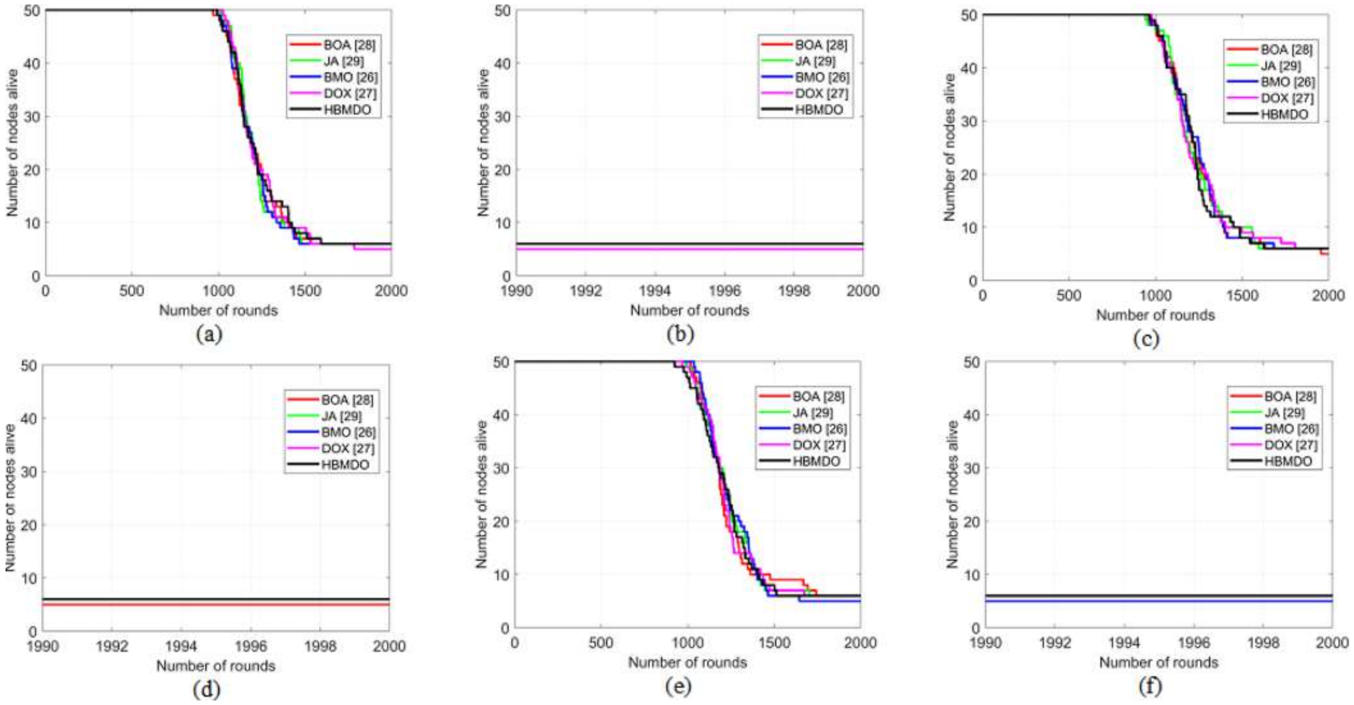
6.1 Stimulation setup

The suggested WBAN with mobile and multiple sink nodes was implemented in MATLAB 2020a, and different computational analyses were performed. The performance analysis of the developed energy-efficient routing protocol in WBAN was contrasted with a heuristic approach to achieve effective routing performance. The experimental analyses are performed by utilising a maximum iteration count in the range of 10, a chromosome length of 10, and a population count of 10. The suggested HBMDO was weighted up with different heuristic algorithms such as "bird optimisation algorithm (BOA) (Reddy and Venkat Ram, 2018), Jaya (JA) (Reddy and Venkat Ram, 2020), BMO (Cao et al., 2020), and DOX (Mishra and Ray, 2016)".

6.2 Analysis of alive node in the developed routing algorithm

The analysis performed on the suggested WBAN routing model with developed HBMDO with mobile and multiple sink nodes over heuristic approaches are represented in Figure 5. The suggested HBMDO model achieved 4.2% better than BOA, 2.5 % higher than JA and 1.05% greater than BMO and 6.6% enhanced than DOX, respectively in the 1500th round. Thus, the suggested model attained better performance than existing approaches.

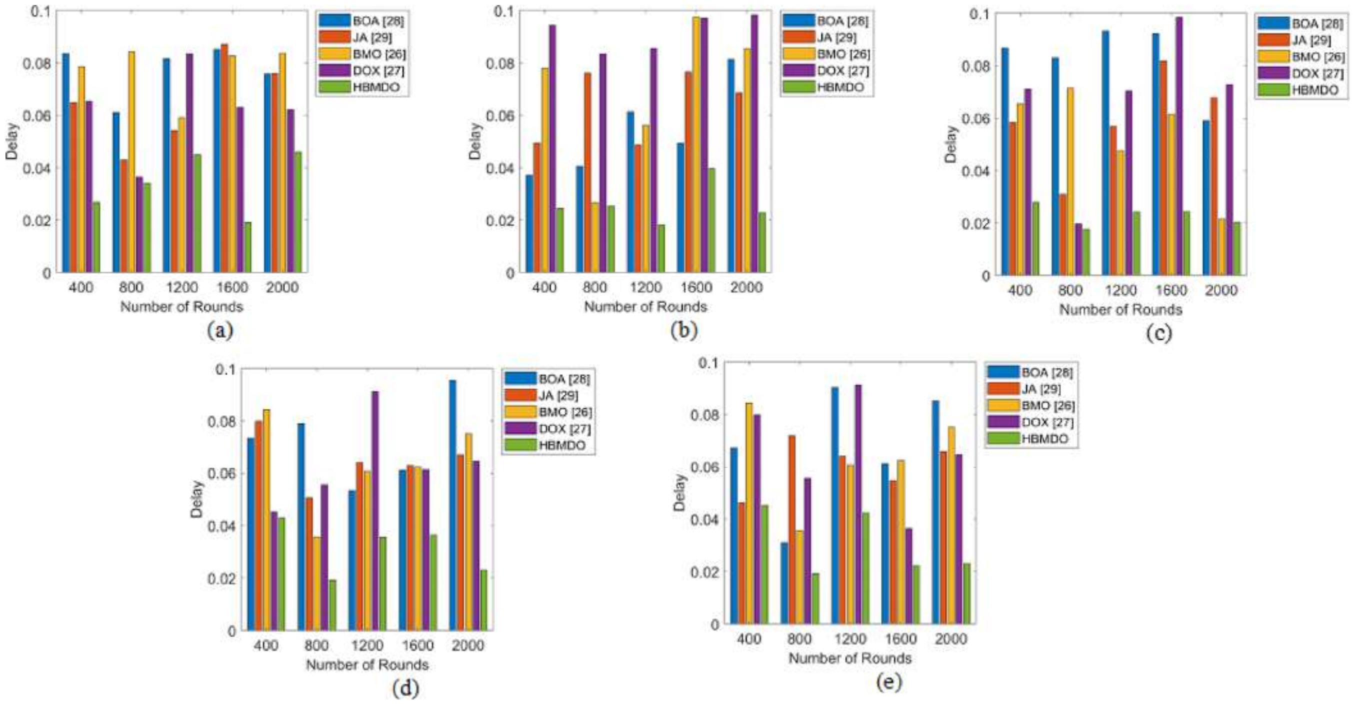
Figure 5 Analysis of alive nodes in developed routing approach in WBAN over "(a) sink node = 1, (b) zoom in of sink node = 1, (c) sink node = 2, (d) zoom in of sink node = 2, (e) sink node = 3, (f) zoom in of sink node = 3, (g) sink node = 5 and (h) zoom in of sink node = 5" (see online version for colours)



6.3 Analysis of delay in developed routing approach

The delay analysis of the developed WBAN with mobile and multiple sink nodes over different baseline approaches are presented in Figure 6. The developed routing approach based on implemented HBMDO achieved 67.4%, 67.8%, 65.8%, and 54.8% better performance rate over BOA, JA, BMO, and DOX, respectively in 1600th round. So, the suggested HBMDO in WBAN routing achieved enhanced performance than existing approaches.

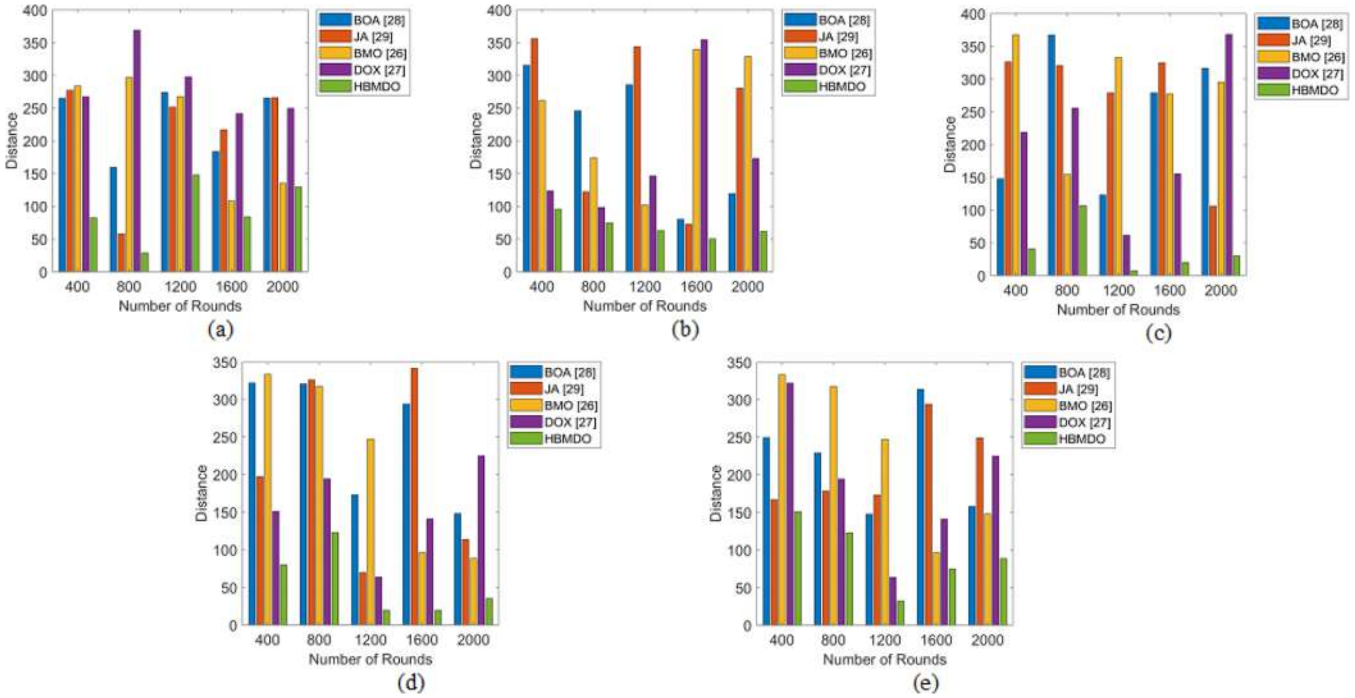
Figure 6 Analysis of delay on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) sink node = 2, (c) sink node = 3, (d) sink node = 5 and (e) sink node = 8" (see online version for colours)



6.4 *Analysis of distance on developed routing approach*

The distance analysis performed on the developed HBMDO with mobile and multiple sink nodes over heuristic approaches is showcased in Figure 7. The suggested HBMDO secured 8.4%, 6.6%, 9.1%, and 9.3% superior efficiency than existing approaches like BOA, JA, BMO and DOX in 1st node. The recommended WBAN routing model with developed HBMDO scored enhanced performance than existing approaches.

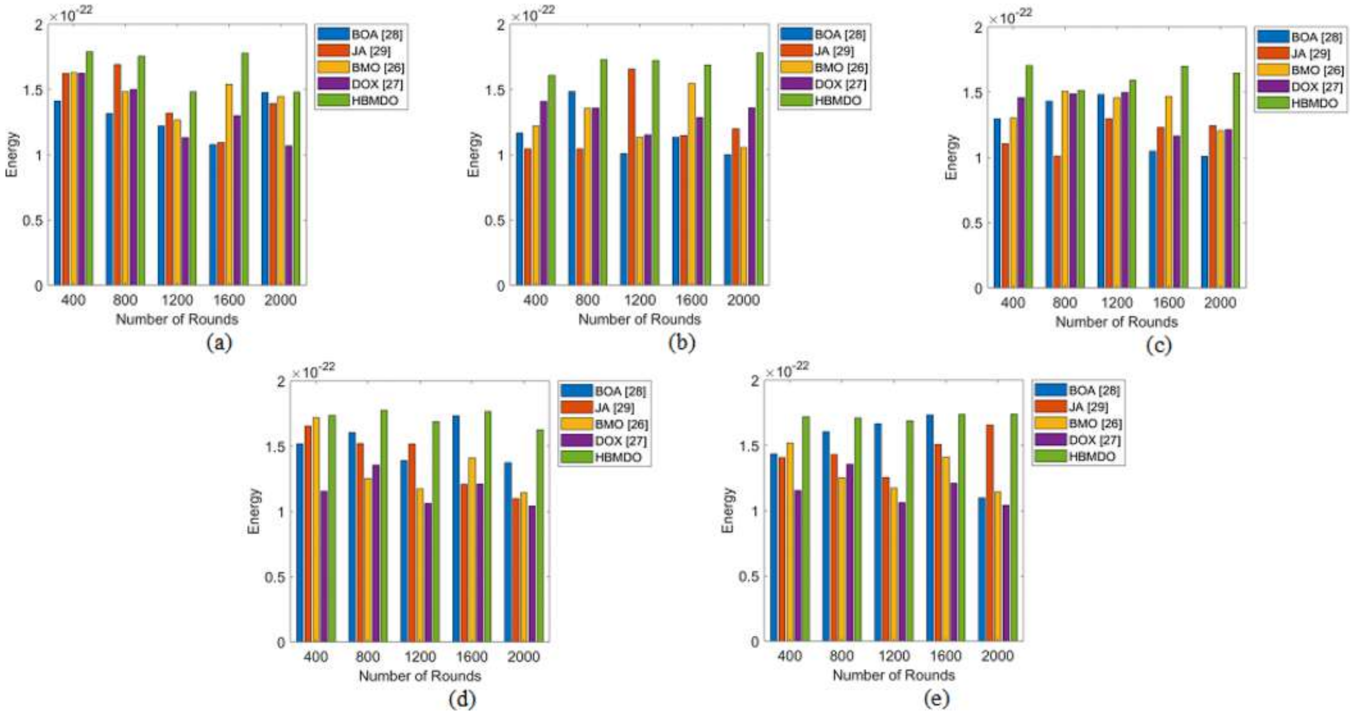
Figure 7 Distance analysis on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) sink node = 2, (c) sink node = 3, (d) sink node = 5 and (e) sink node = 8" (see online version for colours)



6.5 Analysis of energy in the developed routing algorithm

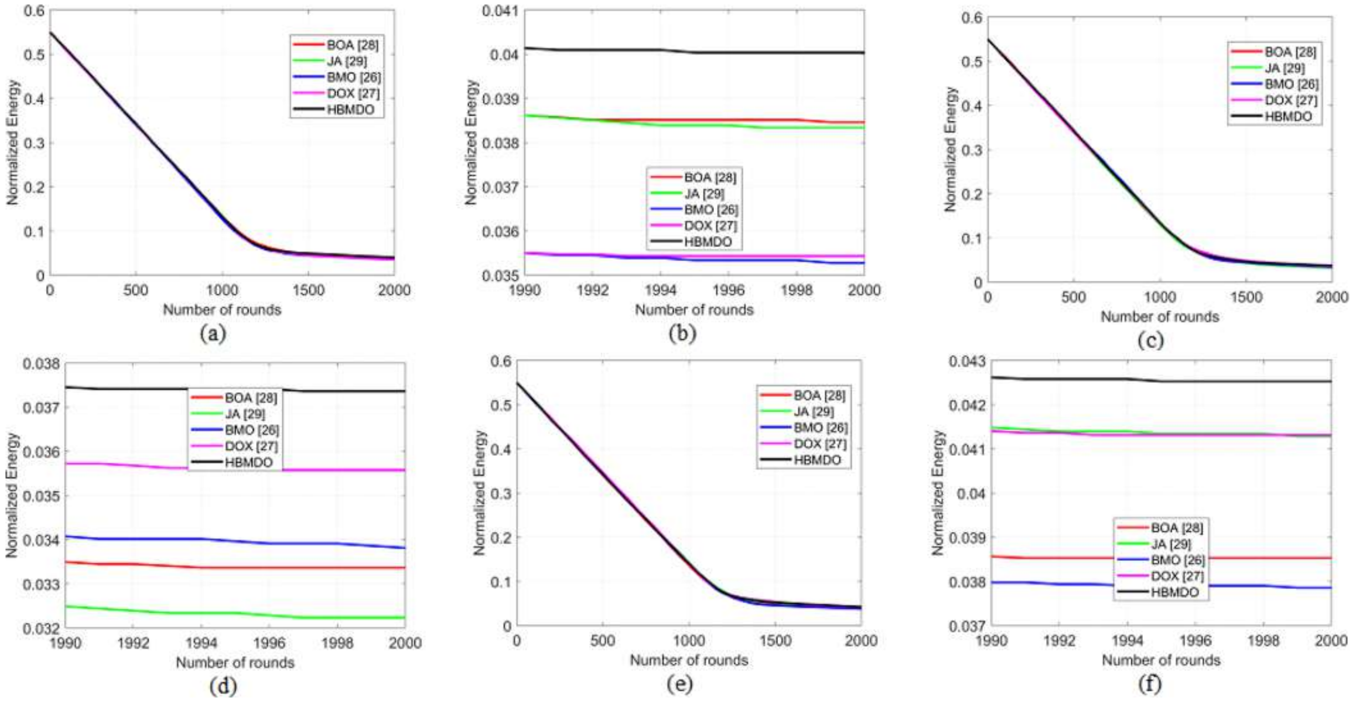
The energy performance-based evaluation of suggested WBAN routing with developed HBMDO over various heuristic approach is represented in Figure 8. The suggested HBMDO offer an improved performance rate than BOA, JA, BMO, and DOX, in the 2nd node. Different observations performed on other approaches achieved enhanced performance in the nodes. Thus, the developed WBAN-based HBMDO routing approach achieved more efficiency than conventional schemes.

Figure 8 Analysis of energy on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) sink node = 2, (c) sink node = 3, (d) sink node = 5 and (e) sink node = 8" (see online version for colours)



(a) (b) (c) (d) (e)

Figure 9 Analysis of normalised energy on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) zoom in of sink node = 1, (c) sink node = 2 (d) zoom in of sink node = 2, (e) sink node = 3, (f) zoom in of sink node = 3, (g) sink node = 5 and (h) zoom in of sink node = 5" (see online version for colours)



(a) (b) (c) (d) (e) (f)

6.6 *Normalised energy analysis on suggested routing approach*

The normalised energy analysis performed on WBAN routing protocol with the proposed HBMDO approach with different evaluation nodes is given in Figure 9. The developed HBMDO secured 5.5%, 2.7%, 3.2%, and 2.1% better than BOA, JA, DOX, and HBMDO, respectively. Thus, the developed WBAN routing with suggested HBMDO with mobile and multiple sink nodes achieved an enriched performance rate when weighted up with existing models.

6.7 *Analysis of packet delivery ratio with proposed routing approach*

The packet delivery ratio analysis with a developed routing model in WBAN with different algorithms is presented in Figure 10. The developed HBMDO with mobile and multiple sink nodes achieved an effective performance rate in node analysis at the time of contrasted with existing heuristic approaches like BAO, JA, BMO, and DOX. Thus, the developed model offers enhanced performance than conventional algorithms.

Figure 10 Analysis of packet delivery ratio on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) sink node = 2, (c) sink node = 3, (d) sink node = 5 and (e) sink node = 8" (see online version for colours)

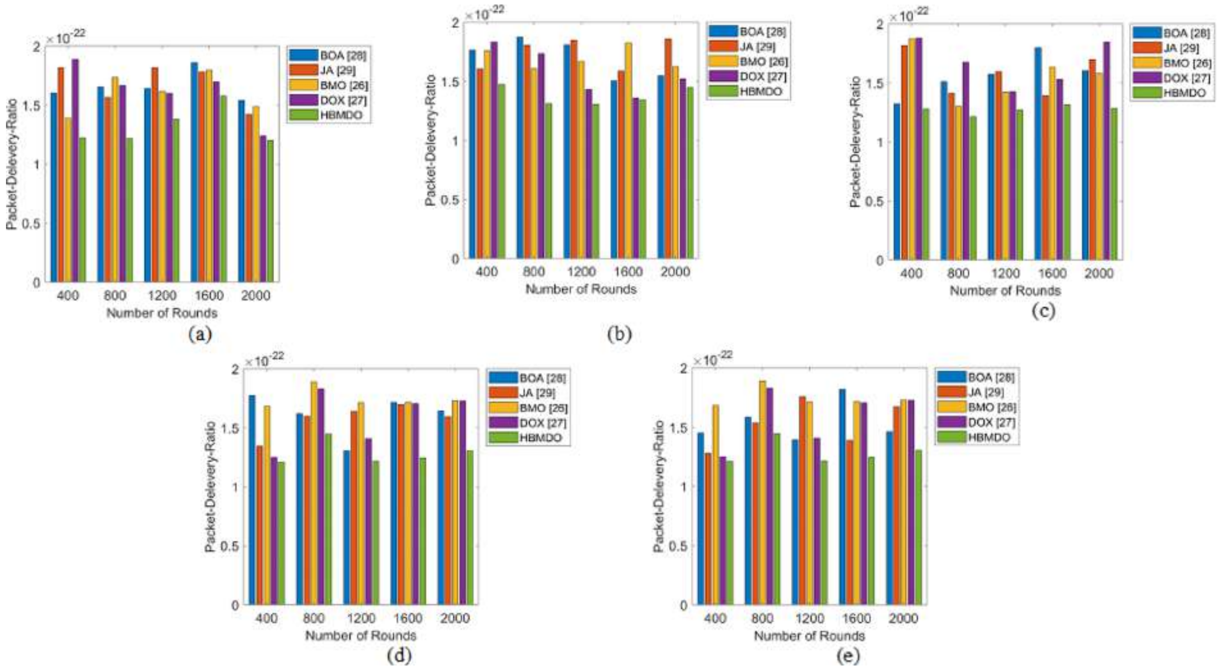
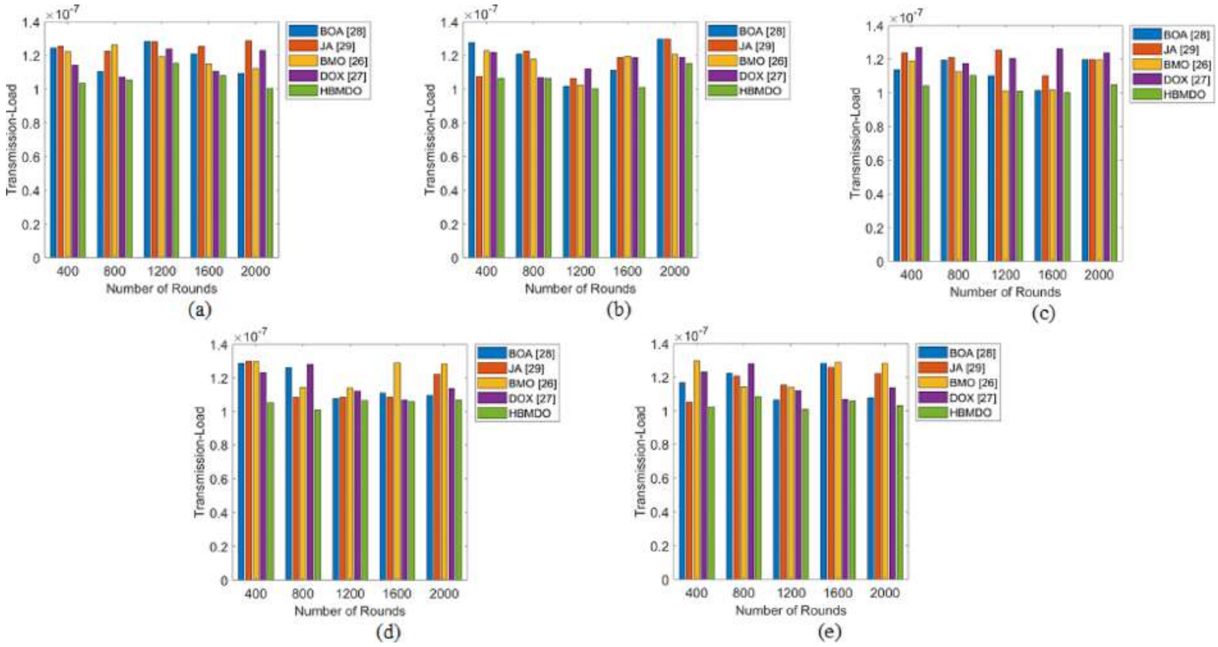


Figure 11 Analysis of transmission load on suggested routing approach in WBAN with respect to "(a) sink node = 1, (b) sink node = 2, (c) sink node = 3, (d) sink node = 5 and (e) sink node = 8" (see online version for colours)



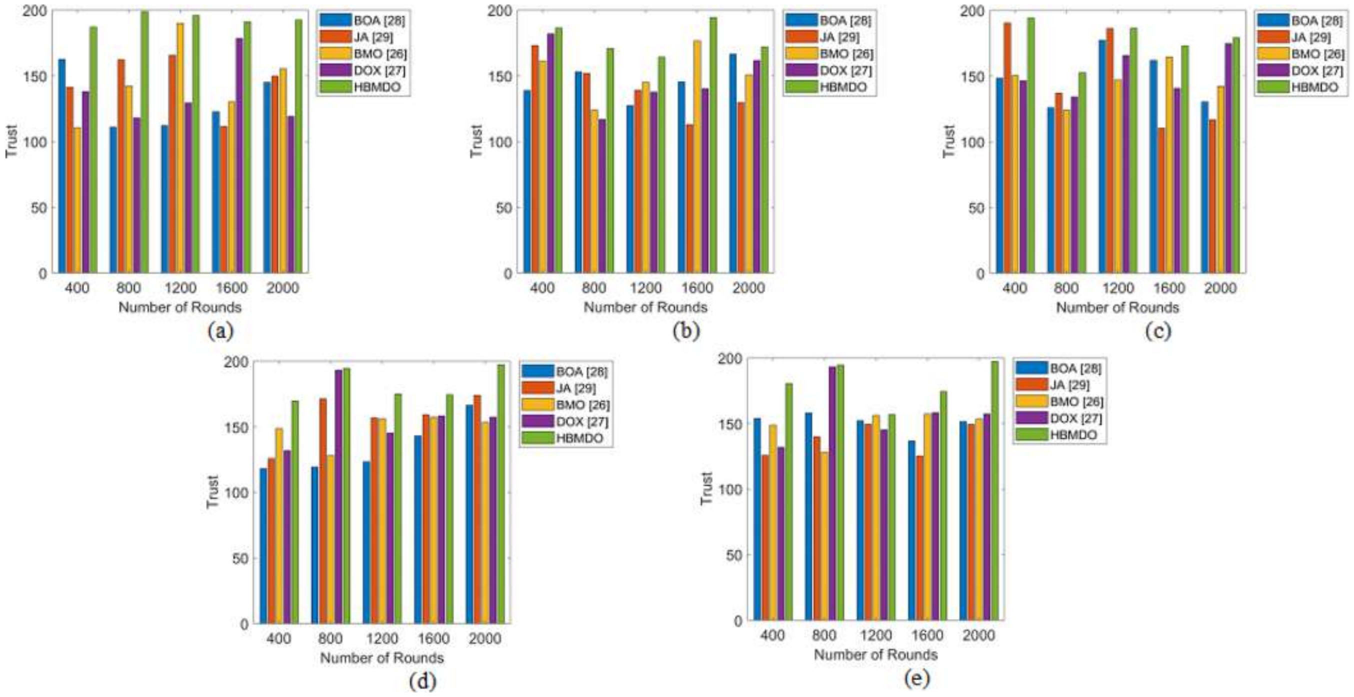
6.8 Transmission load analysis on the developed model

The transmission data analysis performed on the developed HBMDO model with convergence approaches is showcased in Figure 11. The suggested HBMDO with mobile and multiple sink nodes utilised comparatively low transmission energy than diverse approaches like BOA, JA, BMO, and DOX, respectively. The transmission analysis performed on the developed HBMDO model gained more efficient performance than existing techniques.

6.9 Analysis of trust factor in the developed model

The trust factor analysis executed on the developed energy-efficient routing protocol in WBAN with mobile and multiple sink nodes over heuristic-based approaches is provided in Figure 12. The developed energy-efficient routing model attained 28.5% higher than BOA, 7.7% better than JA, 16.1% superior to BMO and 3.4% enhanced than DOX. Thus, the developed energy-efficient routing model secured an enhanced network lifetime rate than existing WBAN approaches.

Figure 12 Trust analysis on suggested routing approach in WBAN with respect to "(a) node 1, (b) node 2, (c) node 3, (d) node 5 and (e) node 8" (see online version for colours)



6.10 Overall performance analysis on a developed model for a number of sink nodes = 1

The suggested energy-efficient routing protocol with multiple measures like "best, worst, mean, median and standard" in node 1 is showcased in Table 3. The standard deviation achieved some changes at the time of execution, and also best, and median didn't attain any values in the dead node analysis. The suggested energy-efficient approach HBMDO achieved 2.1%, 2.2%, and 1.13% enhanced than BOA, BMO, and DOX, respectively. The suggested HBMDO with mobile and multiple sink nodes model achieved a better performance rate than existing routing approaches.

6.11 Overall performance analysis on a developed model for a number of sink node = 2

The developed energy-efficient routing model in WBAN is contrasted with multiple baseline approaches represented in Table 4. The developed HBMDO achieved a better performance rate in dead node analysis performed in the standard deviation phase. The developed HBMDO secured 3% enhanced than BOA, 6.1% enhanced than JA, 8.5% enhanced than BMO, and 6.18% enhanced than DOX, respectively. Hence, the developed energy-efficient model HBMDO with mobile and multiple sink nodes attained an effective performance rate than existing models.

6.12 Overall performance analysis for sink node = 3

The overall performance analysis performed in the developed routing model HBMDO with various meta-heuristic-based approaches is displayed in Table 5. The developed energy-efficient HBMDO model scored 0.3%, 0.5%, 6.5%, and 1.1% more effective than BOA, JA, BMO, and DOX, respectively, in node 3. Thus, the developed WBAN with mobile and multiple sink nodes routing approach achieved an improved performance rate than conventional schemes.

Table 3 overall efficacy analysis on developed routing approach with a heuristic approach for a number of sink node = 1

Measures	*BOA (Cao et al., 2020)*	*JA (Mishra and Ray, 2016)*	*BMO (Sulaiman et al., 2020)*	*DOX (Bairwa et al., 2021)*	*HBMDO*
Dead node					
Best	0	0	0	0	0
Worst	2	2	2	2	2
Mean	0.022011	0.022011	0.022011	0.022511	0.022011
Median	0	0	0	0	0
Standard deviation	0.15013	0.15343	0.15013	0.15171	0.15343
Normalised energy					
Best	0	0	0	0	0
Worst	0.000509	0.000509	0.000509	0.000509	0.000509
Mean	0.000256	0.000256	0.000257	0.000257	0.000255
Median	0.000386	0.000394	0.000392	0.000395	0.000393
Standard deviation	0.0002	0.000202	0.000201	0.0002	0.000202
Distance					
Best	0.35186	0.055871	0.020679	0.25298	0.80417
Worst	369.84	369.92	369.75	369.86	369.87
Mean	184.82	184.3	184.73	184.41	184.17
Median	183.36	183.37	182.91	185.86	186.08
Standard deviation	107.14	108.36	106.45	105.17	106.18
Energy					
Best	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}
Worst	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}
Mean	1.41×10^{-18}	1.39×10^{-18}	1.41×10^{-18}	1.40×10^{-18}	1.40×10^{-18}
Median	1.41×10^{-18}	1.38×10^{-18}	1.42×10^{-18}	1.39×10^{-18}	1.40×10^{-18}
Standard deviation	2.28×10^{-19}	2.29×10^{-19}	2.33×10^{-19}	2.30×10^{-19}	2.32×10^{-19}
Delay					
Best	167.85	167.42	167.34	167.87	167.21
Worst	987.96	987.85	987.75	986.17	986.22
Mean	576.08	583.08	581.03	579.6	575.84
Median	573.64	596.02	586.8	582.74	580.24
Standard deviation	239.26	233.2	236.14	236.45	240.25
Transmission load					
Best	0.001	0.001	0.001	0.001	0.001
Worst	0.0013	0.0013	0.0013	0.0013	0.0013
Mean	0.001149	0.00115	0.00115	0.001147	0.00115
Median	0.001145	0.00115	0.001151	0.001147	0.001149
Standard deviation	8.64×10^{-05}	8.68×10^{-05}	8.60×10^{-05}	8.66×10^{-05}	8.68×10^{-05}
Trust					
Best	198.94	198.92	199	198.99	198.93
Worst	110.03	110.14	110.02	110.03	110.04
Mean	154.36	153.45	155.06	153.59	154.48
Median	154.27	154.17	155.8	153.14	154.83
Standard deviation	25.653	25.634	26.113	25.451	25.922
Packet delay					
Best	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}
Worst	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}
Mean	1.54×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}
Median	1.54×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.56×10^{-18}
Standard deviation	1.99×10^{-19}	2.02×10^{-19}	2.03×10^{-19}	2.03×10^{-19}	2.03×10^{-19}

Table 4 overall analysis of developed routing protocol with heuristic algorithms for the number of sink node =2

Measures	*BOA (Cao et al., 2020)*	*JA (Mishra and Ray, 2016)*	*BMO (Sulaiman et al., 2020)*	*DOX (Bairwa et al., 2021)*	*HBMDO*
Dead node					
Best	0	0	0	0	0
Worst	2	2	2	2	2
Mean	0.022511	0.022011	0.022011	0.022011	0.022011
Median	0	0	0	0	0
Standard deviation	0.15817	0.15343	0.15013	0.15343	0.16292
Normalised energy					
Best	0	0	0	0	0
Worst	0.00052	0.000501	0.00052	0.000501	0.00052
Mean	0.000258	0.000259	0.000258	0.000257	0.000256
Median	0.000382	0.000392	0.000375	0.000375	0.000374
Standard deviation	0.000199	0.000195	0.000199	0.000194	0.000199
Distance					
Best	0.29453	0.11711	0.10176	0.15253	0.47395
Worst	369.97	369.88	369.94	369.99	369.89
Mean	186.14	184.55	183.58	185.28	184.17
Median	183.99	181.09	181.18	183.29	184.61
Standard deviation	107.29	106.73	108.48	107.73	106.46
Energy					
Best	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}
Worst	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}
Mean	1.39×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.40×10^{-18}
Median	1.39×10^{-18}	1.41×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.39×10^{-18}
Standard deviation	2.29×10^{-19}	2.31×10^{-19}	2.31×10^{-19}	2.34×10^{-19}	2.32×10^{-19}
Delay					
Best	167.06	167.52	167.7	167.3	167.09
Worst	987.93	987.72	986.67	987.24	987.67
Mean	583.82	583.24	576.16	572.66	576.35
Median	589.43	585.61	573.16	578.37	569.09
Standard deviation	239.24	233.52	235.3	240.2	238.17
Transmission load					
Best	0.001001	0.001	0.001	0.001	0.001
Worst	0.0013	0.0013	0.0013	0.0013	0.0013
Mean	0.001152	0.001153	0.001151	0.001147	0.001149
Median	0.001155	0.001154	0.001151	0.001146	0.001148
Standard deviation	8.60×10^{-05}	8.45×10^{-05}	8.61×10^{-05}	8.66×10^{-05}	8.63×10^{-05}
Trust					
Best	198.89	199	198.91	198.99	198.99
Worst	110.02	110.01	110	110.06	110.04
Mean	154.12	154.25	154.67	154.33	153.75
Median	153.94	154.81	154.13	154.18	153.93
Standard deviation	25.461	24.767	26.057	25.816	25.869
Packet delay					
Best	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}
Worst	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}
Mean	1.56×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}
Median	1.56×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}
Standard deviation	2.03×10^{-19}	2.04×10^{-19}	2.04×10^{-19}	2.02×10^{-19}	2.01×10^{-19}

Table 5 overall efficacy analysis on developed routing approach with conventional approaches for a number of sink nodes = 3

Measures	*BOA (Cao et al., 2020)*	*JA (Mishra and Ray, 2016)*	*BMO (Sulaiman et al., 2020)*	*DOX (Bairwa et al., 2021)*	*HBMDO*
Dead node					
Best	0	0	0	0	0
Worst	2	1	1	2	1
Mean	0.022011	0.022011	0.022511	0.022011	0.022011
Median	0	0	0	0	0
Standard deviation	0.15343	0.14676	0.14838	0.15343	0.14676
Normalised energy					
Best	0	0	0	0	0
Worst	0.000506	0.000506	0.000506	0.000501	0.000501
Mean	0.000256	0.000254	0.000256	0.000254	0.000254
Median	0.000378	0.000386	0.000391	0.00039	0.000381
Standard deviation	0.000195	0.000196	0.000197	0.000197	0.000197
Distance					
Best	0.76524	0.25094	0.013983	0.67318	0.15304
Worst	369.77	369.83	369.48	369.79	369.94
Mean	183.52	185.98	183.32	189.99	185.85
Median	182.34	185.83	182.94	195.67	183.7
Standard deviation	107.43	107.68	106.37	107.19	107.07
Energy					
Best	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}
Worst	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}
Mean	1.39×10^{-18}	1.40×10^{-18}	1.39×10^{-18}	1.39×10^{-18}	1.40×10^{-18}
Median	1.39×10^{-18}	1.40×10^{-18}	1.39×10^{-18}	1.39×10^{-18}	1.39×10^{-18}
Standard deviation	2.36×10^{-19}	2.29×10^{-19}	2.34×10^{-19}	2.34×10^{-19}	2.32×10^{-19}
Delay					
Best	167.14	167.52	167.19	169.18	167.15
Worst	987.68	987.52	987.95	987.09	987.92
Mean	575.23	577.13	572.95	575.51	582.07
Median	581.19	573.92	575.16	575.8	577.12
Standard deviation	236.1	237.81	235.03	237.42	237.74
Transmission load					
Best	0.001	0.001	0.001	0.001	0.001001
Worst	0.0013	0.0013	0.0013	0.0013	0.0013
Mean	0.001153	0.001148	0.001148	0.001149	0.00115
Median	0.001153	0.00115	0.001149	0.001147	0.001148
Standard deviation	8.62×10^{-05}	8.72×10^{-05}	8.64×10^{-05}	8.64×10^{-05}	8.76×10^{-05}
Trust					
Best	198.98	198.9	198.99	198.9	198.79
Worst	110.08	110.03	110.02	110.14	110.16
Mean	154.06	155.44	153.32	154.97	155.03
Median	153.9	155.81	152.85	155.62	154.81
Standard deviation	25.499	25.67	26.122	25.73	25.553
Packet delay					
Best	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}
Worst	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}
Mean	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}	1.55×10^{-18}
Median	1.55×10^{-18}	1.56×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.55×10^{-18}
Standard deviation	2.04×10^{-19}	2.03×10^{-19}	2.01×10^{-19}	2.01×10^{-19}	2.05×10^{-19}

Table 6 Overall performance analysis on developed routing approach over conventional heuristic approaches for the number of sink node 5

Measures	*BOA (Cao et al., 2020)*	*JA (Mishra and Ray, 2016)*	*BMO (Sulaiman et al., 2020)*	*DOX (Bairwa et al., 2021)*	*HBMDO*
Dead node					
Best	0	0	0	0	0
Worst	2	2	2	2	2
Mean	0.022511	0.022011	0.022011	0.022011	0.022011
Median	0	0	0	0	0
Standard deviation	0.15171	0.15982	0.15343	0.15013	0.15665
Normalised energy					
Best	0	0	0	0	0
Worst	0.00051	0.00051	0.00051	0.00051	0.00051
Mean	0.000256	0.000255	0.000256	0.000257	0.000254
Median	0.000392	0.000393	0.00039	0.000392	0.000386
Standard deviation	0.0002	0.000202	0.000198	0.000199	0.000201
Distance					
Best	0.14809	0.15534	0.01174	0.1118	0.2665
Worst	369.87	369.45	369.56	369.95	369.98
Mean	190.36	190.49	184.92	183.69	187.65
Median	192.48	196.63	185.3	182.94	186.87
Standard deviation	105.6	106.73	107.91	106.52	105.33
Energy					
Best	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}
Worst	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}
Mean	1.39×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.40×10^{-18}
Median	1.39×10^{-18}	1.40×10^{-18}	1.41×10^{-18}	1.40×10^{-18}	1.41×10^{-18}
Standard deviation	2.27×10^{-19}	2.26×10^{-19}	2.35×10^{-19}	2.30×10^{-19}	2.29×10^{-19}
Delay					
Best	167.28	167.6	167.17	167.13	168.1
Worst	987.55	987.46	987.92	987.59	987.84
Mean	579.47	585.59	577.47	587.39	575.79
Median	577.9	585.29	576.88	596.37	563.61
Standard deviation	235.25	235.55	231.61	237.16	232.57
Transmission load					
Best	0.001001	0.001	0.001	0.001001	0.001
Worst	0.0013	0.0013	0.0013	0.0013	0.0013
Mean	0.00115	0.001144	0.001153	0.001151	0.00115
Median	0.001152	0.00114	0.001154	0.001155	0.001153
Standard deviation	8.70×10^{-05}	8.67×10^{-05}	8.64×10^{-05}	8.59×10^{-05}	8.74×10^{-05}
Trust					
Best	198.97	198.87	199	198.98	198.96
Worst	110	110.04	110.08	110.02	110.02
Mean	153.99	154.14	155.04	154.45	153.48
Median	153.21	153.37	155.03	154.51	153.48
Standard deviation	25.774	25.655	25.976	25.786	25.985
Packet delay					
Best	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}
Worst	$1.90E \times 10^{-18}$	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}
Mean	1.55×10^{-18}	1.55×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.55×10^{-18}
Median	1.55×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.55×10^{-18}
Standard deviation	1.97×10^{-19}	2.03×10^{-19}	2.01×10^{-19}	2.03×10^{-19}	2.01×10^{-19}

Table 7 Overall performance analysis on developed routing protocol in WBAN over heuristic approaches for a number of sink node = 8

Measures	*BOA (Cao et al., 2020)*	*JA (Mishra and Ray, 2016)*	*BMO (Sulaiman et al., 2020)*	*DOX (Bairwa et al., 2021)*	*HBMDO*
Dead node					
Best	0	0	0	0	0
Worst	2	2	2	2	2
Mean	0.031211	0.031211	0.031211	0.031211	0.031211
Median	0	0	0	0	0
Standard deviation	0.16544	0.16943	0.16943	0.16865	0.16643
Normalised energy					
Best	0	0	0	0	0
Worst	0.000517	0.00053	0.000523	0.000527	0.000513
Mean	0.000255	0.000256	0.000259	0.000255	0.000259
Median	0.000397	0.000393	0.000377	0.000366	0.000366
Standard deviation	0.0002	0.000202	0.000199	0.000211	0.000201
Distance					
Best	0.088285	0.05097	0.01174	0.1118	0.2665
Worst	369.98	369.4	369.56	369.95	369.98
Mean	184.98	185.2	184.92	183.69	187.65
Median	184.29	188.06	185.3	182.94	186.87
Standard deviation	106.69	104.94	107.91	106.52	105.33
Energy					
Best	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}	1.80×10^{-18}
Worst	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}	1.00×10^{-18}
Mean	1.40×10^{-18}	1.39×10^{-18}	1.40×10^{-18}	1.40×10^{-18}	1.40×10^{-18}
Median	1.40×10^{-18}	1.38×10^{-18}	1.41×10^{-18}	1.40×10^{-18}	1.41×10^{-18}
Standard deviation	2.29×10^{-19}	2.32×10^{-19}	2.35×10^{-19}	2.30×10^{-19}	2.29×10^{-19}
Delay					
Best	167.25	167.24	167.17	167.13	168.1
Worst	987.9	987.99	987.92	987.59	987.84
Mean	579.36	571.06	577.47	587.39	575.79
Median	581.88	567.91	576.88	596.37	563.61
Standard deviation	235.72	236.64	231.61	237.16	232.57
Transmission load					
Best	0.001	0.001	0.001	0.001001	0.001
Worst	0.0013	0.0013	0.0013	0.0013	0.0013
Mean	0.001149	0.001151	0.001153	0.001151	0.00115
Median	0.00115	0.001151	0.001154	0.001155	0.001153
Standard deviation	8.60×10^{-19}	8.71×10^{-19}	8.64×10^{-19}	8.59×10^{-19}	8.74×10^{-19}
Trust					
Best	198.96	198.95	199	198.98	198.96
Worst	110.09	110.01	110.08	110.02	110.02
Mean	154.64	154.18	155.04	154.45	153.48
Median	154.65	154.64	155.03	154.51	153.48
Standard deviation	25.583	25.165	25.976	25.786	25.985
Packet delay					
Best	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}	1.20×10^{-18}
Worst	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}	1.90×10^{-18}
Mean	1.55×10^{-18}	1.56×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.55×10^{-18}
Median	1.55×10^{-18}	1.57×10^{-18}	1.54×10^{-18}	1.54×10^{-18}	1.55×10^{-18}
Standard deviation	2.01×10^{-19}	2.05×10^{-19}	2.01×10^{-19}	2.03×10^{-19}	2.01×10^{-19}

6.13 Overall performance analysis on a developed model for a number of sink node = 5

The overall performance analysis achieved over the suggested model in the 5th node with conventional models is showcased in Table 6. The developed HBMDO model achieved an effective routing performance rate of 0.2%, 1.4%, 1.1%, and 0.8% than existing approaches like BOA, JA, BMO, and DOX in the 5th node, respectively. Thus, the developed HBMDO with mobile and multiple sink nodes model in WBAN routing achieved an improved performance rate than other models.

6.14 Overall performance analysis on a developed model for a number of sink node = 8

The efficiency analysis suggested the HBMDO approach with heuristic approaches are tabulated in Table 7. The developed energy-efficient model HBMDO secured relatively higher than the existing models. The developed HBMDO achieved 1.27%, 3.7%, 2.39%, and 1.11% higher than conventional approaches. Therefore, the suggested energy-efficient routing protocol in WBAN with mobile and multiple sink nodes achieved an effective performance rate than the existing routing models by considering network lifetime.

7 Conclusion

A new energy-efficient routing protocol in WBAN with mobile and multiple sink nodes was developed to achieve better data transmission by establishing an optimal path by utilising an optimisation strategy. Hence this model has developed an enhanced heuristic approach named HBMDO to enhance the lifetime of the WBAN with mobile and multiple sink nodes. The shortest optimal paths were determined by considering the shortest distance from the target node to the destination node with the help of the developed HBMDO. The developed energy-efficient routing approach utilised multi-objective constraints such as packet delivery ratio, distance, delay, energy, transmission load trust, and path loss. At the time of analysis, the developed HBMDO with mobile and multiple sink nodes model achieved 5.5%, 2.7%, 3.2%, and 2.1% better than BOA, JA, BMO, and DOX, respectively, in normalised energy. So, it was understandable that the designed energy-efficient routing protocol for WBAN with proposed HBMDO with mobile and multiple sink nodes has achieved a superior efficiency rate than existing approaches.

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