PSOBAN: a novel particle swarm optimization based protocol for wireless body area networks

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Abstract

In the modern world, wireless body area networks (WBAN) is projected to play a vital role in biomedical and psychological applications. The practical implementation of WBAN technology suffer from various deployment issues that have to be dealt with. The more serious concern is associated with the energy consumption of these networks. Biosensor nodes continuously sense the signals and send the same to sink. Sending data to sink is an energy-consuming operation, so routing is done to optimize energy utilization in WBAN. The continuous data sensing and the transmission of information over long-distances result in huge energy consumption of these nodes. So, conservation of energy is the need of the hour. The main focus of the current study is to invise a routing mechanism that makes use of particle swarm optimization based on metaheuristic algorithm along with the relay node selection based on distances and residual energies. Experimental results show that the proposed protocol strikes a perfect balance between minimizing the number of relay nodes (to be positioned on subject) along with the energy efficient WBAN.

Keywords Wireless body area networks · Optimization · Routing · Cost function · Relay · Energy-efficiency

1 Introduction

Healthcare in today's age has advanced to a new level. With discoveries every day, it is taking a unique shape. Critical analysis of the human body is required for early detection of diseases and their cure, and for this purpose advanced technologies are required. Wireless body area networks (WBAN) have shaped the modern-day medical facilities; they have been well received by healthcare industry due to their low cost and dependable network capabilities. WBAN enables the positioning of minuscule biomedical sensors, on, or inside the human body to examine vital body signs. The purpose of WBAN is to improve the pace, precision, and reliability of communication of sensors inside, on, or in the direct contact of a human body. The performance assessment of WBAN is primarily conducted in terms of model-based studies [1–3].

With the mounting needs in ubiquitous communications and current advances in very-low-power wireless technologies, there has been significant curiosity in the development and relevance of wireless networks for humans [4]. The growing use of wireless networks and the stable efficiency of biosensors have empowered the expansion of WBAN. In these networks, a variety of sensors are attached either on the wear or on the body or even placed under the skin [5]. WBAN has tiny biosensor nodes which like other wireless devices have limited energy resources, hence it has become a necessity to make the proper utilization of the energy of these nodes effectively and conveniently for the long-term monitoring of human subjects [6–8]. Biosensor nodes continuously sense the signals and send the same to sink. Sending data to sink is an energy-consuming operation, so routing is done to optimize energy utilization in WBAN. On the other side two very paramount aspects raise a major objection to

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the core architecture of WBAN: (1) reduction of energy consumption for the wireless data transfer and (2) sensor performance. The continuous data sensing and the transmission of information over the long-distances result in huge energy consumption of these nodes. So, conservation of energy is the need of the hour.

With the objective of overcoming the above-mentioned issues, we propose an optimized protocol called PSOBAN.

In this paper, our main contributions are:

1. The proposed method uses a befitting accessory, termed relay (forwarder) node, which is appended to the WBAN, in the interest of gathering complete information from various nodes and circulating data through an optimal path to the sink, hence increasing the lifespan and improving the reliability of WBAN. It exercises a decisive influence in decreasing the energy requirement (to transfer data), which results in duplexing the benefits of having relay nodes (1) shielding the human tissue from harmful emissions and other side effects (since number of deployed nodes is less), and (2) reducing the energy expenditure of these sensors (through optimal path). Each sensor node can route and relay information to the core node, named sink, for judgment and recommendation.
2. The original optimization PSO evaluates the best fitness value of objective function after updating the velocity and position along with the verification of WBAN equality and inequality constraints. Finally, PSO evaluates each of the updated particles for objective functions and determines: (1) the best fitness value of objective function in body area network, (2) the ideal amount and proper deployment of relay nodes, (3) ideal appointment of sensors to relay nodes, (4) energy and lifetime of the network and (5) furthermore, the apt traffic (data-transfer) route for various scenarios.
3. PSOBAN algorithm is deployed in numerous practical WBAN scenarios and furthermore is tested in more generic topologies, at various cost functions, and is tested if PSOBAN can overcome WBAN related design issues.

We moreover contrast our model's efficiency to the highly esteemed and most remarkable methodologies in the literature, specifically with reference to the stability period, residual energy, path loss and throughput of PSOBAN.

4. After conducting experiments, two points are very clear: (1) our model strikes a perfect balance between minimizing the amount of relay nodes (to be positioned on the subject) and increasing the energy efficiency as well as lifetime of WBAN, furthermore (2) be a cost-effective WBAN reconfigurable (dynamic) algorithm design.

2 Related work

To optimize energy consumption is the main concern of contemporary researchers while designing protocols for WBAN [9–14]. In WBAN, routing protocols have been categorized into mobility-aware, thermal-aware, link-aware, distance aware, etc. from the perspective of energy. A Thermal Aware Routing Algorithm (TARA) [15] is claimed to have the ability to optimize temperature and reduce the use of energy through the process of hot spot detection. A dynamic routing strategy is proposed [16], which uses a cost function with the selection of co-operative nodes so as to use energy efficiently. Biosensor location-based routing protocol [17] is said to improve performance and minimize delay by sending a number of copies of a packet to the destination through various routes. Environment adaptive routing (EAR) protocol, proposed in [18], for both single and multi-hop communication between sink and nodes are used by the authors. Multi-hop communication results in delays in data delivery, so multi-hopping is not appropriate for emergency data. A distance-based energy-aware routing (DEAR) algorithm is proposed by Wang et al. [19], who have considered individual distance as the primary parameter for routing process in order to adjust and equalize energy consumption among all the sensors involved, while taking residual energy as a secondary aspect for consideration. Elias et al. [20] have proposed a mixed integer linear programming model for developing energy-aware WBAN design model. This optimized the locations for deploying the relay nodes and also optimized the data routing towards the sink node. Distance aware relaying energy efficient (DARE) protocol, proposed by the researchers [21], monitors the patients in multi-hop network based on distance by the sink position. For heterogeneous WBAN, Javaid et al. [22] proposed a new routing protocol named as M-ATTEMPT, which routes the data away from the Hot-Spot links. In this, the authors introduced mobility support, as there is uninterrupted mobility of human body which results in the extrication between the links. A cost function has been calculated in the protocol [23] by the authors for selecting the forwarder node, which is selected based on the highest residual energy and is located closest to the sink node. Ahmed et al. [24] proposed a new energy-efficient routing protocol for WBAN in which nodes are placed according to their energy levels. Multi-hop and direct transmission is used for transmitting the emergency and normal data packets. Ahmed et al. [25] selected the route by prioritizing the route having the least number of hops for transmission of the data. This scheme uses a cost function for selecting the best route to the sink. Energy-efficient routing protocols

like topology-based WBAN [26], multi-hop based WBAN [27], medium access control based WBAN [28, 29], and priority-based WBAN [30] are proposed by the authors. In order to reduce the consumption of energy in an efficient manner, various optimization algorithms [31–36] have been explored in the area of wireless technology [37–45]. However, such algorithms don't focus much on WBAN.

Kennedy and Elberhart have introduced a new method [37] using particle swarm optimization for the optimization of nonlinear function. This method is highly dependent on the stochastic process. In modified particle swarm optimizer proposed in [38], inertia weight is introduced into original PSO. Vimalarani et al. [39] have used PSO for clustering and the selection of cluster head for minimizing power consumption and proposed an enhanced PSO-based clustering energy optimization algorithm for WSN. Dhadwal et al. [40] have proposed a novel hybrid GA technique for optimized increase the search proficiency. For selecting the best route out of many different possible routes, genetic algorithm (GA) combined with PSO provides natural evolutionary process for this purpose. An energy-efficient routing mechanism is proposed by Wang et al. [41], which is based on genetic ant colony algorithm (GACA). This particular algorithm, divided into two phases, uses DEAR algorithm and GACA algorithm to balance the available amount of energy and to select the optimal path respectively. Andreagiovanni et al. [42] have presented a first robust optimization model that addresses the traffic uncertainty in the design of body area networks with relays and single-path routing. Wu et al. [43] have used particle swarm optimization to find the location for positioning the relay nodes. The authors specify lower specific absorption rate (SAR) is used for the choice of path, which improves the success rate of packets. For generation of

route from sensor nodes to the sink based on some parametric adjustment, under architectural constraints, optimization to the routing approach is defined Sangwan et al. [44]. Kaur et al. [45] have proposed two protocols optimized cost effective and energy efficient routing protocol (OCER) and extended-OCER (E-OCER). In OCER, GA is used for optimization and applied to the multi-objective cost function with residual energy or selecting the optimal route. In E-OCER, inter-BAN communication is considered.

From the above-reviewed works, it can be comprehended that most of the authors focused on reducing distance and energy usage for designing algorithms for optimal path. This paper, along with these vital concerns, also concentrates on providing efficient routes for emergency data transfer. The purposed optimization framework helps define the optimal position and minimum number of relays required in designing WBAN. This helps in reducing installation costs and increasing energy efficiency as well as lifetime for both multi-hop and single-hop (emergency situation) transfers in WBAN scenario.

The classification of routing protocols in WBAN with reference to energy is shown in Fig. 1.

3 WBAN design model

WBAN design model represents the proposed WBAN optimization structure. A cost function of the proposed PSOBAN represents the routing objective, and a multi-objective optimization technique is applied on the proposed model. The proposed model (1) optimally finds the best solution for the proposed scenarios, and (2) studies and evaluates the effect of network parameters and thus, solutions are obtained.

Fig. 1 Routing protocols classification in WBAN with reference to energy

3.1 Network model

In our scheme, eight biosensor nodes ($S_1, S_2, S_3, \dots, S_8$) are deployed on the subject. All the biosensor nodes have similar power and same computation capabilities. Sink node has been placed at the center of the human body. Each biosensor node in this scheme performs different tasks. S_1 is used for BP; S_2 is used for temperature; S_3 is used for EEG; S_4 is used for lactic acid; S_5 is used for EMG; S_6 is for blood oxygen; and S_7 is for ECG and S_8 is for Glucose as per shown in Fig. 1.

As per the biosensor nodes deployed in the body, the following assumptions were considered:

- All nodes are static and used the bi-directional link in WBAN.
- Initially, energy distributed to each biosensor node is equal.
- Each biosensor node is aware of its distance from neighbor nodes and as well as from the sink.

3.2 Energy model

All the nodes in WBAN remain active all the time, so all the nodes need energy for sensing, processing, and transmitting the data. For physical realization of the protocol, energy model proposed has been used. Energy consumed in transmitting the data can be calculated using Eq. (1).

$$En_{trans} = En_{T_elec} \times p + En_{amp} \times p \times d^2 \quad (1)$$

Energy consumed in receiving the data can be calculated as per Eq. (2).

$$En_{rec} = En_{R_elec} \times p \quad (2)$$

In WBAN, data transmission takes place through the human body hence some losses may occur. The loss in the signal power as it travels from one sensor to another due to the attenuation of the human body is called as path loss. Hence to include the path loss, a difference coefficient n has been included in the scenario for overall energy calculation. The total energy consumed in transmitting the data after adding path loss, n can be calculated using Eq. (3).

$$En_{trans} = En_{T_elec} \times p + En_{amp} \times n \times p \times d^2 \quad (3)$$

where En_{trans} , Transmission energy consumption; En_{rec} , Reception energy consumption; En_{T_elec} , Energy required by the electronic circuitry of transmitter; En_{R_elec} , Energy required by the electronic circuitry of receiver; En_{amp} , Amplifier energy consumption; p , Packet size; n , Path loss coefficient; d : Distance from a source node to destination node (Fig. 2).

3.3 Path loss model

The path loss depends upon various parameters such as varied thickness, the dielectric constant and characteristic impedance of the human body. This can correspond to a high loss due to the operating frequency band adopted by the nodes during their communication. Path loss may include the consequences which are associated with transmission distance and the interaction of the wave with the physical objects during propagation. The total path loss during the data transmission can be calculated using Eq. (4).

$$P_{Loss} = P_{Loss_0} + 10 \log_{10} \left(\frac{d_1}{d_0} \right) \quad (4)$$

Fig. 2 WBAN architectural model

$$\text{where, } Ploss_0 = 10 \log_{10} \left(\frac{4\pi d_0}{\lambda} \right) \quad (5)$$

$Ploss$: path loss, d_0 : path distance; d_0 : threshold distance (taken as 0.1) [23]; λ : the value of wavelength (0.125 m) has been used [16].

4 Particle swarm optimization algorithm

In 1995, a metaheuristic population-based optimization scheme was developed by Russell Eberhart and James Kennedy, named as particle swarm optimization (PSO). This was one of the most popular metaheuristic optimization schemes that were inspired by nature [37, 38]. This optimization scheme was motivated by the social behavior of birds for searching food. Every bird shares the information with its further associates during their search for food. So, according to their individual best experience and the swarm's best experience they carry on adjusting their route to get food for each entity. In the search space, all the birds fly toward the same route. Along the same lines, each particle keeps the stored record for all its coordinates, which relates to obtaining a better solution by following the current best particles. Steps in particle swarm optimization algorithm are as follows:

4.1 Initialization

In the first step, across the search space, the population is generated randomly using Eq. (6a) and initial velocities to the particles are assigned using Eq. (6b). In the search space, each particle space has its own location and velocity. Fitness value corresponds to the location of the particle in the search space, which denotes a possible solution to the problem. The speed and direction of the particles are represented by velocity and on the basis of this, in the next iteration, particle changes its location.

$$Pos_i^0 = LB + rand() * [UB - LB] \quad (6a)$$

$$vel_i^0 = zeros(NP, N) \quad (6b)$$

where Pos_i^0 , initial allocation or position of the particle i ; vel_i^0 , initial velocity of the particle i ; UB , Upper bound for search variable; LB , Lower bound for search variable; $rand()$, Random number between (0,1); NP , Number of the population (Population size of particles is chosen as 100); N , Total number of dimensions in the search space; * number of iterations taken is 100.

4.2 Calculation of fitness function

During the process of problem-solving, the fitness function is expressed as a mathematical expression. The fitness function for every particle is executed and its value can be obtained as per Eq. (7) depicted below:

$$f_{fit} : En_{trans} = En_{T_elec} \times p + En_{amp} \times n \times p \times d^2 \quad (7)$$

where f_{fit} , function of fitness; $f_{fit}(Loc_i^k)$, is the value of fitness for the particle i at the k th iteration.

4.3 Searching

In this step, the search process takes place in which each particle searches for its new position and finds the new fitness value with respect to its position. Then new position is stored by the particles.

4.4 Update the position and velocity of the particles

Every particle has its own velocity and position. Each particle updates its location and velocity by using the current velocity and position of the P_{best} and G_{best} . The following are the equations that are used by the particle to update their velocity as per Eq. 8 and position as per Eq. 9:

$$Vel_i^{k+1} = wVel_{i,k} + c_1 r_1 (Pos_{i,k}^{Local} - Pos_{i,k}^{Current}) + c_2 r_2 (Pos_{g,k}^{Global} - Pos_{i,k}^{Current}) \quad (8)$$

$$Pos_{i,k+1}^{Current} = Pos_{i,k}^{Current} + wVel_{i,k} \quad (9)$$

where $Vel_{i,k}$, velocity of the i -th particle at k -th iteration; $Pos_{i,k}^{Current}$, current position of i -th particle at k -th iteration; $Pos_{i,k}^{Local}(P_{best})$, local best position of i -th particle at k -th iteration; $Pos_{g,k}^{Global}(G_{best})$, global best position of the i -th particle at k -th iteration; c_1, c_2 , acceleration coefficients for the PSO algorithm; r_1, r_2 , uniformly distributed random numbers between (0, 1).

A smaller acceleration coefficient increases the probability of finding the global best, whereas a large acceleration coefficient speeds up the convergence and shortens the computation time, which causes the PSO to easily get trapped into the local best. So to get better solutions [43], sets c_1 and c_2 is fixed as 2.0 value. In the proposed protocol, the values for parameters c_1 and c_2 is 1.0 for achieving the best solutions.

The parameter w represents the inertia weight of the particles and depends upon the following mathematical relation:

$$weight = weight^{max} - \frac{(weight^{max} - weight^{min})iter}{iter_{max}} \quad (10)$$

where $weight^{min}$ and $weight^{max}$ are the minimum and maximum values of the inertia weights. For the proposed algorithm, the minimum value of inertia weight $weight^{min}$ has been taken as 0.2 and the maximum value of inertia weight $weight^{max}$ is taken as 0.9 [43].

4.5 Update local best and global best

In this step, a comparison is made between the particle's local best fitness value and the value of the fitness found by the particle in the next iteration. Value of the fitness of the local best solution is replaced by the current fitness value, only if the value of fitness of the current position is superior to the local best solution. Then a comparison is made between the new fitness value which is replaces by the local best fitness value with the global best solution, if the new fitness value is better than the global best fitness value than global best solution is replaced by the new fitness value and update the position of the global best solution with the current new position. The mathematical expression is below:

$$Pos_{i,k+1}^{Local} = \begin{cases} Pos_{i,k+1}^{Current}, f_{fit}(Pos_{i,k+1}^{Current}) \leq f_{fit}(Pos_{i,k}^{Local}) \\ Pos_{i,k}^{Local}, f_{fit}(Pos_{i,k+1}^{Current}) > f_{fit}(Pos_{i,k}^{Local}) \end{cases} \quad (11)$$

$$Pos_{g,k+1}^{Global} = \begin{cases} Pos_{i,k+1}^{Local}, f_{fit}(Pos_{i,k+1}^{Local}) \leq f_{fit}(Pos_k^{Global}) \\ Pos_k^{Global}, f_{fit}(Pos_{i,k+1}^{Local}) > f_{fit}(Pos_k^{Global}) \end{cases} \quad (12)$$

where $Pos_{i,k}^{Local}$, local best position of i -th particle at k -th iteration; Pos_k^{Global} , global best position at k -th iteration; $Pos_{g,k+1}^{Global}$, Global best position at $(k+1)$ th iteration; $Pos_{i,k+1}^{Local}$, local best position of i -th particle at $(k+1)$ th iteration.

Algorithm 1 Particle swarm optimization algorithm

Step 1:	Initialize the particles with random position Pos_i^0 and velocity Vel_i^0 using Eqs. (6a) and (6b).
Step 2:	Calculation of fitness value using fitness function $f(Pos_{i,k}^{Local})$ using Eq. (7) and find out $Pos_{i,k}^{Local}$ local best position and Pos_k^{Global} global best position using Eqs. (11) and (12).

Step 3:	Particle search for new location and velocity are updated using Eqs. (8) and (9) and the new position are stored.
Step 4:	Local best and global best fitness value according to the best solution is updated.
Step 5:	New position and velocity of the particles is updated.
Step 6:	If the stopped criteria has been met or reaches at the maximum number of iterations then stop, if not then go back to step 3.

5 Proposed approach

In the development of WBAN, network lifetime and energy consumption are the two major challenges. This is due to the fact that in WBAN, recharging, and replacement of batteries of biosensors attached to a human body may lead to one's uneasiness. Hence, energy preservation is a major consideration in WBAN. So, deployed nodes require the optimized use of the battery to have extended network lifetime. All biosensor nodes send data to the sink through relay node. Biosensor nodes select a route that has least distance to the sink node and consumes less energy. In our proposed work, we have discovered the route for transmitting the data which is optimal and efficient. We have used energy model to calculate energy and path loss models to calculate path loss in the selected route. PSO algorithm is used for finding the best route for data transmission in WBAN. The following are the main steps of our proposed approach to finding the best route.

The flow chart for PSOBAN protocol for energy-efficient routing is shown in Fig. 3.

5.1 System model

In the first step, a WBAN network is formed which has 8 biosensor nodes and one sink node. All the nodes have to sense the data and transmit that data to the sink by finding the shortest route. An initially equal amount of energy is distributed to all the biosensor nodes for participating in the network communication. Biosensor nodes on human body are deployed as shown in Table 1.

Fig. 3 Flow chart for proposed PSOBAN protocol **Table 1** Biosensor node's deployment on the human body

Node	Location (X, Y)
S_1	(0.55, 1)
S_2	(0.25, 1)
S_3	(0.28, 0.2)
S_4	(0.48, 0.25)
S_5	(0.3, 0.5)
S_6	(0.5, 0.5)
S_7	(0.45, 0.13)
S_8	(0.35, 0.9)
SINK	(0.4, 1.1)

5.2 Initialization phase

In the proposed network, all the biosensor nodes are separately prioritized. For nodes $S_1, S_2, \dots, S_6$, priority is set as 1 while priority is set as 2 for biosensor nodes S_7 and S_8 . The main idea is setting different priorities to S_7 and S_8 as they have critical data. These two nodes can send data directly to the sink. Other nodes that have 1 priority can relay data to the sink through the relay node.

In this case, node S_3 is to send data to the sink, the data can be relayed through nodes 4, 5 and 6. Next, the task of

the selected protocol is to find the best route or path from node 3 to sink. First of all, the proposed protocol checks for residual energy of node 3. If node 3 has enough energy for forwarding the data, only in that case this node can forward the data to the next node. Otherwise, this node will be declared as a dead node and node 3 will not participate in further communication. If the node has enough energy for transmitting the data, then the next step is to select the relay node for selecting the route.

5.3 Computational phase

In this phase, if the selected relay node is node 5, it will be used only if it has enough remaining energy for transmitting the data. In case, it is dead then some other node will be checked for the same on the basis of cost function. Suppose that node 5 is not a dead node, then it is will be selected as a relay node on the basis of cost function which is calculated by dividing the distance from node 3 with the residual energy. Cost function (CF) is defined as the ratio of distance from the biosensor node to the sink and the residual energy of the sensor node [23].

$$CF(i) = \frac{D(i)}{RE(i)} \quad (13)$$

The value of cost function is calculated by using particle swarm optimization. The same calculation for calculating the cost function of node 4 is made and a comparison of the values of both the cost function is done. A node that has the minimum value of cost function will be selected as the relay node and the same procedure will be applied for selecting the next node. This is worth mentioning here that the nodes that carry critical data will not participate in the selection process and thus will not act as a relay node. Hence, by following this procedure, finally a route is established with minimum value of cost function.

5.4 Routing phase

In the next round, the same procedure is used for selecting the shortest route. At each round, our optimized protocol gives the optimal route in minimum time. After each round the matrix for cost function is generated and updated according to the remaining energy until all the nodes are declared dead. The nodes which are selected as relay nodes using cost function will give the shortest route. Moreover, the features of prevailing routing protocols are compared with the proposed PSOBAN as shown in Table 2.

5.5 Data transmission phase

In the last phase, data is transmitted from the source node to the sink by using the shortest route as selected by particle swarm optimization. Each biosensor on the path route with a minimum value of cost function is selected for data transmission as calculated by the PSOBAN. The flow chart for handling various WBAN constraints in PSOBAN shown in Fig. 4.

6 Results and discussions

To evaluate the proposed PSOBAN protocol and compare its performance with the existing WBAN routing protocol RE-ATTEMPT and the Random selection method, MATLAB R2013 [46] is used with the parameters for simulations as mentioned in Table 3. Key performance metrics for both the protocols are defined in the following subsections.

The following are some performance matrices:

1. **Stability period:** The time necessary for a network to complete its operation, i.e. till the death of the first

Table 2 Comparison of PSOBAN with existing algorithms

Algorithms	Network type	Communication mode	Technique used	Distance-aware	Energy-efficient	Emergency data
TARA [15]	Homogeneous	Multi-hop	Finite-difference time-domain	No	Yes	Yes
OBSFR [17]	Homogeneous	Single-hop	Flooding	Yes	No	No
EAR [18]	Heterogeneous	Single-hop	Communication costs	Yes	Yes	No
DARE [21]	Heterogeneous	Multi-hop	Relay mechanism	Yes	Yes	No
ATTEMPT [22]	Heterogeneous	Single-hop/multi-hop	TDMA, Mobility	No	Yes	Yes
M-ATTEMPT [22]	Heterogeneous	Single-hop/multi-hop	TDMA, mobility	No	Yes	Yes
RE-ATTEMPT [24]	Heterogeneous	Single-hop/multi-hop	TDMA, CAP, CFP	No	Yes	Yes
OCER [39]	Heterogeneous	Single-hop/multi-hop	Genetic algorithm	Yes	Yes	No
Proposed PSOBAN Protocol	Heterogeneous	Single-hop/multi-hop	PSO	Yes	Yes	Yes

Fig. 4 Flowchart for the handling of various WBAN constraints

node. The time that is consumed, after the stability period, until the death of the last node is coined as an unstable period.

- Throughput: The totality of packets that are successfully received by the sink.
- Residual energy: The remaining energy at individual nodes, after enough utilization for network operation, is termed as the residual energy of the respective node.

- Path-loss: The power that is lost while transmitting data from the transmitting to the receiving node is termed as path-loss. It is measured in decibels (dB).

The pseudo code as proposed for PSOBAN is implemented for the routing of biosensors.

Table 3 Simulation parameters for WBAN

S. no.	Parameters	Description of parameters	Value	Unit
1	Energy	Initial energy	0.6	J
		En_{T_elec} for transmitter	16.7	nJ/bit
		En_{R_elec} for receiver	36.1	nJ/bit
		En_{amp} for amplified circuit	1.97	nJ/bit
2	Node	Numbers of biosensors node	8	node
3	Sink positions	At the center of the body	1	node
4	Current	DC current for transmitter	10.5	mA
		Dc current for receiver	18	mA
5	Voltage	Supply voltage minimum	1.9	V
6	Frequency	Total frequency	2.4	GHz
7	Wavelength	Total wavelength	0.125	meter
8	Packet size	Total numbers of packet size	4000	bits
9	Rounds	Total number of rounds	10,000	round

Fig. 5 Stability period: No. of dead nodes with respect to rounds (r)

Pseudo-Code of Proposed Approach

```

Begin
Input:
i ← Source Node
S(i).E ← Residual Energy of the node i
Ethres ← Threshold Energy
S(i).P ← Priority of the node i
dij ← Distance of node j from node i
S(j).E ← Residual Energy of node j
CF ← Cost Function
Output:
Routei,sink ← Shortest route from Source node to sink
For each i do
  If (S(i).E > Ethres) then,
    If (S(i).P == 2)
      Transi,sink ← Data Transmission from i to sink
    Else-if
      For each neighboring node of i
        Relayj ← choose relay node j for route
        If (S(j).E > Ethres) && (S(j).P == 1) then,
          CF = dij / S(j).E
          add S(j) to Routei,sink
        Else
          choose another neighboring node as relay
      End-if
      Transi,Relay ← forward data to relay node
    End For
    End-if
    TransRelay,sink ← Data Transmission from Relay to sink
    S(Relay) ← Routei,sink
  End-if
Repeat all the steps until all nodes becomes dead
End For
End Begin

```

6.1 Stability period

In this paper, the proposed protocol is tested against the conventional RE-ATTEMPT protocol and also with random (random selection) of nodes for data transmission. It can be inferred from Fig. 5, that the proposed protocol PSOBAN has better stability period in comparison to RE-ATTEMPT protocol and random selection. It is because of the fact that in PSOBAN, the transmission only occurs from the nodes which have the least value of distance and have higher residual energy.

It is a fact that the nodes which only send emergency data die slower because these nodes aren't selected as the relay nodes. In the proposed protocol, data is transmitted discretely as per the requirement, and hence requires comparatively less energy than contracts.

In the case of RE-ATTEMPT and random selection, the first node dies at circa 2480 and 4500 rounds respectively. In PSOBAN, the first node dies at 3800 rounds but later on more stability is observed. The PSOBAN shows a far more significant improvement over the other competitors.

6.2 Throughput

Since WBAN has very vital data about the patient, it requires a protocol that has minimum package drop and a high rate of throughput. In comparison to RE-ATTEMPT, the proposed protocol PSOBAN achieves a higher rate of throughput, as depicted in Fig. 6. The number of live nodes determines the number of packets that are sent to the sink, which in turn leads to a higher throughput rate of the network.

Fig. 6 Throughput: packet received versus rounds (r)

As clearly depicted in the graphical representation below, the PSOBAN achieves a much higher throughput rate (circa 30,900 packets per 10,000 rounds) in comparison to RE-ATTEMPT (circa 22,000 packets per 10,000 rounds) and Random selection (circa 30,700 packets per 10,000 rounds) protocols. It is found that the protocol used by the researcher is more efficient in terms of energy consumption and stability.

6.3 Residual energy

Multi-hop mode of communication is deployed in our proposed protocol PSOBAN, in which a relay node aids the farthest node to transmit data to the sink. A relay node is selected on the basis of the cost function, which in turn contributes to saving energy in each round. This results into a longer execution period of the WBAN. In the case of the RE-ATTEMPT and random selection, some nodes exhaust early due to heavy traffic load on the sink. The multi-hopping technique, in the proposed protocol, selects a different relay node each round, which helps in load balancing on the nodes.

4.8 J of the total initial energy of the network is distributed amongst all the nodes present in the network; each node is given 0.6 J. The simulation results exhibit that the proposed protocol consumes lesser amount of energy up to 73% of the simulation time; this establishes that the nodes have more energy, during the stability period, to transmit more data packets to the sink. This helps to show that PSOBAN is highly energy efficient and with it, a higher throughput rate is achievable, as shown in Fig. 7.

Fig. 7 Residual energy versus rounds (r)

Fig. 8 Path-loss versus rounds (r)

6.4 Path-loss

Path loss plays a vital role in the design and analysis of the link. Path loss is the result of the function of frequency and distance. It is calculated as the distance of the node from the sink at a frequency of 2.4 GHz. For practical implementation purposes, the path loss coefficient is taken to be 3.38.

Path loss excessively depends on communication distance, so the proposed protocol has used multi-hop technique; it remarkably reduces communication distance, which results into lesser path loss in comparison to RE-ATTEMPT, as shown in Fig. 8.

At the initial stage, the proposed PSOBAN, RE-ATTEMPT and RANDOM protocol perform quite well. After approximately 2000 rounds, RE-ATTEMPT topology is depleted of its energy and after 3800 rounds, Random topology is depleted of its energy whereas the proposed protocol shows no such signs until 6100 rounds. The proposed protocol PSOBAN has higher number of live nodes, which result into a longer stability period and thus less cumulative path loss. In PSOBAN, path loss is thus observed much later in the network lifetime. Our proposed protocol PSOBAN shows dramatic improvements by dropping the path loss to 109.2 dB. Comparative analysis of REATTEMPT, Random selection method and PSOBAN in terms of different simulation parameters are displayed in Table 4.

7 Conclusions

This research proposes an Energy-efficient routing protocol for heterogeneous WBAN based on Particle Swarm Optimization Algorithm. It is evident from the name that this protocol is well aware of the distance between the

Table 4 Comparison of various parameters for different protocols

Parameters	Protocols		
	RE-ATTEMPT	RANDOM	PROPOSED PSOBAN
First node died (rounds)	2480	4500	3800
Last node died (rounds)	8912	5400	8995
Throughput (packets received) ^a	21,523	30,700	30,900
Residual energy (J)			
At 2000 rounds	2.6894	2.6444	3.3661
At 4000 rounds	1.6029	1.0002	2.2095
At 6000 rounds	0.9041	0.4257	1.2652
At 8000 rounds	0.3359	0.2394	0.3990
At 10,000 rounds	0	0	0
Path-loss (dB)			
At 2000 rounds	422	370	372
At 4000 rounds	260	110	372
At 6000 rounds	260	110	372
At 8000 rounds	210	110	109.2
At 10,000 rounds	0	0	0

^aFor 10,000 rounds

different biosensor nodes and is also sensitive to the energy of biosensor nodes. The proposed protocol selects the relay node between the source node and the sink node by optimizing residual energy and distance using particle swarm optimization algorithm and transmitting the data packets in multi-hop fashion. For validating the accuracy of the proposed work, simulations have been carried out for the different parameters. The simulation results show that the proposed protocol performs better in terms of residual energy. The route is not only selected based on the number of hops in the route but on the basis of two main parameters- energy and distance.

8 Future scope

Also, in future research work, authors would like to work on a hybrid PSO-simulated annealing algorithm (hPSO-SA) in order to further improvise our results. The focus will be to optimize the energy consumption in WBAN using the hybrid approach.

The future studies may include the analysis of multiple BANs having a mobile sink node. Implementing such mobility of sink protocol in WBAN, in which the sink itself gathers the data from all the biosensor nodes by finding the optimum path using an optimization algorithm, will be revolutionary. The main focus will also be on the reliable and secure delivery of critical information of WBAN data.

Compliance with ethical standards

Conflict of interest Authors declare that, there is no conflicts of interest for this work.

References

- Movassaghi S, Abolhasan M, Lipman J, Smith D, Jamalipour A (2014) Wireless body area networks: a survey. *IEEE Commun Surv Tutor* 16:1658–1686
- Latré B, Braem B, Moerman I, Blondia C, Demeester P (2011) A survey on wireless body area networks. *Wirel Netw* 17:1–18
- Cook DJ, Song W (2009) Ambient intelligence and wearable computing: sensors on the body, in the home, and beyond. *J Ambient Intell Smart Environ* 1:83–86
- Ali A, Mohammed MA (2015) Modeling of wireless sensor networks with minimum energy consumption. *Arab J Sci Eng* 42:2631–2639
- Crosby GV, Chin CA, Ghosh T, Murimi R (2015) *Mobile health*. Springer, Berlin. <https://doi.org/10.1007/978-3-319-12817-7>
- Khan JY, Yuce MR, Karami F (2008) Performance evaluation of a wireless body area sensor network for remote patient monitoring. In: 2008 30th annual international conference of the IEEE engineering in medicine and biology society, pp 1266–1269
- Li HB, Takahashi T, Toyoda M, Mori Y, Kohno R (2009) Wireless body area network combined with satellite communication for remote medical and healthcare applications. *Wirel Pers Commun* 51:697–709
- Tran TV, Chung W-Y (2014) IEEE-802.15.4-based low-power body sensor node with RF energy harvester. *Biomed Mater Eng* 24:3503–3510
- Movassaghi S, Abolhasan M, Lipman J (2013) A review of routing protocols in wireless body area networks. *J Netw* 8:559–575
- Effatparvar M, Dehghan M, Rahmani AM (2016) A comprehensive survey of energy-aware routing protocols in wireless body area sensor networks. *J Med Syst*. <https://doi.org/10.1007/s10916-016-0556-8>
- Yusuf Khan J, Yuce MR, Bulger G, Harding B (2012) Wireless body area network (WBAN) design techniques and performance evaluation. *J Med Syst* 36:1441–1457
- Gondogdu K, Calhan A (2016) An implementation of wireless body area networks for improving priority data transmission delay. *J Med Syst* 40:75
- Sandhu MM, Javaid N, Akbar M, Najeel F, Qasim U, Khan ZA (2014) FEEL: forwarding data energy efficiently with load balancing in wireless body area networks. In: 2014 IEEE 28th international conference on advanced information networking and applications, pp 783–789
- Heinzelman WR, Chandrakasan A, Balakrishnan H (2000) Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd annual Hawaii international conference on system sciences, vol 1, p 10
- Tang Q, Tummala N, Gupta SKS (2005) TARA : thermal-aware routing algorithm for implanted sensor networks. In: Proceedings of 1st IEEE international conference on distributed computing in sensor systems, pp 206–217
- Ahmed S, Javaid N, Yousaf S, Ahmad A, Sandhu MM, Imran M, Khan ZA, Alrajeh N (2015) Co-LAEEBA: cooperative link aware and energy efficient protocol for wireless body area networks. *Comput Hum Behav* 51:1205–1215
- Quwaider M, Biswas S (2009) On-body packet routing algorithms for body sensor networks. In: 2009 1st international conference on networks and communications, pp 171–177
- Kim D, Kim WY, Cho J, Lee B (2010) EAR : An Environment-Adaptive Routing Algorithm for WBANs. In: Fourth International Symposium on Medical Information and Communication Technology, pp 1–4
- Wang J, Cho J, Lee S, Chen K-C, Lee Y-K (2010) Hop-based energy aware routing algorithm for wireless sensor networks. *IEICE Trans Commun* 93(2):305–316
- Elias J (2014) Optimal design of energy-efficient and cost-effective wireless body area networks. *Ad Hoc Netw* 13:560–574
- Tauqir A, Javaid N, Akram S, Rao A, Mohammad SN (2013) Distance aware relaying energy-efficient: DARE to monitor patients in multi-hop body area sensor networks. *Proc - 2013 8th Int Conf Broadband. Wirel Comput Commun Appl BWCCA 2013*:206–213
- Javaid N, Abbas Z, Fareed MS, Khan ZA, Alrajeh N (2013) M-ATTEMPT: a new energy-efficient routing protocol for wireless body area sensor networks. *Procedia Comput Sci* 19:224–231
- Nadeem Q, Javaid N, Mohammad SN, Khan MY, Sarfraz S, Gull M (2013) SIMPLE: stable increased-throughput multi-hop protocol for link efficiency in wireless body area networks. In: 2013 eighth international conference on broadband and wireless computing, communication and applications BWCCA, pp 221–226
- Ahmad A, Javaid N, Qasim U, Ishfaq M, Khan ZA, Alghamdi TA (2014) RE-ATTEMPT: a new energy-efficient routing protocol for wireless body area sensor networks. *Int J Distrib Sensor Netw* 10(4):464010
- Ahmed S, Javaid N, Akbar M, Iqbal A, Khan ZA, Qasim U (2014) LAEEBA: link aware and energy efficient scheme for body area networks. In: 2014 IEEE 28th international conference on advanced information networking and applications AINA, pp 435–440
- Cai X, Li J, Yuan J, Zhu W, Wu Q (2014) Energy-aware adaptive topology adjustment in wireless body area networks. *Telecommun Syst* 58:139–152
- Javaid N, Ahmad A, Nadeem Q, Imran M, Haider N (2014) iM-SIMPLE: iMproved stable increased-throughput multi-hop link efficient routing protocol for wireless body area networks. *Comput Human Behav*. <https://doi.org/10.1016/j.chb.2014.10.005>
- Jing L, Ming L, Bin Y, Wenlong L (2015) A novel energy efficient MAC protocol for wireless body area network. *China Commun* 12:11–20
- Yuan X, Li C, Yang L, Yue W, Zhang B, Ullah S (2016) A token-based dynamic scheduled MAC protocol for health monitoring. *EURASIP J Wirel Commun Netw* 2016:125
- Kim J, Song I, Choi S (2015) Priority-based adaptive transmission algorithm for medical devices in wireless body area networks (WBANs). *J Cent South Univ* 22:1762–1768
- Shakya A, Mishra M, Maity D, Santarsiero G (2019) Structural health monitoring based on the hybrid ant colony algorithm by using Hooke–Jeeves pattern search. *SN Appl Sci* 1:1–14
- Mishra M (2019) Multiverse optimisation algorithm for capturing the critical slip surface in slope stability analysis. *Geotech Geol Eng*. <https://doi.org/10.1007/s10706-019-01037-2>
- Mishra M, Ramana V, Damodar G (2019) Teaching–learning-based optimisation algorithm and its application in capturing critical slip surface in slope stability analysis. *Soft Comput*. <https://doi.org/10.1007/s00500-019-04075-3>
- Mishra M, Kumar S, Damodar B, Dipak M, Maiti K (2018) Ant lion optimisation algorithm for structural damage detection using vibration data. *J Civ Struct Heal Monit*. <https://doi.org/10.1007/s13349-018-0318-z>
- Yu Y, Li Y, Li J (2014) Parameter identification of a novel strain stiffening model for magnetorheological elastomer base isolator utilizing enhanced particle swarm optimization. *J Intell Mater Syst Struct*. <https://doi.org/10.1177/1045389X14556166>
- Yu Y (2018) Expansion prediction of alkali aggregate reactivity-affected concrete structures using a hybrid soft computing

- method. *Neural Comput Appl*. <https://doi.org/10.1007/s00521-018-3679-7>
37. Kennedy J, Eberhart R (1995) Particle swarm optimization. In: *Proceedings of 1995 IEEE international conference on neural networks*, vol 4, pp 1942–1948
 38. Shi Y, Eberhart R (1998) A modified particle swarm optimizer. In: *1998 IEEE international conference on evolutionary computation proceedings. IEEE world congress on computational intelligence* (Cat. No. 98TH8360), pp 69–73
 39. Vimalarani C, Subramanian R, Sivanandam SN (2016) An enhanced PSO-based clustering energy optimization algorithm for wireless sensor network. *Sci World J*. <https://doi.org/10.1155/2016/8658760>
 40. Dhadwal MK, Jung SN, Kim CJ (2014) Advanced particle swarm assisted genetic algorithm for constrained optimization problems. *Comput Optim Appl* 58:781–806
 41. Xu G, Wang M (2014) An energy-efficient routing mechanism based on genetic ant colony algorithm for wireless body area networks. *J Networks* 9:3366–3372
 42. D'Andreagiovanni F, Nardin A (2015) Towards the fast and robust optimal design of wireless body area networks. *Appl Soft Comput J* 37:971–982
 43. Wu T, Lin C (2015) Low-SAR path discovery by particle swarm optimization algorithm in wireless body area networks 15:928–936
 44. Sangwan A, Bhattacharya PP (2016) An optimization to routing approach under WBAN architectural constraints. In: Berretti S, Thampi SM, Dasgupta S (eds) *Intelligent systems technologies and applications*, vol 385. Springer, Cham, pp 75–89
 45. Kaur N, Singh S (2017) Optimized cost effective and energy efficient routing protocol for wireless body area networks. *Ad Hoc Netw* 61:65–84
 46. <https://in.mathworks.com/products/matlab>

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