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Intelligent Hybrid Heuristic-Metaheuristic Algorithm for Lifetime Extension in Wireless Body Area Networks

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Abstract

Wireless body area network (WBAN) is a type of wireless communication network, which consists of tiny bio-sensor nodes attached to or implanted in the human body, to continuously monitor the patient by medical staff. Energy efficient routing in WBANs is of utmost importance, as bio-sensors are highly resource-constrained. Although many heuristic- and metaheuristic-based routing protocols have been proposed for WBANs, they suffer from some drawbacks: low solution quality of heuristics and low speed of metaheuristics in online routing. To overcome these drawbacks and simultaneously benefit from the advantage of both techniques, we present an ensemble heuristic-metaheuristic protocol (called CHM) as an adjustable routing solution for WBANs. In CHM, a multi-criteria heuristic based on the residual energy, distance to sink, path loss, and history of becoming a relay node, is used to select proper cluster heads. Furthermore, a metaheuristic algorithm using a genetic algorithm is applied to automatically tune the heuristic protocol. Simulation results in MATLAB using IEEE 802.15.6 on different WBANs demonstrate the performance of the introduced CHM protocol when compared with the existing routing protocols in terms of prolonging the application-specific network lifetime definition.

Keywords: Wireless body area networks (WBANs), clustering, routing, heuristic algorithms, genetic algorithm.
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1. Introduction

Wireless sensor network (WSN) is a spatially dispersed network comprising dedicated sensors to monitor the physical condition of the environment and transmit the sensed data to the sink (i.e., base station) [1, 2]. Over the past years, there has been increasing interest in using monitoring systems based on Wireless Body Area Networks (WBANs), because of their continuous real-time monitoring in different applications ranging from sports and entertainment to telemedicine and disease detection and treatments [3]. To this end, vital information about the patients is continuously transmitted to the medical servers. A WBAN contains a set of low-power, ultra-short-range communication, and tiny bio-sensors attached to, or implanted in the human body. Process mining consists of process discovery, conformance checking, and enhancement [4], capable of communicating among themselves and with the central processor unit known as a base station (sink) through wireless links [4].

The general architecture of the WBAN-based monitoring systems can be seen in Fig. 1, which includes WBAN on the patient side, network connection side, and medical service side. A WBAN comprises several bio-sensor nodes and a central control unit (i.e., sink node) [3]. Each node collects physiological or non-physiological data such as the body temperature, blood oxygen, blood pressure, electroencephalograph (EEG), electrocardiograph (ECG), and electromyograph (EMG) [5]. In each round of the network operation, every node may transmit the sensed data packet directly or with the help of a relay node (CH: cluster head) to the sink node, and then, sink forwards the gathered data packets to a medical server through wired/wireless connection networks [6]. Due to the limitations in the power of bio-sensor nodes (battery), wireless communication channels, bandwidth, memory, and processing capacities, various challenges should be carefully considered when designing a WBAN [7]. The challenges related to the minimum energy consumption and maximum satisfaction with the quality of service (QoS) requirements are among the most essential aims in designing WBANs.

Generally, reliability and energy efficiency have major impacts on the network lifetime and the stable period of WBAN [8]. Reliability denotes whether sensitive data packets may be successfully transferred to the sink in a correct and timely manner or not. Moreover, the stability period implies the number of rounds that the network is operated on before the first node dies, i.e., the FND definition.

Wireless bio-sensors are resource-constrained with low-power batteries, so recharging the batteries is difficult [8]. Therefore, utilizing energy-efficient routing protocols is of utmost importance. Cluster-based routing protocols are the most popular techniques, which have been widely used to achieve energy efficiency in WBANs [9]. It has been proved that the clustering problem in WBANs are of NP-hardness [10-12], and thus, various heuristic and metaheuristic methods have efficiently been applied to solve it. However, the existing methods suffer from some low solution quality of heuristics and low speed of metaheuristics in online routing. Moreover, the parameters of the existing protocols are typically tuned manually, without any optimization procedure.

To alleviate the drawbacks of the existing methods, we present a hybrid heuristic-metaheuristic model (named CHM) based on the IEEE 802.15.6 standard. The primary objective of the Combined Heuristics and Metaheuristics (CHM) approach is to leverage the advantages of both techniques. Specifically, it aims to harness the high-speed capabilities of heuristics, as seen in just-in-time routing [13], while also benefiting from the superior solution quality offered by metaheuristics [14-16].

In the proposed CHM protocol, a multi-objective heuristic based on the energy level, distance to sink, path loss, and history of becoming a relay node, is used to select proper CHs as relay nodes. To achieve the best efficiency, the controllable parameters of CHM are adjusted via genetic algorithm (GA) in a pre-processing phase before programming the tuned CHM model in the processor located at the sink node, for online clustering in WBANs. Key contributions of this paper can be mentioned as follows:

– We introduce a new routing model, namely CHM, as a tunable protocol to select proper CHs in WBANs. Our aim is to leverage the high-speed of heuristics and superior solution quality offered by metaheuristics.
– Utilizing GA to tune controllable parameters of the CHM model to achieve the best efficiency and improve the overall performance of the clustering process.
– The proposed CHM model is shown to improve the efficiency of the clustering process in WBANs by reducing the energy consumption and prolonging the network lifetime. The use of a multi-objective heuristic and GA helps to select optimal relay nodes, which in turn results in improved network performance.
– The results show the effectiveness of the CHM model through experiments on a set of WBAN. The results show that the proposed CHM model outperforms existing methods in terms of network lifetime, energy consumption, and packet delivery ratio.

In the rest of this paper, the existing methods are discussed in Section 2. The proposed CHM clustering protocol is introduced in Section 3. The results of the CHM model and comparisons with other techniques are provided in Section 4. Finally, concluding remarks and future directions are discussed in Section 5.

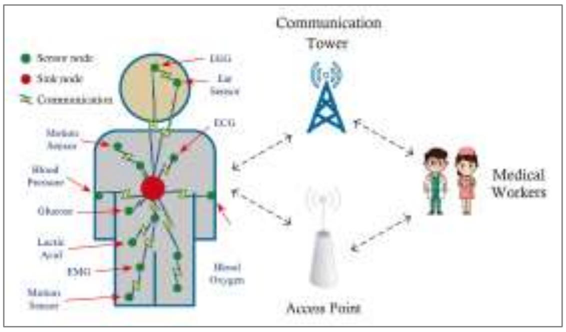

Fig. 1. General architecture of a WBAN-based monitoring system.

2. Related work

Typically, existing routing techniques in WBANs could be grouped into delay-tolerant, cross-layer, QoS-aware, thermal-aware, and cluster-based protocols [17]. Among these techniques, cluster-based protocols are the most widely used techniques, which have proven to have better results than other techniques, as they lead to more energy efficiency through the distribution of the load between different sensor nodes [18]. In clustering methods, the different sensor nodes are divided into separate groups, each contains a relay (i.e., CH) [7]. In the following, the existing clustering-based routing techniques are reviewed.

Mobility Adaptive Threshold Temperature Energy Multi-Hop Protocol (M-ATTEMPT) [19] is an energy-efficient protocol that aims to route data away from hotspot nodes. In M-ATTEMPT, each node selects the path with the fewest number of hops. In cases where multiple paths have the same number of hops, the path with the least dissipated energy is chosen. It's important to note that while M-ATTEMPT considers the hop count to select optimal paths, it does not consider the total distance to the sink. Furthermore, this method has certain limitations. Firstly, the relay nodes are selected solely based on the minimum hop count, without considering the residual energy of the sensors. Secondly, the total distance to the sink is not taken into consideration, potentially impacting the overall efficiency of the routing process.

Stable Increased Multi-Hop Protocol for Link Efficiency (SIMPLE) [20] is an energy-efficient and distance-aware model, wherein a node with a higher energy level and less distance to the sink has more chance to be selected as CHs. It utilizes the energy level to distribute the dissipated energy between different nodes. Moreover, considering the distance of nodes to sink ensures obtaining maximum throughput. Although the SIMPLE can prolong the network lifetime better than the M-ATTEMPT, the path loss is not considered. Moreover, a node may be continuously chosen as a CH, which may lead to the hot-spot problem.

IMproved SIMPLE (IM-SIMPLE) protocol [21] is a routing protocol that considers mobility and throughput in selecting Cluster Heads (CHs). In IM-SIMPLE, during each round, the sink node chooses the current CHs and communicates their role to them at the beginning of the round. In the steady-state phase, each node sends its data packets to the selected CH node using time division multiple access (TDMA), and subsequently, the corresponding CHs transmit all the received packets directly to the sink. One potential drawback of this method is that a node located in close proximity to the sink may be repeatedly chosen as a CH. Consequently, its energy reserves may deplete quickly due to the increased responsibilities associated with being a CH.

Energy Consumption Backside Routing (ECBR) protocol [22] is a technique that focuses on energy efficiency. It considers nodes located on both the frontside and backside of the body. When the transmitter and receiver nodes are positioned on the same side, line of sight (LOS) communication is utilized. However, if the nodes are on opposite sides, non-line of sight (NLOS) communication is employed. It should be noted that NLOS consumes more energy and experiences greater path loss compared to LOS.

Evolutionary Multihop Routing (EMRP) [10] is another clustering technique, which utilizes GA to maximize FND. It considers the residual energy of nodes, their distance to sink, the link path losses, and the estimated dissipated energy of CHs, to properly select the CH nodes at every round. This technique also considers both LOS and NLOS models for the communications between different nodes.

Energy Reliable Routing Scheme (ERRS) [5] is another cluster-based routing technique, which aims to enhance the reliability and stability period of the network. The ERRS protocol contains different mechanisms to select proper forwarder nodes and rotate them at successive rounds. However, this method suffers from imbalanced load distributing among all nodes, path loss, and hotspot problems.

Energy Aware WBAN Design (EAWD) [23] is a topological technique, that aims to reduce the energy consumption of nodes. It considers the relay nodes and sensing nodes along with their position to select the proper CHs and improve the number of selected relay nodes. It tries to search for the best traffic routes from each sensor node to the sink node.

Energy Efficient Routing Protocol in WBANs (EERPW) [24] utilizes a combined routing mechanism comprising single- and multi-hop communications to send the gathered data from different sensor nodes to sink. At every round, a node is chosen as a relay node with the multi-hop transmission using a cost function, in order to maximize energy efficiency and reliability.

Dual Sink Cluster Based routing (DSCB) [25] is a cluster-based technique considering two sink nodes to reduce the dissipated energy and path loss of the NLOS communications. The main objectives of the DSCB are to minimize the data transmission losses, congestion of the data traffic, and coverage losses. Moreover, it tries to find the paths with the minimum end-to-end transmission delay while prolonging the network lifetime via dual sink nodes.

Distance-aware MAC (DT-MAC) [26] is an extension of the popular MT-MAC protocol, to ensure successful message delivery in WBANs. It considers different criteria such as node handover mechanism among the different clusters and performs the concept of the minimum connected dominating set to form clusters. The objective function of DT-MAC is considered to obtain proper energy efficiency.

Fuzzy-based relay node selection (FbRNS) [27] focuses on creating clusters based on reliability and energy efficiency. It generates routes by forwarding packets through Cluster Heads (CHs), utilizing distance and direction as input parameters for the fuzzy inference system. While FbRNS is a dependable and energy-efficient protocol, it does not consider path loss and load balancing when determining the routes.

Minimum Edge Vertex Path Selection (MEVPS) protocol [28] is designed as a data collection method for edge devices. Its objective is to address congestion issues and minimize latency in emergency data forwarding scenarios. MEVPS employs the ant colony optimization technique to identify the shortest paths, shared by edges and vertices, connecting each root node to the sink node.

Max-Min Power Control (MMPC) [29] is a routing protocol for WBANs comprising many sensor nodes. These nodes are distributed around the human body and are able to communicate with access points (APs). To enhance the WBAN throughput, the APs with the best channel condition are selected to receive the information from nodes. In this protocol, a power control strategy has been used to control the transmit power of nodes in uplink and downlink conditions depending on the current channel state. This protocol considers the number of sensor nodes within WBAN, the number of APs, uplinks, and downlinks.

Generally, metaheuristic-based routing protocols in WBANs have acceptable results to prolong the WBAN lifetime. However, they boost some overheads and extra delay at the data transmission phase, which may lead to irreparable damages in transmitting critical data packets. Although heuristic algorithms can provide the routing solution very fast, they suffer from low solution quality, e.g., low network lifetime. To address these drawbacks, we present a hybrid heuristic-metaheuristic clustering model named CHM. It not only achieves high performance but also can respond to real-time routing requests.

3. Proposed CHM routing protocol

In each round, the CHM protocol operates in two steps: the setup step (routing design) and the steady-state (communication) step. At the beginning of every round, the sink designs all routes via the CHM protocol and broadcasts them through advertisement messages to inform all nodes about the designed routes (setup). In the steady-state step, each member node forwards its own data to the related CH. Then, each relay node (i.e., each CH node) transmits the gathered data packets from all its member nodes in addition to its own data directly to the sink.

A) Network model

The CHM routing protocol utilizes IEEE 802.15.6 architecture, in which, only one-hop communication (for CHs) and two-hop communication (for non-CHs) can be utilized. Therefore, the routing procedure can be reduced to CH selection at every round.

Energy model: The dissipated energy (in Joule) to transmit a data packet with k bits from a transmitter n to a receiver m can be expressed as follows:

$$E_T(n) = E_{TE} \times k + E_{amp} \times k \times {d_{n,m}}^{\eta} \tag{1}$$

$$E_R(m) = E_{RE} \times k \tag{2}$$

where $d_{n,m}$ is the distance between nodes n and m, E_{TE} and E_{RE} are the energy consumption factors (per bit) respectively due to the electrical circuits of transmitter and receiver nodes, E_{amp} is amplifier energy consumption factor of the transmitter, and η is path loss exponent which is considered between 3 to 7 based on the line-of-side or non-line-of-side communications [22].

Path loss model: It can be calculated in dB for a communication between nodes n and m as attenuation of signal from transmitter to receiver, as follows:

$$PL_{n,m} = 20\log\left(\frac{4\pi d_0 f}{c}\right) + 10\eta\log\left(\frac{d_{n,m}}{d_0}\right) \tag{3}$$

where f is frequency, c is the light speed, and d_0 is the reference distance, which is typically determined as 0.1 meters (10 cm).

B) CH selection using CHM protocol

To select proper CH nodes, for any node n, a node m may be chosen as the relay node using the CHM protocol. As shown in Fig. 2, the CHM takes four input parameters from each candidate node m comprising energy level Em, distance to sink Dm, path loss Lm, and the history of nodes in selection as a CH in the past rounds Hm, Then, the CHM model calculates the priority of node m to be chosen via a weighted averaging formula as:

$$P_m = w_E E_m + w_D D_m + w_L L_m + w_H H_m \tag{4}$$

where E_m, D_m, L_m, and H_m, can be calculated as follows:

$$E_m = \frac{\left(E_0 - E(m)\right)}{\frac{1}{N}\sum_{o=1}^{N}\left(E_0 - E(o)\right)}; \quad m = 1, 2, ..., N \tag{5}$$

$$D_m = \frac{\left(d_{n,m} + d_{m,sink}\right)}{\frac{1}{N}\sum_{o=1}^{N}\left(d_{n,o} + d_{o,sink}\right)}; \quad m = 1, 2, ..., N \tag{6}$$

$$L_m = \frac{\left(PL_{n,m} + PL_{m,sink}\right)}{\frac{1}{N}\sum_{o=1}^{N}\left(PL_{n,o} + PL_{o,sink}\right)}; \quad m = 1, 2, ..., N \tag{7}$$

$$H_m = \frac{h_{m,r}}{\frac{1}{N}\sum_{o=1}^{N} h_{o,r}}; \quad m = 1, 2, ..., N \tag{8}$$

where E0 is initial energy level of nodes, E(m) is current energy level of node m, dm,sink is distance of node m to sink, PLm,sink is path loss of the communication from node m to sink, and hm,r is history of node m for becoming CH at round r, i.e., the number of rounds from the beginning to round r at which node m has been selected as a CH node.

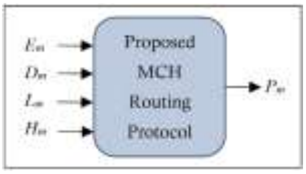

Fig. 2. CH selection using CHM protocol.

In each round, when priority factor of all nodes for becoming the CH node for the root node n have been calculated via the CHM protocol, the node m that has obtained the maximum priority factor, is chosen as relay node of the root node n. If any node m is chosen as the relay node, the node n is considered as a non-CH node (member); otherwise, it is a CH node.

C) Optimization of CHM using GA

The flowchart of the GA to optimize the CHM protocol can be seen in Fig. 3. At first, a population of initial chromosomes is randomly generated. Then, the quality of population is iteratively justified, and eventually the population is updated using recombination, crossover, and mutation. After termination of the pre-determined iterations of GA, the algorithm is finished, and eventually, the globally best chromosome is selectd as optimized CHM protocol. To gain more insights into the details of the proposed hyperparameter tuning process, the pseudo-code of the GA for optimization of the CHM protocol can be seen in Algorithm 1.

Solution encoding & decoding: To obtain the best efficiency, we utilize GA to tune the CHM model parameters comprising wE, wD, wL, and wH, as seen in Fig. (4). Encoding of a feasible solution (chromosome) to the problem is shown in Fig. 4, wherein each weight should be optimized in the range of [0,1].

Fitness evaluation: To justify the quality of the generated solution (chromosome) i, it should be firstly decoded and considered for a fully network simulation of the WBAN via the CHM protocol, utilizing the corresponding weights of chromosome i. Afterward, fitness of the solution is measured according to the obtained FND, HND (half nodes die), and LND (last node dies), via a weighted averaging function, which can be expressed as:

$$\text{Fitness}(i) = w_{FND} \times FND(i) + w_{HND} \times HND(i) + w_{LND} \times LND(i) \quad (9)$$

where w_{FND}, w_{HND}, and w_{LND} (w_{FND}+w_{HND}+w_{LND}=1) respectively determine the relative importance of FND, HND, and LND within the fitness function of Eq. (9). The more weight of a measure (i.e., FND, HND, or LND), the more influence of the corresponding performance lifetime measure in the overall fitness function. It should be mentioned that the weights w_{FND}, w_{HND}, and w_{LND} can be determined based on the specifications of the application. As an instance, if only FND measure would be important in an application, we must specify the weights as: w_{FND}=1, w_{HND}=0, and w_{LND}=0.

w_E	w_D	w_L	w_H

Fig. 3. A feasible solution (chromosome).

Algorithm 1. Hyperparameter tuning of the CHM using GA

Inputs:

Controllable parameters of GA: population, iteration, …

WBAN dataset: no. nodes, position of nodes, …

Output:

Optimized CHM protocol.

GA Algorithm:

1. Generate random initial population
2. Fitness evaluation for each chromosome using Eq. (9)
3. *it* = 0;
4. ***while*** (*it* ≤ maximum iterations)
5. Sort population from highest fitness to the lowest fitness
6. Direct transfer P_R% of the best chromosomes
7. ***for*** *s* = 1: P_C% of the population
8. Select two chromosomes via roulette wheel method
9. Construct a new chromosome via uniform crossover
10. ***end for***
11. ***for*** *s* = 1: P_M% of the population
12. Select a chromosome via roulette wheel method
13. Construct a new chromosome via swap mutation
14. ***end for***
15. Fitness evaluation for each chromosome using Eq. (9)
16. Update global best solution, found so far
17. *it* = *it*+1;
18. ***end while***
19. Consider global best chromosome as optimized CHM

Population updating: In each iteration of GA, the current population of chromosomes can be updated via recombination, mutation, and crossover on PR%, PM%, and PC% of the population, respectively. To achieve recombination, PR% of solutions with the highest fitness value are transferred into the next iteration. In crossover step, two solutions are chosen via roulette wheel method, and then, combined via a crossover operator (e.g., one-point, two-points, or uniform) to generate a new chromosome. In mutation step, a single chromosome is selected via roulette wheel method, and then, is mutated via a swap mutation operator, in order to obtain a new chromosome. In the roulette wheel method that has been used to select parents in both crossover and mutation steps, the probability of each chromosome to be chosen as a parent is proportional to its fitness value which has been calculated by Eq. (9).

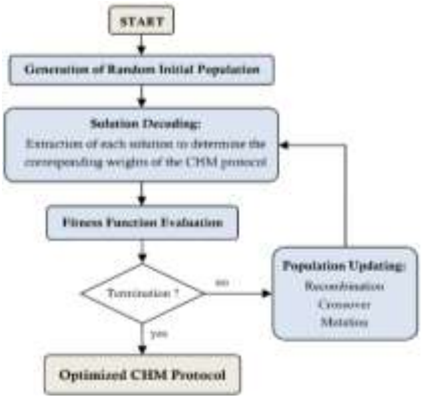

Fig. 4. Flowchart of GA to optimize CHM protocol.

4. Simulation results

A) Settings

We have tested the proposed CHM protocol as well as the ECBR and EMRP on two WBANs. The network parameters are provided in Table 1. In our experiments, the WBAN is considered to be a 3D human body with a size of 0.8 × 1.8 × 0.3 meters. In WBANs 1 and 2, there are 10 and 20 sensor nodes, respectively, plus a sink node which is attached at the position of (0.4 m, 0.9 m, 0.3 m). Each node has an initial power supply with 1 Joule energy. At every round, each alive sensor node transmits a packet of data with length of 400 bits using a direct (one-hop communication) or using a cluster head (two-hop communication) to sink. In order to adjust the GA parameters, according to [30], at first, each parameter has been evaluated via different values, and then, the value which has obtained the best fitness and convergence has been set for final experiments. Final value of the GA parameters are provided in Table 2.

B) Offline tuning results

The optimization results of the GA to tune the CHM protocol for both WBAN applications can be seen in Table 3. Based on the achieved results, energy level, path loss, distance, and history of becoming CH, are respectively the most important factors to select proper CHs.parameters

C) Online routing results

Comparison of the FND, HND, and LND by the different techniques are shown in Table 4. Moreover, the number of alive nodes and successfully delivered packets to the sink can be summarized respectively in Tables 5 and 6. According to Table 4, CHM extends FND for WBAN 1 by 253% and 121%, as compared with ECBR and EMRP, respectively. For WBAN 2, this improvement rate is 337% and 73%, as compared with ECBR and EMRP, respectively. As CHM obtains better FND and HND than ECBR and EMRP, the number of delivered packets is much more than ECBR and EMRP.

Table.1.
Parameters of network.

Parameter	***Value***
MAC	IEEE 802.15.6
Workspace size	0.8 × 1.8 × 0.3
Number of nodes in WBAN 1	10
Number of nodes in WBAN 2	20
Sink position	(0.4, 0.9, 0.3)
Initial energy of sensor nodes	1 J
Data packet size	400 bits
E_{TE}	16.7 nJ/bit
E_{RE}	36.1 nJ/bit
E_{amp}	1.97 nJ/bit/m$^{\eta}$
d_0	0.1 m
f	2.4 GHz
c	3×10^{8} m/s
η	3-7

Table.2.
Parameters of GA.

Parameter	***Value***
Iteration	100
Population	30
P_R (recombination percentage)	10%
P_C (crossover percentage)	60%
P_M (mutation percentage)	30%
Selection mechanism	Roulette Wheel
Crossover operator	Uniform
w_{FND} (weight of FND in Eq. 9)	0.5
w_{HND} (weight of HND in Eq. 9)	0.3
w_{LND} (weight of LND in Eq. 9)	0.2

Table.3.
Optimized CHM parameters.

Parameter	***WBAN 1***	***WBAN 2***
w_E	0.72	0.76
w_D	034	0.27
w_L	0.45	0.41
w_H	0.25	0.17

The total number of alive nodes in different rounds for WBANs 1 and 2 are respectively shown in Figs. 5 and 6. According to the results, CHM is more stable than ECBR and EMRP, as it prolongs the death of the first node. However, the LND of

CHM is less than that of in ECBR and EMPR for both WBANs. It should be mentioned that perishing a node in WBANs may result critical damages, and thus, the WBAN is not so valid after reaching FND. Comparison of the fitness value of Eq. (9) obtained by different techniques for both WBANs can be seen in Fig. 7. According to the results, CHM is superior against ECBR and EMRP in term of the overall fitness. The gain of CHM for WBAN 1 is 77.6% and 21%, as compared with ECBR and EMRP, respectively. This gain for WBAN 2 is 54.1% and 18.9%, as compared with ECBR and EMRP, respectively.

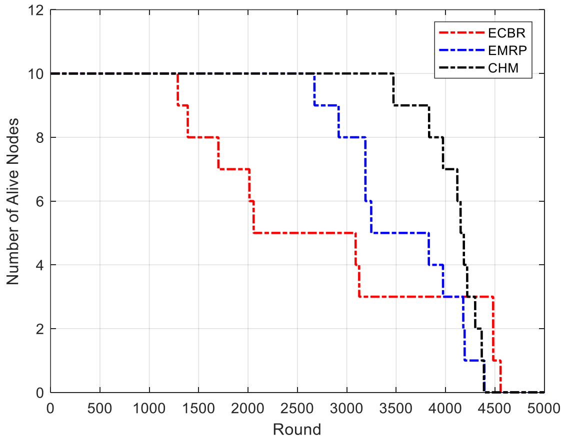

Fig. 5. No. alive nodes per rounds in WBAN 1.

Table.4.
Comparison of FND, HND, and LND

Algorithm	*WBAN 1*			*WBAN 2*		
	FND	*HND*	*LND*	*FND*	*HND*	*LND*
ECBR	1289	2057	4558	1013	2559	4427
EMRP	2673	3248	4394	1974	3101	4409
CHM (Proposed)	3473	4153	4389	2786	3669	4175

Table.5.
No. alive nodes per different rounds.

Round	*WBAN 1*			*WBAN 2*		
	ECBR	*EMRP*	*CHM*	*ECBR*	*EMRP*	*CHM*
0	10	10	10	20	20	20
500	10	10	10	20	20	20
1000	10	10	10	20	20	20
1500	8	10	10	18	20	20
2000	7	10	10	17	18	20
2500	5	10	10	11	17	20
3000	5	8	10	9	11	19
3500	3	5	9	5	6	15
4000	3	3	7	3	3	2
4500	1	0	0	0	0	0
5000	0	0	0	0	0	0

Table.6.
Round history of successfully received packets by sink.

Round	*WBAN 1*			*WBAN 2*		
	CBR	*MRP*	*HM*	*CBR*	*EMRP*	*HM*
0	0	0	0	0	0	0
500	5000	5000	5000	10000	10000	10000
1000	10000	10000	10000	20000	20000	20000
1500	14677	15000	15000	29357	30000	30000
2000	18376	20000	20000	38215	39952	40000
2500	20945	25000	25000	45337	48857	50000
3000	23445	29589	30000	50299	55887	59785
3500	25159	32712	34972	53664	60029	68706
4000	26659	35016	39279	55326	62212	72904
4500	28123	35781	41008	56311	63184	73152
5000	28180	35781	41008	56311	63184	73152

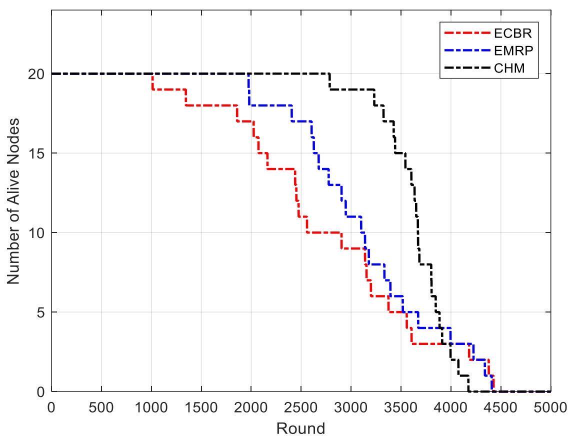

Fig. 6. No. alive nodes per rounds in WBAN 2.

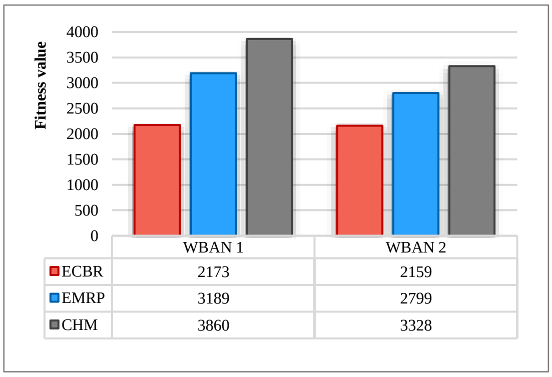

Fig. 7. Comparison of the fitness function in different methods.

5. Conclusion

In this study, a hybrid heuristic-metaheuristic algorithm (named CHM) has been introduced as an adjustable clustering algorithm for routing in WBANs. The CHM model adopts a multi-criteria heuristic utilizing energy level, distance to sink, path loss, and history of becoming cluster head, for the selection of the most appropriate relay nodes in each round. The parameters of CHM have been optimized via genetic algorithm, to prolong the network lifetime as much as possible based on the specific application definitions.

Obtained results in MATLAB on two WBANs have demonstrated the superiority of CHM against the existing technique. The results showed that the proposed CHM protocol outperforms the existing methods in terms of FND and HND for all WBANs. This indicates that CHM is more effective in prolonging the network lifetime than the existing techniques. Moreover, the CHM model achieved a higher number of delivered packets than the other methods. However, the proposed CHM protocol has a lower LND compared to the existing techniques for both WBANs. Overall, the evaluation of the obtained results has provided strong evidence of the superiority of the proposed model over existing techniques in terms of network lifetime, energy consumption, and packet delivery ratio.

In this paper, a classical heuristic has been used to select relay nodes. As a future research direction, fuzzy-based heuristics could be applied to select proper cluster heads, while a metaheuristic is used for the fuzzy rule tuning. Moreover, other metaheuristic-based techniques such as whale optimization algorithm, artificial bee colony, simulated annealing, and grey wolf optimizer, can be used to tune the CHM protocol.

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