Metaheuristic based routing incorporated with energy harvesting for enhanced network lifetime in WBAN

Ganeson Sathya, Daniel Jasmine Evanjaline
Department of Computer Science, Rajah Serfogi College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli, India

Article Info

Article history:

Received Aug 20, 2022
Revised Sep 30, 2022
Accepted Oct 24, 2022

Keywords:

Ant colony optimization
Energy harvesting
Metaheuristics
Multi criteria decision making
Routing
Wireless body area networks

ABSTRACT

Wireless body area networks (WBAN) have improved healthcare industries to a large extent by providing contactless measurements and remote data analysis. However, the challenges encountered are mostly in the form of energy depletion scenarios, which results in the reduction of network lifetime to a large extent. This work presents an effective model to provide energy-efficient routing and enhanced energy harvesting mechanisms to improve network lifetime. The ant colony optimization (ACO) method has been extended to include a fitness function that takes into account several factors, and this is the basis for the routing model. These processes ensure effective routing, which conserves energy and, in turn, results in enhanced network lifetime. Performance of the proposed model has been compared with the existing state-of-the-art models in the domain. Comparison with the metaheuristic-based model, cooperative energy efficient and priority based reliable routing protocol with network coding (CEPRAN), indicates the efficiency of the energy harvesting mechanism used in the proposed work. When compared with models using energy harvesting mechanisms, results exhibit higher network lifetime, depicting the efficiency of the proposed routing mechanism.

Corresponding Author:

Ganeson Sathya
Department of Computer Science, Rajah Serfogi College (Autonomous)
Affiliated to Bharathidasan University
Palkalaiperur, Tiruchirappalli, Tamil Nadu 620024, India
Email: rschlrsathya@outlook.com

1. INTRODUCTION

Microelectronics have become more powerful and can handle higher memory computations [1]. They are also found to exhibit increased computing capabilities and battery capacity levels. These positive changes in microelectronics have reshaped technology to a large extent. They have enabled better and more powerful sensors [2]. Further, these devices are incorporated with wireless communication capabilities to ensure external communications. Hence, they can be deployed even in inaccessible locations for collecting information. The collected information undergoes low levels of processing and is transmitted to the base stations. Base stations are more powerful computing machines. Hence they collect the data and process them to derive better and more powerful insights [3]. Varied types of sensor networks can be created using these devices, of which wireless body area networks (WBAN) are a special type of network mainly used in healthcare applications.

Several physiological indicators may be measured by deploying WBAN networks either within or outside the human body [4]. They monitor, collect and transmit several parameters within and outside the human body. These sensors are small. Hence, they can be effectively deployed on or inside the human body without any disturbance to the person. The sensors vary considerably based on the location of deployment and the measure they will record. WBAN sensors can effectively measure parameters like blood pressure, body temperature, and glucose levels [5]. The collected data is transmitted to the base station, the sink node. These are again transmitted to devices outside the body for remote examinations by physicians [6]. With the increase in the number of diseases worldwide, a huge demand arises for effective measuring tools and physicians. The usage of WBAN systems can provide an effective solution to this issue.

The major advantage of using WBAN systems is that it does not require a medical practitioner to be present with the patient. Several critical measurements, such as electroencephalogram (EEG) and electrocardiogram (ECG), can be easily remotely collected with these sensors. Doctors can analyze the reports and can provide contactless prescriptions to patients. These models, however, pose several challenges. The major challenge arises due to their small size. The small size restricts battery capacity to a large extent.

Further, another issue is the problem of packet loss and the need for retransmissions [7], [8]. These requirements tend to increase battery usage further, resulting in faster depletion. The high mobility associated with the human body also poses a challenge, as the network tends to become dynamic. The constraint of limited node deployment and the absence of opportunities for redundancy results in the requirement of routing models with low failure rates. Energy efficiency also plays a vital role in deciding the routes. This work presents an effective model that uses modified ant colony optimization (ACO) to provide energy-efficient routes.

Energy efficiency is of paramount importance in WBAN architecture. Most of the proposed modeling techniques deal with routing models with a major concentration on providing energy-efficient routes. The latest research in this area is discussed in this section.

An energy-efficient modeling technique that integrates an energy harvesting mechanism for improving the network lifetime was proposed by [9]. This work is based on a clustering technique for identifying energy-efficient routes. The model uses a multi-attribute-based clustering mechanism and identifies cluster heads to perform cooperative routing. The model operates in two phases; the cluster head identification phase and the routing phase. The model mainly focuses on reducing retransmission to improve energy efficiency. An energy-efficient model was proposed by [10]. The model uses a low-overhead tree-based routing scheme and specializes in multi-hop routing. The model concentrates on energy utility and conserving transmission power. The model also concentrates on issues arising due to body shadowing. A dual sink approach using clustering techniques was proposed by [11]. The work mainly focuses on reducing the path loss levels in the transmission process. Another energy efficiency-based extension approach was proposed by [12].

An energy-aware routing model used for health monitoring was proposed [13]. The model uses critical data routing techniques to transmit information from the sensor nodes deployed inside the body to the sensor on-body. The work also uses threshold-based data transmission controllers to ensure the effective transmission of emergency traffic. This ensures redundant transmission of regularly lost packets. A reliable and energy-conserving model for transmission between body sensors was proposed [14]. The work uses a stealing signal to ensure lossless transmissions and to conserve energy. Another similar energy efficiency-based model to conserve energy was proposed in [15]. A cooperative energy efficient, and priority-based reliable routing protocol, cooperative energy efficient and priority based reliable routing protocol with network coding (CEPRAN), was proposed [16]. This work is based on enhancing the reliability and cooperative behavior among the nodes to ensure faster and energy-efficient transmissions. The work uses cuckoo search-based optimization to identify the relay nodes for data transmission. A link aware and energy efficient scheme (LAEEBA) was proposed [17]. This work introduces the concept of a forwarder node. The forwarder node is identified in a route based on the distance and residual energy levels.

A thermal energy-aware routing model for effective routing in [18] WBAN systems was proposed. This work has its major focus on maintaining stability and providing effective routing. The work provides an effective balance between maintaining the charge and reducing the temperature levels of the nodes to reduce overheating. An energy-aware peer routing protocol was proposed in [19]. This work aims to create a patient monitoring framework that improves energy efficiency and provides peer routing for WBAN. An energy-aware routing protocol was proposed by [20]. The work identifies the major sources of energy depletion and follows up with a 2-hop routing model that can be energy efficient and also can effectively handle issues occurring due to posture changes. Other similar routing models for energy awareness include the grey wolf optimization-based model [21] and the energy harvesting-based model [22]. A comparative analysis of the discussed literature works has been tabulated and provided in Table 1.

Table 1. Comparative analysis of works from literture

Technique	Energy harvesting	Energy aware routing	Routing technique	Notes
E-HARP [9]	Yes	Yes	Cooperative routing	Cluster based node grouping
Liang *et al.* [10]	No	Yes	Tree based routing	Retransmission reduction
DSCB [11]	No	No	Dual sink approach	Handles body shadowing
EH-RCP [12]	Yes	Yes	Multi-hop routing	Clustering based node grouping
CDR [13]	No	Yes	Critical data routing	Threshold based transmission
Tsouri *et al.* [14]	No	Yes	Multi hop transmissions	Relaying of creeping waves for transmission
REEC [15]	No	Yes	Critical data routing	
CEPRAN [16]	No	Yes	Cooperative routing	Reliable routing
LAEEBA [17]	No	Yes	Multihop routing	Forwarder node-based routing
Shahbazi and Byun [18]	No	Yes	Thermal energy aware routing	Balances charge and temperature of nodes
EPR [19]	No	Yes	Peer routing	
Shaik and Subashini [20]	No	Yes	2-hop Routing	Handles posture changes
Bedi *et al.* [21]	No	Yes	Grey wolf optimization-based routing	Uses Q learning
Gherairi [22]	Yes	No	Priority based routing	

2. METHOD

Identifying effective and energy-efficient routes is important in WBAN to ensure a longer network lifetime. The system model for the proposed routing architecture is provided in Figure 1. This work proposes a metaheuristic-based algorithm for route detection. The proposed metaheuristic model is based on multi-criteria decision-making to incorporate all the necessary criteria for effectively identifying nodes for the route creation process. The major advantage of using a metaheuristic-based model is that it can be time constrained. Hence the model can be operated upon even in applications with short-time requirements. Energy efficiency is incorporated using two mechanisms; the first is using energy-effective routes, and the second mechanism is using energy harvesting techniques. Energy harvesting mechanisms ensure continuous energy supply to the nodes, reducing the need to replace batteries and the probability of dead nodes. The proposed routing mechanism is performed in three phases; network initialization phase, data transmission and state analysis phase, and metaheuristic-based energy efficient route identification phase.

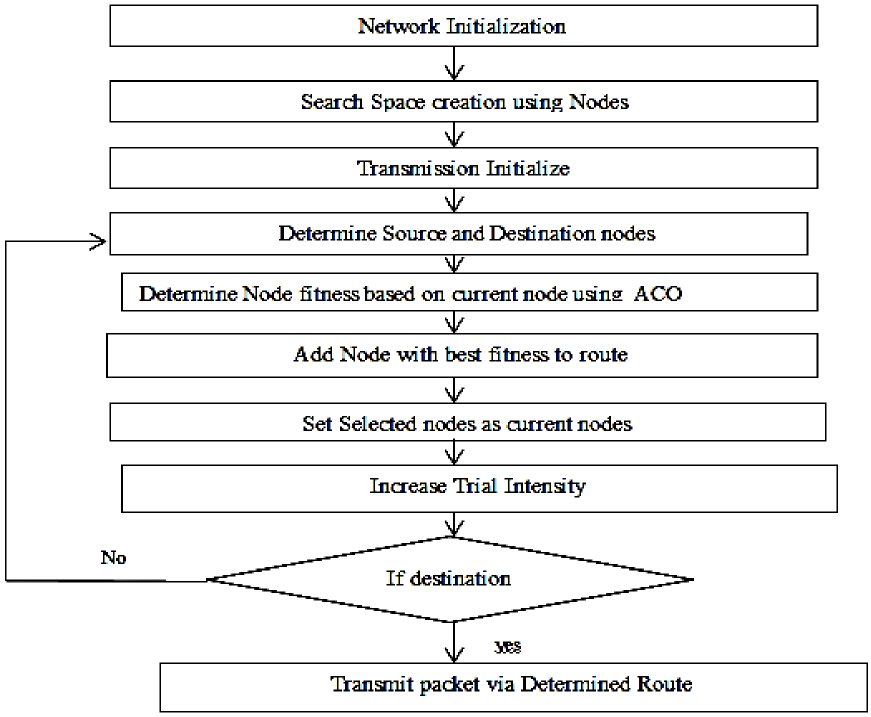

Figure 1. Metaheuristics based energy effective routing (MEER) system model

2.1. Assumptions

WBAN has 14 sensor and 2 sink nodes, network has 16 nodes. All sensor nodes acquire bodily data and send it to sink nodes. The sink nodes send information to body-surface devices or external devices for transmission and processing. Single-hop or multi-hop communication is used to send data to sink nodes. In emergencies, single-hop data transmission is employed, while typical data is multi-hop. Emergency, delay-sensitive, reliability-sensitive, and general data are collected. Sensor node data categorization determines transmission type. General data uses multi-hop transmissions, while other traffic uses single-hop. Single-hop broadcasts raise node temperatures more than multi-hop transmissions. The following are the major assumptions adopted in the proposed model:

- During data collection, processing, transmission, and reception, nodes use power. Data transmission and reception stages consume more electricity than other activities. Thus, processing power usage is neglected [23].
- Although the sensors are deployed in the human body, body and limb movements can result in changes in the deployment locations. Hence the network is considered to be dynamic in nature, and so path identification is performed prior to every transmission.
- The sensor nodes deployed within human body are highly power constrained in nature. Once deployed, they cannot be accessed for battery replacements. Hence, the sensors are considered to be equipped with energy harvesting mechanisms [9]. Charge of sensors are considered to increase in a periodic manner as shown in (1).

$$E_{Harvest} = \int_a^t C_i(\tau)d\tau \tag{1}$$

  where C_i represents node is charge rate between a and t.
- Deployment is performed within the human body, hence loss due to human body interference is expected during transmissions. The path loss model follows the standard IEEE 802.15.6 BAN standards [24]. The path loss levels are given by:

$$PathLoss_{ij} = \propto * \, log_{10}(D) + \beta * log_{10}(f) + N_{df} \tag{2}$$

  N_{df} is the distributed variable with a value of 158 dB, and are linear coefficients with values of -27.6 and -46.5 [24], and D is the distance between nodes I and j.
- The Euclidean distance between two points is defined as

$$D_{ij} = \sqrt{(yi - yj)^2 + (xi - xj)^2} \tag{3}$$

  where x and y represent the nodes' I and j coordinates.
- The first order ratio model [25], given by, is used to determine the amount of energy used for data transmission and reception.

$$E_{Trans} = E_{Tcharge} * K + E_{Amp} * n * K * D \tag{4}$$

$$E_{Rec} = E_{Rcharge} * K \tag{5}$$

  where E_{Tcharge} and E_{Rcharge} are the node's transmission and reception costs respectively, K is the amount of bits sent, D is the distance travelled, and n is the route loss experienced.

2.2. Network initialization

Network initialization is the first phase to be performed after the deployment of sensor nodes and the sink nodes. The first process after deployment is to ensure all nodes are aware of their neighbors and the sink nodes. Hence all nodes identify their locations and calculates their distance with other nodes and the available sink nodes. A beacon message is sent in the network based on the time division multiple access (TDMA) protocol. The beacon contains sender and receiver IDs, the residual energy contained in the node, location of the node and the transmitted signal power. On receiving such a message, the receiving nodes calculates the path loss levels and identifies the distance between the sender and themselves. This information update is performed on all the available nodes. Distance and loss levels of nodes are however tentative in nature, as they dynamically vary due to change in postures of the person. Hence prior to every transmission, these are calculated.

2.3. Data transmission and state analysis

Nodes collect and transmit data after initialization. All nodes collect data for sink nodes—the sink nodes transport all data to external devices for processing and analysis. The type of gadget deployed determines the data acquired. EEG, ECG, insulin levels, temperature, and heart rate. Every device has different parts. Hence the network is heterogeneous. Data can be sent in any of the four states. Regular and customary traffic or emergency, delay-sensitive, and reliability-sensitive communications. General communications are not delay-sensitive, but others are. High-priority traffic is fatally delayed. To accommodate this traffic, single and multi-hop broadcasts are used. Regular traffic uses multi-hop transmissions, while sensitive traffic uses single hop transmissions, which are time restricted. Single-hop transmissions use more power and raise node temperatures more than multi-hop traffic. If it's emergency traffic, the packet is sent immediately to the sink node; otherwise, the routing model is invoked. The routing model determines the best route.

2.4. Metaheuristic based energy efficient route identification

The routing model shows the source-to-sink path. The routing process uses a modified ACO model. ACO's discrete search space is a big advantage over particle swarm optimization (PSO) and firefly's continuous search space. Discretization is avoided. ACO allows for several extra fitness criteria. ACO is the ideal routing approach since the current job requires numerous fitness criteria. The ACO [26], [27] model has been updated to accommodate many criteria, turning the routing process into a multi-criteria decision model.

Sensor data determines a node's status. Regular traffic triggers ACO-based routing. Every package needs a route. ACO's speed and minimal computing requirements make it ideal for constructing models. ACO transmits via distance and pheromone trail. These two elements determine the ACO model's fitness. Distance, the receiving node's temperature, and its charge are utilised in the modified ACO model's decision-making process. For route creation, low-distance, high-charge nodes are preferred. The modified fitness function using multiple criteria for node selection is given by.

$$p_{ij}(t) = \frac{[\tau_{ij}(t)]^{\alpha}.[\eta_{ij}]^{\beta}.[\varepsilon_j(t)]^{\gamma}.[\vartheta_j(t)]^{\delta}}{\sum_{j=1}^{n}[\tau_{ij}(t)]^{\alpha}.[\eta_{ij}]^{\beta}.[\varepsilon_j(t)]^{\gamma}.[\vartheta_j(t)]^{\delta}} \tag{6}$$

Where τ_{ij} denotes the pheromone intensity between nodes, i and j, η_{ij} is the distance between the nodes i and *j*, ε_j is the charge of node j, and contained in the exemplar node j and, ϑ_j is the temperature in node j.

As a transmission is triggered, the modified ACO model begins predicting the route by selecting the nodes one at a time based on the fitness probability. Existing and unused nodes are considered as probable nodes for building the route. After every successful inclusion of a node in the route, the train intensity between the two nodes is increased. The increase in trail intensity is given by:

$$\tau_{ij}(t+1) = \rho.\tau_{ij}(t) + \Delta\tau_{ij}(t, t+1) \tag{7}$$

where ρ is the evaporation parameter, *t* is is the time and $\Delta\tau_{ij}$ is given by:

$$\Delta\tau(i,j) = \begin{cases} (L_k)^{-1} & if\ (i,j)\ belongs\ to\ the\ global\ best\ tour \\ 0 & Otherwise \end{cases} \tag{8}$$

where L_k is the total distance covered by the ant from the source to the destination.

The process is repeated until any one of the sink nodes is reached. After successful transmission, the charge in the node reduces, and its temperature tends to increase. However, the energy harvesting mechanism embedded in the sensor node ensures periodical replenishment of charge, while the temperature is automatically reduced when the node is in its resting period. The entire process is performed for every multi hop transmission requirement from a sensor node.

3. RESULTS AND DISCUSSION

Performance of the proposed ACO model has been analyzed by comparing the model with the E-HARP model proposed by Ullah *et al.* [9], EH-RCP model proposed by Ullah *et al.* [12] and CEPRAN, a metaheuristic-based routing model proposed by Geetha and Ganesan [16]. The experimentation model used in the E-HARP model is adopted in the proposed MEER architecture to enable performance comparisons. The deployment locations of the nodes form the search space for the modified ACO model. The search-space for the modified ACO has been constructed by using the co-ordinates proposed in E-HARP model. The location points are presented in Table 2. After deployment, the nodes are considered to collect information and perform transmissions at defined epochs. Every transmission is considered as a single round of data transmission, and transmissions were performed for every second. The analysis begins from the first round and is performed for 18,000 rounds, as this was the identified point when all the nodes have lost their charge.

Table 2. Deployment locations of sensor nodes

Node number	X-axis	Y-axis
1.	0.32	1.77
2.	0.35	1.37
3.	0.22	1.35
4.	0.36	1.01
5.	0.35	0.01
6.	0.08	1.45
7.	0.06	0.98
8.	0.37	1.27
9.	0.4	1.01
10	0.22	0.91
11.	0.45	0.45
12.	0.15	0.5
13.	0.15	0.45
14.	0.25	0.17
15.	0.3	1.03
16.	0.09	1.05

A comparative analysis of the network lifetime is shown in Figure 2. Network lifetime refers to the total working time of the network. It is measured beginning from the node deployment stage until the point where all the nodes are entirely depleted of their charge. Network lifetime is considered to be one of the major parameters of measurements in WBAN, as node replacements as impossible when considering nodes that are deployed inside human body. It could be observed that the E-HARP and EH-RCP models have reached their end of lifetimes at 16,000th round, while the proposed MEER model exhibits enhanced lifetime extending to 18,000th round. This depicts that the MEER model exhibits a better routing strategy that effectively extends the network lifetime better than the other models.

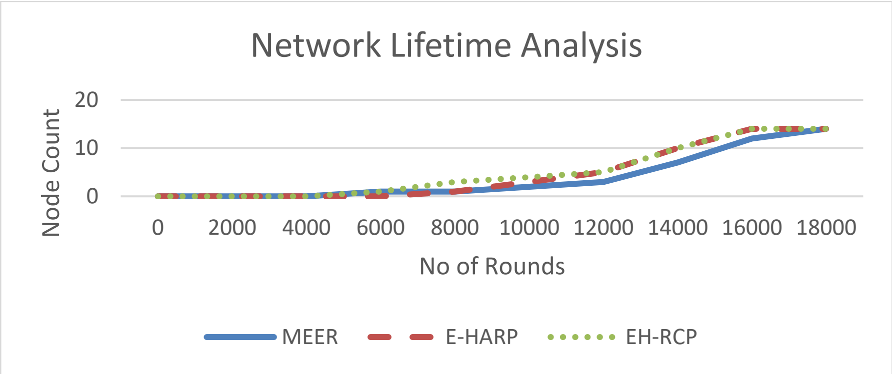

Figure 2. Network life time analysis of MEER

An analysis of the network lifetime is shown in Table 3. Total number of nodes that are alive are recorded in intervals of 2,000 rounds. It could be observed from the measurements that at the 16,000th round, the network lifetime of E-HARP and EH-RCP has ended, while the proposed MEER model still has two nodes left in the network. At the 18,000th round, all the available nodes were depleted of charge. Since all the three models use energy harvesting mechanisms, performance improvement is totally attributed to the modified ACO based routing mechanism.

A comparative analysis of the dead nodes in the networks is shown in Figure 3. The comparisons have been performed with CEPRAN, a cuckoo search-based routing model. It could be observed that the level of dead nodes in MEER and CEPRAN begin at the same iteration, and remain same until 6,000th iteration. However, after this point, the CEPRAN model exhibits higher node depletions leading to more dead nodes, while the proposed MEER model exhibits slower node depletions, resulting in longer network lifetime. Further, the CEPRAN model does not incorporate energy harvesting mechansims. Hence, apart from the effective routing process, the extended network lifetime is also attributed to the energy harvesting mechanism adopted in MEER.

Table 3. Network life time

	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000
MEER	0	0	1	1	2	3	7	12	14
E-HARP	0	0	0	1	3	5	10	14	14
EH-RCP	0	0	1	3	4	5	10	14	14

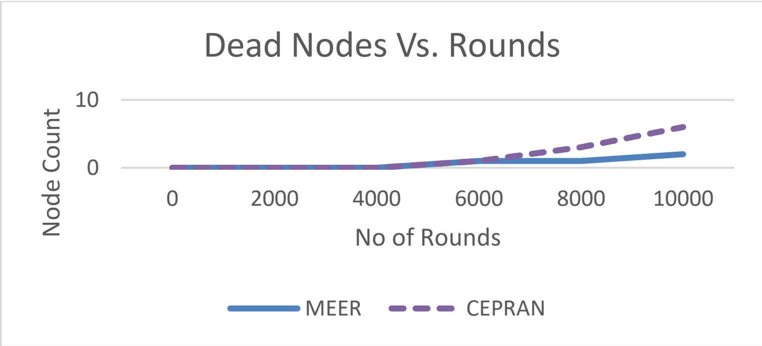

Figure 3. Dead nodes Vs. rounds

The stability period of a network refers to the time that has transitioned between the deployment of the nodes and the death of the first node in the network. It can also be defined as the period until all the nodes in the network are alive. This is another performance criteria that indicates how stable a network can be, as death of the first node is indicative that the network is starting to deteriorate. Networks with better stability are considered to exhibit longer live and transmission periods. A comparative view of the stability levels is shown in Figure 4. It could be observed that the network supported by MEER, EH-RCP and E-HARP are stable till 4,000th round, which indicates that the network has performed 4,000 successful transmissions. However, in the 6,000th transmission, MEER and EH-RCP indicates loss of one node in the network. E-HARP exhibits its initial loss in the 8,000th transmission. However, it could be observed that EH-RCP and E-HARP models exhibit steep deterioration curves, indicating that once a node fails, the network begins to lose its stability in a rapid manner. However, the proposed MEER model exhibits slower deterioration levels, depicting better stability even after node failures.

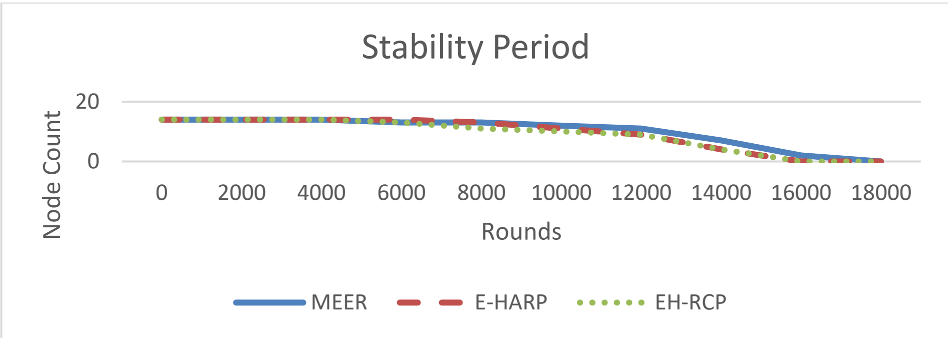

Figure 4. Aggregated metric comparison

Stability analysis of the MEER model and the other compared models have been tabulated and shown in Table 4. It could be observed that, although the deterioration levels begin at round 6,000 for the MEER model, node depletion levels remain consistent, rather than being rapid, ensuring better stability. Transmission time defines the time interval that has elapsed for every 2,000th round. Low time requirements are indicative of better routing models. It could be observed from Figure 5 that the first 2,000 rounds exhibit high time requirements. However, as the initial transmissions incur node identification transmissions. Hence this increase in time requirements can be justified. It could be observed that further transmissions exhibit reduced time requirements, and stability in time requirements has been achieved at round 6,000, after which fluctuations in the time requirements are observed to be minimal.

Table 4. Stability analysis

	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000
MEER	14	14	13	13	12	11	7	2	0
E-HARP	14	14	14	13	11	9	4	0	0
EH-RCP	14	14	13	11	10	9	4	0	0

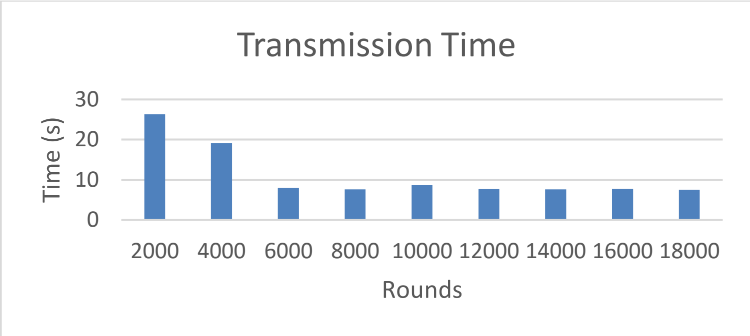

Figure 5. Transmission time requirements

4. CONCLUSION

Improving the energy efficiency of WBAN during the routing process has become paramount importance, due to the limited battery capabilities of the sensors in WBAN systems. Effective routing can not only improve the communication speed, but also provide better energy usage of sensors. This work presents a MEER, that presents a modified ACO based routing model. The fitness function of ACO has been modified to include multiple criteria such as node energy and temperature. The nodes are considered to adopt an intrinsic energy harvesting mechanism, which enables nodes to gain charge after periodical time intervals. These routing mechanisms have been observed to exhibit high efficiency in the routing process and have also enabled energy efficiency. Comparisons with E-HARP and EH-RCP, energy harvesting based models show that the routing model operates effectively by providing effective load balancing and highly effective routes. Comparison with CEPRAN, a metaheuristic-based routing model indicates that the energy harvesting mechanism of the MEER model is highly effective, enabling higher network lifetime levels.

The major advantage of this model is the improved network lifetime compared to the other existing models. However, initial node failures were observed to occur at earlier time periods. Future enhancements of this model include mechanisms that can handle this issue. Further, future works can also include components that can identify old, stale or redundant data to ensure faster delivery of new packets and also provides better energy efficiency.

REFERENCES

[1] M. Arshad *et al.*, "Beacon trust management system and fake data detection in vehicular ad-hoc networks," *IET Intelligent Transport Systems*, vol. 13, no. 5, pp. 780–788, May 2019, doi: 10.1049/iet-its.2018.5117.
[2] M. M. Baig, "Smart vital signs monitoring and novel falls prediction system for older adults," Ph.D. dissertation, Auckland Univ. of Technology, Auckland, New Zealand, 2014.
[3] World Health Organisation, "Telemedicine: Opportunities and Developments in Member States - Report on the second global survey on eHealth," *World Health Organisation*, 2010. https://apps.who.int/iris/handle/10665/44497 (accessed Aug. 10, 2022).
[4] S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, and A. Jamalipour, "Wireless body area networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 3, pp. 1658–1686, 2014, doi: 10.1109/SURV.2013.121313.00064.
[5] I. Ha, "Technologies and research trends in wireless body area networks for healthcare: A systematic literature review," *International Journal of Distributed Sensor Networks*, vol. 11, no. 6, pp. 1–14, Jun. 2015, doi: 10.1155/2015/573538.
[6] M. H. Rehmani, E. Ahmed, S. U. Khan, and M. Radenkovic, "IEEE Access special section editorial: Body area networks for interdisciplinary research," *IEEE Access*, vol. 4, pp. 2989–2992, 2016, doi: 10.1109/ACCESS.2016.2580464.
[7] A. Kumar and G. P. Hancke, "A zigbee-based animal health monitoring system," *IEEE Sensors Journal*, vol. 15, no. 1, pp. 610–617, Jan. 2015, doi: 10.1109/JSEN.2014.2349073.
[8] R. Challoo, A. Oladeinde, N. Yilmazer, S. Ozcelik, and L. Challoo, "An overview and assessment of wireless technologies and co-existence of ZigBee, Bluetooth and Wi-Fi devices," *Procedia Computer Science*, vol. 12, pp. 386–391, 2012, doi: 10.1016/j.procs.2012.09.091.
[9] Z. Ullah *et al.*, "Energy-efficient harvested-aware clustering and cooperative routing protocol for WBAN (E-HARP)," *IEEE Access*, vol. 7, pp. 100036–100050, 2019, doi: 10.1109/ACCESS.2019.2930652.
[10] L. Liang, Y. Ge, G. Feng, W. Ni, and A. A. P. Wai, "A low overhead tree-based energy-efficient routing scheme for multi-hop wireless body area networks," *Computer Networks*, vol. 70, pp. 45–58, Sep. 2014, doi: 10.1016/j.comnet.2014.05.004.
[11] Z. Ullah, I. Ahmed, K. Razzaq, M. K. Naseer, and N. Ahmed, "DSCB: Dual sink approach using clustering in body area network," *Peer-to-Peer Networking and Applications*, vol. 12, no. 2, pp. 357–370, Mar. 2019, doi: 10.1007/s12083-017-0587-z.
[12] Z. Ullah, I. Ahmed, T. Ali, N. Ahmad, F. Niaz, and Y. Cao, "Robust and efficient energy harvested-aware routing protocol with

clustering approach in body area networks," *IEEE Access*, vol. 7, pp. 33906–33921, 2019, doi: 10.1109/ACCESS.2019.2904322.
[13] A. K. Sagar, S. Singh, and A. Kumar, "Energy-aware WBAN for health monitoring using critical data routing (CDR)," *Wireless Personal Communications*, vol. 112, no. 1, pp. 273–302, May 2020, doi: 10.1007/s11277-020-07026-6.
[14] G. R. Tsouri, A. Sapio, and J. Wilczewski, "An investigation into relaying of creeping waves for reliable low-power body sensor networking," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 5, no. 4, pp. 307–319, Aug. 2011, doi: 10.1109/TBCAS.2011.2160060.
[15] M. M. Sandhu, M. Akbar, M. Behzad, N. Javaid, Z. A. Khan, and U. Qasim, "REEC: Reliable energy efficient critical data routing in wireless body area networks," in *2014 Ninth International Conference on Broadband and Wireless Computing, Communication and Applications*, Nov. 2014, pp. 446–451, doi: 10.1109/BWCCA.2014.101.
[16] M. Geetha and R. Ganesan, "CEPRAN-cooperative energy efficient and priority based reliable routing protocol with network coding for WBAN," *Wireless Personal Communications*, vol. 117, no. 4, pp. 3153–3171, Apr. 2021, doi: 10.1007/s11277-020-07798-x.
[17] S. Ahmed, N. Javaid, M. Akbar, A. Iqbal, Z. A. Khan, and U. Qasim, "LAEEBA: Link aware and energy efficient scheme for body area networks," in *2014 IEEE 28th International Conference on Advanced Information Networking and Applications*, May 2014, pp. 435–440, doi: 10.1109/AINA.2014.54.
[18] Z. Shahbazi and Y.-C. Byun, "Towards a secure thermal-energy aware routing protocol in wireless body area network based on blockchain technology," *Sensors*, vol. 20, no. 12, pp. 1–26, Jun. 2020, doi: 10.3390/s20123604.
[19] Z. A. Khan, S. Sivakumar, W. Phillips, and N. Aslam, "A new patient monitoring framework and energy-aware peering routing protocol (EPR) for body area network communication," *Journal of Ambient Intelligence and Humanized Computing*, vol. 5, no. 3, pp. 409–423, Jun. 2014, doi: 10.1007/s12652-013-0195-6.
[20] M. F. Shaik and M. M. Subashini, "Two-hop interference conscious and energy-efficient routing protocol for WBAN," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 11, pp. 466–477, Feb. 2019, doi: 10.5373/JARDCS/V11SP11/20193055.
[21] P. Bedi, S. Das, S. B. Goyal, P. K. Shukla, S. Mirjalili, and M. Kumar, "A novel routing protocol based on grey wolf optimization and Q learning for wireless body area network," *Expert Systems with Applications*, vol. 210, p. 118477, Dec. 2022, doi: 10.1016/j.eswa.2022.118477.
[22] S. Gherairi, "Healthcare: A priority-based energy harvesting scheme for managing sensor nodes in WBANs," *Ad Hoc Networks*, vol. 133, p. 102876, Aug. 2022, doi: 10.1016/j.adhoc.2022.102876.
[23] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," *Computer Networks*, vol. 38, no. 4, pp. 393–422, Mar. 2002, doi: 10.1016/S1389-1286(01)00302-4.
[24] N. Katayama, K. Takizawa, T. Aoyagi, J. I. Takada, H. B. Li, and R. Kohno, "Channel model on various frequency bands for wearable body area network," *IEICE Transactions on Communications*, vol. 92, no. 2, pp. 418–424, 2009, doi: 10.1587/transcom.E92.B.418.
[25] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, 2000, pp. 1–10, doi: 10.1109/HICSS.2000.926982.
[26] A. Prakasam and N. Savarimuthu, "Metaheuristic algorithms and probabilistic behaviour: a comprehensive analysis of Ant Colony Optimization and its variants," *Artificial Intelligence Review*, vol. 45, no. 1, pp. 97–130, Jan. 2016, doi: 10.1007/s10462-015-9441-y.
[27] A. Prakasam and N. Savarimuthu, "Novel local restart strategies with hyper-populated ant colonies for dynamic optimization problems," *Neural Computing and Applications*, vol. 31, no. 1, pp. 63–76, Jan. 2019, doi: 10.1007/s00521-018-3638-3.

BIOGRAPHIES OF AUTHORS

Ganeson Sathya was born in 1983 at Thanjavur District, Tamilnadu. She completed her M.Phil in 2007 and pursuing her Ph.D under the guidance of Dr. D. J. Evanjaline, Department of Computer Science, Rajah Serfoji Government College (Autonomous), Affliated to Bharathidasan University, Trichy. Now she is working as Guest Lecturer in Government Arts and Science College (W), Orathanadu. She is having 14 years of teaching experience. Her area of research interest includes network security, data mining.she has published nearly 5 papers in national and international journals. She can be contacted at email: rschlrsathya@outlook.com.

Daniel Jasmine Evanjaline was born 1973 at Cuddalore District, Tamilnadu. She completed Ph.D from Mother Teresa Women's University, Kodaikanal in the year 2012. Currently she is working as Assistant Professor, Departmentof computer science in Rajah Serfoji Government College (Autonomous), Affliated to Bharathidasan University Trichy,, Tamilnadu. She has more than 20 years of teaching experiences. She also guided 7 research scholars from Bharathidasan University. His area of research interest includes network security, data mining, and big data. She has published more than 25 research papers in top most Elsevier and Scopus Indexed Journal. She can be contacted at email: drevanglin@outlook.com.