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Energy-Harvesting And Metaheuristic-Based Routing For Longer Network Life In WBAN

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Abstract

By enabling contactless measurements and distant data analysis, Wireless Body Area Networks (WBAN) have significantly enhanced the healthcare sectors. However, the difficulties faced typically take the shape of energy depletion events, which significantly shorten the network lifetime. In order to improve network lifetime, this work proposes an efficient model that attempts to provide energy-efficient routing as well as improved energy harvesting technologies. The routing model is based on a modified Ant Colony Optimization method, and its fitness analysis also includes multi-criteria decision making. These procedures guarantee efficient routing, which reduces energy consumption and lengthens the lifespan of the network. The proposed model's performance has been contrasted with the domain's current state-of-the-art models. Higher network lifespan results demonstrate the effectiveness of the suggested transmission mechanism.

1. Introduction

Electronics now have more processing power and are capable of higher memory computations [1]. Additionally, they are discovered to have better battery capacities and enhanced computing capabilities. Technology has significantly changed as a result of these encouraging developments in microelectronics. They have made it possible for stronger and better sensors [2]. To ensure external communications, these gadgets also include wireless communication capabilities. They can therefore be used to gather data even in inaccessible regions. Low-level processing is applied to the gathered data before it is sent to the base stations. Base stations have stronger computer capabilities. As a result, they gather the data and process it to produce more accurate and potent insights [3]. These devices can be used to form a variety of sensor networks, with Wireless Body Area Networks (WBAN) being a unique sort of network that is mostly utilised in healthcare applications.

The deployment of WBAN networks within or outside the human body is specifically intended to measure a number of physiological indicators [4]. They track, gather, and communicate a variety of internal and external parameters. Since these sensors are tiny, they can be installed on or inside the human body without causing the user any discomfort. Depending on where they are deployed and what measurement they are going to record, the sensors come in a wide variety. WBAN sensors are capable of accurately measuring a variety of variables, including body temperature, blood pressure, and glucose levels [5]. The base station, often referred to as the sink node, receives the data that has been collected. These are once more communicated to equipment outside the body so that doctors can conduct remote examinations [6]. There is a huge demand for accurate measuring devices as well as doctors due to the rise in diseases across the globe. WBAN systems can be used to solve this problem successfully.

The main benefit of adopting WBAN systems is that a doctor does not have to be present when the patient is using them. With these devices, crucial measurements like the EEG and ECG may be conveniently taken remotely. Doctors can review the reports and write patients contactless medications. These models, however, provide a number of difficulties. Due to their diminutive size, the main problem emerges. The compact dimension severely limits battery capacity. The issue of packet loss and the requirement for retransmissions is still another concern [7],[8]. These demands frequently lead to further increases in energy utilisation, hastening battery depletion. The human body's high degree of mobility is a problem since it makes the network more dynamic. Low failure rate routing models are necessary due to the restriction of limited node deployment and the lack of opportunities for redundancy. The routes are also heavily influenced by energy efficiency. In order to create energy-efficient pathways, this work presents a powerful model that makes use of modified Ant Colony Optimization (ACO). In WBAN architecture, energy efficiency is of utmost importance. The majority of the suggested modelling approaches deal with routing models, which focus primarily on presenting energy-efficient routes. The most recent studies in this field are covered in this section.

2.Related Works

[9] put out a technique for energy-efficient modelling that incorporates an energy-harvesting mechanism to extend the lifetime of the network. This approach uses clustering to find the most energy-efficient routes. In order to accomplish cooperative routing, the model employs a multi-attribute based clustering approach and finds the cluster leader. The cluster head identification phase and the routing phase are the two stages of the model's operation. To increase energy efficiency, the model primarily concentrates on lowering retransmission. [10] suggested a model that conserves energy. The model focuses on multi-hop routing processes and uses a low-overhead tree-based routing approach. The model focuses on energy efficiency and transmission power conservation. The model also focuses on problems brought on by body shadowing. [11] presented a dual sink strategy utilising clustering techniques. The work primarily focuses on lowering the transmission process route loss levels. Another extension strategy based on energy efficiency was put up by [12].

A proposed routing model with energy awareness for health monitoring was constructed [13]. In order to transmit data from sensor nodes placed inside the body to sensors that are located on the body, the model incorporates crucial data routing algorithms. In order to assure efficient transmission of emergency traffic, the work additionally employs threshold-based data transmission controllers. This makes sure that regularly missing packets are transmitted redundantly. For transmission across body sensors, a trustworthy and energy-efficient approach was put out [14]. In order to guarantee lossless transmissions and to save energy, the work employs a stolen signal. Another model to conserve energy based on energy efficiency was put up in [15]. CEPRAN, a cooperative priority-based and energy-efficient routing protocol, was proposed [16]. To assure quicker and more energy-efficient transmissions, this study is centred on improving the nodes' reliability and cooperative behaviour. The relay nodes for data transmission are found using Cuckoo search-based optimization. There was a proposal for a Link Aware and Energy Efficient Scheme (LAEEBA) in [17]. The forwarder node concept is introduced in this study. The distance and remaining energy levels are used to determine the forwarder node in a route.

In order to effectively route in WBAN systems,[18] a thermal energy conscious routing model was suggested. The main goals of this endeavour are to preserve stability and provide efficient routing. The research offers a practical compromise between preserving the charge and lowering node temperatures to prevent overheating. In [19], a peer routing system with energy considerations was presented. With the help of peer routing for WBAN, this work attempts to build a patient monitoring system that is more energy-efficient. [20] presented an energy-aware routing scheme. The work identifies the main energy-draining factors and then develops a 2-hop routing model that can be both energy-efficient and capable of handling problems brought on by changes in posture

3. Proposed Model

Two sink nodes and 14 sensor nodes make up the WBAN network. The network consists of 16 nodes in total. Each sensor node gathers information from the human body and transmits it to a different sink node. For additional transmissions and better processing, the sink nodes send the data to the devices attached to the body's surface or to equipment outside the body. Data is often sent to sink nodes via single-hop or multi-hop communication mechanisms. While multi-hop transmissions are utilised for routine data, the single-hop data transmission model is employed in emergency situations. The gathered information is divided into four categories: general, emergency, delay-sensitive, and reliability-sensitive. In the sensor node, data categorization is carried out, and the transmission mode is chosen. While all other traffic categories follow single-hop transmissions, general data is transmitted over many hops. Additionally, it is widely accepted that single hop transmissions heat up nodes more than multi-hop transmissions do. The suggested model's key underlying assumptions are as follows:

1. Data collection, processing, transmission, and receiving are all regarded to be times when nodes use power. Data transmission and reception phases are thought to have substantial power consumption, compared to all other activities, which have remarkably low power consumption levels. Therefore, power usage values during processing phases are disregarded [21].

2. Despite the sensors being implanted in the human body, limb and body motions may cause the deployment locations to alter. As a result, the network is thought to be dynamic and path identification is carried out before each transmission.

3. The human body's sensor nodes are extremely power-constrained by design. They can't be accessed for battery replacements once they've been deployed. The sensors are therefore thought to have energy-harvesting processes [9]. Sensor charges are thought to rise periodically in the way shown below.

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

Where C_i is the charging rate of node i from time a to t.
Since deployment takes place inside the body, transmission loss owing to interference from the human body is to be expected. The path loss model adheres to the BAN standards specified by IEEE 802.15.6 [22]. Path loss levels are provided by

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

Where D is the distance between nodes i and j, f is the operating frequency of the nodes, N_{df} is the distributed variable with value 158dB, α and β are linear coefficients with values -27.6 and -46.5 [22].
Distance between the nodes is calculated using the Euclidean distance measure, given by

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

Where x and y are the co-ordinate points of nodes i and j.
6. Energy levels required for transmission and receiving data are calculated using the first order ratio model [23], given by

$$E_{Trans} = E_{Tcharge} * K + E_{Amp} * n * K * D$$
$$E_{Rec} = E_{Rcharge} * K$$

Where $E_{Tcharge}$ and $E_{Rcharge}$ are the transmission charge and receiving charges incurred for a node, K is the number of bits of data transmitted, D is the distance and n is the path loss incurred for the transmission.

2.2 Initialization of Network

After sensor nodes and sink nodes have been deployed, the network must first be initialised. Making ensuring all nodes are aware of their neighbours and the sink nodes is the first step following deployment. As a result, each node pinpoints its location and determines how far it is from other nodes and any accessible sink nodes. In the network, a beacon message is transmitted via the TDMA protocol. The beacon includes sender and recipient IDs, the amount of remaining energy in the node, its position, and the strength of the sent signal. When such a message is received, the receiving nodes determine the distance between the sender and themselves and the path loss levels. On all the available nodes, this information update is carried out. However, the nodes' distance and loss levels are provisional in nature because they dynamically fluctuate in response to a person's shifting postures. Therefore, these are determined before each transmission.

2.3 **Data Transmission and State Analysis**

Nodes start the process of data collecting and transmission after the initialization phase. Data is collected by all nodes and sent to the sink nodes. All data are received by the sink nodes, which then send them to other devices for processing and analysis. The type of deployed device will have a sole bearing on the data that needs to be gathered. EEG, ECG, insulin levels, temperature, heart rate, and other types of data can be gathered. As a result, each device has a variety of parts, and the network is always heterogeneous.

Any of the four specified states can apply to the data that needs to be transferred. General transmissions, which are routine and expected traffic, or other transmissions, such as emergency transmissions, transmissions that must be reliable while also taking into account delays. While the other broadcasts are very sensitive to delay, the general transmissions are not. Because of their high priority, delays may prove lethal. Therefore, single and multi hop transmissions are the two types of data transmission strategies used to handle these various traffic circumstances. Single hop transmissions are used for other critical traffic since they are severely time constrained, while multi hop transmissions are used for ordinary traffic. However, compared to multi hop traffic, single hop transmissions consume more power and cause a greater rise in node temperature. If it is emergency traffic, the packet is sent straight to the sink node after the kind of traffic has been determined; otherwise, the routing model is activated. The routing model determines the appropriate path.

2.4 Metaheuristic based Energy Efficient Route Identification

The route from the source node to the sink is identified by the routing model. The routing procedure employs a modified version of the Ant Colony Optimization (ACO) model. Multiple criteria have been added to the ACO [24, 25] model, turning the ACO routing process into a multi-criteria decision-making model.

The state of a node is established following the collection of data by sensors. If it qualifies as normal traffic, the ACO-based routing process is started. Each packet that needs to be sent makes a route request. The speed and minimal computation needs of ACO are the main benefits of using it as the base for the model. As the primary selection factor for the transmission process, ACO uses distance and pheromone trail. As a result, these two parameters account for all of the fitness of the ACO model. The distance, receiving node temperature, and receiving node charge are the three main factors considered during the decision-making process in the modified ACO model. For the route-creation process, nodes with minimal distance, high temperature, and high charge are preferred. Given by is the updated fitness function that uses many criteria to choose nodes

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

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.

The improved ACO model starts predicting the route as soon as a transmission is triggered by choosing the nodes one at a time based on the fitness probability. Nodes that are already in use and those that aren't are thought of as likely candidates for the route. The train strength between the two nodes increases upon each successful inclusion of a node in the route. Increased trail acuity is caused by

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

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

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

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

Until one of the sink nodes is reached, the procedure is repeated. The node's temperature rises and its charge decreases after a successful transfer. The sensor node's energy-harvesting system, however, ensures that the charge is periodically replenished, and when the node is in its resting state, the temperature is automatically lowered. Every time a sensor node needs to send a multihop transmission, the full process is carried out.

3. RESULTS AND DISCUSSION

Ullah et alE-HARP .'s model and Ullah et alEH-RCP .'s model were compared to the performance of the suggested ACO model in order to examine its performance. For performance comparisons, the suggested MEER architecture adopts the experimental paradigm from the E-HARP model. The search space for the updated ACO model is formed by the nodes' deployment sites. The coordinates suggested in the E-HARP model were used to build the search-space for the improved ACO. The coordinates are shown in table 1. The nodes are thought to collect data and send broadcasts at specific epochs after deployment. Every transmission is regarded as one round of data transmission, and every second, transmissions were made. Since this was the time at which it was determined that all of the nodes had lost their charge, the analysis starts with round one and lasts for 18000 rounds.

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

Figure 1 displays a comparison study of the network lifetime. The overall functioning time of the network is referred to as its lifetime. It is calculated starting with node deployment and continuing until all nodes have completely used up their charge. Given that nodes implanted inside the human body make node replacements possible, network longevity is one of the key measuring criteria in WBAN. While the proposed MEER model shows an enhanced longevity extending to 18000th cycle, the E-HARP and EH-RCP models have achieved their end of lifetimes at 16000th round. This shows that the MEER model has a superior routing technique that more successfully increases the network lifetime than the other models

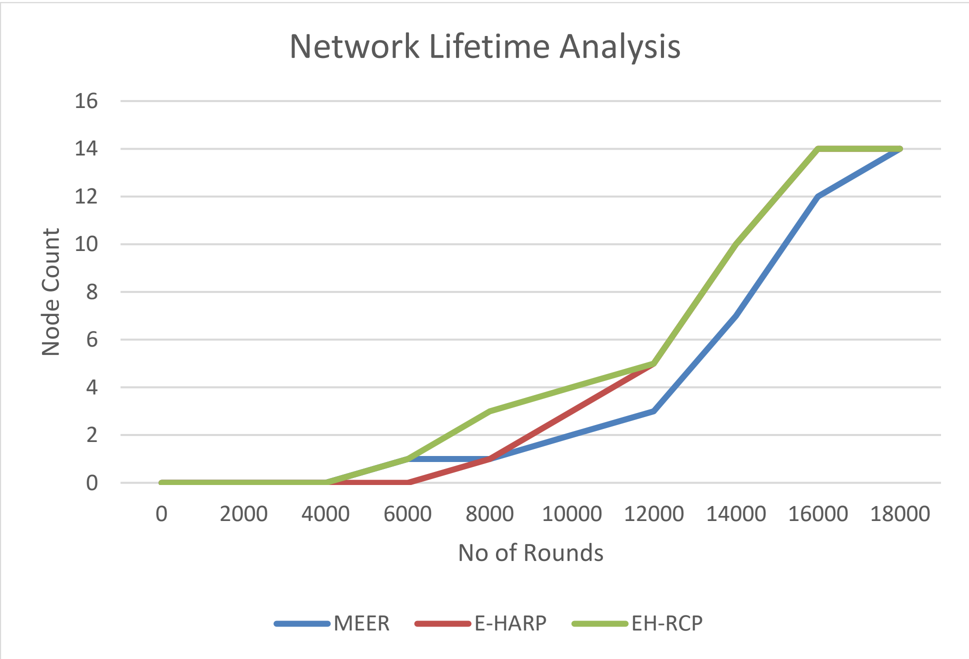

Figure- 1 Network life time analysis of MEER

Table 2 displays a network lifespan analysis. Every 2000 rounds, the total number of active nodes is counted. The data show that during the 16000th round, E-HARP and EH-network RCP's lifetimes have expired, but the proposed MEER model still has two nodes in the network. All the accessible nodes ran out of charge after the 18000th round. All three models use energy harvesting strategies, hence the updated ACO-based routing mechanism is solely responsible for the performance gain.

	2000	4000	6000	8000	10000	12000	14000	16000	18000
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

The time between the deployment of the nodes and the death of the network's initial node is referred to as the stability period. It can also be described as the amount of time until every node in the network is operational. The first node dying is a sign that the network is beginning to degrade, hence this performance criterion also shows how stable a network may be. Longer life and transmission times are thought to be a sign of more stable networks. Figure 2 displays a comparison of the stability levels. The network backed by MEER, EH-RCP, and E-HARP is observed to be stable up to the 4000th round, indicating that the network has completed 4000 successful transmissions. However, MEER and EH-RCP show a network node loss in the 6000th transmission. In the 8000th transmission, E-HARP displays its initial loss. The EH-RCP and E-HARP models, on the other hand, show steep deterioration curves, which suggests that as soon as a node fails, the network rapidly starts to lose its stability. The proposed MEER model, however, shows slower levels of deterioration and shows higher stability even after node failures.

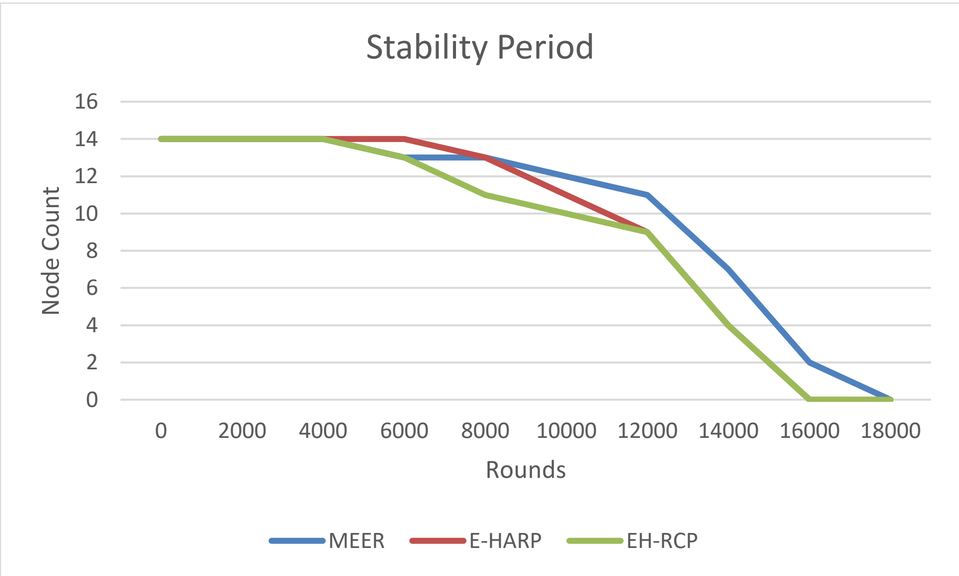

Figure-2 Aggregated Metric Comparison

Table 3 contains the stability analysis results for the MEER model and the other models that were compared. Although the MEER model's deterioration levels start at around 6000, it can be seen that node depletion levels remain constant rather than increasing quickly, ensuring improved stability.

	2000	4000	6000	8000	10000	12000	14000	16000	18000
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

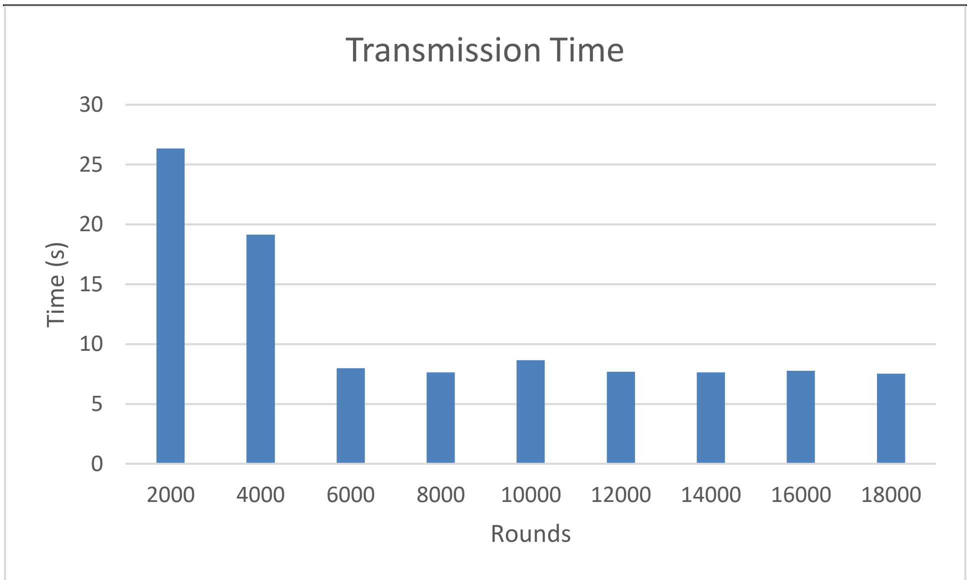

Figure 3: Transmission Time Requirements

The period of time since the 2000th round has passed is known as the transmission time. Better routing models are likely to have low time needs. Figure 3 shows that the first 2000 rounds have significant time needs. However, node identification broadcasts result from the initial transmissions. Therefore, the increased time needs are acceptable. Further transmissions may be seen to have shorter transmission times, and at around 6000, the time needs have stabilised, with subsequent broadcasts showing fewer oscillations.

4 CONCLUSION

The restricted battery capabilities of the sensors in WBAN systems have made it essential to increase the energy efficiency of WBAN during the routing process. Effective routing can increase sensor energy efficiency in addition to communication speed. This research provides a modified ACO-based routing model called Metaheuristics based Energy Effective Routing (MEER). ACO's fitness function has been altered to take into account a number of factors, including temperature and node energy. The nodes are thought to use an inbuilt energy harvesting system that allows them to charge up after regular intervals of time. These routing mechanisms have been seen to offer energy efficiency as well as high routing process efficiency. Compared to other models now in use, this model's improved network longevity is its main benefit. Initial node failures, however, were seen to happen earlier in time. This model will be improved in the future with mechanisms that can address this problem. Future works may also contain parts that may detect outdated or redundant data to ensure that fresh packets arrive more quickly and use less energy.

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