Temperature-Aware Routing in Wireless Body Area Network Based on Meta-Heuristic Clustering Method

Seyed Reza Nabavi, Nafiseh Osati Eraghi, Javad Akbari Torkestani
Department of Computer Engineering, Arak Branch, Islamic Azad University, Arak, Iran
sr.nabavi95@iau-arak.ac.ir, n-osati@iau-arak.ac.ir, j-akbari@iau-arak.ac.ir

Corresponding author: *n-osati@iau-arak.ac.ir*

Abstract- **Wireless body area networks (WBANs) are a kind of wireless sensor network created in order to make more acceptable utilization of the hospital resources, detect medical signs or symptoms earlier, and consequently reduce the costs of medical care. Like majority of the wireless networks, it has no infra-structure, and thus sensor nodes embedded in the body enjoy small level of energy. Therefore, initial termination of the wireless node energy on the basis of the message transmission in the network may interrupt the entire network process. Also, increasing the temperature of the sensor node due to sending and receiving information can cause an increase in normal body temperature and disrupt the body's functioning process. In this article, a temperature-aware routing in the wireless body area network based on meta-heuristic clustering method is presented. In this method, in order to find the appropriate cluster head to transfer data to the root, network parameters are examined in the form of membership function of the ant colony optimization meta-heuristic method. The simulation results indicate the greater ability of this new method in comparison to other available techniques under the same conditions.**

Index Terms- Temperature-Aware, Routing, Ant Colony Optimization, Wireless Body Area Network.

I. INTRODUCTION

Wireless body area networks, WBANs, have been introduced as a branch of wireless sensor networks, which are considerably investigated because of the respective increased potential value. The advent of WBAN can reduce or even solve some social problems such as common chronic diseases, aging population, stressful medical personnel and equipment, etc. [1]. The application of these technologies goes beyond continuous monitoring systems and is a powerful technology, which

Manuscript received 6-Sept.-2020 and revised 17-Nov.-2020,
Accepted on 4- Dec.-2020

P- ISSN: 2322-4088
E- ISSN: 2322-3936

has provided numerous successful utilizations in the medical as well as non-medical areas. Notably, the main purpose of the WBAN is to continuously monitor a person's health status in order to provide alert when a critical situation arises for the patient. WBAN has been proposed to be capable of communicating and recognizing physiological information. Physiological monitoring systems are actually designed for monitoring human health concerns and thus have been regarded to control tracking evaluated data from wireless sensor nodes to the medical as well as non-medical servers for additional analyses [2].

The WBANs are becoming more and more useful, while the challenges in the network are not being fully addressed. A key issue in the wireless sensor networks has been proposed to be the transfer of information from the nodes in the network to the base-station and selection of the most acceptable path for transmitting this information. Therefore, selection of the most acceptable route may be affected based on diverse parameters like energy consumption, latency, transmission channel quality, response speed sensor node temperature, etc. Methods may be provided to address some of the challenges in the WBAN, but due to the relationship of network parameters, improving one parameter can weaken another parameter. Therefore, in providing methods for solving problems in wireless networks, especially wireless networks of the body that have a special sensitivity, a comprehensive view should be established and a balance should be established between all parameters [3]. In general, a WBAN consists of some nodes embedded in a patient's body for collecting crucial signals from important regions of the body. Among the above nodes, 1 node acts as the coordinator node (CN) and the remaining are the sensor nodes. Then, sensor nodes will sense a number of the criteria necessary for monitoring, like body temperature, heart rate, blood pressure, and more. In fact, they continuously transfer those data that feel wirelessly to the CN and hence wirelessly transmit the data to a remote server. In the WBAN, the nodes power supply are usually composed of a number of batteries (as long as they may need to work) depending on the application, the network lifetime is required from 24 hours to several days. The problem in relation to replacing the battery has been identified to be the fact that it uses up power. Replacing the node battery will cause severe discomfort to the patient in case of installation of the node on the body or severe pain in case of its installation inside the body. Therefore, it is practically impossible to replace the node battery in the WBAN. Therefore, energy efficiency is the key needed for such a network to maximize network lifetime, and to reduce this problem, a significant goal is to increase battery life, but common tasks focus on reducing node power consumption, while not interfering with the overall performance of the network [4]. Routing approaches try to send message packets in the shortest distances and between several intermediate nodes to reach the destination so that the average consumption of the nodes' energy is balanced and overall consumption of the network energy reduces. For this purpose, clustering approaches are one of the most effective routing solutions in the WBAN that by assigning each node to the nearest source with the most residual energy, tries to reduce network energy consumption and increase network lifetime.

Another important parameter that is considered as a challenge in WBAN is the temperature of the sensor nodes embedded in the body. If the nodes receive more sensor and send messages, the higher their temperature will naturally rise. The higher the temperature of the sensor nodes, the more harmful they can be to the human body. In WBAN, temperature awareness routing contributes importantly to the prevention of the damages to the tissues of body due to increased node temperature. However, temperature-aware routing protocols usually select the next hop based on the temperature, regardless of the delay in transmission and loss of data due to deployment in the human body [5]. Therefore, in order to provide efficient solutions for WBAN, the amount of nodes energy consumption can be combined with the temperature parameter of nodes and compromises between nodes temperature, energy consumption, message transmission delay and data delivery rate in sensor networks gained.

Therefore, in order to overcome the mentioned challenges, one of the temperature-aware routings in the wireless body area network based on meta-heuristic clustering method using ant colony optimization algorithm is presented. In this method, in order to find a suitable cluster head to transfer data to the root, channel quality, residual node energy and temperature of the sensor node are used as proportion function parameters to adjust the amount of pheromones in each path. This method, by combining the temperature factor of sensor nodes embedded in the body with the quality of the information transmission channel and thus the remaining energy of the sensor nodes, has tried to select an optimal cluster head and provide the optimal routing solution.

II. RELATED WORK

Due to the importance of routing in WBAN, researchers have performed numerous researches in this field, and we will review some of these researches in the following.

In 2020, Rupali et al. presented their own routing protocol on the basis of the genetic algorithm for WBAN that has been considered to be effective with regard to the network life-time as well as energy efficiency. Moreover, cost performance has been described based on the energy parameter and the remaining distance in order to select the nodes close to each other in a cluster that causes a reasonable distribution and declines consumption of energy. This new algorithm emphasizes communications between WBANs. In addition, simulation outputs of that protocol with regard to various variables like energy efficiency, throughput, network lifetime, average latency as well as packet delivery ratio have been compared with the earlier certain schemes and show improved performance [6].

In 2020, Omar Ahmad et al. proposed a temperature-aware energy-efficient routing algorithm (EOCC-TARA) with the use of the Monkey-Spider Multi Objective Optimization (EMSMO) method for SDN-based WBAN. The algorithm resolves the basic difficulties like energy efficiency, non-interference communications as well as reduction of bad thermal impacts in the WBAN routing. Firstly, this new routing algorithm, EOCC-TARA, addresses the impact of temperature because of the heat loss of the sensor nodes, and develops an approach for adaptive selection of intermediate nodes to send information with regard to energy and temperature. It consequently adds the concept of congestion avoidance to the energy efficiency, path loss as well as link reliability for cost-performance modeling on the basis of the EMSMO optimal routing. The simulations created and the evaluation outputs show superiority of this new EOCC-TARA routing algorithm over the conventional routing methods with regard to the consumption of energy, network life-time, temperature control, throughput, latency, substantial transmission speed as well as compression overhead [7].

In 2019, Ghofran Ahmad et al. introduced a heat-aware, energy efficient routing protocol called Thermal and Energy Awareness Routing. Based on the mentioned protocol, conscious thermal and energy routing deals with the weighted average of 3 costs when choosing the nodes in routing; that is, energy consumption, connection quality and heat dissipation (between the communication nodes). Therefore, validity of this new protocol is determined by comparison with the modern wireless body area network routing protocol. The simulation outputs show it has sufficient efficiency regarding the consumption of energy, packet reception and thermal effect [8].

In 2019, Jamil et al. introduced an adaptive energy and temperature-aware algorithm for WBAN called ATAR. ATAR has been devised for overcoming the problem of temperature elevation in the implanted biomedical sensor nodes. Increasing the biomedical sensor nodes' temperature shows the whole routing operation highly important because the implanted nodes' temperature elevates and eventually hurts the body tissues. Such a condition eliminates the need for data scattering at different nodes by selecting different paths while preventing temperature rise. This paper develops a novel protocol on the basis of a multi-loop routing method for finding another path if the temperature increases. However, simulation outputs show higher efficiency of this new protocol for power and temperature in comparison to the available methods [9].

In 2018, Kim et al. proposed a mobility-based, temperature-aware routing protocol with regard to a multi-objective decision-making approach. This new protocol proceeds an analytical hierarchy procedure and a simplified weighting technique in order to determine the appropriate weight and select the next step option, taking into account multiple routing criteria. The simulation results show that this protocol is capable of highly improving the transmission delay as well as data loss in comparison to the available protocols via prevention of the temperature increase in the nodes [5].

In 2019, Ali Reza Bangvar et al. proposed a service quality-based, energy-based, and temperature-aware routing protocol for wireless body area network, which is a combination of routing criteria with respect to residual node energy and temperature and uses link quality and latency estimation in the route selection decisions. Moreover, simulation outputs, which have been proposed in the study, show effectiveness of this new design with regard to the prevention of the temperature elevation, considers the focal nodes, and thus enhances the network life-time [10].

III. Proposed Method

In this study, in order to provide a temperature-aware routing in the wireless body area-network based on meta-heuristic clustering method ant colony optimization algorithm is used. This is comprehensively illustrated in the following method.

A. Clustering in WBAN

According to research, it can be proven that one of the efficient schemes in enhancing lifetime as well as scalability of the wireless sensor networks is clustering. According to the clustering schemes, 2 types of nodes exist in a cluster, namely, numerous cluster members (CM) and1 cluster head (CH). Cluster members periodically collect the data from the environment and transmit them to the cluster head. Then, the cluster heads collect data from their cluster members and send them to the base station (BS). Moreover, 2 types of communication between the BS and cluster head, multi-hop communication and single-hop communication. Within the multi-hop clustering algorithms, consumption of the energy of the cluster head includes energy of receiving, accumulating as well as sending data from the members of the respective cluster (consumption of energy within the cluster) and energy for sending information to neighboring clusters (intergroup energy consumption).

In network clustering, energy imbalance between the nodes has been considered to be the main parameter influencing the network life-time. Therefore, for balancing the consumption of energy between the nodes, network clustering algorithms with the uniform node distribution usually make the cluster heads smoothly in a way that the clusters possess the same approximate number of the members as well as areas covered. Therefore, the energy consumption within the cluster is almost equal for the clusters, and thus it becomes possible to balance the consumption of the clusters' energy. However, for the cluster members, due to the uniform size of the cluster, the maximum communication distance between the cluster members is approximately equal. Therefore, balance may be established in the consumption of the cluster members' energy. Hence, uniform distribution of the cluster heads may balance the energy consumption amongst the nodes and ultimately extend the network life-time [11].

B. Ant Colony Optimization Algorithm (ACO)

This algorithm describes the mechanism for optimizing problems based on the behavior of ants to find food. Using this method, the solution of complex problems can be optimized. As the ants detect the path between the nest and the food source using symbols called pheromones, and the movement of other ants (repetition) the shortest path is discovered, so does the ACO algorithm to optimize Uses this method. The higher the number of pheromones in the path, the more ants has crossed that path [12]. Using a positive reinforcement strategy, the greater the number of ants crossing a path, the greater the number of pheromones produced by the ants in the path. In contrast, according to the negative amplification strategy, some pheromones may evaporate and be destroyed. For this reason, the pheromones produced by an ant are between zero and one ($0 < \alpha < 1$). Finally, the path with the most pheromones is the more optimal path (the closer path between the nest and the food source).

C. Temperature-Aware Routing in WBAN

As mentioned, in this new method, a cluster method on the basis of the ant colony optimization algorithm according to energy and temperature parameters is introduced in which in each hop in order to transfer information to the coordinating node outside the body, the optimal path is the base of the optimized cluster head node is chosen with the highest residual energy, link quality as well as lowest temperature. Nodes in each cluster need to be reported regularly and then send their data to the cluster head node. In the next step, the cluster head nodes aggregate data, and if a data appears to be critical, send it to the next cluster head for transfer to the coordinator node outside the patient. Of course, it is possible that a cluster head node be closer to the coordinator node than other cluster heads, in which case the data is sent directly. Coordinating nodes must send reliable and sensitive data to the destination so that they can be informed of the patient's condition at the appropriate time. Therefore, cluster heads are formed to transmit only critical information to the destination and to avoid continuous data transmission and excessive energy consumption of the nodes in the network.

Selecting an appropriate cluster head node to aggregate and send critical data to the coordinating node is very important because energy consumption in cluster head nodes is higher than other cluster head nodes and if a lower energy node is selected as cluster head, the possibility of running out of energy and disrupting the network is obvious. In the proposed method, in order to find the cluster head node in each hop, the factors of energy, temperature and link quality have been used as parameters of pheromone update in ACO algorithm.

In the proposed method, in determining the pheromone and the optimality of the cluster heads nodes and the optimal path, in addition to the amount of pheromone, the temperature of the cluster head nodes is also considered. On the other hand, due to the fact that the temperature of the wireless sensor nodes decreases if they don’t send data, it is necessary to add the temperature evaporation factor to the pheromone evaporation factor in calculating the evaluation function. Due to the fact that the evaporation factor plays an essential role in the ant colony optimization method among the meta-heuristics methods, this method has been used in this paper to select the optimal path. It should be noted that in the proposed method, each time the data is transferred, a new path may need to be explored, depending on the amount of pheromone and temperature, which is consistent with the principle of meta- heuristics methods.

In wireless body area network, cluster heads are created in the organization itself and its purpose is to consume the nodes' balanced energy and enhance the network life-time. Therefore, clustering in these networks consists of two stages called steady-state phase and configuration phase. In the configuration phase, the cluster heads are formed, while in the steady phase, data transfer takes place. In the proposed method, sensor nodes are defined as ants that try to send the sensed data to the access point (AP) through optimal path. These nodes try to choose the shortest path to send the data. Given that the information transferring in clustering methods in sensor networks, is done through clustered nodes, the clustered nodes are selected as agents in the path. In other words, each sensor node is an ant that sends its data to the AP from the path in which cluster head is an agent there.

So, cluster head nodes are selected as the agents and the transfer of information to the access point is done through these agents. Cluster member nodes send sensed data to cluster head nodes, which sends data to the AP. In the proposed method, the evaluation function calculates the amount of pheromone in each agent and other sensor nodes at each stage of information transferring. It is normal for some of the pheromone to evaporate as the energy of the cluster head nodes decreases and the cluster head node optimality decreases. In this case, another node with a higher optimality value replaces the previous cluster head node as a new agent.

In the configuration step, the ants create a random number from 0 to 1 and compare it with the threshold value $T(n)$. If the initial value for each ant is $< T(n)$, that node is selected as the cluster head of the cluster, where Equation 1 shows the threshold $T(n)$.

$$T(n) = \frac{p}{1-p*\left(r \ mod \frac{1}{p}\right)} * \frac{ph_{current}}{ph_{initial}} * \frac{E_{current}}{E_{initial}} * \frac{temp_{current}}{temp_{initial}} \quad (1)$$

Where p is the percentage of cluster head selection, r is the sensor node communication range, $r \ mod \ \frac{1}{p}$ is the threshold for sensors distance, in which a sensor with more distance has low chance to select as cluster head node, $ph_{current}$ node pheromone values, $ph_{initial}$ initial pheromone values, $E_{current}$ node current energy, $E_{initial}$ node initial energy, $temp_{current}$ node current temperature and $temp_{initial}$ node initial temperature. The node selected as the cluster head informs its position to the other nodes and updates the cluster table. Upon the identification of the cluster head nodes in the configuration phase, the sensor nodes embedded in the body are clustered based on their distance to the nearest cluster. In the steady-state phase, when the sensor nodes send their messages to the cluster head node, data aggregation by the cluster head nodes occurs, if critical data is considered, transfer it to the another cluster head node. Therefore, the closer node transmits the coordinator. At this time, the cluster head node chooses the next cluster head with regard to the cost function to ensure optimal data transfer and optimal energy consumption to reach the destination. In this way, according to the cost function, the optimal cluster head is selected between the cluster heads of the clusters. By choosing the cluster-head node, therefore, the pheromone value is updated and possible paths are created to be recorded in the routing table. The various paths recorded in the routing table are then announced to the ants from origin to destination, and the path discovery process begins. If the cost function for cluster head nodes in a path is minimal in the routing table, then the optimal path from origin to destination is discovered. The routing table contains information about the list of visited nodes in each path. This data may vary based on pheromone values and evaluation function. The evaluation function in the proposed method is a combination of energy, link quality and temperature parameters. In the proposed method, the link quality is represented by a criterion called the expected transfer (ETX) between two cluster head nodes. For a current cluster head node, ETX path has been considered as the total cost of the path from the source node to the current cluster head Etx_{cons_i} and the estimated cost between the next cluster head to the destination node $Etx_{predicted_j}$. Given that the highest cost in the WBAN is related to energy, we can use the expected transfer criterion based on $EETX$ energy to measure the quality of the link and view it as the transfer cost. The smaller the $EETX$ link between the two cluster head nodes, the better the transmission quality. Equation (2) shows the $EETX$ calculation.

$$EETX_{ij} = \sum_{i=1}^{n} Etx_{cons_i} + \sum_{j=1}^{m} Etx_{Predicted_j} \tag{2}$$

$$Etx_{cons_i} = \sum_{i=1}^{n} D_i * (B_i * \varepsilon) * h_{di} \tag{3}$$

$$Etx_{Predicted_j} = \sum_{i=1}^{n} \sum_{j=1}^{m} D_{St_j} * (B_i * \varepsilon) * h_{St_j} \tag{4}$$

Where D_i is the distance between the current cluster head and the source node, B_i is the volume of data sent in terms of packets in node i, ε is the energy consumption per packet, h_{di} is the hops' number taken from the source node to the current cluster head, D_{st} is the estimated distance between the next hop is to the destination node and h_{st} is the estimated number of hops to the destination node. Hence the cost function is calculated based on Equation (5).

$$Cost\ function(i,j) = \min\left(\sum_{i \in N} CH_{prob}(\tau_{ij})\right) \tag{5}$$

$$CH_{prob_i}(\tau_{ij}) = EETX_{ij} + \frac{D_{ij}*\alpha + [P_{ij}]*\beta*\tau_i}{\sum_{i=0}^{N} D_{ij}*\alpha + [P_{ij}]*\beta*\tau_i} + \gamma \times B_i + \frac{temp_{current}}{temp_{current} - temp_{last}} \tag{6}$$

Where α is the pheromone generation coefficient, β is the pheromone evaporation coefficient, τ_{ij} is the amount of pheromone between two cluster head nodes and the amount of τ_{ij} pheromone is calculated as the ratio of the packets transmitted between the two factors to the total messages transmitted at that stage, τ_i is the amount of pheromone in the i^{th} cluster head node.

Due to the fact that data transmission by sensor nodes increases the temperature of the sensor node and, on the other hand, cluster nodes collect information from other cluster member nodes and send it to the access point, the temperature of cluster head nodes has increased more than the other nodes. Therefore, in each data transmission, the estimation of increasing node temperature due to transferring the B packets must be calculated to ad to relative the current temperature of the node temperature to the time of the last transfer temperature. So, in each information transfer, in addition to the amount of pheromones in each cluster node, the temperature of the cluster node must also be examined. In the proposed method, in order to investigate the temperature of the cluster head nodes, Equation 6 is used, in which γ is defined as the temperature increase coefficient for each data packet, $temp_{current}$ is the current temperature of the next node and $temp_{last}$ is the temperature of the next node in sending the last message transmission. Therefore, the probability of selecting a node is determined based on Equation (7).

$$P_{ij} = \frac{(\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}}{\sum_{i \in U} (\tau_{ij})^{\alpha} * (\eta_{ij})^{\beta}} \tag{7}$$

Where η_{ij} is the amount of evaporated pheromone between two cluster head nodes, which is calculated from the difference between the current pheromone value and the previous pheromone value. According to the cost function, a cluster node is selected in each step and recorded in the routing table. Based on this, several paths may be generated, which is selected as the optimal path in the transmission of the message with the least amount of cumulative cost. Fig. 1 shows this new method flowchart.

IV. SIMULATION AND EVALUATION

In order to simulate the proposed method, first simulate the data transfer scenario in the WBAN network for recording information about the nodes using the NS-2 network simulator and the data related to the location, number of packets sent and We receive from the nodes in the network, temperature as well as energy of the nodes, time of sending and receiving packets and confirmation messages and other useful information from the network. Table I shows simulation factors. In Fig. 2 data transmission steps in proposed method has shown.

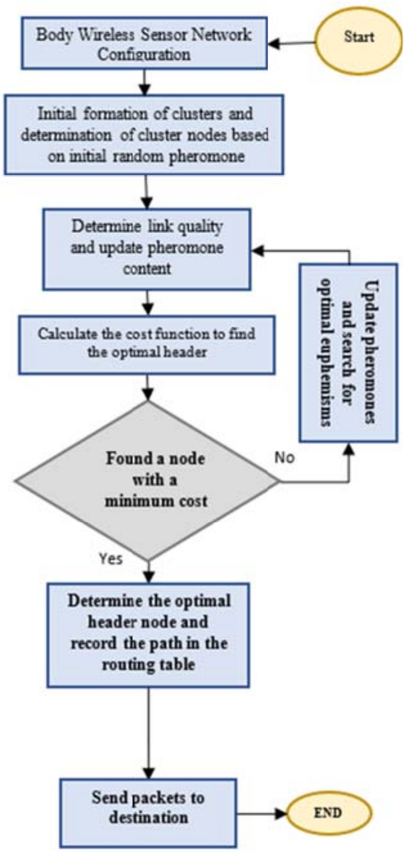

Fig. 1. The flowchart of proposed method.

Table I. The simulation parameters

Parameter	Value
MAC	IEEE 802.15.6
Buffer Size	32 packets
Packet Size	1024 bytes
Number of Nodes	15
Node Initial Energy	10 joules
Traffic Type	CBR
Network Area	5×5 m^2
Simulation Time	1000 seconds

For evaluating this new method in this paper, the criteria of residual energy and energy consumption, life-time of the network, delay transmission of node messages in the network have been used. Fig. 3 shows the energy consumption and Fig. 4 shows remaining energy of the sensor nodes embedded in the body.

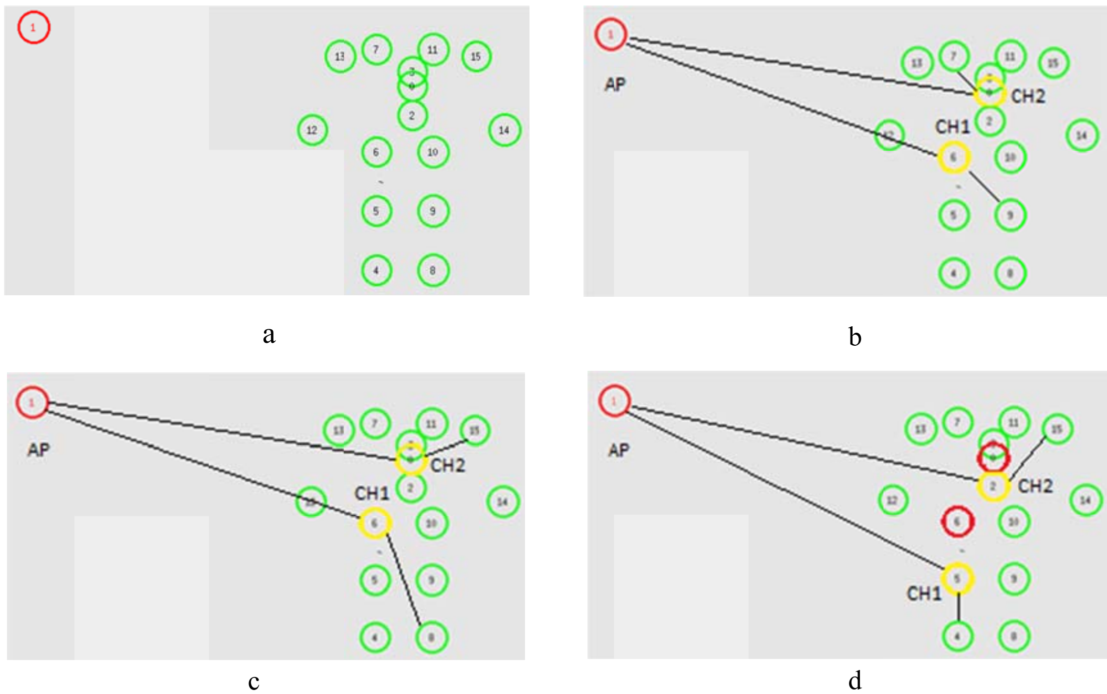

Fig. 2. Data transmission steps in proposed method.

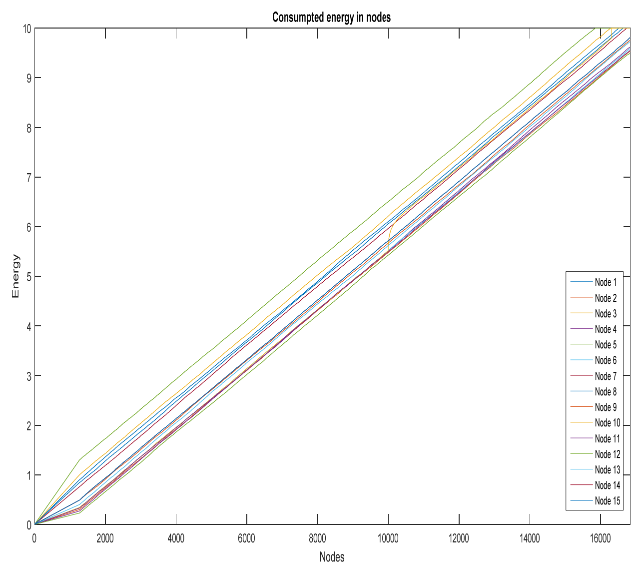

Fig. 3. Node energy consumption.

As shown in Figs. 3 and 4, the energy consumption in the network nodes is almost symmetrical. Therefore, the energy of some nodes does not end sooner than others, and the end of energy will be the same in all nodes. Therefore, the end of energy of each node in the network will be done slowly, which indicates the long life of the network. Fig. 5 shows the trend of reducing network lifetime. As

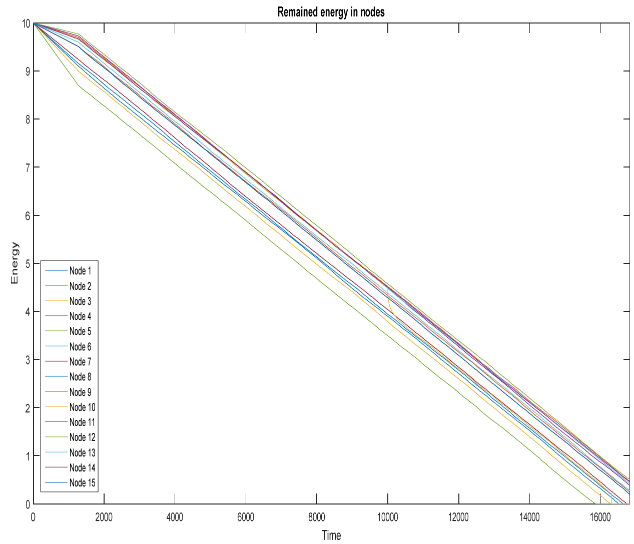

Fig. 4. Node remaining energy.

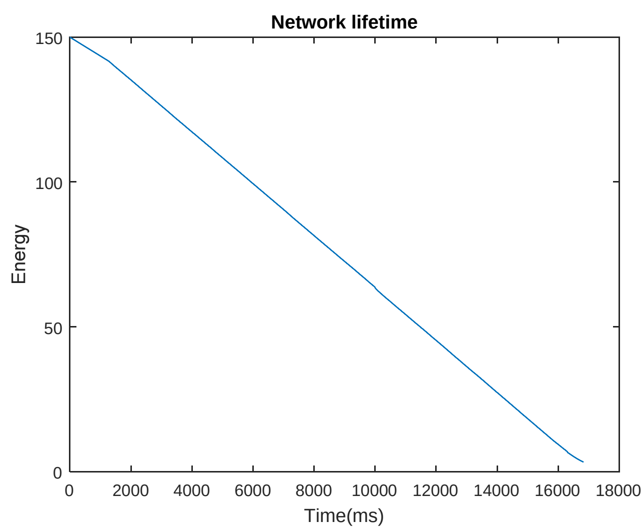

Fig. 5. Network lifetime.

shown in this figure, the network lifetime is reduced linearly, which shows the optimal energy consumption of the network nodes.

Therefore, the present research compares this new method with some previous methods, including in terms of network lifetime. Fig. 6 compares this new method with other approaches.

As shown in Fig. 5, this new approach outperforms than the other methods in terms of the network lifetime. Fig. 7 also shows the temperature of the sensor nodes embedded in the body.

As shown in Fig. 7, the temperature of the sensor nodes embedded in the body does not increase over time and tends to be constant. These diagrams show that the proposed method tries to regulate the temperature of the sensor nodes and the overall body temperature of the patient by selecting nodes

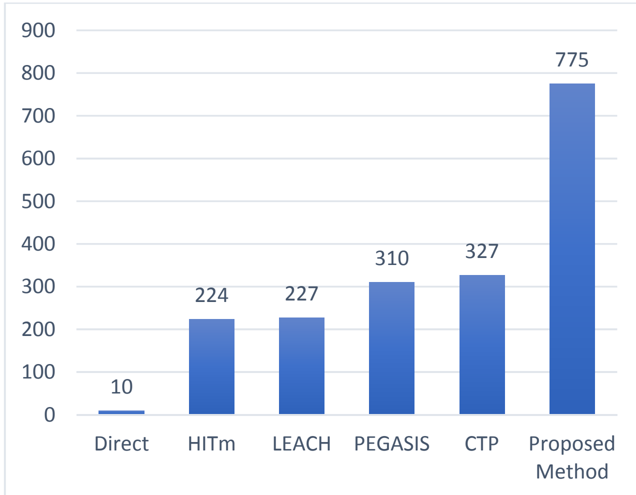

Fig. 6. Comparison of proposed method with other methods.

with lower temperatures. As mentioned, excessive patient body temperature may pose risks to the patient.

V. Conclusion and Future work

As mentioned earlier, the wireless body area networks have been proposed as a type of wireless sensor network devised to make better use of hospital resources, detect medical symptoms earlier, and ultimately reduce medical care costs. The reason for the importance of using physical sensor networks in medical settings is the unique opportunity that these networks have created to transfer medical care from hospital settings to patients' own environments. However, the major problem in the wireless sensor networks has been considered to be the transmission method of information from the nodes into the network to the BS due to the limited level of energy of the sensor nodes embedded in the body. Therefore, in this study, in order to overcome this challenge, a routing based on the tree aggregation protocol is presented. In this paper, when the sensor node senses a message in the network, the optimal neighbor node is selected based on the optimal channel quality, the least energy consumed and the lowest sensor node temperature. The sensor node temperature is directly proportional to the number of packets sent and inversely proportional to the time elapsed since the last packet sent by the node. The optimally selected neighbor or parent node has a close distance to the source node, high residual energy and low temperature. The simulation outputs indicated outperformance of this new approach in comparison to Direct, LEACH, HITm CTP, PEGASIS algorithms with regard to the life-time of the network.

Therefore, to propose future tasks, a routing method based on increasing the number of short hops to transmit messages can be used instead of sending the message directly to the hole.

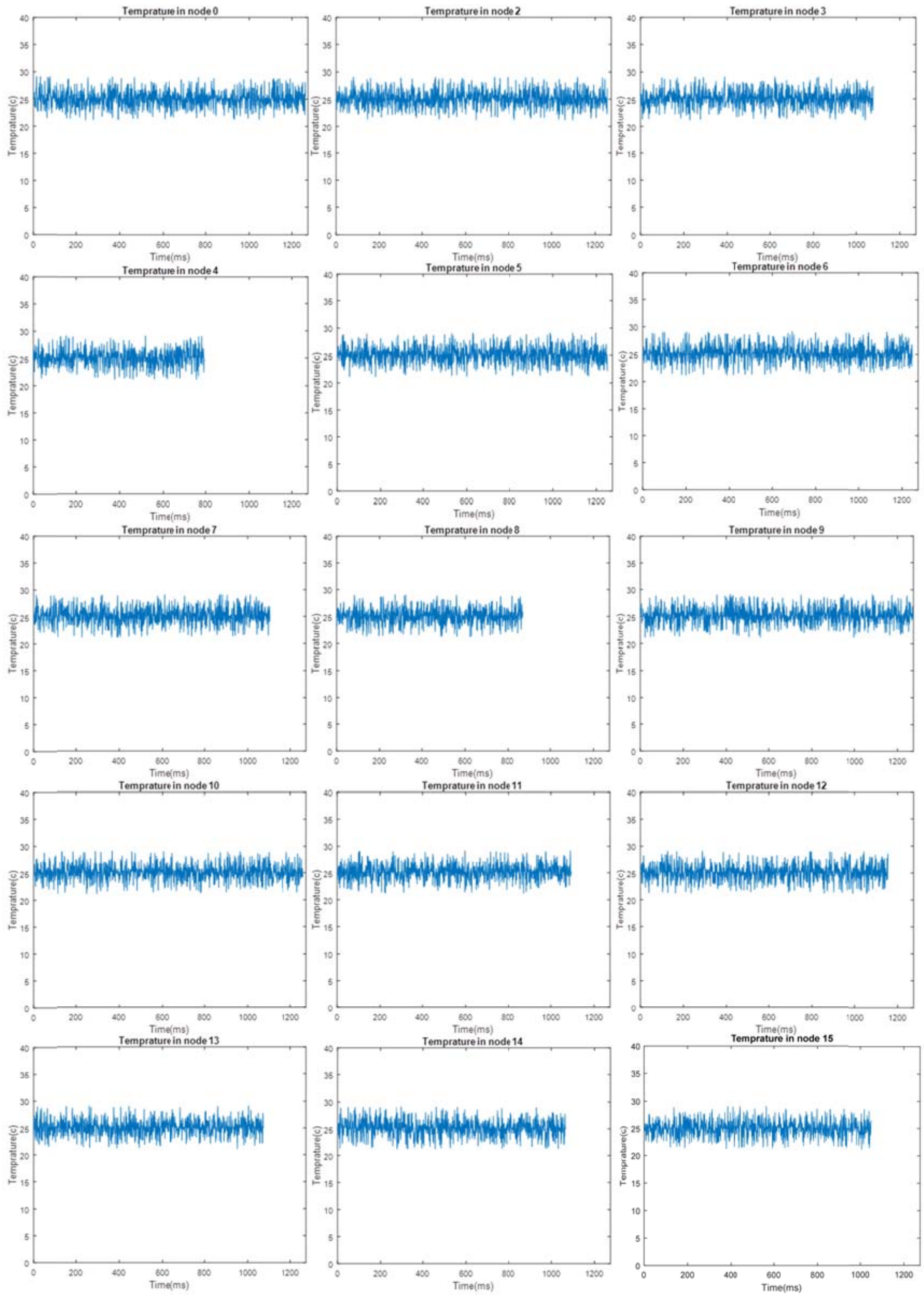

Fig. 7. Temperature of sensor nodes embedded in the body.

REFERENCES

[1] Y. Qu, G. Zheng, H. Ma, X. Wang, B. Ji, and H. Wu, "A Survey of Routing Protocols in WBAN for Healthcare Applications," *Sensors*, vol. 19, no. 7, p. 1638, Apr. 2019.

[2] F. T. Zuhra, K. A. Bakar, A. Ahmed, and M. A. Tunio, "Routing protocols in wireless body sensor networks: A comprehensive survey," *Journal of Network and Computer Applications*, vol. 99, pp. 73–97, 2017.

[3] S. Al-Janabi, I. Al-Shourbaji, M. Shojafar, and S. Shamshirband, "Survey of main challenges (security and privacy) in wireless body area networks for healthcare applications," *Egyptian Informatics Journal*, vol. 18, no. 2, pp. 113–122, 2017.

[4] E. Selem, M. Fatehy, S. M. A. El-Kader, and H. Nassar, "THE (Temperature Heterogeneity Energy) Aware Routing Protocol for IoT Health Application," *IEEE Access*, vol. 7, pp. 108957–108968, 2019.

[5] B.-S. Kim, B. Shah, F. Al-Obediat, S. Ullah, K. Kim, and K.-I. Kim, "An Enhanced Mobility and Temperature Aware Routing Protocol through Multi-Criteria Decision Making Method in Wireless Body Area Networks," *Applied Sciences*, vol. 8, no. 11, p. 2245, Nov. 2018.

[6] Roopali and R. Kumar, "Energy Efficient Dynamic Cluster Head and Routing Path Selection Strategy for WBANs," *Wireless Personal Communications*, vol. 113, no. 1, pp. 33–58, 2020.

[7] O. Ahmed, F. Ren, A. Hawbani, and Y. Al-Sharabi, "Energy Optimized Congestion Control-Based Temperature Aware Routing Algorithm for Software Defined Wireless Body Area Networks," *IEEE Access*, vol. 8, pp. 41085–41099, 2020.

[8] G. Ahmed, D. Mahmood, and S. Islam, "Thermal and energy aware routing in wireless body area networks," *International Journal of Distributed Sensor Networks*, vol. 15, no. 6, p. 1550147719854974, Jun. 2019.

[9] F. Jamil, M. A. Iqbal, R. Amin, and D. Kim, "Adaptive Thermal-Aware Routing Protocol for Wireless Body Area Network," *Electronics*, vol. 8, no. 1, p. 47, Jan. 2019.

[10] A. R. Bhangwar *et al.*, "WETRP: Weight Based Energy & Temperature Aware Routing Protocol for Wireless Body Sensor Networks," *IEEE Access*, vol. 7, pp. 87987–87995, 2019.

[11] J. Yu, Y. Qi, G. Wang, and X. Gu, "A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution," *AEU - International Journal of Electronics and Communications*, vol. 66, no. 1, pp. 54–61, 2012.

[12] X. Liu, "Routing Protocols Based on Ant Colony Optimization in Wireless Sensor Networks: A Survey," *IEEE Access*, vol. 5, pp. 26303–26317, 2017.