Grenze International Journal of Engineering and Technology, June Issue

Energy-Aware Dynamic Cluster Head Selection in WBANs using Fuzzy Logic

Megha K M[1] and U B Mahadevaswamy[2]
[1-2]Department of Electronics and Communication Engineering, JSS Science and Technology University, Mysuru, India
Email: meghakm@jssstuniv.in, mahadevaswamy@sjce.ac.in

***Abstract*— WBANs have become an essential technology for continuous healthcare monitoring by enabling real-time collection and transmission of physiological data such as heart rate, temperature, and electrocardiogram signals. In the long-term monitoring of WBAN sensor nodes, efficient energy management and reliable communication is one of great challenges, considering the limited battery resources of sensor nodes. A conventional clustering protocol like LEACH or E-LEACH typically chooses CHs without taking into account healthcare related parameters like energy, packet loss, and network lifetime, leading to unequal energy depletion, packet loss and shortened network lifetime. To overcome these drawbacks, a DCHS mechanism, which is based on fuzzy logic is proposed in this paper to select cluster head in an energy efficient manner for the healthcare monitoring application. The proposed approach aims to select the most appropriate CH for every communication round based on several decision criteria. The fuzzification process is used to deal with the uncertainty and to dynamically check the suitability of the nodes in the network under different network conditions. NS-3 simulations are used to evaluate the performance of the proposed model and its performance is compared with existing clustering approaches like LEACH and E-LEACH. The results of the simulation show that the proposed DCHS method achieves better network lifetime, low energy consumption, high PDR and low EED. The intelligent CH selection strategy also ensures that nodes that are likely to be overheated are not involved in intensive communication activities, so as to ensure patient safety and communication reliability. The presented approach is an adaptive and scalable routing approach suitable for the continuous and delay-critical healthcare monitoring applications.**

***Keywords*— Wireless Body Area Networks, Wireless Healthcare Monitoring Systems, Cluster Head Selection, Fuzzy Logic, NS-3 Simulation.**

I. INTRODUCTION

Wireless Body Area Networks (WBANs) are one of the most important elements to be found in modern healthcare systems which rely on wearable and implantable sensor devices for continuous monitoring of physiological parameters [2, 3]. These sensors can be used to gather relevant data can be sent to health care providers for immediate diagnosis and medical assistance [10]. The potential application of WBAN technology to healthcare monitoring, support services for elderly and chronic disease management, and emergency medical services have received a great deal of focus [21], [24]. All of this is to say that the wireless communications in healthcare further enhance patient mobility, lower hospitalization expenses, and allow for a continuous monitoring process to be conducted outside of the clinical environment [17].

Grenze ID: 01.GIJET.12.2.5_25

In Wireless Sensor Networks (WSNs), clustering techniques have been successfully used to enhance the scalability and communication overhead reduction [6]. In cluster-based routing, the cluster is a group of sensor nodes and a Cluster Head (CH) collects data from the member nodes and relays it to the Sink node. This helps to minimize unnecessary communication and helps to optimize the use of energy on the network. In the current clustering solutions, one of the popular solutions is LEACH which is simple and distributed in nature [7]. LEACH, however, chooses the CHs based on probability, disregarding the factors of nodes, like residual energy, link quality, thermal state, communication distance, etc. However, when the nodes have lower energy and poor communication conditions, they become the CHs and then their energy gets depleted rapidly and network lifetime decreases [8].

In order to overcome the above limitations, researchers have investigated intelligent decision making approaches in the selection of CHs. In WSNs, fuzzy logic has proven to be an effective approach to deal with uncertainties and multi-parameter optimization [9]. Fuzzy systems can make adaptive decisions based on the linguistic rules and membership functions in contrast to conventional threshold-based approaches, which can combine multiple input parameters. A few fuzzy based clustering techniques have been found beneficial in achieving energy balancing and network stability [18] - [19] - [25] - [26]. Most of the existing methods, however, are mainly geared towards energy and distance measurements and ignore other factors of interest to healthcare, such as node temperature and communication reliability.

In the light of these challenges, this paper suggests DCHS algorithm for WBAN using fuzzy logic. The proposed method is based on energy conservation, distance to sink, node temperature and link quality determination to find the most appropriate CH for each communication round. Such a fuzzy inference system would be able to process these parameters intelligently and dynamically change the selection of CH based on the network condition. The proposed model is implemented and analysed in the NS-3 simulators. The performance of the proposed approach is compared with the conventional clustering protocols like LEACH and E-LEACH in terms of network lifetime, energy consumption, Packet Delivery Ratio, Throughput, and End to End delay.

This work has contributed to the major points as follows:

- DCHS mechanism using fuzzy logic is proposed for WBAN health care applications.
- The parameters involved in the CH selection process are multiple and are related to the health field such as residual energy, node temperature, distance, link quality.
- The proposed model enhances network lifetime and communication reliability and decreases the energy consumption and transmission delay.

The rest of this paper is organized as follows. In section 2, the related works on clustering and routing in WBANs and WSNs are discussed. In Section 3, the proposed fuzzy logic based DCHS methodology is presented. In Section 4, The Simulation results and performance analysis are described. Finally, Section 5 concludes the paper and discusses future research directions.

II. Literature Survey

WSNs and WBANs, the limited battery capacity of sensor nodes has been a major research interest in the communication methods that can be used to conserve energy [1]. Many clustering methods have been developed to reduce communication overheads and extend network lifetime. The available clustering protocols include one of the most popular, LEACH, where CHs are randomly selected to spread the energy consumption, [7]. But, the randomly selected CHs may result in quick energy exhaustion and unstable communication since the energy level of the nodes and link quality are not taken into account [8].

Some energy-efficient protocols have also been proposed based on the concept of CH selection using residual energy and communication costs for better clustering performance, including HEED [13] and enhanced LEACH variants [14]. While these approaches enhance load balancing and network stability, they come with certain constraints in healthcare environments where reliability and thermal safety are paramount requirements.

Fuzzy logic-based CH selection methods have attracted attention since they can deal with uncertainty and have the ability to make decisions through multi-parameter. In order to optimize network lifetime and energy efficiency, several studies have fused together parameters like residual energy, distance and node degree into fuzzy inference system [18], [19] and [25]. To improve the delivery performance of packets, Li et al. modified fuzzy clustering algorithms by incorporating communication-related parameters [26].

Other challenges like thermal effects, communication reliability and QoS also need to be taken into account in WBAN healthcare systems [2] [16]. Overheating in BSMN is reduced by Rao and Reddy in their proposed thermal-aware routing protocol[20]. Likewise, QoS-aware and reliable routing methods were proposed to enhance the packet delivery and transmission delay in healthcare applications [22] and [23].

While the previous works enhanced the energy efficiency and the communication performance, many of the considered approaches considered energy and distance metrics and ignore the temperature and the quality of the link at the same time. In this regard, this work introduces a fuzzy logic based DCHS mechanism that combines energy, distance to sink, link quality and node temperature for reliable and energy efficient healthcare monitoring.

III. METHODOLOGY

The proposed work proposes a Fuzzy Logic based DCHS mechanism for WBANs. The main goal of the method is to boost energy efficiency, communication reliability and network stability in continuous healthcare monitoring. In the proposed approach, the CHs are dynamically selected based on several network and physiological parameters, instead of random or fixed selection approaches. The whole system is simulated and analyzed using NS-3 simulation environment.
The proposed methodology consists of four major stages:

- Network Parameter Collection
- Fuzzification Process
- Fuzzy Rule Evaluation
- Cluster Head Selection

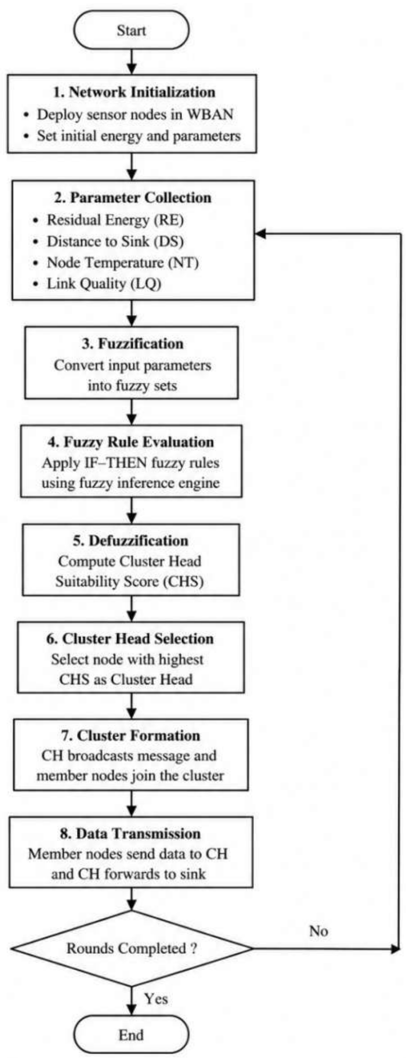

Fig. 1. Proposed Fuzzy Logic-based DCHS Method Flowchart

The Fig.1 describes the working process of the proposed Fuzzy Logic-based DCHS method for WBANs. Initially, sensor nodes are deployed and network parameters are initialized. Each node then collects important parameters such as residual energy, distance to sink, node temperature, and link quality. These values are converted into fuzzy linguistic variables through the fuzzification process. The fuzzy inference engine applies IF–THEN rules to evaluate the suitability of each node for CH selection. After defuzzification, the node with the highest suitability score is selected as the CH. The selected CH forms clusters, collects data from member nodes, and forwards the aggregated data to the sink node. This process is repeated in every communication round to improve energy efficiency and network stability.

A. Network Parameter Collection

During each communication round, every sensor node gathers important operational parameters required for CH selection. These parameters represent the current condition of the node and its communication capability within the network.

- ➢ Residual Energy (RE): Residual energy indicates the remaining battery power available in a sensor node. Since CH nodes perform additional communication and data aggregation tasks, nodes with higher residual energy are preferred for CH selection to avoid early node failure.
- ➢ Distance to Sink (DS): The distance between a sensor node and the sink node affects transmission energy consumption. Nodes located closer to the sink require lower transmission power and therefore consume less energy during communication.
- ➢ Node Temperature (NT): Continuous communication may increase the temperature of wearable sensor devices. High node temperature may affect patient comfort and device safety. Therefore, nodes with lower temperature values are given higher preference during CH selection.
- ➢ Link Quality (LQ): Link quality represents the reliability of communication between the sensor node and the sink. A node with better link quality can transmit healthcare data with lower packet loss and improved reliability.

The collected parameters are periodically forwarded to the fuzzy inference system for decision-making.

B. Fuzzification Process

The acquired input parameters are numerical values and cannot be directly processed using fuzzy logic rules. Therefore, each parameter is converted into linguistic variables through the fuzzification process. The fuzzy linguistic levels used in the proposed model are shown in Table 1.

TABLE I: FUZZY LINGUISTIC LEVELS

Parameter	Linguistic Levels
Residual Energy	Low, Medium, High
Distance to Sink	Near, Moderate, Far
Node Temperature	Low, Medium, High
Link Quality	Poor, Average, Strong

Triangular and trapezoidal membership functions are used to represent these linguistic values. Fuzzification allows smooth decision-making under uncertain and dynamic network conditions.

C. Fuzzy Rule Evaluation

The fuzzy inference engine uses a set of IF–THEN rules to evaluate the suitability of each node for Cluster Head selection. These rules are designed according to network behavior and healthcare communication requirements.
Example rule:

- ➢ IF Residual Energy is High AND Distance is Near AND Temperature is Low AND Link Quality is Strong. THEN Cluster Head Suitability is Very High.

Similarly, multiple fuzzy rules are defined to analyze different combinations of network conditions. The fuzzy system intelligently combines all input parameters and produces a suitability level for every sensor node.

D. Defuzzification and Cluster Head Selection

After fuzzy rule processing, the output is obtained in linguistic form. To select the final CH, the fuzzy output is converted into a numerical value using the Centroid Defuzzification Method.

The node with the highest Cluster Head Suitability Score is selected as the CH for the current communication round. Dynamic CH rotation helps distribute energy consumption evenly among sensor nodes and improves overall network lifetime.

E. Mathematical Model

The mathematical expressions used in the proposed model are described below.

Residual Energy Ratio

$$RE_i = \frac{E_{current}}{E_{initial}} \quad (1)$$

Where:

- ➢ $E_{current}$ represents the remaining energy of the sensor node
- ➢ $E_{initial}$ represents the initial node energy
- ➢ Distance Factor

$$DS_i = \frac{d_i}{d_{max}} \quad (2)$$

Where:

- ➢ d_i is the distance between node iii and the sink node
- ➢ d_{max} is the maximum node distance in the network
- ➢ Link Quality Index

$$LQ_i = \frac{PRR_i}{PRR_{max}} \quad (3)$$

Where:

- ➢ PRR_i represents the packet reception ratio of node iii
- ➢ PRR_{max} represents the maximum packet reception ratio in the network
- ➢ Cluster Head Suitability Function

$$CHS_i = F(RE_i, DS_i, NT_i, LQ_i) \quad (4)$$

Where:

- ➢ RE_i denotes residual energy
- ➢ DS_i denotes distance to sink
- ➢ NT_i denotes node temperature
- ➢ LQ_i denotes link quality
- ➢ $F(.)$ represents the fuzzy inference function used to compute the Cluster Head Suitability Score.

IV. Results and Analysis

The evaluation of the proposed Fuzzy Logic-based DCHS method was done on NS-3 simulation platform. The proposed model was then contrasted with the currently used clustering algorithms like LEACH and E-LEACH to analyze the enhancement in energy efficiency, communication reliability and network stability. Healthcare related WBAN communication scenarios were used to evaluate it. Table 2 shows the settings used in the simulations for performance evaluation.

TABLE II: SIMULATION PARAMETERS

Parameter	Value
Simulator	NS-3
Network Type	WBAN
Number of Sensor Nodes	50
Simulation Area	100 m × 100 m
Initial Energy	0.5 J
Communication Standard	IEEE 802.15.6
Packet Size	512 Bytes
Simulation Time	1000 s
Traffic Type	Constant Bit Rate (CBR)
Compared Protocols	LEACH, E-LEACH, Proposed DCHS

A. Network Lifetime Analysis

In WBAN applications, one of the most critical performance metrics is its network lifetime due to sensor nodes' limited battery energy. The proposed DCHS method will dynamically select the Cluster Heads according to the

residual energy, node temperature, communication distance and link quality. This is a well-balanced CH rotation mechanism which minimizes energy wastage at individual nodes.
The results of the simulation show that the DCHS method has a significant improvement in the network lifetime, compared with LEACH and E-LEACH.
The period from First Node Dead (FND) and Last Node Dead (LND) are lengthened because of efficient load balancing and low communication overhead.
As can be observed from Fig.2, the proposed approach has resulted in an improvement in the network lifetime by around 41% as compared to E-LEACH. Intelligent CH selection strategy avoided the nodes with low energy and overheated to be CH, resulting in a stable cluster network.

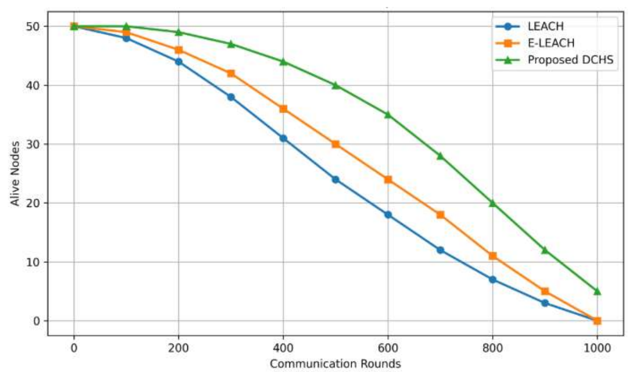

Fig. 2: Network Lifetime Comparison

B. Energy Consumption Analysis

The use of energy directly influences the efficiency of the operation of WBAN systems. However, the CH selection method is generally random in traditional clustering methods, which may lead to uneven energy consumption of the sensor nodes. The proposed DCHS mechanism, on the other hand, has a more efficient communication load spreading.
The simulation results demonstrate that the proposed model consumes less average energy as compared to LEACH and E-LEACH. This reduces the energy consumed in transmission because nodes with higher communication qualities are chosen as CHs and they are located near to the sink.

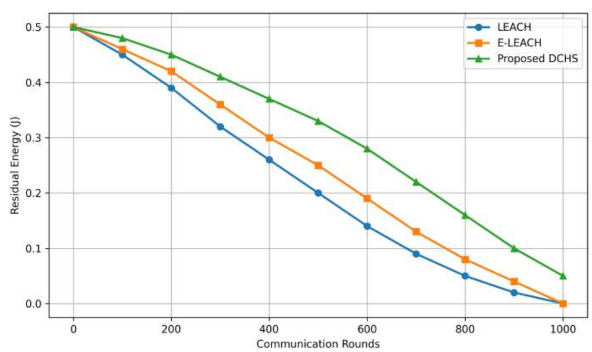

Fig. 3: Residual Energy Comparison

As seen in the Fig.3, the proposed DCHS method gradually reduces the energy while the traditional protocols significantly reduce the energy in limited number of communication rounds.

C. Packet Delivery Ratio (PDR)

PDR is the reliability of transmitting the healthcare data in the WBAN environment. In medical applications, packet delivery is critical because if that data is delayed or lost, it could impact patient monitoring.
The proposed DCHS method has better PDR than other protocols because of the stable CH selection and better communication links. The packet loss and transmission reliability were improved by adding link quality to the CH selection.

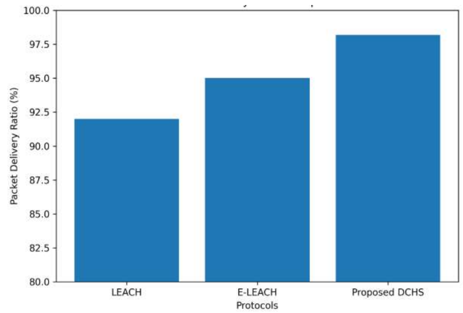

Fig. 4: Packet Delivery Ratio Comparison

The proposed approach resulted in almost 98% packet delivery performance as shown in Fig.4 which is better than LEACH and E-LEACH.

D. End-to-End Delay Analysis

The end to end delay is the time taken to send data from the sensor nodes to the sink node. In health care systems that demand real-time monitoring, it is important to have low delay.
The communication delay was reduced due to the efficient cluster formation and fewer transmission failures using the proposed DCHS method. Minimized retransmissions and communication interruptions due to Stable Cluster Head selection.

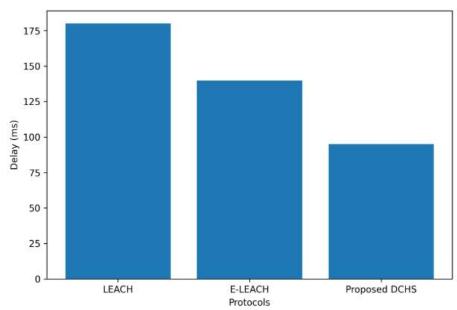

Fig. 5: End-to-End Delay Comparison

The results of the simulation showed that the proposed model reduced the delay during the communication process as compared to the conventional clustering methods shown in Fig.5.

E. Throughput Analysis

Throughput denotes the successful data transmission quantity in the network in the time period of the simulation. The more throughput, the more efficient the communication and network reliability.
The proposed DCHS mechanism was beneficial in terms of higher throughput due to stable communication paths and lesser packet drops. Optimized CH rotation resulted in more efficient data aggregation, and minimized communication congestion.

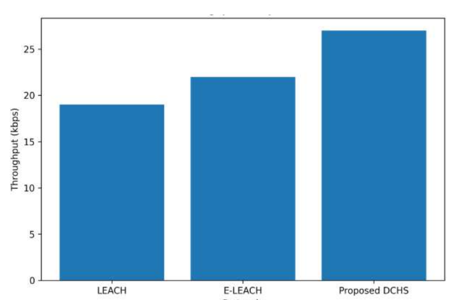

Fig. 6: Throughput Comparison

As per Fig.6, the proposed model achieved the throughput performance of around 27 kbps which is better than LEACH and E-LEACH protocols.

F. Discussion

The overall simulation results show that the proposed DCHS mechanism based on Fuzzy logic enhances the communication performance of the WBAN in terms of reducing the network lifetime, energy efficiency, packet delivery ratio, throughput and delay. The use of residual energy, temperature, distance, and link quality for the CH selection process allowed adaptive and reliable communication in dynamic healthcare monitoring conditions. The proposed method performs energy balance and enhances the stability of communications, which can be useful in continuous healthcare monitoring applications including ECG monitoring, patient activity tracking and remote medical assistance.

V. CONCLUSION AND FUTURE WORK

In this paper, a Fuzzy Logic based DCHS scheme for the enhancement of the performance of WBANs for monitoring applications in healthcare field was proposed. For efficient Cluster Head selection, multiple parameters like residual energy, distance to sink, Node temperature and Link quality were taken into consideration in the proposed approach. The proposed fuzzy-based model dynamically selected nodes for the cluster in consideration of the network condition at the current moment, which is different from any traditional clustering model that relies on a random or fixed CH selection. NS-3 simulations were used to test the performance of the proposed algorithmary method, and were compared to other protocols, such as LEACH and E-LEACH. The simulation results demonstrated that the proposed DCHS approach could achieve better network lifetime, energy consumption, packet delivery ratio and end-to-end delay. The addition of the decision parameters temperature and link quality further helped increase the reliability of communication and patient safety when monitoring their health in real time. The dynamic behavior of CH rotation resulted in a balanced energy usage, which led to network stability and longer operational lifetime of sensor nodes. In conclusion, the presented DCHS method offers an effective and dependable communication system for healthcare systems based on WBAN, which need continuous monitoring and low-power operation. Future research can be directed towards incorporating machine learning techniques into fuzzy logic to enhance adaptive Cluster Head prediction, under dynamic healthcare conditions. Patient mobility can also be modeled to enable communication in real-time medical environments. Moreover, the proposed method can be validated practically through hardware implementation with wearable sensor devices and real-time healthcare data to demonstrate its effectiveness in real-world applications.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks," IEEE Communications Magazine, vol. 40, no. 8, pp. 102-114, 2002.

[2] R. Gravina, P. Alinia, H. Ghasemzadeh and G. Fortino, "Multi-sensor fusion in body sensor networks: State-of-the-art and research challenges," Information Fusion, vol. 35, pp. 68-80, 2017.

[3] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao and V. C. Leung, "Body area networks: A survey," Mobile Networks and Applications, vol. 16, no. 2, pp. 171–193, 2011.

[4] K. P. Shih, S. Y. Wang, H. Y. Chen and P. Y. Lin, "Energy-efficient scheduling mechanism for wireless sensor networks," Journal of Information Science and Engineering, vol. 23, no. 4, pp. 1349–1362, 2007.

[5] A. Bari, S. Roy, S. Bandyopadhyay and A. Kumar, "Modeling and analysis of energy-efficient routing in wireless sensor networks," Computer Communications, vol. 32, no. 7–10, pp. 1423–1436, 2009.

[6] J. Yick, B. Mukherjee and D. Ghosal, "Wireless sensor network survey," Computer Networks, vol. 52, no. 12, pp. 2292–2330, 2008.

[7] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in Proc. 33rd Hawaii Int. Conf. System Sciences, 2000.

[8] S. Lindsey and C. Raghavendra, "PEGASIS: Power-efficient gathering in sensor information systems," IEEE Aerospace Conf., 2002.

[9] L. A. Zadeh, "Fuzzy sets," Information and Control, vol. 8, no. 3, pp. 338–353, 1965.

[10] J. Ko et al., "Wireless sensor networks for healthcare," Proceedings of the IEEE, vol. 98, no. 11, pp. 1947–1960, 2010.

[11] [11] D. P. Kumar, T. Amgoth and C. S. R. Annavarapu, "Machine learning algorithms for wireless sensor networks: A survey," Information Fusion, vol. 49, pp. 1–25, 2019.

[12] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” Proc. 33rd Annual Hawaii Int. Conf. System Sciences, 2000, pp. 1–10.

[13] M. Younis and S. Fahmy, "HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks," IEEE Trans. Mobile Comput., vol. 3, no. 4, pp. 366–379, Oct.–Dec. 2004.
[14] A. R. Al-Ali, A. S. Al-Saqabi, and M. Q. Shatnawi, "An enhanced LEACH protocol for improving the energy efficiency in wireless sensor networks," IEEE Sensors Lett., vol. 3, no. 1, pp. 1–4, Jan. 2019.
[15] N. Javaid et al., "A new energy-efficient protocol for wireless body area networks," Procedia Computer Science, vol. 19, pp. 224–231, 2013.
[16] S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, and A. Jamalipour, "Wireless body area networks: A survey," IEEE Commun. Surveys Tuts., vol. 16, no. 3, pp. 1658–1686, 2014.
[17] H. Alemdar and C. Ersoy, "Wireless sensor networks for healthcare: A survey," Computer Networks, vol. 54, no. 15, pp. 2688–2710, 2010.
[18] R. K. Kodali, M. K. Sahu, and A. Kar, "Fuzzy-logic-based cluster head selection in wireless sensor networks," Proc. IEEE Int. Conf. Advanced Computing (ICoAC), 2014, pp. 221–226.
[19] A. H. Abdullah, N. Z. M. Nor, R. Alsaqour, and H. N. Saeed, "Energy-efficient clustering using fuzzy logic for wireless sensor networks," Proc. IEEE Int. Conf. Information and Multimedia Technology, 2009, pp. 360–364.
[20] K. R. Rao and B. V. R. Reddy, "Thermal-aware routing protocol for wireless body area networks," IEEE Sensors J., vol. 16, no. 13, pp. 5121–5130, Jul. 2016.
[21] B. Latré, B. Braem, I. Moerman, C. Blondia, and P. Demeester, "A survey on wireless body area networks," Wireless Networks, vol. 17, pp. 1–18, 2011.
[22] H. Wang, Y. Qian, H. Sharif, and H. C. Chao, "Design and analysis of a QoS-aware routing protocol for body sensor networks," IEEE Trans. Mobile Comput., vol. 14, no. 7, pp. 1397–1410, Jul. 2015.
[23] S. Ullah, B. Shen, S. Khan, and K. S. Kwak, "A reliable and energy-efficient routing protocol for wireless body area networks," Sensors, vol. 16, no. 12, pp. 1–24, Dec. 2016.
[24] M. Patel and J. Wang, "Applications, challenges, and prospective in emerging body area networking technologies," IEEE Wireless Commun., vol. 17, no. 1, pp. 80–88, Feb. 2010.
[25] A. Quintero, L. Villalba, and C. F. García, "A fuzzy-based clustering protocol for wireless sensor networks," Sensors, vol. 10, no. 5, pp. 4771–4787, 2010.
[26] J. Li, M. T. Le, and L. H. Truong, "Energy-efficient fuzzy-logic-based clustering algorithm for wireless sensor networks," Proc. IEEE ICCE, 2015, pp. 258–263.
[27] O. Gama, F. Silva, and M. L. Rocha, "Trust-based routing for wireless body area networks," IEEE Access, vol. 7, pp. 10332–10342, 2019.
[28] S. N. Mohanty and B. Sahu, "A survey on energy-efficient protocols in wireless body area networks," Int. J. Distrib. Sensor Networks, vol. 11, no. 6, pp. 1–14, Jun. 2015.