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Research paper

DTEC-MAC: Diverse Traffic with Guarantee Energy Consumption for MAC in Wireless Body Area Networks

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Abstract

Wireless body area networks (WBANs) is an innovative technology that has greatly promoted the healthcare monitoring systems. WBANs includes the biomedical sensors that can be worn on or implanted in the body. The sensors monitor the vital signs, and then process the data that is then transmitted to a central server. The biomedical sensors are limited in energy resources and require an improved design in order to manage energy consumption. DTEC-MAC (Diverse Traffic with Energy Consumption-MAC) is proposed in this work based on the priority of data classification in the cluster nodes, and provides the medical data based on energy management. The proposed method uses fuzzy logic based on the distance from the sink and the remaining energy and length of data in other to select the cluster head. The MATLAB software is used in order to simulate the method. This method is compared with similar methods including iM-SIMPLE, M-ATTEMPT, and ERP. The simulation results obtained indicate that it works better to extend the lifetime and guarantee the minimum energy and packet delivery rates, maximizing the throughput.

1. Introduction

Wireless body area networks (WBANs) is a novel technology for remote monitoring used to obtain the patients' health data. The sensing node collects the health data at a regular interval time, and transmits it to a sink node for further processing [1]. Most patients go to the doctor when they have abnormal symptoms in their bodies. Thus usually, the patient should be treated promptly. The time for disease prevention is over, and the patient has to spend a lot of cost and time on treatment. However, using the sensor network can not only monitor the patient's physical health but also prevent the disease in its early stages and reduce the cost and risks of treatment. WBANs requires to evolve for more accurate monitoring in the future. Today, simpler sensors are used in advanced hospitals in order to monitor a patient's drug use and monitor the patient's vital signs [2]. Recently, the healthcare system requires more attention. The medical data for elderly people and patients should be monitored for a long time. The sensors are used for monitoring and measuring the blood pressure (BP) in order to diagnose the muscle activity. This network can monitor the activities such as falling, lack of consciousness, vital signs, diet, and exercise quality for an elderly person. They are necessary to be monitored in daily care and hospitals for real-time data from a patient's body [3, 4]. The researchers believe that with the advent and use of this technology in the future, this network can help diagnose the symptoms of a disease in the human body. Monitoring the people's health can promote telemedicine for identifying dangerous diseases, and save lives and reduce the treatment costs. Nowadays, we can remotely monitor the health of the patient's body but there is still a long way to complete these systems. Despite the small size of these networks, they can transmit large amounts of information and improve the health and

medical care conditions in order to reduce the cost of treatment and help to prevent diseases [5].
There are some limitations and challenges in the design of WBANs. In the following, some of the limitations of WBANs are expressed: Network availability: Since this system carries important information with high sensitivity and vital signs for life saving the patient, it is significant that the network should always be available. Also, the system must be adjusted to the changing conditions.
Localization: in most WBANs applications, it is better to estimate the exact place of nodes. The lack of location-based methods causes to transfer incorrect information.
Limited capabilities: A maximum number of implantable and wearable sensors work with batteries, and endure intense limitations in their computing and communication capabilities [6, 7].
The current research works on WBANs have focused on the energy management, patient mobility, routing, and lifetime of the nodes [8]. The lifetime of each node is limited in battery, and there is no possibility of recharging the battery. Thus, energy efficiency is a critical issue that we can improve in two ways. First, we can reduce the energy consumption bypass time. Secondly, we can improve energy consumption based on the changing architecture such as routing and data transmission. Recently, the energy management of medical data in WBANs has been more attentive [9]. However, the use of innovative technologies in healthcare applications, regardless of energy, endangers the privacy of the patient [10]. Also, the physiological data of a person is sensitive.
In this work, we present a protocol according to the priority of traffic for multi-constrained QoS with a new superframe structure. The objective of this protocol is to enhance the lifetime and maximize the throughput of the network. Then we use fuzzy logic to reduce the energy consumption by three input parameters such as the distance from the sink and the remaining energy and length of data, and one output for calculating the probability of selecting a cluster head.
The rest of this paper is organized as what follows. Section 2 presents the related works. Section 3 discusses the details of the proposed DTEC-MAC protocol. Section 4 shows the performance evaluation. In Section 5, analysis of the simulation and discussion of the proposed method are presented. In the final section, the conclusions of the work and the future directions are given.

2. Related Works

WBANs is one of the subsets of the wireless sensor networks (WSNs) that has been increasingly considered today. Alanbany et al. [11] have investigated WBAN as an innovative sensor network with performance capabilities in a variety of subjects, including the healthcare applications. He has addressed the applications of these networks in the health care systems. WSNs can be used in order to monitor the healthcare of the patients and the old people. This network could significantly improve the health status data and reduce the health care costs. In the medical monitoring systems, wearable sensors can integrate the data into the wireless sensors in order to monitor the vital symptoms, environmental parameters, and geographic location to provide continuous and mobile monitoring of the patients [12]. Also, the elderly provides real-time responses in an emergency in order to alter the monitoring centers about the current health status of the users [13].
The nodes attaching to the human body transmit their medical records to the doctor or the hospital center for studies and make a scientific assessment. The medical data is related to the vital signs of the humans. Disturbance in the medical data may be harmful to the patients. Much research work has discussed the energy management issues [14]. The available systems focus on the efficiency improvement in WBANs including energy consumption, packet delivery ratio, and throughput and lifetime [15].
Since getting the correct diagnosis of the disease is the fundamental purpose of the healthcare system, some researchers have used various computer-aided techniques in order to make better the diagnosis of diseases [15-20]. The researchers have attempted to explain the medical procedure in the Boolean or binary model. However, it is hard to describe all the factual issues in binary logic or crisp value. A novel model is essential to design these ambiguous and non-linear clinical issues. Ultimately, fuzzy logic has been presented for scheme uncertainty in medicine [21].
Fuzzy logic can describe the facts with more than a true and false expression. It is calculated based on the degrees of truth. Fuzzy logic was presented by Zadeh [22] since multiple computerized systems were improved with fuzzy logic [23, 24]. Fuzzy logic has been used in a multitude of sciences. Based on the feature of symptom and the complexity of medical data, fuzzy logic is used in order to overcome the accurate diagnosis of treatment.

Zadeh [23] has examined the challenges of fuzzy logic to improve the decision system to develop the medical diagnosis [25, 26]. Fuzzy clustering and categories are the concerned schemes that are applied in medicine. Both clustering and category are the data gathering models but they are distinct schemes. Clustering is applied to divide the information into classes in order to detect the hidden models based on the object. In each cluster, the objects have similar attributes. An energy-efficient adaptive clustering protocol based on fuzzy logic (ERP) has been presented in [27]. ERP is a multi-hop model with TDMA in order to avoid data packet collisions at the clustering and sink for prolonging the network lifetime and improve the stability period. The cluster head is selected based on fuzzy logic with three inputs including the remaining energy and distance from the sink and RSSI.

The Fuzzy Logic Collection Tree Protocol (F-CTP) has been designed for distributed dynamic optimization [28]. The simulation results obtained explain that the sensor can transfer information to the coordinator node immediately with a better reliability, and improve energy consumption. The sensor node can use the network resources and extend the network lifetime.

In [29] an energy-saving routing architecture has been presented to limit the energy consumption in WBANs with the same clustering algorithm. In order to evaluate this constraint, a fully automatic method for designing a fuzzy logic controller (FLC) has been recognized as a fundamental research subject with a major practical value. Moreover, an evolutionary process has been presented to automate the design of FLC for MAC in [30]. This scheme utilizes two evolutionary algorithms, particle swarm optimization (PSO) and differential evolution (DE). Several automatic schemes have been utilized in order to design FLCs as the table lookup methods [30], gradient descent [31], clustering and gradient descent [32], and EAs [33-34]. EAs including the Genetic Algorithm (GA) [35], Particle Swarm Optimization (PSO) [36], and Differential Evolutionary (DE) [37] have become public schemes for designing FLCs.

Another research work has designed the Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol (M-ATTEMPT) with the mobility for heterogeneous WBANs [38]. In order to reduce energy and eschew hot spots, the Stable Increased-throughput Multi-hop Protocol for Link Efficiency (SIMPLE) protocol has been suggested [39]. In this protocol, the cost of the selected route is computed according to the maximum remaining energy and a minimum distance from the sink. The simulation outcomes have depicted that SIMPLE has maximized the network stability period and a long-life network time for a high level of reliability. In [40], a cost function has been presented based on multi-hop for communication called iM-SIMPLE. A node with a maximum low energy and minimum distance from the sink has been select. Also, this method supports the mobility of the body. This protocol investigates two body postures.

The context-aware home care system has been proposed in [41]. This health care system uses the multiple theories and a fuzzy inference module as the core theory. The system reserves the physiological and environmental data of the patients, and transmits it to the server for decision. Using fuzzy logic, the system can propose notice and rapidly execute service to guarantee safety and comfort for elderly people and prevent emergency situations.

Z. Ling et al. [42] have investigated energy-consumption for a point-to-point communication in WBANs. This protocol has been analyzed in two conditions for data transmission including the normal and abnormal situations. In a normal situation, the time switching protocol is used, whereas for an abnormal condition, enhanced power splitting and radios or time switching. H. Mosavat-Jahromi et al. [43] have evaluated the spectral effectiveness of a communication link based on the energy management. The authors used two scenarios including the single and dual-hop analysis of the proposed protocol.

3. Purposed Method

In the proposed model system, each node collects and processes the data. The experiments show that the quality of human wireless communication is variable, and decreases over time. Even in some physical communication conditions, it may be completely interrupted. The energy consumption model depends on the hardware, data processing, and communication interfaces. In general, there are three energy consumption models: a data-driven model, in which the objective is to reduce the size of each node's data; a node-driven model, which is most commonly used for the case where the nodes moving on the network (such as car networks); a model based on the round or a data transfer cycle that is used in the sleep mode or low-energy mode. We propose an energy-efficient MAC protocol based on the data traffic priorities and superframe structure in order to guarantee the quality of service (QoS) with multi-constraints.

3.1. Data Types

The crucial and non-crucial data traffic has been categorized into two types in WBAN. In some situations, the data must be transmitted instantly. Thus, we require a prioritization mechanism to transfer the data into the first priority. In this way, we classified the data into four types based on the priority of data. Normal data (ND) contains the data in a normal situation. The delay data (DD) includes the data with a constrained delay such as audio/video information for monitoring the patients. Reliability data (RD) contains the high threshold value of the data, for example, a high heartbeat and a high respiratory rate. Critical Data (CD) comprises the critical data by considering a low latency and a high reliability for a low blood pressure and a low heartbeat rate. Thus, we classified the data traffic for providing the optimal solutions to guarantee a minimum energy consumption in WBANs.

3.2. Data Priority Classification

In WBANs, for the quality of service guarantee by the data priority, we classified the priority data into four classes. ND is determined by $\text{Data}_{\text{Normal}}$ which the lowest priority in a normal condition. DD is defined by $\text{Data}_{\text{Delay}}$ which is the third priority level of the guarantee transmitting data without any delay. RD is assigned by $\text{Data}_{\text{Reliability}}$ which is the second priority level based on the commitment to the reliability of data. CD is determined by $\text{Data}_{\text{Critical}}$ that the highest priority of life-critical data that is transmitted immediately without a delay and packet loss with a minimum energy consumption. Therefore, the data should be classified based on the packet size, priority, and data rate. Therefore, the resource energy is assigned as the node's priority. Table 1 shows the priority level of the data.

Table 1. Diverse classes of the data priority.

Priority	Classification of parameters	Sample
P_0 **(highest)**	Delay, Reliability	Critical warning signal, life emergency data(vital)
P_1	Reliability	Medical images (X-ray) or medical monitoring vital sign (PH-level, respiration)
P_2	Delay	Telemedicine medical signal (video/audio imaging)
P_3 **(lowest)**	Normal	Discontinuous medical signal (e.g. temperature, glucose level, SPO)

The priority in each class of data is expressed as Equation 1:

$$Output\,(PCHS) = \frac{\int x\,\mu_A^{(x)}dx}{\int \mu_A^{(x)}dx} \tag{1}$$

λ_T expresses the traffic generation rate and P_{Size} is the length of the data packet in WBANs. Therefore, the small packet size and low data traffic rates increase the priority of data for transmitting the packets.

3.3 Superframe Structure

The DTEC-MAC protocol is according to the IEEE 802.15.4 standard with a priority of mechanism. The suggested protocol is appropriate for multiple constraints (delay and energy and reliability) to guarantee QoS in WBANs. This protocol categorizes four traffic groups. In a superframe structure, each traffic group has different periods.

The superframe consists of Beacon, CAP, CFP, ETS, and EX based on IEEE 802.15.4. Figure 1 depicts the superframe structure for the proposed protocol. Beacon consists of the data for the next phase and synchronization data and the address of the body coordinator. All the information is allocated to CAP for contention in order to access the channel. Each node uses the CSMA/CA procedure. The information of the P_0 and P_2 nodes is transmitted immediately after accessing CAP.

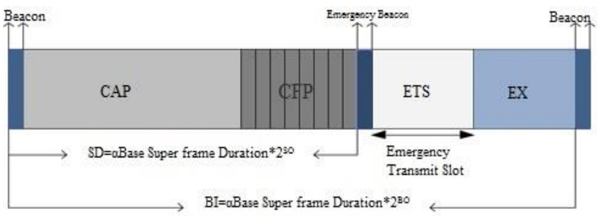


Figure 1. Suggested superframe structure of DTEC-MAC protocol.

In the contention-free period (CFP), the coordinator node assigns assurance timeslots in order to capture access in CAP without contention with the other nodes. In the first level, the coordinator node broadcasts the data of the beacon for all of the sensors. Then the critical data according to the contention in the CAP channel access the priority. Also, if the critical data is simultaneously received with the same priority, the information order is based on FIFO. The data transmitted is given in Figure 2.

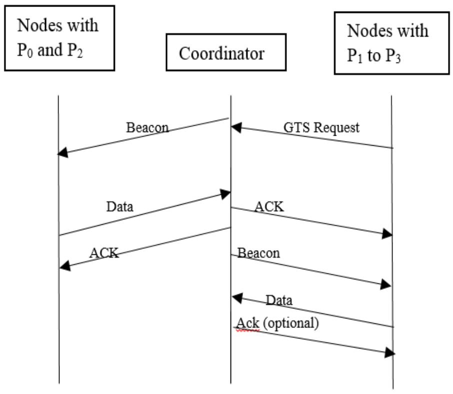


Figure 2. Data transfer production.

In the superframe, BI has the two parts of active and inactive. The active part comprises a beacon, CAP, and CFP. Moreover, BI and SD are dependent on the Beacon Order (BO) and Superframe Order (SO). BO defines the time length of all the superframe structures that are denoted as Equation 2. Also, SO defines the time length of the active part of the superframe by Equation 3.

$$BI = \alpha BaseSuperframeDuration \times 2^{BO} \quad (2)$$

$$SD = \alpha BaseSuperframeDuration \times 2^{SO} \quad (3)$$

In order to compute BI that expresses the time length of the protocol, it is obtained following Equation 4. SD is computed by Equation 5 in order to calculate SD that expresses the SF duration.

$$BI = \frac{\alpha BaseSuperframeDuration \times 2^{BO}}{Data\_Rate} \quad (4)$$

$$SD(SFDuration) = \frac{\alpha BaseSlotDuration \times \alpha numSuperframeSlot \times 2^{BO}}{Data\_Rate} \quad (5)$$

3.4 Clustering Data

In this work, the remaining energy of the nodes, distance from the sink, the length of data, and the cost of all nodes were calculated in order to select the cluster head (CH) with fuzzy logic. Then the node with the minimum cost in each round was selected as the cluster head. The general aim of this proposed method increased the stability period and more residual energy and extended the network lifetime.

We used the radio model in [40] for simulation. The energy is consumed by the radio model for transmitting a K-bit packet over a distance d. d^2 is the cost of energy for delivering the data in the channel. It is obtained using a radio model in Equation 6 and 7:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \quad (6)$$

$$E_{Tx}(k,d) = E_{Tx-elec} \times k + E_{amp} \times k \times d^2 \quad (7)$$

In this regard, E_{elec} is the amount of energy consumption by the transmitter per bits. Thus, the cost of receiving medical data will be obtained according to 8:

$$E_{RX}(K) = E_{Rx-elec}(K) = KE_{Rx-elec} \quad (8)$$

In this work, the reduced energy consumption of WBANs was considered as prolonging the network lifetime of the nodes. In this equation, E_{Tx} is the energy necessary to transmit the delivery, E_{Rx} is the energy consumed by the receiver, ET_{x-elec} and ER_{x-elec} are the energies to run the electronic circuit of the transfer and receiver, respectively. E_{amp} is the energy required for a suitable functioning of the amplifier circuit to the receiver. The energy consumption for N sensor nodes in the cluster head node is given in Equation 9.

$$E_{CH} = KE_{elec}\frac{N}{C} + KE_{DA}\frac{N}{C} + KE_{amp}d^2_{toBS} \quad (9)$$

In this equation, N/C is the average number of nodes per cluster, and E_{DA} is the energy consumption in aggregation. The average d_{toBS} is the distance from the base station to the cluster node. In the non-cluster head, the energy consumption of a node is given in Equation 10. The energy consumption in non-cluster to the cluster head nodes is calculated by the average distance that is denoted by Equation 11. As a result, the total energy is expressed in Equation 12.

$$E_{non-CH} = K_{Eelec} + KE_{amp}d^2_{toCH} \quad (10)$$

$$d^2_{toCH} = \frac{M\,2}{2\Pi C} \quad (11)$$

$$E_{cluster} = E_{CH} + E_{non-CH}\frac{N}{C} \quad (12)$$

The distance from the sink is computed as shown in Equation 13. Here, S_i is the sensor node in the cluster (i=1, 2 …m) and C_J is the cluster head (j=1, 2… k). The distance between the cluster head and the sink can be obtained using Equation 14. X_{CH} and X_{Sink} are the spots of the cluster head and the sink on the x-axis. y_{CH} and y_{Sink} are the spots of the cluster head and the sink on the y-axis.

$$Dis\tan ce(S_i, C_J) = \sum_{i=1}^{m}\sqrt{(S_i - C_j)^2} \quad (13)$$

$$Dis\tan ce(\mathrm{Sin}k, CH) = \sqrt{(X_{CH} - X_{\mathrm{Sin}k})^2 + (y_{CH} - y_{\mathrm{Sin}k})^2} \quad (14)$$

First of all, in each case, the cluster heads and clusters are selected. Afterward, each body sensor sends the data to the cluster head. Each cluster head collects the received data with a specific density aggregation and sends it to the sink. For the data aggregation, the length of the data is calculated by the relation 15.

$$L_{agg} = L_{rec} + (L_{rec} \times R_{agg} \times N) \quad (15)$$

where L_{agg} shows the length of the data aggregated in bits. Whenever the variable L_{rec} depicts the length of the data of each cluster, the variable R_{agg} is expressed as the aggregate ratio, and N is the variable number representational of the cluster heads.

We used a Fuzzy Interference System (FIS) that was a Mamedani's deduction algorithm. The logical results are expressed in a relatively simple structure and more use of decision support systems that are capable of interpreting the rules. The output of the combination non-linear fuzzy Mamadani inference algorithm is the linear derivation system. In this work, three input linguistic variables were determined. This parameter represents the residual energy and distance from the sink and the length of the data. The remaining energy (E) was fuzzified into three fuzzy levels including high, medium, and low. The distance from the sink (D) was fuzzified into three different fuzzy levels, i.e. nearby, reachable, and distant. The length of the data (L) was further partitioned into five different fuzzy levels containing very high, high, medium, low, very low. The FIS system in this protocol is depicted in Figure 3.

Generally speaking, there are 45 different fuzzy logic rules, (i.e. 3 fuzzy levels of the remaining energy (E) × 3 fuzzy levels of distance from the sink (D) × 5 fuzzy levels of the length of data (L)). Besides, the structure has one output level probability of cluster head selection (PCHS). Therefore, our FLC contains 45 distinct fuzzy rules. Each rule conforms to a basic architecture as depicted in Equation 16.

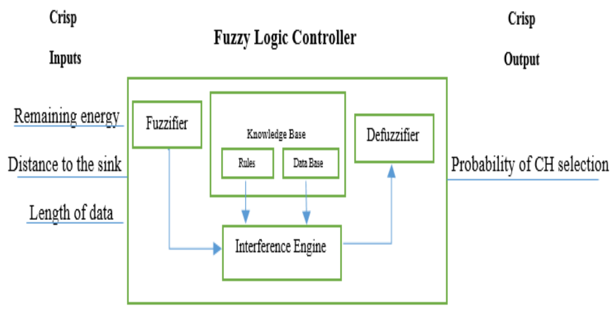


Figure 3. Architecture of fuzzy logic for DTEC-MAC.

$$\begin{aligned} R^{(n)} &: \text{If } E_n \text{ is } a_1^i \\ &\text{and } D_n \text{ is } a_2^i \\ &\text{and } L_n \text{ is } a_3^i \\ &\text{Then } PCHS \text{ is } C^i \end{aligned} \quad (16)$$

Figure 4 shows that the fuzzy system including three levels of fuzzification and rules evaluation and defuzzification. The fuzzy collection is three input parameters, and the output probability of cluster head is as presented in Figure 5. Fuzzy rules are logically defined in Table 2.

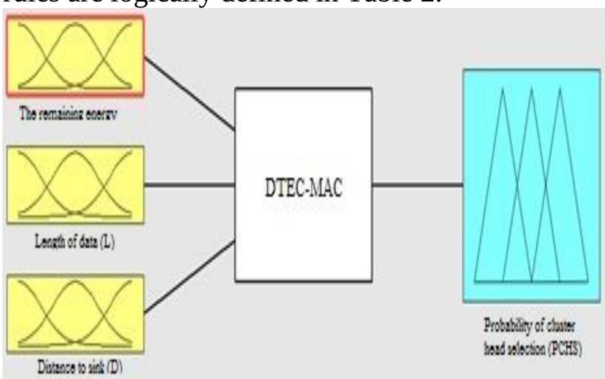
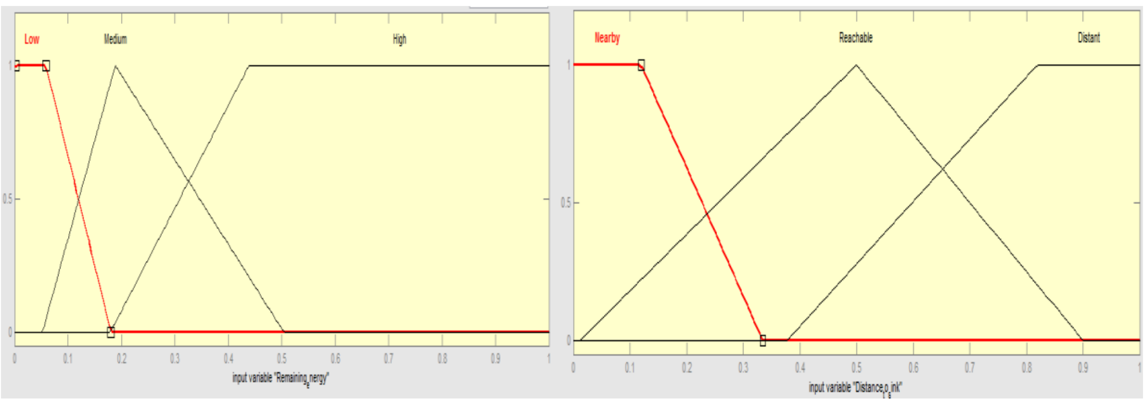
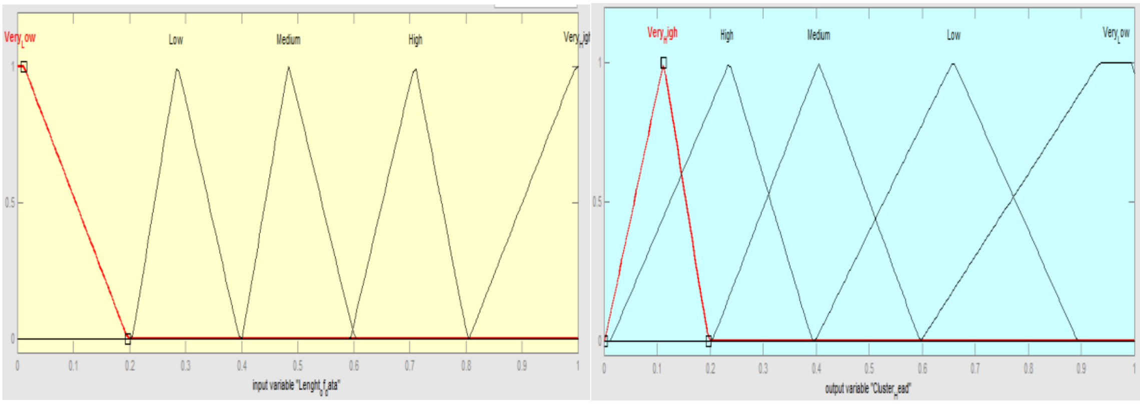


Figure 4. The FIS DTEC-MAC input and the output membership function.



(a) (b)



(c) (d)

Figure 5. (a) Function of remaining energy, (b) function of distance, (c) function of length of data, (d) function of cluster head possibility.

Table 2. Fuzzy rules in the proposed method.

Row	Remaining energy (E)	Distance for sink (D)	Length of data (L)	Possibility of cluster head selection (PCHS)
1	High	Nearby	Very high	Very high
2	High	Nearby	High	Very high
3	High	Nearby	Medium	High
4	High	Nearby	Low	Medium
5	High	Nearby	Very low	Low
6	High	Reachable	Very high	Very high
7	High	Reachable	High	High
8	High	Reachable	Medium	High
9	High	Reachable	Low	Low
10	High	Reachable	Very low	Low
11	High	Distant	Very high	High
12	High	Distant	High	High
13	High	Distant	Medium	Medium
14	High	Distant	Low	Low
15	High	Distant	Very low	Low
16	Medium	Nearby	Very high	High
17	Medium	Nearby	High	Medium
18	Medium	Nearby	Medium	Low
19	Medium	Nearby	Low	Low
20	Medium	Nearby	Very low	Low
21	Medium	Reachable	Very high	Medium
22	Medium	Reachable	High	Medium
23	Medium	Reachable	Medium	Low
24	Medium	Reachable	Low	Low
25	Medium	Reachable	Very low	Low
26	Medium	Distant	Very high	Medium
27	Medium	Distant	High	Low
28	Medium	Distant	Medium	Low
28	Medium	Distant	Low	Low
30	Medium	Distant	Very low	Low
31	Low	Nearby	Very high	Low
32	Low	Nearby	High	Low
33	Low	Nearby	Medium	Low
34	Low	Nearby	Low	Very low
35	Low	Nearby	Very low	Very low
36	Low	Reachable	Very high	Low
37	Low	Reachable	High	Very low
38	Low	Reachable	Medium	Very low
39	Low	Reachable	Low	Very low
40	Low	Reachable	Very low	Very low
41	Low	Distant	Very high	Very low
42	Low	Distant	High	Very low
43	Low	Distant	Medium	Very low
44	Low	Distant	Low	Very low
45	Low	Distant	Very low	Very low

Transmitting the data to the coordinator node is done through an intermediate node for selecting each cluster head with regard to fuzzy logic according to which, energy of node reduction (sending and receiving the cluster head is selected). In each round, a selection of the cluster head is done according to fuzzy logic. By considering the distance from the sink, the remaining energy of the sensor and the length of data are transmitted to the sink and the cost of each node is calculated for selecting the cluster head. Then the cost of selecting nodes is sent to all nodes. The node with the lowest cost is selected as the cluster head. The level is constantly repeated until all nodes become the cluster head or the cluster member. The defuzzification scheme uses the center of gravity (COG), and is denoted as Equation 17. $\mu_A^{(x)}$ is the function of collection A.

$$Output\,(PCHS) = \frac{\int x\, \mu_A^{(x)} dx}{\int \mu_A^{(x)} dx} \quad (17)$$

4. Performance Evaluation

In this part, the suggested scheme is simulated in the MATLAB software, and the parameters used for simulation are presented in Table 3. We consider NORDIC nRF2401 transceiver. The assumptions of the proposed method are given as the following. The location of all nodes and the sink are always fixed. All nodes have the same primary energy. The battery of the sensors is not reachable. Moreover, DTEC-MAC is evaluated and compared with ERP [27], M-ATTEMPT [37], and iM-SIMPLE [40].

Table 3. Network configure ration.

Parameter	Value
Network size	(200 × 200) cm
Base station location	(100, 100) cm
Number of sensor nodes	8
Initial energy (E_0)	1 J
Data packet size	4000 bits
Amplification energy (E_{amp})	1.97nJ/b
Transmitting energy ($E_{tx-elec}$)	16.7 nJ/bit
Receiving energy ($E_{rx-elec}$)	36.1 nJ/bit
Aggregation ratio	10%

Table 4 depicts the simulation outcomes of this scenario. As shown in this table, the suggested protocol accomplishes better than iM-SIMPLE, M-ATTEMPT, and ERP in the FND (First Node Dead), HND (Half Node Dead), and LND (Last Node Dead) criteria. The FND parameter represents an estimated value at the first node that is dead in the cycle. This criterion is useful for small WBANs. Therefore, the FND, HND, and LND criteria are chosen in order to evaluate the algorithm's performance.

Table 4. The FND, HND, and LND values.

Algorithm	FND	HND	LND
M-ATTEMPT	2200	7200	7500
iM-SIMPLE	5200	6200	7300
ERP	3300	7000	7500
DTEC-MAC	6500	7800	9000

In this analysis, according to Table 4, M-ATTEMPT has the weakest performance among the three algorithms. The total nodes of M-ATTEMPT, iM-SIMPLE, and ERP die at 7500 and 7300, and 7500 rounds, respectively, while ERF-W can stay alive longer than 9000 rounds. The result of the DTEC-MAC protocol has a greater network lifetime contrast compared to the other protocols.

4.1 Prioritization of Traffic According to Energy Consumption

For the prioritization of information, we classified the data according to the delay and reliability constraints. The priority of information is guaranteed by Carrier Sense Multiple Access with Collation Avoidance (CSMA/CA). The average energy consumption for each bit is presented in Equation 18.

$$E_b = \frac{E_{avg}}{S_b} \quad (18)$$

In this formula, E_{avg} computes the average energy consumption and S_b shows the throughput of the relation. Energy consumption is raised as packet collisions. Traffic prioritization reduces collision rates and retransmission of packets. In the DTEC-MAC protocol, the data is divided into four categories: ND, RD, DD, and CD. In ND, the normal data is delivered by the CSMA/CA method. In RD, the reliable data is transferred through the TDMA scheme. DD is the delay data constrained, and the data is transmitted by the CSMA and TDMA mechanism.

4.1.1 Normal Data (ND)

In ND, the data is not considered as delay or reliable, and includes the regular monitoring of the vital signs and physiological data in the normal body situations, for instance, temperature, and pressure.

By decreasing the back-off time, the add-up of node has a higher frequency with a shorter interval time, causing to save energy to access to the channel. The probability of access to the nodes in the channel is a higher contrast to the nodes with a longer back-off period. Thus, the optimal back-off time is calculated according to the priority to eschew the frequent search when the channel is busy.

4.1.2 Reliable Data (RD)

The reliable data has strict reliability requirements but is not delay-constraint, for instance, for data transfer of medical images such as X-ray or some vital sign monitoring applications, i.e. PH-level monitoring, respiration monitoring, etc.

The reliable data is sent according to the kind of data for the medical team requirements as audio or video data over an interval time such as the threshold value of a high heartbeat and high respiratory rate that they can endure delay. Such data does not have the restriction of delays. The nodes are transferred in the CFP section of the superframe. In this section, the coordinator usage of the TDMA mechanism to transmit nodes is discussed.

4.1.3. Delay Data (DD)

Delay-constrained that impose delay that includes the packet loss without a reliability constraint such as audio/video-based data of vital sign of the patient's body via telemedicine video imaging and motion sensing and electromyography (EMG). Therefore, this data is transmitted to the CFP superframe by the CSMA and TDMA mechanisms.

4.1.4 Critical Data (CD)

Critical data comprise emerging data with significant vital sign data of the patient such as low threshold value. This data puts constraint on reliability and delay. Therefore, this type of data is transmitted to the ETS section superframe.

The Critical traffic happens accidentally, and the size of the packets is commonly similar to the other normal packets. The critical data is transferred with a higher priority and a smaller back-off in shorter periods. In the critical nodes, small-size data packets are sent over a short period without interruption. If the channel is busy, the sensors will have access to the channel for a more back-off time, resulting in long delays in the channel access. In the CD phase, the back-off period is computed according to the length and priority of the data packets in the superframe.

5. Discussion

We evaluated the performance metrics of the DTEC-MAC protocol by comparing it with iM-SIMPLE, M-ATTEMPT, and ERP for review of performance, stability period, network lifetime, dropped packets, remaining energy, and throughput. DTEC-MAC uses a fuzzy model in order to guarantee energy consumption in medical data. The definitions of the performance parameters are given in the following.

1) Stability round: it is the time coverage of the network function before the death of the first node. The time round after the death of the first node is called an unstable round.

2) Network lifetime: it demonstrates the full network function till the death of all nodes.

3) Residual energy: Average total energy consumption of the nodes per round.

4) Throughput: it is the whole number of successfully received packets at the sink.

Round is an essential time to construct a network. Most research works in the field of WBANs are looking for a maximum lifetime node. Many factors affect the lifetime of nodes, such as location, scheduling, and securing medical data. The cost function for selecting the cluster head plays a significant role to increase the lifetime of the network. In iM-SIMPLE, a new forwarder node is selected based on the cost function of distance and the remaining energy per round. In M-ATTEMPT, the number of forwarder nodes is more than iM-SIMPLE. Thus, the nodes die sooner in M-ATTEMPT. In other words, all sensor nodes of M-ATTEMPT die very earlier as compared with the proposed protocol. In M-ATTEMPT, the first three nodes die at 2200 rounds. Also, in iM-SIMPLE and ERP, the first node dies at 5200 and 3000 rounds, respectively, while in DTEC-MAC, the first node dies as 6000 rounds. According to the results obtained, the DTEC-MAC protocol has a longer stability than the iM-SIMPLE, M-ATTEMPT, and ERP protocols. Therefore, the network is a better load balancing as contrasted with the other protocols. Figure 6 depicts a comparison of the average network lifetime of iM-SIMPLE, M-ATTEMPT, and ERP.

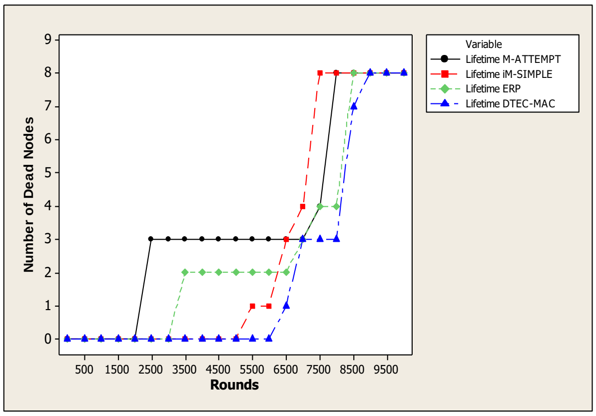


Figure 6. Analysis of network lifetime.

The number of packets received by the nodes has a good criterion for evaluating the effectiveness of the algorithms. When the number of packets received by the nodes is higher than the normal situation, the algorithm transmits more data to the nodes and has a better performance. In Figure 7, the most important comparison is made in throughput. The throughput of the proposed method for the number of packets received is higher than the other methods. The DTEC-MAC protocol achieves a higher value of successfully received packet that causes a prolonged stability of the networks, while M-ATTEMPT has the lowest performance due to the mobility scheme and using a thermal effect together, where the increased number of alive nodes produces more data packets toward the sink. In other words, an additional number of alive nodes transfer more data packets to the sink. Therefore, the throughput of the network increases. The packet drop occurs when the packet fails to attain the network.

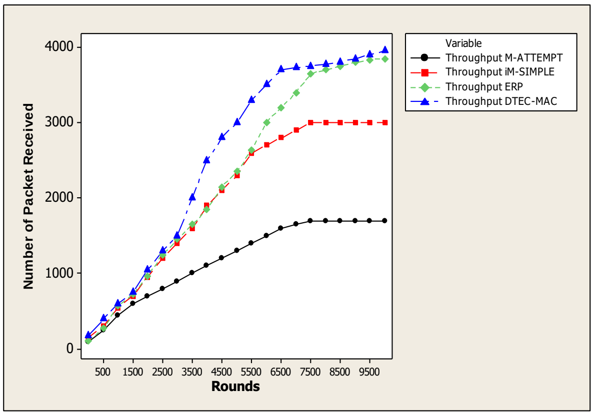


Figure 7. Analysis of network throughput.

Figure 8 shows the number of packets drop as compared to the M-ATTEMPT and iM-SIMPLE protocols. M-ATTEMPT has the highest packet drop rate because the forwarder nodes do not have suitable energy for the data transmitted. The cost function according to the selection forwarder node in iM-SIMPLE decreases in comparison to M-ATTEMPT because of considering the distance and residual energy in selecting the forwarder node. Moreover, it is a mobility protocol that causes a higher packet drop rate in comparison to a static protocol, while DTEC-MAC has a lower number of packet drops. Thus, the throughput and packet drops are dependent on the others. Also, more throughput results in reducing the number of packets drops and increases the reliability of the network.

The next important parameter for evaluating the efficiency of the algorithm is the energy consumption. The amount of energy in this section is used for the sum of energy consumption for all nodes and the sink. Choosing the suitable forwarder node in each round depends on the resume energy. The energy consumption of the four algorithms is depicted by joule in Figure 9.

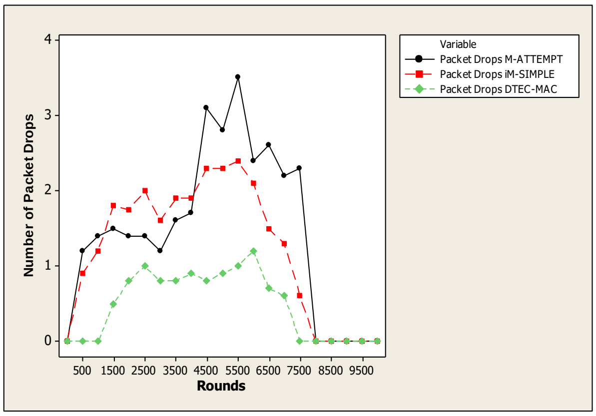


Figure 8. Analysis number of packet drops.

The energy consumption in the DTEC-MAC protocol is a higher number of residual energy than the other protocols because of using the selection of optimal cluster heads. Thus, the stability period has enough energy for transmitting more data packets to sink and enhance the throughput. When the selection of cluster heads is the more optimal result, the nodes are not required to transmit their data at a large distance to reach the cluster head. Thus, energy consumption is reduced. Moreover, the number of hops to transmit the data is decreased.

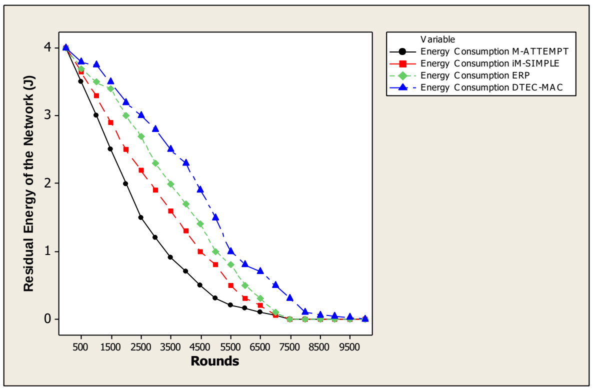


Figure 9. Analysis of amount of energy consumption.

To sum up, M-ATTEMPT uses a probabilistic scheme for clustering which is not enough to achieve the best solution. Since iM-SIMPLE considers the energy parameters and local distances in each cluster cycle, it performs better than M-ATTEMPT. Moreover, M-ATTEMPT and DTEC-MAC consider the remaining energy of each cluster head to calculate the competitive radius. This means that if the selected cluster head has more energy, the radius of the cluster will be larger. In other words, more sensor node is given service in that area. This feature guarantees that the cluster head has more energy.

6. Conclusions

Despite the advances in the field of WBANs, more attention is required for energy consumption and the lifetime of the nodes. Usually WBANs are placed implant or around the body. Thus, there is no possibility of recharging or replacing the sensors. Moreover, WBANs are sensitive to changes in the physiological values. Therefore, energy management is significant.

In this work, we suggested a scheme according to the fuzzy model and data gathering by clustering to the sink node and between nodes for an improved energy consumption and lifetime. The reason for using the fuzzy algorithm to minimizes energy consumption in WBANs is the ability to optimize the problem by considering the number of different parameters that can have a great impact on the function of problems. We used a fuzzy logic system based on three parameters: the remaining energy, the distance from the sink, and the length of the data. These are considered as the inputs, and the probability of selecting the cluster head is considered as the output. At this phase, the best route is selected for monitoring. The simulation results show that using the DTEC-MAC protocol improves energy consumption, and extends the lifetime and increases the stability period of the network.

By analyzing the outcomes, we can conclude that the suggested algorithm provides an appropriate framework for the medical data in WBANs. The first reason is that the number of receiving packets is higher in comparison to iM-SIMPLE, M-ATTEMPT, and ERP, which indicates that more packets are received with a high degree of remaining energy. Also, the proposed method guarantees the results such as ensuring the energy management of medical data to extend the lifetime. For future work, consideration of the other criteria that can be useful and appropriate as the inputs of the fuzzy system is suggested. Moreover, the use of evolutionary algorithms (EAs), particle swarm optimization (PSO) and differential evolution (DE), and genetic algorithm (GA) is suggested an improved energy management to improve the challenges and developments in the large dimensions of the network.

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DTEC-MAC : تضمین مصرف انرژی با اولویت‌بندی داده‌ها با استفاده از پروتکل MAC در شبکه‌های بی‌سیم بدن

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چکیده:

شبکه‌های بی‌سیم بدن یکی از فن آوری‌های جدید هستند که استفاده از آن‌ها در نظارت و مراقبت‌های پزشکی به میزان قابل توجهی افزایش و بهبود یافته است. هر شبکه بی‌سیم بدن متشکل از گره‌های حسگر پزشکی است که می‌تواند روی بدن انسان قرار گیرد یا در بدن کاشته شود. این گره‌های حسگر می‌توانند علائم حیاتی انسان را دریافت کنند و داده‌ها را پردازش و به سرور پزشکی منتقل کنند. حسگرهای پزشکی در منابع انرژی محدود هستند و برای کاهش مصرف انرژی و افزایش طول عمر شبکه نیاز به طراحی پروتکل‌های بهبود یافته است. بنابراین در این مقاله، پروتکل DTEC-MAC (ترافیک متنوع با در نظر گرفتن مصرف انرژی با پروتکل MAC در شبکه بی‌سیم بدن) با توجه به اولویت طبقه‌بندی داده‌ها در خوشه‌ها ارائه شده است و داده‌های پزشکی بر مبنای مصرف انرژی مدیریت می‌شوند. در روش پیشنهادی از منطق فازی و بر اساس فاصله تا سینک و انرژی باقیمانده و طول داده برای انتخاب سرخوشه استفاده می‌شود. این روش با روش‌های مشابهی به نام iM-SIMPLE و M-ATTEMPT و ERP مقایسه شده است. نتایج شبیه سازی نشان می‌دهد که طول عمر شبکه و سرعت تحویل بسته‌ها و گذردهی افزایش یافته است و در مقابل مصرف انرژی و تاخیر کاهش یافته است.

کلمات کلیدی: شبکه‌های بی سیم بدن، اولویت‌بندی داده‌ها، پروتکل‌های MAC، منطق فازی، مدیریت انرژی.