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A Novel MAC Protocol for Energy Conservation in Wireless Body Area Networks

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Abstract: Body sensor networks are an example of wireless sensor networks. Body Sensor Network is a kind of wireless sensor network for a special purpose that uses wireless sensor nodes to measure a person's biological parameters and monitor his or her health remotely and is available in both wearable and implantable types. These systems also monitor physical activity such as environmental parameters. These systems can provide significant assistance by supplying services such as medical observations and the provision of medicinal and medical information, improving the memory of individuals and controlling home devices and communicating in emergencies. Body wireless sensor network is a wireless technology featuring small, smart devices that connect to the body and monitor it continuously, enhancing early detection of emergency situations in patients at high health risk and providing a wide range of health services, therefore of paramount importance. The most important challenges in wireless sensor networks are sensor nodes, resource constraints, reliability and quality of service, security and routing, and energy consumption constraints. In this article, we focused on energy consumption due to small sensors with limit power resource and latency for emergency data to improve network lifetime, energy consumption, network efficiency and lower latency. This research will provide a way to optimize energy consumption by examining the energy exhaustion and network performance in the MAC layer. It assumed that by improving the access to MAC in wireless body area network can have better operation power and by propound the energy parameter in data transition priority. Optimizing energy consumption and minimizing delays and increasing the latency are the goals of this study by modify the IEEE 802.15.4 superframe structure based on MAC layer protocol.

Keywords: Body Network, Wireless Sensor Networks, Energy Consumption Optimization, Network Efficiency

1. Introduction

Recent advances in wireless sensor technologies have led to the advent of low-cost short-range transmitters, which has led to the expansion of wireless networks in the body [1]. Wireless body sensor networks are used because of their applicability in medical and non-medical applications, and because of the use of low-cost measurement devices, such as body nodes, different patient information can be obtained and delivered to the central station. In this regard, the development of small, wearable sensors that can replace patient admissions has attracted researchers [2]. This is one of the latest technologies in the field of diagnosis and health care management. The sensors in this network are very small and portable. Each sensor node is usually capable of receiving one or more vital signals and processing these signals and storing processed information and transmitting information to other sensor nodes or a wireless sensor network server. The physical sensor network has a smaller number of nodes than the wireless sensor network. Smaller nodes have smaller batteries and this has a significant impact on reducing power consumption, processing and storage, communication resources, accuracy, and transmission delay. In physical sensor networks sensors are installed on the patient's body to monitor the patient's vital signs or detect movement (such as motion sensors and electrocardiogram sensors). In fact, the body sensor network consists of several biosensors. A wireless sensor network, while able to monitor vital signs, provides real-time feedback to the user, allowing the user to monitor the progress of their illness and take the necessary precautions. Wireless Physical Sensor Network is a subsystem installed as a case sensor network on the patient's body. Components of the body sensor network include RFID tags and electrocardiogram sensors. Physical sensor networks share many of the challenges and opportunities with wireless sensor networks. Emergency data are the most important data that can even save the patient life if they have high priority in transition to the hospital or a doctor [11]. So we should find the way to improve network efficiency on emergency data. MAC protocol in physical layer is an interesting topic for researchers that can have study on it to improve the network lifetime by reduce energy consumption, network latency, operation power and etc [13]. How can change the accessibility to the MAC to improve network efficiency features? and how can decrease network latency and energy consumption in wireless body area network? To achieve the answers of these questions, one proposed way is study in MAC protocol especially on IEEE 802.15.4 superframe structure. Means that if modify the structure might have been a good results on network lifetime and efficiency.

2. Related Work

Here as pointed will have introduced MAC protocols that other researchers proposed about wireless body area networks and will have considered their advantages and disadvantages.

In 2002 Ye et al [16] proposed an optimized MAC protocol in energy consumption that has specially designed for wireless sensor networks. S-MAC is about sensor network that the major parts of communication between nodes are in point to point state and have no base station. The main idea of designing of S-MAC was to increase network efficiency versus stability and collision avoidance [14]. To aim to this goal, S-MAC protocol has tried to reduce energy consumption from resources that have misuse from energy resource [15].

In a study, the researchers looked at DS-Macs and examined the energy consumption of different states, and found that the highest energy consumption was in the transition from, from active to inactive, meaning that the energy consumption was higher when the nodes in the data transfer modes are in place, and they rank all steps as follows, with low power consumption respectively. Thus, it first consumes the passive mode, active mode, passive listening and transfer mode [10].

Mac is a new mechanism, in which the nodes are configured to be commensurate with the amount of active data packets received. When the amount of data packets reaches its peak, DS-MAC shortens the time when nodes do not participate in data exchange. This causes much less energy to be wasted as the transition from active and inactive state wastes a lot of energy [9]. The energy that nodes store in the passive state is less than when the nodes are in the active-passive state. When the data packets of the nodes are reduced to a certain extent, a great deal of energy is lost which is due to inactive listening. At this point, the sensors act like CMACs. The number of source nodes in the DSMAC protocol is not limited, thus increasing the range of software [3]. In 2009, Malkovich et al. [4] proposed a single-hop TDMA approach to maximize network lifetime and increase protocol energy efficiency based on passive listening avoidance. In this protocol, listening and communication are reduced by the TDMA method, which is suitable for a static type of network with a limited number of sensors. The main purpose of this protocol is to minimize the relevance of the sensors to the sleep state of the nodes. In 2011, Zhang et al. [5] proposed a free-communication-based approach to prevent collisions by separating control channels from data channels. The protocol consists of two periods: CAP used by the control channel and CFP used by the data channel. This protocol shows significant improvements in energy efficiency and productivity. Access and power consumption delays for emergency traffic are minimized. In 2008, O'Manie et al. [6] used the MASTER-SLAVE-based MAC protocol, which coordinates the nodes with SLAVE, to achieve both of the above two proposed protocols, namely passive listening and network collision. CCA / TDMA time sharing is used to reduce collisions in normal time or interference and alert modes. The disadvantage of this method is that the maximum number of slaves can join a cluster at a time of eight and only one node. The slave can join the network at one time and this will set up a great time for the network. In another article, Fongjie et al., 2009 [7], deactivated the use of flexible bandwidth allocation and critical event reporting by a node in two modes of closed-loop listening. In 2013, Shui JG [8] presented a priority-based adaptive time slot allocation scheme, which classifies data by priority to obtain service quality and is able to cope with the dynamic size of the network. The aim is to develop a plan for Time Slot allocation and management in WBAN to handle emergency information.

3. Proposed Protocol

Different classifications have been made based on the amount of energy limitation and data load delay. This data classification is mostly done to calculate Back Off courses and data priorities. Throughout the process, the coordinator uses this classification to calculate the priority of the data, back off time. Back off periods are used by body nodes before sending packets. Below we will explain the data transfer steps and structure of the proposed protocol.

3.1. Data Transfer Steps

We consider three types of normal, periodic, and emergency data. Body nodes use the CSMA / CA mechanism to transmit normal data [4]. If the transmission medium is idle they use CCA to increase reliability, but if the transmission medium is busy, it waits for time nodes (this is considered random) according to IEEE 802.15.4 and the like. The node re-checks the transfer media after the process of access to the media has been successful, transferring its data to the CAP super-frame. Periodic data is data that has been collected over specified intervals, for example data that the specialist physician has recorded after several patient visits. This type of data has no latency constraints, and the body nodes transmit it during the superficial CFP. The coordinator for the nodes having periodic data considers the TDMA-based scheduling slot.

As mentioned in the assumptions section, CSMA / CA and TDMA mechanisms have disadvantages that do not support emergency data transfer mechanisms. We assign different priorities to the volume of data and the nature of the data. To this end, this thesis generally seeks to provide emergency data transfer without delay and with higher priority.

In the following we will classify the priority and explain how different data are given priority for sending data. We assume that the body nodes have different priorities for their data. We define these priorities on the basis of normal, periodic, and emergency data. Based on these priorities, the nodes and coordinators make the decision during the transfer and allocation of resources and use the following formula to obtain priority.

$$\text{Priority} = \frac{D_{type}}{P_{size} \times \lambda_t} \quad (1)$$

In this formula λ_t is the traffic generation rate, P_size is the packet length produced by the body nodes, and D_type is the type of emergency data and normal data. Emergency data packets with lower traffic generation rates as well as smaller packets have high priority and should be delivered in a timely and reliable manner. Normal priority data packets must also be delivered on time, otherwise the buffer overflows and the packets may be lost.

3.2. Proposed New Superficial Structure

The IEEE 802.15.4 modified superframe structure for wireless sensor networks comprises four periods. CAP, CFP, IP and EP Round are our suggested super courses. The superframe structure begins with the sending of the Beacon message (the beacon message contains all the information about the time slots, the coordinator, the body nodes and the start and end of the period).

In the CAP era, all nodes compete for channel access and normal data transmission. Nodes that have periodic data messages that require fixed slots send their data during the CAP period. In times of emergency, the nodes of the body send a request to the coordinator to send their data quickly and without delay, then the Emergency Beacon Coordinator Sends EP to send emergency data. In this situation, normal data transfer should not be interrupted, meaning that transmission will not be interrupted. In an emergency, if there is no data node to send, go to sleep or idle mode to wake up by sending data using radio wake-up and sending an interrupt.

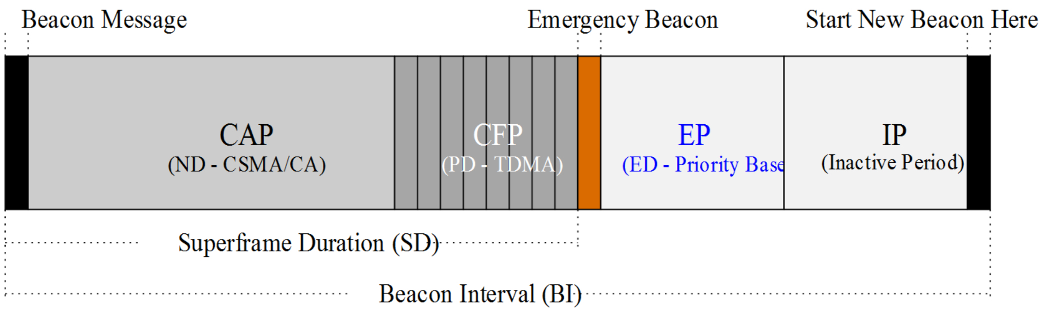

Figure 1. *IEEE 802.15.4 Modified Superframe Structure.*

Wake-up radio is a special type of circuit that can connect to the main circuit of the body's nodes. The main purpose of this device is to turn off the main radio when there is no data to be transmitted to save energy. A wake-up radio can detect control signals from an external device and produce an interruption to turn off the main radio. Many researchers have used the concept of radio wake-up in sensor networks. Since the cost of adding an awake radio to the nodes of the main body is very low, it is of great use. Also, a radio wake-up call does not use the energy of the body's nodes, so it will not cost extra. A regular wake-up radio has a range of 1 to 15 feet, so it is suitable for short applications such as wireless sensor networks and has easy and easy hardware.

3.3. Further Optimization of Energy Consumption

To optimizing energy consumption we propose a method by considering the priority in which the energy of the nodes is taken into account. Nodes that have low energy and may end their life and lose their data are included in the back off calculation. Considering the residual energy of a node over the primary energy of a node, the node that has the least residual energy is given a higher priority and prioritized before it expires and wins and sends the competition against the rest of the nodes. Nodes will improve network performance. In the back-off setting, multiply the desired interval by $\frac{E_{residual}}{E_{total}}$. We will explain how to calculate the back off in the next section.

3.4. Calculate the Back off Period

Priority-based Back Off process is performed in CAP Each node performs a random Back Off process before transferring data packets. The value of the Back Off period is calculated using the interval [2 + 2 ^ (D_type), 0] that will be multiplied by the energy of the nodes D_type Specifies the data type. Emergency data has less latency than normal data during the transmission process. During transmission, if the channel is busy, the arrays perform a random Back Off in CAP. Random Back Off Period As stated in Equation 1, it depends on the volume and priority of the data and the energy of the nodes. They have a high volume and lower priority, and have a longer life and energy waiting for longer to avoid congestion.

Figure 2 and Figure 3 illustrate the channel access mechanism for both normal and emergency data.

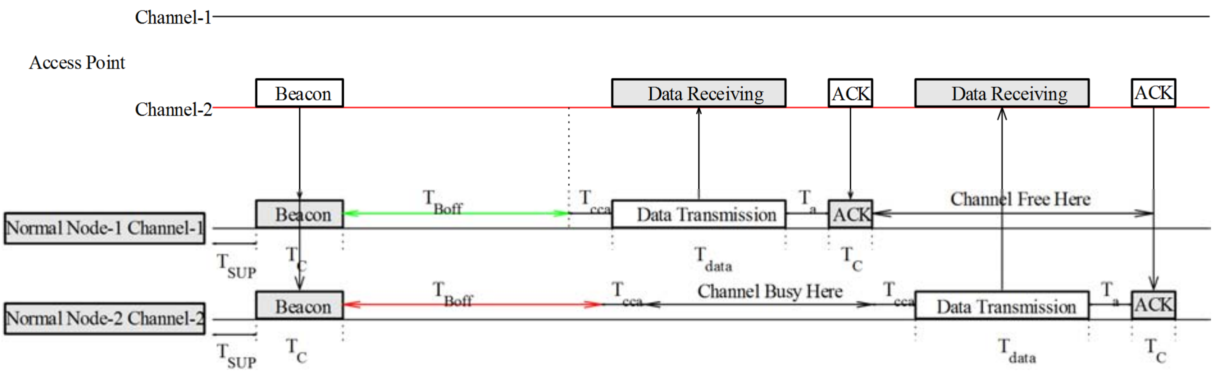

Figure 2. *Normal data channel access mechanism.*

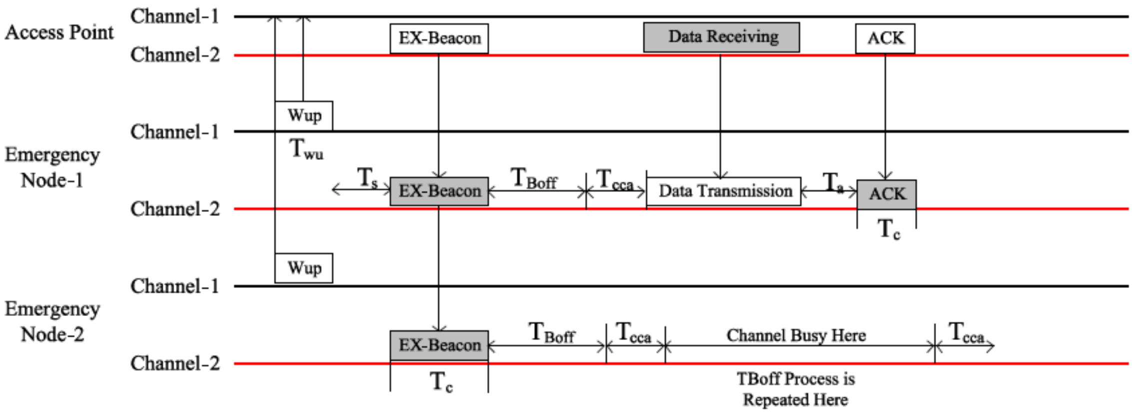

Figure 3. *Emergency data access mechanism.*

4. Simulation of the Proposed Method

We consider wireless sensor networks with one coordinator and 10 sensors. Body sensors vary according to the basic model and functional requirement. Body sensors sense the data and send it to the coordinator in one step.

4.1. Simulation Parameters

The basic parameters of the simulation are as follows.

Table 1. *Simulation parameters.*

Amount	parameter
10	Nodes
78 Byte	Payload
80e-3 millisecond	T_{sup}
8*16e-3	T_{cca}
12*16e-3	T_a
15,360 symbols	Beacon interval (BI)
7860 symbols	Super frame duration (SD)
8 symbols	CCA
131.5 Watt	Transmission power
1.8 Watt	Receiving power
1.8 Watt	L_{phy}
3	$L_{mac\text{-}HDR}$
2	$L_{mac\text{-}FDR}$
2	$L_{address}$
250	R_{data}
2	DataType (ED)
1	DataType (ND)
13 Byte	ACK packet size
20*16e-6	Unit backoff time
120*16e-6	Ack wait time
4.00E-04	Turnaround time
8*16e-6	Sensing time
20 Symbols	Backoff period
Variable	Inactive period
250 Kbps (2.4 GHz)	Data rate

4.2. Average Power Consumption of Normal Data

The average energy consumption during transmission, reception, ACK and normal data control packages are as follows:

$$E_{total} = E_{normal} + E_{bwate} + E_{rec} + E_{tran} \quad (2)$$

We denote the sum of the energy of the normal data with E_{total}, which is the sum of the energy over the lifetime of that normal data.

$$E_{normal} = P_i(T_{sup} + T_{bn} + T_{cca} + T_{data} + T_{ack} + T_b)$$

$$E_{bwait} = P_{rec} \times T_b$$

$$E_{tran} = P_{tran} \times T_{data} \quad (3)$$

$$E_{total} = P_i(T_{sup} + T_{bn} + T_{cca} + T_{data} + T_{ack} + T_b) + (P_{rec} \times T_b) + (P_{rec} \times T_{sup} + 2T_c \times 2T_p) + (P_{tran} \times T_{data})$$

$$T_{data} = \frac{8 \times (L_{PHY} + L_{MAC-HDR} + L_{adress} + X + L_{MAC-FTR})}{R_{data}} \quad T_c = \frac{8 \times L_{PHY} + L_{MAC-HDR} + L_{MAC-FTR}}{R_{data}}$$

P_i, P_{rec} and P_{tran} are idle, receive and transfer respectively. T_{sup} is the startup time from idle to transition or listening. T_{bn} is the time of sending Beacon packets. T_{cca} and T_{data} are the channel listening time and data transfer time, respectively. T_b specifies the average arrival time between two beacons, T_{ack} is the ACK response time, and T_c and T_p are the control packet transfer and packet playback times.

After examining the formulas for the normal data and its average energy consumption, we will present the energy consumption diagram of the normal data.

Here's a graph of the power consumption of normal data in Mini Joul, which is compared to our proposed protocol PG-MAC 2016. As you can see in the figure, the energy consumption of the proposed protocol is better than that of the protocol. As the nodes enter (we have 10 nodes here), each node randomly selects a Back Off and the winner will send its information, which will consume the energy consumed for Modes 1 as 10 nodes compete., We've shown.

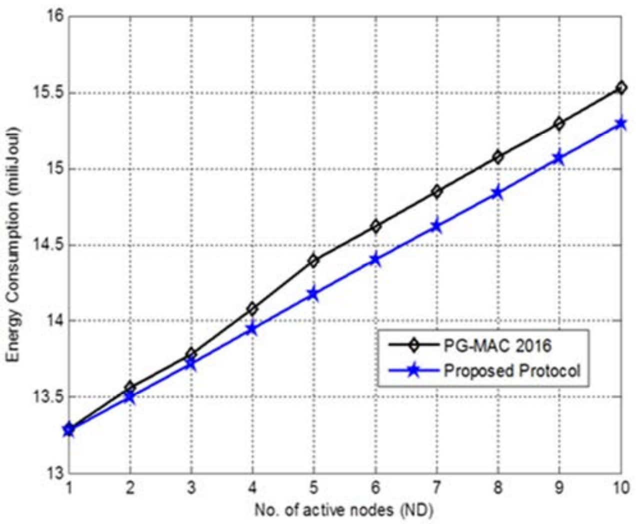

Figure 4. *Energy consumption Diagram for Normal Data.*

4.3. Emergency Data Power Consumption

As we know the average service time is the interval of packet arrival until the packet is successfully transmitted. Emergency data packets are transmitted because of radio wake and Beacon packet transmissions.

$$T_n = \frac{1}{1-T} \quad (4)$$

In this formula, T_n represents the total number of data and T represents the total delay in the busy channel.

$$T = \frac{(T_{wup} + E_{Boff} + T_{sup} + 2T_{td} + 2T_{cont} + T_{data})}{\lambda_p} \quad (5)$$

The duration of waking up to waking state is displayed for sending emergency data by T_{wup}. E_{Boff} shows the average back-off time during the busy channel Pcaa is the power used in C_{aa} with a maximum value of 2. TN_{cca} The total number of CCA until the data packet is successfully transmitted to the destination node.

$$E_{emergency} = [P_i(T_{wup} + T_{sup} + 2T_{td} + 2T_{cont} + T_{cca} + T_{data} + T_{bn})]$$
$$+ P_{tranb}T_{wup} + P_{rec}T_{bn} + P_{rec}(T_{sup} + 2T_{td} + 2T_{cont})$$
$$+ P_{cca}TN_{cca}T_{cca} + E_n(T_{bn} + E_{Boff}) \quad (6)$$

After showing the formulas related to the energy consumption of emergency data in the diagram below, we will examine the emergency data consumption when 1 to 10 nodes are simultaneously logged.

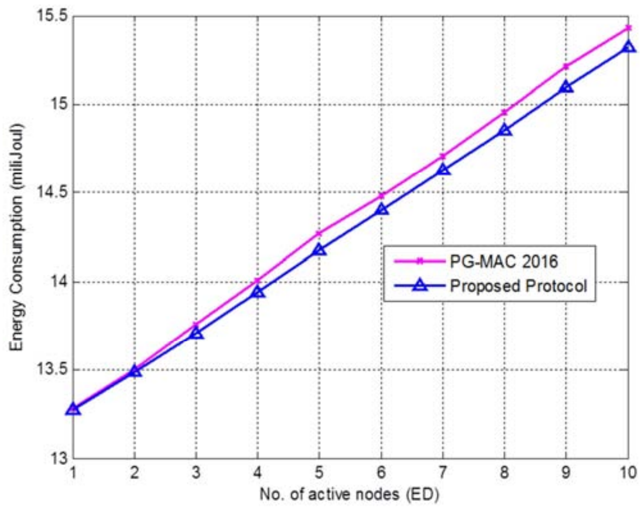

Figure 5. *Emergency data diagram for power consumption.*

4.4. Performance Analysis of Normal and Emergency Delay Data

The average delay is actually the time interval between packet generation and receipt in the coordinator. Nodes can cause delays over time Back Off, CCA and ACK. The average delay in emergency data is calculated using the following formula

$$D_{emergency} = T_{Boff} + \left(E_{bn} + T_{wup} + (T_{data} + 2T_{td} + 2T_{cont})\right) \quad (7)$$

Nodes can cause a lot of delays during the cross-access process when there is little chance of finding a free channel. In addition, the channel is equally likely to be free to transmit data at the same time. During each unsuccessful attempt to access the channel, the back off time at IEEE 802.15.4 will double as more power will be required to access the channel again. This process will require a lot of energy and delay during normal and emergency packet transfer. In addition, as the packet arrival time increases, the average delay also increases because the nodes have to wait for packets to be transmitted. This increases the likelihood of successful packet transfers, which increases the throughput.

Using the formula below, the average delay of the normal data is obtained.

$$D_{normal} = T_{Boff} + T_{CAP} + T_{CFP} + T_{data} + 2T_{td} + 2T_{cont} \quad (8)$$

In wireless sensor networks, sensor nodes use the CSMA / CA protocol. A key parameter of CSMA / CA-based methods is that they can increase or decrease the delay during data transfer of the total back off effort. Figures 6 and 7 show the average delay, a function of the time back off during emergency data and normal data.

The delay is increased because the nodes in the body wait for the ACK message to be successfully transmitted. Otherwise, the transfer process will be repeated until the packet reaches its destination successfully. During normal data transfer, the body nodes generate the delay when the channel is occupied only with respect to the CCA and the back off period. There is also a lot of delay when transferring emergency data. When transferring emergency data, we have improved the superstructure structure so that the duration of the Back Off time is calculated according to the length and importance of the data packet. While in IEEE 802.15.4, every PG-MAC 2016 protocol doubles the Effective Back Off period effort. Therefore, our proposed method performs better when transferring emergency and normal data.

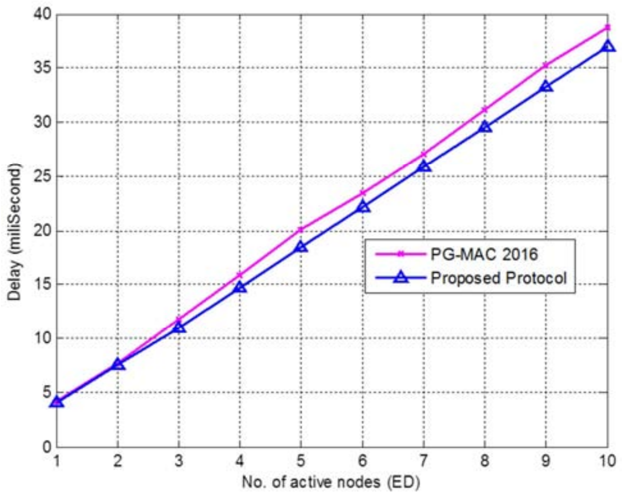

Figure 6. *Average delay diagram in emergency data.*

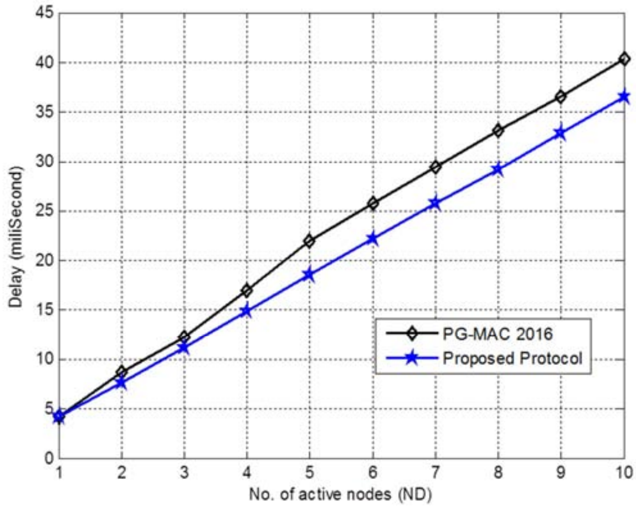

Figure 7. *Average delay diagram in normal data.*

4.5. Passing

In wireless sensor networks, the sum of the packets that have successfully reached the coordinating node is called passing [9]. Our proposed protocol is less delayed compared to the PG-MAC protocol, and when packet delays are less, it can be concluded that more packets arrive in shorter time, thus making our proposed protocol overlap optimal. It is improved and improved. In Figures 5-6 and Figures 5-7, the node permissions are compared to the comparable protocol.

4.6. Throughput

The throughput or throughput in kilobytes per second is the number of packets delivered to the destination per unit of time [12]. In the proposed method, the focus is on the data transmission, which we have examined in the form of 1 to 10 nodes. For the sake of improvement, we give the more important data a better chance of winning the data submission competition, as in Figures 5-7, with 3 nodes sending data. We have received an average of packets of 3 nodes, and we have improved on the proposed protocol as compared to past research and compared to the PG-MAC 2016 article.

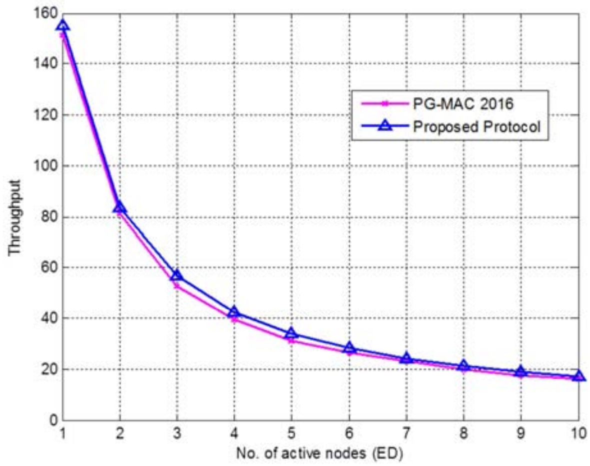

Figure 8. *Passing Analysis of Proposed Method and PG-MAC 2016 Protocol in Normal Data.*

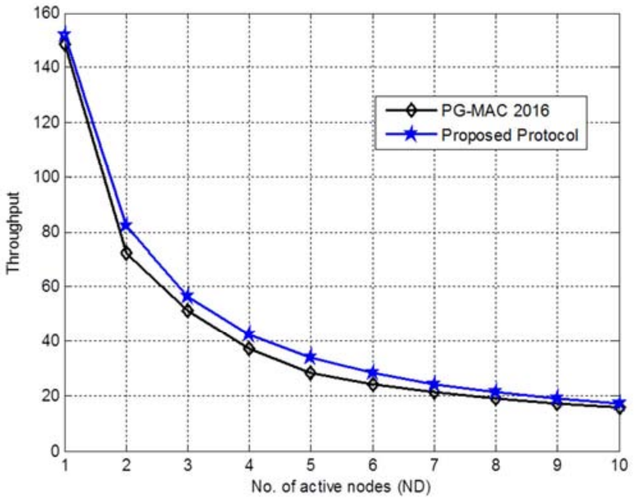

Figure 9. *Passing Analysis of Proposed Method and PG-MAC 2016 Protocol in Normal Data.*

5. Conclusion

There are many obstacles to improving the challenges of body sensor networks. One of the challenges in these types of networks is the issue of lifetime. Ideal for sensor networks is that the network implementation, design and planning are as long as possible. Therefore, our main concern is how to extend the lifetime by taking into account all possible criteria in network design. This will increase the network lifetime to a reasonable time. The IEEE 802.15.4 standard protocol reduces the life span of sensor networks due to the use of some mechanisms. This paper presented a way to extend the lifetime factor to this standard. A CSMA / CA Priority Assurance Mechanism is presented, in which different priorities are taken into account depending on the type of data and its size. To save energy, a wake-based radio mechanism is used to control sleep and the active state of body sensors. The results show that the average power consumption and latency during the transmission of emergency data is higher with confirmation and we attempted to optimize them during the transmission of data packages. Since in this paper is coordinated as an out-of-body mobile device, technology called radiology, an emerging technology that is related to channel access, can be applied. Radiological means something like the landlord-tenant relationship, as the frequency bands increase, and we are experiencing a shortage of bandwidth. So when the primary user is not using their frequency band it can be used to send emergency data. These can be used as a research topic for those interested in this field.

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