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# A DATA COLLISION AVOIDANCE AND DELAY-ENERGY EFFICIENT MAC PROTOCOL FOR WIRELESS BODY AREA NETWORK

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## ABSTRACT

Traffic collision is one of the main reasons for the excessive delay and higher energy consumption in Wireless Body Area Networks (WBANs). WBAN is an emergent healthcare technology that has been designed for urgently monitoring patients. To transmit patients' physiological data to the healthcare center, it is very important to design a delay tolerant and energy efficient Medium Access Control (MAC) protocol. Medical data are time-bounded; hence any delay in transmission may impede patients' life. Hence, in this research, we propose a data collision avoidance and delay-energy efficient MAC protocol which is designed considering the Contention Access Phase (CAP) of IEEE 802.15.4 based MAC superframe structure and also Exclusive Access Phase (EAP) of IEEE 802.1.5.6 based MAC superframe structure. We experiment with the proposed scheme using the Castalia simulator and compare the results using different scenarios. First of all, we compare the delay and energy efficiency considering different numbers of nodes ranging from 1 to 12 nodes. Secondly, the results are compared with data of various sizes ranging from 16 to 255 bytes. In both cases, results are verified for both IEEE 802.15.4 and IEEE 802.1.5.6 standards and it is found that delay and power consumption is much lower in EAP enabled IEEE 802.15.6 based MAC protocol. In addition, in the third scenario, we consider five different types of data with different priority levels and the experiment result shows that data with the higher priority level consumes lower energy and minimum delay than that of data with lower priority levels in IEEE 802.15.6 based collision avoidance MAC protocol. Finally, we compared the proposed EAP enabled IEEE 802.15.6 based MAC protocol with conventional IEEE 802.15.6 and state-of-the-art i-MAC protocol. The performance comparison is done for both delay and energy consumption. The results show that our proposed MAC model performs better than that of the existing protocol and standard.

**Keywords:** *WBAN, MAC, Delay, Energy, Traffic Collision*

## 1. INTRODUCTION

Every year during various religious festivals e.g. Hajj and Kumbh Mela at overcrowded and harsh environment; many pilgrims suffer from different diseases. The foremost healthcare challenges at Hajj ritual sites and Kumbh Mela include the growth of elderly pilgrims with various chronic and infectious diseases, increased death rate because of numerous emergency circumstances such as diseases, accidents, unavailability of real-time healthcare facilities and the rise in healthcare costs. The crowd density at Hajj ritual sites increases to seven individual (pilgrims) per m2, which is one of the significant indicators of overcrowding that leads to infectious diseases, loss of pilgrims and injury. On the other hand, during Kumbh Mela at different four ritual sites in India, the number of pilgrims increased to a hundred million. Naturally, existing healthcare systems must be overloaded due to overgrowth rate in the population. Hence, there is a demand for meaningful shifting to the current healthcare systems for reasonable and approachable healthcare solutions [1].

During Hajj and Kumbh Mela, pilgrims undergo a variety of infectious or contagious or communicable diseases and chronic or non-communicable diseases. We consider the health burden as medical emergency condition weighing Hajj into account. An emergency could lead to life-threatening if there is dissimilarity in the behavior of the present circumstance. Moreover, the emergency condition could be diagnosed or measured in a way

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when patients' physiological condition suddenly and unexpectedly falls. During the emergency, patients' ambient environment may encounter an erratic and sudden extreme high or low blood pressure, body temperature, pulse, humidity, oxygenation, and blood sugar. For example, body temperature could be life-threatening if its readings exceed the standard value which is between higher and lower values [6].

To provide healthcare facilities for pilgrims during Hajj and Kumbh Mela, the government of Kingdom of Saudi Arabia (KSA) and the government of India incorporation with Ministry of Health (MoH), World Health Organization (WHO), and Ministry of Hajj and Umrah (MoHU) have taken several initiatives which are mainly health awareness guidelines, healthcare guidance apps, pre-Hajj healthcare and Hajj preparation guidelines [1]. The initiatives described above and medical services for pilgrims are not enough and don't meet and support real-time healthcare facilities. Therefore, there is a potential research opportunity to improve the instantaneous healthcare systems for the pilgrims during Hajj and Kumbh Mela to ease their pilgrimage life and time at holy sites. A healthcare monitoring service must be resourceful, timely, easily accessible, and well-organized to examine the patients. Hence, deploying Wireless Sensor Network (WSN) for medical and healthcare purposes would be an outstanding solution. The IEEE 802.15.4 standard centered wireless communication technologies are generally used in industrial applications hence may not support medical applications that require high throughput, speedy service. WSNs are homogenous, static and are required high power and are not delay constraints. Therefore, for medical applications, wireless sensor networks require a standard that should cope with energy-efficient, low delay, no collision, no data loss and higher throughput. The IEEE 802.15 TG6 initiated and launched the IEEE 802.15.6 standard exclusively for WBANs [2]. A WBAN is particular sensor network proposed for medical and healthcare applications. WBAN is composed of in-on-off body sensors or nodes and a coordinator. WBAN should support short-range, lower delay, low power and inconstant data rates for its body nodes. Sensors are supposed to assemble physiological data to facilitate patients with medical services in a real-time manner. As oppose to WSNs, WBAN is heterogeneous and dynamically support changing of sensor nodes, channel access and its mobility. Healthcare domains principally have strict functional requirements such as delay and data loss hence ensuring timely data delivery is urgent. Because WBAN deal with human life and its physiological data; thus, any delayed or lost data may jeopardize patients' life [3-5]. Figure 1 shows an overall WBAN structure that can be deployed at the overcrowded environment. In WBAN, MAC protocol is accountable for defining the data communication channel for quick access to medical data, data prioritization. MAC is liable for the processing of sensor nodes and coordinator and allocating slots of its superframe. The performance of WBAN, such as overalls delay, collisions, energy consumption, throughput, and packets drop rate is strongly associated to the adopted MAC protocol [7]. Besides, the MAC protocol directly controls the activities of the radios and leads to create the underlying network infrastructure. As of preliminary study, one of the fundamental tasks of MAC protocol is to avoid data collision that aims to ensure power-efficient data transmission.

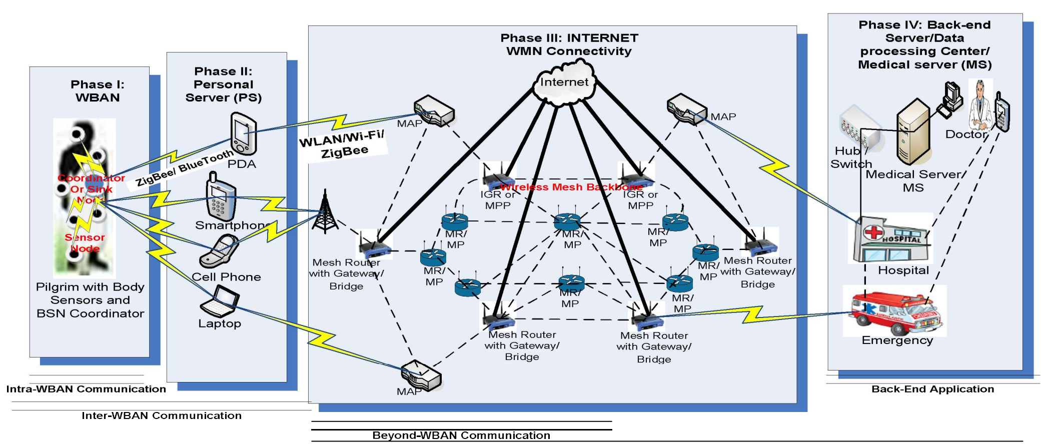

*Figure 1: Overall WBAN structure*

The remaining of the research paper is arranged as follows: Related work is presented in Section 2. Effective method and technology in developing suitable mac protocol for WBAN are explained in Section 3. Numerical analysis to design collision avoidance MAC protocol based on IEEE 802.15.4 and IEEE 802.15.6 standards is depicted in Section 4. The Results are deliberated in Section 5. Finally, Section 6 ends the article with conclusion.

## 2. RELATED WORK

This section explores the existing literature to find the available MAC protocols, their strengths and limitations for WBAN operations considering diverse Quality of Service (QoS) issues. WBANs are human body-centric communication network where the IEEE 802.15.4 and IEEE 802.15.6 standards can be deployed as communication technology. The main reasons for energy inefficiency in WBANs are idle listening, data re-transmission, overhead, and data collision. So far, various MAC protocols with different functionalities have been developed for wireless and wire-based communication. Include contention-free or schedule-based TDMA or Time Division Multiple Access protocols and contention-based CSMA/CA or Carrier Sense Multiple Access / Collision Avoidance protocols. Schedule-based approaches are periodic, contention-free and are tightly synchronized. Schedule-based method does not support random deployment of network topology and mobility in network [8].

On the other hand, contention-based and aperiodic protocols are appropriate for networking with random deployment of network topology is random. It is shown that [9], CSMA/CA protocol encounters serious collision in network results in high energy consumption and network instability. On the contrary, TDMA protocols are power-saving because there are no collision or contention, idle listening and over-hearing and contention problems. TDMA protocol encounters no collision in network results in higher delay in the network. However, for periodic time synchronization, some standard TDMA protocols need extra energy. WBANs are usually optimized for the specific application; hence the MAC protocol requirements differ.

In consequence, one specific MAC protocol or any particular communication technology will hardly be appropriate for every possible WBAN application. Hence MAC protocol is considered as an appropriate vehicle in maintaining the quality of service (QoS) under diverse traffic conditions in WBANs environment. The IEEE 802.15.6 standard based MAC superframe uses a hybrid medium access phase include contention-free phase or schedules phase and contention access phase that deals with different heterogeneous traffics as mentioned earlier [2].

According to MAC superframe of the IEEE 802.15.6 standard, emergency traffic or traffic with different priority level needs to contend for accessing the channel thus results in a data re-transmission, collision, excessive delay, low throughput, data loss and energy inefficiency that may threaten the life of patients. In IEEE 802.15.6, standard based communication technology, Exclusive Access Period 1 (EAP1) and Exclusive Access Period 2 (EAP2) is entirely reserved for the traffic with higher priority to be transmitted. Considering of all existing wireless communication standards and different MAC techniques into account a novel superframe structure of priority MAC protocol is necessary to satisfy the functional characteristics and QoS requirements [2].

The use of MAC protocol and its associated superframe structures for WBAN has been proposed so far by some researchers. A priority MAC protocol is offered by [10] where it supports high priority traffic over comparatively low-priority traffic by limiting its access to particular phase may affect the overall network throughput, energy, contention and latency. The same authors [11] have presented an improved MAC superframe structure based on IEEE802.15.4 for different data traffic, where, CAP period is divided into different four phases, and the length of all phases are variable except the phase 1 which is fixed. All the phases of CAP except phase 1 can change dynamically to avoid wasted timeslot utilization. A non-preemptive priority queue method is proposed by [12]. In this MAC model, a fixed and first time slot is assigned for the transmission of emergency data, the second slot is designed for on-demand traffic and the third slot for regular medical traffic, and other seven slots out of ten remain idle. In another research [13] a Markov model based model is presented to find the node states. Authors in their research deployed priority guaranteed IEEE 802.15.4 CSMA/CA method for designing the MAC. Besides, the authors [14] presented a MAC protocol, where the CSMS/CA technique is deployed to transfer normal medical data. To send the data with different priority level, the central coordinator deploys a new phase along with the inactive period of MAC superframe. Authors in [19] proposed an in-body sensor (i-MAC) protocol for WBAN. For emergency data transmission they have proposed scheduled access phase in order to avoid data collision. Moreover, they have also proposed updated superframe structure for the WBAN MAC protocol along with critical event management scheme for handling priority and emergency of in-body sensors.

Moreover, the IEEE 802.15.6 standard enabled MAC superframe uses hybrid medium access phases include CAP and CFP that deals with different heterogeneous traffics [2]. Hence, for emergency traffic, the CSMA/CA mechanism can be deployed for communication which is contention-free and should use EAP for emergency data transmission. To deal with various emergency data simultaneously and to be transmitted in WBAN medium the emergency traffic should be privileged with the top priority level followed by the low priority level of medical data . The WBANs coordinator may use and apply the traffic classification method to set the priority of the emergency traffic for fast allocation of time slots. Hence, there is a need for further modification of MAC superframe on the basis of IEEE802.15.6 data communication model that should support emergency data access based on data priority and data criticality level. In the event of an emergency, the low energy consumption of each biosensor node, low delay, high throughput or high data transmission rate is of significant importance in WBANs. Therefore, the central motivation of this work is to establish lower delay-energy guaranteed MAC protocol. The proposed collision avoidance MAC should support data with different priority levels to be transmitted quickly with no delay and lower energy consumption.

## 3. EFFECTIVE METHOD AND TECHNOLOGY IN DEVELOPING SUITABLE MAC FOR WBAN HEALTHCARE SOLUTIONS

### 3.1 Problem Statement

Based on different medical reports and research works, as presented earlier, it is understandable that during Hajj and Kumbh Mela, pilgrims suffer from various medical problems. However, current healthcare services and facilities may not be suitable for monitoring patients' physiological conditions in a real-time and speedy manner. Therefore, there is an urgent need to build an efficient technology to ease pilgrims' health-related problems at overcrowded ritual sites.

According to the study in earlier sections, WBAN is an emergent healthcare providing technology; hence, some researchers have proposed to deploy it in various medical applications. However, one particular MAC technique and any specific communication technology will hardly be appropriate for all WBAN applications. As mentioned earlier, for some applications, the IEEE 802.15.6 technology based MAC protocol is likely to deal with different types of heterogeneous data and thus requires different access phase to communicate properly. In WBANs MAC superframe, EAP I and EAP II are suitable for medical emergency data transmission, however, both of them are designed to work on the basis of CAP where traffics to contend each other for accessing the channel. The CAP leads to data loss and data collision that leads to excessive delay and higher energy consumption in WBAN transmission medium. Other than EAPs, for accessing the channel, on-demand traffic usage Random Access Phase (RAP) and normal medical data is supported by Managed Access Phase (MAP). It is notable that, in WBAN medical applications, any delayed or lost data can endanger the patient's life.

Moreover, emergency data must be given higher priority than normal medical data to transmit to the communication channel as compared to the lower priority physiological data. Hence, it is important to choose the suitable priority and queue method for handling medical heterogeneous traffics. The IEEE 802.15.6 based MAC superframe is not suitable to be used due to the lack of mechanisms to give priority to different critical data. On the other hand, some researchers have also discussed the use of IEEE 802.15.4 based MAC protocol for medical applications. Where, they proposed to use both CAP and Contention Free Phase (CFP) or scheduled phase for designing the MAC. Some researchers have proposed to deploy CFP for handling medical emergencies, but emergency events are not time bounded and can be happened at any moment. Hence, any time restricted periodic scheme may not be appropriate for healthcare applications.

Moreover, the IEEE802.15.6 standard has suitable data classification and prioritization features than that of other IEEE standards including IEEE 802.15.4 which rarely supports data classification issues, hence, is not appropriate for emergency medical applications.

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Besides, for WBAN medical applications and priority-based data transmission, some researchers have proposed priority based non-preemptive queue model. In this model, a packet in service is allowable to complete the job without interruption even if a packet with higher priority arrives within the service time. Besides, non-preemptive technique does not support prioritized medical traffic to deal with emergencies which results in extreme delay and greater energy intake. Moreover, some researchers have discussed IEEE 802.15.4 and IEEE 802.15.6 standard based protocols but due to lack of instantaneous communication method significantly affected the outcomes. In some proposed method, the receiver should always be either in sleep or active mode. When the receiver remains active at all the time, then it consumes more energy. On the other hand, when the receiver is in the sleep stage then it has to wait until it awake thus unable to communicate even in a medical emergency; as a result, it may prolong waiting time and high energy consumption. Table 1 presents the research problem that includes all the essential features in a tabular form described earlier.

*Table 1: Effective method for developing suitable MAC protocol for WBAN*

| Protocols | Important WBANs features related to healthcare applications | Features required by application that is missing | Improvements proposed by other researchers |
|---|---|---|---|
| IEEE 802.15.6 technology | The standard is designed for medical application supporting wearable sensors for low range communication (range varied from 2 to 5 m); hence it helps low power requirement. Supports high data rate that may support for sending pilgrims' medical data quickly. Data classification and priority features are available that allow classifying pilgrim's data based on the critical level of emergency. The standard supports dynamic and random network deployment. It also supports the CSMA/CA-based aperiodic approach for medical data transmission. Hence, IEEE802.15.6 can be deployed for pilgrims medical application. | Does not provide a mechanism to deal with emergency data of various severity/criticality levels simultaneously, thus resulting in a delay in sending pilgrims' physiological data at Hajj or overcrowded ritual sites. Moreover, IEEE 802.15.6 MAC provides EAP I and EAP II slots for emergency medical data, which is the contention-based access phase. Pilgrims' critical data should contend with each other for transmission, which may lead to data collision, delay in communication and more energy consumption. Also, any data collision, delay in transmitting pilgrims' data may obstruct urgent treatment, endanger pilgrims' life | Researchers mainly focus on to handle heterogeneous traffic includes both emergency, on-demand and normal traffic. The mechanisms proposed by other researchers include modification of MAC superframe to handle various traffic. These are some mechanism and techniques are offered by researchers for possible WBAN MAC solution include a non-preemptive priority queue model, adaptive MAC approach to cope with different data types. Moreover, different data classification and priority model are presented by some researchers in their WBAN research. |
| IEEE 802.15.4 technology | IEEE802.15.4 supports CSMA-CA based aperiodic approach; thus, | IEEE802.15. does not provide data classification and priority features for | Hybrid MAC approach comprising both CAP and CFP phases. |

| | | | |
|---|---|---|---|
| | it can be used in pilgrims' medical purposes. In a short interval of time, the emergency body sensor nodes can transmit small-size data packets, and the max data size is supported, but IEEE802.15.4 is 127 bytes; hence IEEE802.15.4 can be deployed in Hajj application. | medical applications; hence, it is not suitable for medical pilgrims' medical use. It provides a low data rate that supports environment monitoring. It is delay tolerance and requires high power supply hence not ideal for pilgrims' medical applications. TDMA method is proposed for medical data transmission, where medical data is aperiodic, and any scheduled based approach may be fatal for health application, especially for handling the emergency. | A preemptive priority model, an adaptive MAC mechanism, TDMA MAC is also proposed. |

### 3.2 Research Design

The present research is classified as quantitative research which examined and investigated the particular phenomenon by utilizing the experimental method emphasizes objective measurements. Scientific research design is a class of research methodology. The current research proposed specific strategies to support researchers to find the appropriate answer for various research questions aiming to develop a delay-energy efficient MAC protocol for WBAN that should satisfy lower delay, low energy consumption in WBAN environment. In this research work, experimental methods and techniques are used and took place to design, evaluate and validate the desired MAC protocol for WBAN. The following are the methods and techniques that are used for this research work, as presented in Table 2 below.

*Table 2: Research techniques and Methods*

| Research Methods and Techniques | Purpose of deploying |
|---|---|
| Literature Review | Study and analysis the medical emergency at the overcrowded environment and the suitability of designing WBAN MAC protocol for patients' health healthcare. |
| Data classification method based on modified CAP of IEEE 802.15.4 and EAP of IEEE 802.15.6 for MAC protocol | Modify WBAN MAC superframe considering IEEE 802.15.4 and IEEE 802.15.6 standards to fast delivery of emergency data through the communication channel. Result is obtained and justified using various mathematical data considering data classification and priority issues. |
| Carrier Sense Multiple Access and Collision Avoidance (CSMA/CA) scheme | Design of a collision avoidance MAC protocol for WBAN various algorithms are proposed based on IEEE 802.15.4 and IEEE 802.15.6 standards that ensures low delay and energy efficient data transmission. |
| Sleep and wake-up method | Design of an energy-efficient MAC protocol for monitoring emergencies |

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| | |
|---|---|
| Experimental method | Experiment the proposed delay-energy efficient MAC protocol using rigorous simulation and justify the result with the predefined values of delay and energy consumption have been proposed by Target Group-TG4 for WSN and TG6 for WBAN of IEEE 802.15 standards |

## 4. NUMERICAL COMPARISON FOR EFFICIENT MAC PROTOCOL ON THE BASIS OF THE IEEE 802.15.6 AND THE IEEE 802.15.4 TECHNOLOGY

### 4.1 Overall MAC Superframe Structure

The traditional IEEE 802.15.4 standard is originated from WPANs and well suited for WSN. Low data rate communication thus does not satisfy and supports the rising and promising requirements of WBANs. The IEEE 802.15.4 scheme typically does not support energy-efficient, short distant and higher data rate applications. There are some circumstances due to which this standard is not able to provide an adequate conciliation between delay, energy consumption and other QoS issues simultaneously. The IEEE 802.15.4 scheme usually prefers star topology along with short-range radio frequency.

On contrary, the IEEE 802.15.6 technology is mainly designed and proposed for WBANs healthcare applications. WBANs technology and its protocols must be energy efficient, delay efficient, high data rates, and must support data priority based on emergency and criticality levels. The IEEE 802.15.4 technology-based MAC protocols and corresponding MAC superframe targets to transmit data using two dissimilar modes include non-beacon mode and beacon modes. The MAC superframe for the IEEE 802.15.4 is demonstrated in Figure 2, where each superframe divides the total time slots into two different portions namely CAP and CFP. CAP has 9-time slots of equal duration and CFP has7 time slot.

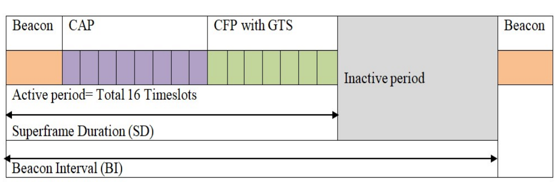


*Figure 2: The IEEE 802.15.4 MAC superframe with Beacon mode*

On the contrary, the IEEE 802.15.6 standard is mainly designed for medical applications that must support minimum power consumption, lower delay, high data rates, low complexity, and low cost and sophisticated data communication. This standard aims to cope with short-range data communication between tiny body sensors, body coordinators and the surrounding environment. The IEEE 802.15.6 technology operates on DLL (MAC) and PHY layers and functions with star topology [2].

In WBANs MAC superframe is surrounded by a beacon period of similar length along with EAP I and EAP II which are suitable for emergency or higher priority data transmission. But, both of them are designed to work based on CAP where traffics contend with each other for accessing the channel. The CAP leads to data loss and data collision that results in excessive delay and higher power consumption in WBAN. Other than EAPs, for accessing the channel, on-demand traffic usage Random Access Phase (RAP) and normal medical data is supported by Managed Access Phase (MAP). It is notable that, in WBAN medical applications, any delayed or lost data can endanger the patient's life. The IEEE802.15.6 oriented MAC superframe is presented in Figure 3 which is mainly separated into two periods, such as CAP and CFP. The significant features of the two standards are illustrated in Table 3.

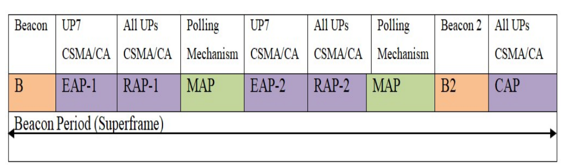


*Figure 3: The IEEE 802.15.6 MAC superframe with Beacon mode*

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*Table 3: The significant features of IEEE 802.15.4 and IEEE 802.15.6 standards*

| Technology | Data rate | Frequency | Distance Range | Peak power | Applications |
|---|---|---|---|---|---|
| The IEEE 802.15.4 standard | Up to 250 Kbps | Different frequency level: 2.4 GHz, 868 MHz and 915 MHz | 10m-100m and more | ~16.5m A | Different applications in medicine and entertainment |
| IEEE 802.15.6 | Ranging 10 Kbps -10 Mbps | 2.4 GHz, Narrowband, HBC and UWB communication | 1m-5m, 1m-3m | ~1mA | E-health and sport applications |

In general MAC protocols are applications-oriented; hence, one particular MAC protocol will hardly be applicable for all possible healthcare solutions. Moreover, according to the functionality and size of WBAN, MAC should be openness, scalable, reliable, and efficient. Furthermore, MAC protocols for WBANs should adjust to changes in the network (dynamic) and must adapt to a random deployment of any node in the networking system. Furthermore, it depends on the applications WBANs must support mobility, data heterogeneity, high data rates, and also must cope with different data priorities in the network.

### 4.2 Proposed Algorithms for IEEE 802.15.4 and IEEE 802.15.6 Based MAC Protocol

The CSMA/CA scheme of the IEEE 802.15.4 based MAC protocol has been divided into two main categories including slotted and unslotted mode which are presented in Figure 4 and Figure 5 respectively. In both cases, the algorithms are executed using backoff periods, which is equal to a unit of times. Three important variables are used to control the CSMA/CA mechanism, namely, Number of Backoffs (NB), Content Window (CW) and Backoff Exponent (BE). To diminish the contention in the transmission channel the value of CW must be considered as minimum as possible, where NB is adjusted to zero. The default value of BE is

considered to be 3. The BE is principally associated with how many backoff periods (BP) a sensor node shall delay or wait before accessing the network communication channel.

In IEEE 802.15.6, UPs or user priorities are allocated to diverse medical data based on the level of priority, where, $CW_{min}$ and $CW_{max}$ are to be selected based on UPs. Moreover, in IEEE 802.15.6, the sensor nodes primarily set Backoff Counter (BC) to a random interval [1, CW], where CW ∈ ($CW_{min}$, $W_{max}$). In the algorithms, m is the total number of times the sensor node had failed to perform constantly. Moreover, the value of pSIFS is 75 µs, where pSIFS should be located before employing the CSMA/CA mechanism. CSMA/CA algorithm for IEEE 802.15.6 technology is demonstrated in Figure 6.

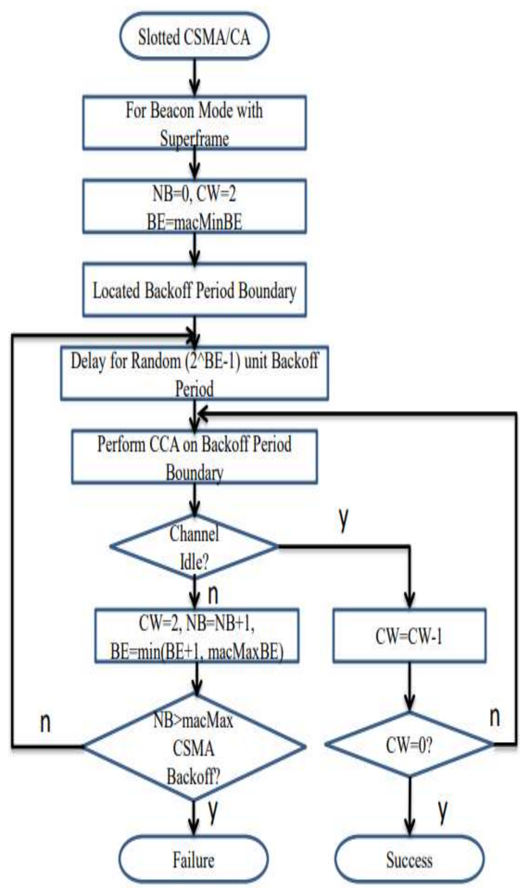


*Figure 4: The slotted CSMA/CA algorithm in IEEE 802.15.4*

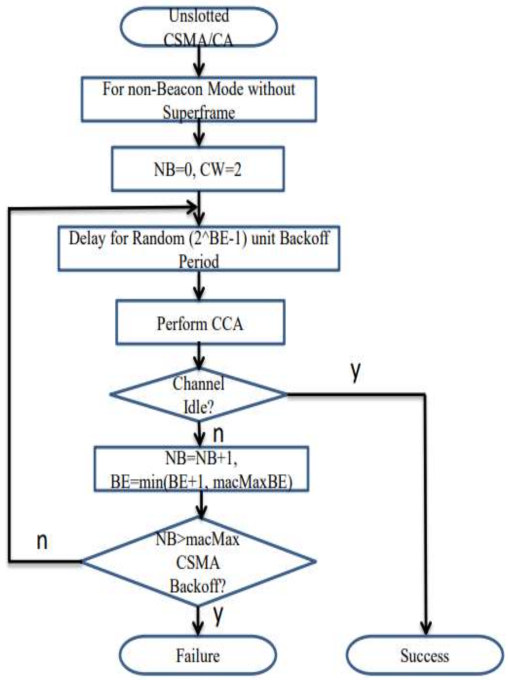


*Figure 5: The unslotted CSMA/CA algorithm in IEEE 802.15.4*

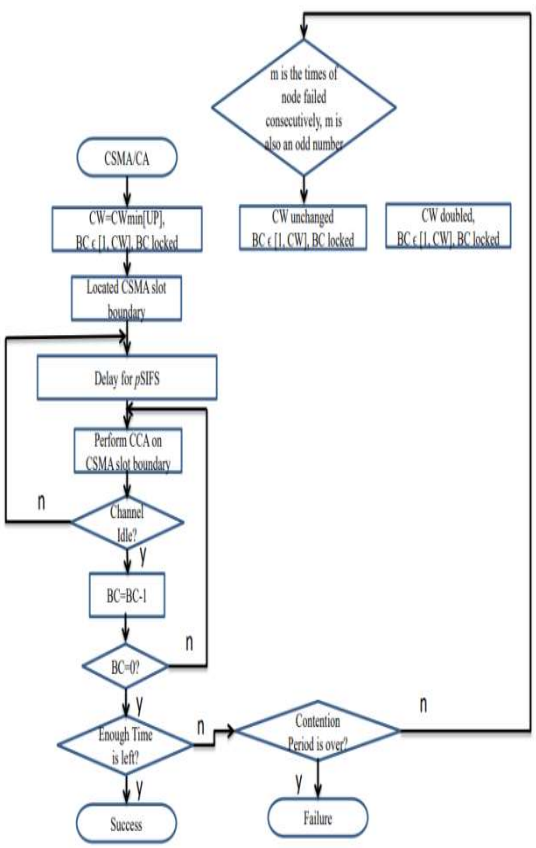


*Figure 6: The CSMA/CA algorithm in IEEE 802.15.6*

Since there are some similarities and dissimilarities in CSMA/CA-based IEEE 802.15.4 and IEEE 802.15.6 technologies, however, to detect the channel they both use Clear Channel Access (CCA) model.

### 4.3 Analysis of Delay Considering CAP and EAP Based MAC Protocol

Traffic classification and prioritization is important issue in WBAN. WBAN traffic is categorized into emergency, on-demand and normal medical. Emergency traffic must get the highest priority to be transmitted using the communication channel. Again, emergency traffic can be categorized into different types based on the level of criticality. Traffics should be delivered in a reliable way including no delay and lower power consumption. In wireless communication, the IEEE 802.15.4 support CAP and CFP which are suitable for transferring non-continuous medical data and continuous medical data respectfully. However, CAP can be a better choice to deal with emergency traffic. Since IEEE 802.15.4 does not support traffic prioritization; hence, to access the channel traffics need to contend with each other (when several nodes are tightly and densely positioned in a narrow region) which result in excessive delay and huge power consumption [15].

In order to settle down the aforementioned problem, the CAP can be considered to be divided into several sub-phases according to the requirement of the application. In our research, CAP is divided into six different sub-phases for six different priority levels of traffic. Nodes that transmit data with higher priority DP1 can access the communication channels through all the existing phases from 1 to 6. Phases 2 to 6 for DP2, similarly, DP3 can access the channels via Phases 3 and 6. The node that transmits data with priority level DP4 can access channels via Phases 4 and 6. Similarly, data with the priority level DP5 uses Phase 5 and 6 to access the channel. The node that transmits data with priority level DP6 can practice only Phase 6 for accessing the channel. The length of Phase 1 represented by L1 is fixed and always conquers the first timeslot of the CAP which is one timeslot long [16]. The total lengths of the remaining periods or phases are denoted using the equations 1 to 5 as depicted below.

$$L_2 = \frac{N_2(L-1)}{\sum_{i=2}^{6} N_i} = \frac{N_{DP}\ (L-1)}{N_{DP2}+N_{DP3}+N_{DP4}+N_{DP5}+N_{DP6}} \; ..... (1)$$

$$L_3 = \frac{N_3(L-1)}{\sum_{i=3}^{6} N_i} = \frac{N_{DP}\ (L-1)}{N_{DP}\ +N_{DP}\ +N_{DP5}+N_{DP}} \; ........... (2)$$

$L_4 = \frac{N_4(L-1)}{\sum_{i=4}^{6} N_i} = \frac{N_{DP4}(L-1)}{N_{DP4}+N_{DP5}+N_{DP6}}$.....................(3)

$L_5 = \frac{N_5(L-1)}{\sum_{i=5}^{6} N_i} = \frac{N_{DP5}(L-1)}{N_{DP5}+N_{DP}}$.......................... (4)

$L_6 = L-L_5-L_4-L_3-L_2-1$............................. (5)

Where, $L$ is the length of CAP of IEEE 802.15.4 based MAC. $Ni$ is the number of $i^{th}$ priority nodes.

On the other hand, as we discussed earlier, in wireless communication, the IEEE 802.15.6 technology allows different access phases of MAC superframe structure including EAP I, EAP II, MAP, CAP, RAP for transmitting data, where EAPs are specially designed and proposed for transferring emergency medical data which is based on data contending methods. Hence, in order to transfer data in an effective way with lower delay and lower energy consumption we proposed modified MAC superframe as portrayed in the following Fig. 7. The proposed scheme allocates the phases such as beacon phase-B, EAP, RAP, and MAP and other phases are set to zero. $T_{SF}$ is used to indicate the length of the superframe, including $T_{EAP}$ suggests the size of EAP, $T_{RAP}$ denotes RAP, and $T_{MAP}$ represents MAP.

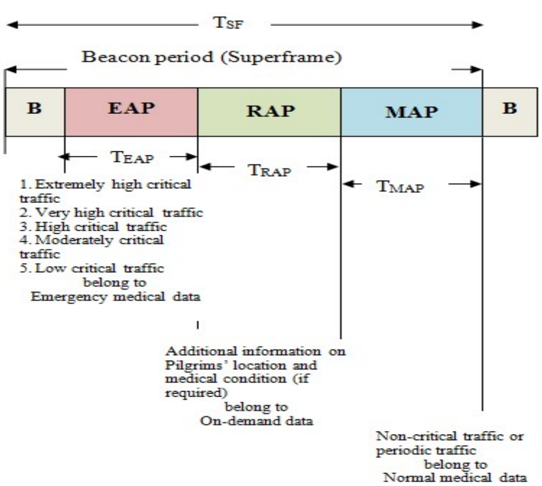


*Figure 7: The proposed MAC superframe structure*

For delay efficient data transmission in WBAN using the EAP phase of IEEE 802.15.6 we propose a collision-avoidance MAC scheme. In this method, traffic with the uppermost priority is supposed to access the network channel ahead of low priority traffic. The traffic intensity level or traffic rate which is the ratio of the arrival and service rates at the coordinator is defined by $\rho$. The traffic intensity is defined by the individual priority for any designated critical traffic which is defined as below.

$\rho = \frac{\lambda}{\mu} = \rho_{p1c1} + \rho_{p1c2} + \rho_{p1c3} + \rho_{p1c4} + \rho_{p1c5}$ .....(6)

The probability that extremely high critical emergency traffic/packets find other low critical medical traffics in service is equivalent to the proportion of the time spent at body coordinator on the emergency traffic with priority level 2, 3, 4, 5 and so on. These are calculated as mentioned below.

$\rho_{p1c2} = \frac{\lambda p1c2}{\mu}$ ................................... (7)

$\rho_{p1c3} = \frac{\lambda p1c3}{\mu}$ ................................... (8)

$\rho_{p1c4} = \frac{\lambda p1c4}{\mu}$ ................................... (9)

$\rho_{p1c5} = \frac{\lambda p1c5}{\mu}$ ................................... (10)

As we find, in a queuing system, Little's law gives a significant estimation or relationship about the queue behaviour. From the law, a basis for forecasting the performance of the individual queues is defined by:

$E(n) = \lambda * E(t)$ .................................. (11)

Here, $E(n)$ is the number of data in the queue, $\lambda$ is the data/traffic arrival rate, and $E(t)$ is the average delay time per critical traffic in the queuing system. The Little's law for the extremely critical data traffic is

$E(n_{p1c1}) = \lambda_{p1c1} * E(t_{p1c1})$ ........................ (12)

Hence, the mean time for data the highest priority level can be considered as follows.

$E(t_{p1c1}) = \frac{\frac{1}{\mu}}{1-\rho_{p1c1}}$ and hence, $E(n_{p1c1}) = \frac{\rho_{p1c1}}{1-\rho_{p1c1}}$.......................................... (13)

Delay can be planned and formulated as follows for the data with different level of priority using the formula as mentioned below.

$E(t_{p1c2}) = \frac{E(n_{p1c2})}{\lambda p1c2} = \frac{\frac{1}{\mu}}{(1-\rho_{p1c1})(1-\rho_{p1c1}-\rho_{p1c2})}$ ... (14)

$E(t_{p1c3}) = \frac{E(n_{p1c3})}{\lambda p1c3} = \frac{\frac{1}{\mu}}{(1-\rho_{p1c1}-\rho_{p1c2})(1-\rho_{p1c1}-\rho_{p1c2}-\rho_{p1c3})}$........... (15)

$E(t_{p1c4}) = \frac{E(n_{p1c4})}{\lambda p1c4} = \frac{\frac{1}{\mu}}{(1-\rho_{p1c1}-\rho_{p1c2}-\rho_{p1c3})(1-\rho_{p1c1}-\rho_{p1c2}-\rho_{p1c3}-\rho_{p1c4})}$ ......................................................... (16)

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$$E(t_{p1c5}) = \frac{E(n_{p1c5})}{\lambda p1c5} = \frac{\frac{1}{\mu}}{(1-\rho_{p1c1}-\rho_{p1c2}-\rho_{p1c3}-\rho_{p1c4})(1-\rho_{p1c1}-\rho_{p1c2}-\rho_{p1c3}-\rho_{p1c4}-\rho_{p1c5})} \quad \ldots (17)$$

### 4.4 Analysis of Energy Efficiency for the Proposed MAC Protocol

Energy efficiency has a significant consequence in decreasing overall delays and thus increasing the networks lifetime. The level of energy consumption has a great influence on determining the lifetime of the network [17-19]. The energy usage is dependent upon a node's operat ion. To ensure less energy consumption in our research effort, we assume sensor node interface goes through two states which are active state and an inactive state, where total energy consumption, power consumption at the active state and at an idle or inactive state are denoted by $E_{tec}$, $E_{active}$ and $E_{inactive}$ respectively. The total energy consumption can be obtained from the following expression:

$$E_{tec} = E_{active} + E_{inactive} \quad \ldots (18)$$

The active state is usually denoted as a busy state, and the inactive state is generally denoted as idle state or sleep state. Hence, the inactive state can be presented as,

$$E_{inactive} = E_{sleep} \quad \ldots (19)$$

$$E_{sleep} = T_{sleep} \text{ x } P_{sleep} \quad \ldots (20)$$

$T_{sleep}$ is an sleep or idle time duration, $P_{sleep}$ is the energy consumed in a sleep mode.

Energy consumption during the active state is comprised of the wake-up state which is usually a transition state from inactive or sleep state to busy state along with the power consumed by the node during data transmission and the energy consumption during data receiving or sensing by the node. Energy consumption due to the wake-up node and during data transmission and receiving or sensing data are denoted by, $E_{wakeup}$, $E_{tx,}$ and $E_{rx}$ respectively. Hence, the energy consumption during active state can be formulated as:

$$E_{active} = E_{wakeup} + E_{tx} + E_{rx} \quad \ldots (21)$$

$$E_{wakeup} = T_{wakeup} \text{ x } P_{wakeup} \quad \ldots (22)$$

$T_{wakeup}$ is the wakeup time duration, $P_{wakeup}$ is the power or energy spent in a wakeup mode.

$$E_{tx} = T_{tx} \text{ x } P_{tx} \quad \ldots (23)$$

$T_{tx}$ is data transmission time duration, $P_{tx}$ is the power or energy spent in a data transmission mode.

$$E_{rx} = T_{rx} \text{ x } P_{rx} \quad \ldots (24)$$

$T_{rx}$ is receiving or sensing data time duration, $P_{rx}$ is the power consumed in a data receiving or sensing state.

Now, the value obtained from equations (19) and (21) we put into the equation (18) and find the total energy consumption by a node from the following expression.

$$E_{tec} = E_{wakeup} + E_{tx} + E_{rx} + E_{sleep} \quad \ldots (25)$$

Hence, the total energy consumed is further can be expressed by:

$$E_{tec} = T_{wakeup} \text{ x } P_{wakeup} + T_{tx} \text{ x } P_{tx} + T_{rx} \text{ x } P_{rx} + T_{sleep} \text{ x } P_{sleep} \quad \ldots (26)$$

## 5. RESULT AND DISCUSSION

### 5.1 Simulation Environment

The intended collision-avoidance MAC protocol for WBAN has been investigated using the OMNeT++ platform based Castalia simulator which is planned for networks of low-power and other QoS enabled embedded devices.

### 5.2 Simulation Parameters

Different scenarios have been considered in order to assess various QoS competencies including network overall delay and energy efficiency for the proposed collision-avoidance MAC protocol. The scenarios have been taken evaluating the proposed scheme including diverse traffic size, network size and different levels of traffic priority. Diverse network size has been considered for both IEEE 802.15.4 and IEEE 802.15.6 based networks ranging from 1 to 12 sensor nodes with different priority levels and diverse traffic sizes considering the ranges from 16 bytes to 255 bytes for experiment with WBAN operating range from 3 to 5 meters, frequency of 2.4 GHz and 250 kbps of channel bandwidth. Table 4 presents the simulation parameters.

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*Table 4: Simulation parameters*

| Parameters | Values |
|---|---|
| Total Nodes | Variables up to 12 |
| WBAN Coordinator | 1 |
| Range of Data Transmission | 3m to 5m |
| mMaxBANSize | < 64 Nodes for IEEE 802.15.6 Standards |
| MAC Superframe | IEEE 802.15.4 and IEEE 802.15.6 Standards |
| Channel Mode | Wireless Mode |
| Simulation Runtime | 150 Seconds |
| Operating Frequency | 2.4 GHz |
| Packet Size | Variable, up to 256 bytes considering both modes |

### 5.3 Results Discussion and Performance Assessment

For assessing the overall delay and energy consumption using the proposed collision-avoidance MAC protocol, we consider data transmission using the CAP and the EAP phases. In the case of CAP, the time slots are divided into sub-slots to avoid collision in IEEE 802.15.4 technology. On the other hand, we set EAP1 and EAP2 phases to EAP in the proposed MAC superframe scheme which is based on IEEE 802.15.6 technology and set other phases to zero to avoid the collision. The IEEE 802.15.6 scheme allows and supports data classification procedures. However, IEEE 802.15.4 does not comply with such classification features. The proposed MAC protocol was compared and validated using both CAP and EAP period/phase respectfully.

#### *5.3.1. First Scenario*

The first scenario depicts the delay and energy consumption estimation considering the different number of nodes for both CAP and EAP based IEEE standards respectively. The number of WBAN nodes increases from 1 to 12. Table 5 and Table 6 compare the simulation results of the proposed MAC mechanisms. The obtained results of the proposed model are validated by observing the delay using the equations 6 to 10 for IEEE 802.15.4 and equations 13 to 17 for IEEE 802.15.6. Moreover, we validate the simulation results of the proposed model by observing the energy efficiency is given in equation 26 for both models. We observe from the result that CAP based MAC requires 51.2 ms for transmitting data whereas EAP based MAC requires 16.87 ms for the number of nodes 2. The delay in the network continues to increase when we increase the node numbers in the WBAN environment. Accordingly, the energy consumption level for CAP based MAC is 044 µj, whereas 0.33 µj is found in EAP based MAC for 2 nodes. The energy consumption level increases when we increase the number of nodes in the network. The result as illustrated in Figure 8 and Figure 9 confirm that the delay efficiency and energy consumption rate for EAP based collision avoidance MAC protocol is better than that of CAP based proposed MAC scheme.

*Table 5: Delay comparison of CAP and EAP based MAC protocol*

| Proposed MAC Protocol | Delay (ms) per number of nodes | | | | | |
|---|---|---|---|---|---|---|
| Bytes | 2 | 4 | 6 | 8 | 10 | 12 |
| IEEE 802.15.4 CAP based MAC | 51.13 | 57.45 | 61.34 | 70.67 | 75.11 | 83.87 |
| IEEE 802.15.6 EAP based MAC | 16.87 | 19.37 | 22.73 | 25,46 | 29.06 | 33.50 |

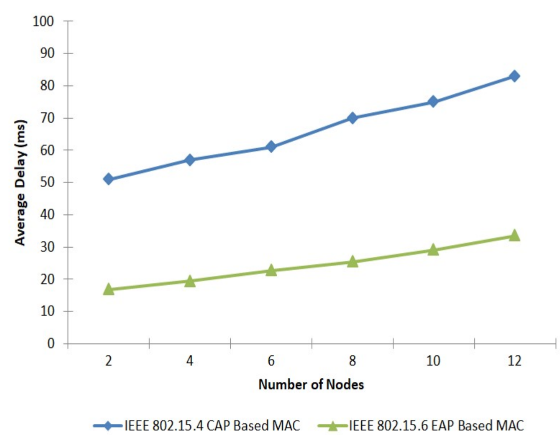


*Figure 8: Delay assessment of medical data transmission under varying nodes*

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*Table 6: Energy consumption analysis of CAP and EAP based MAC protocol*

| Proposed MAC Protocol | Energy Efficiency (µj/bit) per number of nodes | | | | | |
|---|---|---|---|---|---|---|
| Bytes | 2 | 4 | 6 | 8 | 10 | 12 |
| IEEE 802.15.4 CAP based MAC | 0.44 | 0.5 | 0.62 | 0.71 | 0.85 | 1.14 |
| IEEE 802.15.6 EAP based MAC | 0.33 | 0.4 | 0.46 | 0.54 | 0.57 | 0.62 |

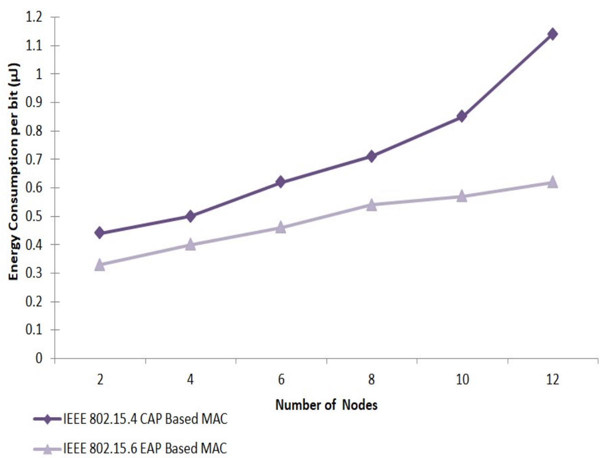


*Figure 9: Energy consumption assessment of medical data transmission under varying sensor nodes in the network*

### 5.3.2. Second Scenario

The second scenario depicts the delay and energy consumption estimation considering various packet sizes for both CAP and EAP phases respectively. The packet sizes up ranged from 16 to 255 bytes. Table 7 and Table 8 compare the simulation results of the proposed MAC mechanisms. We validate the simulation results of the proposed model by observing the delay is given in equations 6 to 10 for IEEE 802.15.4 and equations 13 to 17 for IEEE 802.15.6. Moreover, we validate the simulation results of the proposed model by observing the energy efficiency is given in equations 26 for both IEEE 802.15.4 and IEEE 802.15.6 standards. We observe from the result that CAP based MAC requires 5.12 ms for transmitting data whereas EAP based MAC requires 3.34 ms for the packet size of 16 bytes. The delay in the network continues to increase when the packet size is also increased in the WBAN environment. Accordingly, the energy consumption level for CAP based MAC is 0.045 µj, whereas 0.077 µj is found in EAP based MAC for 16 bytes data packets. The energy consumption level increases when the packet size is also increased. The result as illustrated in Figure 10 and Figure 11 indicates that the delay efficiency and energy consumption rate for EAP based collision avoidance MAC protocol is better than that of CAP based proposed MAC scheme.

*Table 7: Efficiency of delay analysis of CAP and EAP based MAC protocol*

| Proposed MAC Protocol | Delay (ms) comparison per packet size (bytes) | | | | |
|---|---|---|---|---|---|
| Bytes | 16 | 64 | 127 | 192 | 255 |
| IEEE 802.15.4 CAP based MAC | 5.12 | 6.37 | 7.12 | 7.79 | 8.53 |
| IEEE 802.15.6 EAP based MAC | 3.34 | 4.22 | 5.57 | 6.34 | 7.41 |

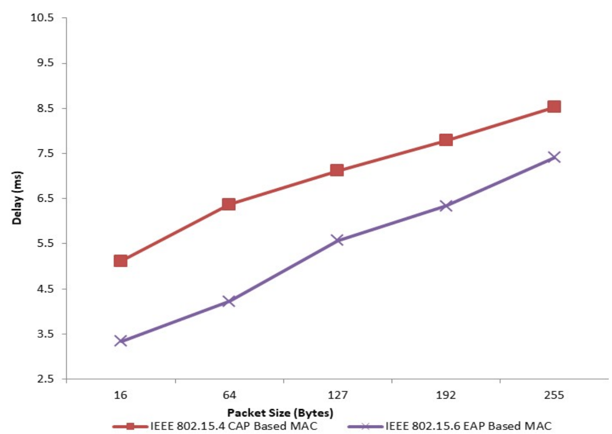


*Figure 10: Delay assessment of data transmission considering various packets sizes*

*Table 8: Energy efficiency analysis of CAP and EAP based MAC protocol*

| Proposed MAC Protocol | Energy Efficiency (µj/bit) comparison per packet size (bytes) | | | | |
|---|---|---|---|---|---|
| bytes | 16 | 64 | 127 | 192 | 255 |
| IEEE 802.15.4 CAP based MAC | 0.04 5 | 0.05 | 0.05 8 | 0.06 5 | 0.07 2 |

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| | | | | | |
|---|---|---|---|---|---|
| IEEE 802.15.6 EAP based MAC | 0.077 | 0.081 | 0.084 | 0.093 | 0.1 |

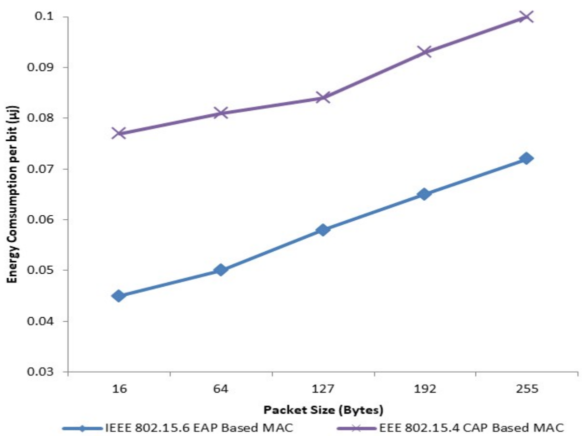


*Figure 11: Energy efficiency rate assessment of data transmission considering various packets sizes*

### *5.3.3. Third Scenario*

The third scenario depicts the delay and energy consumption estimation considering various packet sizes for only EAP based IEEE 802.15.6 standards. In this experiment, we compare the delay and energy consumption of different data types based on their level of priority as presented in IEEE 802.15.6 standard. The packet sizes up ranged from 16 to 255 bytes. Table 9 and Table 10 compare the obtained results of the proposed MAC mechanisms. We validate the simulation results of the proposed model by observing the delay is given in equations 13 to 17 for IEEE 802.15.6 standard. Moreover, we validate the simulation results of the proposed model by observing the energy efficiency is given in equations 26 for all types of data priority levels of IEEE 802.15.6 standards. We observe from the result that EAP based MAC requires 5.74 ms for transmitting data with priority level 1 whereas the delay is slightly increased to 7.64 ms for the data with a lower priority level for 16 bytes data. Accordingly, the energy consumption level for EAP based MAC is 0.035 µj for data with the highest priority level, whereas 0.07 µj is found for data with the lowest priority level and also for 16 bytes data length. The energy consumption level increases when the packet size is also increased. The result as illustrated in Figure 12 and Figure 13 indicates that the delay efficiency and energy consumption rate for data with upper priority level is much lower than that of data with lesser priority level in our proposed EAP based MAC protocol.

*Table 9: Delay analysis of CAP and EAP based MAC protocol considering varying data size*

| Proposed MAC Protocol | Delay (ms) comparison per packet size (bytes) | | | | |
|---|---|---|---|---|---|
| bytes | 16 | 64 | 127 | 192 | 255 |
| Data Priority Level 1 | 5.78 | 6.87 | 7.34 | 7.89 | 8.22 |
| Data Priority Level 2 | 6.12 | 7.37 | 7.87 | 8.2 | 8.67 |
| Data Priority Level 3 | 6.78 | 7.87 | 8.12 | 8.89 | 9.23 |
| Data Priority Level 4 | 7.34 | 8.22 | 8.67 | 9.34 | 9.67 |
| Data Priority Level 5 | 7.64 | 8.87 | 9.21 | 9.89 | 10.22 |

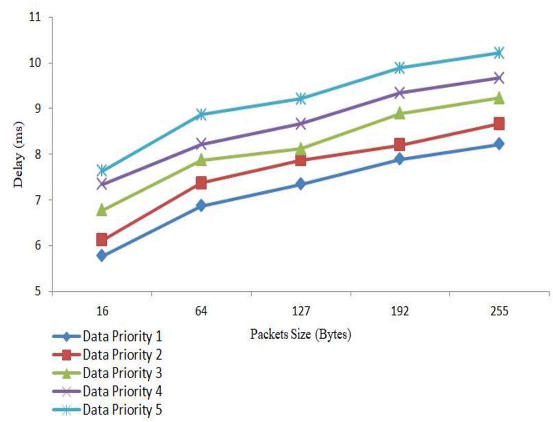


*Figure 12: Delay (ms) comparison among different data types based the IEEE 802.15.6 EAP based Proposed MAC Protocol*

*Table10: Energy efficiency analysis of CAP and EAP based MAC protocol considering varying data size*

| Proposed MAC Protocol | Energy efficiency (µj/bit) comparison per packet size (bytes) | | | | |
|---|---|---|---|---|---|
| bytes | 16 | 64 | 127 | 192 | 255 |
| Data Priority Level 1 | 0.035 | 0.05 | 0.058 | 0.065 | 0.076 |
| Data Priority Level 2 | 0.04 | 0.064 | 0.067 | 0.074 | 0.09 |
| Data Priority Level 3 | 0.049 | 0.073 | 0.077 | 0.083 | 0.1 |
| Data Priority | 0.06 | 0.081 | 0.084 | 0.093 | 0.12 |

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| | | | | | |
|---|---|---|---|---|---|
| Level 4 | | | | | |
| Data Priority Level 5 | 0.07 | 0.093 | 0.097 | 0.11 | 0.15 |

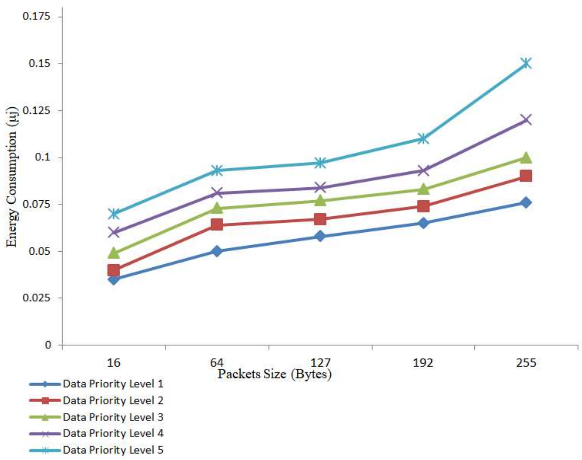


*Figure 13: Energy efficiency comparison among different data types based the IEEE 802.15.6 EAP*

### 5.3.4. Benchmark Comparison

Finally, we have compared the proposed collision avoidance delay and energy-efficient EAP enabled MAC protocol with conventional IEEE 802.15.6 [2] and state-of-the-art i-MAC protocol [19]. In our proposed MAC protocol a modified MAC superframe is proposed for immediate channel communication for emergency data. A separate EAP phase for the superframe is employed for emergency data transmission in the WBAN medium. It can be observed in Table 11 and Figure 14 that the EAP enabled MAC incurs less delay in case of emergency data transmission than that of conventional IEEE 802.15.6 and i-MAC protocol. In the proposed EAP based MAC protocol, data with higher priority need not wait for the channel access due to the dedicated access phase for emergency data, hence the data collision probability dramatically decreases. Hence, results in lower delay in data transmission in WBAN medium. The performance comparison is done for both delay and energy consumption. The results show that our proposed MAC model performs better than that of the existing protocol and standard. On the other hand, it can be observed in Table 11 and Figure 15 that due to no collision and no retransmission in the modified EAP enabled CSMA/CA-based communication the overall energy consumption decreases than that of the existing i-MAC and conventional IEEE 802.15.6 standard. The i-MAC protocol deployed a scheduled access mechanism that may rarely be suitable for medical and healthcare applications. Medical data are random and may arise at the moment; hence any scheduled based approach may not be applicable for medical applications. Thus, from our experiment, it is observable that the proposed collision avoidance EAP enabled MAC protocol performs better than that of the existing MAC schemes.

*Table 11: Average delay comparison between existing MAC and the proposed EAP based MAC protocol*

| Proposed MAC Protocol | Delay (ms) per number of nodes | | | | | |
|---|---|---|---|---|---|---|
| Bytes | 2 | 4 | 6 | 8 | 10 | 12 |
| Conventional IEEE802.15.6 | 42 | 56 | 77 | 100 | 120 | 150 |
| i-MAC | 9 | 27 | 40 | 57 | 75 | 90 |
| IEEE 802.15.6 EAP based MAC | 16.87 | 19.37 | 22.73 | 25,46 | 29.06 | 33.50 |

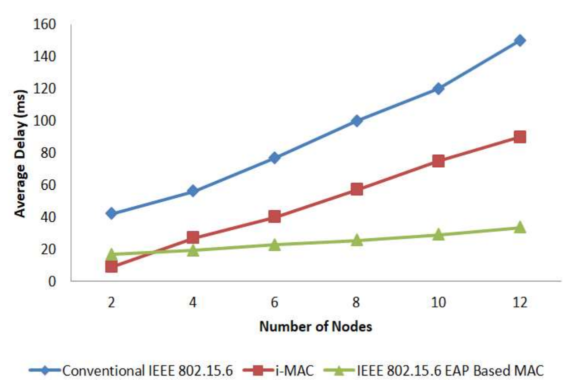


*Figure 14: Analysis of average delay*

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*Table 12: Average energy consumption comparison between existing MAC and the proposed EAP based MAC protocol*

| Proposed MAC Protocol | Energy Efficiency (μj/bit) per number of nodes | | | | | |
|---|---|---|---|---|---|---|
| Bytes | 2 | 4 | 6 | 8 | 10 | 12 |
| Conventional IEEE802.15.6 | 4.8 | 5.2 | 6.9 | 8.1 | 9.2 | 9.7 |
| i-MAC | 2.8 | 3.7 | 4.8 | 5.7 | 6.8 | 7.7 |
| IEEE 802.15.6 EAP based MAC | 0.33 | 0.4 | 0.46 | 0.54 | 0.57 | 0.62 |

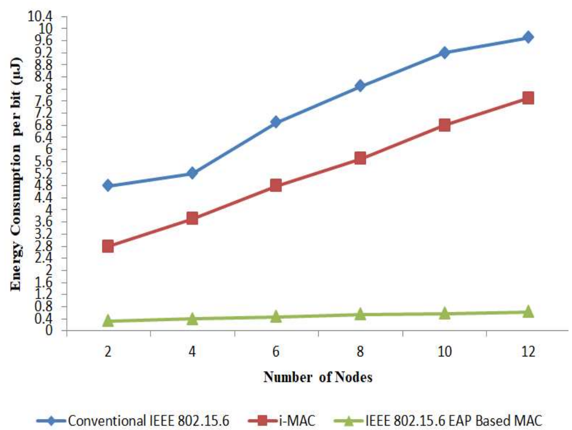


*Figure 15: Analysis of average energy consumption*

## 6. CONCLUSION AND FUTURE WORK

To equip patients with quick and real-time healthcare facilities in an overcrowded environment we propose collision avoidance MAC protocol for WBAN application. Data collision, idle listening, overhearing are the main reasons for the excessive delay and higher energy consumption in the wireless communication network. MAC protocol of the DLL layer is responsible for ensuring QoS issues in networking hence, in our proposed MAC protocol we examined both IEEE 802.15.4 and IEEE 802.15.6 technology-based modified CAP and EAP phases respectively. We experiment and compare the results with different scenarios and found that EAP based collision avoidance MAC performs better considering delay and emergency consumption issues in WBAN medium than that of CAP based MAC. In addition, we also consider five different types of data with different priority levels and the experiment result shows that data with the higher priority level consumes lower energy and minimum delay than that of data with lower priority levels in IEEE 802.15.6 based collision avoidance MAC protocol. Finally, we have compared the proposed collision avoidance delay and energy efficient EAP enabled MAC protocol with conventional IEEE 802.15.6 and state-of-the-art i-MAC protocol. In our proposed MAC protocol a modified MAC superframe is proposed for immediate channel communication for emergency data. A separate EAP phase for the superframe is employed for emergency data transmission in WBAN medium. The performance comparison is done for both delay and energy consumption. The results show that our proposed MAC model performs better than that of the existing protocol and standard. We plan to extend our research for monitoring heterogeneous traffics using various IEEE communication standards, queue methods and techniques to provide better QoS in WBAN communication.

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