

Enhanced model for improving QOS in wireless sensor networks for healthcare monitoring application

Rishika Yadav *

Department of Computer Science & Engineering

Graphic Era Hill University

Dehradun

Uttarakhand

India

Raghuraj Singh [†]

Department of Computer Science & Engineering

Harcourt Butler Technical University

Kanpur

Uttar Pradesh

India

Abstract

Wireless Sensor Network (WSN) is made up of numerous sensor nodes that are dispersed at random and form themselves into a cooperative network. WSN fulfils the three basic tasks of communication, computation, and sensing. WSN research and analysis have grown into a significant exploratory field of healthcare monitoring, particularly because of the difficulties they can address. Current technologies on healthcare system focus on the wearable and implantable Wireless Body Area Networks (WBANs), which are a subclass of WSNs. A medical sensor implanted in or attached to the body using a wireless media forms the basis of a WBAN. This technology allows the collection of physical information about the human body. The WBAN network is made up of different node coordinators that gather data from the devices (e.g. Heartbeat sensor) and transmit it to the closest access point (AP) of the healthcare system. Maintaining the Quality of Service (QoS) parameters such as delay, throughput, energy consumption in the real or active environment caused by different activity of human motion are the main issues faced by body area networks. In this research, we combine Time Division Multiple Access (TDMA) with Carrier Sense Multiple Access (CSMA/CA) to propose a Combined Enhanced Multiplexing Algorithm (CEMA). With the implementation of this strategy, performance of the MAC protocol in congested networks

* E-mail: ryrishikayadav@gmail.com (Corresponding Author)

[†] E-mail: raghurajsingh@rediffmail.com

can be enhanced. An improvement in the performance of the MAC protocol in WBAN was observed considering multi-channel transmission by integrating two algorithms.

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1. Introduction

The wireless sensor network (WSN) ^{1,2}technology has the ability to transform lives and impact the way we live. New generation of wireless sensor networks has been made possible by the rapid advancement of physiological sensors, low-power integrated circuits, and wireless communication. These are used to monitor things like road transport, precision agriculture³, architecture, and medical diseases⁴. A WSN that can detect health-related parameters is known as the Body Sensor Network (BSN). The area of WSN which enables remote patient monitoring in healthcare sector is called as wireless body area network (WBAN^{5, 6}). A WBAN is composed of a variety of biosensors that are employed to detect the body's vital signs and an on-body controller. The medium access control (MAC) protocol ⁷provides a group or set of regulations in a WBAN which govern the network's sensing equipment. The communication systems (sensors) of WBAN are incapable of data packet delivery and reception while they are sleeping or inactive. Inadequate communication systems might cause energy loss because of a variety of reasons. These include collisions, packet loss, staying ideal, over-reacting, over emitting, and transitions which are fluctuating [27-33]. The energy constraints of the sensor nodes in WBAN limit the life span of the sensor⁸s. WBAN can be defined as three tier architecture⁹. Tier-1 sensors are affixed to or implanted within the body. Its goal is to gather and send diverse biological data of the human body. Tier-2 sensors are autonomous electronic equipment. The mode of such sensors for transferring and receiving the data is wireless in nature. Tier-3 sensors of WBAN are primarily comprised of remote servers that serve a wide range of applications. Its purpose is to aggregate and analyse the data received from the human body to generate a dynamic response.

The data handling is extremely delicate in the healthcare application area of WSN. It must be handled carefully. Therefore, designing of MAC protocols¹⁰ for a WBAN requires additional care¹¹. Academia and industry have designed the IEEE 802.15.6^{12, 13}(Baseline MAC) specification as the

future WBAN standards for the sensitive medical data¹⁴. The physical and MAC layers are defined in IEEE 802.15.6. The current IEEE 802.15.6 standard specifies three physical layers: narrow band (NB), ultra-wide band (UWB), and human body communications (HBC).

The MAC protocol in the WBAN is divided into two categories called contention-free and contention-based¹⁵. The carrier sense multiple access with collision avoidance (CSMA/CA) protocol necessitates a node which perform the sensing of channel. This is to make sure that the channel is available for transmission. During the contention access period (CAP)¹⁶, The node contends with other nodes for channel access and uses the CSMA/CA protocol to transmit packets to the coordinator^{17,18} mechanism. The node can use time division multiple access (TDMA) slots to send the packets in a collision-free manner during the contention-free period (CFP) without the use of any carrier-sensing mechanism¹⁹. There are several disadvantages of TDMA. The packet transmission delay increases in TDMA with increasing frame length due to the fixed frame length. The channel is under-utilized in the TDMA when traffic demand is low. Only a fixed amount of bandwidth is available in TDMA when there is a high volume of traffic. Some of the problems can be avoided by using CSMA/CA transmissions during CAP²⁰. The packet transmission requirements may be met only with CAP, especially when the network is congested²¹. Therefore, there is a need of new energy efficient techniques²².

Here, we propose a new energy efficient technique named as Combined Enhanced Multiplexing Algorithm (CEMA) by combining the CSMA/CA and TDMA algorithms. TDMA scheduling has been used on nodes with lower priority and the ones that do not transmit frames for an extended period. The CSMA/CA mechanism will be adopted by the rest of the nodes. The CSMA/CA strategy, on the other side, involves carrier sensing to ensure that the channel is available for transmission. The proposed work considers multi-channel WBAN environment^{13,23,24}

2. Proposed Methodology and System Model

The MAC standards control the protocol in the WBAN which regulates the devices within in the network. The primary duties of sensing device are to transfer and receive the packets in the active and passive modes. A poorly constructed MAC protocol may result in energy loss because of various reasons like idling, fluctuation in transition etc. The quality of service (QOS) attribute is an essential part in the WBAN MAC protocol. The advantage of CSMA/CA is its scalability. The advantage of

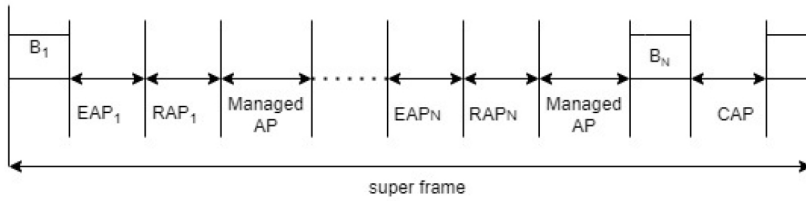


Figure 1

Access phases in beacon period

TDMA is its collision free protocol. The proposed work integrates the advantages of both the protocols to improve the performance of baseline MAC protocol over multi-channel WBAN. TDMA will be used for the packet that is idle for long time. On the other side, the remaining nodes will adhere to the CSMA/CA protocols. The proposed algorithm determines which node should be contacted via which channel (CSMA/CA or TDMA). This will improve the QOS in multi-channel network. We have assumed that the hub works in beacon mode with frame boundaries. The coordinator would send a beacon mode throughout each beacon period or super frame. The node would initiate communication in contended allocations with the sequence shown in Figure 1. The EAP in the figure represents exclusive access phase, RAP represents random access phase, CAP represents contention access phase and CFP represent contention free period.

2.1 Transmission scheme of the algorithm

In a multi-channel Wireless Body Area Network let us assume the following

n = number of sensor nodes

d_i = Delay (where $i = 1$ to n)

Average_delay in i^{th} node = calculated in the rounds ($1^{\text{st}}, 2^{\text{nd}}, \dots, \dots, N^{\text{th}}$ round till the converged node delay).

N_s = Total count of sensor nodes in the WBAN

R_k = Number of rounds ($0 \leq \alpha \leq 1$) in the WBAN

N_p = Average delay of priority groups with similar priorities

SOP = Starts of procedure.

EOP = End of the procedure.

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1.  If the channel is busy
2.  Then
3.  select available free channel (here from 1 to 4)
4.  for the available channel (follow step 5)
5.  SOP
6.      y=0;
7.      for i= 1 to Ns do
8.      {
9.          for j=1 to Rk
10.     {
11.     Calculate (  $\text{delay}_{\text{new}+1} = \alpha * \text{delay}_{\text{old}} + (1 - \alpha) * \text{delay}_{\text{new}}$  )
12.     }
13.     Assign the value of (delaynew+1) to (avrg_delay_node[i])
14.     i=i+ 1
15.     for N= 1 to n do (assuming n=7)
16.     {
17.         for( i= 1 to y) do
18.         {
19.             if (node[i]. priority == Np)
20.             {
21.             {
22.             (s=s+avrg_delay_node [i])
23.             y= y + 1;
24.             }
25.             Else
26.             Calculate avrg_waiting_time [Np]
27.             }
28.             for (i= 1 to Ns )
29.             do {
30.             if node[i]. priority == Ns then
31.             {
32.             if (avrg_waiting_time [Np] <= avrg_delay_node [i])
33.                 Allocate TDMA
34.             else
35.                 Allocate CSMA/CA
36.             }
37.             }
38.             }
39.     EOP

```

2.2 Proposed transmission scheme

During the beacon frame, coordinator will install the GTS (guaranteed time slots) at the beginning of each super frame. Figure 2 shows the complete method of channel access mechanism in CEMA.

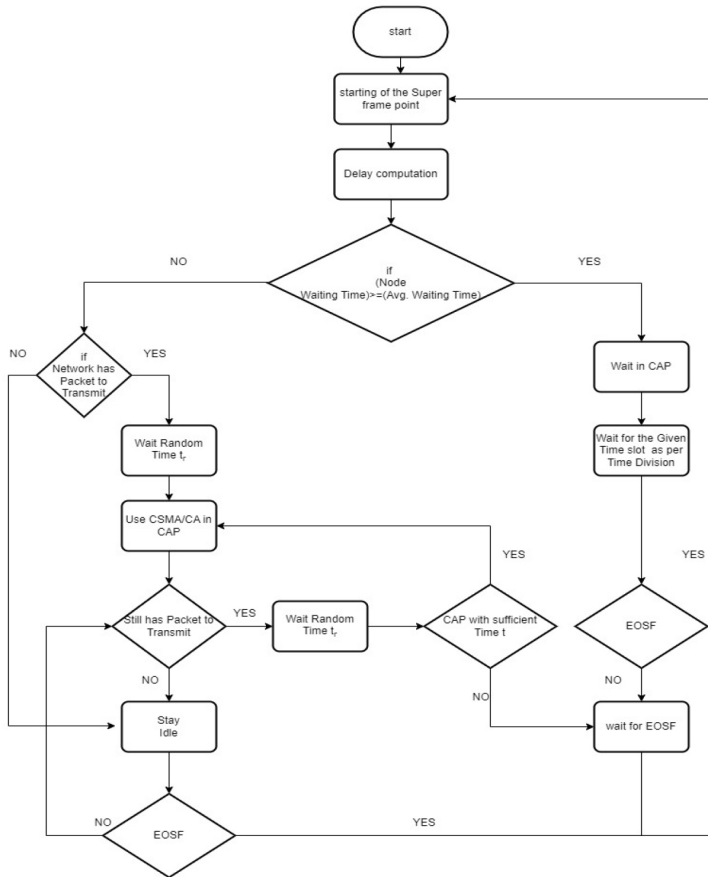


Figure 2
Flowchart of the proposed transmission scheme

2.3 Proposed mathematical model of Network

The number of successful received packets at a given time is characterized by the throughput²⁵. Let us assume, a WBAN consist of one coordinator and SNnode sensor nodes where (SNnode = 10, 20). The number of data channel is assumed as K. The number of time slots in each

of these channels are assumed to be Tslot with G_{pack} is packets generated in each time slot. The probability of a packet to transmit in time slot Slotti, p_i would be $1/\text{Tslot}$. While the probability of successful channel sensing by node, q would be $1/\text{CWindow}$ where If the, CWindow is mean value of the contention window. In the Slottislot the the likelihood of a transmission being successfully received is given by $p_s(\text{Slotti},)$ would be given by equation (1).

$$p_s(\text{Slotti}) = p_i \binom{SN_{\text{node}}}{1} q(q-1)^{SN_{\text{node}}-1} \quad (1)$$

The probability of a channel Channelk to be idle is $p_{\text{idle}}^{(k)}$, assuming the equal probability of selecting the channels. The probability that node Bj selects a random channel is $1/K$ if Bi selects channel Channelk, and the probability of selecting an un chosen channel by Bi would be $(K-1)/K$. The probability of selecting the same channel is given by equation (2) and the probability that Channelk is given by equation (3). The probability $p_{s,i}^{(k)}$ of successful transmission in the given slot ti at an idle channel Channelk will be given by equation (4). The probability $p_s^{(k)}$ is used for the successful packet transmission in Channelk is given by equation (5). Thus, the probability of successful transmission across channelK channels, p_s is given by equation (6).

$$p_{\text{col}}^{(k)} = 1 - \frac{(K-1)}{K} \quad (2)$$

$$p_{\text{idle}}^{(k)} = \frac{K-1}{K} \quad (3)$$

$$p_{s,i}^{(k)} = p_{\text{idle}}^{(k)} \times p_s(\text{Slotti}) \quad (4)$$

$$p_s^{(k)} = \sum_{i=1}^T \left[p_{\text{idle}}^{(k)} \times p_i \binom{SN_{\text{node}}}{1} q(q-1)^{SN_{\text{node}}-1} \right] \quad (5)$$

$$p_s = \sum_{k=1}^K p_s^{(k)} \quad (6)$$

A data collision will take place at a channel WBAN transmission when the packets are simultaneously transmitted by two of the sensors of same channel (say Channelk) at slot ti. If the probability of a successful transfer of the packet at the coordinator is p_s , then the total number of successful packets (P_s) transferred will be given by equation 7.

$$P_s = G\text{Pack} \times p_s \quad (7)$$

The sensing time is the amount of time that a sensor node spends sensing an idle channel, TI_s . It could be divided into two scenarios as follows. In first scenario as an idle channel, the sensor node, while it transmits the data and is calculated by equation (8). In the second scenario when many nodes perform (more than two) through the same channel, then the sensor node perform sensing on another channel with sensing time TI_s by locking the counter channel at random time, TI_{rand} between 0 and T_{data} . TI_s is given by equation (9). The transmission delay, $TI_{d,R}$ is a measure of the time spent by the packet in the retransmitted data part. It is given by equation (10). The time TI_w in this equation represents the priority-based part in the super frame. The total transmission time for i th packet is transmission time is the sum of Several time intervals were measured during the experiment, including the time it took to transmit a data packet (TIdata), the time it took to sense the channel (TIs), the time it took to receive an acknowledgement (Tlack), the time it took to receive two different types of beacons (TIB1 and TIB2), and the delay caused by retransmission (TId).. It is given by equation (11) and the total transmission delay of all the Gpack packets is given by equation (12).

$$TI_s = TI_{b0} N_{b0} p_{s,i}^{(k)} \quad (8)$$

$$TI_s = (1 - p_{s,i}^{(k)}) TI_{rand} + TI_{data} \quad (9)$$

$$TI_{d,R} = TI_w + TI_{data} \quad (10)$$

$$TI_i = TI_s + TI_{data} + TI_{ack} + TI_{B1} + TI_{B2} + TI_{d,R} \quad (11)$$

$$TI_D = \sum_{i=1}^{Gpack} TI_i \quad (12)$$

The number of successful received packets at the coordinator is characterized by the throughput. It is given by equation (13)

$$Throughput = \frac{P_s}{TI_D} \quad (13)$$

p_{idle} represents the probability that out of total of K channels, ST are the successful transmissions. It is given by equation (14). The sum of the probabilities for all channels channel K calculates the average number of idle channels by equation (15). If the bandwidth of the idle channel is W then the mean bandwidth utilized for transmitting data across the BN network, $E_{BW,n}$ is given by equation (16).

$$p_{idle} = \binom{K}{ST} (p_{idle})^{ST} (1 - p_{idle})^{k-ST} \quad (14)$$

$$E_{idle,n} = \sum_{k=1}^K p_{idle}^k \quad (15)$$

$$E_{BW,n} = W \times E_{idle,n} \quad (16)$$

The utilization of a channel can be determined by calculating the ratio between the average bandwidth achieved for successful data transmission and the designated bandwidth. It is given by equation (17).

$$w_n = \frac{E_{BW,n}}{K \times W} \quad (17)$$

3. Result and analysis

The simulation of the proposed (CEMA) using MATLAB is performed to determine the effectiveness of the proposed algorithm [26-30]. The network is made up of 4 channels having two different sensor nodes. The simulation parameters are shown in Table 1. Total 30 trials of the proposed algorithm conducted on 10 and 20 nodes to determine the average delay. Our findings indicate that the proposed protocol effectively mitigates the delay for a specific group of nodes. The results are presented in Figure 3, which illustrate the baseline MAC and CEMA delay. Figure 3 reveals that the number of nodes does not significantly impact on the delay, because only a limited number of sensors are positioned for taking vital observation.

Table 1
Simulation parameters [31-34]

Parameter	Value
Number of channels in WBAN	4
Transmission range	1m
Total number of sensor	10,20
Simulation Area	10 m * 10 m
Super frame length	100 ms
Traffic priority	(Maximum 20% to 80% minimum)

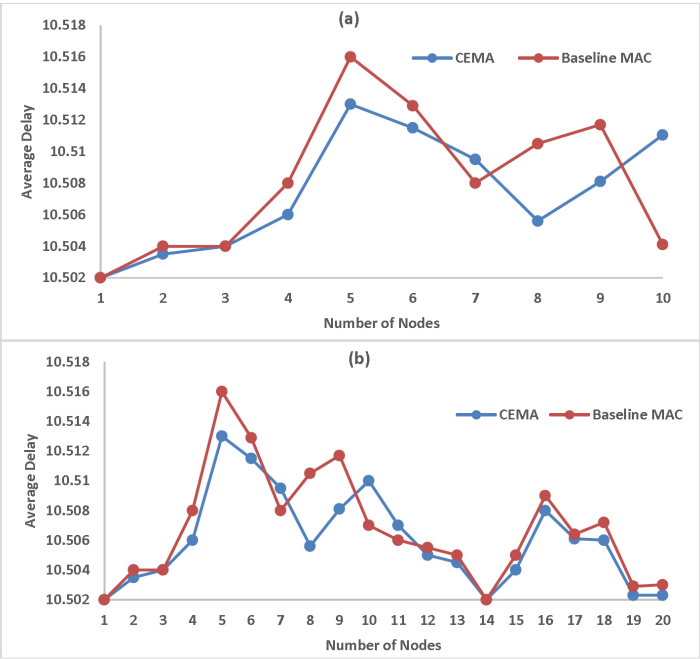


Figure 3
Average delay on node

The throughput is defined as the total number of data packets that were received successfully divided by the total transmission time. This is measured as packet/second. The node with a high-priority node status in CEMA transmits data during the baseline MAC CSMA/CA segment of the super frame. The low-priority nodes in CEMA only send data during the TDMA segment without switching the channel unless the channel is congested. If the channel is congested, the nodes Transition to an alternative channel. Figure 4 presents the average throughput of each WBAN. The figure demonstrates the relationship between the packet payload and the throughput variation across the two distinct data rates.

The computation of energy consumption involves assessing the energy demands associated control packets (transmitting and receiving), negotiation packets, data packets, as well as the energy required for channel switching. Figure 5 shows total energy consumption in Joules/packet. This figure shows the promising performance of CEMA over the baseline MAC.

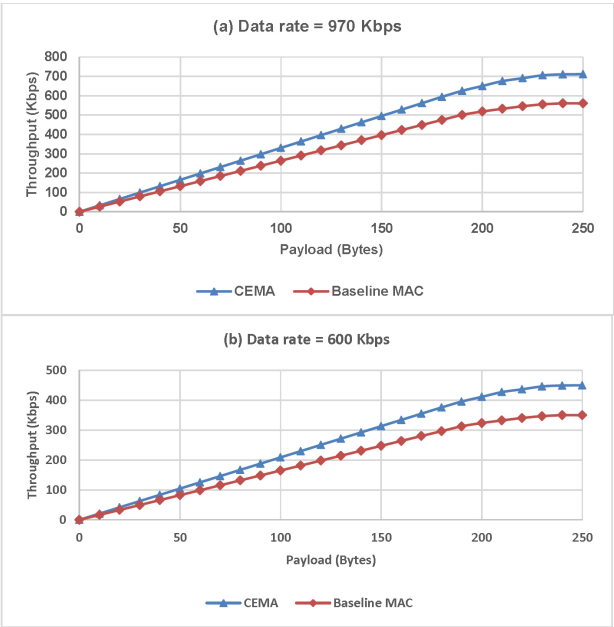


Figure 4
Network Throughput vs payload

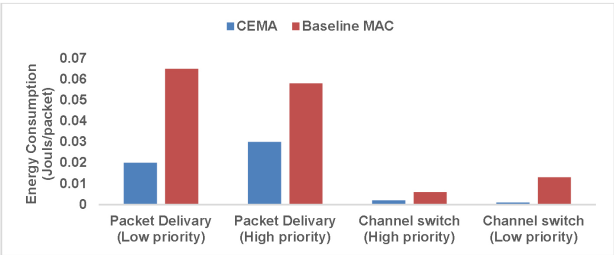


Figure 5
Energy consumption of WBAN

4. Conclusions and future work

This research study explores different multiple channel access techniques employed in MAC protocols utilized within WBAN. An energy efficient protocol CEMA is proposed in this work. Several trial simulations were conducted to compare the proposed protocol CEMA with the baseline MAC. The relationship between the number of nodes and the

average delay is evaluated. The channel selection algorithm of CEMA enables coordinators to choose channels in the WBAN transmission to adjust priority load conditions. This avoids the collisions. The resultant throughput shows a promising performance over convention techniques. In addition, the CEMA protocol is shown to have lower energy consumption when compared to the baseline protocol.

The findings also indicate that increasing the number of sensor nodes has a negligible impact on the performance. Nonetheless, this outcome is not concerning in practical WBAN applications. This is primarily because WBANs typically incorporate a restricted number of sensor nodes that are positioned on the human body. For future study the model can be extended for inter WBAN network.

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