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Prioritized data based Energy Efficient MAC protocol in Wireless Body Area Network

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Abstract*—Wireless Body Area Network (WBAN) is an exclusively designed Wireless Sensor Networks that used in today's health-care system. The central challenge in WBAN is to transfer the medical data with limited energy and with high reliability. The IEEE 802.15.4 MAC Protocol is a standard model used to consume less energy by providing low data rate. This paper aimed to present a novel protocol PD-MAC, an enhanced version of IEEE 802.15.4 to achieve the above goal. The main objective of this protocol is to transmit the packets according to their priorities. It also improves the retransmission and packet drop process by introducing an additional slot to define Starvation Index in the super-frame of IEEE 802.15.4. A node has to start its transmission when the timer is set to zero. A node has to sense the channel status before transmission begins. The data are transmitted according to their priorities only when it senses the free channel. However if the channel is not free then retransmission of packet will be carried out and in each retransmission process the starvation index increments the priority of the packet. When the packet priority raises to high then it transmits the packet by considering it as high emergency packet. For energy efficiency a max limit is define to retransmit a data packet. This protocol has been simulated using Castalia 3.2 environment and the result validate that our proposed protocol provides better service in terms of least Packet Delay and lowest Energy Consumption to its counterparts.

***Keywords*—WBAN,IEEE802.15.4 standard, MAC, Starvation Index, Back-off period.**

I. INTRODUCTION

The healthcare issue of human being is a very challenging task at present era. The Splendid technological world, we are living made possible to design the smart solutions to make our lives easier and comfortable. Thus, the technological advancement in the field like micro-electronics, smart bio-sensors and wireless communication systems introduces a new human type of network so-called as Wireless Body Area Networks (WBAN) [1]. These networks have been widely used in various applications such as remote health-care systems, entertainment, games and sports, etc. WBANs are considered as a new innovation in the health-care system that monitors the patient data periodically. Through this Remote Monitoring service it makes better quality of life (QOL). This special-purpose network composed of various bio-medical sensors (BMS). These tiny bio-medical sensors are implanted in distinct parts of a human body in order to collect various critical and non-critical patients' data and deliver them to a sink node which is the central coordinator (BANC). The hub then transfers these received data to an externally situated medical server for the medical diagnosis. In some situations the data is critical or emergency that should be delivered to the medical server for taking immediate action to save the patient's life. Therefore these data should be transmitted in priority basis rather than first-cum first-serve. Hence in the data transmission field, QOS (Quality of service) plays a vital role. Wireless body area sensor nodes are battery powered devices, where the battery life of a sensor node is directly related to the battery size. So it is very important that, WBANs must sense, process and communicate data in a power efficient manner. Energy efficiency, hence, is of most significant for WBAN protocols and key emphasis should be given to this feature, while designing the WBAN. The Medium Access Control (MAC) is an appropriate solution of this said problem [2]. MAC protocols are very efficient because it improves the lifetime of the network by reducing data rate and energy wastage. An efficient MAC protocol also reduces collision and gets achievable throughput flexibility for various applications. WBANs support several types of patient's data like normal and abnormal data, periodical routine checkup data, critical and non-critical data. Among these critical data indicates the aberrant changes in the patient's body like increasing or decreasing in the pressure, pulse rate, body temperature, glucose level, sodium level or heart-rate, etc. Whereas non-critical data are the normal data in a patient's body such as body temperature, number of sleeping hours, etc. Hence another issue in WBAN is the transmission of such critical data in a reliable and real-time manner as it indicates life threatening data for a patient. For this data should be transmitted in priority basis rather than first-cum first-serve. Thus, to improve QOS this paper introduce an advanced MAC protocol that influenced by initial IEEE 802.15.4 protocol. In this protocol we focus on prioritized traffic type. Additionally on giving the priority to different data packets, we also improve the retransmission and packet drop functions using starvation index. The remainder of this paper is organized as follows. Section 2 contributes a brief sketch of IEEE 802.15.4 protocol and some related literature works of PD-MAC protocol. Section 3 extensively describes the proposed enhanced mechanism starts with the types of packets followed by the working mechanism.

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The simulation results presented in Section 4 demonstrates the performance analysis. In Section 5 finally, we conclude our study.

II. RELATED WORKS

Some of the authors try to modify the super-frame structure of IEEE 802.15.4 to increase the QoS of WBAN. The IEEE 802.15.4[3] is a standard model for MAC layer of WBAN. The super-frame structure of this model is separated into three parts such as Beacon, Contention Access Period (CAP) and Contention Free Period (CFP). The CAP and CFP use CSMA and TDMA for transmission of data. Two types of MAC protocols are used such as contention-based protocols and non-contention based protocols. In the contention-based protocols like ALOHA and CSMA, there is a possibility that collision may occur. But it does not need any program to synchronize, so the network configuration is independent to the network topology. For this reason, contention-based protocol is more flexible. However in these protocols high collision rate can degrade the network performance in heavy traffic rate. Whereas a non-contention based protocol like FDMA, TDMA and CDMA, is the suitable solution as it reduces the chances of collision and improves the network efficiency. However it needs a suitable program for synchronization that will affects the network topology [7]. LTDA-MAC (Low Delay and Traffic Adaptively) protocol [8] has 6 slots and does not consider the priority of data types. In this protocol BMS faces higher delay, higher collision and consume high quantity of energy which is not acceptable for life threatening data. In [9] by considering two types of traffic such as non-critical and critical, a priority mechanism for the critical traffic type is presented as U-MAC. To reduce delay it ignores the packet retransmission after the collision occur, which increases the energy efficiency. The author in [10] developed a PNP-MAC protocol to improve the QOS. It uses IEEE 802.15.4 standard, in which the modified super-frame structure is composed of five phases that are beacon, contention Access Period (CAP), Data Transmit Slot (DTS), Emergency data Transmit Slot (ETS) and inactive period. The normal periodic data are transmitted in CAP in short back-off time. When time slot is assigned, then DTS phase is used to send the nodes data. An additional phase ETS is used for sending emergency data. Though it can improve the QOS through preemptive slot allocation and non-preemptive transmission, but due to its fixed sized CFP it is very inefficient during heavy traffic load means it does not take traffic load into account. The author in [11] proposed Mc-MAC a multi constraint MAC protocol to minimize delay, energy consumption and maximize reliability of the network to improve quality of service in WBANs. It considered five different types of traffic such as emergency, only reliability, only delay, both delays and reliability and without delay and reliability. A Priority based traffic-Load Adaptive medium access control protocol (PLA-MAC) is developed [12] using IEEE 802.15.4 model. In this work the super-frame structure was modified based on traffic load. It divides the data packets into four different categories: Critical-Data Packet (CP), Ordinary-Data Packet (OP), Reliability-Data Packet (RP) and Delay-Data Packet (DP). It improves the QOS performance with the help of dynamic sized CFP. However some data packets are lost when the buffer used for storing packets that transmit in the next super-frame is overflow.

A Priority-Adaptive MAC protocol (PA-MAC) was proposed in [13] for WBANs. In the modified super-frame structure to ensure the quality of service, the beacon is used to transmit the beacon frames. Data packets in CAP are divided into four classes where the emergency data can transmit in all four phases. In [4] a traffic adaptive MAC (TA-MAC) protocol as presented to improve the energy efficiency for different data types. It improves delay, energy and data transfer. However it considered periodic traffic only.

In [5] a priority-based MAC protocol for energy consumption and delay guaranteed in wireless body area networks (ECTP-MAC) was proposed to manage energy consumption and reduce delays, that increases network lifetime and guaranteed quality of service. The modified super-frame structure introduces an additional period EX (Extended Period) to transmit emergency data. But it has no special mechanism to transfer non-emergency periodic data that suffers aging problem. Our proposed work PD-MAC solves the above said problem through sending alarm signal if any emergency data are generated during CAP. The emergency data can also transmit in inactive period by giving more number of chances to access the medium. Also the aging problem can be solved in our proposed work by introducing starvation index for non-emergency periodic data in the modified super-frame structure.

III. PROPOSED WORK

The proposed protocol is based on IEEE 802.15.4 model. This section describe the detailed information about the MAC protocol for energy consumption and delay reduction in order to improve the performance and lifetime of the network in WBAN by using protocol IEEE 802.15.4.

A. Prioritization of Packets

The packets are according to their priority where the priority for each packet is calculated using the following equation

$$\text{Priority} = \frac{\textit{threshold value of vital sign}}{\textit{generaion time} \times \textit{data rate}} \quad (1)$$

B. Types of Packets

There are three types of data packets are used such as Hard Real-Time Data Packets (HRD), Firm Real-Time Data Packets (FRD) and Soft Real-Time Data Packets (SRD).

- Hard Real-Time Data Packets (HRD): These are the highest priority data packets. These are nothing but the emergency i.e. critical and unpredictable data packets. These data should have the deadline and reliable constraints means it requires hard real time and reliable transmission. For example. Heart bit rate, BP, ECG, EEG are monitored periodically in a day after surgery of a patient
- Firm Real-Time Data Packets (FRD): These are the periodic emergency type of packets that are generated at irregular intervals. It has the medium priority. For example BP, sugar level data are monitored in irregular intervals and sent to the doctor for further treatments. The FRD packets also have the deadline and reliable constraints.

- Soft Real-Time Data Packets (SRD): These types of packet are the normal medical data with lowest priority. These are neither delay constraint nor reliable constraint. For example, a person wants to gain/loss wait or wants to share the normal check-up data in daily basis.

C. Back-off Period

Timer's zero status initiates the node to start its transmission. The node starts transmission by hearing the channel status. When the channel status shows idle, it will transmit RTS i.e. Request-to Send message to the target node, but scenario will be change if it listen as busy channel. When the busy status is found, then at first it go to waiting state for a random back-off period in Cap. Estimation of this back-off time period is based on the priority of the packet. After completing this random waiting time, node again come to the field to listen the channel state but unfortunately if the channel is not free till now, then it will wait again for a unit back-off period. This process of channel sensing continues until the node's attempts do not reach to MAX back-off limits.

After receiving a CTS i.e. Clear-to Send message, then the sender node sends the data packet. After receiving, the receiver node also delivers an ACK message. Furthermore after successful transmission of the packet, the packet is removed from the buffer.

D. Starvation Index

The failure of transmission/ retransmission of packets in IEEE 802.15.4 CSMA/CA channel access method can be caused due to the following reasons [6]:

- During the access attempt channel sensed busy. Unfortunately this has not been recorded in WBAN.
- The duration required to send the entire packet is more than that of the duration of the super-frame period.

Hence, we feel to introduce a starvation index, to define the number of times that a node attempts for transmitting/ retransmitting a packet when the channel is sensed busy. This supplementary parameter projects a view for the nodes that are attempted for channel access by considering the fact that waiting time of a node in its back-off period should not be more than 2 * BE (Back-off Exponent) periods.

The starvation index is initially set to 0. It gets incremented when a node tries to access channel but it not get. Also simultaneously the priority of the packet is incremented. The index value is incremented in each time slot as long as it senses the channel busy. As it sensed free channel, transmission/ retransmission is performed.

During the busy state of channel, number of transmission attempts evaluate the waiting time of a given packet. This will help to identify efficient mechanisms to make a balance in sending data of different priority in acceptable time delay.

E. Modified Super-frame structure

The proposed protocol is based on IEEE 802.15.4 model. The proposed modified super-frame structure of PD-MAC protocol consists of a beacon period which indicates boundaries of super-frame structure, Contention Free Period (CFP), Contention Access Period (CAP) and optional Inactive/IP slots as shown in below fig.

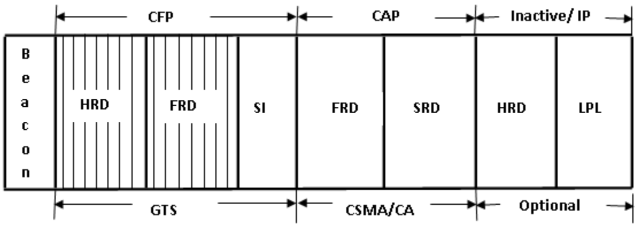


Fig. 1.Modified Superframe Structure

Where, AS = Alarm Signal, SI = Starvation Index and LPL = Low Power Listening

In the proposed modified structure the beacon occupies a single slot. Before transmitting data packet the proposed protocol first broadcasts a beacon that contains synchronization, information required for synchronization and address of body coordinator node.

In the proposed modified model guaranteed slots are reserved for transmitting HRD and FRD in CFP. If the data is in normal range i.e. SRD, then it perform contention to access the channel in CAP. In IP one slot is allocated for FRD and SRD. If these data are generated at the time of transmission, otherwise it will go for the sleep mode called inactive period. This IP slot is used to minimize energy consumption and hence lifetime of the network can be improved.

The CFP slots are allocate to HRD and FRD, which uses TDMA mechanism for data transmission. The CFP also used for maintaining starvation index.

The CAP slot is allocated to HRD and SRD that uses CSMA mechanism to transmit data packets.

F. Priority Queue Mechanism

TABLE I. WBAN USER PRIORITY QUEUE MECHANISM FOR CSMA/CA PROTOCOL

Packet Type	User Priority	Channel Access Phase	Packet Designation	CW_{min}	CW_{max}
Hard Real-Time Data Packets (HRD)	PP2	CFP, CAP	Emergency or Critical data	1	1
Firm Real-Time Data Packets (FRD)	PP1	CFP, IP	Periodic Emergency data	2	8
Soft Real-Time Data Packets (SRD)	PP0	CAP, IP	Normal data	8	16

G. Algorithm for Proposed model

TABLE II. NOTATIONS AND DESCRIPTION OF PD-MAC

Packet (i)	Packet in the waiting queue of priority i
BiMax	Maximum Back-off value
RiMax	Maximum number of Retransmission that can be done
SiMax	Maximum Starvation Limit
Ri	Number of Retransmission
Tr-Decision	Transmission Decision
Tr-Progress	Transmission Progress
Tr-Success	Successful Transmission
Tr-Failure	Transmission Failure
UPi	User Priority of Packet (i)
Rem-time	Remaining Time of Packet (i)
Req-time	Required Time to transmit packet (i)
I	Data Interval Time
N	No. Of GTS

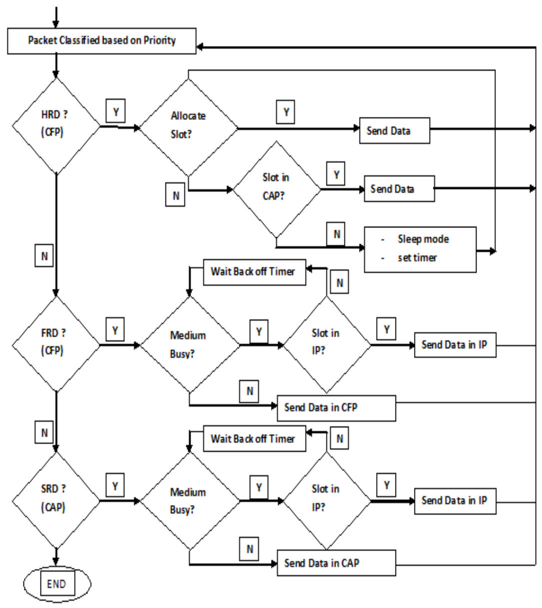
Algorithm 1: Transmission of packets using CSMA/CA mechanism

Input: BiMax, RiMax, Packet(i)
Output: Tr-Decision
1. Packet(i) is False
2. Repeat
3.   Packet(i) is verify-Packet(i)
4. Until Packet(i) is true
5. Ri = 0
6. Tr-Decision = “Tr-Progress”
7. While (Tr-Decision = “Tr-Progress”) and (Ri < RiMax) do
8.   If (Channel-State = “Success”) then
9.   Tr-Decision = “Tr-Success”
10.   Else
11.   Ri = Ri + 1
12.   End if
13. End while
14. If (Tr-Decision != “Tr-Success”) then
15.   Drop (Packet(i))
16.   Tr-Decision = “Tr-Failure”
17. End if

Algorithm 2: PD-MAC Transmission/ Retransmission process of packets

Input: BiMax, RiMax, SiMax, UPi, Packet (i), K, N
Output: Tr-Decision and slot allocation
1. UPi= 1
2. Period = CFP
3. For i=1, K do
4.   If d!= I then
5.   I request a GTS from coordinator
6.   UPi= 2
7.   End if
8. End for
9. UPi= 1
10. Period = CFP
11. For i=1, K do
12.   If UPi= 1 then
13.   i= N
14.   End if
15. End for
16. N=N-1
17. Packet (i) is False
18. Repeat
19.   Packet (i) is verify-Packet (i)
20. Until Packet (i) is true
21. Ri = 0 , Si = 0
22. Tr-Decision = “Tr-Progress”
23. While (Tr-Decision = “Tr-Progress”) and (Ri < RiMax) and (UPi = “PP1”) and (Rem-time < Req-time) do
24.   If (Channel-State = “Success”) then
25.   Tr-Decision = “Tr-Success”
26.   Else
27.   Ri = Ri + 1 and Si = Si + 1
28.   UPi = UPi +1
29.   End if
30. End while
31. If (Tr-Decision != “Tr-Success”) and (Si = SiMax) or (Ri = RiMax) then
32.   Drop (Packet(i))
33.   Tr-Decision = “Tr-Failure”
34. End if

H. Flow Chart



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IV. SIMULATION AND RESULTS

A comparative study of the proposed protocol is carried out with IEEE 802.15.4[3], ECTP-MAC [5]. These above mentioned protocols have the same objective with the proposed protocol. The simulation was conducted on Castalia [14] simulator.

A. Simulation Parameter

TABLE III. SIMULATION PARAMETER

Parameter	Value
Data Rate	250 Kbps
Nodes	10
Beacon Interval (BI)	15,360
symbols payload	78 bytes
Super-frame Duration (SD)	7860 symbols
Acknowledgment Packet Size	13 bytes
Back-off Period	20 symbols
min Back-off Exponent	3
Inactive Period	variable
Max Back-off Exponent	5
Clear channel assessment (CCA)	8 symbols
Beacon order (BO)	4
Sensing time	Sensing time
Super-frame order (SO)	3
Super-frame order (SO)	120 * 16e−6 s
Receiving power	1.8 W
Turnaround time	400e−6 s
Transmission power	31.5 W
Wakeup time	800e−6 s
Transmission voltage	1.5 V
Unit back-off time	20 * 16e−6 s
Receiving voltage	0.9 V
Inter-arrival time	0 – 2 s

B. Packet Delivery Delay

The fig.2 represents packet delivery ratio of PD MAC, ECTP-MAC and IEEE 802.15.4.The proposed protocol PD-MAC has least delay as compared to their counterparts. IEEE 802.15.4 has limited number of slots. Therefore, the waiting time of various types of data increases as a result it exhibit maximum delay. IN ECTP though there is extra slot for emergency data but starvation problem occurs for other types of data. As a result the waiting time in the buffer increases. However in PD MAC there are dedicated slots are available for emergency data and IP period is effectively utilized for sending emergency data exhibit less delay.

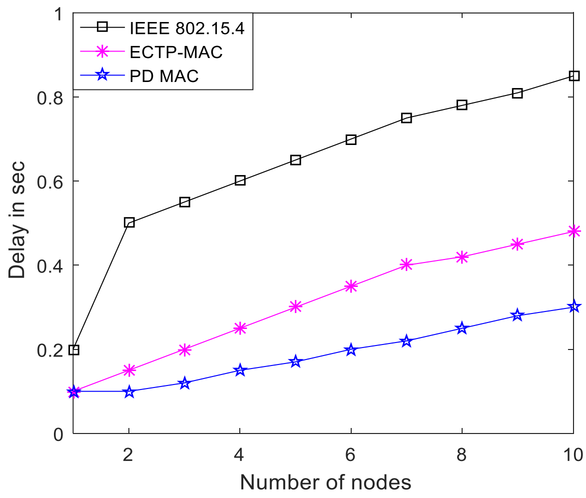

Fig. 2.Packet Delivery Delay Vs Simulation time

C. Energy Consumption

The fig.2 represents energy consumption of PD MAC, ECTP-MAC and IEEE 802.15.4.The proposed protocol PD MAC consume more energy since it has maximum delay due to limited number of slots. In ECTP though there is extra slot for emergency data but starvation problem occurs for other types of data. As a result the waiting time in the buffer increases. Therefore, energy consumption is more. However in PD MAC there are dedicated slots are available for emergency data and IP period is effectively utilized for sending emergency data exhibit less delay resulting least energy consumption.

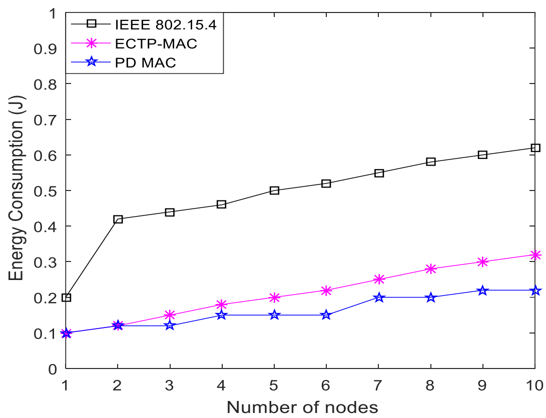

Fig. 3.Energy Consumption Vs Simulation Time

D. Throughput

The fig..4 represents throughput of PD MAC, ECTP-MAC and IEEE 802.15.4.The proposed protocol PD MAC has maximum throughput in comparision above protocols. IEEE 802.15.4 protocol has minimum throughput due to limited number of slots. In ECTP though there is extra slot for emergency data but starvation problem occurs for other types of data. As a result the throughput of this protocol decreases However in PD MAC there are dedicated slots are available for emergency data and IP period is effectively utilized for sending emergency data exhibit less delay resulting maximum throughput.

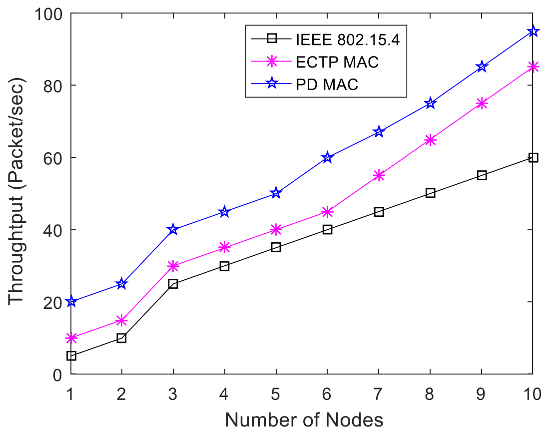

Fig.4 Throughput vs Number of nodes

V. CONCLUSION AND FUTURE WORK

An energy efficient prioritized medium access control protocol has been presented for instantaneous and accurate deliver of various types of data and extends lifespan of WBAN network . The PD-MAC protocol announces a special slot for transmitting HRD during CFP. Aging problem in FRD is solved through Starvation Index in the proposed super-frame structure. IP an optional slot is effectively utilized for sending HRD when there is no slot is allocated in CFP. The Simulation result demonstrates that PD-MAC protocol conveys considerable enhancements delay and energy efficiency than other protocols.

The next plan is to use IEEE 802.15.6 in this protocol. For extending reliability relay nodes can be used for our future work.Multichannel MAC protocol can be designed for maximize throughput of WBAN.

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