A PSPT-MAC Mechanism for Congestion Avoidance in Wireless Body Area Network

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Abstract A Remote Health Monitoring System (RHMS) is known as one of the promising applications that has been successfully developed with the help of Wireless Body Area Network (WBAN) technology nowadays. This RHMS offers a continuous monitoring of health's status by sensing and collecting the physiological signals (medical data) from bio-sensors that are attached or implanted in the body. Then, these medical data are furthered transmitted to the clinicians to diagnose the diseases. If any abnormalities are detected, a quick medical actions would be carried out. However, these collections of medical data could lead to heavy traffic which increase the risk of data congestion in the network. Congestion could severely impact the overall's network performances in terms of longer delay and packet loss. Thus, a Priority Selective Packet Timeslot (PSPT-MAC) mechanism is proposed to avoid congestion during transmitting these bulk of medical data in the network. This mechanism is initiated by classifying and prioritizing the data according to their importance through ECG Packet Classification and Prioritization (ECG-PCP) mechanism. Later, corrupted packets are earlier discarded by Prioritized Selective Packet Discarding (P-SPD) mechanism to save the limited network's resources. Finally, the remain packets (after discarding packets from P-SPD mechanism) undergo fragmentation according to slot time via Fragmentation based Slot Time MAC (FST-MAC) mechanism in the MAC IEEE 802.15.4 protocol. From the findings, this mechanism has outperformed the standard IEEE 802.15.4 protocol and FCA-MAC mechanism by yielding low delay and packet loss as well as high throughput and packet delivery ratio (PDR) under different number of nodes in the network.

Keywords WBAN · Congestion · Priority · Discarding · Fragmentation

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1 Introduction

A progressive advancement in bio-sensors and wireless technology has enabled the development of Remote Health Monitoring System (RHMS) nowadays. This application offers an efficient delivery of medical services to the patients since it reduce the waiting time for the patients to be treated by doctors [1]. This is because patients with RHMS technology can be wirelessly monitored anywhere and anytime. If any abnormalities are detected in the reading of vital signals, the medical practitioners would be alerted and prompt medical actions would be carried out to avoid risk of mortality among patients. In addition, this application also has been part of Internet of Things (IoT) technology [2].

RHMS is developed by using technology namely Wireless Body Area Network (WBAN) that comprises several intelligent and miniature bio-sensors are attached or implanted in the body [3]. Then, the readings of vital signals are detected and forwarded these medical data to the database of the hospital. However, transmission of these bulk medical data could lead to congestion in the network which might lead to increment in delay and packet loss.

Moreover, according to [4, 5], medical data in WBAN are significant and can be categories as normal, critical and on-demand data. Loss of normal data are still acceptable but loss of critical data may cause severe impact to the patients such as late in delivery of medical response and to be worst lead to mortality. This is due to the significant information that has been carried by critical data and thus poses strict delay and packet loss in order to avoid misdiagnosing the diseases. Thus, a mechanism of congestion avoidance should be designed to meet the requirements of low delay and packet loss in WBAN so that a reliable RHMS can be established.

The paper is organized as follows: Sect. 2 (Literature Review) provides discussions on the previous or existing mechanisms in congestion for WBAN. The design of proposed mechanism to avoid congestion is delivered in Sect. 3 (Methodology) including with the simulation parameters used in the experiments. Section 4 (Results and Discussion) elaborates the findings from the collected results of simulation experiments for the proposed mechanism in WBAN. Finally, the achievements of the proposed mechanism and some future works are concluded in Sect. 5 (Conclusion).

2 Literature Review

Congestion control mechanisms can be divided into three classes which are congestion avoidance, congestion mitigation and reliable data transport [6]. However, this paper specifically focuses on reviewing existing congestion avoidance mechanisms in the WBAN. Congestion avoidance is defined as mechanism that avoid occurrence of congestion in the first place. There are several congestion avoidance mechanisms in the network as shown in Fig. 1 as follows.

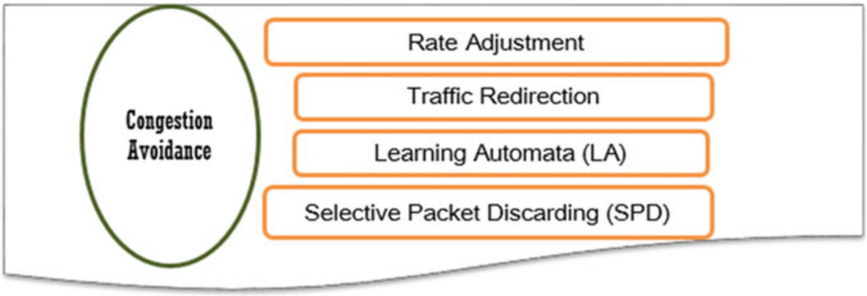

Fig. 1 Congestion avoidance mechanisms in the network

Generally, there are two techniques namely rate adjustment and traffic redirection are considered for congestion avoidance mechanism [7]. In rate adjustment, transmission rate of the nodes is regulated once the notification of congestion is received [8, 9]. Nevertheless, this technique could degrade the network's performance due to occurrence of packet drop. This packet dropping could lead to misdiagnosing the disease especially when the critical packets are dropped. This is because these type of packets carry significant information of the patient's health status. Thus, rate adjustment is not an optimum choice in handling congestion in the network. Meanwhile, the nodes are highly recommended to transmit their packets to other uncongested path in traffic redirection congestion control method. In other words, once the congestion is detected, the packets should not be routed through the affected, congested path. Thus, the packets should be redirected to the other alternative path to arrive at the destination [10]. However, there could be a possibility that the congested path might be the shortest route for the packets to reach the destination. Thus, redirection of packets may bring to time consuming that lead to increment in delay especially to the critical packets in WBAN. This is because this type of packet need to be timely delivered to the base station to avoid late delivery of medical response.

Another congestion avoidance mechanism which is termed as Learning Automata (LA) is initiated in [11]. The concept of LA is placing an automaton in every node. This automaton refers to small piece of code that is able to perform intelligent action such as controlling data flow's rate which depends on packet's drop probability when certain flow rate is kept constant as in [12, 13]. Optimal data rate is selected by learning from past performance of the flow in the network through the computation of dropped packet. In other words, the rate's flow with least number of dropped packets will be chosen as optimal rate. The implementation of Selective Packet Discarding (SPD) schemes are mainly used in voice packet and Asynchronous Transfer Mode (ATM) [14, 15]. This mechanism is selectively dropped the packets in the data transmission.

Precisely, most of these existing mechanisms are done in Wireless Sensor Network (WSN) which is not suitable to be directly implemented in the WBAN [6, 16]. This is due to strict requirements of WBAN in terms of delay and packet loss compared to WSN. Thus, some improvements and adjustments of existing congestion control mechanisms are critically needed to be suited in WBAN environment.

3 Proposed Methodology

There are three stages of mechanisms involve in the proposed congestion avoidance for WBAN. To be exact, this proposed mechanism is only concerned on Electrocardiogram (ECG) medical data. These three stages of mechanisms are integrated and designed as Priority Selective Packet Timeslot (PSPT-MAC) mechanism as tabulated in Table 1 as follows.

At initial stage which involves ECG packet Classification and Prioritization (ECG-PCP) mechanism (Stage 1), the ECG medical data are classified and prioritized based on the value of RR-intervals in the ECG's reading. The range of interval RR-intervals plays a major role in determining the significance of the ECG medical data. For instance, if the RR-intervals is ranging from 0.6 to 1.0 s, the medical packets would be classified as Normal packets with Low Priority. Meanwhile, if the value of RR-intervals is less than 0.6 s, the medical packets are assigned with Critical packets and High Priority. The concept and details of this ECG-PCP mechanism can be referred to our previous work in [17].

After classifying and prioritizing the data through ECG-PCP mechanism, the normal and abnormal data would undergo Prioritized Selective Packet Discarding (P-SPD) mechanism (Stage 2). For the purpose of this work, the corrupted packets are referred to packets with bit errors. This type of packet is not worth to be transmitted as it might be discarded at the base station. Hence, earlier discarding process of corrupted packets could avoid waste of network resources such as bandwidth and power consumption. Also, the concept of P-SPD mechanism has been extensively discussed and elaborated in our earlier work as in [18]. It is worth to note that P-SPD mechanism is not carried out to the critical packets as these type of packet should be quickly transmitted in the network.

Later, after completing ECG-PCP (Stage 1) and P-SPD (Stage 2) mechanisms, a Fragmentation based Slot Time MAC (FST-MAC) mechanism is carried out by fragmenting the medical packets according to slot time in the IEEE 802.15.4 protocol. Generally, the typical slot time in IEEE 802.15.4 is 0.96 ms [19]. However, in this FST-MAC mechanism this value is decreased to 0.2 ms after data is being fragmented.

Table 1 Stages of PSPT-MAC mechanism for congestion avoidance in WBAN

PSPT-MAC mechanism	Stage 1	ECG Packet Classification and Prioritization (ECG-PCP) mechanism
	Stage 2	Prioritized Selective Packet Discarding (P-SPD) mechanism
	Stage 3	Fragmentation based Slot Time MAC (FST-MAC) mechanism

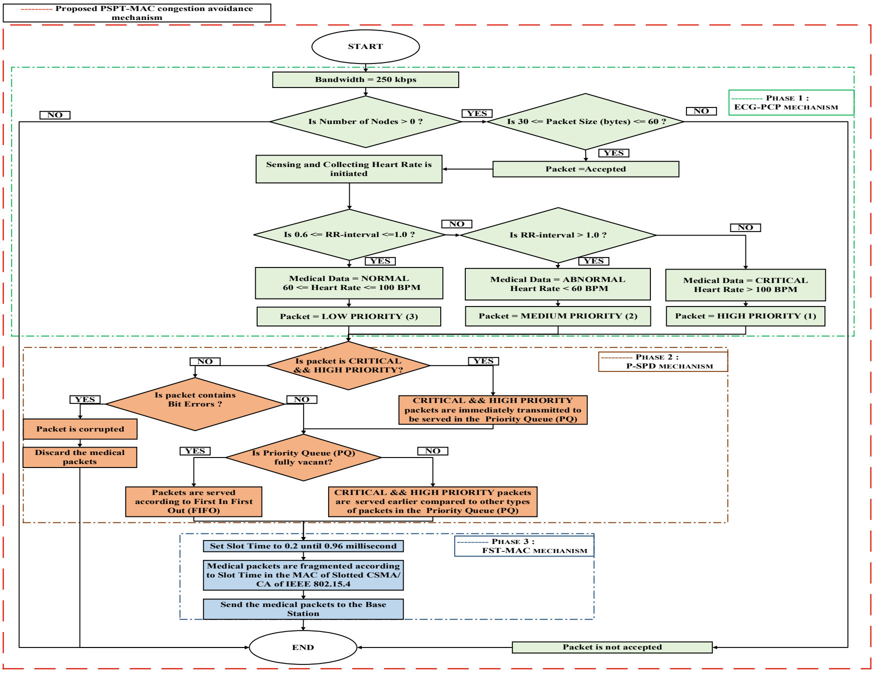

Fig. 2 Flowchart of PSPT-MAC mechanism

The details on FST-MAC mechanism are explained in our previous work in [20]. Finally, these three stages of mechanisms are integrated together to be designed as Priority Selective Packet Timeslot (PSPT-MAC) mechanism to avoid congestion in WBAN at the first place.

A flowchart of PSPT-MAC mechanism is illustrated in Fig. 2 as follows.

In addition, the proposed PSPT-MAC mechanism is carried out and analysed in OMNeT++ simulator tool with integration of INET framework which is known for its suitability to be adapted in Wireless Body Area Network (WBAN) [21]. Apart from that, most of previous studies have selected the short-range wireless technology namely IEEE 802.15.4/Zigbee for WBAN as it offers low data rate and power consumption [22, 23]. Specifically, the setting of parameters for this proposed mechanism is chosen based on [24]. In concise, the proposed mechanism is tested under different number of nodes from 10 to 60 within $50 \times 50\ m^2$ area of coverage for WBAN and compared with standard IEEE 802.15.4 protocol and FCA-MAC mechanism in [24]. The packet size is set to 30 bytes as it offers low end to end delay for WBAN [7, 25]. The network performances are measured in terms of delay, throughput, packet delivery ratio (PDR) and packet loss as tabulated in Table 2.

Table 2 Network performances in WBAN

Network performance	Definition
Delay	The duration of time required by a packet to travel through the network to its last destination and measured in time unit (second)
Throughput	The amount of data that a network system is able to transfer in a time unit and measured in bits per seconds (bps)
Packet delivery ratio (PDR)	The ability of the network to successfully delivered information as the ratio between total number of successfully received packets and total number of packets sent
Packet loss	The amount of packet loss in the delivery of the packets in the network

4 Results and Discussions

This section provides a detailed discussion and analysis from the measured performances of the proposed mechanism against standard IEEE 802.15.4 protocol and FCA-MAC mechanism.

4.1 Delay

From Fig. 3, the delay for all schemes are increasingly proportional to the number of nodes. However, PSPT-MAC mechanism has lower delay by outperforming FCA-MAC and typical IEEE 802.15.4 when number of nodes are 40 with 0.235 s compared to 0.62 s in FCA-MAC and 0.661 s in IEEE 802.15.4. In addition, it can be seen that delay for PSPT-MAC mechanism are still in range of allowable delay for WBAN for nodes between 10 and 60 compared to other two mechanisms. To be exact, the allowable delay's threshold for transmitting one ECG packet is 500 ms [26].

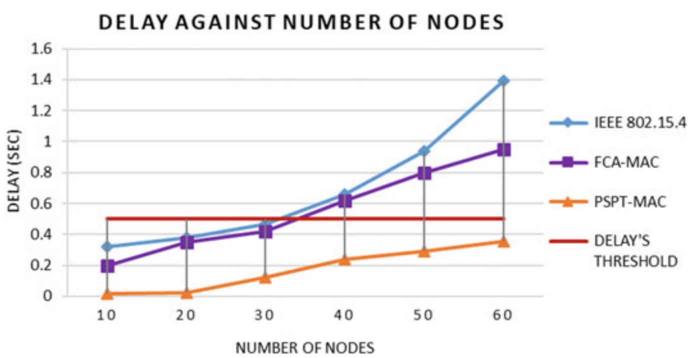

Fig. 3 Performance of delay between PSPT-MAC, FCA-MAC and IEEE 802.15.4 mechanisms

Typically, increment number of nodes directly lead to generation of high number of packets. However, PSPT-MAC mechanism has earlier discarded the corrupted packets compared to other schemes which lead to less number of traffics. After discarding process, the remaining packets would be fragmented into smaller size before furthered transmitted to the base station. Typically, no fragmentation is carried out in typical MAC IEEE 802.15.4 protocol. Thus, PSPT-MAC mechanism offered packet fragmentation which is done by using shorter slot time of 0.2 ms in MAC IEEE 802.15.4 protocol. This has resulted in many fragmented packets to easily access the superframe slots as these smaller packets do not need to wait for longer time compared to typical slot time of 0.96 ms in FCA-MAC and IEEE 802.15.4 protocol. These smaller packets lead to lower delay compared to other schemes. In contrast, FCA-MAC mechanism and IEEE 802.15.4 standard, the packets are sent without being earlier discarded and fragmented. These packets might contain corrupted packets that might be dropped and retransmitted in the network and result in longer delay of the WBAN. This could be worst if the congestion happened in the network. From the results, PSPT-MAC has shown noticeable trend in providing lower delay to alleviate the congestion in WBAN.

4.2 *Throughput*

Figure 4 shows the collected throughput of PSPT-MAC mechanism and IEEE 802.15.4 standard in the WBAN. High value of throughput is noticed under PSPT-MAC scheme compared to other mechanisms under increasing number of nodes. Although the throughput displayed an increment for 30 nodes which is 167.92 kbps for PSPT-MAC and 100.30 kbps for IEEE 802.15.4 standard, but the value of throughput is declined which is when the nodes are 40 for both schemes. The measured throughput for 40 nodes PSPT-MAC mechanism and IEEE 802.15.4 protocol is 155.41 kbps and 98.32 kbps respectively. In addition, lowest throughput is

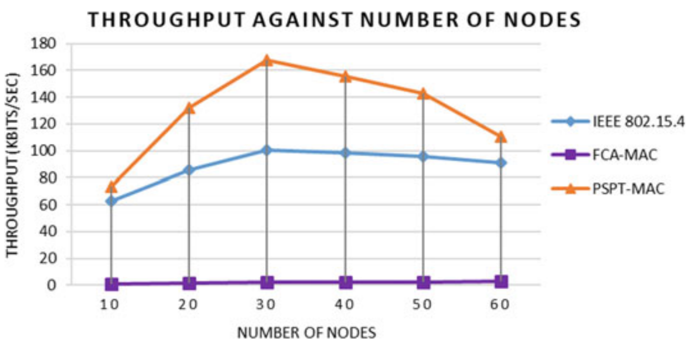

Fig. 4 Performance of throughput between PSPT-MAC, FCA-MAC and IEEE 802.15.4 mechanisms

yielded by FCA-MAC scheme for nodes between 10 and 60. This phenomenon might indicate that congestion has occurred in the network. Consequently, this has resulted to reduction in the successful number of packets received at the base station of the network. However, high throughput is still dominated by PSPT-MAC mechanism as this mechanism has discarded the corrupted packets earlier before being further transmitted and fragmented in the network. Meanwhile, IEEE 802.15.4 protocol and FCA-MAC scheme might transmit high number of packets as these mechanisms do not undergone discarding and fragmentation processes. Nevertheless, the transmitted packets in the IEEE 802.15.4 protocol and FCA-MAC scheme might be dropped or undergone retransmission if there is existence of corrupted packets. This might cause to less number of received packets in the network. Hence, earlier discarding of corrupted packets and fragmentations helps to promote high network performances in the WBAN.

4.3 Packet Delivery Ratio (PDR)

Based on Fig. 5, the resulted PDR for PSPT-MAC mechanism for 10 to 20 nodes is up to 95.48% compared to 57.24% of PDR under IEEE 802.15.4 standard. However, the PDR for both methods are declined linearly over time under increment number of nodes. The obvious changes are clearly shown when number of nodes are ranging between 40 and 60 nodes. The PDR for PSPT-MAC mechanism are half-yielded which is only 50.44% and IEEE 802.15.4 standard produced PDR of 25.05% with 40 nodes. This performance is worst for 60 nodes as PSPT-MAC provided only 27.01% of PDR and 16.38% of PDR for IEEE 802.15.4 standard. These values are clearly reflected that lower ratio of number of packets received to the number of packets sent in the network Typically, increment number of nodes also would increase the number of packets in the network. Thus, more packets generated might lead to congestion in the network and degraded the network performance in the WBAN. However,

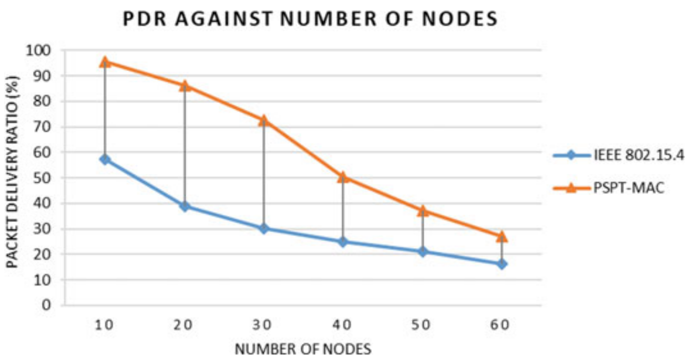

Fig. 5 Performance of PDR between PSPT-MAC and IEEE 802.15.4 mechanisms

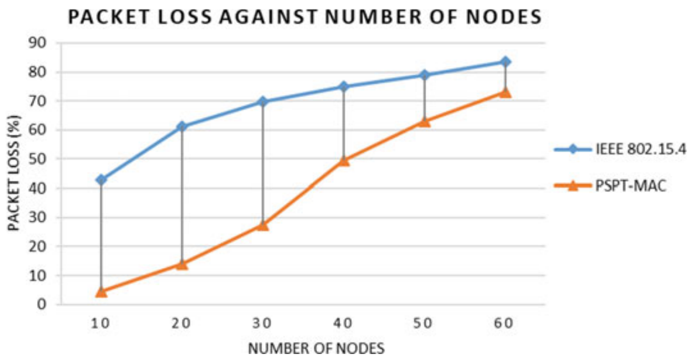

Fig. 6 Performance of packet loss between PSPT-MAC and IEEE 802.15.4 mechanisms

PSPT-MAC mechanism is still outperformed and reflected positive performances compared to IEEE 802.15.4 protocol. This has revealed the effectiveness of PSPST-MAC mechanism in alleviating the congestion of the network.

4.4 Packet Loss

Figure 6 displays the measured packet loss of PSPT-MAC mechanism and IEEE 802.15.4 standard against number of nodes. An incline trend of packet loss for both schemes can be seen as the number of nodes increased. However, PSPT-MAC mechanism still outperformed IEEE 802.15.4 standard through 30 nodes with 27.44% of packet loss compared to IEEE 802.15.4 standard with 69.62%. This resulted from less total number of packets transmitted under PSPT-MAC mechanism due to earlier discarded of corrupted packets compared to IEEE 802.15.4 standard. Later, the packets of PSPT-MAC would undergo fragmentation by using shorter slot time of 0.2 ms in the MAC IEEE 802.15.4 superframe. Hence, these packets could be served earlier in the network compared to IEEE 802.15.4 which has longer slot time of 0.96 ms before being served in the network. Thus, the possibility of congestion is lowered in PSPT-MAC mechanism than IEEE 802.15.4 standard. However, both schemes reflect high packet loss for 60 nodes which might indicate presence of congestion in the network.

5 Conclusion

Based on the findings, it is clearly shown that PSPT-MAC mechanism has yielded better performances in terms of delay, throughput, PDR and packet loss compared to standard IEEE 802.15.4 protocol and FCA-MAC mechanism. However, some improvements need to be fulfilled for future works in order to offer high reliability in the network of WBAN such as elimination of redundant data during transmitting a bulk of medical data in the network of WBAN should be considered to avoid waste of the scarce network resources.

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Conflict of Interest The authors declare that there is no conflict of interest.

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