

Performance Evaluation of Saturated Medical Body Area Network using Priority Reassignment.

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Abstract—IEEE 802.15.6 standard defines the Physical and Medium Access Control layers for Medical Body Area Networks (MBAN), where many sensor nodes can communicate with a central hub using a wireless medium. The standard specifies the user priorities and contention window range for the sensor nodes to enable them to achieve the best throughput and high reliability. However, there are eight distinct priority levels (UP0-UP7) which may be assigned to a maximum of sixty-four nodes, resulting in multiple nodes being assigned the same user priority. In such cases local priority needs to be assigned to the nodes within the UP and data throughput must be optimized. In this work, we have used Criteria Importance Through the Intercriteria Correlation (CRITIC) where nodes are put in a priority queue by assigning them local user priority within one of the eight priority levels UP0 to UP7, as defined in IEEE 802.15.6. The method optimizes the backoff count value to minimize the delay for data packets from these nodes in the queue. We have done simulations where results show that the backoff values and the local priorities calculated using CRITIC based upon sensor parameters – packet size, packet generation rate, and data transmission rate improve the throughput of sensors in UP0-UP6.

Keywords—CRITIC, Packet Size, Throughput, Transmission delay.

I. INTRODUCTION

Medical Body Area Networks (MBANs) have emerged as a transformative technology for remote health monitoring, offering a myriad of benefits for patients and healthcare providers alike. By utilizing wireless sensors, MBANs enable patients to move freely while continuously transmitting crucial medical parameters for real-time monitoring. In our proposed system, we utilize 64 sensors, which are categorized into 8 distinct user priorities (UPs), to collaboratively collect and transmit critical health-related information. This system is characterized by a wide spectrum of data transmission rates, ranging from as low as 1 kbps to as high as 600 kbps. Furthermore, the sensors employed in this system encompass a diverse range, from basic physical activity sensors to more complex ECG and EEG sensors. This diversity in sensor types and data transmission rates presents unique challenges in ensuring the reliability and throughput of wireless communication within this context. To address these issues, we present a novel approach that involves queueing the sensing nodes within the eight defined user priorities (UP0-UP7), strategically avoiding collisions, and significantly increasing throughput. This paper delves into the various applications of

MBAN technology for remote health monitoring and highlights how our innovative solution can enhance the efficiency and effectiveness of this groundbreaking healthcare technology.

II. STATE OF ART

In [1], authors investigated the impact of the IEEE standard-defined user priorities UP scheme created for the various types of data for the MAC layer utilizing slotted ALOHA channel access. The work compares the packet delivery ratio for sensors assigned priority and corresponding backoff values as per IEEE 802.15.6 method and a random backoff scheme. The IEEE standard type backoff scheme performs better in terms of packet delivery ratio as compared to random backoff schemes, especially when both medical and nonmedical (background) data are transmitted.

The MAC layer of the IEEE 802.15.6 was analyzed in saturation and non-saturation situations by the authors of [2] and [3]. It was found that nodes with higher user priority have higher throughputs as they must wait for short backoff times for packets to be transmitted. The models used in these papers show that the IEEE 802.15.6 standard ensures that higher-priority nodes can transmit data with higher reliability and minimum delay. The drawback of this standard is that lower-priority nodes must wait for a long time before they can get the time slot for transmission.

The standard defines various access phases for sensors namely the Emergency Access Phase (EAP), Random access phase (RAP), and Contention Access phase (CAP) and it is found that short-length access phases EAP and MAP may result in inefficient use of bandwidth, as the slots at end of phase may not be sufficient for the complete frame to transmit. It was also found that four user priorities instead of eight were sufficient for MBAN to work efficiently even under stringent conditions [4,5]. Modified IEEE 802.15.6 superframe structure with redundant phases eliminated and RTS/CTS access mechanism has been compared with the standard MAC, and it is found that this modified framework provides better channel utilization for same number of nodes as compared to the standard CSMA/CA due to use of RTS/CTS [6].

The state-of-the-art study shows that though IEEE 802.15.6 provides the guidelines for MBAN and recommends the use of eight different priority levels for nodes, there exist limitations to the network performance in terms of throughput and transmission efficiency. Achieving efficient channel access and

maximizing throughput is of paramount importance for successful remote health monitoring. Various research methods are being developed to minimize the collisions between sensor nodes of different user priorities, though the IEEE 802.15.6 standard recommends a smart approach by assigning higher-priority nodes a small size of contention window (CW) compared to lower-priority nodes. This prioritization ensures that higher-priority nodes have a higher probability of transmitting data through the channel, reducing the likelihood of contention and collisions between different priority levels. However, there may be more than one node that is assigned the same UP, and contention for the channel may arise when these multiple nodes attempt to access the channel simultaneously, such nodes are called homogeneous nodes. This contention can lead to delays in transmitting critical medical parameters, adversely affecting overall throughput. In this work, we propose an innovative queuing mechanism for homogeneous nodes to efficiently manage channel access and minimize contention, ultimately enhancing the reliability and throughput of the MBAN system.

Therefore, a method for addressing the homogeneous collision problem is defined in this study. The primary aspects and contributions of this work are as follows:

1. Using a multiparameter decision-making algorithm called Criteria Importance Through Intercriteria Correlation (CRITIC) to provide a mechanism to prevent a homogenous collision.
2. Implement a simulation model for saturated channel using local priorities and backoff counter values calculated by CRITIC and measure throughput and transmission efficiency.

III. THE IEEE 802.15.6 MAC

The IEEE 802.15.6 standard supports three access mechanisms for communication between the central hub and various nodes: the most common being the beacon mode with a superframe. The beacon mode with superframe allows time-slotted communication to enable efficient coordination and synchronization of devices within MBAN. The beacons provide the timing and synchronization information to nodes and time slots are assigned by the hub for nodes using information shared by the node during the beacon period.

The nodes may access the hub using various access phases which may be the Exclusive access phase (EAP), Random access phase (RAP), Contention access phase (CAP), or Management access phase (MAP) used in the slotted aloha and CSMA/CA mechanism as shown in Fig. 1 [7]. Nodes are distinguished by the user priority (UP) according to the data and have values for the contention window which determines the backoff count value, as specified in IEEE 802.15.6. The transmission process may be based on the CSMA/CA mechanism where a node must set its backoff counter to a random integer value from the range of [1, CW]. If the backoff counter reaches 0, the node is permitted to transmit one frame of user priority (UP) over the even number of failures, the value of the CW is doubled, whereas it remains constant irrespective of successful transmission for an odd number of failures.

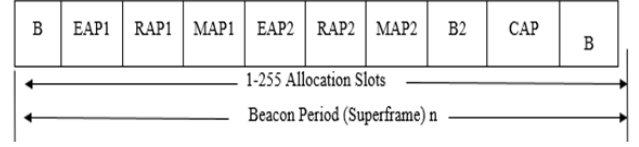


Fig. 1. Superframe Structure as defined in IEEE 802.15.6 standard, showing the different access phases for nodes and the beacons for communication between hub and nodes.

IV. METHODOLOGY

The goal of this work is to improve the throughput for homogeneous nodes (multiple sensor nodes having the same user priority). CRITIC reassigns the priorities by correlating parameters including user priority, packet size, packet generation rate, packet transmission rate, and buffer size. The process flow for the CRITIC method is shown in Fig. 2. For computing the local user priority, the hub gathers the node parameters, and these parameters are stored in a Table whose columns are indexed with variable 'q'. The method computes the correlation between any two parameters of a node ($X_{q,c}$) and uses this to calculate the degree of conflict (D) which in turn is used to compute the quality of information Q_q . The equations used for these calculations are shown below:

$$D = \sum_{c=1}^N (1 - X_{q,c}) \quad (1)$$

$$Q_q = \sigma_q * \sum_{c=1}^N (1 - X_{q,c}) \quad (2)$$

$$W_q = \frac{Q_q}{\sum_{q=1}^N Q_q} \quad (3)$$

σ_q is the standard deviation for the parameter under study and N is the maximum number of parameters for a node (N=5, packet size, user priority, data transmission rate, packet generation rate, and buffer size). These computed weights are used to compute the local user priority for the nodes using equation 4.

$$P_p = \sum_{q=1}^N a_{p,q} \times W_q \quad (4)$$

where coefficients $a_{p,q}$ are the normalized parameters values for sensor p.

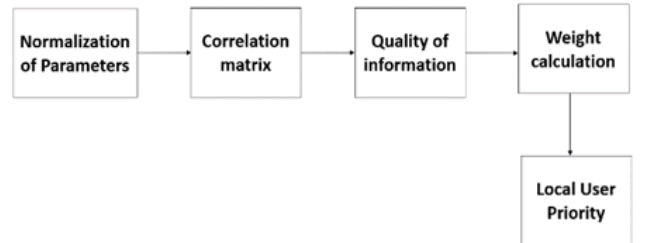


Fig. 2. Steps for the CRITIC method, where local priority of node is computed using user priority, packet size, packet generation rate, data transmission rate, and buffer size as node parameters.

Sensor nodes have different packet sizes, packet generation rates, data transmission rates, and other characteristics as shown in Table I which have been obtained from state of art study of references [8-27]. Node's packet generation rate determines how frequently these packets are generated, while packet size refers to the amount of data that is delivered in each packet. The data transmission rate also determines the speed at which the sensor node can provide data to the primary monitoring system. These parameters are important specifications that affect sensor node priority.

V. SIMULATION

The nodes are placed in a queue for the simulator, where all nodes belonging to the same UP are ordered as per the local priority calculated by CRITIC as shown in Fig. 3. In addition to the value of the backoff counter (BC), backoff stage (BS), retransmission index (R), packet size (PS) and number of packets (PN) for each node are loaded into the simulator. In addition to the node parameters, various channel parameters like the access phases, slot time duration, superframe, and beacon duration are defined for the simulator as shown in Table I. The Table also shows the various timers that are updated during the simulation and used for the calculation of throughput and transmission efficiency.

In the study, simulation is run as per the p persistent CSMA/CA mechanism so if a channel is found busy node waits till the next timeslot and further checks the busy status of the channel.

We use the total time and the number of collisions that happened throughout the iteration to compute the throughput and efficiency as shown in equations 5-6 for computing the outcomes in the simulation. For the study, we performed a total of 50 iterations for each node, with each iteration considering 8 nodes to produce the homogeneous scenario.

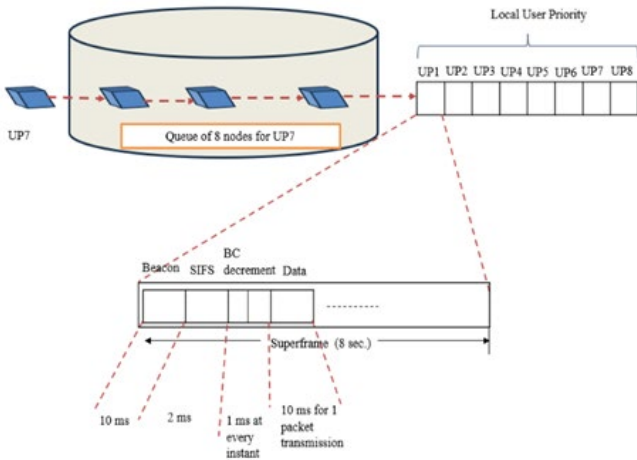


Fig. 3. Timing Diagram for transmission in the super frame.

The simulation process flow is shown in Fig. 4. The back-off counter is decremented in section 'A' with every time clock until it reaches zero. At each time clock, the slot length is reduced by one, and the remaining slot length is calculated. If the new slot length is greater than the required time, the packet is transmitted, otherwise, the backoff counter

freezes, and the backoff stage is updated as shown in section 'C'. When the channel is busy, the node waits for sleep time before checking the status of the channel once again and repeating the steps in section 'A'. Once the node's backoff counter value reaches zero, the node transmits the packet and waits for acknowledgment from the hub. The status of packet transmission is considered unsuccessful if an acknowledgment is not received within a specific time frame.

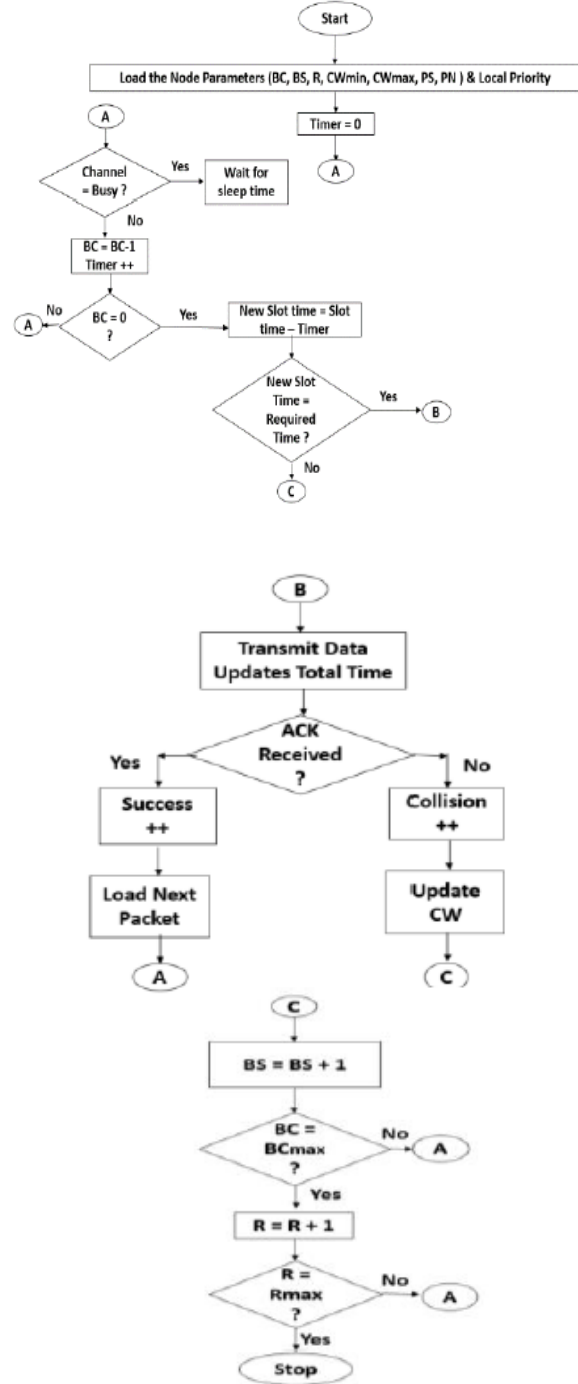


Fig. 4. Flow Chart for Simulation Process, showing the process for CSMA/CA channel access by a node.

When an acknowledgment is not received, the backoff stage is updated as shown in section ‘C’ of the flowchart and the steps of section ‘A’ are repeated. If the maximum backoff stage is reached but the packet is not transmitted successfully, the retransmission counter is updated, and the steps of section ‘A’ are repeated where attempts are made for transmission of the packet. If these attempts exceed the retransmission limit $R_{\max}$, the simulation loops are stopped and computation for throughput and efficiency are done, as explained in the next section.

VI. THROUGHPUT AND EFFICIENCY

We use the total time and the number of collisions which are updated during simulation, to compute the throughput and efficiency as shown in equations 5-6. For the study, we performed a total of 50 iterations for each node in each user priority.

$$\text{Throughput} = \frac{\text{Number of packets} \times \text{Packet Size}}{\text{Propagation Time}} \quad (5)$$

$$\text{Efficiency} = \frac{\text{Utilized Time}}{(2 * n * \text{Propagation Time}) + \text{Propagation Time} + \text{Utilized Time}} \quad (6)$$

where n is the number of packets undergone collision. The throughput has been calculated for all eight nodes for UP0-UP7, where each of these nodes transmits 100 packets as per local priority assigned to it by CRITIC.

TABLE I. SIMULATION PARAMETERS

Parameters and Variables	Values
MAC Protocol	CSMA/CA
Packet Size Range	(1-750) bytes
Packet Generation Rate	(0.13-100) packets/sec.
Data Transmission Rate	(0.8-600) kbps
Buffer Size	(1-6) Kbytes
Access Phase	EAP1, RAP1
Slot Length	15ms (10 ms of transmission time + 1ms of backoff counter update)
Superframe Duration	8 sec.
Beacon duration	10 ms
Short inter space-time (SIFS)	2 ms
No. of Packets (PN)	100
Sleep Time	1ms
Required_time (Average time to transmit one packet)	10 ms
Collision	Number of packets undergone collision
Success	Number of packets successfully transmitted
time_clock	Clock intervals at which backoff counter updates
Overhead_time	Sleep time + Timer (time taken to decrement BC)
Propagation Time	Simulation time
Util_time	Utilized time

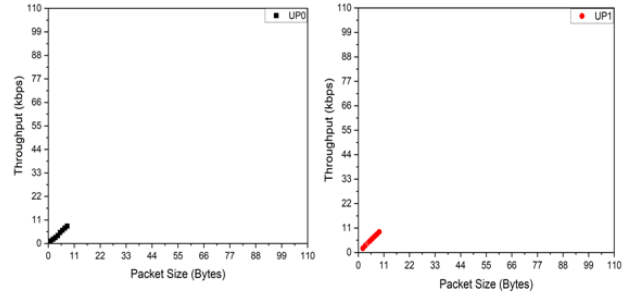


Fig. 5. (a). Graphs for UP 0 and 1 for Throughput at various packet sizes.

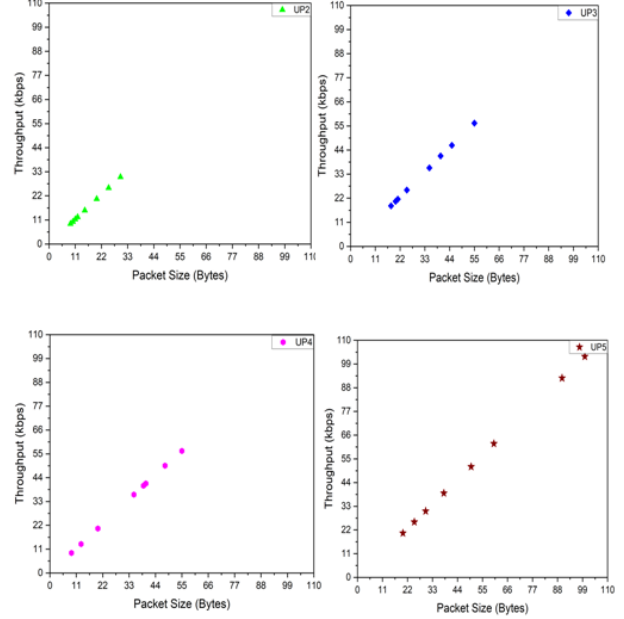


Fig. 5 (b). Graphs for UP 2 to 5 for Throughput at various packet sizes.

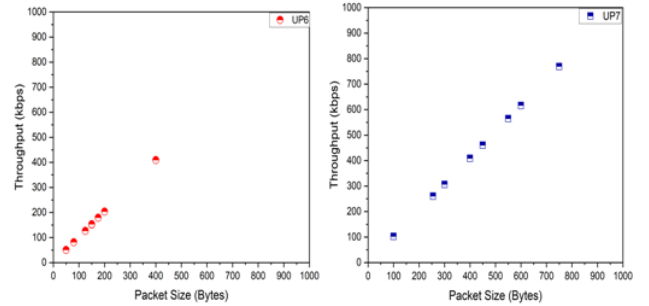


Fig. 6. Graphs for UP 6 and 7 for Throughput at various packet sizes.

Fig.5(a),5(b), and 6 illustrate how throughput is impacted by packet size. It is seen that nodes with bigger packets may transmit data with lesser delay in a single transmission while requiring less bandwidth for headers and inter-frame gaps, thereby the throughput is high for these nodes. It is seen that for nodes in UP7, the throughput is significantly higher than that of the other user priorities as transmission overheads are low when the packet size is large. Also, when the packet size is

large the channel remains occupied for a longer duration, and therefore lower priorities do not attempt to transmit, consequently, the collision instances are minimized. The results show low throughput for UP0 and UP1 where packet sizes are small as well as the overhead time (sleep time+ time to decrement backoff counter) is high, whereas for nodes in UP2 to UP6 the throughput is moderate. The efficiency of packet transmission has been computed with equation 6 and the results of Table II show that the best efficiency is 50%, and this happens when there is no collision as observed using the variable ‘collision’ in the simulation.

TABLE II. EFFICIENCY FOR UP0 TO UP7 WITH VARIOUS NODES (NUMBERED 1 TO 8)

UP/No. of nodes	1	2	3	4	5	6	7	8
UP0	0.0007	0.0033	0.0114	0.0111	0.5	0.5	0.5	0.5
UP1	0.0117	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
UP7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

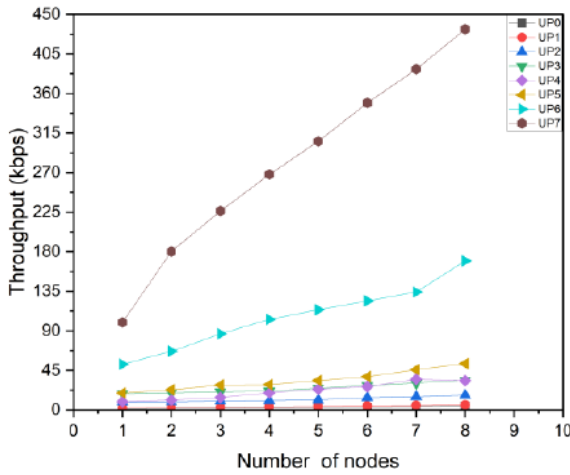


Fig. 7. Average Throughput per UP where the number of nodes is varied between 1 to 8.

Fig. 7 shows the throughput variation when the number of nodes is varied between 1 to 8 for different UPs. It is noted that the average throughput of UP7 and UP6 increases when the number of nodes is increased. This is an improvement over the standard IEEE 802.15.6 superframe, as in this work, CRITIC computes backoff counter values which are smaller than the standard values. As well as CRITIC assigns local priorities to

nodes with specific UP, so the effect of collisions is reduced, and throughput is increased. For UP0-UP6, it is observed that the throughput is maintained even when the channel saturates due to transmission by a greater number of nodes.

VII. CONCLUSION

Through this study, we have demonstrated that we can use CRITIC to reliably transmit data with variable packet size, data rates, and node count so as to have high throughput and efficiency for an MBAN. We conducted simulations using optimized values of the backoff counter and local priorities for nodes in a UP. Our results compared with the state-of-the-art studies show that while the IEEE 802.15.6 standard ensures higher throughput and transmission efficiencies for UP7, our simulations using CRITIC have shown improved throughputs for lower priority of UP2-UP6, in addition to UP7 during saturated traffic conditions. In the present work, the simulator assigns time slots to nodes at the start of the superframe based on node parameters shared by the node with the hub statically. As a future scope of work, we plan to work out an algorithm for dynamic slot allocation in the superframe, where we can make more intelligent decisions for slot allocation.

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