An Enhancement to Channel Access Mechanism for the IEEE 802.15.3C MillimeterWave (5G) Standard to Support Stringent QoS Requirements of IoT

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Abstract. The ubiquitous nature of the Internet of Things (IoT) constitutes a set of stringent quality of service (QoS) requirements from the underlying 5G network. To address the issues, this paper proposes an enhancement for the channel access period (CAP) of the widely used IEEE 802.15.3C (millimeter wave (mmW)) standard using a priority mechanism that fulfills the requirement of prioritized channel access for the IoT based applications. According to the hybrid medium access control (MAC) protocol of the IEEE 802.15.3C, to reserve time-division multiple access (TDMA) based slot in channel time allocation period (CTAP), a node will first send a channel time allocation (CTA) request to piconet controller (PNC) by using carrier-sense multiple access with collision avoidance (CSMA/CA) mechanism in the contention-access period (CAP). After successful delivery of CTA's request, PNC will reserve a CTA for a specific node. However, there is no guarantee that a node will get a channel in the contention process in the existing standard. Hence, the existing CAP mechanism could demonstrate a bottleneck for a data sending device in terms of less delay and high throughput. To solve this issue, we first design a numerical model of CAP using the IEEE 802.15.3C standard's specification, and then we propose a priority-based mechanism with three priority classes: high priority (HP), medium priority (MP), and low priority (LP) with each class having different contention windows (CW) range that makes the value of backoff period shorter. To evaluate the performance of the proposed mechanism, modifications are applied to the proposed numerical model. The performance comparison is conducted among prioritized classes devices in terms of transmission delay, channel access delay, and throughput. The conducted evaluations include two types of data rates i.e., 1.5 Gbps and 3 Gbps. The proposed scheme shows promising results for a node that requires high priority in an IoT environment.

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1 Introduction

IoT is considered as a system of interrelated computing devices [1]. IoT uses standard communication protocols and various access technologies depending on the application. Machine to Machine (M2M) communication is one of the promising areas for future IoT. It is estimated that more than 30 billion IoT devices in 2025 [2]. Such a high volume of devices will generate massive data and require time bounded and reliable data delivery services so that it could be useful for the application layer at the destination. The standards IEEE 802.15.4 [10], IEEE 802.15.6 (WBAN) [11], ZigBee [12], 6lowPAN [13] and 6tisch are widely used as IoT networks.

Concurrently, 5G has evolved and promises to provide higher throughput and less delay for a huge number of inter-connected devices [3]. Mostly, 5G is associated with cellular networks; however, it is important to understand that 5G is expected to employ stand-alone in personal and local area networks as well as cellular networks. The FP7 Project METIS for 5G, discussed the machine-type communications (MTC) with its issues and challenges to incorporate 5G with IoT [4]. Both academia and industry are enthusiastically working on the integration of 5G with IoT-based networks so that IoT could take advantage of this gigabit networks [5].

In recent years, millimeter wave (mmW) appeared as one of the potential candidates for 5G by providing data rates up to gigabits/sec. It uses the spectrum between 30 and 300 GHz and corresponds to wavelengths between 10 mm to 1 mm. The characteristics of mmW include high bandwidth, short-wavelength/high frequency, and high attenuation [18]. Huge path loss is expected in mmW communications, to overcome these high power levels are required. Due to high attenuation from solid material (bricks and buildings), mmW requires line of sight (LoS) for efficient and reliable communication. The interference levels in mmW communication are much lower than the 2.4 GHz and 5 GHz. Multiple-antennas solutions in mmW allow the transmission to use narrow beams which help to reduce the attenuation and the interference [19]. There have been several standardization activities for mmW MAC in the 60 GHz band. Most of these standardization efforts are for personal and local area networks under IEEE 802.15.3c and IEEE 802.11ad. IEEE 802.15.3c standard also known as piconet specifies the mmW by supporting a high data rate over 2 Gbps in the 60 GHz band. Among a cluster of IEEE 802.15.3c based devices, one will be selected as the piconet coordinator (PNC) and it manages the synchronization among devices by broadcasting beacon messages. The devices content for the time slots using carrier sense multiple access/collision avoidance (CSMA/CA) and send data using time division multiple access (TDMA) [16]. The IEEE 802.11ad introduced several modifications at MAC and physical layer of existing IEEE 802.11 standard to enable mmW support. It claims to provide a 6.75 Gbps data rate.

The coordinator uses a superframe structure to manage the channel access of the connected stations which is composed of beacons, contention access period (CAP) and contention-free period (CFP) [17].

There are several pre-standardization activities for mmW in cellular networks such as in the FP-7 EU project (METIS); however, more efforts are still.

1.1 Required Level of Integration

Before jumping to the integration's discussion between 5G and IoT, it is important to revisit the IoT applications with a communication requirements perspective. Figure 1 describes some of the popular IoT applications with their delay and data rate requirements. Further, it also identifies that either 5G or legacy networks can fulfill these requirements. It can be seen that most of these applications which are in the white area have bandwidth requirements up to 100 Mbps maximum. Further, delay values for these applications are between 10 ms and 1000 ms. These applications (white area) are performing well under various existing standards and technologies for low power wireless sensor and body area networks i.e., IEEE 802.15.4 (WSN) [10], IEEE 802.15.6 (WBAN) [11], ZigBee [12], 6lowPAN [13] and 6tisch [14].

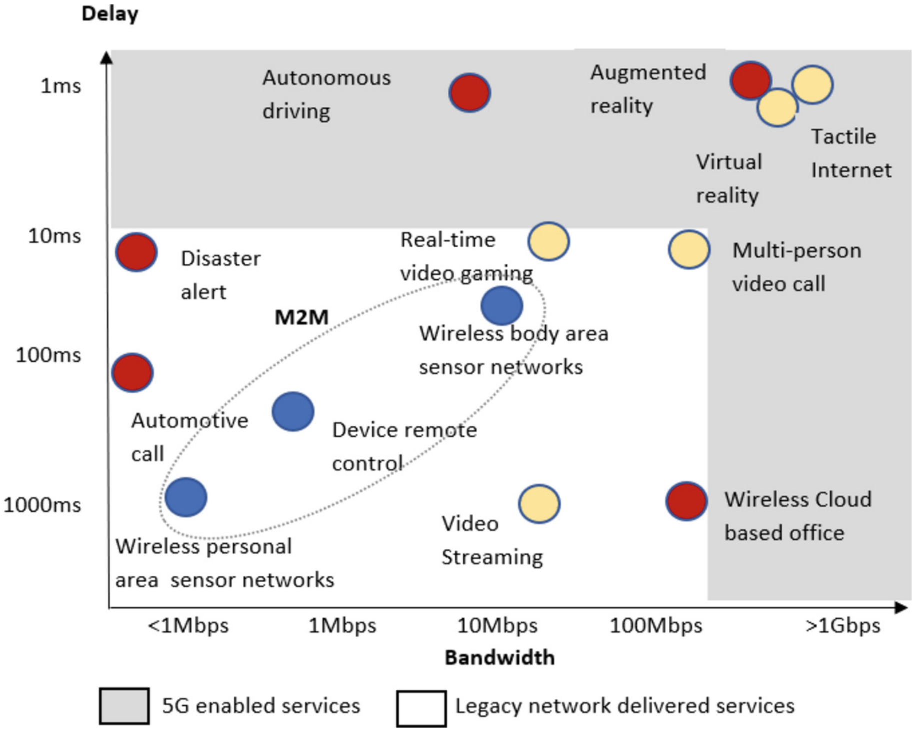

Fig. 1. Popular IoT applications with QoS requirements

The grey area in Fig. 1 represents the IoT application for which we need 5G technologies. These applications demand high bandwidth (greater than 1 Gbps) and a lower delay i.e., between 1 ms and 10 ms. mmW [15] is considered as one of the promising key enabler band for 5G, and IEEE 802.15.3c [16] and IEEE 802.11ad [17] provide support for mmW. The sensors sense the environment and send data frequently to the controller to an IEEE 802.15.4 or IEEE 802.15.6 based network. The controller requires high data rate links to transmit the huge data received with a very short delay. For this, we need to link these networks to the IEEE 802.15.3C-mmW based devices to take advantage of advanced technologies like mmW. A dual-frequency enabled device (2.4 GHz and 60 GHz) can create this link. However, it is also important for mmW based devices to provide the required quality of service (QoS) for the application data received from these devices after integration. In this regard, the main objective of this paper is to propose an enhancement for the hybrid MAC scheme of the IEEE 802.15.3C standard in terms of a channel access priority mechanism at CAP. Similar enhancement with different parameters was also proposed in IEEE 802.11; however, IEEE 802.11 deals with high spectrum with long range and takes WiFi into consideration. Our proposed enhancement is particularly for IoT devices under IEEE 802.15.3C with short range.

To reserve the slot in CTAP, a node must contend for the channel to transmit CTA requests to the piconet. A node that wins the contention process would be able to reserve the time slot in CTAP, the other nodes need to wait for the next contention period. This could add to the delays and for some of the applications like biomedical etc., these delays are not affordable. To overcome this, our proposed priority-based scheme introduced three priority classes including HP, MP, and LP which have different CW ranges. We also present an analytical/numerical model for the CAP process of the IEEE 802.15.3C standard under the proposed scheme. With the help of extensive performance evaluation results, we establish that the proposed scheme provides the priority to a specific node which ultimately reduces the transmission delay and increases throughput. The rest of the paper is organized as follows: Sect. 2 discusses the challenges, requirements, and architecture of IEEE 802.15.3C standard, Sect. 3 presents the analytical model of CAP under the proposed priority scheme, Sect. 4 provides the performance evaluation with results, and the paper is concluded in Sect. 5.

2 Challenges, Requirements and Architecture of IEEE 802.15.3C-mmW

The unique characteristics of mmW pose various challenges including blockage, deafness, synchronization, concurrent transmissions, multiple access, and user association and mobility relay. Optimal association of mmW devices with wireless access points is a challenging task. The recent mmW standards are using receive signal strength indicator (RSSI) as a link quality to select an access point as coordinator; however, higher RSSI values do not always mean a good link [20]. Therefore, it is critical for mmW devices to select a reliable access point as a coordinator to accommodate delay-sensitive and bandwidth-hungry applications.

IEEE 802.15 is a working group for the specification of WPAN communications. The IEEE 802.15.3x working group specifies the physical (PHY) and medium access control (MAC) layer for high data rate WPAN. The IEEE 802.15.3C standard amends the PHY and MAC layer for the existing IEEE 802.15.3 to support the operation of the 60 GHz mmW band. This standard proposed a piconet wireless network that permits a number of independent devices (DEVs) to communicate using a piconet controller (PNC).

2.1 Architecture and Channel Access Mechanism in CAP

IEEE 802.15.3c standard specifies that multiple DEVs can autonomously connect in form of a piconet. The standard defines four radio channels as stated in Table 1. A PNC is selected among DEVs and PNC has the responsibility of registering the DEVs, broadcasting timing allocations, coordinating, scheduling, and synchronizing devices with the channel by transmitting beacons. The standard proposes a hybrid MAC protocol having contention-based and scheduled channel access schemes. The timing in IEEE 802.15.3C WPAN is based on a superframe structure that consists of three parts: beacons, contention access period (CAP), and channel time allocation period (CTAP). Figure 2 shows the superframe structure of the omnidirectional mode of IEEE 802.15.3C.

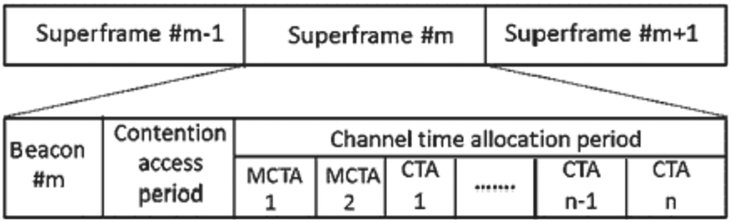

Fig. 2. IEEE superframe structure of omni-directional mode [16]

Beacon. The PNC broadcast beacons at the start of each superframe. The beacons consist of timing allocations for DEVs and the management information for a piconet.

Contention Access Period. During the CAP period, DEVs contend for channel access using CSMA/CA. CAP uses binary exponential backoff (BEB) algorithm to manage the channel access. The DEV first waits for a backoff interframe spacing (BIFS) duration, as described in the standard. After the BIFS wait, DEV calculates backoff_count (BC) = bw_random(retry_count) and maintains this counter for BC that is decreased when the medium is idle for the duration of pBackoffSlot. *BC* is calculated based on random function taking range zero to backoff window (BW) (A BW table is provided by the standard that has predefined values). The retry_count (RC) shall be set to zero for the first transmission attempt of a frame. If the channel is sensed as busy, the BC should be suspended. The channel shall remain idle for the duration of a BIFS period before it is resumed. When the BC reaches zero, the DEV may transmit a data frame.

If a collision occurs while sending data, the DEV needs to retransmit the data/request frame by initiating a new backoff stage with a doubled CW size. DEV is capable of dropping a frame from its queue after a few retransmission attempts (suggested by the standard). If the CAP period is not sufficient then DEV has to defer the frame and may try in the next CAP. CAP is designed for small asynchronous data transmission.

An Imm-ACK is expected when sending a CTA request to PNC, before that the DEV shall check whether there is enough time remaining in the time slot to accommodate the current frame that is 2 SIFS periods, and the Imm-ACK frame at the same PHY rate as the transmitted frame. If there is not enough time remaining for this entire frame exchange sequence, then the DEV shall abort the transmission and not use the remainder of the CTA. Figure 3 shows the flow chart of the CAP mechanism used in 802.15.3C.

Channel Time Allocation Period (CTAP). In CTAP, scheduled-based frame transmissions occur. CTAP is further divided into CTA and management channel time allocation (MCTA). DEVs send their CTA requests during CAP to their PNC. The information about allocated CTAs for the current superframe is sent to the DEVs using beacons. MCTA is used to send the command where CTA is utilized for data transmission.

2.2 Aggregation and Block Acknowledgement

The aggregation process is introduced to handle the QoS requirements of high-speed and delay-sensitive applications. In the aggregation process, multiple data frames are combined to transmit in a single superframe. When the data is received in the form of MAC service data unit (MSDUs) from the upper layer, the MAC headers are applied, and then it is called MAC protocol data unit (MPDU) and is ready for the physical layer. The combination of multiple MPDUs creates aggregated MPDU (A-MPDU). A-MPDU is generated before passing to the PHY layer for final transmission. The MAC does not wait for a certain number of MPDUs to create A-MPDU, so if a node gets channel access, the MAC takes available MPDUs to make A-MPDU for transmission. The destination of all MPDUs must be the same. Further, for reliable data transmission of five different types of acknowledgments (ACKs) are defined in Piconet: block ACK (Blk-ACK), immediate ACK (Imm-ACK), delayed ACK (Dly-ACK), implied ACK (Imp-ACK), and no ACK (no-ACK). Mostly Blk-ACK is used to acknowledge the sender for an A-MSDU frame.

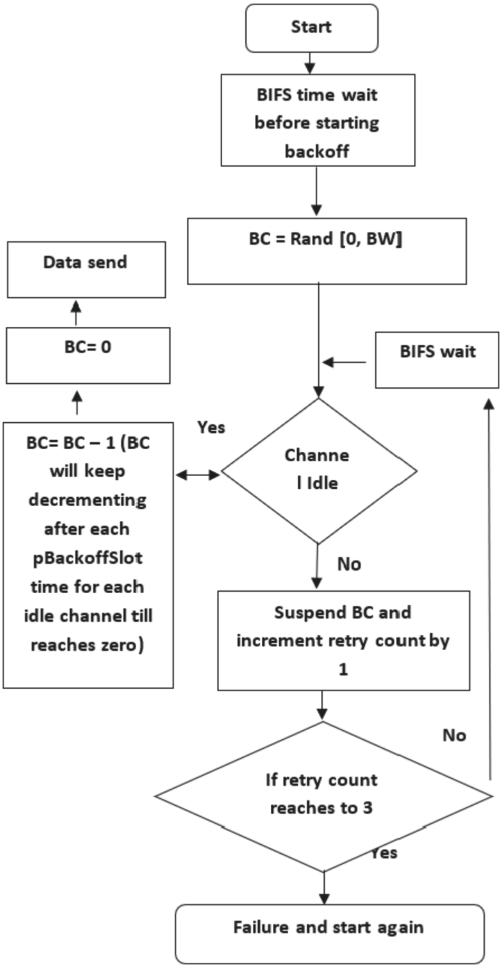

Fig. 3. Flow chart for the CAP process [16]

2.3 Communication Procedure of Piconet

The communication procedure in IEEE 802.15.3C can be sub-divided into five. When a DEV is turned on it starts scanning for the channel and if it finds the beacon of an existing Piconet network, it joins the Piconet as a slave device. In case, the DEV receives a beacon and doesn't find the desired Piconet then it starts operating like a PNC and waits for DEVs to join by periodically broadcasting beacon frames. In the second step, if the DEV receives a beacon from desired PNC then it sends an association request to PNC. When the PNC receives an association request, it sends back the response. The PNC may request for encryption key from the sender. After this, access is given to the requesting node. A DEV needs to make a request for a time slot if it wants to send data in CTA. Once the DEV sends the data, it waits to receive the ACK in the allocated period. Finally, if the communication finishes, then PNC sends a beacon announcing the end of the piconet and turns its power off.

3 Proposed System

In this section, we provide the analytical modelling to evaluate the CAP and our proposed mechanism.

3.1 Analytical Modelling of the CAP

We present an analytical model to evaluate the end-to-end delay (ED) and throughput (TP) for the CAP mechanism of the IEEE 802.15.3C. The purpose is to understand how much time it takes for a CTA request in the worst-case scenario. The ED can be calculated as given in Eq. (1):

$$ED = T_{frame} + T_{ACK} + T_{CH} \tag{1}$$

where T_{frame} represents frame transmission time for a CTA request frame. Further, T_{frame} can be computed as given in Eq. (2):

$$T_{frame} = T_{Preamble(PHY)} + T_{Header(MAC+PHY)} + T_{Payload} \tag{2}$$

where T_{Preamble} is the duration of PLCP preamble, T_{Header} is the duration of PLCP header and T_{Payload} is the duration of the payload. These duration are given in the IEEE 802.15.3C standard.

T_{ACK} represents the time duration of the ACK, in this case, ACK duration computed as given in Eq. (3):

$$T_{ACK} = T_{ImmACK} + 2SIFS \tag{3}$$

Figure 4 describes the Imm-ACK procedure given by the standard.

Fig. 4. Immediate ACK [16]

Where T_{ImmACK} is time duration of the immediate ACK and can be computed as given in Eq. (4):

$$T_{ImmACK} = T_{Preamble} + T_{Header} \tag{4}$$

The ACK of the ImmACK has only MAC header and not a payload as each packet is expected to be acknowledged immediately.

T_{CH} represents the time to access the channel, it is computed as given in Eq. (5):

$$T_{CH} = (RC * BIFS) + (BC * pBackoffSlot) \tag{5}$$

where RC is the retry counter in the backoff process and its value will be 3 in the worst case, BIFS is the backoff IFS and it is calculated by Eq. (6):

$$BIFS = pSifsTime + pCcaDetectTime \tag{6}$$

The values of pSifsTime and pCcaDetectTime are given in the Table 1 mentioned by the in the IEEE 802.15.3C standard.

BC is the backoff counter calculated as given in Eq. (7):

$$BC = Rand(0, BW) \tag{7}$$

BC is computed using a random function that finds a random integer value between zero and BW (backoff window). The value of BW is given in Table 1.

Table 1. Timing and space parameters mentioned by IEEE 802.15.3C standard [16]

PHY parameter	Duration HSI (μs)
pSIFSTime	2.5
pCcaDetectTime	2.5
pBackoffSlot	5
T_Preamble	1.31
T_Header	0.44
Backoff Windows	[7, 15, 31, 63]
Retry Count	0 to 3
CAP duration (μs)	0 to 65,535
Superframe duration (μs)	0 to 65,535
MAC header (bytes)	10
PHY header (bytes)	48
Acknowledgement (bytes)	10
Beacon packet (bytes)	100
Data frame (bytes)	512 to 8,388,608
Channel data rate (Gbps)	1.5, 3, 5

3.2 Proposed Priority Mechanism

We consider an independent piconet having a PNC and N number of DEVs. According to IEEE 802.15.3C specifications, for the transmission of data frame during the CTAP, a DEV have to send a CTA request in CAP. For that, it will first use CSMA/CA mechanism specified in the standard. After successful delivery of the CTA request, the PNC will reserve a CTA for a specific node. Therefore, the CAP mechanism could become a bottleneck for a DEV that needs to send data with less delay and high throughput.

We propose to use a priority mechanism for IEEE 802.15.3C DEVs. This mechanism uses CAP to provide a priority to a certain DEV by sending its CTA request to PNC at a low, high, or medium priority.

We apply this scheme to the HSI and AV PHY mode of IEEE 802.15.3C with NLOS. It is suited for applications that require bidirectional, high speed, and low latency NLOS communications. The purpose of NLOS with HSI/AV is to organize an ad hoc network that can provide connectivity to computers and other nearby devices.

We define three levels of priorities: low, medium, and high as given in Table 2. In the proposed scheme, the priority is assigned to low, high, and medium DEVs using multiple sizes of the contention windows (CW) ranges under a user priority level. A node with a minimum CW value gets the higher priority and vice versa. Similarly, when a node tries to access the channel and finds it busy then the BC computed based on the prioritized level of CW will be freeze and the priority for the next retry will remain the same. The ranges of CW levels are selected in a way that each level has a different range to obtain a specific priority.

3.3 Analysis of Proposed Priority Mechanism

A DEV that uses high priority will select the CW range of high priority. The value of CW will be used when calculating the BC value which actually produces an integer as waiting for factor for channel access. Higher the BC, lower will be the priority and vice versa. BC can be computed using Eq. (8):

$$BC = Rand(0, CW) \tag{8}$$

In case of highest priority, the equation will be:

$$BC = Rand(1, 8)$$

For lower priority

$$BC = Rand(25, 50)$$

Figure 5 describes the updated flowchart under the proposed scheme.

The probability that a node can successfully get the channel access by considering n number of maximum backoff periods is given by Eq. (9) [21–23]:

Table 2. Timing and Space parameters mentioned by IEEE 802.15.3C standard [16]

DEV priority	CW range
Low (1)	25–50
Medium (2)	12–20
High (3)	1–8

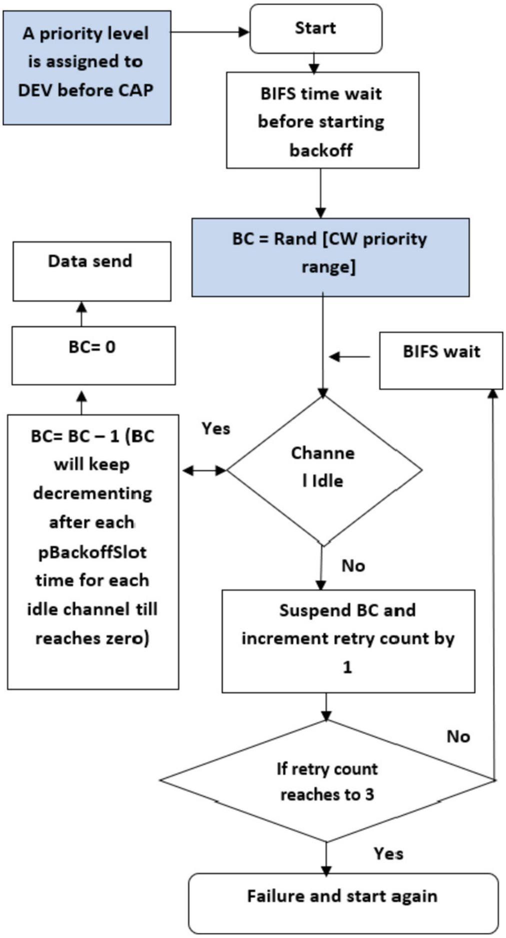

Fig. 5. Flowchart of CAP under proposed priority scheme

$$P_s = \sum_{i=1}^{n} p_a(1 - p_a)^{(i-1)} \tag{9}$$

where P_a represents the success probability that a node accesses the channel at the end of backoff period. For k number of DEVs in the network, P_a is given by Eq. (10)

$$P_a = (1-q)^{(k-1)} \tag{10}$$

The ED value for each priority can be computed as:

$$ED_{AL} = T_{frame} + T_{ACK} + T_{CHL}$$

$$ED_{AM} = T_{frame} + T_{ACK} + T_{CHM}$$

$$ED_{AH} = T_{frame} + T_{ACK} + T_{CHH}$$

where T_CHL represents the channel access time for low priority, T_CHM denotes the medium priority and T_CHH represents high priority.

Average delay of a network where devices have low, medium and high priorities is given by Eq. (11):

$$EDA = 1/ED_{T_{CHH}} + 1/ED_{T_{CHL}} + 1/EDT_{CHM} \tag{11}$$

The presented numerical needs to be validated, which is conducted by comparing the maximum throughput (MT) values of the analytical/numerical model (values through statistical equations described above) with MT theoretical values mentioned by the IEEE 802.15.3C. The MT is defined as a ratio of transmitted information in bits to the transmission duration. Throughput is defined as the ratio of payload size (x) to total time required to transmit payload, in the case when there is no priority set the maximum network throughput (MT) can be computed as given in Eq. (12):

$$MT = X/ED \tag{12}$$

The MT for prioritized network can be computed as given by Eq. (13):

$$MT = X/EDA \tag{13}$$

4 Experiments and Discussion

The performance of the proposed priority scheme is evaluated based on analytical and numerical models. We explored various simulators including network simulator version 2 (NS2), NS3, OMNet++, and MATLAB but could not find any implementation regarding the channel access mechanism (i.e., CSMA/CA in our case) defined by the IEEE 802.15.3C standard for mmW. The performance of the proposed priority scheme is evaluated in terms of delay, throughput, and bandwidth efficiency (BE). We assume that a PNC initially managing a network for 4 nodes, out of 4, 3 nodes require a specific priority class i.e., HP, MP, LP.

The remaining one node will operate on no priority (NP) mode. We are assuming that each node is trying to transmit a CTA request packet to the PNC so that it could reserve a TDMA slot in CTAP. The performance is evaluated for two different data rates: 1.5 Gbps and 3 Gbps.

Figure 6 shows a comparative analysis of the channel access delay among 4 nodes having different priorities. Further, the scenario also considers the number of retries to access the channel. There is a total of three retries. It can be seen from Fig. 6 that a node having HP shows the minimum delay i.e., 25 µs if it gets access in the first retry. The reason for such a low value of the delay is less BC values which are obtained from the average CW range for HP which is [1–8]. The maximum value of delay for HP goes to 35 µs which is in the third retry. Similarly, the node using MP shows the delay starting from 70 µs (1st retry) and goes to 85 µs in the third retry. The node with NP shows the highest delay values in all retries i.e., 170 µs, 175 µs, and 180 µs. The reason for the high delay is the high value of BC obtained from the average CW range [15–67]. Due to the high value of BC, a node needs to wait longer.

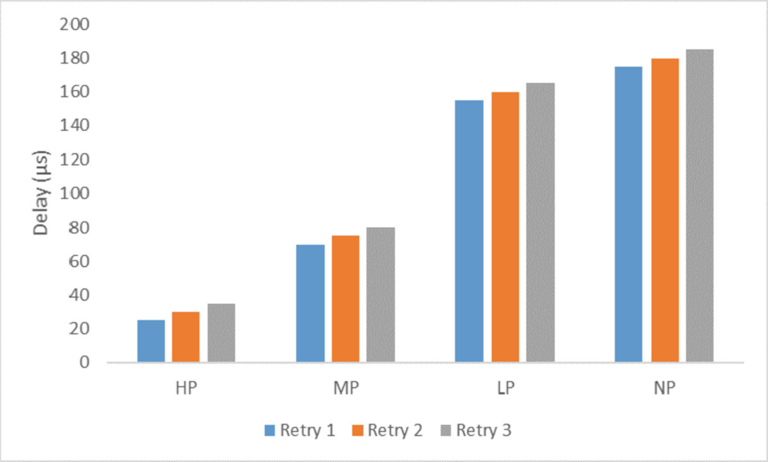

Fig. 6. Delay involve in channel access for priority classes

Figures 7, 8 and 9 show the comparative analysis of the total delay with different values of packet sizes. The minimum value of the packet is considered as 32 bytes and it goes up to 138 bytes. We selected the maximum value of packet size 138 bytes because the maximum size of CTAP packet is 138 bytes and we are assuming that nodes are trying to send a CTA request to reserve a TDMA based slot in CTAP. The CTA request packet can vary from 32 to 138 bytes. The considered data rate is 1.5 Gbps for these scenarios.

Figure 7 shows the delay comparison in the first retry case. It can be seen that the node with HP performs better than the other nodes. The transmission delay keeps increasing with the packet size. The minimum delay value for HP is

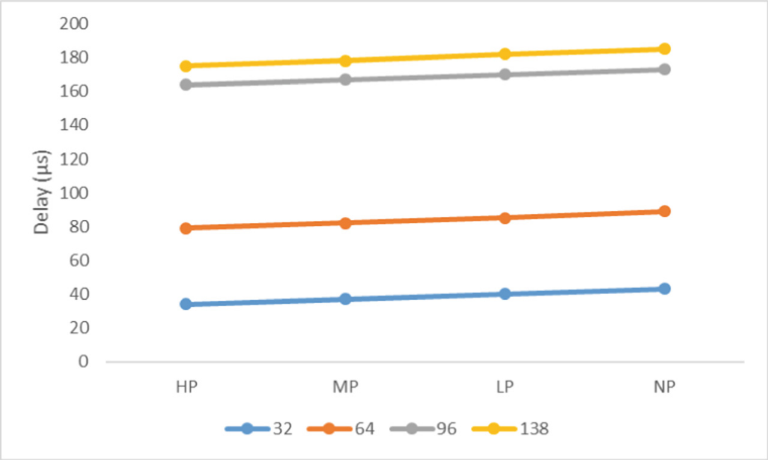

Fig. 7. Total transmission delay comparison among prioritized and non prioritized classes in 1st retry

35 µs for the 32 bytes packet and the maximum delay for HP is 55 µs for the 138-byte packet. It can be seen that the delay values of LP and NP are close to each other, the reason is that both nodes attained higher CW values in the backoff process and they need to spend more waiting time. It is also noticed that the channel access delay's value is the main contributor to the total delay. The data and ACK transmission delay have very short values.

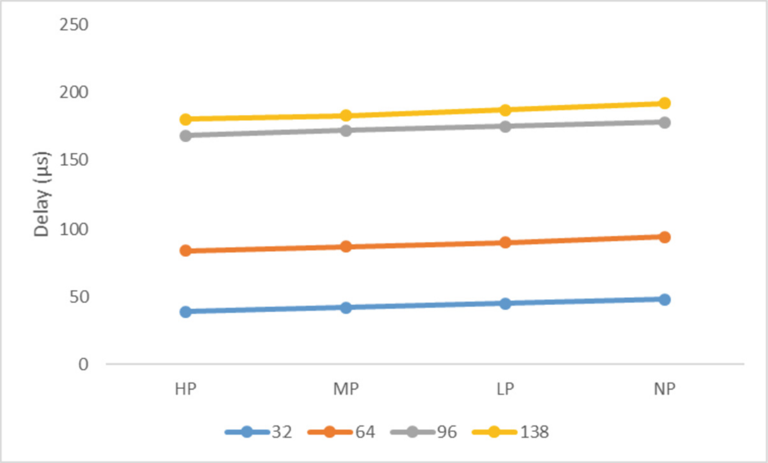

Fig. 8. Total transmission delay comparison among prioritized and non prioritized classes in the second retry

Figures 8 and 9 show the delay comparison for the 2nd and 3rd backoff retry case. It can be seen that the node with HP performs better than the other nodes in the 2nd and 3rd retry. The 3rd retry in Fig. 9 shows the worst case for HP, MP, LP, and NP in terms of delay. The HP shows a delay of 60 µs for 138 bytes of CTA request; whereas this delay is 110 µs, 170 µs, and 210 µs for MP, LP, and NP respectively. The reason for higher delay values in this scenario is that channel remains busy in two retries and a node gets a chance to transmit in the third retry.

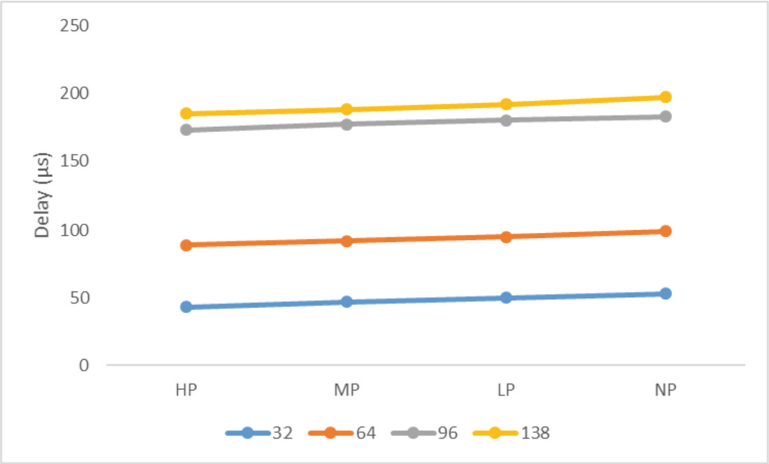

Fig. 9. Total transmission delay comparison among prioritized and non prioritized classes in third retry

Figures 10, 11 and 12 show the comparative analysis of throughput with different values of packet sizes in with various retries. The minimum value of the packet is considered as 32 bytes and it goes up to 138 bytes. We selected the maximum value of packet size 138 bytes because the maximum size of CTAP packet is 138 bytes and we are assuming that nodes are trying to send a CTA request to reserve a TDMA based slot in CTAP. The CTA request packet can vary from 32 to 138 bytes. The considered data rate is 1.5 Gbps for these scenarios.

Figure 10 shows the TP comparison in the first retry case. It can be seen that the node with HP performs better than the other nodes. The TP keeps increasing with the packet size. The minimum TP value for HP is 8 Mbps for the 32 bytes packet and the maximum TP for HP is 25 Mbps for the 138-byte packet. It can be seen that the TP values of LP and NP are close to each other, the reason is that both nodes attained higher CW values in the backoff process and they need to spend more waiting time. The NP gives a maximum of 6 Mbps for the 138-byte CTA request packet. The MP's TP values are also promising. It is also noticed that TP grows as a function of packet size. Figures 11 and 12 show the TP comparison for the 2nd and 3rd backoff retry case. It can be seen

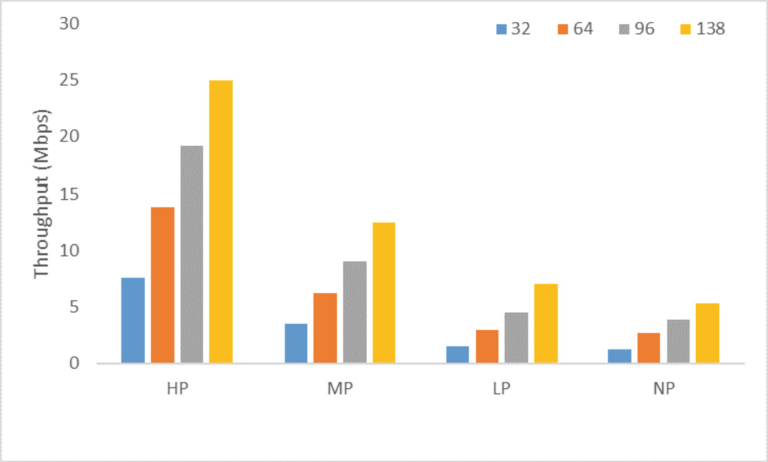

Fig. 10. Throughput comparison among prioritized and non prioritized classes in first retry

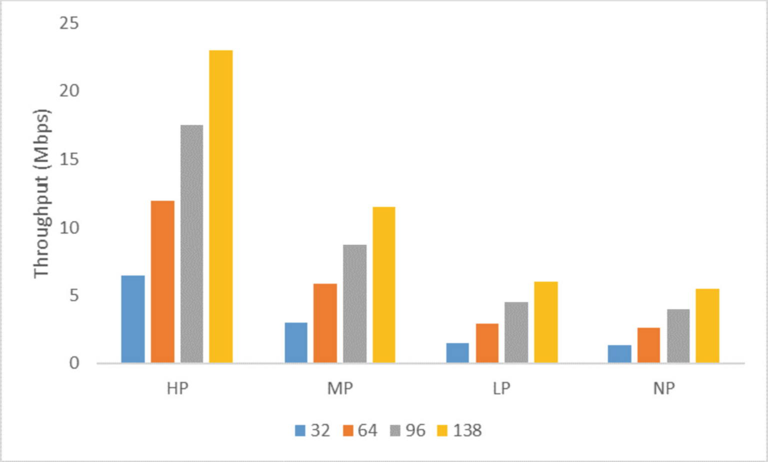

Fig. 11. Throughput comparison among prioritized and non prioritized classes in second retry

that the node with HP performs better than the other nodes in 2nd and 3rd retry.

The 3rd retry in Fig. 12 shows the TP comparison in the 3rd retry. The HP shows a minimum TP of 6.5 Mbps for 32 bytes of CTA request and for 138 bytes packet TP is 22.5 Mbps. The reason for the reduction of HP's throughput is the increased channel waiting time due to the third retry. Similarly, NP shows a degraded TP value for all the packet sizes from 32 bytes to 138 bytes.

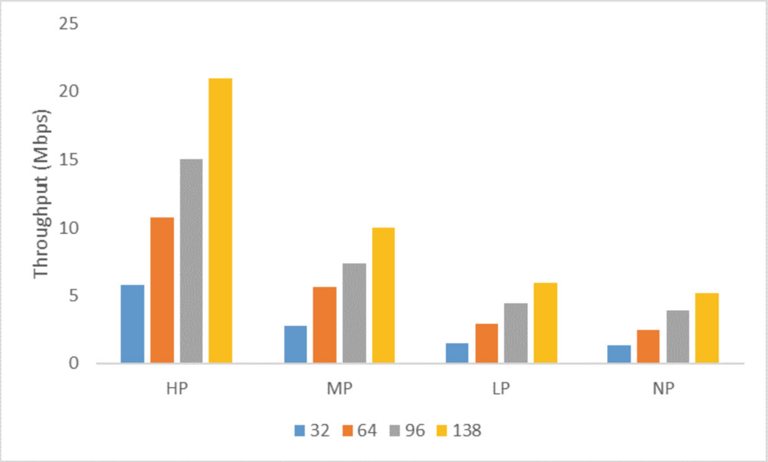

Fig. 12. Throughput comparison among prioritized and non prioritized classes in third retry

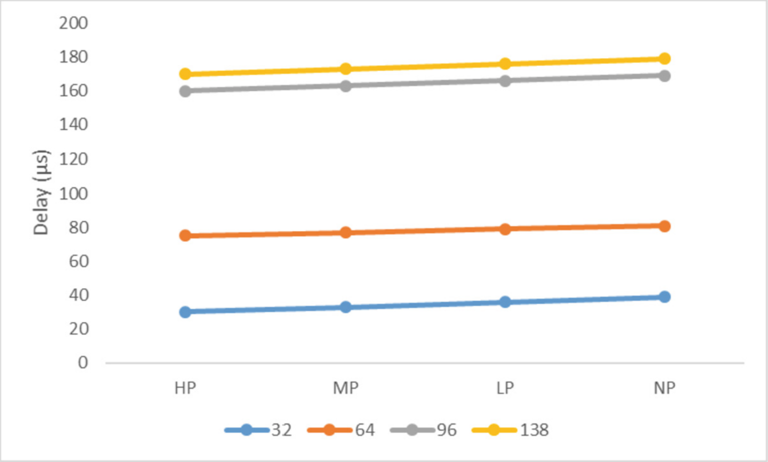

Fig. 13. delay comparison among prioritized and non prioritized classes in first retry for the 3 Gbps

Figures 13 shows the delay comparison in the first retry case where the data rate is considered as 3 Gbps. It can be seen that the node with HP performs better than the other nodes. The delay keeps increasing with the packet size. The minimum delay value for HP is 20 µs for the 32 bytes packet and the maximum delay for HP is 40 µs for the 138-byte packet. If we compare Figs. 13 and 7, it can be clearly seen that results of Fig. 13 are better due to higher data rate i.e., 3 Gbps; with 1.5 Gbps of data rate. Higher data rates help to reduce the transmission delay.

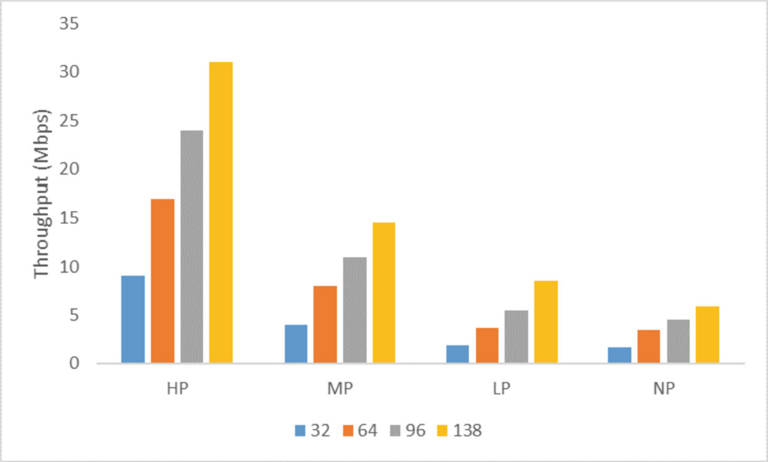

Fig. 14. Throughput comparison among prioritized and on prioritized classes in first retry for 3 Gbps

Figure 14 shows the TP comparison in the first retry case for 3 Gbps. It can be seen that the node with HP performs better than the other nodes and provides higher TP values i.e., 32 Mbps for the packet of 138 bytes. The TP keeps increasing with the packet size. The MP, LP, and NP show the TP of 15 Mbps, 10 Mbps, and 5 Mbps respectively for the packet size of 138 bytes. The reason for the lesser TP value than the HP is the channel access delay which is different for MP, LP, and NP. The delay reduces the transmission time. If we compare Fig. 14 and 10, it can be clearly seen that Fig. 14 shows better results than Fig. 10. The reason is the higher data rate value which is 3 Gbps in Fig. 14 as compared to Fig. 10 where the data rate is 1.5 Gbps. A higher data rate will transmit the payload quickly, hence results in lesser delay and high TP.

5 Conclusion

In this paper, a prioritized channel access mechanism is proposed as an enhancement to the IEEE 802.15.3C's CAP mechanism. The aim is to provide priority to a CTA request so that it could reserve a TDMA-based time slot in CTAP, otherwise, the contention process could cause more delay to the nodes which have delay-sensitive data. The priority mechanism provides three different priority classes: HP, MP, and LP. Each class has a different range of values for the CW. In this paper, initially, numerical modeling is proposed for the IEEE 802.15.3C CAP, and then the performance of the proposed priority mechanism is evaluated using our proposed model. The evaluation is performed by assessing channel access delay, transmission delay, and throughput. The comparative analysis is provided between prioritized and non-prioritized traffic by considering two levels of data rates: 1.5 Gbps and 3 Gbps. The results show that the channel access process with HP outperforms the others and it is also noticed that the delay increased as a function of packet size. The main contributor to the delay value is channel access delay. Shorter channel access delay leads towards higher priority. CW values play a key role in assigning the priority process. On the other hand, the HP provides the highest TP value compared to MP, LP, and NP, with different sizes of CTA requests, which is 138 bytes for a maximum-sized CTA request. The higher the packet size, the higher will be throughput and less delay. A comparison is also provided between delay and TP values of nodes having data rates of 1.5 Gbps and 3 Gbps. The higher data rate with HP provides the best results.

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