The Claim-Based Channel Access (CCA) Method for IEEE 802.11ah

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Abstract. This work proposed the Claim-based Channel Access (CCA) method for IEEE 802.11ah, which is designed for Internet of Things (IOT). The proposed CCA method uses the newly devised Claiming RAW to let those stations having uplinked data frames to claim their intentions for uplinking data frames to reduce collisions. In addition, this work adopted the registered backoff time mechanism, for which a station registers its next backoff time to AP when its current channel access is finished. In this way, AP is able to schedule stations according to their registered backoff time in advance to avoid collisions more effectively. Comparing with the traditional IEEE 802.11ah, the proposed CCA method has the lower collision rate and higher throughput in the network environment having the more number of stations in each time slot for accessing the channel.

Keywords: IEEE 802.11ah · Internet of Things · Throughput improvement · Collision reduction

1 Introduction

Due to the development and advancement of sensor and wireless network technologies, the emergence of the Internet of Things (IOT) [1] has brought a new way of life, which allows devices to communicate with each other whenever and wherever, using the Machine to Machine (M2M) communication method. The IEEE Task group (TGah) therefore define a new protocol called IEEE 802.11ah, which is also known as Wi-Fi HaLow [2], for IOT. WiFi HaLow combines the advantages of (1) low-power communication technologies and the original WiFi's features and (2) possessing the higher throughput than LPWAN and higher transmission range than WPAN.

Since an IEEE 802.11ah AP is allowed to connect with up to 8192 stations, IEEE 802.11ah devises (i) the hierarchical organization through association identifier (AID) and (ii) the Traffic Indication Map (TIM) and Restricted Access Window (RAW) mechanisms to cluster stations into some groups and each group's stations can access the channel on different time. The AP can accurately determine each station through the AID, IEEE 802.11ah adopts the concept of Restricted Access Window (RAW), for

Y.-B. Lin and D.-J. Deng (Eds.): SGIoT 2020, LNICST 354, pp. 516–526, 2021.
https://doi.org/10.1007/978-3-030-69514-9_39

which each TIM period is divided into several RAWs, to alleviate the conflict of a large number of stations competing for channel access at the same time. In this way, hopefully, it can reach the goal of avoiding collision, improve throughput, power saving, etc., and ensure smooth operation [3].

However, the legacy IEEE 802.11ah still cannot avoid collisions even with the aforementioned devised mechanisms because many stations in a time slot may still need to access the channel at the same time, which causes collisions and decreases throughput. The main problem is stations' spontaneous actions, i.e., uplinking data frames from stations to the IEEE 802.11ah AP. Thus, how to have a method that can schedule stations' uplinking data frames is the key problem to be resolved.

This paper proposed a method called Claim-based Channel Access (CCA) for avoiding collision and improving throughput for IEEE 802.11ah. Two key ideas of the proposed CCA method are as follows: (1) A station generates the new backoff time for its next channel access when it finishes its current uplinking or downloading data frame and then registers the new backoff time in AP, i.e., a station generates its backoff time before accessing the channel and lets AP know in advance [4]. (2) The 1st RAW in a TIM period becomes the Claiming RAW, for which those stations having uplinked data frames to be transmitted can make claims in the Claiming RAW to notify their desire of uplinking data frames to the AP. In this way, the AP can thus know (i) the backoff time of each station in advance and (ii) which stations have uplinked data frames to be transmitted and then schedule stations' channel accesses accordingly. As a result, the collision rate can be reduced and the throughput can be improved.

The remaining part of this paper is organized as follows. Section 2 presents related works. Section 3 introduces the functional scenario of the proposed CCA method. Section 4 presents the proposed CCA method in details. Section 5 shows the performance analysis. Finally, conclusion remarks are given in Sect. 6.

2 Related Work

This Section presents related works of improving the performance of 802.11ah.

In [5], the authors considered that the performance of grouping is closely related to the demand of device traffic, thus they proposed a grouping algorithm for traffic-aware sensors. Based on the observation of analysis, a traffic-aware grouping algorithm was proposed to partition the sensors considering (i) the sensors' heterogeneous traffic patterns and (ii) dynamic channel condition. Then, a regression-based model is derived to estimate the competitive success's probability of sensors with heterogeneous traffic requirements. Compared with the unified random grouping, the proposed grouping algorithm improves the average channel utilization for about 6%.

In [6] the authors analyzed a new strategy for grouping stations in the dense network. The authors applied the Max-Min fairness standard to achieve the goal of improving stations' performance and fairness. In addition, the authors applied the ant colony optimization method to avoid the problem of hidden nodes. The proposed method can increase the total throughput for about 40%, and reduce the number of hidden terminals by 11%.

In [7], the authors analyzed a station regrouping algorithm based on competing WLANs to minimize potential transmission collisions caused by the hidden node problem. Information about the traffic demand of (1) potential hidden node pairs and (2) stations in the network is obtained through the AP. Stations are then redistributed into different groups according to a centralized Viterbi-like algorithm or a decentralized iterative update method. The simulation results shown that the collision situation can be reduced significantly through the regrouping algorithm.

In [8], the authors proposed a method to reduce the maximum delay by preferentially assigning those stations that cannot access the channel to reserved slots. The authors set the first slot of each RAW group as the reserved slot, which gives the opportunity of being able to send data to those nodes that cannot access the channel due to collisions. Furthermore, an algorithm was proposed to dynamically change the reserved slot time according to the traffic.

3 The Functional Scenario

This Section introduces the functional scenario of (i) the traditional IEEE 802.11ah and (ii) the proposed CCA method.

Figure 1 depicts an illustrated transmission process used in the traditional 802.11ah. Let station (STA) 1 and STA7 be in the same slot, and they have the same backoff value 5. After the DIFS time, they start to count down their backoff value until to 0, and then begin to uplink data. At this time, since they uplink data simultaneously, the collision has happened. Since stations didn't receive ACK from AP, after a DIFS time, STA 3 and STA 7 generate a new backoff value 7 and 5, respectively, after a DIFS time period and then continue to contend for the channel.

In this work, stations are divided into two categories: (1) known station and (2) unknown station. A known station means that AP knows the station having data to receive/send in its corresponding time slot, i.e., (i) the stations that have downlinked data frames in the AP and (ii) the stations that have more data frames to be transmitted after successfully uplinking a data frame. An unknown station means that AP doesn't know whether the station having data to send in its corresponding time slot or not, i.e., the stations having data to be uplinked are classified as unknown stations.

In the proposed CCA method, when a station finishes (i) receiving a downlinked data frame or (ii) transmitting an uplinked data frame, it generates a backoff value, which is called registered backoff value, for the next data communication, which can be uplinking or downlinking data, and registers the value in the AP. If the station's currently processing data is the uplinked data, the new backoff value will be piggybacked on the station's uplinked data frame and then delivered to AP. If the station's currently processing data is the downlinked data, the new backoff value is piggybacked on the station's PS-Poll frame and then delivered to AP. If a known station has both uplinked data and downlinked data at the same time, it performs the uplinking data at first and then the downlinking data. When a station is associating with an AP, it generates a registered backoff value and it is piggybacked on the association request and then delivered to the AP. AP records the registered backoff value and schedules it when the station intends to uplink its data frame immediately after the association processing, i.e., it is marked as the known station.

A new RAW called "Claiming RAW" is allocated in the 1st RAW of each TIM period such that those stations that have data frames to be uplinked can make claims about their intensions of uplinking data frames in the Claiming RAW. When the AP receives a claim from a station, it marks the station as the known station, and then schedules the station' uplinking data during the data communication stage. In the communication stage, if there are some known stations in a time slot, AP schedules these known stations according to their registered backoff time and informs them to send/receive data immediately by directly modifying the corresponding station's backoff value to 0. In this way, stations don't have to wait for backoff values' countdown to send/receive uplinked/downlinked data frames. In other words, the registered backoff values of these known stations are the reference values for AP scheduling.

Figure 2 depicts an example of the station's transmission and AP's notification behaviors. Let three known stations 4, 7 and 10 be in the same slot and their registered backoff values be 8, 5, 3. According to the order of backoff values, the AP sequentially informs known station 10, station 7 and station 4 to access channel. The station that is informed by the AP changes its backoff value to 0 and then uplinks its data frame immediately.

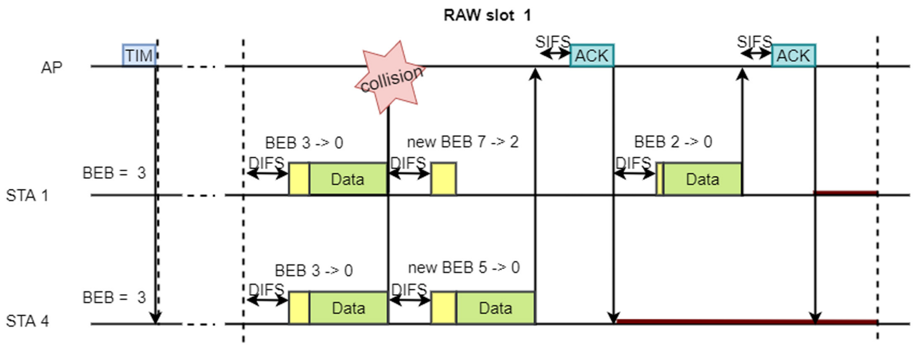


Fig. 1. An example of the collision situation.

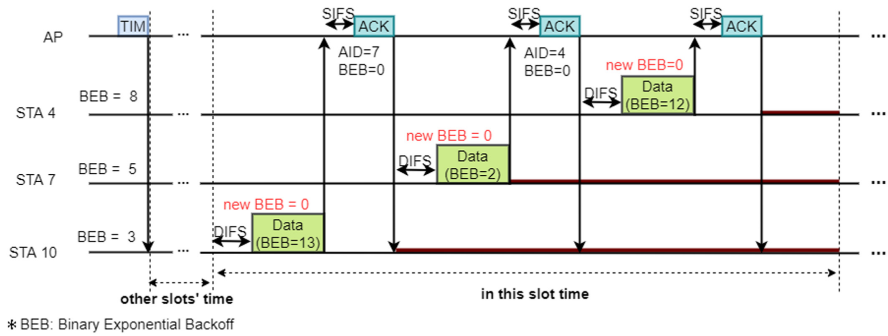


Fig. 2. An example of the station's transmission behavior.

4 The Proposed Claim-Base Channel Access (CCA) Method

The proposed CCA method is divided into three stages: (i) the association stage, (ii) the claiming stage and (iii) the communication stage.

4.1 The Association Stage

In the association stage, when a station is entering into the signal coverage of an AP, it needs to have some actions to associate with the AP. The station will randomly generate a backoff value from the contention window and put it in the association request message as the registered backoff value for its future channel access, and then sends the request to the AP. If the AP accepts the association of this station, it assigns an AID to this station and records its registered backoff value in the Binary Exponential Backoff (BEB) bit-vector for the scheduling of channel access.

4.2 The Claiming Stage

Please note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

In this work, a BEB bit vector is used to record the registered backoff value of each station. The BEB bit vector is stored in the AP: each time slot is associated with a BEB bit vector, which indicates a backoff value's state in the corresponding time slot, and bit x in the bit vector represents the registered backoff value x. In the BEB bit vector, each bit, e.g., the x^{th} bit, is associated with an AID list, for which each one y in the AID list denotes that the registered backoff value of the corresponding station y is x. When one or more known stations have registered backoff value x, bit x of the BEB bit vector is set to 1. When there is not any station registered backoff value x or only unknown stations registered backoff value x, bit x of the BEB bit vector is set to 0.

Figure 3 shows an illustrated example of the BEB bit vector, in which there are six stations whose AID is 1, 3, 5, 7, 9 and 11, respectively, assigned to the same time slot. The registered backoff values for these six stations are 7, 10, 13, 4, 10 and 13, respectively. Initially, these stations are unknown stations and the BEB bit vector is shown in Fig. 3-(a). When station 1 and station 9 become known stations, e.g., the AP finds that there are some downlinked data are for them, the BEB bit vector is modified accordingly, which is shown in Fig. 3-(b). After a while, station 3 and 5 have some downlinked data and they become known stations too. The BEB bit vector is modified accordingly in Fig. 3-(c).

At the end of the claiming stage, AP generates a bitmap called First Accessor Indication Map (FAIM), whose size depends on the number of AIDs. FAIM indicates which station is the first station that can access the channel in each time slot, i.e., marking these stations as 1 in the associated bits of FAIM and broadcasting FAIM using the ACK frame to all stations on the end of the Claiming RAW. Stations that belong to corresponding TIM period receive FAIM and check the corresponding bit associated with themselves; if the bit is equal to 1, the station changes its backoff value to 0. At the same time, those unknown stations whose registered backoff values are 0 and belong to the same time slot should change their backoff values to avoid collision with the first accessor.

An example of using FAIM is depicted in Fig. 4.

Let there be 12 stations in a RAW, which has 4 time slots, and be evenly assigned in these 4 time slots, which is depicted in Fig. 4-(a). The station marked with a star is the known station with the minimum backoff value in each time slot, i.e., stations 4, 5, 7 and 10. The AP marks these four stations as the first station that can access the channel in their assigned time slot, and sets their corresponding bits in FAIM to 1, which is depicted in Fig. 4-(b). However, it is observed that most of the bits of the FAIM are 0. Thus some compressing scheme is needed. The compression rule is as follows:

- Each 8 bits are grouped together and concentrated in one bit.
- The first 8 bits of the bitmap indicate a total of 8 groups.
- When the group's bit is 1, it means that one or more stations in the group are set to 1, and then the details of the group are added after the bitmap.
- Otherwise, it doesn't need to add any information.

Thus, the aforementioned FAIM example depicted in Fig. 4 can be compressed, which is depicted in Fig. 4-(c).

Figure 5 depicts the situation at the end of the Claiming RAW. The AP sends the bitmap of FAIM on the end of the Claiming RAW using the ACK frame. Those stations belonging to this TIM can receive it. After receiving the bitmap of FAIM, those stations belonging to the first station for accessing the channel, i.e., those stations whose associated bits are marked as 1 in FAIM, can change their backoff values. The illustrated FAIM depicted in Fig. 5 denotes that stations 1, 4 and 12 can change their backoff value to 0.

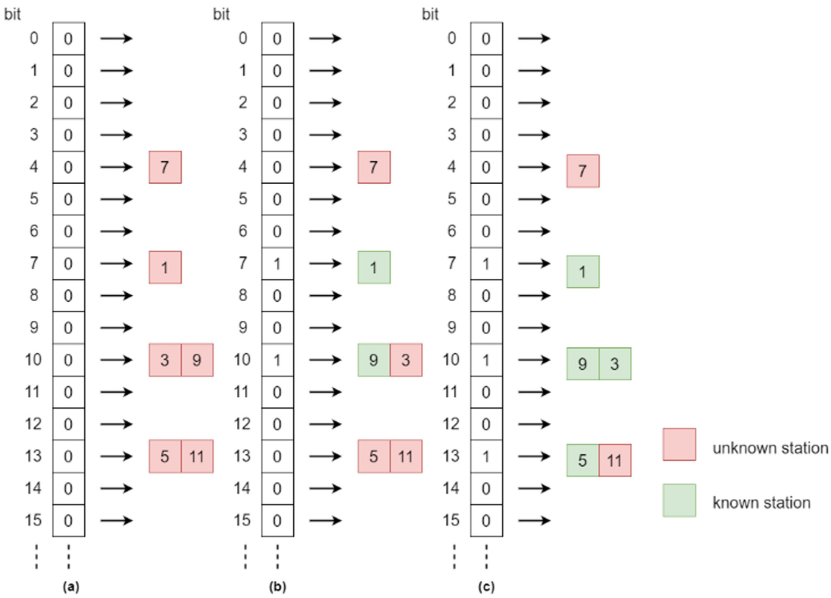


Fig. 3. An illustrated example of the BEB bit vector.

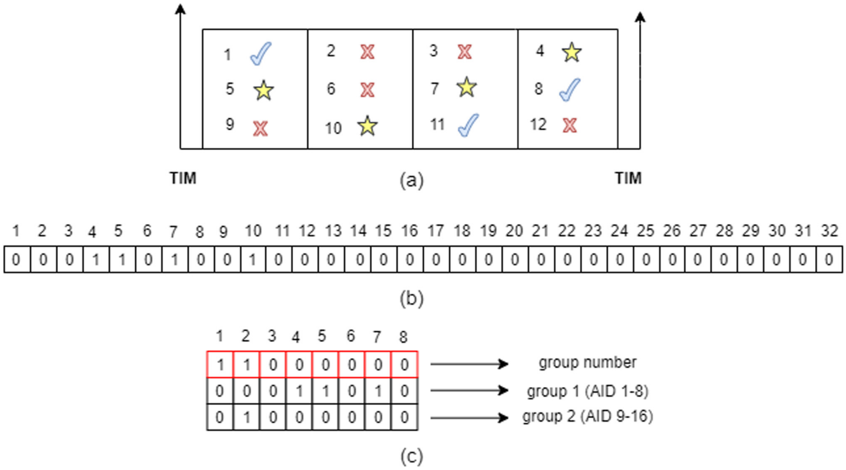


Fig. 4. An illustrated example of using the FAIM; (a) slot assignment, (b) the FAIM without compression and (c) the FAIM with compression.

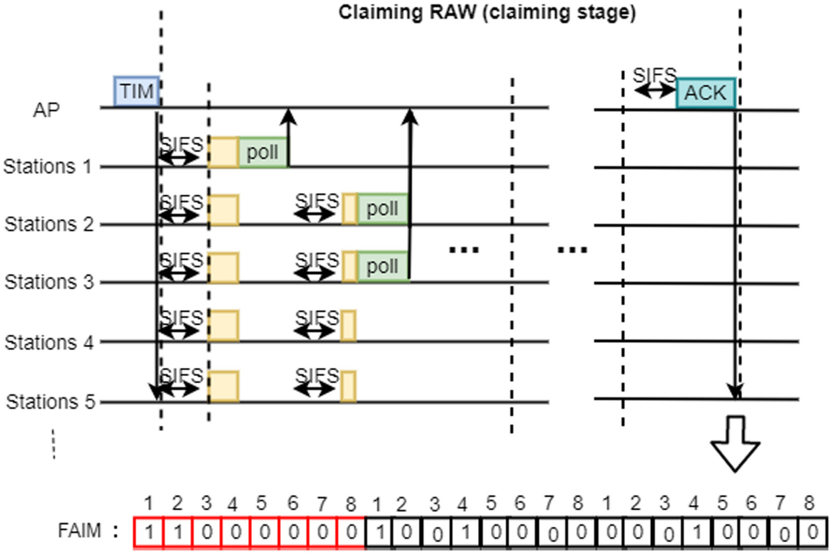


Fig. 5. An example of using FAIM in the Claiming RAW.

4.3 The Communication Stage

There are two phases in the communication stage: (i) the scheduling phase and (ii) the uplinking data and downlinking data phase. The AP schedules and notifies which station can access the channel in the scheduling phase. The selected and notified station can uplink or downlink its data frame, and also deliver its next registered backoff value to AP in the uplinking data procedure or the downlinking data procedure.

Since AP will calculate to which RAW sub-group each station belongs and record the stations' expected backoff values based on their previously registered backoff values, regardless of the station has or does not have data to send/receive, AP can know all of the registered time of all involved stations in a time slot. Thus, AP can arrange the channel access's sequence and time accordingly. Note that both the known and unknown stations can generate backoff values for registration, but the AP only schedules the known stations for the channel access.

When a station sends an uplinked data frame, it generates a new registered backoff value for its next channel access and piggybacks it on the data frame and sends it to the AP. After the AP has received the uplinked data frame, the AP is switched to the scheduling phase to select the next station for accessing the channel and indicates it in the ACK frame. When the AP selects a station to receive its downlinked data frame in the scheduling phase, the selected station generates a new registered backoff value for its next channel access and piggybacks it on the PS-Poll frame, which indicates its readiness to receive its downloaded data frame, and then delivers it to the AP. Note that if the backoff value of an unknown station is the same as the known station's backoff value notified by the AP, this unknown station will generate a new backoff value to avoid collision. The AP does not know the backoff value's change of the unknown station at this time. If the unknown station has downlinked data in the future, the AP schedules it according to its originally registered backoff value, which is recorded in the BEB bit vector.

5 Performance Evaluation

This Section presents the performance evaluation of the proposed CCA method. The proposed CCA method is compared with the traditional IEEE 802.11ah. The simulator uses a network model based on the IEEE 802.11ah infrastructure and uses the C++ programming language to implement the TIM and the RAW mechanisms. The simulation environment and simulation results are presented in detail in this Section.

5.1 The Simulation Environment

The simulation environment deployed an AP and 512 stations to build the 802.11ah network. At the beginning, all stations associated with the AP, and each station randomly generated 0 to 4 data frames. The proposed CCA method can reduce the chance of collision and let known stations' uplinked/downlinked data frames to be sent/received as earlier as possible. Table 1 lists the parameters and their values used in the simulation environment.

Table 1. The parameter setting.

Parameter	Value
CWmin	16
CWmax	1024
Number of stations	512
Payload size	128 bytes
MAC header type	Legacy header
DTIM Interval	1.2.8 s
Number of RAW	2
Number of slots	4
Wi-Fi Mode	MCS10, 1 MHz

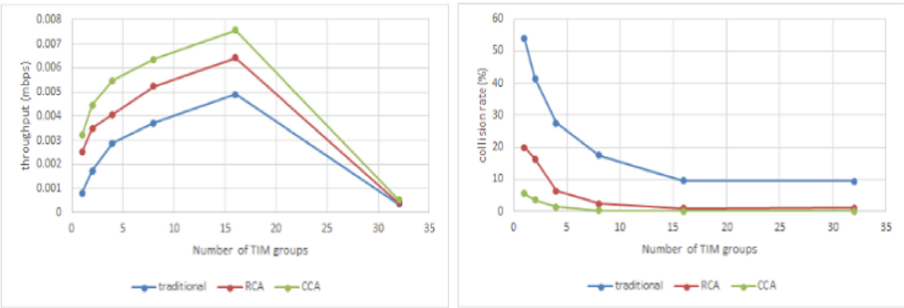
5.2 Results of the Performance Analysis

Hereafter, "traditional" means using the traditional IEEE 802.11ah protocol, "RCA" means using the RCA method [4] and "CCA" means using the CCA method. In the following Figures, the x-axis denotes the number of TIM groups and the y-axis denotes the performance metrics.

Figure 6 depicts the simulation results of the throughput and collision rate using the RCA method and the traditional IEEE 802.11ah, and the CCA method. In the case of fewer TIM groups, the number of stations allocated to each time slot is more than that for the situation of more TIM groups, i.e., the number of known and unknown stations in each time slot is increased. Referring to Fig. 6-(a), when the number of groups increases, the throughput increases and the collision rate decreases, which is depicted in Fig. 6-(b). Since the number of stations in each slot is reduced, the collision rate is reduced and stations have more time to access the channel. Comparing with the traditional IEEE 802.11ah, the proposed CCA method has higher throughput, and has almost no collision. The reason is that, through the use of the Claiming RAW, stations having uplinked data frames to be transmitted can do claims to AP to become known stations using the CCA method. AP informs these known stations to transmit data sequentially to reduce collision. However, the collision situation still exists using the proposed CCA method because AP cannot predict unknown stations' behaviors and thus it may cause some collisions, which result from the same backoff value between some unknown stations.

The performance results shown that in a more crowded network environment (1 TIM groups), the throughput of using the CCA method is 27.49% better than that of using the RCA method and 295.06% better than that of using the traditional IEEE 802.11 ah, and the collision rate of using the CCA method is 28.02% of that of using the RCA method and 10.41% of that of using the traditional IEEE 802.11ah; in a sparse network environment (32 TIM groups), the throughput of using the CCA method is 30% better than that of using the RCA method and 52.94% better than that of using the traditional IEEE 802.11 ah, and the collision rate of using the CCA method is 6.48%of that of using the RCA method and 0.75% of that of the traditional 802.11ah.

Figure 7 depicts the simulation result with 16 groups. Referring to Fig. 7, when the number of stations increases, the collision rate and transmission time increases and the throughput decreases. The CCA method has the lower collision rate than that of using the RCA method and the traditional IEEE 802.11ah because the CCA method uses the Claiming RAW to let the stations having uplinked data frames to be transmitted do claims to become known stations and thus AP can schedule them to transmit data frames earlier and sequentially to avoid collision. Furthermore, the transmission time using the CCA to be transmitted is lower than that of using the RCA method and the traditional IEEE 802.11ah.



(a) (b)

Fig. 6. The results with 512 nodes: (a) the throughput, and (b) the collision rate.

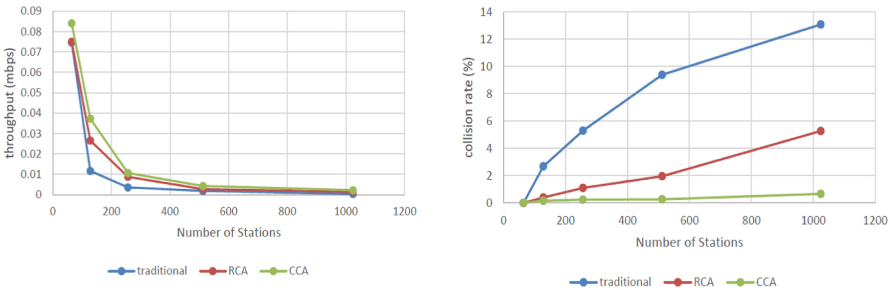


Fig. 7. The results of the environment with 16 groups: (a) the throughput, (b) the collision rate, and (c) the transmission time.

6 Conclusion

This paper has proposed a claim-based control scheme called Claim-based Channel Access (CCA) to schedule stations' channel access. Based on the registered backoff time mechanism, each station can register a random backoff value after its current channel access is finished. The proposed CCA method allows stations that have uplinked data frames to be transmitted sending claims to AP through the proposed Claiming RAW. AP can thus (i) know which stations have data to be processed and (ii) be able to schedule their channel access sequence. Simulation results have shown that the proposed CCA method is better than the traditional IEEE 802.11ah in terms of throughput, collision rate and transmission time. For the future work, it can consider how to have the dynamic distribution of stations to different TIM groups and different RAW groups such that the collision rate, transmission time and throughput can be further improved.

Acknowledgment. This work was supported by the Ministry Of Science and Technology (MOST), Taiwan (R.O.C.) under the grant number MOST 108-2221-E-006-056-MY3 and MOST 108-2221-E-240-002.

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