Performance Analysis of Association Procedure in IEEE 802.11ah

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***Abstract*—IEEE 802.11ah is an emerging wireless local area network standard at sub 1 GHz license-exempt bands for cost-effective and large-scale wireless networks. One of the most challenging issues in IEEE 802.11ah is supporting a large number of stations efficiently. To reduce heavy channel contention in IEEE 802.11ah networks, stations are divided into groups and each group of stations are allowed to access in only the designated channel access period. This grouping strategy enables fair channel access among a large number of stations. However, grouping strategy cannot improve channel usage efficiency at the time of network initialization. Therefore, during association, heavy contention results in longer association delay. Also, already associated stations can contend for data transmission. In this paper, authentication/association process is analyzed. Our analysis shows that the association process may take up to several minutes. Therefore, there is a need for a new mechanism to avoid collisions of authentication requests and traffic from already associated stations.**

***Keywords*–IEEE 802.11ah; association delay; Machine-to-Machine communication.**

I. Introduction

The wide use of IEEE 802.11-based wireless networks in indoor and outdoor applications has crowded 2.4/5 GHz frequency bands. New technologies like smart grid applications, internet of things (IoT), and Machine-to-Machine(M2M) communication will further saturate the spectrum if same 2.4 GHz/5 GHz are used. IEEE 802.11ah Task Group (TGah) is working on new WiFi standard to design a sub 1 GHz protocol which will allow up to 8191 devices attached to a single access point (AP) to get access for short-data transmissions [1]. IEEE 802.11ah wireless LAN standard group targets to support sensor networks, backhaul communications of sensor/meter data, and possibly M2M communications [2].

In IEEE 802.11ah network, thousands of stations are connected with a single AP. As the number of station increases, the network throughput and delay performances can be rapidly deteriorated due to the serious channel contention. While the contention becomes serious as the number of stations increases, one method to solve the problem is to limit the number of contending stations at a time by grouping. Same idea is adopted by IEEE 802.11ah. IEEE 802.11ah introduces a new mechanism, called restrict access window (RAW). One or more RAWs can be allocated in a beacon interval (BI) and only designated stations can access the channel in a RAW using the prevalent distributed coordination function (DCF) or enhanced distributed channel access (EDCA) [3][4]. Moreover, a RAW can be further divided into RAW slots, and they are allocated to different stations. Thus, IEEE 802.11ah can provide two-level grouping to alleviate the contention in a dense network [4]. It is expected that the RAW strategy can improve the channel access efficiency in a dense network.

IEEE 802.11ah is mainly designed for low data traffic, thus, even the large number of stations can be fairly serviced by RAW. RAW performs only after the stations are associated. Thus, even though RAW limits the number of associated stations contending for the channel, it cannot improve channel usage efficiency at the stage of network initialization. The main contribution of this paper is to emphasize the need of a new method to handle data and association traffic simultaneously in IEEE 802.11ah. A network can reset due to various reasons, such as power failure, AP reboot, system crash, and so on. Once AP restarts, stations try to associate. Therefore, during the network initialization, how to avoid collisions of authentication requests and traffic of already associated stations is a big question [5]. To demonstrate our point, an analytical model of the authentication/association process is developed to analyze and evaluate the performance of IEEE 802.11ah networks. Since it may take up to several minutes for all stations to get associated, the obtained results clearly indicate that the traffic from stations contending for network association can collide with the traffic from stations contending for data transmission. Therefore, a new method to handle data and association traffic is necessary.

The rest of this paper is organized as follows. Section II shows the overview and main features of IEEE 802.11ah. Section III discusses the the obtained experimental results. Finally, we conclude the paper in Section IV.

II. Overview of IEEE 802.11ah

A. IEEE 802.11ah Features

IEEE 802.11ah is designed for supporting applications with the following requirements: up to 8191 devices associated to an AP, having the mechanism for power saving strategies, minimum network data rate of 100 kbps, operating carrier frequencies bands below 1 GHz with coverage up to 1 km in outdoor areas, and short and infrequent data transmissions [1]. One of the goals of the IEEE 802.11ah TGah is to offer a standard that, apart from satisfying these previously mentioned requirements, minimizes the changes with respect to the widely adopted IEEE 802.11.

IEEE 802.11ah uses orthogonal frequency division multiplexing (OFDM) on the physical layer (PHY) operating in the license-exempt bands below 1 GHz. IEEE 802.11ah maintains

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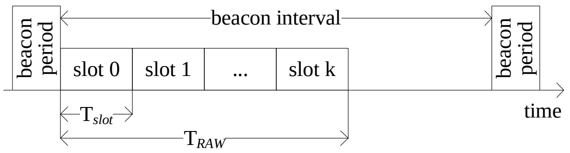

Figure 1. The superframe structure of IEEE 802.11ah.

the similar network architecture with the 802.11. The most popular applications of IEEE 802.11ah are in sensors and meters which consist of a huge number of battery powered stations.

B. Restricted Access Window (RAW)

Figure 1 shows the superframe structure of IEEE 802.11ah. In order to provide the service to large number of stations, IEEE 802.11ah introduces RAW. The RAW mechanism enables fair channel access among the large number of stations. Right after the beacon period (BP), there could be hundreds or thousands of stations trying to access the medium for data transmission. RAW mechanism restricts channel access to a small number of stations at a given time and distributes their access attempts over a much longer period of time. In this mechanism, the AP allocates a medium access period in the BI, called RAW, which is divided into several time slots of T_{slot} duration each as shown in Figure 1. The AP may assign a time slot inside the RAW to a group of stations during which only those certain stations are allowed to contend for medium access. RAW allocation information is broadcast in a beacon to notify whether a station is allowed to use RAW interval or not. The allocation information in the beacon also includes the start time and the duration of the RAW (T_{RAW}). If a station is allowed to access the channel within the RAW, it may contend for medium access at the start of its assigned time slot. However, stations should stop attempting to access the medium as soon as their assigned time slot is finished. It should be noted that there may be some stations, which are not allowed to use the RAW. During the channel time assigned to others, a station can go to sleep to save energy.

There is a parameter called cross slot boundary encapsulated in the beacon that defines the behavior of the RAW [4]. If the cross slot boundary is allowed, uplink transmissions can cross the boundary of the allocated time slot. However, if it is not allowed, then the stations try to access the medium only if the remaining time in the allocated slot boundary is enough to complete the transmission.

C. Association in IEEE 802.11ah

Stations can use RAW only after they are associated. Even though RAW limits the number of stations contending for the channel, it cannot be used at the stage of network initialization. Thus, IEEE 802.11ah has developed an authentication control mechanisms for limiting the contention that works as follows. In every beacon, Authentication Control Threshold (ACT) is selected according to some implementation dependent rules [2]. The AP may change this ACT dynamically. When a station is initialized, it shall generate an authentication control number randomly from the interval [0, L]. Having received a beacon, the station tries to associate with the AP only if its authentication control number is less than the received ACT. Otherwise, it shall postpone association till the next BI. To avoid unfairness in the future, the station may regenerate its random number after authentication is finished.

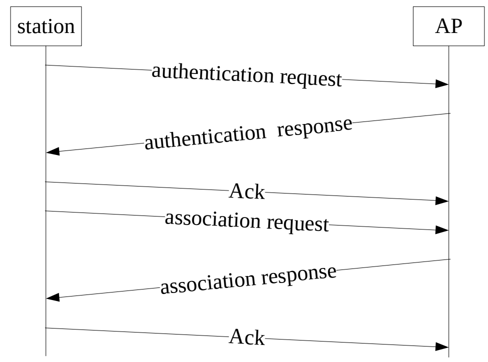

Figure 2. Authentication/association in IEEE 802.11ah.

Figure 2 shows the association process. If a station is eligible for the association, it starts the association process. The association procedure starts by sending the authentication request to AP. After the station is authenticated, AP responses with authentication response frame and is acknowledged by the station. Once the station is authenticated, it will send an association request to the AP. The association request contains chosen encryption types if required and other compatible 802.11 capabilities. If the elements in the association request match with the capabilities of the AP, the AP will create an association ID (AID) for the station and respond with an association response message granting network access to the station. The association response is again acknowledged by the station. Once a station is associated with AP, it can start communication.

D. Co-existence of Data and Association Frames

As mentioned above, during association ACT is used, whereas RAW is used for data communication. Even though both ACT and RAW are used to limit the number of contending stations, they come into the picture at different network stages. However, they may co-exist during network initialization stage. During network initialization, there will be two types of stations, one using ACT and another using RAW. However, how these two type of stations co-exist and how to manage the traffic from these two types of stations are unanswered in the draft of 802.11ah. An open issue is how to avoid collisions of authentication requests and traffic of already associated stations. So, these questions can be topics for future research.

III. Simulation Results and Analysis

A. Experimental Setup

The overall purpose of our study is to see how long stations spend for association in a large network. The transmission behavior of the devices in IEEE 802.11ah can be approximated by that of IEEE 802.11 stations [6]. Therefore, the default implementation of IEEE 802.11 that is readily available in ns-2 is used to study the behavior of IEEE 802.11ah. The problem in ns-2 is that it cannot simulate thousands of stations. However, IEEE 802.11ah implements authentication control mechanism

TABLE I. NETWORK PARAMETERS AND VALUES.

Parameter	Value
Beacon Period	0.25 ms
Physical rate	1 Mbps
Physical layer header	24 Bytes
Association request length	28 Bytes
Association response length	30 Bytes
Authentication request length	34 Bytes
SIFS	10 μs
DIFS	50 μs
Time duration of a Back-off slot	20 μs
CWmin	32
CWmax	1024

TABLE II. AVERAGE TIME REQUIRED BY A STATION FOR ASSOCIATION.

Stations (g)	Average time (AT_{asso})	Stations (g)	Average time (AT_{asso})
10	0.014 secs	35	0.054 secs
15	0.017 secs	40	0.073 secs
20	0.026 secs	45	0.080 secs
25	0.033 secs	50	0.090 secs
30	0.047 secs		

that allows only limited number of stations to contend for channel access at a time. Therefore, even though we are assuming a large network with N stations, we assume only g stations are active at a time. All simulations are performed under ns-2.34. Table I depicts the parameters used for the simulation. An AP is deployed at the center of the network. All stations try to associate with the AP. Once the stations are associated, they stay idle. To simulate the behavior of IEEE 802.11ah, in our simulation we varied the number of stations from 10 to 50 and evaluated the average time taken by each station for the association. From the trace file, we first obtained the total time taken for association by all stations. Then, the average time is calculated by dividing total time by the number of stations. Table II shows the average time (AT_{asso}) taken by (g) stations for successfully getting associated with AP. Note that average association time do not depend on BI and is always fixed for g stations in a network [4]-[9].

Once the average time taken by a station is known, the total time spent for association by N stations can be easily calculated. Out of g contending stations, the total number of stations, n_{bi}, that can be successfully associated in a BI is given by

$$n_{bi} = \frac{BI - BP}{AT_{asso}}. \quad (1)$$

If $n_{bi} \geq g$, then all g stations can be successfully associated in a BI and remaining duration of BI is unused. Also, the next g stations have to wait until the next BI. Therefore, the total time (TT_{asso}) required by N stations for the association can be obtained as

$$TT_{asso} = \begin{cases} \frac{N \times BI}{g}, & \text{if } n_{bi} \geq g \\ \frac{N \times BI}{n_{bi}}, & \text{otherwise.} \end{cases} \quad (2)$$

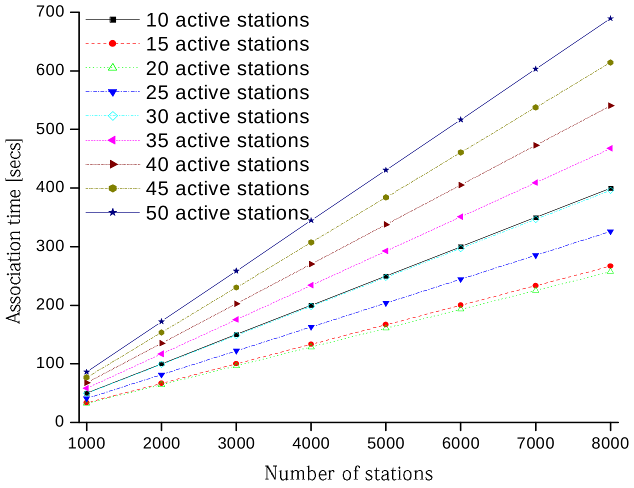

Figure 3. Total association time for various network size.

B. Experimental Results And Discussions

The results presented have been obtained by using AT_{asso} obtained from the simulation and substituting that value in above-derived equations. Unless specified, the default value used for the total number of stations is 8000 and for BI is 0.5 sec.

The total association time experienced by IEEE 802.11ah stations for various network sizes is plotted in Figure 3. At 50 active stations in a BI, it takes 723.61 secs for all 8000 stations to associate with AP. Note that this time is calculated in the absence of data traffic. However, in the real situation, there shall be a heavy collision between data traffic and association frames and the association time can be much larger than shown above. Also, channel error may also prolong the delay. Another interesting result that can be seen from the figure is that the total association time of 15 and 25 active stations almost overlaps. The reason for this is because of the fact that n_{bi}=15.07 for 25 active stations. Also, from the figure it can be observed that the total association time for 10 stations is much greater than for 30 stations. Therefore, another important observation from the figure is that less active stations do not always means less association time.

Figure 4 shows the total association time experienced by IEEE 802.11ah stations when fixed number of stations are allowed to contend under various BI. The results can be interpreted as follows. Let us take the case of g=20 active stations. As the number of contending station is always fixed, the average time taken by a station to associated is also fixed for a BI. Therefore, for a given number of g active stations, as long as $g \geq n_{bi}$, the total time taken for the association of all stations is almost same regardless of the BI duration. However, once $g < n_{bi}$, then the association duration increases because of the unused portion of BI. Therefore, the important conclusion from this experiment is that it is not possible to decrease the total association duration by changing BI.

To see how varying the number of active stations effect the association time for a BI, another experiment was performed. Figure 5 shows the total association time experienced by IEEE 802.11ah stations when the number of active stations

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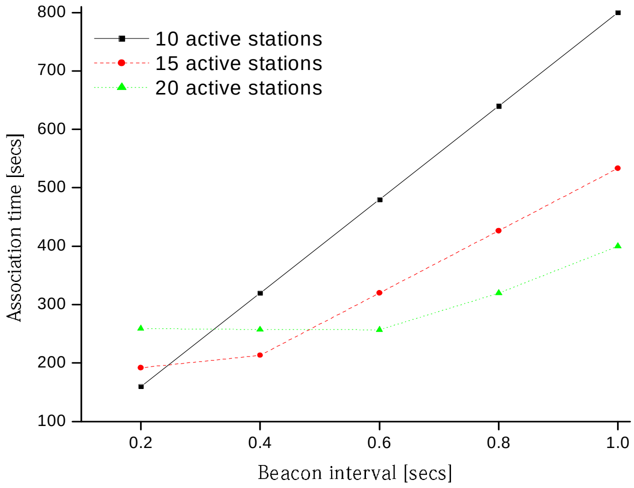

Figure 4. Total association time for varying no. of active stations and BI.

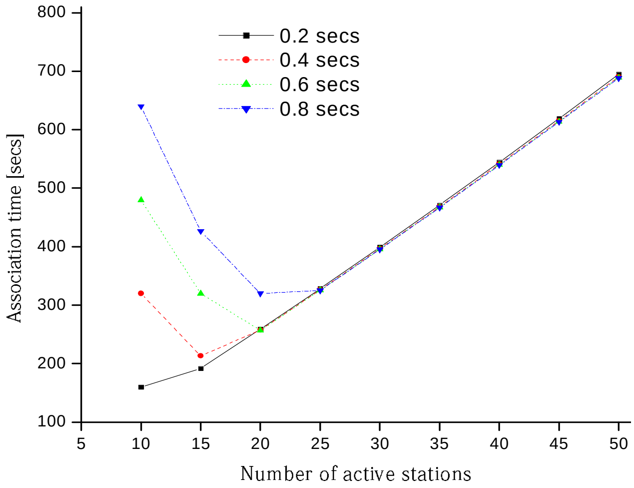

Figure 5. Total association time for varying no. of active stations and BI.

are varied. It can be seen from the figure that changing the number of active stations changes the association time for a given BI. Also, it can be seen from the figure that for any given BI, there exist a number that gives the least association time. For example, for BI=0.2, 15 active stations gave the least association time whereas, for BI=0.8, 25 stations gave the least association time. Therefore, authentication control mechanism should limit the number of active stations to the optimum number that gives the least association time. The important observation from the figure is that for a given BI, there is an optimum number of active stations that gives the lowest association time.

IV. Conclusion

IEEE 802.11ah has introduced RAW strategy to address heavy channel contention for large network size. However, RAW cannot improve channel access at the stage of network initialization. Therefore, in the case of network reset or during network initialization, every station tries for association and network suffer from heavy contention. In this paper, the association process of IEEE 802.11ah is analyzed. Our analysis and results demonstrate that during network reset, stations experience heavy contention and long association delay. Also during network initialization phase, there exist two types of stations. One which are already associated (using RAW) and the another that are trying to get associated (not using RAW). However, no mechanism has been proposed in the draft of IEEE 802.11ah to handle the collision of authentication requests and traffic from already associated stations. Minimizing the association time as lower as possible can reduce the collision to some extend. However, a new mechanism to avoid collision of frames from above mentioned two different types of stations is necessary.

Our analysis and results show that here is an optimum number of active stations for a BI that gives the least association delay. This motivates future work to develop an efficient algorithm that calculates an optimum number of active stations for a BI and used that number for minimizing the association delay.

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