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Fairness Improvement in Internet of Things Networks implemented by IEEE 802.11ah Standard

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Abstract

Fair throughput provisioning is a major issue in the internet of things (IoT) networks with large coverage area, where the stations are distributed in long distances from the access points (AP). The stations experience different path-loss, consequently different throughput. In this paper, we suggest a grouping method to maintain fairness among the stations of an IoT network implemented by IEEE 802.11ah standard over a wide geographical region. The de facto standard assigns a time slot of each frame portion to each randomly chosen group of stations to contend. To enhance fairness, we propose a distance-based grouping method that separates the stations based on their distance from the AP. Moreover, we find the optimal distance for grouping and the optimum proportion of time slots assigned to each group that maximize fairness. The simulation results indicate that the fairness of the proposed method outperforms the one's of the de facto standard.

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I. INTRODUCTION

The IEEE 802.11ah standard supports connections of thousands stations on IoT networks. To reduce the probability of collision among stations, the standard uses a restricted access window (RAW) mechanism. The space between two beacons is divided into multiple RAWs, and each

RAW is split into several time slots as depicted in Fig. 1. The AP divides the stations into a number of groups and assigns a specific time slot to each group. The stations of a group only wake up in the allotted time slot and compete for channel access and return to sleep at the end of the time slot[1].

To enhance the performance of the RAW mechanism in reducing contention and increasing resource utilization efficiency, some grouping methods and resource allocation schemes have been proposed in the literature.

In[2], agrouping method is presented to obtain load balancing among the sensor

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groups of a heterogeneous network where the sensors have different sending and sampling rates. The method maximizes the channel utilization by assigning sensors to appropriate groups. In[3], the stations select the transmission time slots of the RAWrandomly, but if a collision happens, the first vacant time slot of the RAW is selected for retransmission to boost energy efficiency. The optimal number of time slots in a RAW is determined by an algorithm in[4]. Based on the probability of success in accessing the channel, the algorithm estimates the number of active stations trying to reach the channel.

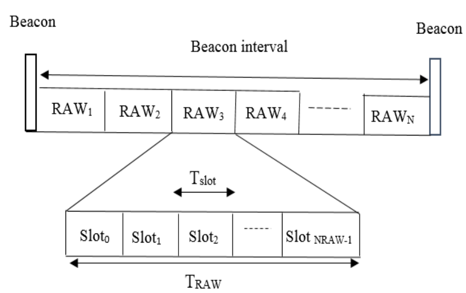

Figure 1. An IEEE 802.11ah frame Structure

The optimal number of time slots is determined by considering the linear relationship between the estimated number of stations and the number of slots. In[5], the effect of stations handover among slots on the throughput of a saturated network is investigated. The authors suggest that the AP divides the stations into the same sized groups and avoids re-grouping upon the arrival of a new station by allowing the station to randomly select a time slot. To reduce competition, a dynamically allocation of stations among the channel sub-bands, based on the amount of interference, is proposed in[6].In addition to grouping, sectoring the coverage area helps reducing the competition as reported in[7]. The focus of the most researches in the literature has been improving the throughput of the IoT network by reducing the competition. In many applications of IoT networks, the stations expect equal opportunity for channel access and data transmission. However, the geographical extent of large IoT networks makes the stations farther from the AP have lower transmission rate due to the path-loss.

In this paper, to maintain fairness, sectorization and grouping methods are proposed. The AP divides its coverage area into several spatial sectors, and the stations far from the AP and near it are divided into two groups in each sector. Each sector is then allocated to one of the time slots, and the time interval of each time slot is assigned to the two groups proportional to their average throughput. The optimal distance for grouping and the proportion of time slot dedicated to each group that maximizes fairness is determined.

In the remaining of the paper, the network model is presented in section 3. The proposed grouping method is described in section four, and the simulation results are demonstrated in section 5. Section 6 concludes the paper.

II. SYSTEM MODEL

The IoT network is an IEEE 802.11ah WLANwith *N*uniformly distributed stationsaround the AP. The stations buffers are saturated, and the data is transmitted in the same size packets.The interval between the two beacons is considered as one RAW which is divided into Ktime slots. The stations are divided into K groups, with a time slot allotted to each one. In each time slot, N_k $(k = 1,2, 3,\ldots, K)$ stations of group $k$compete to access the channel using the distributed coordination function (DCF) protocol. The DCF protocol uses carrier sense multiple access/ collision avoidance (CSMA/CA)for channel access. In this method, when stations want to send data, they sense the channel and if it is idle as a DIFS, they enters the Backoff phase which randomly select a counter from the $[CW_{min} CW_{max}]$ and count down to zero before accessing the channel. If the transmission is successful, the AP sends an ACK frame after waiting for the SIFS. The transmission time of a packet and acknowledge (ACK) message are T_{DATA} and T_{ACK}, respectively, depending on data rate r and calculated according to equations (1) and (2)[1].

$$T_{ACK} = \frac{L_{ACK}}{r}, (1)$$

$$T_{DATA} = \frac{(L_{payload} + MAC)}{r}, (2)$$

where the header length of the medium access control frame is MAC, and $L_{payload}$ and L_{ACK}epresent the data frame length and ACK frame length.

The throughput of each RAW time slot is calculated in [5] as

$$TH = \frac{L}{T_{slot}} \times E_{tr} \times P_S, (3)$$

where, L, T_{slot}, E_{tr}, and P_S indicate the data length, time slot duration, number of packet transmission per time slot, and the probability of a successful packet transmission, respectively. In[8], $P_S$is calculated:

$$P_S = \frac{N\tau(1-\tau)^{N_k-1}}{1-(1-\tau)^{N_k}}, (4)$$

where, $N_K$and τ refer to the number of stations per timeslot and the transmission probability of a station per time slot, respectively. The values of τ and E_{tr}depends on the number of stations per time slot or group as well as the duration of each slot[5].

III. THE PROPOSED GROUPING METHOD

In this section, a grouping method is proposed to enhance the fairnessamong the stations. As shown in Fig. 2, the area covered by the AP is divided into K sectors, and each sector is divided into two groups, G1 and G2, based on radius X. Each sector is served with

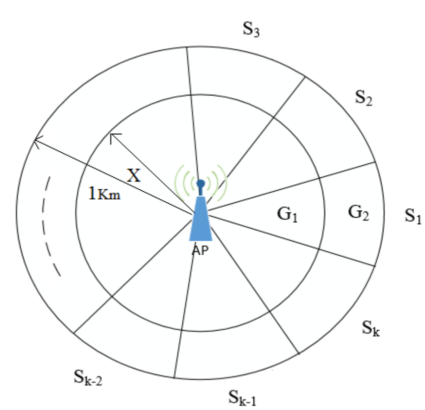

Figure 2. Sectorization and grouping the stations

a time slot in RAW. The duration of each time slot is $T_{slot} = \frac{T_{RAW}}{K}$, and α_k and $1-\alpha_k, 0 < \alpha_k < 1$, portion of T_{slot} are dedicated to *G1* and *G2*, respectively.

Providing that fairness exists, the throughput of the two groups over each time slot should be the same. Hence, in sector *k*, equation (5) should be held.

$$\alpha_k T_{slot} \times \underbrace{\frac{L}{T_{slot}} \times E_{tr_1} \times P_{S1}}_{TH_1} = (1-\alpha_k) T_{slot} \times \underbrace{\frac{L}{T_{slot}} \times E_{tr_2} \times P_{S2}}_{TH_2}, \quad (5)$$

where *TH1* and *TH2* are the throughput obtained by *G1* and *G2* groups, respectively. The probability of successful transmission, P_S, is calculated according to the number of stations in each group. Since the stations have different path-loss depending on their location, the average data transmission rate of the stations in each group is calculated via $PL\ (X\ /\ 2)$ in the first group and $PL(X + \frac{1000-X}{2})$.Using these values, the average data transmission rate r is calculated for the stations of each group. Then T_{DATA} and T_{ACK} are calculated. Number of transmissions in each group is calculatedtrough the number of stations in each group, the duration of T_{slot}, T_{DATA} and T_{ACK}.Then using equation (5), α is calculated.To calculate fairness[9], we use the fairness index in (6).

$$F = \frac{(\sum_{i=1}^{N} TH_i)^2}{N \sum_{i=1}^{N} TH_i^2} \quad (6)$$

These steps are repeated in *K*-1 other sectors too. Eventually, using the optimized search approach of the Fibonacci series, the optimum radius *X* is determined, providing a maximum level of through put fairness.

Table 1. Simulation Parameters

Values	Parameters
264 µs	DIFS
52 µs	Backoff Time Slot
256 byte	Packet size
4	Maximum number of retransmission
160 µs	SIFS
1023	CW_{max}
15	CW_{min}
272 bits	MAC
128 bits	PHY header
PHY + 112 bits header	L_{ACK}
2 MHZ	Bandwidth
1 s	T_{RAW}
-110 dBm	Noise power

IV. SIMULATION RESULTS

To simulate the proposed method, 100 stations are distributed uniformly in the area covered by the AP within a radius of one kilometer. Path-loss of a station located at distand *d* from the AP is calculated by [10]

$PL(d) = 8 + 37.6 \times \log_{10}(d)$. (7) The simulation parameters are listed in Table 1.A RAW is assumed to be divided into four slots, and

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each slot is assigned to one sector. The stations in each sector are grouped into two groups at different radii from the set of$X$ = {300, 400, …,900}. For different values of X ineach sector, the ratio α is obtained according to (5). The fairness of the network for different grouping, based on distance X, is displayed in Fig. 4.Since the fairness graph is convex, there exist a value for X that maximizes the fairness. We deploy Fibonacci univariate search algorithm to find the optimal value of X[11].

According to Fig. 4, we select the interval [500, 800] as the initial interval to begin the search and obtain the optimal value of X for 5 iterations of the algorithm. As it is illustrated in Table 2, the best possible grouping distance is achieved at a radius of 668.75 m, which results in throughput and fairness values of 0.35 Mbps and 0.97, respectively.

In Figs. 5 and 6, the performance of the proposed grouping method, in terms of throughput and fairness, is compared with the ones of the random grouping and DCF protocol. The proposed grouping for 6sectors

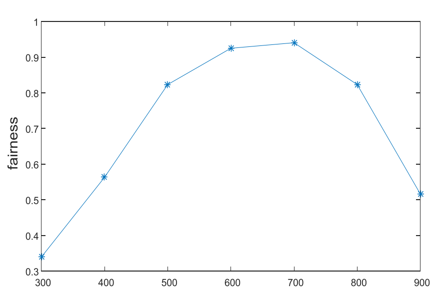

Figure 4. Fairnessof different grouping distance

and X = 650 is investigated. It is observed that both grouping methods enhance the fairness index. However, the proposed method achieves the highest fairness index, with the price of slightly reduction of the throughput compared to the random grouping method. Moreover, by deploying grouping in medium access mechanisms and restricting the medium access of the stations to certain time slots, the overhead of channel access competition reduces and the network throughput increases with respect to the one's of DCF protocol increases. In all three mechanisms, as the number of stations increases, the probability of collision increases and the network throughput drops accordingly.

Table 2. Sequences of Fibonacci Algorithm

Number of iterations (i)	Decision Making Interval	Optimum X	Fairness
1	[500 , 800]	612.5	0.93
2	[612.5, 800]	725	0.93
3	[612.5,725]	687.5	0.96
4	[612.5, 687.5]	650	0.96
5	[650, 687.5]	668.75	0.97

CONCLUSION

In this paper, we have proposed a new grouping method for IEEE 802.11ah standard deployed for IoT network implementation. The grouping method utilizes sectoring and the RAW mechanism to maintain fairness among IoT stations.

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Stations of each sector are divided into two different groups, based on their distance from the AP. Then, each group is assigned an appropriate time interval of each time slot

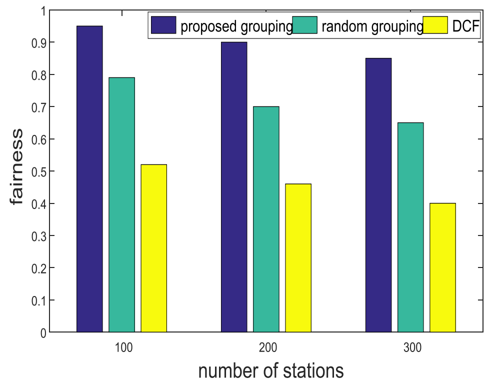

Figure 5. Fairness index of different medium access mechanisms

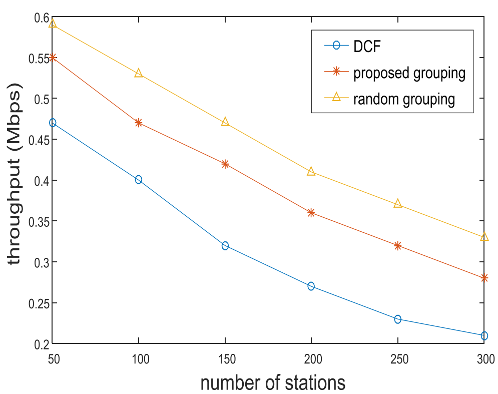

Figure 6. Throughput of different medium access mechanisms

allocated to each sector. The best grouping distance from the AP, resulting in optimal fairness obtained by Fibonacci search method. The simulation results demonstrate that the proposed method outperforms the random grouping and DCF protocol in terms of fairness index, with the price of a slight reduction in throughput.

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