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Fair and Dynamic Channel Grouping Scheme for IEEE 802.11ah Networks

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***Abstract*—IEEE 802.11ah, marketed as Wi-Fi HaLow, is the new Wireless LAN (WLAN) standard for the Internet of Things (IoT) with many enhancements to the 802.11 standard. One of the new features, mentioned as the Restricted Access Window (RAW), focuses on enhancing scalability in extremely dense deployments. RAW divides stations into groups and reduces contention and collisions by permitting channel access to one group at a time. However, the standard does not mandate any optimum RAW grouping strategy. Existing station grouping schemes for enhanced throughput and Quality of Service (QoS) considered a fixed number of groups, though it is one of the important factors in determining the overall throughput. In this paper, we have proposed a real-time grouping scheme non-constrained on the number of groups for homogeneous periodic traffic with the same QoS. The proposed scheme uses Agglomerative Hierarchical Clustering for station grouping where fairness and throughput are used as metrics for distance measure and level selection. Level throughput is estimated from its clusters(groups), using a Neural Network regressor with a 3-dimensional input vector. Evaluation of the network is done after every beacon interval and optimum station grouping and group parameters are broadcasted before the start of a next beacon interval. The proposed model was tested against uniform grouping and random grouping, an improvement of 20%, and 50% in the normalized throughput was observed. Fairness ratio of 0.945 was achieved with the proposed model.**

***Index Terms*—IEEE 802.11ah, RAW, Homogeneous Periodic Traffic, QoS, Throughput, Fairness, Trained Model**

I. Introduction

The Internet of Things (IoT) is the concept of connecting devices to the internet and to other connected devices, which have the ability to transfer data without the help of any human intervention. There are many areas where IoT plays a crucial role, some of which being Human Heart Rate Monitoring, Smart Meters for Utilities such as Electricity and Water, Remote control for home appliances, Vehicular Communication's, etc,. According to a recent survey[1], it is estimated that IoT will expand to 75 billion connected devices by 2025.

Supporting IoT in cellular networks is a whopping task. Therefore, individuals tend to take advantage of a less expensive unauthorized band like WLANs (Wireless LANs), to meeet the traffic requirements of IoT communications. In any case, the standard IEEE 802.11 was intended for small scale networks like WLAN in a workplace or a housing with portable devices like smart phones, laptops, tablets, etc. IEEE 802.11 standard mainly focuses on achieving high data rates which directly contributes towards throughput. In contrast to a traditional WLAN, an IoT network comprises of a copious amount of contending battery-powered sensors, each of which has a lightweight traffic demand and desires to consider energy potency.

In order to support networks with such dense deployments, the IEEE task group ah (TGah) developed IEEE 802.11ah Wi-Fi standard (Wi-Fi HaLow). IEEE 802.11ah essentially works in the unlicensed sub-1 GHz frequency bands (e.g., 863–868 MHz in Europe, 755–787 MHz in China and 902–928 MHz in North-America). Decent data rates varying from 0.15 Mbps to 346.67 Mbps are supported in the standard, also the transmission ranges from 100m up to 1km are supported. Due to this extended range, it can be used to support various applications. Many Innovative mechanism are introduced in the Media Access Control layer (MAC), so as to improve efficiency of a large range of densely deployed, and energy constrained stations, such as hierarchical wise organization for Station Identifier, reduced MAC header, RAW based channel access, and target wake time (TWT).

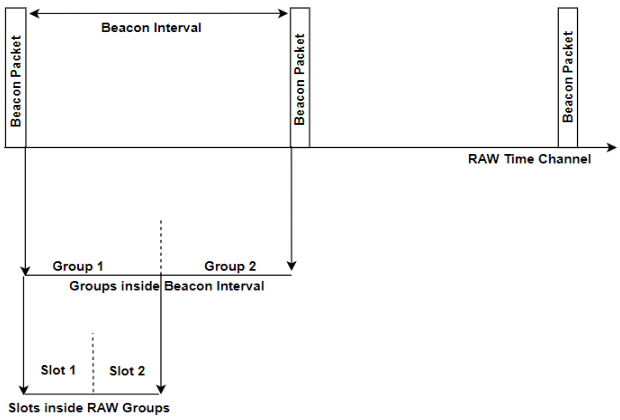

Fig. 1. RAW Channel Access

In RAW based channel access, sensors are partitioned into groups which are further partitioned into RAW slots as shown in the Figure 1. Sensors belonging to the group can only contend for access in the assigned RAW slot.

Though IEEE 802.11ah has proposed RAW based channel access scheme, the standard has given the choice to the users to select appropriate station grouping and RAW parameters. To have complete utilization over RAW channel access scheme, station grouping and selection of RAW parameters have to be optimal.

Hence, there's a need to employ a station grouping algorithm at the access point level which helps in station grouping, computation of RAW parameters and dynamical adaption of all these parameters to network conditions. In this work we have proposed a real time dynamic channel grouping scheme to predict optimum grouping strategy and RAW parameters based on the packet arrival rate. This configuration is broadcast at the start of each beacon interval. In IoTs since the traffic is majorly uplink, unless and until mentioned assume the traffic to be of uplink. And wherever throughput is discussed always normalised throughput discussion is done.

The rest of the paper is organized as follows. Section II describes about IEEE 802.11ah, RAW based channel access scheme and Previous studies in standard. In Section III, 802.11ah Group Modelling for normalised throughput estimation is described. Section IV describes in detail about the Proposed Model using Hierarchical Agglomerative clustering. Section V discusses the results and their comparison with random grouping and uniform grouping. Finally, Section VI concludes the paper and discusses the future work.

II. Present Model

IEEE 802.11ah also marketed as WiFi HaLow is a networking protocol, which was drafted to IEEE 802.11 standard in 2017. The protocol mainly focuses on lowering the energy consumption by adopting RAW (Restricted Access Window) based channel access scheme, and extends its support for dense IoT networks. IEEE 802.11ah is designed to provide data connectivity to a maximum of 8191 stations under an access point, whereas in IEEE 802.11, the maximum number of stations under an access point is limited to 2007. A unique 13-bit association identifier (AID) is allocated to each station that is connected to an access point.

A. RAW Channel Access

The main objective of the RAW channel access scheme is to reduce the number of collisions among sensor stations (nodes) and to improve in terms of energy consumption in IoT scenarios because, the nodes in such environments are extremely power-constrained. The channel time is split into periodic intervals, called as Beacon Interval. Inside each beacon interval, stations are divided into groups, and stations belonging to only a particular group can access the channel in it's group duration. Again groups consists of RAW slots, where the stations allocated to the group are assigned to the RAW slots in Round Robin fashion (based on AID). In a particular RAW slot, only the stations assigned will be contending for channel access using CSMA/CA (Standard IEEE 802.11 channel access scheme).

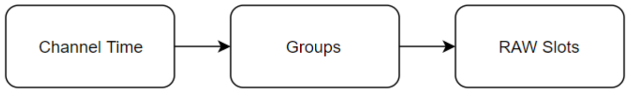

Fig. 2. Time Channel Split

At the beginning of each beacon interval, a beacon frame which contains information about the RAW parameters set (RPS) is broadcasted. RPS contains the information about Number of RAW groups, Station grouping, Number of RAW slots per group and, Group Start Time (RAW Group Duration). Also, RAW Group Duration is divided into equally sized RAW slots into which the stations are split evenly using Round Robin assignment (based on the AID). RPS also contains information about the slot format and slot duration count subfields.

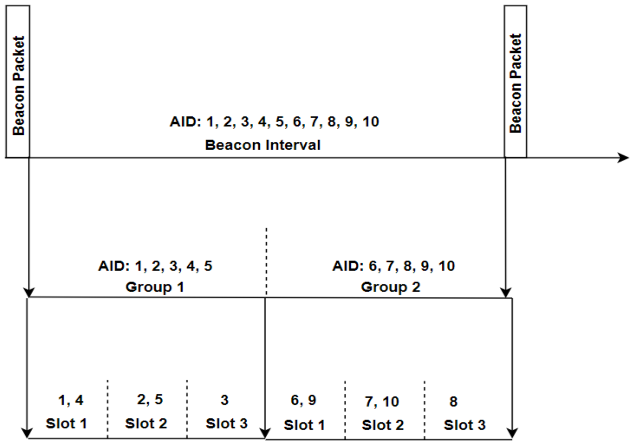

Fig. 3. Grouping Example

Consider a scenario of 10 stations connected to an Access Point (AP), with AID's from 1, 2, 3, .., 10. Let the Number of RAW groups to be 2 (AID's from 1 to 5 in Group-1 and rest in Group-2) and Number of RAW slots in both the groups to be 3. Figure 3 depicts the default assignment in the RAW slots.

B. Previous Works

IEEE 802.11ah doesn't specify any information about how the grouping should be done, it is left for the users to choose among static, uniform and random grouping schemes. Uniform grouping refers to the grouping in which stations are divided uniformly among all the groups and slots whereas random grouping refers to the allocation of stations to groups and slots without any particular order or restriction. There have been many works in the literature focusing on station grouping algorithms for prediction of the RAW parameters and station grouping based on current network conditions such as number of active stations, traffic demand of the stations, and station location. These algorithms mainly differed in the optimization objective (such as throughput, energy, mitigating hidden nodes

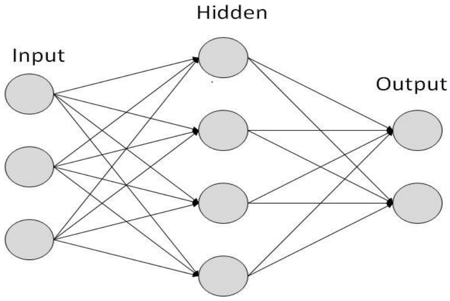

Fig. 4. Three Layer Neural Network

problem). Works based on Analytical modeling mainly used probability theory [1,2], Markov chains [3,4,5], and maximum likelihood estimation [6]. Analytical Modelling is computationally intensive, while the set partitioning algorithms are less complex. In the set partitioning algorithms, they assume fixed number of the groups and slots, and partition the stations among them. The simplicity of such set partitioning algorithms makes them computationally affordable to deploy them in real networks. A series of papers by Le Tian [8][9], gives detailed description of Surrogate Model for Real Time Station Grouping (set Partitioning) and algorithmic implementation of Real Time Station grouping under Dynamic Traffic Conditions.

III. 802.11ah Group Modelling for Throughput

The Calculation of Network throughput involves analytical modelling of the network, and then deriving the throughput from the model. The analytical modelling and throughput derivation is a cumbersome job which in turn increases the load on the Access Point.

A. *Scope of Predictive models in Networking*

When compared to the analytical modeling, prediction based models are better in many ways. The main reason being, predictive models adapt to the present network conditions and give the output accordingly whereas analytical models tend to be static irrespective of the network conditions.

1) Artificial Neural Networks: Artificial Neural Networks (ANN) inspired from biological nervous system, makes use of processing of a brain to develop an algorithm which in turn is employed to unravel complex patterns. This complex structure helps ANN to model non linear relations, which makes it much suitable for parametric estimations in real-time networks. As illustrated in Figure 4, input vectors are passed to an ANN model, which are further processed by hidden layer(s) to yield the outputs which serve as the decision. Unlike any other predictive models or other threshold techniques, the main advantage is that it makes no suppositions about the input such as linearity assumption or Gaussian assumption of second order.

Using the above mentioned algorithm, we have modelled a 802.11ah group to predict the group normalised throughput. Input features to this model are number of stations in the group, number of slots and group duration (all the parameters which comprise a 802.11ah group). This model is used to calculate the normalised throughput of the complete network and to pick the configuration which yields highest throughput.

TABLE I
Input features for 802.11ah group modelling

Feature	Dimension
No. of stations in the group	1
No. of slots	1
Group duration	1

IV. Proposed Model

In this work, we are proposing a Dynamic Channel Grouping Scheme to address IEEE 802.11ah Networks with homogeneous traffic generation rate to have enhanced throughput (normalised throughput) and fairness among the nodes. Agglomerative Hierarchical clustering algorithm is used to group the stations based on the closest average number of packets received by the two clusters.

The reason for choosing average number of packets as the clustering metric is to allocate more time to the cluster which had less number of received packets in the previous beacon interval.This is to improve fairness and also because it's the only parameter about the sensor stations which is available at the access point level.

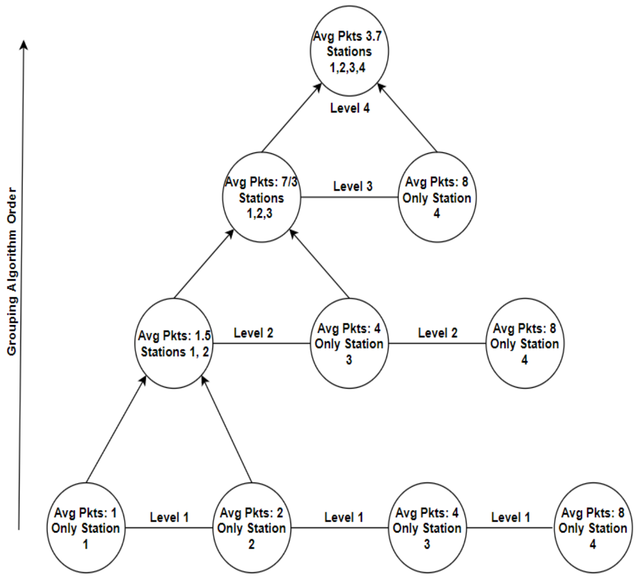

Fig. 5. Agglomerative Hierarchical clustering example

A. *Agglomerative Hierarchical clustering*

Initially each individual sensor station is considered as one group (cluster) and the average packets received per that cluster is considered as the number of packets received by that station. The next level is constructed by combining the two nearest clusters in terms of average packets received metric, and average packets received of the combined cluster is updated.

$$AvgPkt = \sum_{i=1}^{n_{sta}} \frac{Pkt[i]}{n_{sta}} \tag{1}$$

Where $AvgPkt$ is Average Number of Packets Received per cluster, n_{sta} is the number of stations present in that cluster and $Pkt[i]$ is the number of packets received by i^{th} station present in the cluster.

Figure 5 illustrates how agglomerative hierarchical clustering is performed on 4 stations with average number of stations received per station ranging from 1 to 4, producing 4 different levels (grouping configurations) to be selected from.

Since the number of packets received by stations increase as the time proceeds, after every 20 beacon intervals, Number of packets received per each station will be updated by removing one fourth of minimum number of packets received among all the stations from it's existing value. And whenever a new station get added to the AP, it's number of packets received will be updated based on the average of Maximum and Minimum number of packets received among the stations. After the construction of the whole tree (the top level should have a single cluster), throughput at each level is calculated from throughput of clusters present at that level.

$$U = \sum_{i=1}^{n_{gr}} \frac{U_i T_i}{T_R} \tag{2}$$

Where n_{gr} is the number of groups present, U_i is i^{th} group normalised throughput, T_i is i^{th} group duration and T_R is the beacon interval. The level having maximum throughput is selected and the same configuration is transmitted in the next beacon interval.

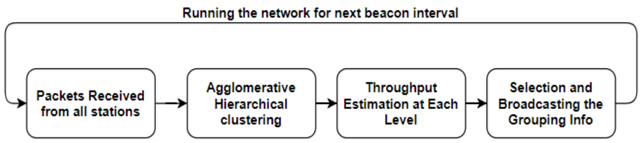

Fig. 6. Agglomerative Hierarchical clustering flow

B. Estimation of Group/Cluster Parameters

1) Estimation of Number of stations: Number of stations in that group can be clearly known from the size of the cluster.

2) Estimation of Group Duration: The key knowledge we have about a level in Agglomerative Hierarchical clustered tree is Average number of packets received per cluster. To emphasise on fair station grouping, station with less number of packets received (with respect to AP) should be given more channel contention opportunity, since the network comprises of stations with homogeneous traffic generation rate.

$$T_i = \left(1 - \frac{AvgPkt[i]}{\sum_{j=1}^{n_{clus}} AvgPkt[j]}\right) * BeaconInterval \tag{3}$$

Where T_i is i^{th} Group Duration, n_{clus} represents number of clusters and $AvgPkt[j]$ represents average number of packets received from j^{th} cluster.

3) Estimation of Number of slots: Number of slots per group can range from 1 to number of stations present in that group. On analysing the variation of group throughput with number of slots in that group, we have found that the variation is a two peak curve (as shown in Figure 7).

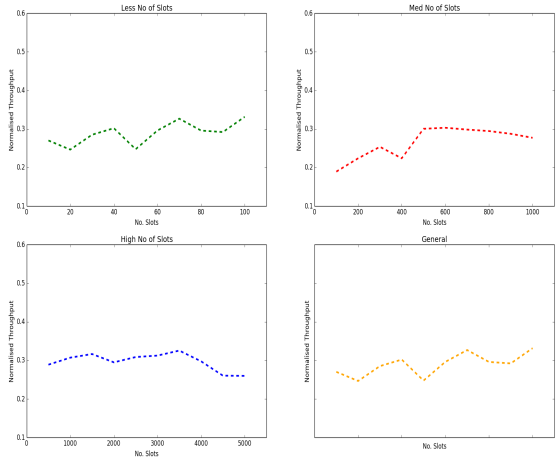

Fig. 7. Variation of Group Throughput over Number of Slots

Figure 7 shows group throughput vs number of slots variations in 4 different scenarios. The top left graph indicates the variations when number of stations are in range of 50 to 100, and similarly top right and bottom left are when number of stations are in ranges of 500 to 600 and 2500 to 2700 respectively. The bottom right sums up all the three scenarios to a generalised one.

A peak finder algorithm (Algorithm 1) is employed to get the optimum number of slots which yield higher throughput. To the Algorithm, number of stations, estimated group duration, number of slots range (1, number of stations) are passed, and the Group Model (M) is used to estimate the group normalised throughput which in turn helps in picking up number of slots giving peak normalised group throughput.

Inside the RAW slots the stations are allocated in round robin fashion and the duration of the slot is estimated based on the average number of packets received per slot (considering fair allocation).

$$AvgPkt_{slot} = \sum_{i=1}^{n_{ssta}} \frac{Pkt[i]}{n_{ssta}} \tag{4}$$

$$T_{slot} \propto \frac{1}{AvgPkt_{slot}} \tag{5}$$

where,n_{ssta} is the number of stations in a slot, T_{slot} is the slot duration and $AvgPkt_{slot}$ is the average number of packets received for a slot in a group.

Algorithm 1: Peak Finder Algorithm

Input: No. Stations, Group Duration

Output: No. Slots

Function `slots`(no_{st}, gp_{dur}, min_{slot}, max_{slot})**:**

```
mid = float(mean(min_slot, max_slot))
/* M - Pre-Trained Group Model */
if M(no_st, gp_dur, mid - 1) < M(no_st, gp_dur, mid)
   M(no_st, gp_dur, mid) > M(no_st, gp_dur, mid + 1)
 then
    return mid
else if
   M(no_st, gp_dur, mid - 1) > M(no_st, gp_dur, mid)
 then
    return slots(no_st, gp_dur, min_slot, mid - 1)
else if
   M(no_st, gp_dur, mid) < M(no_st, gp_dur, mid + 1)
 then
    return slots(no_st, gp_dur, mid + 1, max_slot)
```

4) Estimation of Group Normalised Throughput: With the estimated number of slots and group duration, group's normalised throughput is estimated using the Pre-Trained model based on the group parameters.

After estimating all group or cluster parameters, Normalised level throughput are calculated using equation 2. The level having highest normalised throughput is selected and that configuration is broadcast to all sensor stations for fair grouping and high throughput.

V. Results and Findings

A. Dataset

IEEE 802.11ah Group is modelled in NS3 with PHY specifications mentioned in the standard and datarate of 1Mbps. Group Parameters varying in the range (Table II) with step size (Table II) are given as the parameters to network and the network is run for 100 Beacon Intervals and the mean normalised throughput is noted. A dataset of half a million points is created and used for training the model.

TABLE II
Group Parameter Constraints

Parameter	Values		
	Min	*Step*	*Max*
Number of Stations	30	20	4000
Group Duration (us)	40960	10240	204800
Number of Slots	1	5	No. Stations

B. 802.11ah Group Model

Artificial Neural Networks with 2 hidden layers are used to model a 802.11ah group to estimate its normalised throughput. For training, we have used LM algorithm which is multi-layer feed forward back propagation algorithm. The training set is split into 75% for training, 25% for testing.

TABLE III
R2 score for regression trees at different depths

No. of Neurons	R2 Score		
	Training	*Testing*	*Validation*
3	0.933	0.904	0.9326
6	0.935	0.9113	0.9345
9	0.936	0.912	0.9352
12	0.939	0.9136	0.9381
15	0.941	0.914	0.944

C. Fairness Metric

The standard deviation of the packets gives us the measure of fairness. So, if standard deviation is less it indicates that all the packets are close to the mean and thus there is fair allocation of resources.

So, we have defined fairness metric as,

$$Fairness = 1 - \frac{Standard\ Deviation\ of\ packets}{Mean\ No.\ of\ packets\ received} \quad (6)$$

Thus, when standard deviation is 0, Fairness will be 1 and when standard deviation is high, the fairness value will be less.

A test network is created using Python3 and NS3 employing the proposed model, random grouping model and uniform grouping model, and the comparisons in terms of normalised throughput and fairness metric are presented.

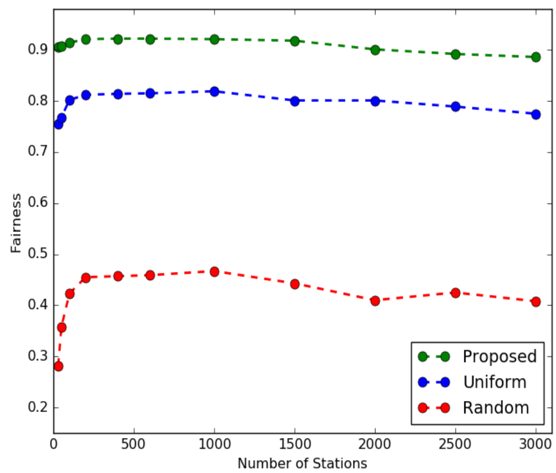

Fig. 8. Fairness vs Number of Stations

D. Fairness Comparison

With the proposed model, there was a 110% and 15% increase in fairness values from random and uniform grouping schemes respectively (Figure 8). This percentage increase is a projection of fairness in group duration estimation (groups with lower packet arrival rate are allocated more duration). Also, with the current model a maximum fairness of 0.948 was observed when there are 1500 contending stations.

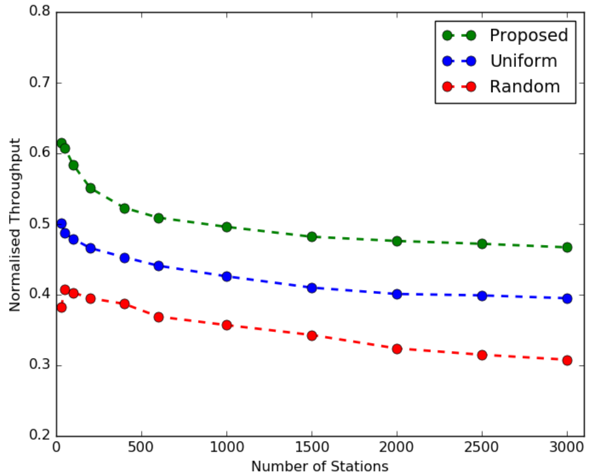

Fig. 9. Normalised Throughput vs Number of Stations

E. *Throughput Comparison*

There was a 50% and 20% increase in throughput values from random and uniform grouping schemes (Figure 9) compared to Proposed Model. A peak normalised throughput of 0.6 was observed with the proposed model when no. of contending sensor station are in the range of 200. Estimation of slots per group and selection of level from Agglomerative Hierarchical clustering led to such percentage increases.

VI. Conclusion

There was significant improvement in throughput and packet fairness in the above proposed scheme in comparison with random grouping scheme and uniform grouping scheme. This approach can be extended for heterogeneous periodic traffic employing a periodicity estimation using exponential averaging (ageing). Once the periodicity of the station is estimated the congestion suffered by the station can be estimated using number of successful transmissions done by the station and the remaining network parameters can be calculated by using the above model.

References

[1] Gilad. David Maayan, 'The IoT Rundown For 2020: Stats, Risks, and Solutions', 2020. [Online]. Available: https://securitytoday.com/articles/2020/01/13/the-iot-rundown-for-2020.aspx. [Accessed: 19- Apr- 2020].

[2] Wang Y, Li Y, Chai K.K., Chen Y, Schormans J, Energy-aware adaptive restricted access window for IEEE 802.11ah based smart grid networks, In Proceedings of the IEEE International Conference on Smart Grid Communications (SmartGridComm), Miami, FL, USA, pp. 581–586, 2–5 November 2015.

[3] Raeesi O, Pirskanen J, Hazmi A, Levanen T, Valkama M, Performance evaluation of IEEE 802.11ah and its restricted access window mechanism. In Proceedings of the IEEE International Conference on Communications Workshops (ICC), Sydney, Australia, pp. 460–466, 10–14 June 2014.

[4] Khorov E, Krotov A, Lyakhov A, Modelling machine type communication in IEEE 802.11ah networks, In Proceedings of the IEEE International Conference on Communication Workshop (ICCW), London, UK, pp. 1149–1154, 8–12 June 2015.

[5] Zheng L, Cai L, Pan J, Ni M, Performance analysis of grouping strategy for dense IEEE 802.11 networks, In Proceedings of the IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, USA, pp. 219–224, 9–13 December 2013.

[6] Zheng L, Ni M, Cai L, Pan J, Ghosh C, Doppler K, Performance Analysis of Group-Synchronized DCF for Dense IEEE 802.11 Networks, IEEE Trans. Wireless Communications 2014, 13, 6180–6192.

[7] Park C.W., Hwang D, Lee T.J., Enhancement of IEEE 802.11ah MAC for M2M Communications, IEEE Commun. Lett. 2014, 1151–1154.

[8] Le Tian, Santi S, Latré S, Famaey, J. Accurate sensor traffic estimation for station grouping in highly dense IEEE 802.11ah networks, In Proceedings of the First ACM International Workshop on the Engineering of Reliable, Robust, and Secure Embedded Wireless Sensing Systems (FAILSAFE'17), Delft, The Netherlands, pp. 1–95, November 2017.

[9] Le Tian, Michael Tetemke Mehari, Serena Santi, IEEE 802.11ah Restricted Access Window Surrogate Model for Real-Time Station Grouping, 19th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WOWMOM 2018), At Chania, Greece.