E-model: An analytical tool for fast adaptation of IEEE 802.11ah RAW grouping strategies

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***Abstract*—IEEE 802.11ah is an Internet of Things enabling technology, where the efficient management of thousands of devices is a key function. To this aim, IEEE 802.11ah provides the restricted access window (RAW) mechanism, which reduces contention by enabling transmissions for small groups of stations. Optimal grouping of RAW stations requires an evaluation of many possible configurations. In this paper, we propose an analytical model (named *e-model*) that provides an evaluation of the RAW configuration performance, allowing a fast adaptation of RAW grouping policies, in accordance to varying channel conditions. We base the e-model in known saturation models, which we adapted to include the IEEE 802.11ah's PHY and MAC layer modifications and to support different bitrates and packet sizes. As a proof of concept, we use the proposed model to compare the performance of different grouping strategies, showing that the e-model is a useful analysis tool in RAW-enabled scenarios. We validate the model with existing IEEE 802.11ah implementation for NS-3.**

Keywords— IEEE 802.11ah, Halow, Random Access window, RAW, IoT.

I. Introduction

The overwhelming appearance of the Internet of Everything (IoE) is present each day and becoming part of modern life in all of its forms as the Internet of Humans (IoH) and the Internet of Things (IoT). Those are the main drivers that are shaping our future in mid and long term along with the researchers' skills and abilities to interconnect the digital and the real world through Internet. Tactile Internet concept was born in the past years [1] with the main aim to provide 'latency zero' in all the applications with similar needs. e.g., autonomous cars, smart cities, telemedicine, tele-surgery, distant robot operations, etc.

In the near future, we could experiment new interactions with objects, applications, platforms even complete digital systems that will be able to predict our choices and our likes, due to the machine learning and artificial intelligence under development nowadays. The integration of IoE, machine learning algorithms, Artificial Intelligence applications or Big Data analysis will open the new requirements for services, applications, and needs that will enhance the wellness of the citizens.

In a broader view, it is clear that IoE brings benefits in many scenarios. Smart Cities, Industry 4.0 and Vehicular ad-hoc networks (VANETs) have a shared key feature to success in their fundamental applications, latency. The latency characteristic will drive applications as smart urban areas, smart grids, smart chains production, smart delivery systems, autonomous cars, autonomous lorries, and smart transportation systems, thus, researchers are working to improve networks throughputs and to reduce latency times.

As a consequence of the IoT concept, there are new scenarios with ultra-dense networks like smart cities and massive devices deployments using wireless networks in different environments (e.g., homes, offices, streets, campuses, industry, farms, warehouses, etc.), where different devices (e.g., sensors, smartphones, computers, wearables, etc.) have to compete to gain communication resources and, at the same time, cooperate to enforce a global interconnection.

IEEE 802.11ah standard or HaLow, as branded by the Wi-Fi Alliance, has been developed for supporting IoT applications and the challenges needed for those IoT networks such as: i) large number of autonomous devices sending traffic simultaneously; ii) low power consumption and long sleep periods; and iii) large coverage range.

PHY layer definition in IEEE 802.11ah inherits its main characteristics form IEEE 802.11ac, but includes the use of low-frequency band (sub-1 GHz) to benefit from better propagation characteristics. Extended range requirement is fulfilled also with the help of the new 1 MHz wide transmission and by introducing a more robust Modulation and Coding Scheme (MCS index 10). Besides 1 MHz channel bandwidth, 2, 4, 8 and 16 MHz are also supported. Note that IEEE 802.11ac's Multiple-Input Multiple-Output (MIMO) features are also available in IEEE 802.11ah (one to four Spatial Streams supported [3]).

Legacy IEEE 802.11 operates on 2.4 GHz (IEEE 802.11b, g, n) and 5 GHz (IEEE 802.11a, n, ac). In contrast, IEEE 802.11ah uses 863-868MHz carrier frequencies, approved for use in Europe by the European Telecommunications Standards Institutes (ETSI) and 902-928MHz frequencies, as allowed by the Federal Communications Commission (FCC) in the USA. Also, the new standard allows the use of long and short preamble types - the first one is used for 2, 4, 8, 16 MHz bandwidth, and the second one for 1 MHz - where the PHY layer is effectively a 10 times downclocked version of IEEE 802.11ac, being the OFDM symbol in IEEE 802.11ah standard 10 times longer than in IEEE 802.11ac.

Technologies like IEEE 802.11ah will be easily implemented and deployed as IoT communication technology. Together with other paramount technologies, such as Zigbee, IEEE 802.11p, IEEE 802.11ax, Low Power Wide Area Networks (LPWA) (e.g., LoRA WAN and SigFox), 3GPP's initiatives (e.g., 3GPP-4G, 3GPP-LTE, 3GPP-Nb-IoT, 3GPP-5G), IEEE 802.11ah will compete for a place in the IoT ecosystem [2].

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IEEE 802.11ah's MAC layer is optimized to encompass low-power operations and methods to support a large number of devices on a single cell. Other features such as compact frame format, where a new header includes only two mandatory address fields as compared to four address fields present in the legacy MAC header, helps in reducing contention, reducing delay and increasing throughput. The short MAC header is able to reduce the overhead from 30 to 18 Bytes.

Null Data Packets (NDP) are used to reduce the overhead induced by control frames. Channel Selective Transmission is a new feature used to restrict the effects of fading. To increase the number of supported devices, IEEE 802.11ah utilizes a new 13-bit hierarchical Association Identifier (AID) structure, assigned by the Access Point (AP) during the association, to alleviate the limited number of available AID´s that can be assigned to each to the associated stations. As a result, the number of stations that an AP can manage is increased to 2^{13} - 1 (8,191) from the 2007 stations supported by a legacy AP. The AID structure consists of four hierarchical levels. i.e., page, block, sub-block and station's index in sub-block).

Efficiency is also enhanced in IEEE 802.11ah by means of speed frame exchange method, which enables an AP and non-AP station to exchange a sequence of uplink and downlink frames during a reserved Transmit Opportunity (TXOP).

The preceding paragraphs offer just a reduced overview of IEEE 802.11ah MAC and PHY layer features, for more details, please, refer to [4]. Another interesting feature introduced by IEEE 802.11ah, which is not mentioned in previous paragraphs, is the Restricted Access Window (RAW). This feature, designed to reduce collisions by improving the channel efficiency, is the focus of this work. RAW can be used to schedule the transmission of groups of stations (STA) within certain periods of time or windows. Although RAW feature has the potential of a reduced contention and enhanced energy savings, the standard provides no definition on how to manage that scheduling, that is, how to optimally set up the RAW grouping parameters. Addressing the RAW enhancements is thus needed to reduce contention (and, hence obtain better throughput and delay performance), and to improve energy savings; for instance, the STAs can be in doze mode while its slot or group is not participating in contention or just waiting for their scheduled transmission time. As discussed in the following, in this paper we aim to contribute to the enhancement of this RAW grouping.

Although developing a fully functional grouping strategy is not the aim of this work, we argue that a metric, capable of quickly assessing the performance of different grouping strategies will ease the development of different grouping and RAW optimization algorithms. Therefore, in this paper, we propose an analytical model that allows a fast evaluation of RAW configurations on IEEE 802.11ah networks at a low computational cost. Our new analytical model (*e-model*) is based on a modified version of [5], adapted to the enhancements of the novel IEEE 802.11ah PHY and MAC layers. As a proof of concept, we use the proposed metric with different baseline grouping strategies.

The main contributions of this paper are: first, we adapted Ergen's model [5] to the MAC and PHY layers of the IEEE 802.11ah; second, we prove the application of the proposed metric comparing the performance of different grouping policies, and showing that, despite the assumptions of the analytical model, it is always able to identify the best strategy among those compared. Unlike other models, our proposed metric considers different RAW combinations based on configurations including different MCSs, payloads and group sizes. Simulation results highlight the proposed model as a useful analysis tool in RAW-enabled scenarios. Additionally, to the best of our knowledge we are the first to evaluate the accuracy of NS-3 IEEE 802.11ah models by comparing it with analytical model results.

The rest of this paper is distributed as follows: Section II reviews the existing analytical models for the RAW feature evaluation and related work. In Section III, we include the details of the RAW throughput evaluation and the e-model explanation. Section IV comprises the performance evaluation of the analytical model, where we validate the simulation results against the analytical model. In Section V, the applicability of the model is presented using different strategies to prove the utility of the proposed e-model. Finally, in Section VI conclusions and future work are presented.

II. RESTRICTED ACCESS WINDOW

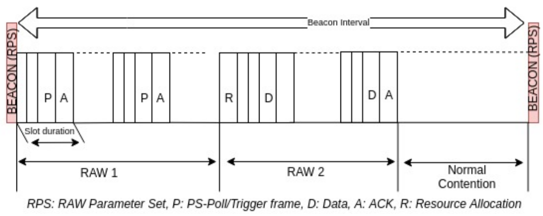

Figure 1. Restricted Access window structure.

New contention-free channel access period called RAW [6] is included in the IEEE 802.11ah standard. RAW is defined and designed to reduce collisions and improving the channel efficiency by splitting stations into different groups and delimiting channel access only to a reduced group during a particular time period.

Notice that the channel air time is divided into multiple intervals, some of these are assigned for RAW groups, alternatively, other periods are shared and can be accessed by all non-RAW stations using the legacy IEEE 802.11 Enhanced Distributed Channel Access (EDCA) [3].

The RAW Parameter Set (RPS), transmitted at fixed intervals within beacon frames, is used to announce the RAW configuration, specifying which stations belong to each group using AID, duration and group start time. A given RAW is further divided into slots of equal duration. Within a RAW, the stations are distributed among slots following a round-robin assignment (cf. Figure 1).

Furthermore, two independent back-off rules are used, one back-off state for EDCA and the second for each RAW slot, continuing the EDCA back-off when the RAW slot is finished.

Notice that the number of groups and their duration have a big impact in the RAW optimal configuration as the authors in [12] highlight. New approaches have been studied since IEEE 802.11ah's RAW mechanism was defined, outstanding related works based on Markovian Chains presented in [7] and [8]. A new grouping scheme is proposed in [9], in which STAs are allocated by the AP to each time slot during a RAW, taking into account geographic positions in an attempt to reduce the collision probability and to decrease the hidden-node problem. As other studies suggest, each RAW slot has the same duration in the entire RAW period. In [10], authors argue that the duration of each slot should be chosen according to the size of the group to enhance the saturation throughput for a uniform grouping scheme in IEEE 802.11ah.

In [11], an AID shuffle mechanism that works with any slot size is proposed for each STA to find, in a distributed way, a different and distinct temporary AID in each RAW to address the fixed subgroup problem. Authors in [12] determine the optimal RAW parameters as a function of the network's conditions with the aim to achieve optimal performance in terms of throughput, latency and energy-efficiency using a network simulator (NS-3), where the sub-1 GHz model and IEEE 802.11ah MAC protocol are implemented [13]. Authors in [14] present a mathematical model, which allows estimating throughput and energy consumption based on two-slot based model with slot boundary crossing option enabled. A surrogate model that predicts RAW performance given specific network conditions and RAW configuration parameters is presented in [15]. Notice that the surrogate model needs an initial set-up configuration to determine the RAW parameters. The optimization of the surrogate model for IEEE 802.11ah in heterogeneous networks is presented in [16].

A sector-based device grouping scheme for fast and efficient channel access in IEEE 802.11ah is proposed by [17]; the performance of this scheme is compared with the conventional DCF and IEEE 802.11ah. MAC layer performance metric of differentiated Quality of Service (QoS) IoT nodes in IEEE 802.11ah RAW mechanism is presented in [18]. In [19] authors study an energy-efficient RAW optimization in IEEE 802.11ah based uplink communications, by identifying the number of slots in each RAW for different group scales and a retransmission scheme to reuse the empty slots. An algorithm based on Markov chain and probability theory is presented in [20]; the optimal solution is derived by applying a gradient descent approach aiming to reduce delay through RAW control and maximizing uplink energy efficiency.

The use of relay-based IEEE 802.11ah networks method is used in [21] to estimate the RAW size based on traffic loads, to provide relay node support for stations to use different MCSs, and to measure the suitability of IEEE 802.11ah based network in covering a large region of a smart city.

In the present work, an analytical tool combined with NS-3 simulator (with specific modifications to RAW group features) are used for RAW evaluation, in scenarios including different MCSs, payloads and group sizes. It is shown that the proposed analytical model becomes a useful analysis tool in RAW-enabled scenarios. Furthermore, to the best of our knowledge, this is the first time that NS-3's IEEE 802.11ah models are validated against analytical models.

III. Analytical model for the RAW evaluation

This study applies and adapts Ergen's model [5] on IEEE 802.11ah RAW slots, where the saturation throughput is calculated taking into account the average collision time ($\overline{T_c}$) and the average successful transmission time ($\overline{T_s}$) for the new IEEE 802.11ah standard with a single AP, one spatial stream, and a varying number of devices, as described in each strategy (cf. Section V). Ergen's model is an extension of the known Bianchi's model [3] to allow heterogeneous scenarios with multi-rate stations (STAs). We modify current Ergen's model to obtain throughputs in saturation by including the IEEE 802.11ah's PHY and MAC layer modifications and to support different packet sizes. We also assume that the STAs within each RAW group show the same traffic pattern (all stations are in saturation). Note that this assumption does not necessarily mean stations are saturated all the time, which is not realistic in a practical IoT scenario; we consider that, at least during their assigned slot, the stations always have frames pending to be delivered. Under these circumstances, we argue that it is safe to consider the expression for the normalized saturation throughput of each STA operating at a given PHY rate based on the aforementioned model [5].

The bit rate of the stations involved, along with their packet size, is a major characteristic that determines the duration of a successful transmission and of a collision. For a multi-rate scenario, $\overline{T_s}$ is the value for the average duration of a successful transmission T_s; similarly, $\overline{T_c}$ stands for the average of T_c values (i.e., duration of a collision), note that the duration of a collision is determined by the STA with the longest transmission time, which depends on the packet size and the transmission rate used. In our e-model, we compute $\overline{T_c}$ and $\overline{T_s}$ per each slot. Within each slot, N STAs compete; and G different packet transmission times are observed, where N_j represents the number of STAs in group $j \in (1, \mathrm{G})$:

$$\overline{T_c} = \sum_{i=1}^{N-1} \sum_{j=1}^{G} \sum_{k=1}^{N_j} \binom{N-k-\sum_{l=1}^{j-1} N_l}{i} * T_{cj} \tau^{i+1} (1-\tau)^{N-1-i} \tag{1}$$

$$\overline{T_s} = \sum_{j=1}^{G} N_j T_{sj} P_{sj} = \tau (1-\tau)^{N-1} \sum_{j=1}^{G} N_j T_{sj} \tag{2}$$

where P_{sj} is the probability, in each group j, that exactly only one station transmits in a randomly chosen slot time, and this transmission is successful, τ is the probability that a station transmits in a randomly chosen slot time. T_{sj} corresponds to the total time required by a STA in group j to successfully transmit a frame (including inter-frame space and corresponding ACK control frame).

Note that Bianchi already defines T_c and T_s (cf. [3]), and Ergen explains how to obtain $\overline{T_c}$ and $\overline{T_s}$ for multi-rate scenarios [5], which we adapted to also support multiple packet sizes. Please, refer to [3] and [5] for more details.

For the calculations of $\overline{T_c}$, consider that a given STA's transmission collides if i other stations also attempt transmission, $i \in (0, \mathrm{N} - 1)$. The duration of a collision is determined by the STA with the largest transmission time (i.e., largest T_{cj}), thus, the order in which the G groups are considered is important: j = 1 stands for the group of stations with the largest transmissions, and j = G for the fastest. Observe that $\overline{T_c}$ expression applies when $N \geq 2$ and $G \geq 2$.

The e-model's per-RAW slot aggregate saturation throughput is then calculated as:

$$S_{slot} = \sum_{j=1}^{G} N_j S_j = \frac{\tau(1-\tau)^{N-1} E_p}{E_s} * N \tag{3}$$

Using the e-model, E_p consists in the average data frame payload size and, according to Bianchi's definition, E_s, the average duration of a slot. Bianchi's slot definition, where a transmission event, collision or absence of transmission at a given instant, not to be confused with a RAW slot (i.e. divisions of a RAW), is as follows:

$$E_s = P_\sigma \sigma + \overline{T_s} + \overline{T_c} \tag{4}$$

where P_σ consists in the probability that the slot time is empty, and σ is the duration of an empty slot (cf. [3]).

The total throughput, considering all R RAW groups, each one consisting of K_r RAW slots, is computed as follows:

$$S_{total} = \sum_{r=1}^{R} \frac{d_r * \sum_{k=1}^{K_r} \frac{S_{slot\_k}}{K_r}}{d_{total}} \tag{5}$$

where d_r is the duration of the rth RAW and d_{total} is the total duration of all R RAWs.

IV. Performance Evaluation of the Analytical Model

The evaluation is carried out by means of simulations using the NS-3 discrete-event event-based network simulator, licensed under the GNU GPLv2 license. NS-3's IEEE 802.11ah models were developed by [13]. We have to note that NS-3's capture effect implementation (the effects of which have not been evaluated yet in the new IEEE 802.11ah radios) was disabled, providing a fairer comparison with the model, which considers all collided packets are effectively lost.

First of all, a set of tests has been designed aiming to evaluate the reliability of the e-model and NS-3's IEEE 802.11ah models for the EDCA simple case. Figure 2 highlights the results at 1 MHz channel bandwidth, 1 spatial stream, utilizing three different MCS (MCS 10 at 150 kbps, MCS 4 at 1.8 Mbps and MCS 9 at 4 Mbps) and packet sizes of 100 Bytes. NS-3 simulator results are obtained averaging over a large number of different simulations, where the STAs are randomly placed within a 50 meters radius from the AP. Confidence intervals are very small and are therefore not shown in the figure to facilitate the reading of Figure 2.

Depicted in Figure 2, our analytical model shows a difference within the ±5%, on average, on all the cases tested, in comparison with the NS-3 results under the same scenario configuration. In the case of 20 stations using the MCS 4 at 1.8 Mbps, the model shows a throughput of 0.276 Mbps, while the simulation result was of 0.270 Mbps, showing a difference of 2.275%. In contrast, in the case of 36 STAs the e-model shows a 0.261 Mbps throughput, while the simulation provides 0.247 Mbps, resulting in the largest average difference observed, of almost 5%.

Similarly, in the case of MCS 9 (4 Mbps), where, for example, 15 stations give us an analytical throughput of 0.340 against the simulation result of 0.335, a 1.46% difference. The case of 27 STAs with 0.325 Mbps obtained with the analytical model throughput versus the 0.307 Mbps simulation throughput shows a difference of 5%.

The novel MCS 10 in IEEE 802.11ah, with 150 kbps, in the case of 11 STAs, shows 0.068 Mbps vs 0.065 Mbps for analytical model and simulation results, respectively (5% difference). Also, 22 STAs case gives an e-model throughput of 0.063 Mbps against 0.060 Mbps with an average divergence of 4%.

For larger groups, the divergence increases, resulting in a difference of more than 10% in some cases. However, note that the use of grouping with RAW is intended to reduce the number of competing STAs so that slots will grant access only to a few STAs, domain in which both simulation and model provide very similar results.

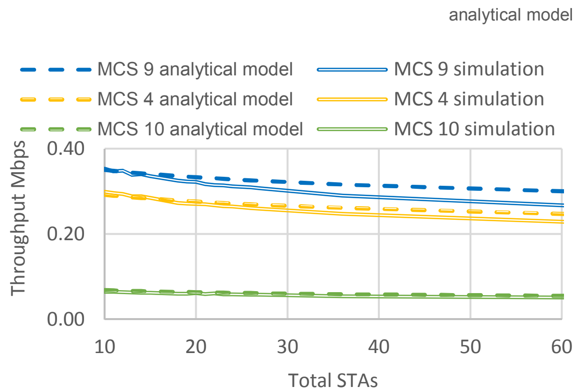

Figure 2. IEEE 802.11ah EDCA analytical model vs NS-3 simulation results.

The presented evaluation highlights the validation of the analytical model against the NS-3 simulation results for IEEE 802.11ah with 3 different PHY rates (low, medium, high). These results constitute a benchmark for saturation models in IEEE 802.11ah for homogeneous scenarios. In the following, we evaluate the performance of the model in heterogeneous scenarios.

The following performance evaluation scenario presented is formed by a variable number of STAs using EDCA. Three different types of STAs are present (i.e., G=3), each group defined by the use of a given MCS and a given packet size; the number of STAs in each group is the same (i.e., $N_j = N/3$ for j = 1, 2 and 3).

EDCA multi-rate analytical model comparison against the EDCA multi-rate NS-3 simulation is depicted in Figure 3. The difference between the model and the simulation varies from 0.113 Mbps versus 0.112 Mbps throughput with a total of 39 STAs (<0.2%), to 0.094 Mbps versus 0.090 Mbps in the case of 90 STAs (~4%).

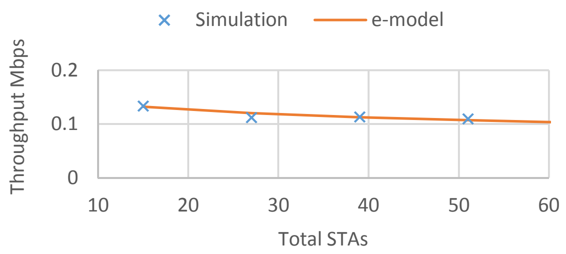

Figure 3. IEEE 802.11ah EDCA multi-rate analytical model vs NS-3 simulation results.

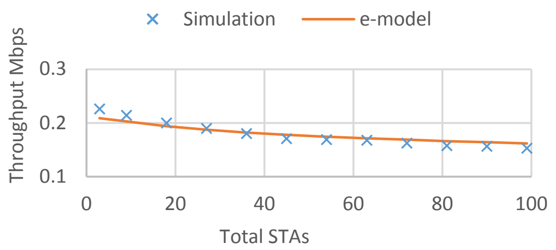

Figure 4. IEEE 802.11ah RAW feature with two groups, analytical model vs NS-3 simulation results.

Finally, Figure 4 depicts the use of the RAW feature considering two RAW groups, each with one slot. The first RAW group is composed of fast STAs employing MCS 9 (4 Mbps), and the second RAW group includes slow stations operating with MCS 4 and 10 (1.8 and 0.15 Mbps). The same trend is observed as shown in Figures 2 and 3, with a difference within ±5% between the results of the e-model and the simulator. Giving as sample the simulation throughput with 36 stations, a simulation result of 0.180 Mbps against the e-model throughput of 0.182 Mbps can be observed, with an average 1.09% difference. With 72 stations, a simulation throughput of 0.162 Mbps is obtained in front of the e-model throughput of 0.168 Mbps, showing an average difference of 3.5%.

All of these results validate the functionality of the proposed e-model, and make it particularly valuable for predicting the performance of a given RAW configuration, thus making the e-model a useful analysis tool in RAW-enabled scenarios.

V. Applicability of the Model

In this section we show a simple e-model-based grouping is capable of enhancing the RAW performance by evaluating different strategies with different RAW configurations, and selecting the best strategy to use in each case. To that aim, we present a timeline (seconds), where RAW grouping is enabled and different stations (with different PHY rate) become active or inactive dynamically. We evaluate the scenario using different baseline RAW grouping strategies, as described below. All the strategies presented below are evaluated in the same scenario with the same configuration (100 Bytes of payload, 1 MHz channel bandwidth, 1 spatial stream), and three different MCS available (MCS 4, 9 and 10), where each strategy combines different number of STAs with fast MCSs or slow MCSs. The number of STAs and their MCS is varying constantly as the transmission evolves.

a) Strategy 1: legacy EDCA mode (i.e., no RAW in use).

b) Strategy 2: three RAW groups defined, one per each MCS (i.e., STAs with different MCS are not mixed). This strategy is focused on medium contention reduction because it splits STAs into smaller groups and reduces the performance anomaly [22] (i.e., performance degradation in the presence of slow STAs).

c) Strategy 3: STAs are split into three RAW groups, equally distributing fast and slow STAs (i.e., mixed MCSs). This strategy aims to reduce contention while keeping fairness among the groups.

d) Strategy 4: two RAW groups, one for the fastest transmission MCSs (1.8 Mbps and 4 Mbps), and a second group where all the stations use the slowest MCS 10 (150 kbps). This strategy maximizes the throughput of the fast STAs by avoiding the performance anomaly; it also reduces contention.

e) Strategy 5: same as strategy 2 (i.e., three groups, no mixed MCS), but in this case, the RAW duration depends on the number of STAs in each group.

f) Strategy 6 (e-model): computes the expected saturation throughput in the current network state for all the above strategies, following the model described in Section III and selects the one providing the best throughput.

Considering the aforementioned strategies for the RAW configuration in IEEE 802.11ah, the evaluation performed, as shown in Figure 5, highlights that the e-model strategy is capable of identifying the best grouping strategy, provided that the number of stations with pending frames, their packet size and their MCS are known.

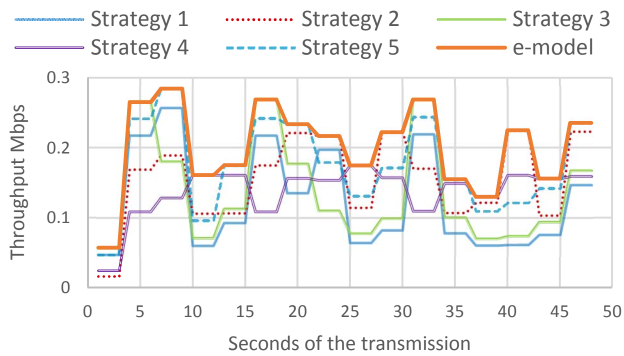

Figure 5. Different RAW grouping strategies against the e-model.

Note that different strategies perform better than others in different scenarios. For example, the network configuration after 10 seconds is better managed by strategy 4, with 0.1608 Mbps throughput thus defeating the other strategies; same applies at 26 seconds time with a maximum throughput of 0.1734 Mbps. Strategy 4 also wins at instant 45 seconds reaching a throughput of 0.1559 Mbps.

A different scenario happened in seconds 9, 15, 21 and 48, where strategy 5 shows the best performance, giving throughputs of 0.2843, 0.1748, 0.2335 and 0.2352 Mbps, respectively. Strategy 3 is the best option in seconds 1, 18, 33, showing a throughput of 0.0565, 0.269 and 0.2689 Mbps, respectively. In all cases, the best performing strategy was properly identified by the e-model and, therefore, strategy 6 was able to match the best performance among the other strategies, identifying the best grouping strategy, provided that the number of stations with pending frames, their packet size, and their MCS are known. The e-model strategy achieves an average throughput of 0.2016 Mbps over the whole simulation, while the second-best strategy, i.e. strategy 5 in the case tested, only achieves 0.1754 Mbps.

Note that the time required to evaluate the throughput yielded by a given strategy can take tens of milliseconds (up to hundreds of ms, depending on the complexity of the network and the processing power available), thus allowing multiple evaluations between consecutive beacon intervals.

These results validate the utility of the e-model as a tool for any strategy in order to assess the performance of a given RAW configuration, set for a given network scenario.

VI. Conclusion

New standards and mechanisms are needed to solve the expected massive number of stations supported by IoT networks using multiple applications with different requirements, such as QoS, latency, energy-consumption and throughput. In the present work, we propose an analytical tool (e-model), together with the NS-3 simulator with specific modifications to RAW mechanism, for evaluating heterogeneous RAW configurations. Additionally, e-model is used to validate the simulations results obtained in NS-3, being this, to the best of our knowledge, the first time that NS-3's IEEE 802.11ah models are compared to analytical models. For the sake of clarity, IEEE 802.11ah evaluation is performed by employing 3 different PHY rates (low, medium, high). These results constitute a benchmark for saturation models in IEEE 802.11ah for homogeneous scenarios, where all STAs are using the same MCS, and for heterogeneous scenarios, with STAs operating at different PHY rates. RAW performance is evaluated by using distinct strategies with different RAW configurations, and the e-model is thus shown to be a useful tool to assess the best RAW performance for a given network scenario. As a part of future work, we will study the dynamic application of the e-model in a scenario with varying network requirements.

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