Management of IEEE 802.11ah networks: providing guarantees for CoAP-based interactions

Research summary

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ABSTRACT

The new IEEE 802.11ah Wi-Fi standard addresses major challenges of the Internet of Things (IoT) domain: a medium range low-bandwidth wireless communication between a large number of constrained devices, at a low cost and low power. However, IEEE 802.11ah supports higher data rates than all other sub-GHz standards, which makes it potentially suitable for more demanding communication scenarios. Moreover, the Constrained Application Protocol can provide reliable interactions without much overhead and offer a management interface. Our research addresses high-performance IoT networks, exploring the feasibility and performance of CoAP-based closed-loop control over managed IEEE 802.11ah networks.

1 INTRODUCTION

IEEE 802.11ah, also known as Wi-Fi HaLow, is a communication standard for heterogeneous Internet of Things (IoT) devices that operate in the unlicensed sub-1GHz frequency bands (e.g., the 868 MHz band in Europe) [4]. Its main goal is to provide a good trade-off between range, throughput and energy efficiency. On the MAC layer, several innovative features were introduced, such as fast association and authentication, restricted access window (RAW), traffic indication map (TIM) segmentation and target wake time (TWT). These features allow 802.11ah to support a large amount of energy constrained stations in dense networks and to achieve up to 1 km range in outdoor environments.

Because of the high data rates that are supported (up to 7.8Mbps), 802.11ah is one of the first IoT technologies in which both high-throughput and low data-rate IoT devices can be supported in an energy efficient manner [5]. Therefore, it will be able to support, apart from typical sensor monitoring scenarios, scenarios where guarantees on performance are needed. One good representative of such scenarios is closed-loop control, which requires reliable bidirectional traffic, limited latency and jitter.

My research therefore explores the limits of this technology as well as the related management problems for properly exploiting its features.

2 PROBLEM STATEMENT

Delay is the arch enemy of feedback systems. It is introduced by (1) both actuation and sensing since neither is immediate in the real world, (2) processing - calculating the control value and (3) packet delivery. This work focuses on the latter. Transport delay contributes to lower stability margins and must be minimized. Round trip time in a closed-loop must be smaller than the sampling period of the system response T_S, i.e. the time between two consecutive sampling moments, otherwise the controlled system might get unstable.

Considering CoAP-based control loops, I explore the limits of the IEEE 802.11ah technology in terms of achievable maximal sampling rates versus the number of supported loops, with respect to performance constraints such as jitter, reliability and latency and while taking into consideration management possibilities of the technology. The goal is to present intuitive and simple mechanism(s) for network management that can enable stable and reliable high performance networks. CoAP is chosen over TCP since it is less verbose and optimized for IoT solutions, while it provides reliability mechanisms. Furthermore, I explore optimal TIM configurations for different setups and combine them with optimal RAW configurations [7], aiming to achieve the best performance (the highest throughput along with the smallest awake time per station).

3 CURRENT RESEARCH

I am considering a scenario where a large set of sensors sends samples of measured values to a large set of controllers, which calculate a control value and send it back to actuators. Sensor and actuator are considered to be hosted on the same device, whereas the controller is a separate device. Each sensor/actuator pair is assigned to its own controller, neither controllers nor sensor/actuator pairs communicate between themselves, and both devices are considered energy constrained. This is representative for closed-loop control of slow processes (i.e. temperature or level regulation in large tanks) since the sampling frequency is usually 2-10 times higher than the frequency of measured value. I updated the ns-3 IEEE 802.11ah implementation [5], [6] with basic CoAP support on top of IPv4 and IPv6 (with 6LoWPAN).

I conduct (1) large scale experiments with different IEEE 802.11ah configurations in terms of both TIM and RAW features. I aim to execute simulations for a very large number of configurations and from the obtained results derive behavior patterns for dense networks with control-loop traffic. Afterwards, I conduct several (2) large scale experiments with fixed number of loops, static TIM and RAW configurations, and different combinations of TIM and RAW assignment procedures. I evaluate inter-packet delay at both controller and sensor/actuator side and measure its standard deviation from the sampling period of the loop T_S. With the results of the experiments, it will be possible to optimize network configuration

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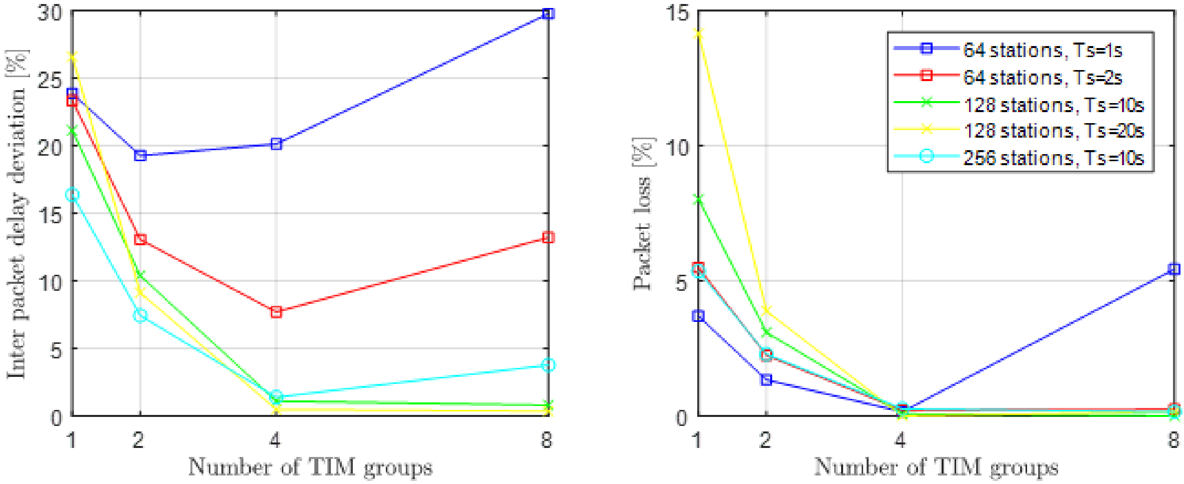

Figure 1: Packet loss and inter-packet delay deviation for CoAP-based control loops with varied number of TIM groups, where long beacon period is constant.

using the following criteria:

$$v* = \min_{l_P, \bar{j}, d \in E} f(l_P, \bar{j}, \overline{|d - T_S|}), \qquad (1)$$

where l_P denotes packet loss percentage, $\bar{j}$ mean jitter and d inter-packet delay at the client side. E denotes the set of simulation results with the same number of stations, same control-loop configurations and different IEEE 802.11ah MAC layer configurations. Insights in such optimized configurations will inspire simpler management algorithms. Figure 1 shows preliminary results of network performance for CoAP-based control loops.

To the best of my knowledge, most of the results achieved with the IEEE 802.11ah technology have been obtained without considering the full protocol stack. Moreover there is only a few research papers that considered both uplink and downlink traffic [1]. The largest number of research performed has focused on the RAW mechanism, where a number of algorithms for RAW optimization are proposed [7]. Others optimize energy consumption [8], [2], but none went so far to adapt the beacon interval to the traffic patterns in the network, which also influences possibilities with RAW configuration since maximum 8 RAW groups are possible in 1 beacon interval. The RAW group duration can also be limited by beacon interval.

The ratio between the traffic interval and beacon interval, with respect to packet size, largely defines the network performance. One control-loop takes 4 transmissions of duration t_{TX}. Therefore, in the ideal case where there is no contention, the traffic interval should be no lesser than $4Nt_{TX}$ and the RAW slot duration must be no lesser than t_{TX}. In the (realistic) case of multiple stations in one RAW slot, medium access is stochastic, therefore it is only possible to estimate the minimal RAW slot duration for N stations to successfully transmit their frames with some predefined probability as elaborated by Khorov et al. [3]. However, Khorov et al. assumed only uplink traffic, and their model is not applicable in my case.

4 CONCLUSIONS

This summary gives a brief introduction to the study of the management of IEEE 802.11ah networks with the aim to provide guarantees for CoAP-based interactions. The considered use case is closed-loop control in a dense IoT networkThis study targets the feasibility analysis of high performance IoT networks and development of self-adapting networks in accordance with traffic demands.

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