The impact of CSMA on LoRaWAN gateways' performance in IoT networks

Tadeusz Czachórski *, Krzysztof Grochla, *, Piotr Pecka, *, Anna Strzoda *, Jean Michel Fourneau †, Lynda Mokdad ‡, Monika Nycz §, and Tomasz Nycz §
* Institute of Theoretical and Applied Informatics, Polish Academy of Sciences, Baltycka 5, 44-100, Gliwice, Poland
e-mail: {kgrochla,tadek,astrzoda,piotr}@iitis.pl
† DAVID, UVSQ, Université Paris Saclay 48 Av. des Etats-Unis, 78000 Versailles, France
e-mail: jean-michel.fourneau@uvsq.fr
‡ LACL, Université Paris Est Créteil, 61 Av. du général de Gaulle, 94010 Créteil
e-mail:lynda.mokdad@u-pec.fr
§ Department of Computer Networks and Systems, Silesian University of Technology
Akademicka 16, 44-100 Gliwice, Poland
e-mail:{monika,tomasz}.nycz@polsl.pl

***Abstract*—The CSMA mode of operation was recently added to the LoRaWAN standard. We investigate, using a queueing model, how the introduction of CSMA in the communication between devices and the gate in LoRaWan may increase the probability of successful transmission. In the proposed model, customers (transmissions) are served by a multichannel station (gate), and the number of channels corresponds to the number of transmissions that can be performed in parallel. We introduce a queueing model with multiple attempts to find a free channel and investigate their impact on transmission throughput and reliability.**

***Index Terms*—LPWAN, LoRa, CSMA, queueing models, transmission losses**

I. Introduction

LoRa, together with LoRaWAN, defines a communication system architecture enabling wireless communication for battery-powered devices to access the Internet. Previously, LoRaWAN has utilized the ALOHA protocol at the MAC layer, which can lead to high collision rates under dense network conditions. To enhance channel access efficiency, the LoRa Alliance, basing on [1], introduced a technical recommendation [2] proposing the use of a CSMA approach. The primary objective of our study is to investigate, using a queueing model, how the introduction of the CSMA protocol affects the probability of successful transmission in LoRaWAN.

II. The gateway model

A group of devices communicates with the network through a communication gate that has K channels and hence may serve up to K communications in parallel. In the ALOHA protocol, when a device demands communication, a random channel is chosen, and if it is not occupied, the communication is successful; otherwise, it fails.

In the case of the CSMA protocol, the number a of checked channels may be higher, $a \leq K$. This policy evidently improves the chances of finding a free channel,

The channel may be modeled by a multichannel queueing system, where customers represent the transmission demands made by devices, and the number of service channels corresponds to the number of parallel transmissions that can be performed.

Probability of a packet rejection. In a typical queueing model, the customers are allowed to enter the system at any time if there is a place to accommodate them. It differs under the ALOHA or CSMA protocol. Assume that n out of N channels are occupied. The probability of finding an occupied channel and be rejected with the single test (ALOHA) is $r^1(n) = n/N$, the probability of being rejected after two trials (CSMA with $a = 2$ trials), if $n > 1$ is

$$r^2(n) = \frac{n}{N}\frac{n-1}{N-1},$$

etc. This way we compute $r^a(n)$ for any a and n. The admission rate for n occupied channels and a admitted trials is $z^a(n) = 1 - r^a(n)$. If λ is the incoming flow; the accepted flow in case of n occupied channels is $\lambda^a(n) = \lambda z^a(n)$; the effective flow $\lambda^a_{eff}(t)$ and efficiency $\eta^a(t)$ are

$$\lambda^a_{eff}(t) = \sum_{n=0}^{K-1} p^a(n,t)\lambda(t)z^a(n), \quad \eta(t)^a = \frac{\lambda^a_{eff2}(t)}{\lambda(t)}. \quad (1)$$

We use M(n)/M(n)/K/K model, e.g. [3], with service intensity $\mu(n) = n\mu$, $n = 1 \ldots K$, and $\lambda(n) = \lambda z^a(n)$ to determine probabilities $p^a(n)$ of n occupied channels in case of at most a trials. In the transient state, we numerically solve the state balance equations for $p(n,t)$. The assumption of an exponential distribution of interarrival times and service times is an approximation; however, we know from measurements

This research was funded in part by the National Science Centre, Poland, under the IMPRESS-U competition, project number 2023/05/Y/ST7/00192. It is also partially supported by the PL-FR PHC Polonium cooperation programme, funded by NAWA, under BPN/BFR/2022/1/00019. r 2023/05/Y/ST7/00192.

that arrival streams to the gate are close to Poissonian, and models without queues are less sensitive to the service time distribution.

Two classes of packets. Suppose that two kinds of packets are sent to the gate, one is allowed to look for a free channel a_1 times and the other a_2 times. Their intensities are λ_1 and λ_2 and service intensities are μ_1, μ_2. If $a_2 = 1$ and $\lambda_2 = \lambda_1 - \lambda_{eff1}$, the second flow may represent the part of the first flow rejected after all trials and sent following the ALOHA protocol. If $a_2 > a_1$, the second is the priority class. The corresponding Markov chain is two-dimensional with states (n_1, n_2), where n_1, n_2 are the number of channels occupied by first and second class, with $n_1 + n_2 \leq K$. We solve balance equations to determine $p^{a_1,a_2}(n_1, n_2, t)$ and compute

$$\begin{aligned}
\lambda_{eff1}^{a_1,a_2} &= \sum_{n=0}^{K-1} p^{a_1,a_2}(n)\lambda_1 z^{a_1}(n), \quad \eta_1^{a_1,a_2} = \frac{\lambda_{eff1^{a_1,a_2}}}{\lambda_1}, \\
\lambda_{eff2}^{a_1,a_2} &= \sum_{n=0}^{K-1} p(n)^{a_1,a_2}\lambda_2 z^{a_2}(n), \quad \eta_2^{a_1,a_2} = \frac{\lambda_{eff2}^{a_1,a_2}}{\lambda_2} \qquad (2)
\end{aligned}$$

in the same way as it was done for one class of customers.

Numerical examples. Figs. 1,2 refer to one class of customers and transient state model; $\mu = 1$, and λ is changing in the following pattern: $\lambda = 2.5$ for $t \in [0, 40]$; $\lambda = 5.0$ for $t \in [40, 80]$; $\lambda = 0.5$ for $t \in [80, 120]$. Fig. 1 presents the mean number of occupied channels if $a = 1$ and $a = 8$, the queue is empty at the beginning. The impact of a on channel utilization is clearly visible, and it increases as the intensity of transmissions rises.

Fig. 2 presents the corresponding transmission efficiency. Again, the impact of the number of trials is significant, especially for higher loads.

Fig. 3 refers to the two-class steady-state model and shows the transmission efficiency for both classes, each curve corresponding to a series of results with $a_1 = 1$ and $a_2 = 1, \ldots 8$. An increase in the number of trials allowed for the second class increases its transmission efficiency at the expense of the first class. At relatively low traffic volumes, the efficiency of the second class increases faster than the efficiency of the first class decreases.

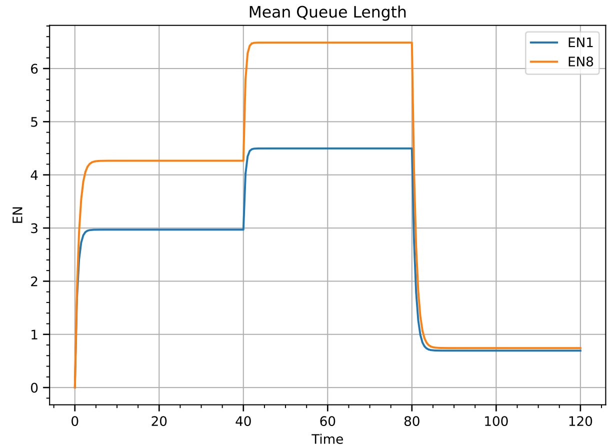

Fig. 1. One class of customers, mean number of busy channels for one and eight trials, $\lambda(t)$ as defined in the text

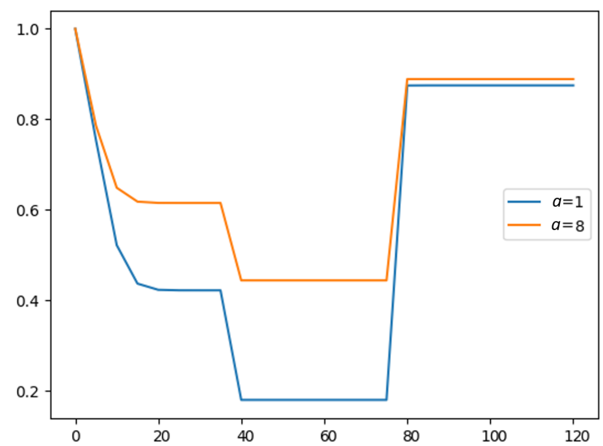

Fig. 2. One class of customers, efficiency $\eta^1(t)$, $\eta^8(t)$ following Eq. (1) , $a = 1, 8$, for $\lambda(t)$ as defined in the text

Fig. 3. Steady-state, efficiency factors $\eta_1^{a_1,a_2}$, $\eta_2^{a_1,a_2}$, Eq. (2), for two classes of customers as a function of a_2: $a_1 = 1$, $a_2 = 1, 2, \ldots 8$ (axis x) for intensities $\lambda = 2.5, 5.0, 10.0, 20$, and $\lambda_1 = \lambda_2 = \lambda/2$

III. Conclusions

The introduction of CSMA to LoRaWAN, which enables multiple trials to find a free channel, significantly enhances the performance of the gate, especially in cases of heavy traffic. The model proposed here allows us to assess it quantitatively.

References

[1] A. Gamage, J. Liando, C. Gu, R. Tan, M. Li, and O. Seller, "LMAC: Efficient Carrier-Sense Multiple Access for LoRa," *ACM Trans. Sen. Netw.*, vol. 19, no. 2, Feb. 2023. [Online]. Available: https://doi.org/10.1145/3564530

[2] CSMA Working Group of the LoRa Alliance Technical Committee, "LoRaWAN CSMA Technical Recommendation TR013-1.0.0," LoRa Alliance, Tech. Rep., September 2023.

[3] L. Kleinrock, *Queueing Systems Vol. 1: Theory*. John Wiley & Sons, 1975.