Experimental Characterization of Packet Reception Rate in LoRaWAN

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We performed extensive experiments to study the impact of varying the payload length on the Packet Reception Rate of LoRaWAN packets with various spreading factors and transmission power levels. The experimental set-up consists of motes connected to The Things Network back-end. Our results show that the payload length only slightly impacts the Packet Reception Rate, for the majority of the gateways. As a result, we conclude that besides the impact of the signal to noise ratio on the bit error rate, it seems that reception is conditioned on the initial packet detection. Our aim is to determine and experimentally model this probability with respect to the signal to noise ratio.

Mots-clefs : LoRa, LoRaWAN, Packet Reception Rate

1 Introduction

The LoRa network is gaining an increasing interest from both academia and industry. It perfectly addresses the Internet of Things (IoT) needs for a low power and long range network able to provide efficient connectivity to a wide area with a large number of IoT devices. To analyze reliability and scalability of LoRa networks, we conducted extensive experimentation on a real testbed. We evaluate the transmission quality with the Packet Reception Rate (PRR). Several factors may impact PRR and we wanted to evaluate how the payload length influences the probability of correct frame decoding. Our main finding is that the bit error rate due to the ambient noise at the receiver and collisions are not the only factors that impact the reception, but there is also an initial reception condition that applies to all frames and strongly affects each frame reception.

In the rest of the paper, we describe the basics of LoRaWAN, the MAC layer of LoRa, present our testbed, and report on the results of our experiments. The conclusion discusses the main findings.

1.1 LoRaWAN Basics

LoRaWAN is a MAC protocol proposed by the LoRa™ Alliance [Sor17] for the interoperable usage of LoRa™ modulation. It defines the network architecture, the radio access method, and the MAC frame structure. LoRaWAN is a star topology network composed of end devices and gateways connected through the Internet to a network server. End devices send data packets according to the ALOHA access method while respecting the duty cycle limitation of the used ISM band. Packets are received by all gateways within the transmission range. They forward the received packets to the server that decides of the further processing. The LoRa™ Alliance promotes an open source operational network, named TTN, that enables free of charge access to a world wide community network based on LoRaWAN.

LoRa™ stands for Long Range. Its physical layer is based on Chirp Spread Spectrum (CSS) modulation. It consists of cyclic frequency varying chirps that encodes the information. Thus, CSS needs very strong synchronization to reach a good decoding level. LoRa™ implements synchronization thanks to a frame preamble that consists of several chirps and ends with two reversed chirps. The frame transmission has several parameters but the most important one is the Spreading Factor (SF), which is linked to the ratio between the bit rate and the channel bandwidth, ranging from 7 to 12; the transmission power (TP) that

Tab. 1: Maximum data payload size at each SF.

SF	7	8	9	10	11	12
PL_{max} (bytes)	230	230	123	59	59	59

Tab. 2: Distance to gateways and altitude parameters.

Id.	gw1	gw2	gw3	gw4	gw5	gw6	gw7	gw8	gw9	gw10
Dist. (km)	0.01	0.03	2.4	-	3.9	4.4	2.9	1.7	5.2	5.5
Alt. (m)	220	240	2.4	-	253	233	246	210	249	256

takes values from 2 dBm to 14 dBm with a step of 2 dB; the Coding Rate (CR) that takes values from 4/5 to 4/8, and the Carrier Frequency (CF). The maximum length of the LoRaWAN frame payload depends on SF, as described in Table 1.

2 Related work

Several authors have performed testbed experiments to assess the network performance with focus on different parameters on different types of hardware and under various network characteristics, however, to the best of our knowledge, we are the first ones to focus on the impact of the payload size on the reception ratio measured while sending LoRaWan traffic to an operational LoRaWAN network (TTN). Mikhaylov et al. [MPJ17] studied the variation of the payload length, however, their testbed was based on wired connected motes and an artificial interferer, therefore, the results were not significant for real operational traffic. Based on a TTN logged dataset, Blenn et al. [BK17] provided in-depth statistics and an analysis of the corresponding TTN traffic but they do not provide any information on the payload length. Rahmadhani et al. [RK18] investigate the frames collision and the capture effect in LoRaWAN, they study the corruption and survival of a collision between strong and weak frames. They show that the weak frame corrupts the strong one when it is sent earlier. Therefore, in the case of high traffic closer node can be impacted by collisions.

3 Testbed and experimental setup

Our testbed consists of five STMicroelectronics motes † that implement the LoRaWAN protocol and several gateways under TTN forwarding traffic to the EU TTN server from which we collect data for measuring PRR. Motes are under control of our platform for network experimentation [LDR+18]. They are configured with several parameters and send packets to gateways within the transmission range that forward them to the TTN server. Each gateway performs a CRC check, and if CRC is valid, it forwards the packet to the TTN server. Otherwise, the gateway drops the packet. The number of gateways correctly decoding a given packet mainly depends on SF of each transmission, since higher SF trades data rate for propagation quality to reach larger distances. Up to 12 gateways received the traffic from motes. We run a background script that saves all generated traffic at a MQTT client. A mote periodically sends packets while varying the payload length (PL) from 0 to PL_{max} respecting the limitations given in Table 1. In our first configuration, CONF-A, we set SF=9, TP=14 dBm, and CR=4/5 with the duty cycle of 1% and we vary the Payload Length from 0 to 120 bytes. We ran the same configuration with various SF for almost one week, while varying PL from 0 to PL_{max}. In the second configuration, CONF-B, we set SF=9 and CR=4/5, and vary TP. Notice that we ran each configuration on the same mote. Table 2 gives, when available based on GPS location, the distance and the altitude of the gateways collecting packets during the experiments. As the GPS information of a gateway is entered by its owner, the accuracy is not fully reliable. Moreover, the distance to the gateway is not the only factor to impact the quality of channels, there are also interference, noise, obstacles. The table presents the gateways sorted by reception quality.

4 Experiment results

Packet Reception Rate (PRR) is a key metric that measures the reliability of transmissions. Fig.1 depicts PRR as a function of the frame size for CONF-A. Notice that a mandatory explicit LoRaWAN frame header

† ST Microelectronics B-L072Z-LRWAN1

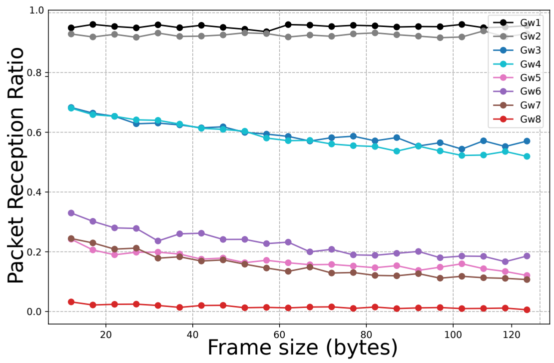

Fig. 1: PRR vs. frame size.

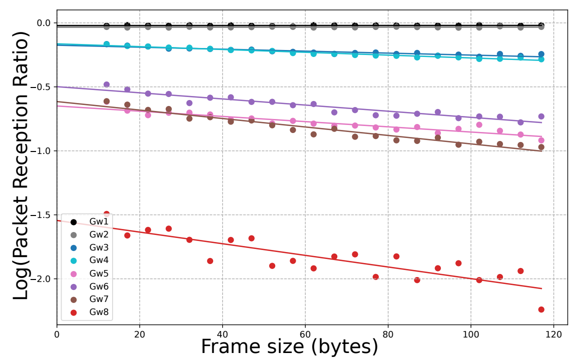

Fig. 2: $\log(\text{PRR})$ vs. frame size.

of 13 bytes is added before the frame transmission—this is why we plot the result as a function of the frame size observed at gateways. We can notice that the PRR curves are almost flat, which demonstrates only a slight impact of PL on the frame reception. The important finding is that this behavior is unexpected on a wireless channel. We provide more in-depth analyses of the behavior in Section 5.

We also notice that the shape of PRR curves is slightly different for each gateway depending on its position as described in Table 2, which strongly impacts channel quality. Indeed, close gateways Gw1 and Gw2 present flat curve due to perfect channel conditions, while Gw3-Gw7 that are more distant, their PRR curves present a slight slope shape that we can considered as almost flat. Moreover, although the distance that separates our mote from both Gw1 and Gw2 is almost the same, PRR of Gw1 is better then Gw2. This effect probably comes from the fact that Gw2 is outdoor on a higher altitude so it captures more traffic, which means more possibility of collisions with our packets.

We have performed an analysis of all the traffic received by Gw2 during one month, and we found out that traffic is scarce except for SF12, so we do not consider that collisions have a significant effect on our results. This is corroborated by the fact that longer frames, that are more subject to collisions during their reception, are only slightly more likely to be dropped.

We ran many other configurations with different values of SF and the results were similar to CONF-A, for which PRR is only slightly impacted by PL.

Fig.3 shows PRR for CONF-B as a function of the frame size for TP $= 2\,$dBm and TP $= 10\,$dBm, and Fig.4 depicts PRR as a function of the frame size for all gateways when TP $= 10\,$dBm. We observe the same behavior—only a slight impact of the payload length on the shape of the PRR curve: when we increase TP, PRR increases, but it keeps the same almost flat shape.

5 Analysis

In general, the Packet Reception Rate (*PRR*) is a function of the bit error probability and the packet length: $PRR = (1 - BER)^{PL}$, where *BER* is the Bit Error Rate. When the PL value approaches 0, *PRR* increases to 1. We would expect that the PRR value of each gateway starts close to 1 and then drops when PL increases. However, our results shown in all figures strongly differ from this expected theoretical PRR dependence on the packet size.

To investigate further the effect of PL on PRR, we propose to introduce an extra multiplicative factor, to represent its impact on PRR in addition to SNR, PL, and SF. In fact, the CSS modulation is sensitive to synchronization issues between the transmitted packet and the reception process at a gateway. We hypothesize that synchronization problems may be the root causes of the measured PRR anomaly. More precisely, we assume that errors occur during the frame detection process, more precisely, in the preamble detection process. We suspect that if the preamble is not correctly detected by the receiver, the complete frame is lost.

So, we need to determine probability P_{i}, which accounts for the uncertainty of successfully initiating the reception. To this goal, we apply the $\log$ function on the PRR formula. Since the majority of the curves are linear, we perform linear regression:

$$\log(PRR) = PL \times \log(1 - BER) + \log(P_{\text{i}}). \tag{1}$$

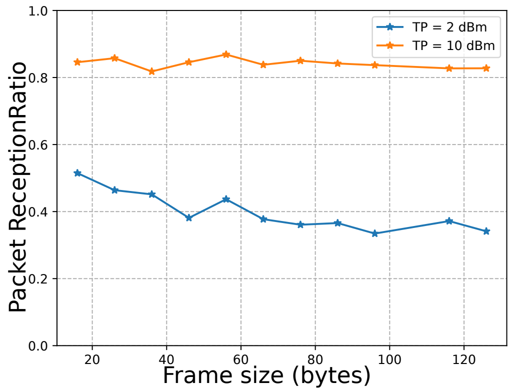

Fig. 3: PRR vs. frame size.

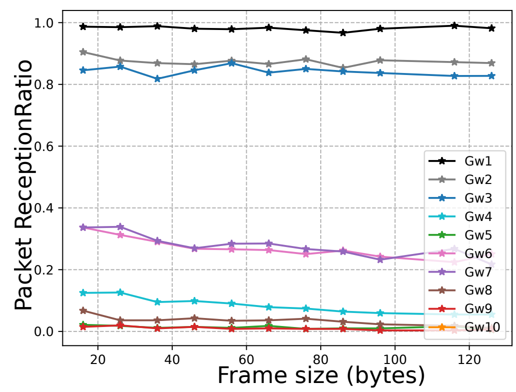

Fig. 4: PRR vs. frame size; trans. power 10 dBm

When we vary the payload of the LoRa™ packets between 0 and 120 bytes, the frame size changes from 13 to 133 bytes because of an additional 13 byte overhead corresponding to the mandatory LoRaWAN header. By extending the regression function to a virtual frame length of 0, we obtain the numeric value characterizing the multiplicative factor as shown in Fig.2.

At this stage, we are convinced that this additional factor plays a prominent role in packet reception. We still need to characterize it with more precision and assess the influence of the LoRa™ physical parameters. We also need to check if the same effect is observed on all gateways.

6 Conclusion

Our results first show that there is only a slight impact of the payload length on the Packet Reception Rate. We also notice that, depending on the signal strength at the gateway, a probability of initial reception is in fact a dominant factor. This finding has important consequences for LoRaWAN application designers: it is always better to favor long frames because the actual frame size has little influence on transmission reliability.

Our future work will focus on studying and characterizing this initial reception probability experimentally, and to do so, we will vary the preamble length and other parameters such as spreading factor, transmission power, and coding rate, although the latter one is not expected to be significant. Finally, we plan to propose a refined model for the computation of the packet reception probability, which will lead to obtain a realistic estimation of the LoRaWAN cell capacity.

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