A LoRaWAN Adaptive Retransmission Mechanism

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***Abstract*—LoRaWAN is a widely used protocol for low-power Internet of Things devices. Due to duty cycle restrictions imposed in sub-GHz unlicensed spectrum, the downlink time resources of the gateways are limited. If many end-devices request acknowledgments for their uplink transmissions, the gateway resources will be depleted fast, especially if retransmissions occur. Apart from the obvious effect on the network congestion, this also has a negative effect on the number of unique transmissions that an end-device can send, because repeated retransmissions of the same uplink may postpone scheduled transmissions of new data and violate the application requirements. This paper examines the impact of retransmission attempts on network performance and proposes an adaptive retransmission mechanism with the main goal of increasing the unique packet transmissions and, at the same time, meeting the application requirements. Simulation results show that, even though the packet delivery ratio is dropped, the proposed mechanism not only increases the unique packets, but it also achieves a better energy consumption as compared to an existing approach in the literature and to an approach that always uses the maximum number of retransmissions.**

I. INTRODUCTION

Low Power Wide Area Networks (LPWAN) technologies promise to connect massive numbers of Internet of Things (IoT) devices at low cost, with a wide coverage of up to several kilometers and many years of battery lifetime. Multiple low-power solutions are already available in the market to support IoT applications such as LoRaWAN, Sigfox, and NB-IoT. LoRaWAN is a popular and emerging LPWAN protocol for energy constrained IoT devices. It is based on LoRa, a chirp spread spectrum modulation which can achieve long communication ranges at a low power cost. The LoRa PHY layer employs a modulation parameter called Spreading Factor (SF) to adjust the data rate and sensitivity. Transmissions with higher SFs achieve longer ranges at the cost of lower data rate, and thus, higher energy consumption for the same channel bandwidth and payload.

LoRaWAN end-devices (EDs) can operate in three modes; Class A, Class B, and Class C. By default, LoRaWAN EDs operate in Class A mode and turn on their radio only when they send or receive data. EDs which operate in Class B open receive windows at specified synchronized times, while Class C EDs are not considered energy efficient because they have their radio always on to receive data [1]. Class A mode supports bidirectional communication between the EDs and the Application/Network Servers (NS); the EDs-gateways communication is done over a pure Aloha channel access mechanism, while the gateways-NS communication is done over a non-LoRa protocol.

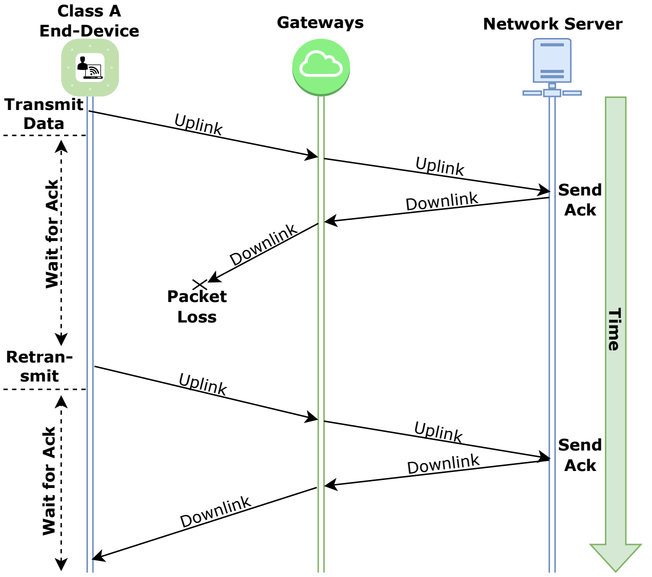

Fig. 1. LoRaWAN Class A retransmission policy.

Class A supports two types of traffic; confirmed traffic and unconfirmed traffic. When confirmed traffic is selected in the uplink packet header, the NS will try to acknowledge the uplink transmission using two receive windows, RX1 and RX2. By default, these two windows open 1 and 2 seconds after the uplink, respectively. EDs expect an acknowledgment from the NS through a gateway in one of these two windows. As it is shown in Fig. 1, if an ED does not receive a downlink packet in any of these windows, it retransmits the uplink after some random time until an acknowledgment is finally received or the maximum number of attempts is reached. In the latter case, the packet is finally dropped. By default, LoRaWAN retransmits an uplink once, but the NS can select a higher value depending on the application requirements.

It is known in the literature [2, 3, 4, 5, 6, 7] that increasing the number of retransmission attempts increases the probability of delivering a packet but it also increases the overall network load and leads to network congestion, which ultimately degrades the overall network performance.

At the same time, every ED has different application requirements to meet in terms of packet rate and packet success ratio. Some applications may require, for instance, 1 uplink per minute while other applications may require a minimum of 5 uplinks per minute in order to capture a specific behavior of a process. Manually setting the retransmission attempts to a max value may cause delays in the next uplink if the uplinks repeatedly fail to be acknowledged, violating the application packet rate requirements. Thus, there is a need for an adaptive solution which adjusts the maximum retransmission attempts for each individual EDs considering the application requirements as well as the congestion in the network.

In this work, we present an adaptive retransmission solution where each ED can dynamically select the maximum retransmission attempts based on its application requirements. Simulation results are presented and compared to the default fixed retransmission selection approach for a variable number of end-devices but also to another approach in the literature.

The rest of the paper is organized as follows. In Section II, the related work relevant to retransmission mechanisms in LoRaWAN is presented. In Section III, we propose our adaptive retransmission mechanism, while in Section IV we evaluate the proposed solution, compare it to another approach, and discuss the evaluation results. The conclusions and potential future directions are presented in Section V.

II. RELATED RESEARCH

Many researchers stress the performance degradation due to the existence of confirmed traffic, retransmissions, and duty cycle restrictions imposed in Europe and other regions. This section goes through the existing research and discusses the impact of retransmissions on the overall network performance.

Benkahla et al. [3] extensively studied possible extensions of the Adaptive Data Rate (ADR[1]) mechanism of LoRaWAN and the impact of the number retransmissions to the overall network performance. The authors stressed the high packet loss and the lack of duty cycle resources due to the large number of retransmissions in the network and the extra generated traffic. Capuzzo et al. [8] also study the LoRaWAN behavior in the presence of confirmed traffic. Similarly to the previous study, the results show that increasing the retransmission attempts the network performance is improved, but at the same time, the congestion in the network increases due to the massive increase of retransmitted packets. The authors highlighted the requirement for an adaptive retransmission mechanism based on the traffic load to improve the network performance. Similarly to the previous works, many other works highlight the issue with the increased packet loss due to the extra retransmissions with similar conclusions [9, 10, 4, 11].

Farhad et al. [9, 10] went a step further and presented a retransmission-assisted resource management solution to reduce interference and, thus, improve the network performance. The solution increases the SF and the transmission power of retransmitted packets in order to increase the chances of successful transmission. The authors also emphasized the massive increase in energy consumption due to retransmissions.

Pop et al. [12] performed a series of simulations to understand the challenges in LoRaWAN communication due to confirmed traffic. The simulation results showed a correlation between the retransmission attempts and energy consumption along with an impact on the network reliability. This research stresses that manually selecting the retransmission attempts is not a good decision because every network or ED has different application requirements.

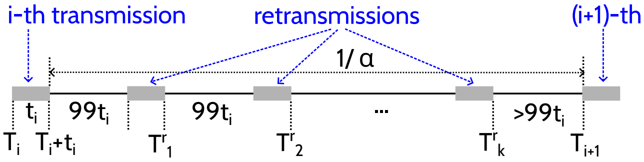

Fig. 2. Timeline of consecutive data transmissions and retransmissions.

As stressed in the literature, increasing the retransmission attempts may increase the chances of delivering the uplink and improve the ED individual performance in terms of packet delivery ratio, but at the same time, it causes an increase in congestion and energy consumption. Unlike other works in the literature, we present a solution to dynamically adapt the generated traffic by introducing an adaptive mechanism for retransmissions taking into account the application requirement at each ED. We study how this decision affects the overall packet delivery ratio, the energy consumption, and the overall unique packets.

III. ADAPTIVE RETRANSMISSIONS BASED ON THE APPLICATION REQUIREMENTS

In the proposed adaptive retransmission (AR) mechanism, each ED n keeps track of two parameters, the number of retransmissions it can afford (k_n) and the individual packet delivery ratio ($IPDR_n$). The rationale of these two parameters is explained in the next paragraphs.

The number of retransmissions an ED can afford denotes how many times an uplink can be retransmitted without having to postpone the next data transmission. It depends on (a) the airtime of the last transmission, (b) the allowed duty cycle of the radio band, and (c) the packet rate of the ED. As illustrated in Fig. 2 assuming one uplink band and a duty cycle of 1%, an ED may have several chances to retransmit packet i until packet $i+1$ has to be transmitted. In this case, it holds that:

$$T_{i+1} - T^r_{k_n} \geq 99t_i, \tag{1}$$

where T^n_{i+1} denotes the time when the $(i+1)$-th transmission of n is performed, $T^r_{k_n}$ denotes the time when the k-th retransmission of ED n occurs, and t^n_i is the airtime of the last transmission of n. T^n_{i+1} can be written as $T^n_i + \frac{1}{60\alpha_n}$, where α is the packet rate of n as a function of minutes (e.g., 1 packet per 3 minutes). $T^r_{k_n}$ is equal to $(99t^n_i + t^n_i)k_n$ because every retransmission round takes $99t^n_i + t^n_i$ seconds. Hence, Eq. (1) can be written for k_n as follows:

$$k_n \leq \frac{99t^n_i - T^n_i - \frac{1}{60\alpha}}{100t^n_i}. \tag{2}$$

At the same time, k_n cannot be higher than R_{max}, the maximum possible number of retransmission attempts for any individual ED which is set up by the NS (usually set to 8). Hence, the value of k_n is given by the following equation:

$$k_n = \begin{cases} R_{max}, & \text{if } \lfloor \frac{99t^n_i - T^n_i - \frac{1}{60\alpha}}{100t^n_i} \rfloor \geq R_{max}, \\ \lfloor \frac{99t^n_i - T^n_i - \frac{1}{60\alpha}}{100t^n_i} \rfloor, & \text{if } \lfloor \frac{99t^n_i - T^n_i - \frac{1}{60\alpha}}{100t^n_i} \rfloor < R_{max}. \end{cases} \tag{3}$$

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[1] https://lora-developers.semtech.com/documentation/tech-papers-and-guides/implementing-adaptive-data-rate-adr/implementing-adaptive-data-rate/

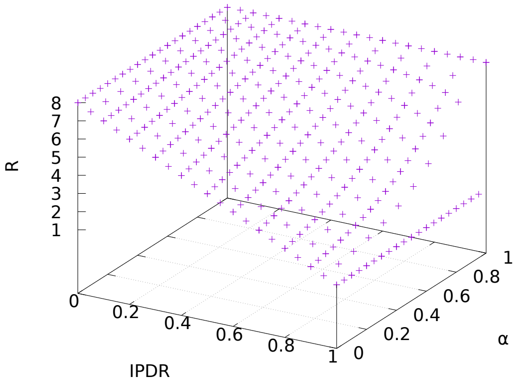

Fig. 3. Possible retransmission attempts (R) based on the Individual Packet Delivery Ratio (IPDR), and the packet rate (α) – ($k = 8$).

On the other hand, $IPDR_n$ keeps track of the ratio between the transmitted uplinks and received downlinks (acknowledgments) of n and its purpose is to provide fairness. This is because k alone is not enough to adapt retransmissions and provide fairness as it could allow EDs to always reach R_{max} even if those EDs have a very high $IPDR$. Thus, $IPDR$ is introduced to bridge that gap. Indeed, as we can observe from the following equation, EDs with a low $IPDR$ value have more chances for retransmissions compared to other EDs.

$$IPDR_n = \frac{P^n_{sent}}{P^n_{ack}}. \tag{4}$$

Combining the two parameters, the final number of retransmission attempts R_n of an ED n is calculated as follows:

$$R_n = \begin{cases} \lceil k_n(1 - IPDR_n)^{\alpha_n} \rceil, & \text{if } IPDR_n < 1 \\ 1, & \text{if } IPDR_n = 1. \end{cases}, \tag{5}$$

R_n can be calculated by any ED n every time a unique transmission occurs based on dynamic metrics that can be easily computed without any changes in the protocol.

Fig. 3 presents how R_n changes with variable $IPDR$ and α values. As it can be observed, Eq. 5 favors higher retransmission attempts for EDs with low $IPDR$ values and packet rates, while the opposite holds when we have high delivery ratios and packet rates.

IV. EVALUATION & DISCUSSION OF THE RESULTS

The proposed AR mechanism is evaluated through a series of simulations using the LoRaWAN-SIM simulator[2]. The simulator implements a path-loss model with shadowing, intra- and inter-SF collisions, capture effect, multiple uplink and downlink channels, ADR, and LoRaWAN header overhead. Three performance metrics are employed; the overall packet delivery ratio (PDR), the number of unique transmissions, and the total energy consumption. PDR is defined as the ratio between the number of uniquely transmitted packets to the number of acknowledgments received at each ED. The energy consumption is measured as the ED energy expenditure due to transmitting, receiving, and idle time. Table I summarizes the simulation parameters. The Retransmission Assisted Resource Management (R-ARM) algorithm [10] is selected for comparison purposes. This approach increases the SF and transmission power of the retransmitted packets to increase the possibility of getting acknowledged. Moreover, we compare AR to the default fixed maximum transmission attempts, which is the traditional method used in LoRaWAN.

TABLE I

SIMULATION PARAMETERS

Parameter	Value
Simulation time	100K sec
Terrain size	1500x1500 m
EDs / Gateways / positions	20-300 / 1 / Random
Spreading Factors	7 – 12
Channel bandwidth	125 KHz
Coding Rate / Preamble symbols	4/5 / 8
SFs for RX 1/2	SF7–12 / SF9 (TTN)
Uplink/Downlink channels	8 / 8+1 (TTN EU868)
Path loss model [13]	$\overline{L_{pl}}(d_0) = 110$dB, $d_0 = 40$m, $\gamma = 2.08$, $\sigma = 3.57$
Tx power	2, 7, 14 dBm (ADR-set)
Max current consumptions (Tx, RX, Idle, Sleep)	75, 45, 30, 0 mA
Voltage	3.3 V
Payload size / Packet rate (α)	16 Bytes / 0.2 (12 pkt / h)
Max. Retransmissions (R_{max})	8

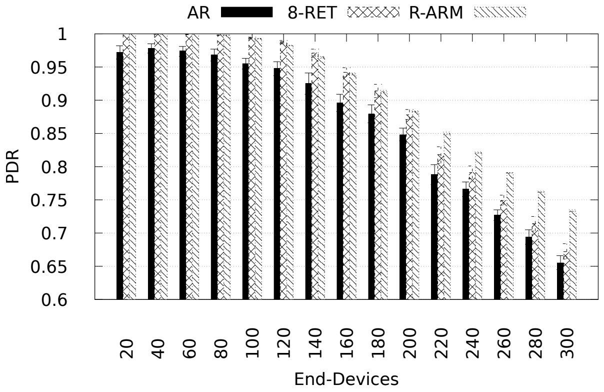

Fig. 4. Packet delivery ratio for a variable number of EDs.

As we can see in Fig. 4, increasing the number of EDs

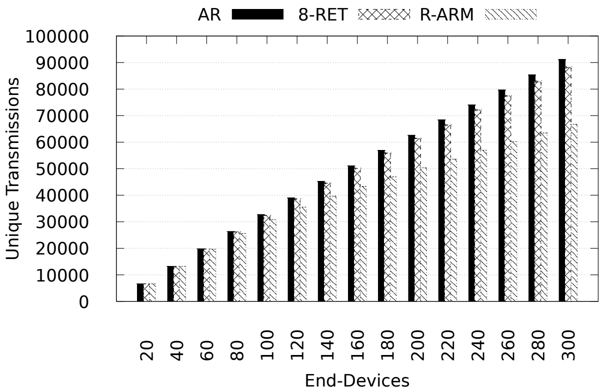

Fig. 5. Unique transmissions for a variable number of EDs.

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[2] https://github.com/deltazita/LoRaWAN-SIM

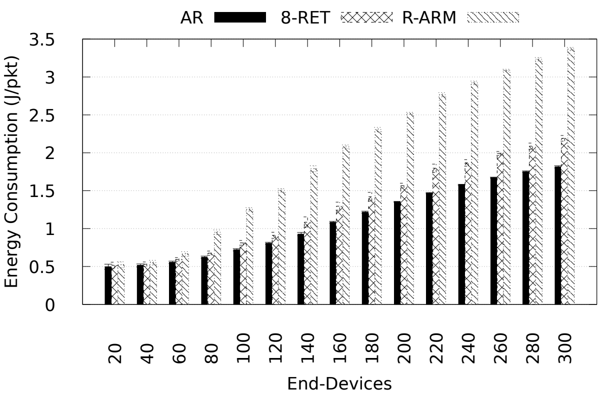

Fig. 6. Energy consumption per unique packet for a variable number of EDs.

leads to network saturation and congestion occurs, which causes interference in the network and packet loss. EDs retransmit the same uplink repeatedly to get acknowledged. As described in Section III, GWs cannot accommodate all downlinks due to the duty cycle restrictions. By using R-ARM and by fixing the retransmission attempts to a maximum of 8, we get a relatively high PDR in congested network scenarios as compared to the proposed scheme. This happens because AR adapts to the network conditions and adjusts the maximum retransmission attempts based on the individual ED performance to meet the application requirements. This can be confirmed by the very low drop in the unique transmissions even in congested networks, as it is shown in Fig. 5. In fact, AR sacrifices some PDR to increase the overall number of unique transmissions. R-ARM and the static selection of retransmission give worse performance in terms of unique transmissions as compared to the proposed approach.

Finally, Fig. 6 presents the energy consumption for the same scenario. As it is illustrated, AR consumes less energy for all instances due to the fewer number of retransmissions in the network, which ultimately allows the device to stay in sleep mode for a longer time.

V. CONCLUSION & FUTURE WORK

This paper presented an adaptive retransmission mechanism to adapt the maximum retransmission attempts of individual LoRaWAN end-devices by taking into account the application requirements. The adaptive selection of retransmission attempts is done based on metrics that the end-devices can easily compute without any special software or hardware addition. Simulation results showed that considering the proposed approach can achieve more unique transmissions which also has a positive effect on the energy consumption with only a compromise on the PDR.

In the future, we are planning to evaluate a hybrid model along with a reinforcement learning method to adapt the retransmission attempts and allocate resources accordingly.

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