Improving LoRaWAN Performance Through Adaptive Data Rate Parameter Selection

Gabriel Germino Martins de Jesus, Richard Demo Souza, Carlos Montez, and Arliones Hoeller Jr.

***Abstract*— LoRaWAN is a Low-Power Wide-Area Network specification that recommends using an Adaptive Data Rate (ADR) algorithm to improve the allocation of the network resources. However, typical configurations of the most used ADR algorithm do not suit all applications due to the optimistic link quality estimates used to compute transmission parameters. This paper shows that the offline optimization of one ADR parameter allows achieving a target performance without adding complexity to the algorithm.**

***Keywords*— Internet of Things, LoRa, adaptive data rate**

I. Introduction

As the number of connected devices increases and the Internet of Things becomes a reality, new technologies support many applications which demand massive numbers of low-cost and low-power devices communicating over long distances. The concept of Low-Power Wide-Area Networks (LPWANs) guides the development of standards to meet these requirements [1].

A remarkable LPWAN technology is LoRaWAN, a network protocol designed using LoRa as its physical layer [2], [3]. LoRaWAN defines three main elements: nodes, gateways, and network servers, and has a star-of-stars topology in which nodes can communicate with any gateway at their reach. The gateways are agnostic to the contents of messages delivered by nodes, transferring the decoded frames to the network server through a standard IP connection. Network servers handle most of the system complexity, such as downlink scheduling, identification of replicated packets, and assignment of new transmission parameters [1].

The physical layer protocol, LoRa, is based on the chirp spread spectrum modulation, allowing the demodulation of messages with a low signal-to-noise ratio (SNR) at lower data rates. The data rates change by selecting one of the available bandwidths and spreading factors (SF), ranging from 7 to 12 (SF7-SF12). As the SF increases, the required SNR at the receiver decreases, improving sensitivity. Moreover, SF selection has a significant impact on time-on-air (ToA) of transmissions [1], impacting both energy consumption and the number of collisions [4]. Transmission power (P_t) in LoRa assumes discrete values, ranging from 2 to 14 dBm in 3 dB steps for the European standard. Typically, the ToA of a LoRa symbol doubles as SF increases, while the required SNR at the receptor decreases by around 3 dB [5].

The assignment of LoRa transmission parameters can be done manually or dynamically by using an Adaptive Data Rate (ADR) algorithm [6], which operates differently at the nodes side and the network-server side. At nodes, if the device does not receive a downlink after a defined number of uplinks (usually 64), it tries to regain connectivity by first increasing P_t and then SF. The network-server side is not explicitly defined, but The Things Network [7], an open global LoRaWAN network implements the ADR-TTN algorithm [6].

For each device, ADR-TTN takes the highest SNR among the N most recently received uplinks, and subtracts the radio's sensitivity and a safety margin ($margin\_db$) to obtain the excess link budget. $margin\_db$ is selected at node installation and configurable as a device profile parameter. Dividing this budget by 3 and rounding it down generates the number of steps used to decrease SF and then Pt until they reach their minimum values for each integer part. If the result is negative, then P_t is increased. The network server is not allowed to increase SF. Typical values for N and $margin\_db$ are 20 transmissions and 10 dB, respectively. Authors in [8] propose a modification to ADR-TTN, ADR+, that considers the average SNR from the last N received transmissions instead of the maximum value, being more conservative in its estimates. ADR in nodes and network server converge differently in parameter selection and time, but enhancements are possible, improving performance and reducing convergence time [6].

In this paper, first, we use simulations to evaluate the performance of LoRaWAN with ADR considering the default $margin\_db$, showing that, in some cases, using ADR is worse than randomly allocating transmission parameters. As a contribution, we illustrate that a significant improvement in reliability can be achieved by optimizing $margin\_db$, which compensates for the optimistic link quality estimates.

II. Simulations

We evaluate the behavior of ADR-TTN in a circular deployment with radius R, where 200 nodes are randomly positioned, with the gateway at the center. We model a single frequency channel with path loss attenuation, and independent and identically distributed Rayleigh fading across time and space [9]. All nodes commit to a 0.1% duty cycle referred to SF12, regardless of their SF usage. We use the FLoRa simulator [8] in its suburban configuration. The energy consumption model is similar to [10]. A data extraction rate (DER) performance metric is the ratio between the number of

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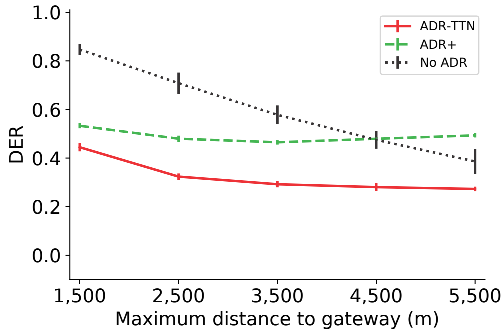

Fig. 1. Average DER in networks when using the default value for $margin\_db$ and varying the maximum distance from nodes to the gateway.

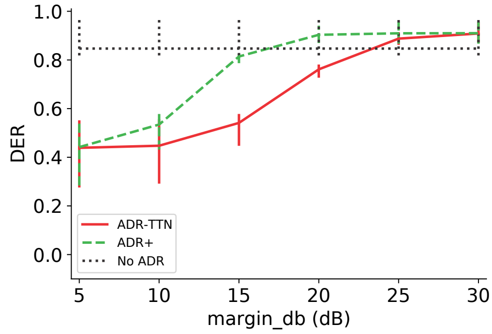

Fig. 2. Impact on average DER when varying $margin\_db$. The vertical lines indicate the first and third quartiles of the data sets.

uniquely received frames by uniquely transmitted frames. We perform 10 independent simulations for each configuration. The simulations last for 10 simulated days with a warm-up period long enough for the network to reach a steady state.

A. Typical $margin\_db$ value

The first set of experiments evaluate the performance of networks when nodes use ADR-TTN and ADR+ with their typical configuration, initialized with SF7 and $P_t = 14$ dBm, compared to a random uniform transmission parameters assignment without ADR. The radius R varies from 1500 to 5500 m. Figure 1 presents the average DER of each case. At shorter distances, networks with ADR-TTN and ADR+ perform worse than those with randomly selected parameters. While ADR+ outperforms ADR-TTN, it requires significant attenuation of the signal quality for the network server to assign higher values of SF and P_t, allowing the average DER of the network to outperform the configuration without ADR.

As ADR-TTN considers the higher SNR from the last N, it is natural that the estimated link quality is optimistic in a Rayleigh channel. However, even ADR+, which considers the average of the last N SNRs, suffers from the same problem. Since the radio's sensitivity limits the SNR measurement, the average SNR is biased by not considering values that are not detected. An algorithm that takes the biased measurement set into consideration could be considered [11], increasing complexity at the network server. Alternatively, the $margin\_db$ parameter can be optimized to overcome this limitation, as shown next.

B. Optimizing $margin\_db$

Altering $margin\_db$ can compensate for the biased link quality estimate in ADR-TTN and ADR+ by making the estimate more conservative. In Figure 2, the margin varies from 5 to 30 dB in 5 dB steps when $R = 1500$ m, showing that both algorithms outperform the configuration without ADR. When a $margin\_db$ value is selected such that the average DER of the system is 90% (25 dB for ADR-TTN and 18 dB for ADR+), both methods have significantly lower energy consumption than the random deployment, with the energy consumption distribution ranging from 50 to 75 J at the end of the simulations. In contrast, in the random deployment, the values range from 50 to over 200 J, excluding outliers. Even though the selected $margin\_db$ values for ADR-TTN and ADR+ differ, they have similar behavior because ADR+ is naturally more conservative. When using the algorithms, more than 95% of nodes transmit with SF7, and almost 80% use $P_t = 11$ dBm and $P_t = 14$ dBm. The use of higher P_t values ensures that nodes will remain connected to the gateway, and using the lowest SF keeps the energy consumption low.

III. Conclusion

In LoRaWAN's ADR algorithm, because of the optimistic link quality estimate, nodes are assigned transmission parameters that lead to undesirable DER performance. By an offline optimization of the $margin\_db$ parameter, the final DER can improve considerably, while still achieving acceptable energy consumption. As future work, we focus on the development of a modification to the ADR algorithm to include the online optimization of the $margin\_db$ parameter.

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