A multi-armed approach of data rate optimization in LoRa

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***Abstract*—LoRaWAN has emerged as a leading technology for long range, low-power communication in Internet of Things (IoT) networks. However, the default Adaptive Data Rate (ADR) mechanism suffers from limitations in balancing energy consumption, coverage, and reliability. In this work, we investigate ADR optimization strategies using the NS-3 LoRaWAN module, focusing on the impact of Spreading Factor (SF), Coding Rate (CR), and Transmission Power (TX). In the literature, this problem appears as a multi-objective optimisation problem. To solve this issue, We design MP-ADR, a multi-armed algorithm tested with the NS-3 LoRaWAN module. We investigate the impact of SF, CR, and TX, and perform a performance comparison with the default ADR. Extensive NS-3 simulations show that MP-ADR improves packet delivery ratio by 8%, reduces energy consumption by 33%, and lowers latency by 16% compared to the default ADR. These results demonstrate the potential of MP-ADR as a scalable and energy-efficient solution for next-generation IoT deployments, heterogeneous environments.**

I. INTRODUCTION

Low Power Wide Area Networks (LPWAN) are the baseline of the Internet of Things (IoT). These networks are characterised by low cost devices capable of long range communication under strict energy constraints. In addition, applications in IoT imply the scalability of a reliable network, wherein nodes must operate as long as possible [1]. A popular PHY technology called LoRa can address these issues. A classical problem in LoRa is the selection of transmission parameters, impacting both the range and the energy consumption of each transmission [2]. These parameters include the Spreading Factor (SF), the Coding Rate (CR), and the Transmission Power (TX). The LoRaWAN describes an Adaptive Data Rate (ADR) algorithm for dynamically balancing communication range and energy consumption based on channel conditions [3].

Yet, the default ADR strategy has some disadvantages: it mainly takes into account SF, responds slowly to channel fluctuations, and is often prone to breakdown in dense or highly dynamic deployments. Recent research has proposed enhancements to ADR, including optimisation models, reinforcement learning, and multi-armed bandit policies. These approaches attempt to find the combination of transmission parameters (SF, CR, TX) for optimising the energy consumption and the resulting data rate. Despite these efforts, systematic evaluations of ADR under diverse network conditions, especially in high density and interference prone deployments are still lacking [4]. These limitations highlight the need for a more comprehensive approach.

In this work, we propose a Multi-Parameter ADR (MP-ADR) framework that jointly adapts SF, CR, and TX power, using multiple link-quality indicators to achieve improved trade-offs between energy efficiency, reliability, and latency. The novelty of MP-ADR is the use of multi-metrics in a reward function that integrates RSSI, SNR, and PDR, combined with a Multi-Armed Bandit formulation to dynamically balance reliability and energy efficiency. Its designs is detailed in the Section II and a performance comparison is performed with the classical ADR algorithm the ns-3 simulator as described in the Section III. To the best of our knowledge, this is the first ADR framework exploiting multiple link-quality indicators in an ADR algorithm.

II. THE MULTI-PARAMETER ADR FRAMEWORK (MP-ADR)

Several ADR algorithms have been designed to take into account a specific link quality to determine a transmission parameter configuration. In practice, LoRa chipsets provide a couple of hardware link quality information, the Signal to Noise Ratio (SNR) and the Received Signal Strength Indicator (RSSI). In addition, software link quality information can be computed based on the packet statistics, such as the Packet Delivery Ratio (PDR). As pointed out in [5], a single metric only assess a particular link property. As a result, a combination of a set of link quality information can help to have a better assessment of the link property. Besides, the performance of an ADR algorithm is not limited to the assessment of the link quality but have to take into account the energy consumption. This can be viewed as a cost for each transmission. As a result, the problem appears as a multi-objective optimisation. To address this, we propose a Multi-Parameter ADR (MP-ADR) Framework that adapts the spreading factor (SF), coding rate (CR), and transmission power (TX) based on real time feedback [6].

The algorithm starts with a default transmission configuration and monitors channel indicators, including the RSSI, the SNR and the PDR over a sliding time window. For each transmission, the algorithm computes a reward function related to candidate transmission configuration (SF, CR, TX) and defined as follows :

$$R = \alpha \times f(RSSI, SNR, PDR) - \beta \times E_{tx},$$

with α and β weighting factors controlling the trade-off between reliability and energy, E_{tx} is the transmission energy cost and $f : \mathbb{N}^3 \to \mathbb{N}$. The transmission cost in LoRa is determined by the air time given by a function [7] and the transmission power. This one can be determined online, if the device embeds a energy monitoring component. Otherwise, the energy consumption can be characterised with a power profiler. The figure 1 depicts the relationship of the measured energy consumption with the transmission power for a FiPy and LoPy devices, performed with an Otii Arc, during experiments. Each one embeds respectively a SX1272 and a SX1276 LoRa chipset.

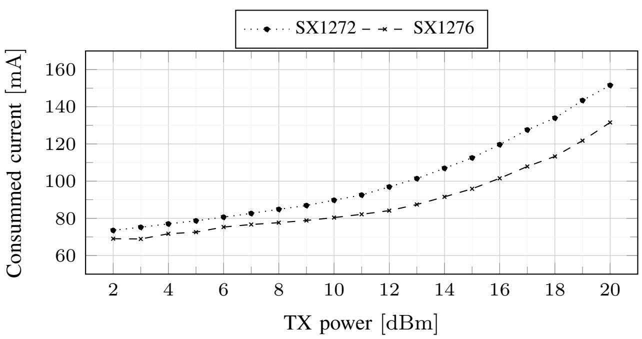


Fig. 1. Energy profiling of the LoRa chipsets

Inspired by multi-objective formulations used in ADR optimization [8], [9], the link-quality function is defined as:

$$f(RSSI, SNR, PDR) = w_1 \tilde{RSSI} + w_2 \tilde{SNR} + w_3 PDR,$$

where $\tilde{RSSI}$ and $\tilde{SNR}$ are normalised values and w_1, w_2, w_3 are tunable weights. This weighted combination allows the algorithm to prioritise different indicators depending on the application requirements. Then, the algorithm selects the configuration with the highest reward, if two candidates are comparable, the one with lower energy consumption is preferred. In the end, the device updates its PHY settings before the next transmission cycle.

This framework can be implemented using a Multi-Armed Bandit (MP-ADR) algorithm, where each "arm" corresponds to a parameter set (SF, CR, TX). The device initially explores multiple arms (exploration phase) and progressively selects the most rewarding configuration (exploitation phase). To address these limitations, we propose a Multi Parameter ADR (MP-ADR) framework that jointly adapts SF, CR, and TX based on real-time link metrics. The framework evaluates candidate configurations using a reward function, selects the optimal parameters, and updates device settings dynamically. The algorithm 1 describes the MP-ADR algorithm.

Algorithm 1: The Multi-Parameter ADR algorithm

Input : A set of link quality (RSSI, SNR, PDR)
Output: Optimal transmission parameters (SF, CR, TX)
$A \leftarrow (SF, CR, TX)$, initialisation;
$R \leftarrow 0$;
for *each transmission cycle* **do**
  Collect channel indicators (RSSI, SNR, PDR);
  for $a \in A$ **do**
    Estimate Energy consumption E_{tx};
    Compute reward $R(a)$;
  Select configuration $a^* = argmaxR(a)$;
  if *if multiple configurations yield similar rewards* **then**
    Choose the one with lower E_{tx};
  Update device parameters $(SF, CR, TX) \leftarrow a^*$;
  Transmit packet using updated configuration;
  Update reward estimates (exploration vs exploitation);

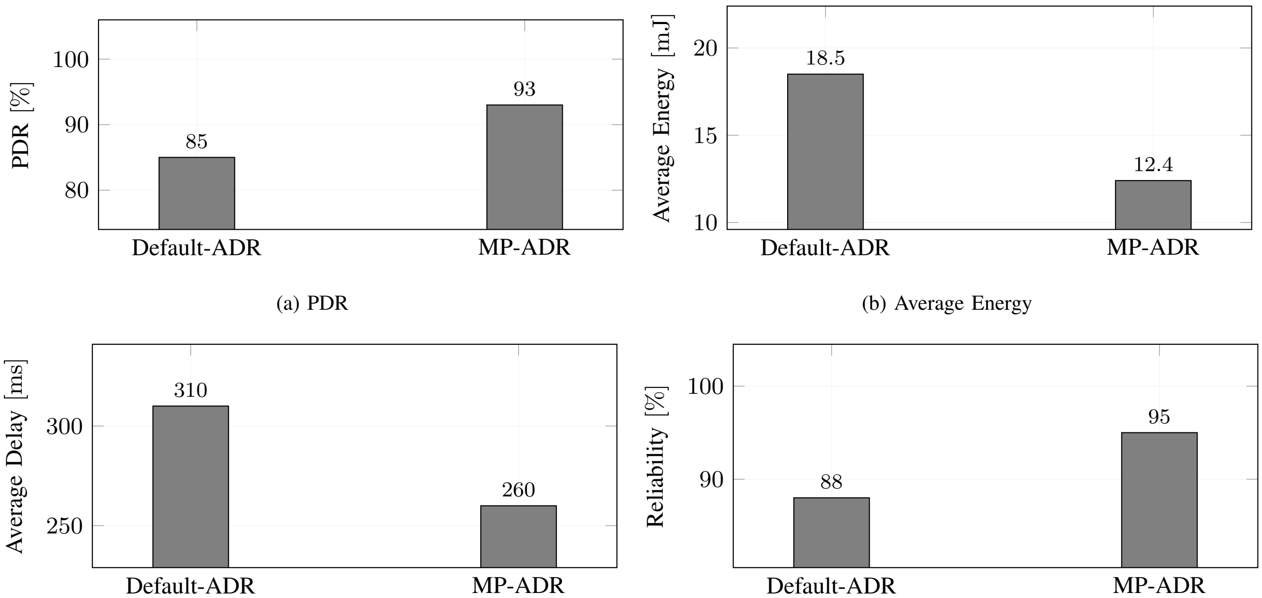
III. Preliminary performances investigation

The aim of this preliminary assessment is to compare the performance of the proposed Multi-Parameter Adaptive Data Rate (MP-ADR) with the classical ADR algorithm in LoRaWAN. This one was performed with the ns-3 simulator including the the LoRaWan model [10]. In the simulated scenario, a single gateway is positioned at the center of a circular deployment area, with end devices uniformly distributed across the coverage region. Each device transmits uplink packets periodically at fixed intervals. The simulation environment enables detailed tracking of radio propagation, interference, and energy consumption. Simulation parameters are summarised in table I.

Parameters	Value
Number of end devices	50,100,150,200
Transmission interval	60 seconds
Simulation duration	2h
Spreading Factors (SF)	7-12
Coding Rates (CR)	4/5 - 4/8
Transmission Power (TX)	2–14 dBm
Channel bandwidth	125 kHz

TABLE I
Simulation Parameters

Results of the performance evaluation are depicted in the Figure 2. A set of four criteria have been selected, each one representing a critical feature in a LoRa network. Three criteria are related to the network performance including the PDR, delay and the reliability of the network. The last one is the energy consumption impacting the node lifetime. Compared to the default ADR, MP-ADR improves PDR by 8%, reduces energy by 33%, and lowers delay by 16 confirming its effectiveness. MP-ADR achieves a higher packet delivery ratio (+8 %), significantly reduces energy consumption (-



(a) PDR

(b) Average Energy

(c) Average Delay

(d) Reliability

Fig. 2. Performance comparison between the default ADR and the proposed MP-ADR framework

33%) and lower average delay (-16%) compared to the default ADR. These results confirm that multi-parameter optimization provides clear benefits over the current LoRaWAN standard.

IV. Conclusion

This paper introduced MP-ADR, a novel adaptive data rate framework that advances beyond existing ADR algorithms by jointly optimizing the spreading factor (SF), coding rate (CR), and transmission power (TX). Unlike prior works [8], [9] that focused on single-parameter adaptation or fairness, MP-ADR integrates multiple link-quality indicators (RSSI, SNR, PDR) into a weighted reward-driven Multi-Armed Bandit framework, enabling a balanced trade-off between reliability and energy efficiency.

Extensive NS-3 simulations demonstrated that MP-ADR significantly outperforms the default ADR scheme. Compared to the baseline, MP-ADR improved packet delivery ratio from 85% to 93%, reduced average energy consumption from 18.5 mJ to 12.4 mJ, and lowered average delay from 310 ms to 260 ms. These results confirm that default ADR, which mainly tweaks SF, is inadequate for dense IoT networks, and that multi-parameter optimization is essential to ensure scalability and sustainability.

As future work, we plan to extend MP-ADR by incorporating advanced machine learning-based techniques, such as reinforcement learning and deep bandit methods, to achieve real-time adaptation in dynamic network environments. This direction will enable self-optimizing LoRaWAN networks with minimal human intervention, paving the way for large-scale, energy-efficient IoT deployments.

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