An Improved Adaptive Data Rate for LoRaWAN Networks

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Abstract

Currently, LoRaWAN employs the use of an adaptive data rate (ADR), which aims to provide reliable and battery-efficient communication by managing the spreading factor (SF) and transmit power. However, the variable channel conditions severely affect the performance of ADR, resulting in massive packet loss. In this paper, we propose an improved ADR (I-ADR), which allocates SFs to end devices based on the received signal strength at the gateway during the initial deployment. The I-ADR algorithm is evaluated in both confirmed and unconfirmed modes under the urban environment. Simulation results show that I-ADR performs better in terms of success ratio by lowering the impact of interference than the typical ADR.

Keywords: LoRaWAN, adaptive data rate, confirmed, unconfirmed, interference.

1. Introduction

Long-range wide area network (LoRaWAN) [1] features the medium access control layer, whereas LoRa describes the physical layer. Due to the long-range, low power, and low cost, LoRaWAN is widely adopted for the Internet of Things. The LoRaWAN network architecture is of a star-of-stars topology and consists of three main components, i.e., end devices (EDs), gateway (GW), and a network server (NS).

In LoRaWAN, the NS implements a control mechanism called adaptive data rate (ADR), which optimizes the network by managing the spreading factor (SF), transmit power (TP), and communication channel to achieve better performance in terms of packet success ratio and low energy consumption [2].

The ADR mechanism in LoRaWAN has been primarily designed for static EDs [2]. However, the performance of ADR is severely affected by variable channel conditions [3], [4]. It is shown in [3] that the ADR scheme lacks the agility to adapt to the variable channel conditions. The ADR scheme requires several hours to days to converge to a stable and energy-efficient communication state when NS starts monitoring the *N* number of UL recent past packets received (i.e., *N=20*). To improve ADR performance in variable channel conditions, the authors propose an ADR+ scheme [5]. The ADR+ method slightly modifies the basic ADR by taking the average of the signal to noise ratio (SNR) of the last *N* packets received at the NS. Recently, the performance of ADR has been evaluated under the mobility environment [6]. It is shown in [6] that the ADR mechanism is not efficient in mobility because it is only applicable to static EDs. To improve the performance of ADR under a static environment, in this paper, we propose an improved ADR (I-ADR). I-ADR allocates suitable SF during the initial deployment based on GW sensitivity values. The I-ADR does not modify the rest of the typical ADR mechanism both at the ED and NS. The proposed I-ADR improves the performance in terms of packet success ratio and decreases the packet loss caused by channel interference.

The rest of the paper is organized as follows: Section 2 presents the proposed I-ADR algorithm. Experimental results and analysis of ADR, ADR+, and proposed I-ADR are given in Section 3, while the last section 4 concludes this paper.

2. The proposed improved ADR scheme

To improve the ADR scheme, the initial SF assignment mechanism is introduced based on the GW sensitivity, as shown in our previous work [7]. The primary purpose of I-ADR is to allocate SF during the initial deployment of the network based on the received signal strength at the GW. As indicated in [8], [9], the SF allocation is mainly based on the range of SF assignment (SF7 to SF12). However, I-ADR does not follow the fixed-width SF range due to the variable channel conditions caused by the shadowing and building penetration losses. As shown in Fig. 1, each ED computes the received signal strength (P_{rx}) at the GW. Based on the value of P_{rx}, SFs are assigned such that the P_{rx} is always higher than each SF sensitivity (S_i, as shown in Table I). The detailed procedure of I-ADR is described in Fig. 1.

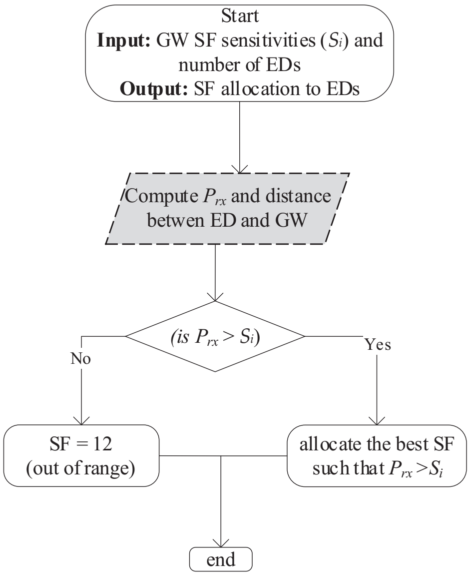


Figure 1. SF assignment procedure of I-ADR during the initial network deployment.

TABLE I. SENSITIVITIES OF EDS AND GW.

SF	BW [kHz]	GW sensitivity (S_i)	ED sensitivity (S_e)
12	125	-142.5	-137.0
11	125	-140.0	-135.0
10	125	-137.5	-133.0
9	125	-135.0	-130.0
8	125	-132.5	-127.0
7	125	-130.0	-124.0

3. Experimental Results

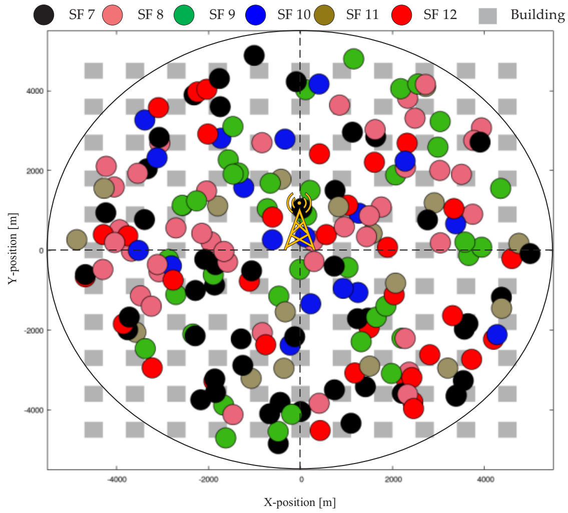
This section evaluates the performance of LoRaWAN-based ADR, ADR+ [5], and proposed I-ADR schemes through simulation of NS-3 [10].

Simulation Background

In the simulation, the M number of EDs is uniformly distributed around a single GW within a 5 km radius. The height of GW and ED antennas is set to 15 m and 1.5 m, respectively. Each ED in the simulation transmits 24 packet/day, where the packet size is 51 bytes. To model a realistic environment, simulation structures square-shaped buildings based on the Manhattan layout model and correlated shadowing [11]. The simulation environment with buildings for I-ADR and typical ADR is shown in Fig 2. The rest of the simulation parameters utilized in the simulation is presented in Table II.

TABLE II. SIMULATION PARAMETERS.

Parameter	Value
Simulation time [days]	2
M	200-1000
ADR	operated both at ED and NS with initial SF = 12 [12]
Communication mode	confirmed and unconfirmed
Path loss exponent	3.76
Propagation loss model	log-distance
Shadowing	de-correlation distance = 110 m and variance = 6 dB [11]
Interference model	as in our previous work [13]
Building penetration loss model	as in our previous work [7]



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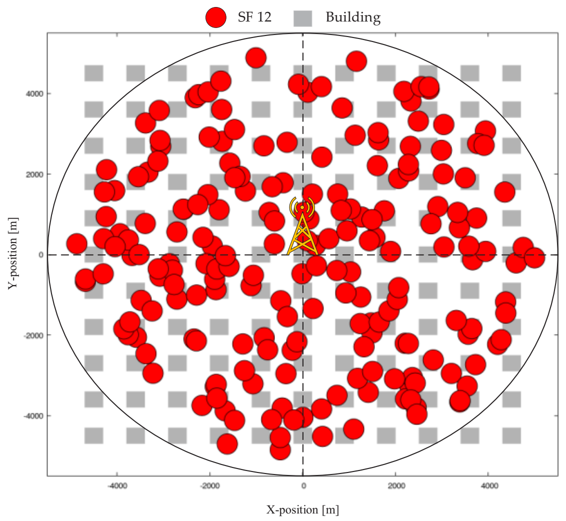

(a)

Figure 2. Simulation environment with N=200: (a) Initial SF assignment using I-ADR, and (b) Initial SF assignment using typical ADR (with SF=12).

Performance Analysis

Fig. 3 shows the per hour packet success ratio of ADR, ADR+, and I-ADR in confirmed mode (CON-urban) for M=400. The trend shown in Fig. 3 indicates that the schemes take about 16 hours in converging to possibly a stable state, which confirms the same fact, as presented in [12]. The primary purpose of Fig. 3 is to highlight the slow convergence that is caused by the time taken by the NS, which monitors the N number of UL packets. However, I-ADR does not suffer high packet loss during the convergence period as compared to ADR and ADR+ due to the initial optimal SF allocation.

The per-hour packet success ratio of ADR, ADR+, and I-ADR for the unconfirmed mode in an urban environment (UNC-urban) is presented in Fig. 4. Generally, the success ratio is higher than in Fig. 4. It is because EDs in ADR usually does not need any DL message from GW. However, EDs in ADR periodically receives a DL message from GW after 64 UL packets. If the corresponding DL message is not received after 64 UL packets, ED enables the *ADRACKReq* for the next 32 packets. In this case, if the ED still has not received a DL message after 92 UL transmission, ED increases SF through the ADR algorithm implemented at the ED side [14].

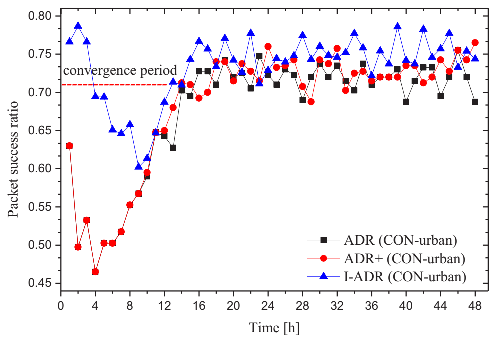

Figure 3. Per hour packet success ratio in the confirmed mode under an urban environment with M=400 (log-distance, shadowing, and buildings).

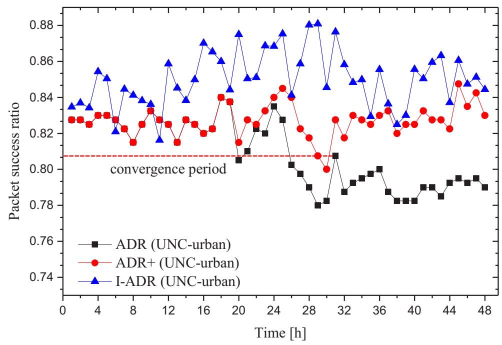

Figure 4. Per hour packet success ratio in unconfirmed under an urban environment with M=400 (log-distance, shadowing, and buildings).

Fig. 5 shows the average packet success ratio of ADR, ADR+, and I-ADR in the CON-urban environment. The decreasing tendency of ADR and ADR+ in both cases shows that packet loss increases as the number of EDs increased from 200 to 1000. Therefore, in the case of ADR confirmed mode, NS takes much more time to receive N packets from EDs to configure the optimal configuration. When NS computes the new configuration, it is responsible for conveying this configuration to EDs using *MAC* commands through GW. Furthermore, due to the 1% duty cycle limitation of GW, it might not be possible to handle bi-directional traffic for an extensive network, resulting in incoming packet loss and additional delay.

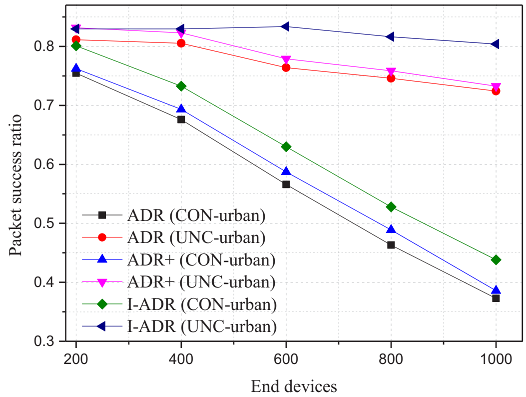

Figure 5. The average packet success ratio in an urban environment (log-distance, shadowing, and buildings).

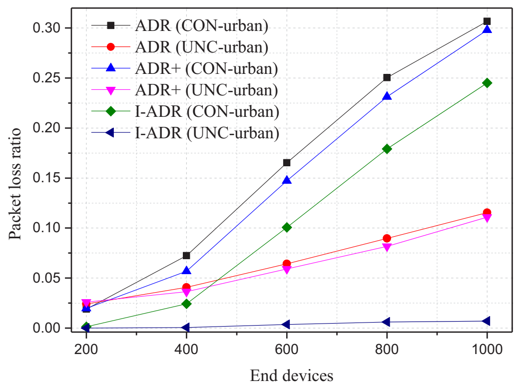

Figure 6. The average packet loss ratio in an urban environment (log-distance, shadowing, and buildings).

On the other hand, the ADR+ scheme takes the average of the N received packets at NS, resulting in a better SF and TP configuration than the typical ADR. However, I-ADR performance in terms of packet success ratio is much better than ADR and ADR+ due to the suitable assignment of SF during the initial deployment. The decreasing pattern of the packet success ratio in the I-ADR (CON-urban) mode is only due to the duty cycle constraints of GW as the network load increases. The I-ADR scheme improves the success ratio on average by 12% and 11% in confirmed and unconfirmed modes, respectively.

The average packet loss ratio observed from ADR, ADR+, and I-ADR methods in the urban environment are shown in Fig. 6. The interference over the same channel among the packets transmitted with the same SFs and different SFs is considered, as presented in [15]. The packet loss in both ADR and ADR+ increases with the increasing *M*. Initially, *M* number of EDs transmitting packets with SF 12, resulting in high ToA (i.e., the ToA is equal to 2.46 s when conditioned with SF 12 and packet size of 51 bytes). Owing to high ToA, the packets transmitted with SF 12 interfered with each other. Hence, the high packet loss is evident that higher SFs are highly vulnerable to interference due to high ToA. Also, it is shown that SFs are not entirely orthogonal among themselves [16], [17].

On the other hand, the packet loss ratio in the I-ADR scheme is much lower in both CON-urban and UNC-urban cases as compared to ADR and ADR+ because it uses different SF during the initial deployment. It is also clear that SFs are not entirely orthogonal among themselves; thus, a packet sent with different SFs can interfere with each other for a small amount of time. If the respective signal to interference plus noise ratio of the two-interfering packet after equalization is higher than the threshold value (as shown in our previous work [13]) can be correctly received. As a result, the impact of interference is much lower in the network.

4. Conclusions

LoRaWAN suggests the use of ADR due to its reliable, battery-friendly, and efficient communication by carefully adapting the SF and TP. Owing to the poor performance of ADR in variable channel conditions, we proposed a new algorithm called I-ADR, which allocates SF to EDs during the initial deployment based on the GW sensitivity. Through simulation results, we showed that our proposed scheme enhances the packet success ratio by lowering the impact of interference. In particular, we verified that the ADR requires high convergence time, which results in massive packet loss. Also, we observed that the duty cycle limitations and bi-directional communication restrict the scalability of the LoRaWAN. In the future, we intend to reduce the convergence period of the ADR mechanism.

Acknowledgment

This research is supported by "Smart city urban infrastructure air quality real-time monitoring and prediction platform technology development" through the Ministry of Trade, Industry, and Energy (MOTIE) (P0006855, 2018).

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