A Comparative Study and Analysis of LoRaWAN Performance in NS3

Arshad Farhad* and Jae-Young Pyun**

Abstract

Long Range Wide Area Network (LoRaWAN) is a widely adopted Internet of Things (IoT) protocol due to its high range and lower energy consumption. LoRaWAN utilizes Adaptive Data Rate (ADR) for efficient resource (e.g., spreading factor and transmission power) management. The ADR manages these two resource parameters on the network server side and end device side. This paper focuses on analyzing the ADR and Gaussian ADR performance of LoRaWAN. We have performed NS3 simulation under a static scenario by varying the antenna height. The simulation results showed that antenna height has a significant impact on the packet delivery ratio. Higher antenna height (e.g., 50 m) has shown an improved packet success ratio when compared with lower antenna height (e.g., 10 m) in static and mobility scenarios. Based on the results, it is suggested to use the antenna at higher allevation for successful packet delivery.

Keywords : LoRaWAN | Adaptive Data Rate | Internet of Things | Network Simulator 3 | Resource Allocation

I. INTRODUCTION

Long Range Wide Area Network (LoRaWAN) is one of the Low Power Wide Area Networks (LPWANs) technology. It is widely considered for the Internet of Things (IoT) applications owing to its lower power consumption and high range [1]. LoRaWAN operates in the sub-gigahertz unlicensed frequency bands, and the specification varies from region to region because of regulatory requirements. For example, the KR920-923 ISM band is used in Korea for the LoRaWAN system. The first three-channel frequencies are 922.1 MHz, 922.3 MHz, and 922.5 MHz, utilized for uplink (UL) and downlink (DL).

LoRaWAN is a Media Access Control (MAC) layer protocol built on top of LoRa modulation. To provide the appropriate transmission rate with reduced power consumption in an IoT environment, LoRaWAN utilized two resource parameters: spreading factor (SF) and transmission power (TP) [2, 3]. The SF ranges from 7 to 12, while the TP ranges from 2 to 14 dBm.

These resource parameters are allocated by the network server (NS) to the end devices (EDs), as illustrated in Fig. 1. The EDs transmit a packet with the allocated SF and TP to the NS via a gateway (GW).

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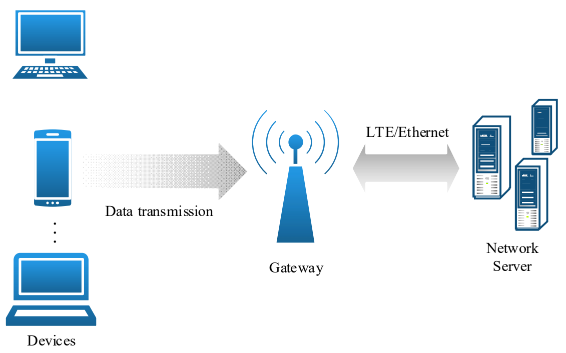

Fig. 1. Architecture of the LoRaWAN.

In the case of a packet drop, a packet is retransmitted by the ED to ensure that data is delivered reliably, even in challenging environmental conditions. When confirmed traffic is expected to be sent, the ED initiates the retransmission procedure. When an ED transmits a message, it starts a timer for retransmission. If the ED does not receive an acknowledgment (ACK) from the NS before the timer expires, the ED will retransmit the message. The ED will retransmit the message several times before giving up. The number of retransmissions is configurable but typically set to 7. The NS can also initiate the retransmission procedure. If the NS does not receive a message from an ED after a certain period, it will send a LinkADRReq MAC command to the ED. The LinkADRReq MAC command tells the ED to retransmit the last message. The retransmission procedure is essential for ensuring reliable data delivery in LoRaWAN. However, it is important to note that retransmissions can consume additional power and reduce the overall network throughput.

Additionally, the SF and TP are computed by the NS using an Adaptive Data Rate (ADR). The ADR determines the SF and TP based on the highest signal-to-noise ratio (SNR) value of the last 20 UL packets received. When selected, both parameters are transmitted to EDs via MAC command. When the ED receives the MAC command containing SF and TP, the ED communicates the data transmission with these new resource parameters.

This paper shows the analysis of the ADR simulated in NS3 under a static environment by varying antenna height. The results have shown that the antenna height significantly impacts the packet success ratio. The higher the GW antenna height, the higher the packet success ratio and the lower the packet collision.

The rest of the paper is organized as follows: Section II elaborates on the existing work related to the ADR. Section III illustrates the LoRaWAN, comprising the working of the ADR. Section IV presents the analysis of the ADR in comparison with the Gaussian adaptive data rate (GADR) in NS3, while Section V concludes this paper.

II. RELATED WORK

This section discusses the existing ADR enhancement methods. Paper [4] introduced a simple variant of the LoRaWAN ADR (i.e., ADR+) by taking the average SNR of the last 20 packets received at the NS. The primary purpose of the ADR+ was to smooth the SNR and lower the SF to the appropriate level, resulting in improved performance compared to ADR.

In [5], two ADRs at the NS were proposed based on Gaussian and Exponential Moving Average (EMA) filters, namely GADR and EMA-ADR. When 20 packets are received at the NS, GADR and EMA-ADR are triggered separately, determining the SF and TP transmitted to the ED.

To prevent the NS from unnecessarily changing the SF of the ED, [6] proposed a congestion classifier. The proposed method determines whether to change the SF or backoff time based on the number of UL and DL packets. If the DL and UL packet ratios are equal, the SF remains unchanged, indicating that no congestion is detected. However, the ED selects a longer backoff time if a packet needs to be acknowledged. Otherwise, the SF is increased to improve coverage.

The enhanced ADR (EADR) scheme proposed in [7] reduces the number of packets (M = 5) used for SF and TP parameter adaptation at the NS side. The EADR computes the packet reception success ratio (PSR) for each ED involved in the communication and compares it to a pre-defined threshold (PSR = 80%). If the PSR exceeds the threshold, the NS side ADR transmits the LinkADRReq MAC command containing the newly identified SF and TP values.

In [8], the authors showed that ADR does not have a convergence period in the unconfirmed mode of communication, where ACKs are not required. In addition to the effects of the convergence period, a new ADR using the detection of ED mobility was introduced to improve PSR [8].

Based on the existing research [4-8], which only deals with modifying or proposing the ADR mechanisms, this paper focuses on the primary parameters dependent on the packet success ratio (e.g., antenna height). However, [4-8] lacks analysis of the packet success ratio regarding antenna height. Therefore, this paper provides an in-depth overview of varying antenna heights and their impact on network performance.

III. Overview of LoRaWAN

LoRa (physical layer) is a low-power wide-area network (LPWAN) technology designed for long-range, low-power communications. It is a proprietary system developed by Semtech, while the LoRaWAN is a MAC layer protocol developed and maintained by LoRa Alliance.

LoRa uses a spread spectrum modulation technique called chirp spread spectrum (CSS), encoding information by varying the transmitted signal frequency over time. This makes LoRa very resistant to interference and noise and allows it to achieve long ranges with low power consumption.

One of the critical features of LoRa is the SF. SF measures how much the transmitted signal is spread out in frequency. Higher SF values result in longer ranges and better noise immunity but also reduce the data rate.

LoRaWAN supports six SFs (SF7, SF8, SF9, SF10, SF11, and SF12). SF7 provides the highest bit rates but supports the shortest transmission range. Meanwhile, SF12 provides the slowest bit rates but supports the longest range and best noise immunity.

The SF used for a particular transmission depends on several factors, including the required range, the desired data rate, and the environmental conditions. For example, a device that needs to transmit data over a long distance in a noisy environment will use a higher SF rather than a lower SF.

Since the selection of SF and TP will affect the network performance, it has to be carefully managed.

ADR allows LoRaWAN devices to balance range, data rate, and power consumption well. It also enables LoRaWAN networks to scale to a large number of devices.

Algorithm 1. ADR at the network server side

```
SNRm = max (SNR of 20 packets at NS)
SNRreq = demodulation floor (current DR)
Devicemargin = 10
SNRmargin = (SNRm - SNRreq - Devicemargin)
Steps = floor (SNRmargin/3)
while steps > 0 && SF >SFmin do
        SF = SF - 1
        Steps = steps - 1
while steps > 0 && TP > TPmin do
        TP = TP - 3
        Steps = steps - 1
while steps < 0 && TP < TPmax do
        TP = TP + 3
        Steps = steps + 1
end
```

To allocate these resources to EDs, LoRaWAN utilizes ADR at the network server side. Algorithm 1 shows the operation procedure of NS side ADR. The NS waits for **M** (20 packets) before identifying new SF and TP parameters. The NS primarily bases its unique SF and TP value selection on the maximum signal–to–noise ratio (SNR_{max}) among the **M** packets.

The NS then calculates the SNR required (SNR_{req}) for the current SF by considering the demodulation floor. The SNR margin (SNR_{margin}) is calculated by subtracting the SNR_{max}, SNR_{req}, and margin. Table 1 lists the minimum SNR_{req}, gateway sensitivity (S_g), and ED sensitivity (S_e) required for demodulation at different SFs.

The NS side ADR iterates over these steps until SF is lowered when the current SF exceeds SF 7 to satisfy the application packet success ratio requirements. On the other hand, the ADR either increases or decreases the TP by a step of 3 to conserve energy. Finally, the NS side ADR transmits a DL MAC command *LinkAdrReq* to the ED with the newly identified SF and TP parameters.

Table 1. The minimum SNR_{req}, gateway sensitivity (S_g), and ED sensitivity (S_e) required for demodulation at different SFs.

SF	S_g [dBm]	S_e [dBm]	SNR_{req} [dB]
7	−130.0	−124.0	−7.5
8	−132.5	−127.0	−10
9	−135.0	−130.0	−12.5
10	−137.5	−133.0	−15
11	−140.0	−135.0	−17.5
12	−142.5	−137.0	−20

IV. COMPARATIVE STUDY AND ANALYSIS

This section presents the in–depth comparative study and analysis of the LoRaWAN ADR and GADR [11] regarding packet success ratio, energy consumption, and convergence period by varying the

GW antenna height.

Table 2. Simulation parameters utilized in the simulation.

Parameters	Value
Simulation tool	NS3
Simulation time	1-day [9]
Packets per day	24 [10]
Retransmissions	7 [12]
Mode of communication	Confirmed
End devices	200-1000
Capability of ED	static

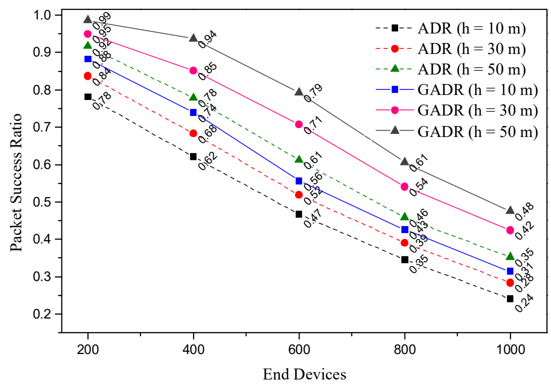

Fig. 1. Average packet success ratio for varying the gateway antenna height from 10 to 50 m.

The simulation study is conducted in ns-3. The experiments are simulated ten times with random seeds, and the average results are shown here. During the simulation, the number of EDs increased from 200 to 100. Throughout the simulation, the EDs are static. Finally, the rest of the simulation parameters are shown in Table 2.

This paper presents the packet success ratio (PSR) performance analysis and energy consumption. PSR mainly depends on antenna height and appropriate SF selection during transmission. Inappropriate SF leads to retransmission, resulting in excessive energy consumption.

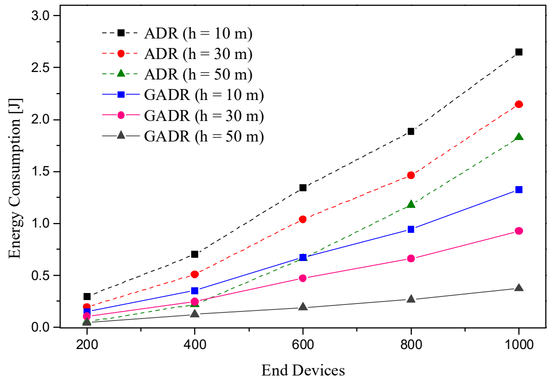

Fig. 2. Average energy consumption for varying the gateway antenna height from 10 to 50 m.

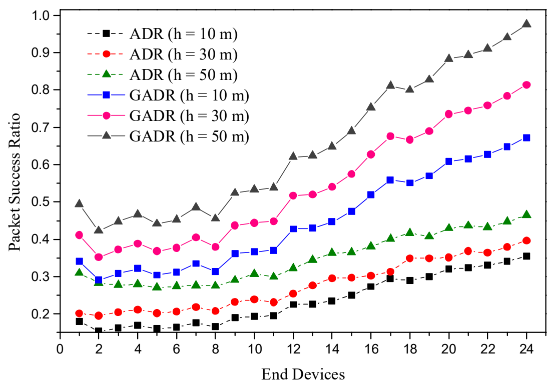

Fig. 3. Convergence period for varying the gateway antenna height from 10 to 50 m.

Therefore, this paper analyzes the LoRaWAN ADR regarding PSR and energy consumption. In addition, the convergence period is also presented, showing the impact of ADR on how much time is required for the network to become stable in terms of PSR and SF.

Fig. 1 shows the average PSR of the LoRaWAN ADR and Gaussian ADR (GADR) for various antenna heights of the GW.

In general, the PSR decreases with the increasing number of EDs owing to packet loss at the GW. Also, it is evident from Fig. 1 that the performance has been improved by increasing the antenna height. It is because the EDs are mostly in line-of-sight, and packets are delivered, thus increasing the PSR. Overall, the GADR resource allocation method outperforms the typical ADR approach of the LoRaWAN.

Fig. 2 illustrates the average energy consumption of the EDs for the ADR and GAR schemes. It can be seen in Fig. 2 that increasing the number of EDs increases energy consumption due to multiple retransmissions. The retransmission significantly impacts energy consumption since the same packet is sent a maximum number of times (i.e., seven times). However, energy consumption has improved considerably when the antenna height is increased to 50 m. On the other hand, GADR reduces the number of retransmissions, resulting in improved energy consumption compared to ADR.

The convergence period with per-hour PSR of the ADR and GADR is shown in Fig. 3. It can be seen that the PSR is increasing with time owing to assigning a suitable SF. Initially, the ADR allocates SF12, resulting in interference and, as a result, reducing the PSR. However, ADR adjusted the SF and TP with time and gained better PSR. However, during 24 hours of simulation, the ADR has not achieved a higher PSR, showing less than 50% and a long convergence period. However, it can also be seen that GADR adjusts SF more efficiently than ADR, resulting in improved PSR.

V. CONCLUSION

LoRaWAN is a popular IoT protocol due to its long range and low energy consumption. It uses ADR to manage resources such as SF and TP efficiently. ADR is controlled by both the NS and the ED. This paper analyzed the performance of LoRaWAN ADR compared to GADR in NS3. Simulations were performed in static scenarios with varying antenna heights. The results showed that antenna height significantly impacts the PSR. An antenna height of 50 m showed improved PSR than lower antenna heights (e.g., 10m). The higher antenna from the ground is recommended for applications requiring high PSR.

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