Performance Analysis of Adaptive Data Rate Scheme at Network-Server Side in LoRaWAN Network

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***Abstract*— LoRa in IoT applications is an attractive solution in the use of low-power and low-cost WAN technology. One of the LoRa features is its capability to use the optimal configuration through an adaptive data rate mechanism (ADR). LoRaWAN Adaptive Data Rate (ADR) is a mechanism for optimizing data rates, airtime, and energy consumption in the network. LoRaWAN Adaptive Data Rate is a mechanism for optimizing airtime, energy consumption, and data rate in the network.**

In this work, we conducted a LoRaWAN ADR simulation using NS3 and analyzed the performance by modifying ADR parameters at Network-Server Side. Our contributions modify the ADR scheme at Network-Server Side with optimum energy efficiency on the LoRaWAN network. It can be concluded that using the modified ADR, and we can save energy consumption up to 25,07% and get a better Packet Success Rate (PSR) value up to 6,86 % compare to Lorawan with standard ADR.

***Keywords*— LoRa, ADR), LPWAN, LoRaWan, NS3**

I. Introduction

Entering the industrial revolution 4.0, the LPWAN are recent outcomes of breakthroughs in communication technologies that provide energy-efficient, low cost but can provide long-range connectivity, enable remote connectivity at low cost, development of new technologies related to IoT applications.

Star topology adopted on the LPWAN network. This network is usually deployed on an unlicensed band. The focus of the LPWAN network is reducing power consumption at the end devices. It aims to increase the life of the device by 10 - 20 years. in addition, increased gateway range to 20 km in rural areas [1].

In everyday life, today's society has a significant dependence on IoT applications. At present, there are approximately more than 20 billion IoT devices worldwide [2]. Examples of applications that include LPWAN are asset tracking, smart grid, and environmental [3].

One of the technologies included in LPWAN is LoRaWAN. LoRaWAN can be used for two-way communication between IoT devices. LoRaWAN supports low-power, low-data rate, and long-distance communications [4].

The adaptive data rate (ADR) algorithm helps the system perform well. The algorithm allows the data rate to be modified based on the environmental conditions around the network [5]. The communication between the end device and the gateway in the LoRaWAN network is distributed on different frequency channels and data rates. The LoRa network server can control the data rate of each device and the transmission power in order to maximize the total network bandwidth and battery life with the ADR scheme. There is a bergain between communication range and Spreading Factor (SF). The slower transmission, and the longer coomunication range, then the higher SF [6]. The main challenge in this case is to determine the proper configuration to enable reliable communication with low energy consumption. The optimal configuration of the data rate is chosen to ensure that devices are operational in an energy-efficient manner and to increase number of devices that can be controlled by a individual gateway [5].

In this work, we try to find out the optimum parameter of ADR at Network-Server Side and how much energy savings we can achieve by modifying the ADR algorithm. In general, this modification does not change the LoRaWAN protocol. Modifications are only do to the ADR algorithm on the NS-Side. The results of this modification provide a better energy efficiency value compared to the original algorithm. In addition, this modification results in an increase in the Packet Success Ratio (PSR) value of the network

The rest of this work is designed as fellows. Section II is an overview of the LoRaWAN protocol and ADR Alogorithm will be described. In section III describes simulation setup and scenario. Section IV gives the performance analysis and simulation result. Section V This paper provides a summary of the contributions made by the authors.

II. LoRaWAN and Adaptive Data Rate

A. LoRa

LoRa is Semtech's proprietary low-cost CSS modulation implementation that enables low-power wireless

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communications over long distances. [6]. The encoding of symbols, called chirps, using wideband linear frequency modulated pulses is done by CSS. LoRa can be configured with various parameters to make it work best in different situations. [7].

B. LoRaWAN

The LoRaWAN specification is a way to wirelessly connect battery operated 'things' to the internet in regional, national, or global networks. It is designed to target essential IoT requirements such as mobility, bi-directional communication, localization services, and end-to-end security [10].

The LoRaWAN is a network topology that uses a star shape. EDs wirelessly receives messages from one or more gateways or sends messages to one or more gateways, which in turn transmit them to a server through high throughput and reliable links. In this topology, sending a single ED message to several gateways is conceivable. ED is not clear that it is attached to one gateway, which receives messages from the wireless channel device and forwards it to NS [9]. The complexity and intelligence are transferred to the server that manages the network, which filters redundant packets, carries out security checks, plans confirmations through the carries out an adaptive data rate, the optimal gateway, and much more. Moving nodes or mobile nodes do not require gateway to gateway switching, which is a key feature of enabling asset tracking applications-an important target application industry for the Internet of Things [10].

Each LoRa transmission includes five parameters: transmission power, bandwidth, spreading factor, data rate, and code rate. This setting affects the range of communication, the data rate, how well the signal can be received, and how well it can be decoded by a receiver [6].

C. ADR

The ADR mechanism is one of the specifications of LoRaWAN. It intends to give solid and battery-accommodating availability by adjusting SF and TP to connect conditions changes. Suppose an ED observes that a downlink response from the network does not follow many consecutive uplink transmissions. In this case, he assumes a loss of connection and solves this problem by gradually increasing his TP to the maximum, before doing the same for SF. These measures gradually increase the reliability of communication [12].

The LoRaWAN fixed nodes use ADR to improve their data rate. The way the LoRaWAN protocol is meant to work is that it is up to the device to decide whether or not to use ADR [13].

ADR consist of two algorithms. One is running on the end and the other one is running on the server. LoRaWAN clearly defines the algorithm of ED [2]. If there is a lack of downlink feedback, the algorithm will determine the decrease in data rate. it aims to increase network coverage. this results in the ED speed will also be reduced.

The next algorithm is an algorithm that is installed on the server part. The server keeps track of the best signal-to-noise ratio for each packet. The ED will determine the most suitable data rate if the ED is not using the best transmission power and the best data rate value.. Algorithm NS is presented in Algorithm 1.

Algorithm 1 NS-Side ADR [5]

with uplink reception (machine, package):
if *length(machine.package)* = *20* **then**
    package.pop()
machine. package.push(package.VsnrMax).

send on downlink (machine, package):
if *package.f_C%20* = 0 **then**
    Valuesnrmaxi ← *max(machine. package.VsnrMax)*

    Valuesnr_m ← *int(Valuesnrmaxi* −*VSNR_VTABLE*(*Valuedata_ratemachine*) − *Valuemargin_datab)*
I ← *Valuesnr_m*/3
while *i* ≠ 0 **do**
    if *i* > 0 **then**
        if *Valuedata* < 5 **then**
            Valuedata ← *Valuedata* + 1.
        Else
            if *Valuetx_p* ≠ *Trans_P_Minimum* **then**
                Valuetx_p ← *Valuetx_p* + 1.
                i ← *i* − 1.
            Else
                if *Valuetx_p* ≠ *Trans_P_Maximum* **then**
                    Valuetx_p ← *Valuetx_p* − 1.
                    i ← *i* + 1.

D. LoRa Network Simulation Using NS3

NS3 software was used to simulate networks of LoRa systems. The simulator has been extended with the addition of LoRa Module. NS3 is community-supported network simulation software licensed under the GNU General Public License (GPL) [14]. The error model and SINR are used in this method. If there is a block, If the reception fails, so does the packet reception [5].

III. SIMULATION SETUP AND SCENARIO

This paper about LoRaWAN uses an NS3 LoRaWAN module. The analysis The module's been enhanced so it can work with different network configurations, and to test out the improvements that have been proposed.

A. Simulation Scenario

Since we are interested in optimizing the ADR Scheme at Network Server Side, we assume one GW serves several EDs, which periodically generate packets. We wanted to know the performance of LoRaWAN using standard ADR enabled and optimizing ADR.

This research will test the effect of modification ADR algorithm at Network Server Side using NS3. The hardware and software used in this research can be seen in Table I, and the LoRaWAN simulation parameters, as shown in Table II.

In this experiment, we used ubuntu 18.04 on VMware with four core processors and 6144MB RAM. Shared graphics used is 768 MB and 40GB of storage. Experiments were performed with the NS3 simulator and with source code from ConstantJoes GitHub [5].

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TABLE I HARDWARE AND SOFTWARE

Parameter	Value
Processor	4 Core
RAM	6144 MB
Shared Graphic	768 MB
Storage	40 GB
Operating System	Ubuntu 18.04

TABLE II SIMULATION PARAMETER

Gateway	1
Nodes	100, 200, 400, 600, 800, 1000
Disk Radius	5000m
Packet Size	21 bytes
Simulation Time	150000 s
Bandwidth	125 kHz
DR start	DR 0

We use the following parameter in Table II to get data about the standard ADR Algorithm. We tried to modify the ADR scheme. We improved the ADR scheme by changing the mechanism that allows the NS side algorithm's timing based on the SNR value of recently received frames. Besides, we also changed the step determination of the data rate change on the NS side algorithm. The modification on the ADR – Network Server Side algorithm can be seen on Algorithm 2. We simulate LoRaWAN Network using Modified Neetwork Server-Side ADR algorithm with n-value equals to 12, 7, and 3.

B. *Performance Metrics*

We define two performance metric from modification on the ADR – Network side Algorithm as follows :

1) Energy Consumption (EC). To calculate the network's energy consumption, we track the energy consumption of all nodes during the simulation runtime. At the End of the simulation, we calculate all consumed energy.

$$EC = \frac{Total\ energy\ consumption\ of\ all\ nodes}{number\ of\ nodes} \quad \text{.........} \ (1)$$

[15]

2) Packet Success Rate (PSR): The probability that both an acknowledged and a received packet will be correctly received on one of the available transmission attempts. To calculate PSR, we divide the number of successfully received packets in Network Server by a total number of sent packets from end devices :

$$PSR = \frac{Successfully\ received\ packets}{total\ number\ of\ sent\ packet} \quad \text{......................} \ (2)$$

[15]

IV. Performance Analysis

We simulate Modified Network Server-Side ADR based on the SNR value of recently received n-values frames. We describe the variance of n-value is 12, 7, and 3. The goal is to get the n-value, which produces the best level of energy efficiency and the best level of PSR Values. We run it on 100, 200, 400, 600, 800, and 1000 nodes. The results of this simulation are shown in Figure 1.

Algorithm 2 Modified NS-Side ADR

with uplink reception (*machine, package*):
if *length*(*machine. package*) = *n* **then** ← *n* = {12, 7, 3}
  package.pop()
machine. package.push(*package.VsnrMax*).

send on downlink (*machine, package*):
if *package.f_C%20 = 0* **then**
  Valuesnr_maxi ← *max*(*machine. package.VsnrMax*)

  Valuesnr_m ← *int*(Value*snrmaxi* − *VSNR_VTABLE*(Value*data_ratemachine*) − *Valuemargin_datab*)
  i_step ← *Valuesnr_m*/2
while *i* ≠ 0 **do**
  if *I* > 0 **then**
    if *Valuedata* < 5 **then**
      Valuedata ← *Valuedata* + 1.
    Else
      if *Valuetx_p* ≠ *Trans_P_Minimum* **then**
        Valuetx_p ← *Valuetx_p* + 1.
        i ← *i* – 1.
      Else
        if *Valuetx_p* ≠ *Trans_P_Maximum* **then**
          Valuetx_p ← *Valuetx_p* − 1.
          i ← *i* + 1.

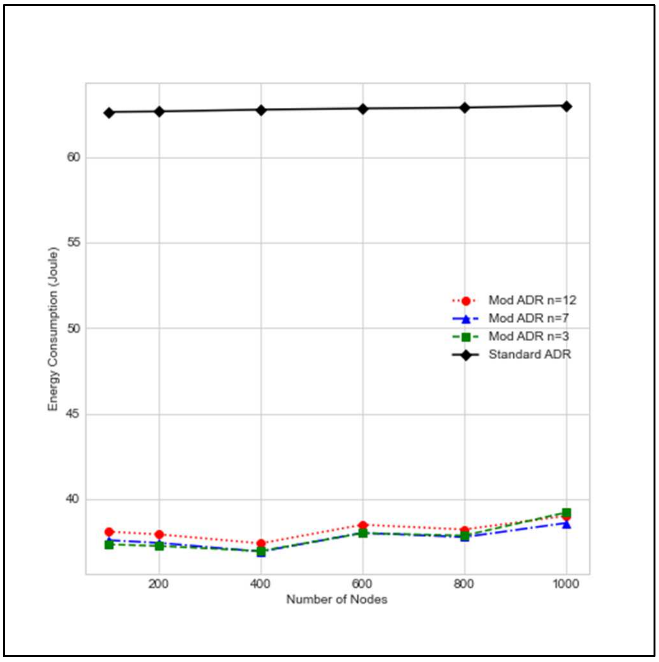

Figure 1. Comparison of energy consumed on the LoRaWAN network using the ADR Standard and the LoRaWAN network using the modified ADR. Modified ADR run with n-value is 12, 7, and 3

From Figure 1, the standard ADR algorithm shows that the energy consumption value is always above 60 joules. In contrast, Modified Network Server-Side ADR shows that the average energy consumption value is below 40 joules. This indicates that the Modified Network Server-Side ADR results in lower energy consumption values than the standard ADR algorithm.

In more detail, the energy consumed by varying of n-value in the Modified Network Server-Side ADR is shown in Figure 2. The value of energy consumption varies across nodes in the network by reducing the n-value in the Modified Network Server-Side ADR algorithm. Figure 2 shows that

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Modified Network Server-Side ADR with n-value equal to 12 shows the highest energy consumption value than the other n-values. However, when 1000 nodes on the network, the highest energy consumption value is obtained when Modified Network Server-Side ADR with n-value equal 3. From Figure 2, Modified Network Server-Side ADR with n-value equal 7 shows the value of energy consumption, which is always below the Modified Network Server-Side ADR with n-value equal 12. whereas when compared with Modified Network Server-Side ADR with n-value equal 3, Modified Network Server-Side ADR with n-value equal 7 shows the lowest energy consumption value when there are more than 400 nodes in the network.

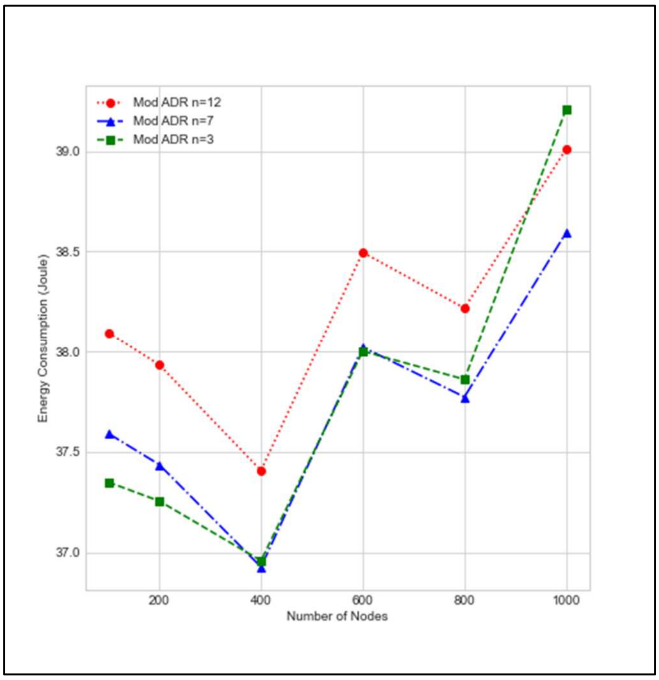

Figure 2. Detail comparison of energy consumed on the LoRaWAN network using the modified ADR with Varian n-values

Furthermore, the PSR value generated on the LoRaWAN network using modified ADR has a better value than the LoRaWAN network using standard ADR. In detail, the results of the comparison of the PSR value are shown in Figure 3.

Based on Figure 3, the PSR value in the standard ADR always sharply decreased when there are additional nodes in the network. The condition also occurred in Modified Network Server-Side ADR. However, the PSR value of the standard ADR has a lower value when compared to the PSR value of Modified Network Server-Side ADR, significantly Modified Network Server-Side ADR with n-value equal to 7 and 12. For the PSR value of Modified Network Server-Side ADR with n-value equal to 3, 100 nodes on the network have a lower PSR value than the PSR value of standard ADR. However, after the number of nodes on the network is more than 200 nodes, the PSR value of Modified Network Server-Side ADR with n-value equal to 3 is greater than the PSR value in the standard ADR. Based on Figure 3, it can also be concluded that the more nodes in the network, the smaller the PSR value.

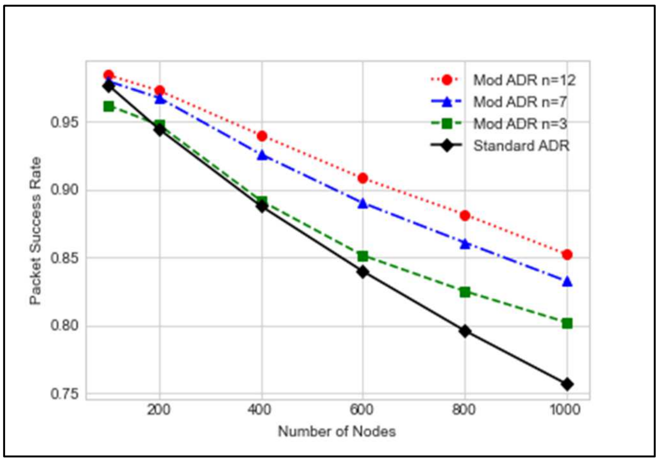

Figure 3. Comparison of Packet Success Rate on the LoRaWAN network using the ADR Standard and the LoRaWAN network using the modified ADR. Modified ADR run with n-value is 12, 7, and 3

TABLE V SIMULATION RESULT

Modified Network Server-Side ADR	Energy Efficiency	PSR Increase
n=12	24,60 %	6,86 %
n=7	25,07 %	5,19 %
n=3	25,02 %	1,71 %

From this simulation, the energy efficiency value and the increase in the PSR value for the implementation of the ADR Modification algorithm on the Lorawan network are shown in Table V. Data in Table V is a comparison of the data obtained from the standar ADR and the data obtained from the Modified Network Server-Side ADR.

Based on Table V, it is concluded that the best energy efficiency value is by implementing Modified Network Server-Side ADR with n-value equals to 7. However, the best PSR increment value is to use Modified Network Server-Side ADR with n-value equals to 12. In that case, it will increase the energy efficiency level by 25,07 % and an increase in the PSR value by 6,86 % when compared to the Lorawan network using ADR standards.

V. Conclusion

This study explains that the ADR algorithm shows considerable energy use in communicating. With the aim to shorten the energy used and increase the Packet Success Rate, it is necessary to modify the ADR algorithm by reducing the packet length by n-values. The algorithm runs immediately and changes the n-step formulation to snr_margin / 2.

The LoRaWAN network has become more efficient in terms of energy consumption by modifying the ADR Scheme on the NS Side. The PSR value of the LoRaWAN network using ADR algorithm modification is better than the network using ADR standard. Finally, Modified Network Server-Side ADR has better performance than the standard ADR algorithm.

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