Iraqi Journal of Information and Communications Technology(**IJICT**)
Vol. 8, Issue 2, August 2025
www.ijict.edu.iq
ISSN:2222-758X
e-ISSN:2789-7362

EFFICIENT ADAPTIVE DATA RATE SCHEME FOR LORAWAN IN MASSIVE IOT ENVIRONMENT

Ameer M. Aboud [1], **Bayan M. Sabbar** [2]
[1] Department of Information and Communication Engineering, College of Information Engineering, Al-Nahrain University, Jadriya, Baghdad, Iraq
[2] Medical Instrumentation Engineering Technologies Department, College of Engineering and Technologies, Al-Mustaqbal University, Hillah 51001, Babil, Iraq
ameermuneer@coie-nahrain.edu.iq [1], prof.dr.bayan.mahdi@uomus.edu.iq [2]
Corresponding Author: **Bayan M. Sabbar**
Received:28/02/2025; Revised:02/06/2025; Accepted:24/07/2025
DOI:**10.31987/ijict.8.2.322**

***Abstract*- Long-Range Wide-Area Networks (LoRaWAN) is among the foremost favored techniques for wireless communication in Internet of Things (IoT) applications, owing to its simplicity and versatility. It utilizes an Adaptive Data Rate (ADR) approach at both the network server and end device levels. In order to provide the necessary downlink radio parameters, the network server could use the allocation of a resource strategy to control the transmit power and spreading factor. Therefore, this work suggests a Uniform Distribution ADR (U-ADR), network server-controlled adaptive data rate, to deal with the fast-fluctuating signal-noise ratio of arriving packets at the network server. The suggested approach seeks the most effective allocation of radio parameters to the end devices to reduce the total network energy consumption and improve the average packet delivery ratio of the network. The findings depict that the suggested approach enhances the average Packet Delivery Ratio (PDR) by 102% and 77.94% for a single and two gateways deployment in an urban scenario respectively while in sub-urban improved by 65.14% and 33.53%. The total Network Energy Consumption (NEC) was reduced by 9% and 16.55% for single and two gateways in the urban scenario while in the sub-urban scenario reduced by 15.92% and 12.53%.**

keywords: **Internet of Things (IoT), Long-Range Wide-Area Network (LoRaWAN), Adaptive Data Rate (ADR), Spreading Factor, Transmission Power.**

I. INTRODUCTION

The integration of the Internet of Things (IoT) has been an enormous benefit to the information and communication industries in recent years [1, 2]. The three main groups of IoT systems are Low-Power Wide-Area Networks (LPWANs), cellular IoT, and Low-Rate Wireless Personal Area Networks (LRWPAN). The market has seen the emergence of both licensed and unlicensed LPWAN technologies, including Long-Term Evolution for Machine (LTE-M), Long Range-Wide Area Network (LoRaWAN), SigFox, and Narrow Band-IoT (NB-IoT). Most LPWANs employ LoRaWAN as their backbone for the IoT due to its low consumption of energy and long-range communication capabilities. Consequently, it has been widely used for IoT projects. In contrast to Sigfox and NB-IoT, LoRaWAN provides flexible and affordable solutions [3-5]. As shown in Fig. 1, the essential elements of a LoRaWAN network design are End Device (ED), Gateway (GW), and Network Server (NS). The most important component of a LoRaWAN network is its EDs, which interact with the surroundings. Between the NS and the ED, the GW acts as a link. At the same time, the NS is in charge of Downlink (DL) acknowledgments and uses Media Access Control (MAC) commands to regulate the Spreading Factor (SF) and Transmit Power (TP) of nodes by means of Adaptive Data Rate (ADR). Every side of the ED and NS employs the ADR method. The responsibility of ED side ADR to restore end device connectivity during communication by advancing one

ISSN:2222-758X
e-ISSN:2789-7362

SF progressively. Even both levels are regulated by the NS-side ADR, the SF and TP can significantly prolong the ED's battery life. However, a highly changeable wireless channel state has a substantial effect on the basic ADR of LoRaWAN.

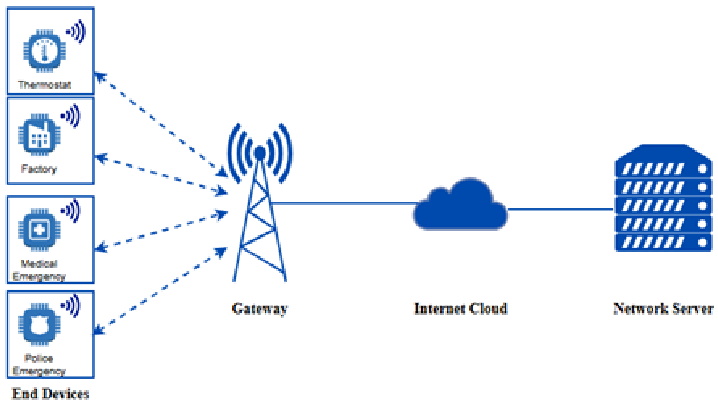

Figure 1: Topology of the LoRaWAN Network.

Network Server-Side controlled ADRs were suggested and assert the following contributions:

1) Suggest a Uniform Distribution ADR (U-ADR) that improves the received packets' SNR reached to the NS through GW. By employing U-ADR, the best SF and TP parameters to allocate resources for the LoRaWAN Network can be efficiently achievable.
2) Enhance the average Packet Delivery Ratio (PDR) for single and two getaways compared to typical and two alternative ADR mechanisms.
3) Reduce the total Network Energy Consumption (NEC) for single and two getaways compared to typical and two alternative ADR mechanisms.

The following is the structure of the remaining section of the article: Section II delves into the relevant work about this study, whereas Section III explains the system model. Section IV demonstrates the suggested approach of ADR. Section V presents and discusses the results of this research. Section VI concludes the work of this study.

II. RELATED WORKS

In [6] made modifications to the traditional ADR algorithm. By optimizing SF and TP for each end node, the algorithm helps the system enhance communication reliability and energy usage. The suggested approach achieves better error performance in channels with poor conditions while lowering the quantity of data messages in the UL and MAC command messages in the DL. This makes it possible to increase the network's range. The algorithm's disadvantage is that big complicated networks are not taken into account by the simulation model that is used.

In [7] calculated the standard deviation of SNR after averaging the SNR in order to increase the typical ADR efficiency. Their suggested approach is efficient for computing the SF and TP from the derived value utilizing standard deviation. Therefore, their approach's results show better ADR performance in terms of utilization of energy.

ISSN:2222-758X
e-ISSN:2789-7362

In [8] the development of a unique ADR algorithm specifically for LoRa networks' core platform was presented. The suggested approach used an ordered weighted average OWA operator to achieve reliable operation across various channel conditions by dynamically customizing transmission parameters. When compared to the typical ADR and other algorithms, the outcomes show that the proposed approach achieves a higher packet delivery ratio while consuming the least amount of energy.

In [9] the authors suggest two ADRs that can be managed by NS; one that uses a Gaussian filter (G-ADR) and another that uses an exponential moving average (EMA-ADR). When compared to typical ADR, the suggested techniques improve EDs' packet success ratio while decreasing convergence time and energy expenditure. In [10], created the energy-efficient approach of ADR using a fuzzy logic ADR algorithm. The packet delivery ratio decreased even though the suggested solution used less energy than the previous schemes.

In [11], suggested an ADR protocol that distributes SFs by distributing the time-on-air of packets sent by each ED evenly. In [12], the authors utilize multi-player multi-armed bandits to deal with the distribution of resources in LoRa networks, with an emphasis on transmission parameter optimization to lessen interference, decrease packet loss, and reduce energy consumption.

In [13], the authors propose a new ADR mechanism to proactively update the data rate based on the estimation of the trajectory of mobile nodes using machine-learning methods used to forecast the Signal-To-Noise Ratio (SNR). Results prove that their method achieves a proper harmony between meeting performance standards while reducing utilization of energy over time even in highly dynamic and unpredictable environments while not taking PDR into consideration.

III. SYSTEM MODEL

The target network for configuration comprises one or many LoRa gateways and LoRa end devices with a single network server. All nodes remain stable and the distance from the ED to the gateway is allocated. Each node can utilize an SF from a range of 7 to 12 and a TP from a range of 2 to 14 dBm. Nodes may be associated with one or many gateways; all nodes may access at least one gateway with the highest throughput. Two distinct deployment scenarios were assessed: urban and suburban. These scenarios are modeled using the log-distance path loss model with shadowing according the following Eq. (1) [14]:

$$PL(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \tag{1}$$

where, $\overline{PL}(d_0)$ is the loss for distance d_0 and n is the path loss exponent. X_σ represents the zero-mean Gaussian distributed random variable with σ.

The path loss parameters utilized vary across the designed scenarios, resulting in differences in the dimensions of the deployment area. Table I presents the typical path loss parameters utilized in both scenarios. The parameters provided were derived from the measurements performed in [15] and [16]. The measurements in [15] pertain to a developed urban partially indoor environment. The measures in [16] pertain to a suburban setting distinguished by a sparse presence of towering structures. The communication range in suburban regions surpasses that of urban areas. The efficacy of a transmission depends on the potential interference among LoRa signals. To achieve that, the collision model described in [15] is

ISSN:2222-758X
e-ISSN:2789-7362

TABLE I
PROPAGATION MODEL PARAMETERS

Scenario	d_0[m]	$\overline{PL}(d_0)$[dB]	n	σ[dB]
Urban	40	127.41	2.08	3.57
Sub-Urban	1000	128.95	2.32	7.08

utilized. The fundamental premise is that two transmissions on orthogonal channels, such as those employing distinct SFs, will not lead to collisions. A collision occurs when two signals carried across non-orthogonal channels overlap temporally, the collision model integrates the capture effect as delineated by experimental findings in [16]. In this scenario, the signal with greater strength is decoded, contingent upon a power difference exceeding 6 dBm and the detection of a minimum of 5 symbols in the preamble. Each scenario consists of two cases: a single gateway and two gateways. The configuration consists of a central gateway linked to a singular network server within the deployment area. Alternatively, a scenario involves two gateways: GW1 positioned at coordinates $(x = x_{max}/4, y = y_{max}/2)$ and GW2 at $(x = 3x_{max}/4, y = y_{max}/2)$, enabling uniform distribution throughout the deployment area. Table II presents the simulation environments. Fig. 2 illustrates the application of the tool in modeling the PHY of LoRa, MAC protocol for LoRaWAN, and the associated network components.

TABLE II
SIMULATION PARAMETERS

Parameter	Description
Simulation Program	OMNeT++ 6.0.2 IDE [17]
Simulation Time	4 Days
Simulation Runs	30
Modulation	LoRa Modulation based on CSS
No. of EDs	100 to 700 with step 100
No. of GW	1 and 2
No. of NS	1
CF	868 MHz
BW	125 kHz
CR	4/5
SF	7 to 12 (initial 12)
TP	2 dBm to 14 dBm (initial 14 dBm)
Deployment Area	Urban (480 m × 480 m) Sub-Urban (9800 m × 9800 m)

IV. SUGGESTED APPROACH FOR ADAPTIVE DATA RATE MODEL

The suggested adaptive data rate approach called uniform distribution ADR (U-ADR) was presented in this section which are operating on the NS-side as in algorithm 1. The suggested approach seeks to reduce total NEC and improving average PDR through the reduction of interference. This approach accomplishes this through the adaptive control of spreading factors and transmission power allocation. It is important to keep in mind that the operation algorithm running on ED-side has not changed.

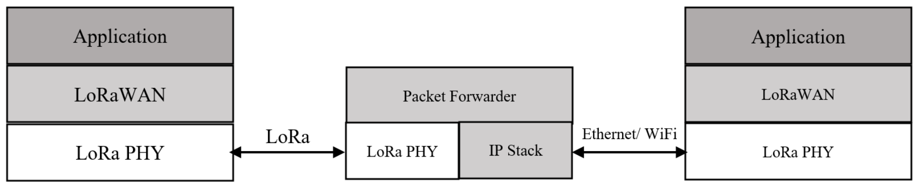

Figure 2: Modelling of LoRaWAN framework.

Algorithm 1 Suggested (U-ADR) Approach

Input: TP = 2 to 14, SF = 7 to 12, P, SNR_{req}, $adr\_devicemargin$
Output: SF_{new} and TP_{new} for each ED
//Computes:
1: mean μ of the SNR using uniform distribution
2: variance σ^2 using uniform distribution
3: Uniform LowPassFilter $U_{LPF} = \mu - \sigma^2$ and Uniform HighPassFilter $U_{HPF} = \mu + \sigma^2$
for $i \leftarrow 0$ *to* M **do**
    $SNR_{test} = getSNR(i)$
    if $SNR_{test} \geq U_{LPF}$ ***and*** $SNR_{test} \leq U_{HPF}$ **then**
        insert SNR_{test} into SNR_{record}
    end
end
for $i \leftarrow 0$ *to* SNR_{record} **do**
    Sum
end
$SNRs = Sum/$size ofSNR_{record}
//Computes:
1: $SNR_{req} =$ demodulation floor (present DR)
2: $adr\_devicemargin = 10$ (LoRaWAN default)
3: $SNR_{margin} = SNRs - SNR_{req} - adr\_devicemargin$
4: $N_{steps} = floor(SNR_{margin}/3)$
while $N_{steps} > 0$ ***and*** $SF > SF_{min}$ **do**
    $SF = SF - 1$ $N_{steps} = N_{steps} - 1$
end
while $N_{steps} > 0$ ***and*** $TP > TP_{min}$ **do**
    $TP = TP - 3$ $N_{steps} = N_{steps} - 1$
end
while $N_{steps} < 0$ ***and*** $TP < TP_{max}$ **do**
    $TP = TP + 3$ $N_{steps} = N_{steps} + 1$
end
$SF_{new} \leftarrow SF$
$TP_{new} \leftarrow TP$
NS transmits LinkADRReq

The following is a list of the procedures that are involved in the U-ADR approach that has been suggested:

1) When a relevant ED sends M packets to NS, the suggested ADR to improve SNR is executed. The U-ADR algorithm

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ISSN:2222-758X
e-ISSN:2789-7362

begins with the calculation of the mean (μ) and variance (σ^2) as outlined in Eqs. (2 and 3) [18] respectively.

$$\mu = \frac{SNR_{\min} + SNR_{\max}}{2} \tag{2}$$

$$\sigma^2 = \frac{(SNR_{\max} - SNR_{\min})^2}{12} \tag{3}$$

2) To get the smoothed SNR, the U-ADR method computed the average of values within the range of effectiveness as outlined below:

$$U_{LPF} = \mu - \sigma^2 \tag{4}$$

$$U_{HPF} = \mu + \sigma^2 \tag{5}$$

$$SNR_s = \frac{\sum_{i=1}^{L} SNR_i}{L} \tag{6}$$

where i is the i-th value among new list of SNR, L = Length of new list of SNR.

3) The U-ADR computes the SNR required, demodulation floor according present DR, as shown in Table III and calculated the SNRmargin and Nstep while using Eqs. (7 and 8) [7], respectively.

$$SNR_{\text{margin}} = SNR_s - SNR_{\text{req}} - adr_{\text{device margin}} \tag{7}$$

$$N_{\text{step}} = \text{int}\left(\frac{SNR_{\text{margin}}}{3}\right) \tag{8}$$

TABLE III
SNR VALUE AND THRESHOLD SENSITIVITY FOR EACH SPREADING FACTOR

Spreading Factor	Required SNR [dB]	Sensitivity [dBm]
7	-7.5	-123
8	-10	-126
9	-12.5	-129
10	-15	-132
11	-17.5	-134.5
12	-20	-137

The suggested approach of ADR (U-ADR) employs the smoothed SNRs values to determine a appropriate SF corresponding to the GW sensitivity, thereby minimizing the probability of losing packets at the GW given the specified sensitivity. The designed ADR delineates the optimal TP for the pertinent ED via a sequence of steps. A value of zero for the steps signifies that the ADR is employing the optimal TP value. The presence of steps greater than zero signifies that the current TP and SF are suboptimal, leading to heightened energy consumption and diminished airtime, which negatively impacts the PDR. The U-ADR consequently reduces the TP by 3 SF by 1, until the lowest value is reached, thereby enhancing energy consumption efficiency, ToA, PDR, and throughput. In contrast, when steps are negative, the U-ADR raises the TP by 3, reaching the maximum value. Using the MAC command LinkADRReq, the ED receives the new SF and TP parameters.

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e-ISSN:2789-7362

V. SIMULATION RESULTS AND ANALYSIS

Informed by the given relevant work, the evaluation of the efficacy of LoRa networks utilizing two assessment metrics, PDR and NEC in two simulation scenarios; urban and sub-urban environment. The comparisons of the suggested approach was accomplished with typical ADR [19], G-ADR [9] and OWA-ADR [8].

A. *Total Network Energy Consumption (NEC)*

In order to calculate the total network's energy consumption, monitor each node's energy use during the simulation. The model calculates the battery life of each ED and provides the overall energy usage for each ED as follows:

$$E_{ED} = E_{tx} + E_{rx} + E_s \tag{9}$$

$$NEC = \frac{\sum_{i=1}^{No.\,ED} E_{ED}(i)}{\textit{Total amount of successfully received messages}} \tag{10}$$

Where E_{tx} is the energy consumption of ED in transmitting mode and E_{rx} is the energy consumption of ED in receiving mode. E_s is the energy consumption of ED in sleep mode. i is the i-th number of ED.

A lower NEC value indicates a more efficient network. The energy consumer module from [20] was utilized alongside the Semtech SX1273 datasheet, which specifies supply voltage of 3.3V [21]. In an urban context, we evaluate the efficacy of a LoRaWAN network within a deployment area measuring 480m by 480m.The number of nodes rises from 100 to 700 with one and two gateways. Fig.3 illustrates that energy usage rises for both the suggested ADR and the typical ADR as the number of EDs grows due to employing SF = 12 during the first network installation, resulting in substantial interference due to elevated ToA. The NEC of the ADR is comparatively more than that of the suggested ADR due to the frequency

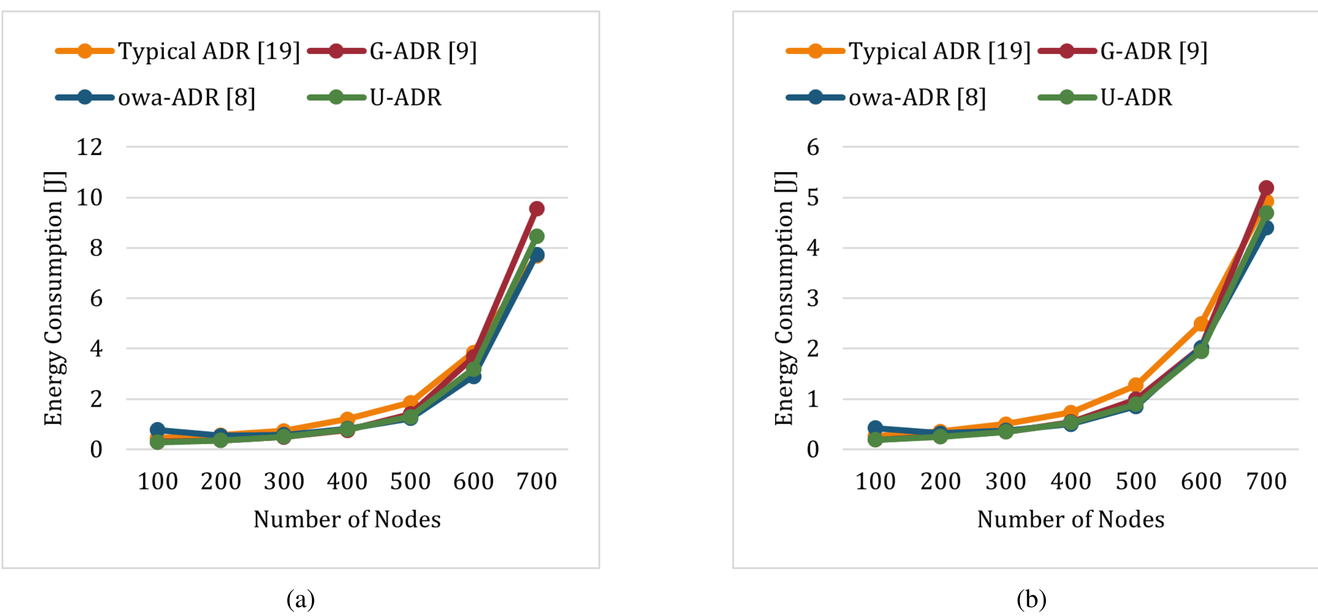
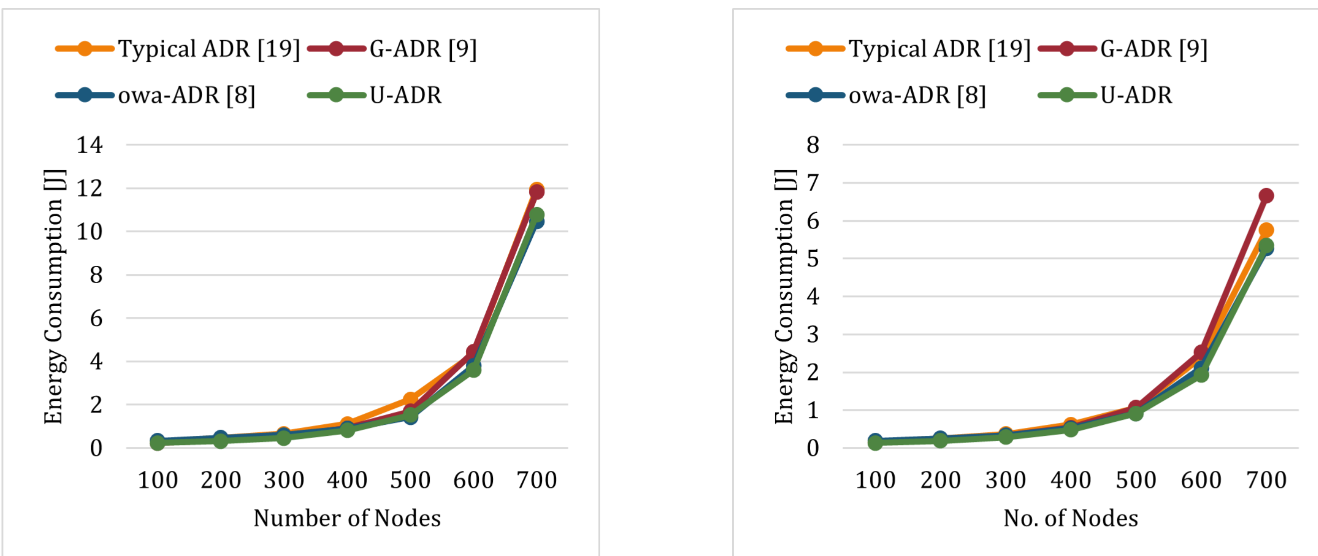


Figure 3: NEC in urban Scenario: (a) Single Gateway (b) Two Gateways.

ISSN:2222-758X
e-ISSN:2789-7362

of retransmissions. This retransmission results in considerable energy expenditure in the context of ADR. In the suggested ADR, NEC is minimized by assigning an appropriate SF and TP by the application of a uniform distribution to enhance SNR. This suitable SF and TP adaption enhances NEC, hence reducing the frequency of retransmissions. Therefore, the U-ADR consumes average NEC of 2.12 j and 1.26 j for single and two gateway while in typical ADR consumes 2.33 j and 1.51 j in single and two gateway. These results indicate an approximate improvement of 9% for single gateway and 16.55% for two gateways in urban scenario in case of U-ADR as compared with typical ADR. In suburban environment, the assess the performance of a LoRaWAN network was tested within a deployment area of 9.8 km by 9.8 km.
Fig.4 demonstrates that NEC rises for both the U-ADR and the typical ADR with the rising number of EDs. The U-ADR utilizes an average of 2.46j and 1.33j for single and dual gateways, respectively, whereas the conventional ADR consumes 2.96j and 1.58j for single and dual gateways. The findings indicate an estimated improvement of 16.89% for a single gateway and 15.82% for two gateways in a suburban context concerning the proposed ADR compared to the traditional ADR.



(a) (b)

Figure 4: NEC in sub-urban scenario: (a) Single Gateway (b) Two Gateways.

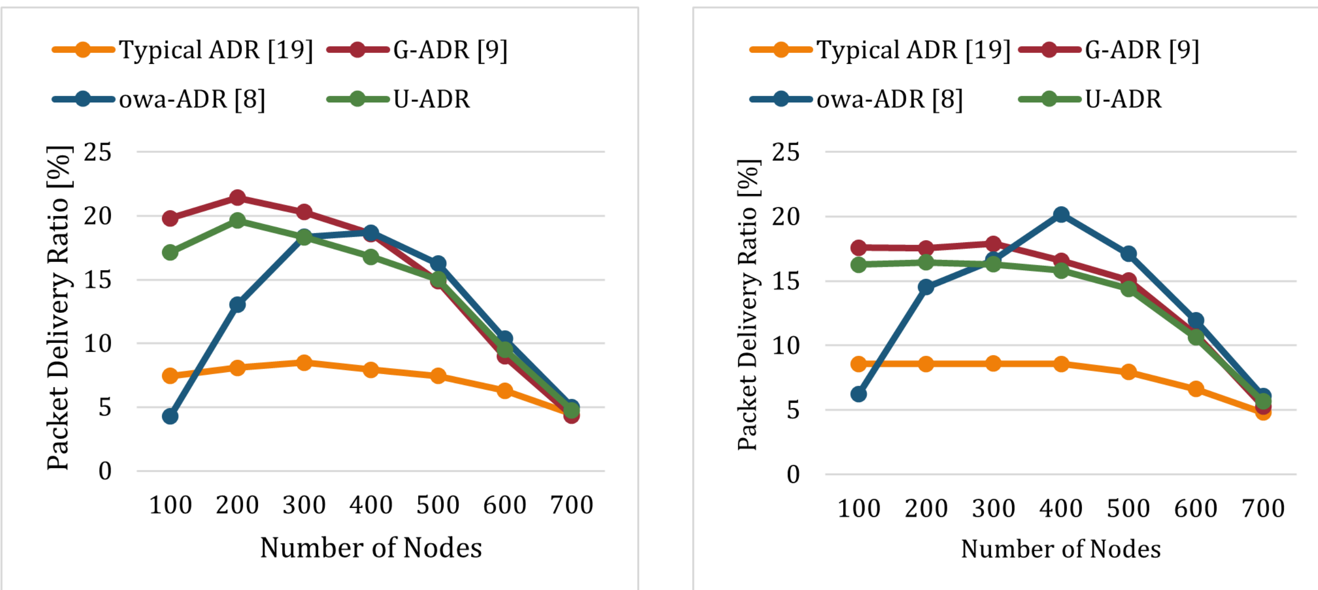
B. Average Packet Delivery Ratio (PDR)

The Packet Delivery Ratio (PDR) for each LoRa node in the network has been computed to characterize their coverage as in as in Eq. (11):

$$PDR = \frac{\textit{Total amount of packets received}}{\textit{Total amount of packets transmitted}} \times 100\% \tag{11}$$

In an urban scenario, the effectiveness of a LoRaWAN network within a deployment area measuring 480m by 480m was examined. The number of nodes increased from 100 to 700, utilizing one or two gateways. Fig 5 illustrates the efficiency of

U-ADR algorithm regarding the uplink PDR in an urban scenario. The simulation results show that, for both single and two gateway deployments, the PDR in U-ADR improved as compared to typical ADR in an urban environment. The main aim of suggested approach is to decrease NEC while maintaining a high PDR through interference mitigation and optimization of data rates for end devices. The evaluation of a LoRaWAN network's performance was conducted with an increasing number of nodes. Fig 5 illustrate that as the number of nodes rises from 100 to 700, the network efficiency declines in both typical and U- ADR, attributed to the heightened incidence of packet collisions. The limited transmission parameters adjustable by ADR in LoRaWAN render the complete elimination of collisions unfeasible. The number of possible interferences during each transmission grows in direct proportion to the density of the network. The U-ADR algorithm attained average PDR of 14.44% and 13.63% for single and two gateways, respectively. In contrast, the typical ADR achieved average PDRs of 7.15% and 7.66% for single and two gateways, respectively. The results demonstrate an approximate improvement of

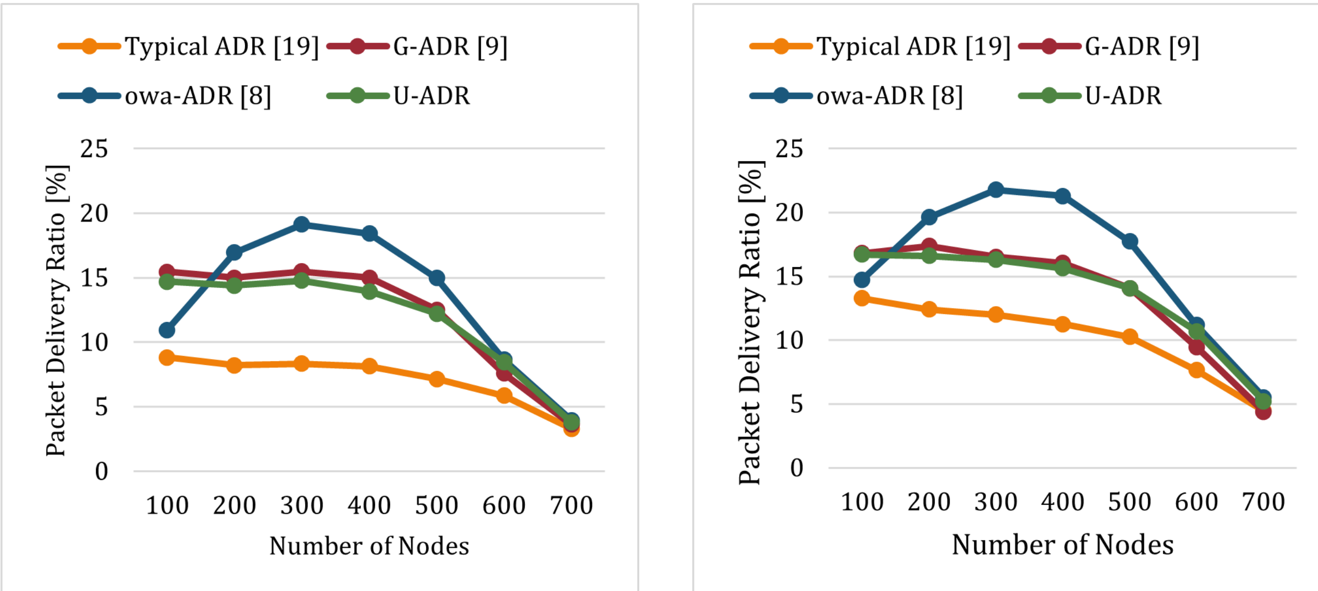


(a) (b)

Figure 5: PDR in urban Scenario. (a) Single Gateway (b) Two Gateways.

102% for a single gateway and 77.94% for two gateways in an urban scenario when comparing the proposed ADR to the typical ADR. In a suburban environment, the deployment area of 9.8 km by 9.8 km used to examine the performance of the designed LoRaWAN network.

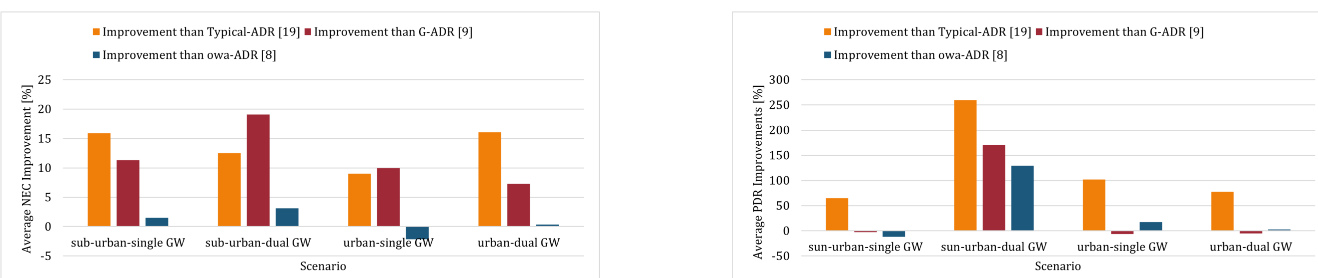
Fig. 6 illustrates that an increase in nodes leads to a decline in network performance, attributed to the increased frequency of collisions among packets transmitted from nodes with identical attributes. Fig 6 demonstrates that the U-ADR algorithm attained average PDR of 11.75% and 13.41% for single and dual gateways, respectively. In contrast, the typical ADR achieved average PDRs of 7.13% and 9.93% for single and dual gateways, respectively. The results demonstrate an approximate improvement of 64.79% for a single gateway and 35.04% for two gateways in a suburban scenario when comparing the proposed ADR to the typical ADR.



(a) (b)

Figure 6: PDR in sub-urban scenario: (a) Single Gateway (b) Two Gateways.

Compared with typical ADR, G-ADR and owa-ADR, the suggested approach enhanced the PDR and NEC as shown in Fig. 7.



(a) (b)

Figure 7: Improvement by percentage of U-ADR: (a) NEC (b) PDR.

VI. CONCLUSIONS

In order to enhance the average PDR and lower NEC in LoRaWAN networks, this work introduces a modification of typical adaptive data rate algorithm called U-ADR. Due to interference and packets coming below the gateway's sensitivity level, the average ADR suffers from high packet loss. Therefore, NS-managed ADRs (U-ADR) to improve the PDR and NEC was suggested. The suggested approach reduce the notable variations in the SNR of M packets by acting as a low-pass filter. To reduce the sudden variations in SNR brought on by interference and collisions, we first smooth the SNR values for each ED of P packets by averaging the SNR values within the uniform distribution's effective range. The adaptive data rate approach is used in the second step to determine the new SF and TP for each node based on the obtained SNR, following the determination of the smoothed SNR for each node. Using thorough simulations, the evaluation of U-ADR approach against the industry standard for ADR and two ADR implementation was performed. The findings show that the U-ADR algorithm achieves notable improvements in important performance metrics. The results gathered show that our suggested method outperforms the conventional ADR in terms of packet delivery ratio and energy consumption. The suggested methods are especially well-suited for dense IoT applications that require low energy consumption with a high PDR and reliability. Enhance the PDR while minimizing the NEC by designing ADR approaches for sustainable massive IoT system using optimization algorithms and study the performance of the suggested approach under different path loss models are some ideas suggested for future work.

FUNDING

None.

ACKNOWLEDGEMENT

The author would like to thank the reviewers for their valuable contribution in the publication of this paper.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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