Improved Configuration of Transmission Parameters for LoRaWAN in High-Noise Channels

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***Abstract*—The long-range wide-area network (LoRaWAN) as one of the Internet of Things (IoT) communication technologies has attracted a lot of attention from both industry and academia. The LoRaWAN covers thousands of things over a wide range network, with low energy consumption. However, increasing the number of things in the LoRaWAN networks affects the reliability, scalability, and energy consumption of the network which results in decreasing the packet delivery ratio. In LoRaWAN networks, the adaptive data rate (ADR) algorithm is a mechanism for adjusting transmission parameters of a thing with the aim of improving the communication quality between the thing and the gateway. In this paper, we study the original ADR algorithm and other proposed algorithms for the LoRa networks involving a high number of things under variable channel conditions. Our studies show that by employing the ADR algorithm when the noise of the channel and the number of nodes are high, the packet delivery ratio is reduced while energy consumption in the node is significantly increased. We propose an improved version of the original ADR algorithm to configure the transmission parameters including the spread factor and transmission power with respect to the high-noisy channels for the LoRa networks. Our proposed algorithm determines the transmission parameters in such a way that the packet delivery ratio is increased while energy consumption is reduced. The simulation results illustrate that our proposed algorithm improves the packet delivery ratio and energy consumption more than 4 times compared to the original ADR algorithm considering the sub-urban area with high-noise channels.**

***Index Terms*—IoT; LPWAN, LoRaWAN, LoRa, adaptive data rate algorithm, packet delivery ratio.**

I. Introduction

Internet of Things (IoT) is a new paradigm that will affect the future of the world and our life. The main idea of IoT is the ubiquitous presence of a variety of things including sensors, actuators, cell phones, etc., which are connected over communication technologies. The things in IoT are uniquely identified through an identifier and are able to communicate with each other to achieve common goals [1]. Many IoT applications such as smart buildings, smart cities, and smart industries require sensors to propagate data over a wide range network. To provide communication for these sensors over a wide range network, the long-range and low power wireless connections are needed. The low power wide-area network (LPWAN) enables things to communicate with each other over a wide range, with low energy consumption [2]. Different protocols have been proposed for LPWAN networks operating in either licensed or unlicensed frequency spectrum bands. The LPWAN networks that use industrial, scientific, and medical (ISM) frequency bands take advantage of the unlicensed frequency spectrum to reduce their time-to-market. In contrast, there are networks standardized by 3GPP which use licensed bands [2]. Currently, the most important LPWAN networks that have been developed include LoRaWAN [3], SigFox [4], and NB-IoT [5].

The LoRaWAN network covers many number of things over long distances in the sub-1 GHz frequency spectrum bands using LoRa modulation. The most important characteristic of the LoRaWAN network, which has led to its rapid growth, is the non-proprietary approach of developing this protocol in the context of a free society with the participation of various technology groups. Therefore, the LoRaWAN network has been used and studied by both industry and academia [6]. Hence, the LoRaWAN network accounts for a large portion of the global IoT market [7]. The transmission parameters in LoRa modulation such as spread factor and transmission power play an important role in determining the capacity and scalability of the LoRa network. The combination of these transmission parameters affects the transmission range, data rate, and energy consumption of the thing [8]. The LoRaWAN network obtains these transmission parameters for each thing by running an Adaptive Data Rate (ADR) algorithm on a central platform. After obtaining the transmission parameters, the LoRaWAN network sends them via a media access control (MAC) message to the things [9]. Due to the limited radio resources and coverage of a large number of things over a wide area, the LoRaWAN network faces several challenges such as scalability and lack of high reliable services [8].

In this paper, we propose an improved version of ADR algorithm for adjusting transmission parameters. This algorithm has 4 times improvement in packet delivery ratio in comparison with the other existing algorithms where there are a high number of things. Our proposed algorithm employs the minimum signal-to-noise ratio (SNR) value of recent received packets in the network. So, we call our proposed algorithm as ADR-MIN. Our contributions in this paper are summarized as follows:

- Our proposed ADR-MIN algorithm employing the min-

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imum SNR of last 20 packets, configures the transmission parameters including spread factor and transmission power.
- We consider a network consists of a large number of nodes under variable channel conditions.
- The simulation results confirm that our proposed ADR-MIN algorithm outperforms other existing algorithms in networks with a large number of nodes and the presence of high noise.

The remainder of paper is organized as follows. In Section II, we review LoRa and LoRaWAN networks and examine the ADR algorithms proposed for LoRaWAN. The related works are reviewed in Section III. In Section IV, we propose our ADR algorithm. Finally, the simulation results and conclusion are presented in Sections V and VI, respectively.

II. Background on LoRa and LoRaWAN

In this section, we first review LoRa modulation and LoRaWAN network and then discuss ADR algorithm as one of the basic features of the LoRaWAN networks.

A. An Overview of LoRa and LoRaWAN

Generally, LoRa refers to two distinct layers in the protocol stack: a physical layer based on the chirp spread spectrum (CSS) developed by Semtech and a MAC layer based on LoRaWAN which is proposed by the LoRa Alliance [9]. LoRa is a proprietary wide spectrum modulation built on CSS. The characteristics of this modulation include low energy consumption in low volume data transfer and inherent robustness against fading, Doppler effect and multi-path. Also, in this modulation, the spectrum is generated by producing a chirp signal that is continuously obtained at periodic frequencies. A LoRa radio signal has four transmission parameters consisting of spread factor, bandwidth, transmission power, and coding rate. The spread factor in LoRa modulation varies from SF 7 to SF 12 that enables the signal to spread and transmit at the same time on the same channel without interference. The modulated signals with different spread factors can only be recovered with their SF and the rest is taken account as noise in the receiver. The communication channels between the end device and the gateway have a bandwidth of 125 kHz, 250 kHz, or 500 kHz. The maximum and minimum transmission power of the end devices[1] are 2 dBm and 1 dBm, respectively. LoRa modulation provides low power communication over a long-range area using the sub-1 GHz frequency bands. The combination of these parameters has an impact on the communication range, data transmission rate, and noise resistance. For example, using a higher spread factor will increase the range and time of data transmission, while using a lower spread factor will reduce the transmission time [10].

LoRaWAN is a MAC protocol for the LoRaWAN network which allows low-power devices to communicate with Internet-based applications. As illustrated in Fig. 1, LoRaWAN network architecture consists of LoRa-based end devices (sensors and actuators), gateways (LoRaWAN gateways), network servers, and user applications and softwares. In fact, the gateway and the network server act as an intermediary between the user application and the end devices and allow data access to the application. On the LoRaWAN network, data is transmitted in an end-to-end manner between devices and the user application via advanced encryption standard (AES) encryption. Therefore, information security of users is also guaranteed. LoRaWAN technology, with the use of symmetric links, allows for completely two-way communication; this is especially important in IoT services that require server-side terminal commands. In LoRaWAN, based on the LoRa physical layer protocol, the data rate is 27 kbps, and each gateway can collect data from thousands of end devices. The radio coverage of each LoRaWAN gateway in urban and suburban areas is up to 15 km [14].

[1] In the rest of this paper, the words things, nodes, and end devices are used interchangeably.

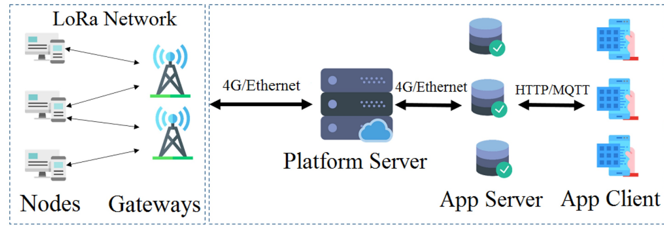


Fig. 1: LoRaWAN network architecture

B. ADR Algorithm in LoRaWAN Networks

The ADR algorithm is a well-known mechanism to determine the spread factor and transmission power. These parameters depend on the channel conditions between the end devices and the gateway. Hence, configuring these parameters can improve the quality of communication between the end devices and the gateway. The ADR algorithm is implemented simultaneously on the end devices and on the platform. Adjustment of the transmission parameters in this algorithm is done in such a way that the near nodes to the gateway uses the lower spread factor and transmission power than the further nodes [6]. By implementation of ADR algorithm in a node, if the number of packets sent from the node to the gateway that did not receive the ACK message exceeds a given limit, the node assumes that the packets are lost and increases its transmission power. The node can request the implementation of the ADR algorithm on the platform by setting a flag in the MAC message. The platform executes the ADR algorithm for each node and sends the transmission parameters as a MAC LinkADRReq message to the nodes. To this end, the platform estimates the maximum SNR of the last 20 packets received from the node, and thus determines the spread factor and transmission power of the node. Details of the ADR algorithm are presented in [9].

III. Related Works

The most of the related researches to the LoRaWAN network can be classified into three categories namely, the real implementation of LoRa network [11]– [12], providing a mathematical model [14]– [15], and computer simulations of LoRa networks [16]– [17]. In addition, recent researches have been conducted to provide solutions for managing the transmission parameters including transmission power and spread factor in the network with different aims. In [18], the impact of each of the transmission parameters on reliability and energy consumption is investigated. Then, an algorithm is proposed to determine the transmission parameters with the aim of reducing energy on a reliable link. The authors in [14] defined an optimization problem to obtain a distribution of the spread factor for things in the network, with the aim of minimizing the packets error rate, fairly. In [14], using the Min-Max method, the optimal value of the spread factor is obtained. However, the transmission power of nodes is not optimally determined in this paper. In [15], the spread factor and transmission power is determined in a similar manner to [14]. However, in [14], the nodes' bandwidth is assumed constant, in [15] nodes can choose their desirable bandwidth.

In [13] a centralized approach is proposed to determine the transmission power as well as spread factor. The authors in [13] considered the shadowing noise environment and showed that by employing the original ADR algorithm proposed in [9], the packet delivery ratio is dramatically decreased. So, to overcome this drawback, they proposed an ADR algorithm which is operated based on the average SNR value of the last 20 packets instead of the maximum SNR value of the last 20 packets in [9]. The authors in [19] have improved the scalability of the original ADR algorithm proposed in [9].

In our proposed algorithm, we assume the channel conditions with high noise. Therefore, unlike [9] which considers the channel condition without noise and uses the maximum SNR of last 20 packets to determine the spread factor and transmission power, we use the minimum SNR of last 20 packets. By doing so, our proposed algorithm improves packet delivery ratio and energy consumption by 4 times in comparison with the presented algorithm in [9].

IV. Our Proposed ADR Algorithm

The ADR algorithm proposed in [9] obtains the spread factor and the transmission power for the end devices based on the maximum SNR value of the last 20 received packets on the platform. The maximum SNR value is not a good estimation of the shadowing noise environment. The determined spread factor and transmission power in that way would increase interference and energy consumption of end devices. The results of [13] show that the choosing a function to combine the information of the last 20 packets stored in the central platform affects the packet delivery ratio and energy consumption. The maximum SNR of the last 20 packets is not a good estimate of noise conditions.

To address this drawback, in [13], the spread factor and transmission power of end devices are calculated based on the average SNR value of the last 20 received packets. By doing so, the packet delivery ratio is increased 20% in the noise environment as compared to the ADR algorithm proposed in [9]. However, the proposed ADR algorithm in [13] has two main drawbacks: (1) considering the average SNR value in environment without noise decreases the packet delivery ratio in comparison with ADR algorithm proposed in [9], (2) in the suburban environments where shadowing noise becomes too high, the average SNR value reduces the packet delivery ratio.

The maximum SNR value of the last 20 packets is an optimistic estimate of noise conditions. So, the original ADR algorithm proposed in [9] does not have a good performance in the noise environment. Also, the ADR algorithm based on the average SNR value [13] does not result in a good performance in suburban. Furthermore, the ADR algorithms proposed in [9] and [13] do not have a good performance in networks with varying channel conditions.

Let $(a_1, a_2, \cdots, a_{20})$ denote the SNR value of the last 20 packets. If F represents the combinatorial function, the aim of F is to combine the SNR of last 20 packets in such a way that an accurate value of the signal-to-noise is given to determine the spread factor and the transmission power. Theoretically, the combinatorial function F should have the following properties:

1) Idempotency: $\forall i \in [1, 2, \cdots, 20]$, if $a_i = a$ then $F(a, a, \cdots, a) = a$.
2) Commutativity: $F(a_1, a_2) = F(a_2, a_1)$.
3) Monotonicity: $\forall i \in [1, 2, \cdots, 20]$, if $a_i \geq b_i$ then $F(a_1, a_2, \cdots, a_{20}) \geq F(b_1, b_2, \cdots, b_{20})$

Accordingly, it is expected that the SNR combination function of the last 20 packets is less than the maximum SNR of the last 20 packets and greater than the minimum SNR of the last 20 packets, i.e.,

$$\min(a_1, a_2, \cdots, a_{20}) \leq F(a_1, a_2, \cdots, a_{20}) \\ \leq \max(a_1, a_2, \cdots, a_{20}).$$

Also, the average SNR of last 20 packets proposed in [13] satisfies the combinatorial function properties. The average SNR function is expressed as

$$\text{Avg} : F(a_1, a_2, \cdots, a_{20}) = \frac{1}{20} \sum_{i=1}^{20} a_i.$$

Hence, to overcome the drawbacks of ADR algorithms proposed in [9] and [13], we propose an improved version of ADR algorithm (named as ADR-MIN) which employs the minimum SNR value of the last 20 packets. Using the minimum SNR value for configuring the transmission parameters results in higher packet delivery ratio and lower energy consumption in networks with varying channels condition. The details of our proposed ADR-MIN is given in Algorithm 1. It should be noticed that in Algorithm 1, the spread factor and transmission power are denoted by SF and TP, respectively. Also, the minimum value of spread factor which is denoted by $\text{SF}_{\min}$ is equal to 7. Furthermore, the minimum and maximum values of transmission power are represented as $\text{TP}_{\min}$ and $\text{TP}_{\max}$, respectively. The minimum value of transmission power is

1dBm (i.e., $\text{TP}_{\min} = 1\text{dBm}$). Likewise, the maximum value of transmission power is 2dBm (i.e., $\text{TP}_{\max} = 2\text{dBm}$).

Due to considering minimum SNR of last 20 packets to configure the transmission parameters, our proposed ADR-MIN algorithm obtains better performance as compared to the proposed algorithms in [9] and [13] when the channels are high noise.

Algorithm 1: Our proposed ADR-MIN algorithm

$SNR_m \longleftarrow \min(SNR$ of last 20 packets)
$SNR_{\text{req}} \longleftarrow$ demodulation factor (current data rate)
deviceMargin $\longleftarrow 10$
$SNR_{\text{margin}} \longleftarrow (SNR_m - SNR_{\text{req}} - \text{deviceMargin})$
step $\longleftarrow \lfloor \frac{SNR_{\text{margin}}}{3} \rfloor$
while step > 0 **and** $\text{SF} > \text{SF}_{\min}$ **do:**
  $\text{SF} \longleftarrow \text{SF} - 1$
  step $\longleftarrow$ step $- 1$
while step > 0 **and** $\text{TP} > \text{TP}_{\min}$ **do:**
  $\text{TP} \longleftarrow \text{TP} - 3$
  step $\longleftarrow$ step $- 1$
while step < 0 **and** $\text{TP} < \text{TP}_{\max}$ **do:**
  $\text{TP} \longleftarrow \text{TP} + 3$
  step $\longleftarrow$ step $+ 1$

V. Simulation Results

To evaluate our proposed ADR-MIN algorithm, we consider a LoRaWAN network consisting of nodes, gateway, and a central platform according to the simulation setup in [13]. The simulation results are obtained using OMNET++ with FloRa framework[2]. The path loss between nodes and gateway denoted by PL is modeled as $PL(d) = \overline{PL}(d_0) + 10\eta\log(d/d_0) + X_\sigma$, where d is distance between nodes and gateway, $\overline{PL}(d_0)$ is the mean path loss at the reference distance d_0, η is is the path loss exponent, and X_σ is a Gaussian random variable with zero mean and σ as standard deviation.

The simulations are implemented in two urban and sub-urban scenarios in the range of $480m \times 480m$ and $980m \times 980m$, respectively. The parameters of the path loss model in these scenarios are illustrated in Table I according to the results of [21]. To implement these scenarios, we consider three different channel models, namely, ideal, moderate, and typical variability by setting different standard deviations (i.e., σ) in the path loss model as shown in Table I.

In each scenario, a gateway is placed in the center of the specified range, and 100 to 700 nodes are uniformly distributed in the range. Each node generates and sends a packet of 20 bytes at a time with an exponential distribution average 1000 seconds. The all other simulation parameters are given in Table II.

In what follows, we evaluate our proposed ADR-MIN algorithm with respect to two criteria:

- packet delivery ratio (%): the total number of packets received in the platform divided by the total number of packets sent by all nodes.

[2]This framework is available at https://github.com/mariuszslabicki/flora.

TABLE I: The parameters of path loss model

Scenario	$d_0(m)$	$\overline{PL}(d_0)$	η	$\sigma(dB)$		
				ideal	moderate	typical
urban	40	127.41	2.08	0	1.785	3.57
sub-urban	1000	128.95	2.32	0	3.540	7.08

TABLE II: Physical layer simulation parameters

Parameter	Value
carrier frequency	868MHz
bandwidth	125kHz
code rate	8\4
spread factor	7 to 12
transmission power	2dBm to 14dBm

- energy consumption (mJ): the total of the energy consumed by all nodes divided by the number of packets received in the platform.

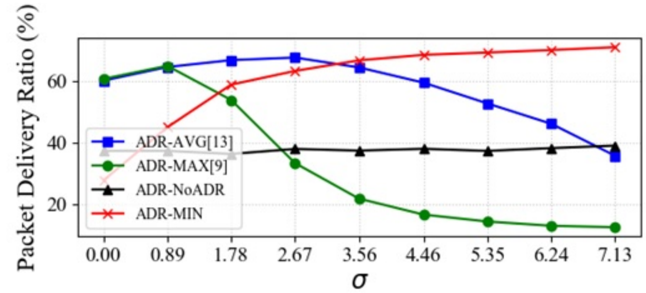
To verify the effectiveness of our proposed ADR-MIN algorithm, we compare it with two state-of-the-art algorithms proposed in [9] and [13]. In simulation results, the ADR algorithms proposed in [9] and [13] are named as ADR-MAX and ADR-AVG, respectively. In addition, we consider an ADR algorithm called as NoADR in which spread factor and transmission power are selected randomly[3]. The simulation results for different scenarios are presented in what follows.

A. The Suburban Scenario

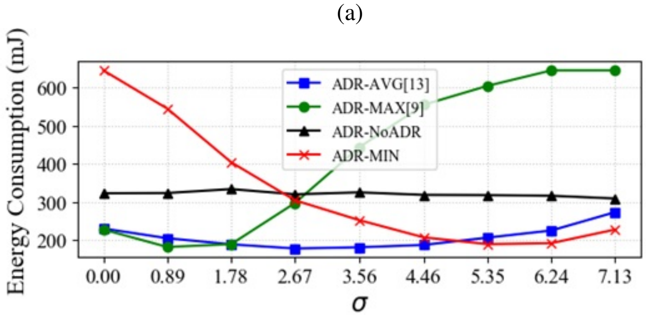
In this section, we verify the performance of our proposed ADR-MIN algorithm in suburban scenario. Figs. 2a and 2b show the packet delivery ratio and energy consumption of our proposed ADR-MIN algorithm and the other existing algorithms, respectively, when the number of nodes is set to 100. As can be seen in Fig. 2a, when σ is equal to 0, the packet delivery ratio in the ADR-MIN algorithm is reduced due to an incorrect estimation of the noise condition. Also, from Fig. 2a, we can see that the ADR-MIN algorithm obtains the highest packet delivery ratio when $\sigma \geq 3.56$ (i.e., in moderate and typical channels). Furthermore, in Fig. 2b, it can be seen that our proposed ADR-MIN algorithm has the lowest energy consumption in typical channels i.e., $\sigma = 7.13$.

Finally, in Figs. 3a and 3b, the performance of the ADR-MIN algorithm is illustrated when σ is set to 7 and the number of nodes increases from 100 to 700. As can be seen from Fig. 3a, our proposed ADR-MIN algorithm outperforms the ADR-MAX, NoADR, and ADR-AVG algorithms in terms of packet delivery ratio. The ADR-MIN improves the packet delivery ratio by 4 times compared to ADR-MAX. From Fig. 3b, we can observe that the ADR-MIN algorithm obtains the lowest energy consumption in comparison with the other algorithms. Also, it can seen that the ADR-MIN algorithm improves the energy consumption by 4 times compared to ADR-MAX.

[3]In this case, the ADR algorithm is executed neither on the platform nor in the nodes.

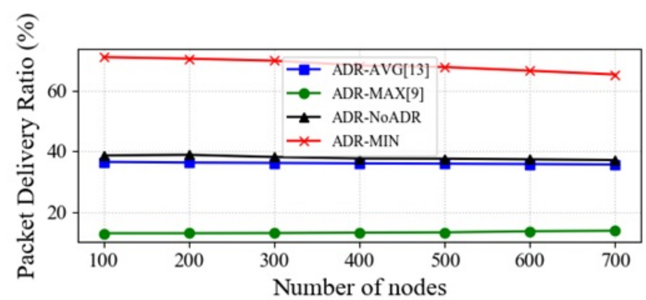


(a)

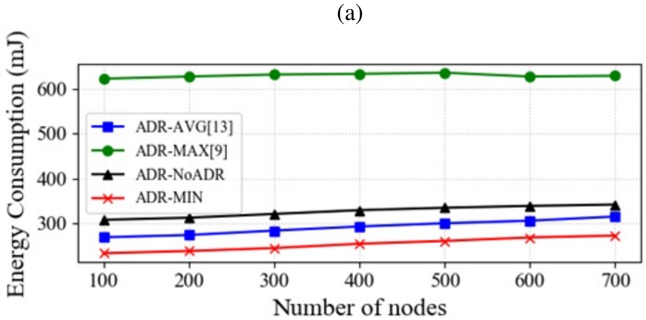


(b)

Fig. 2: The performance of ADR-MIN in terms of (a) packet delivery ratio versus different values of σ and (b) energy consumption versus different values of σ, considering suburban scenario.

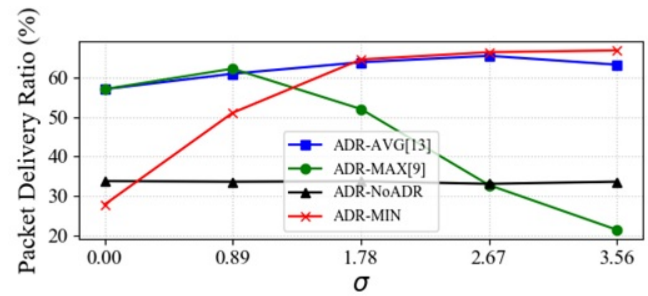


(a)



(b)

Fig. 3: The performance of ADR-MIN in terms of (a) packet delivery ratio versus different number of nodes and (b) energy consumption versus different number of nodes, considering suburban scenario.



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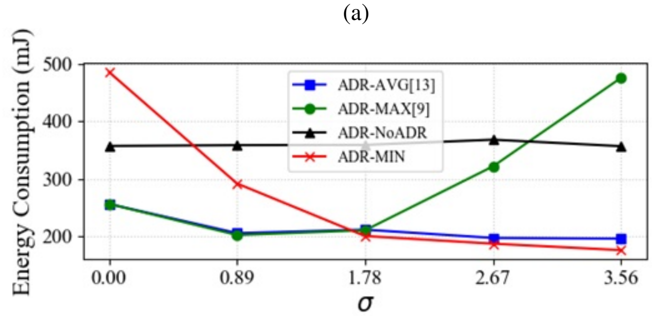
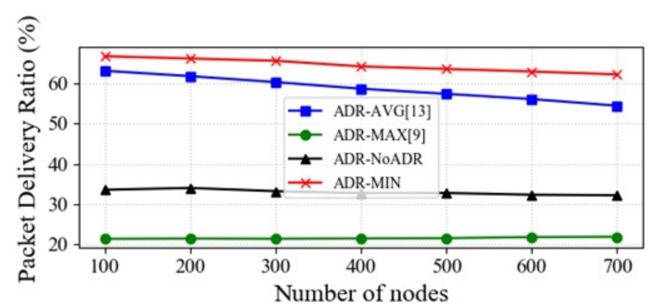
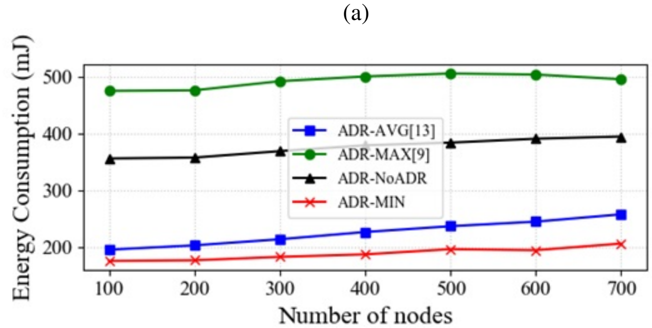


(b)

Fig. 4: The performance of ADR-MIN in terms of (a) packet delivery ratio versus different values of σ and (b) energy consumption versus different values of σ, considering urban scenario.



(a)



(b)

Fig. 5: The performance of ADR-MIN in terms of (a) packet delivery ratio versus different number of nodes and (b) energy consumption versus different number of nodes, considering urban scenario.

B. The Urban Scenario

In this section, we evaluate the performance of our proposed ADR-MIN algorithm in the urban scenario in terms of packet delivery ratio and energy consumption.

Figs. 4a and 4b illustrate the packet delivery ratio and energy consumption, respectively, when the standard deviation (σ) varies from 0 to 3.56. For generating these figures, we set the number of nodes to 100. From Figs. 4a and 4b, we can observe that our proposed ADR-MIN algorithm outperforms ADR-MAX, ADR-AVG, and NoADR algorithms in moderate and typical channels i.e., when $1.75 \leq \sigma \leq 3.56$.

The performance of our proposed ADR-MIN algorithm in comparison with the other state-of-the-art algorithms is shown in Figs. 5a and 5b. To generate these figures, σ is set to 3.56. It can be seen that when the number of nodes increases from 100 to 700, since the interference of using the same spread factor is increased, the packet delivery ratio decreases and energy consumption increases in all of the ADR algorithms. Furthermore, our proposed ADR-MIN algorithm outperforms all of the other state-of-the-art algorithms in terms of packet delivery ratio and energy consumption in ideal, moderate, typical channels i.e., when $\sigma \geq 0$.

VI. Conclusion

In this paper, an ADR algorithm for adjusting the transmission parameters was presented. The proposed algorithm implements on the central platform and configures the spread factor and transmission power in such a way that the packet delivery ratio is increased as compared to the other state-the-art algorithms. This algorithm calculates a suitable estimation of the spread factor and transmission power for end devices when the network noise is high. Through simulation results, we showed that our proposed ADR algorithm outperforms other algorithms for high noise channels in terms of packet delivery ratio and energy consumption.

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