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Dynamic Spreading Factor and Power Allocation of LoRa Networks for Dense IoT Deployments

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***Abstract*—Nowadays, different technologies have been proposed for low-power wide-area networks (LPWAN). The long-range wide-area network (LoRaWAN) as one of the LPWAN technologies is designed for the internet of things (IoT) communications which covers thousands of things in a wide range network, with low battery power consumption. The adaptive data rate (ADR) algorithm is a mechanism in LoRaWAN for configuring transmission parameters in a node with the aim of improving the quality of communication between the node and the gateway. Our studies in this paper show that applying the original ADR algorithm in a network with a large number of nodes and in the presence of channel noise results in significantly decreased packet delivery ratio and increased energy consumption. In this paper, we propose an improved version of the original ADR algorithm which dynamically and almost irrespectively of the number of nodes configures transmission parameters including the spreading factor and transmit power of the nodes in LoRa networks with variable channel conditions. In the proposed algorithm, the ordered weighted averaging (OWA) is employed as a decision-making method capable of considering the channel condition in configuring the transmission parameters. Using OWA makes the proposed algorithm perform well at all channel conditions as demonstrated by our numerical results. Also, simulation results show that the packet delivery ratio of the proposed algorithm in a sub-urban scenario with high channel noise is 4 and 1.5 times of the original ADR and other algorithms, respectively, while it consumes the least energy compared to the others.**

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

I. Introduction

Internet of things (IoT) practically is a new paradigm that will affect many aspects of our near-future life. The core idea of IoT is based on the presence of interrelated things including sensors, actuators, cellular phones and etc. which work together to reach some relatively shared goals [1]. Many IoT applications require the use of sensors to send data in a wide range. Low-power wide-area network (LPWAN) provides the possibility of network connection for a large number of things in a wide range while low battery power is consumed [2].

There are different protocols for LPWAN operating in a different frequency spectrum. The LPWANs that use the industrial, scientific and medical (ISM) radio frequencies, take advantage of the free frequency spectrum to enter the market in comparison to the 3GPP-standardized networks which use licensed frequency bands [2]. Currently, the most important LPWANs developed in the market include LoRaWAN [3], SigFox [4], and NB-IoT [5].

The LoRaWAN network covers a large number of nodes over long distances at the frequency spectrum sub-1GHz on the LoRa modulation. Alongside LoRaWAN technical advantages, a non-proprietary approach to develop this protocol with the participation of various technology groups will increase its rapid evolution. Therefore, LoRaWAN has been used and studied not only by academic research groups but also by industry [6]. The study in [7] shows that LoRaWAN dominates a significant portion of IoT globally because of its advantages. However, in LoRaWAN, there are limited radio resources and thus, covering a large number of nodes introduces challenges such as scalability, high-reliability services, and etc. [8].

The transmission parameters in LoRa modulation including the spreading factor and transmit power of nodes have a significant role in determining the capacity and scalability of LoRaWAN. Combination of these parameters affects the transmission range, data rate, and power consumption of nodes [8]. LoRaWAN runs an adaptive data rate (ADR) algorithm in the central platform to calculate transmission parameters of nodes and sends them as a media access control (MAC) message [9].

In this paper, we study the ADR algorithm in LoRa network with large number of nodes under variable channel conditions. Our studies show that employing the original ADR algorithm in a network with large number of nodes and in the presence of the channel noise leads to a significantly increased nodes' energy consumption and decreased packet delivery ratio. Then, inspired by the original ADR algorithm, we propose a dynamic ADR algorithm to configure transmission parameters of nodes based on the channel condition. Our goal is to propose an efficient dynamic ADR algorithm that can be easily implemented with minimal changes to the original ADR algorithm. Our contributions in this paper are summarized as follows:

- Our proposed improved version of the ADR algorithm dynamically and almost irrespectively of the number of nodes configures the transmission parameters including the spreading factor and transmit power of the nodes in the LoRa network with variable channel conditions.

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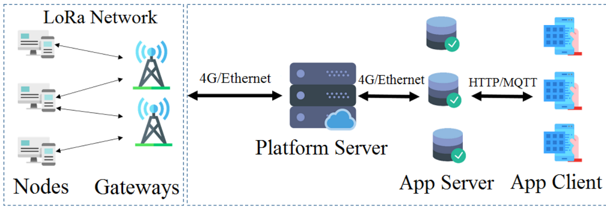

Fig. 1. The LoRaWAN network architecture.

- In our algorithm, we use the ordered weighted averaging (OWA) as a decision-making tool capable of considering channel conditions to configure transmission parameters.
- Through simulation results, we show that our proposed algorithm outperforms other algorithms in scenarios with a large number of nodes and the presence of high noise. Also, our proposed method has the same performance as the other algorithms in scenarios with low number of nodes and channels with a low noise.

The rest of this paper is organized as follows. In Section II, the background, and literature review are presented. We propose our ADR algorithm in Section III. Sections IV and V contain the simulation results and the conclusion, respectively.

II. Background and Literature Review

In this section, we first overview LoRa and LoRaWAN and then study the ADR algorithm and review the related literature.

A. An Overview on LoRa and LoRaWAN

The LoRaWAN network is formed by two core components: LoRa and LoRaWAN, each of which refers to a layer in the protocol stack. LoRa is a physical layer modulation developed by Semtech [4]. LoRaWAN is implemented on top of the LoRa and includes data link and network layers. The specifications of LoRaWAN are documented by LoRa Alliance [9].

The LoRaWAN network architecture is presented in Fig. 1. As seen in this figure, the nodes send data to the platform through the gateways. Note that the nodes are not assigned to a specific gateway. Rather, all the gateways in the transmission range of a node receive its data and send it to the platform. For each node, the platform stores the information of last twenty packets including SINR, packet counter, and the number of gateways that have received it. Then, according to the different defined applications in the platform, the data sent by the node is transferred to the corresponding application server.

In the physical layer of LoRaWAN, each LoRa transmission depends on the following significant transmission parameters: the spreading factor which has a value between $7-12$, the transmit power which has a value of $[2, 5, 8, 11, 14]$ dBm, the bandwidth ($[125, 250, 500]$ KHz), and coding rate. In this paper, we focus on the transmit power and the spreading factor. A combination of these transmission parameters affects the data rate which is $0.3 - 50$ Kbps, the transmission range which is $2 - 5$ km in urban areas and 15 km in sub-urban areas [8], and the power consumption. For instance, the use of a high spreading factor and a high transmit power results in increased power consumption, decreased data rate, and increased transmission range, while using a low spreading factor and a low transmit power increase data rate and decrease the transmission range and power consumption [8].

B. The ADR Algorithm in LoRaWAN

Depending on the channel conditions between the nodes and gateways, the spreading factor and the transmit power are determined. This determination is made by the ADR algorithm which aims at enhancing the quality of the communication between nodes and gateways. The ADR algorithm is executed at the node and platform simultaneously. In this algorithm, the transmission parameters are configured such that a node closer to the gateway consumes lower transmit power and spreading factor in comparison with a node farther to the gateway [6].

The execution of ADR algorithm in the node is such that if the number of sent packets from the node to the gateway whose ACK message has not been received exceeds a limit, the node assumes that the packets are lost and increases the transmit power intending to enhance the communication link. The nodes by setting a flag in the MAC message can request the execution of ADR algorithm on the platform. The platform runs the algorithm for each node and sends the transmission parameters as a MAC LinkADRReq message to it. To do this, the platform considers the maximum SINR of the last 20 packets received from the node as an approximation of packets' SINR, and accordingly determines the spreading factor and the transmit power of the node. The details of ADR algorithm is presented in LoRaWAN Specification (v1.1) [9].

C. Related Work

The existing methods in the literature proposed to control the transmission parameters including the spreading factor and transmit power in LoRaWAN can be classified into two categories named the network-aware approaches [10], [11] and the link-based approaches [12], [13]. In the link-based approach, the transmission parameters between the nodes and gateway are determined in a centralized manner at the platform. In the network-aware approach, the determination of the transmission parameters is done by each node in a distributed manner.

In [10], an optimization problem is formulated to attain a distribution of the spreading factor for nodes in the network, to minimize the packet error rate fairly. However, the optimal value of the transmit power of nodes has not been obtained in [10]. The authors of [11] apply a network-aware approach similar to [10]. However, the bandwidth of nodes is assumed to be constant in [10] while the nodes can dynamically choose their bandwidth as in [11].

The centralized ADR algorithm presented at LoRaWAN Specification (v1.1) [9] is slightly modified in [12] to enhance the scalability of LoRaWAN. It is shown in [13] that selecting a function for combining the data related to the last 20 recorded packets in the central platform is affecting the packet delivery ratio and energy consumption. Specifically, it is shown in [13] that the maximum SINR of the last 20 packets (as used in [9]) is an optimistic approximation of the area's noise condition and is not efficient if there is shadowing noise in the network. Thus, the average SINR of the last 20 packets is used in [13] instead of maximum SINR which enhances the packet delivery ratio by 20%. However, there are two drawbacks to this approach. The first drawback is that if we use this method while there is low noise in the area, a lower packet delivery ratio is achieved compare to the case of the maximum SINR of the last 20 packets. The second drawback is that when this method is used in sub-urban areas which have higher shadowing noise, the packet delivery ratio decreases (as will be shown in Section IV). In the next section, we propose a dynamic ADR algorithm which considers the channel noise condition to configure the spreading factor and transmit power of nodes.

III. The Proposed Dynamic ADR Algorithm

As it has been mentioned in the previous section, using maximum SINR proposed in [9] and average SINR proposed in [13] of the last 20 packets as an approximation of SINR value in ADR algorithm does not result in a good performance in networks with varying channel condition. We propose a dynamic ADR algorithm that uses the OWA operator to dynamically configure the spreading factor and transmit power of nodes based on the channel condition which is implicitly represented by SINR of the last 20 packets. Note that as in the default ADR algorithm in [9], the SINR of the last 20 packets is stored and implemented in the platforms, we also use the last 20 packets in our dynamic ADR algorithm to avoid the overhead for changing this way of implementation. In this section, we first describe the OWA operator and then explain how to use it to propose our dynamic ADR algorithm.

A. The OWA Operator

The OWA Operator which is one of the powerful techniques of the information fusion theory uses the aggregation operators to define the general decision function. This method was first introduced by Yager in 1988 as a tool to address the problem of aggregating multi-criteria objectives to form an overall decision function [14]. The most important area for applications of the OWA operator is decision making.

Generally, an OWA operator in the domain of n dimension is a mapping function of $F_W : R^n \rightarrow R$ such that:

$$F_W(a_1, a_2, \cdots, a_n) = \sum_{i=1}^{n} w_i a_i, \tag{1}$$

where, F_W is the fusion function, n is the number of samples obtained from data aggregated with F_W, $\{a_1, a_2, \cdots, a_n\}$ is the descending sorted set of samples (i.e., $a_1 \geq a_2 \geq \cdots \geq a_n$), and w_i is the weight of the ith sample. The vector of weights is denoted by W, i.e., $W = (w_1, w_2, \cdots, w_n)^T$, where $w_i \in [0,1]$, $1 \leq i \leq n$, and $\sum_{i=1}^{n} w_i = 1$.

The OWA operator is capable of incorporating the amount of the risk-taking of the decision-maker into the final value selection by setting the weight vector W. Note that the higher amount of risk-taking degree of the decision-maker shows the higher optimistic approach, while the lower amount of risk-taking degree shows the higher pessimistic approach. The general approach is to generate the OWA weights such that the designer's desirable risk-taking degree is satisfied. For the optimistic approach, the weights are defined as:

$$\begin{aligned} w_i &= \alpha(1-\alpha)^{i-1}, \quad \forall i \in \{1, \cdots, n-1\} \\ w_n &= (1-\alpha)^{n-1}, \end{aligned} \tag{2}$$

where $0 \leq \alpha \leq 1$. For the pessimistic approach, we have:

$$\begin{aligned} w_1 &= \alpha^{n-1} \\ w_i &= (1-\alpha)\alpha^{n-i}, \quad \forall i \in \{2, \cdots, n\}. \end{aligned} \tag{3}$$

The difference between the two approaches is based on a different amount of risk-taking. More specifically, with the same value for α, the risk-taking of the optimistic approach is more than the pessimistic approach. The value of α is the core parameter to determine the weights. As an instance, if we set $\alpha = 0$ for the pessimistic approach, the OWA operator acts as a minimum function and assigns a higher weight to the sample with minimum value, i.e., a_n, while if we set $\alpha = 1$, the OWA operator acts as a maximum function and assigns a higher weight to the sample with maximum value, i.e., a_1.

B. Dynamic ADR Algorithm Using OWA

In this section, we use the OWA operator as a decision-making method to propose a dynamic ADR algorithm. We define the last 20 packets as the sample set in OWA operator, i.e., $n = 20$. We sort these packets in a descending manner according to their SINR values, i.e., a_1 is the packet with maximum SINR and a_n is the packet with minimum SINR. Since the channels are usually noisy, we take the approach with a lower amount of risk-taking degree and define the OWA weight vector according to the pessimistic approach in (3). As has been mentioned, the value of α has a significant role in the OWA operator. If we set $\alpha = 1$, the OWA operator works as the original ADR algorithm [9] and considers the maximum SINR of the last 20 packets as an approximation for packets' SINR.

In our proposed dynamic ADR algorithm, we configure α dynamically based on the network condition. To do this, we use the packet loss ratio as an indicator of the channel condition. More specifically, the higher value of the packet loss ratio indicates higher channel noise and its lower value represents the channel with lower noise. Let denote the packet loss ratio as PLR. The value of PLR can be calculated using the counter of the first and last packet in the 20-cell array denoted by $FirstCounter$ and $LastCounter$, respectively, that the platform is recording for each node [9]. As an instance, if the values of $FirstCounter$ and $LastCounter$ of the last 20 packets received by the platform from a node are equal to 10 and 60, respectively, it indicates that the node has sent 50 packets, of which 30 packets have been lost which corresponds to 60% of packet loss ratio. Accordingly, PLR is defined as:

$$PLR = \frac{LastCounter - FirstCounter - 20}{LastCounter - FirstCounter}. \tag{4}$$

The value of α should be set such that when PLR is high (or low) which represents a high (or low) channel noise, the weight of packets with low (or high) SINR would be high.

To dynamically configure α, we set it as $\alpha = 1 - PLR$. Specifically, if PLR is high, the value of α would be low, and thus the OWA operator would be closer to the minimum function of the SINR of the last 20 packets. On the other hand, the low value of PLR results in a higher value of α leading to the OWA operator would approximate to the maximum function of the SINR of the last 20 packets.

The proposed dynamic ADR-OWA algorithm is presented in Algorithm 1. Let denote the list of the last 20 packets of the node in the platform including $[PacketCounter, GatewayDiversity, SINR]$ as $ADRlist$, where $PacketCounter$ is the packet's counter incremented with every transmission, $GatewayDiversity$ is the number of gateways to which the node was connected and received the packet, and $SINR$ is the maximum of the various SINRs reported by different gateways who received the packet. Also, the spreading factor and the transmit power of the node are denoted by SF and TP, respectively. The platform obtains PLR of packets and sorts $ADRlist$ descending according to the packets' SINR. Then, it obtains the OWA weight based on the PLR from (3) and uses it to provide an approximation for packets' SINR denoted by $SINR_{owa}$. Afterward, it subtracts $SINR_{req}$ and $deviceMargin$ from the approximated SINR, i.e., $SINR_{owa}$, where $SINR_{req}$ is the expected SINR of the last packet, and $deviceMargin$ is a device-specific static parameter which is part of a device profile and indicate the installation margin of the network (typically 10 dB in most networks [9]). The result is called SINR margin and denoted by $SINR_{margin}$. The calculated SINR margin is used to determine the spreading factor and the transmit power of each node in the same way as the original ADR algorithm in [9].

Algorithm 1: Proposed dynamic ADR-OWA algorithm

```
Input: ADRlist
Output: TP and SF
FirstCounter=first counter(ADRlist)
LastCounter=last counter(ADRlist)
Obtain PLR from (4)
α = 1 − PLR
n = 20
Sort ADRlist descending according to packets' SINR
for i = 1 : ADRlist.size() do
    Obtain w_i from (3)
    SINR_owa+ = w_i ∗ (SINR of ADRlist(i))
end
SINR_req = demodulationfloor(currentdatarate)
deviceMargin = 10
SINR_margin = (SINR_owa − SINR_req − deviceMargin)
step = floor(SINR_margin/3)
while steps > 0 and SF > SF_min do
    SF = SF − 1
    steps = steps − 1
end
while steps > 0 and TP > TP_min do
    TP = TP − 3
    steps = steps − 1
end
while steps < 0 and TP < TP_max do
    TP = TP + 3
    steps = steps + 1
end
```

IV. Simulation Results

We simulate the LoRaWAN network, including nodes, gateway and central platform according to the setup presented at [13] using OMNET++ with FloRa framework[1]. To model the path loss noted by PL, we use log-distance model as $PL(d) = \overline{PL}(d_0) + 10\eta \log(\frac{d}{d_0}) + X_\sigma$, where, d is the distance between the transmitter and receiver, $\overline{PL}(d_0)$ is the mean path loss at the reference distance d_0, η is the path loss exponent, and X_σ is a Gaussian random variable with zero mean and σ as standard variation. The simulation has been done for two urban and sub-urban scenarios in the range of 480 m by 480 m and 9800 m by 9800 m, respectively. The parameters of path loss model for two scenarios are presented in Table I adjusted based on [15]. Also, we consider three different channel conditions called ideal, moderate, and typical variability modeled by different σ in the path loss model presented in Table I. For each scenario, a gateway is placed in the middle of the network and 100 to 700 nodes with specific parameters presented in Table I are uniformly distributed in the network. Each node creates a 20 Byte packet and sends it in a time which has an exponential distribution with the mean as 1000 seconds. The physical layer simulation parameters are summarized in Table II. In all scenarios, simulation results are obtained by averaging over 30 runs with randomly generated nodes' locations.

TABLE I
Parameters of path loss model

Scenario	$d_0[m]$	$\overline{PL}(d_0)$	η	$\sigma[dB]$		
				Ideal	Moderate	Typical
Sub-urban	1000	128.95	2.32	0	3.540	7.08
Urban	40	127.41	2.08	0	1.785	3.57

TABLE II
Physical Layer Simulation Parameters

Parameter	Value	Parameter	Value
Carrier frequency	868 MHz	Transmit power	2-14 dBm
Bandwidth	125 kHz	Spreading factor	7 to 12
Coding rate	4/8		

We evaluate the performance of our algorithm and compare it with other schemes based on two following criteria:

1) **The packet delivery ratio (%)**: defined as the total received packets by the platform divided by the total sent packet from all nodes.
2) **The energy consumption (mJ)**: defined as the total consumed energy by all nodes divided by the number of received packets by the platform.

To compare the performance of our ADR algorithm called as ADR-OWA, we consider two schemes presented in [9] and [13] called as ADR-MAX and ADR-AVG, respectively, as well as the scheme with no ADR algorithm called NoADR. In the NoADR scheme, the spreading factor and the transmit power of nodes are adjusted randomly.

[1]This framework is available in https://github.com/mariuszslabicki/flora.

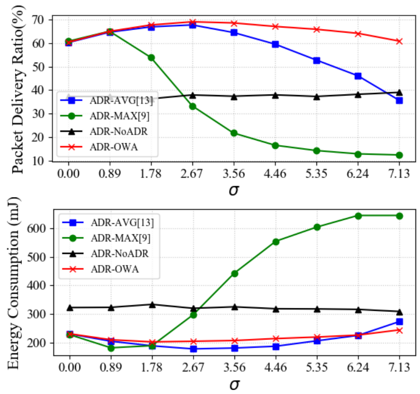

Fig. 2. Packet delivery ratio and energy consumption of different algorithms versus σ in the sub-urban scenario (100 nodes).

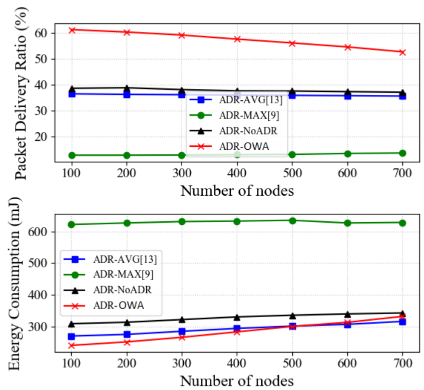

Fig. 3. Packet delivery ratio and energy consumption of different algorithms versus the number of nodes for typical channels in the sub-urban scenario.

A. The Sub-Urban Scenario

In this section, we investigate the performance of our proposed ADR-OWA algorithm in the sub-urban scenario. Fig. 2 shows the packet delivery ratio and energy consumption of the algorithms for different σ in the path loss model when there are 100 nodes in the sub-urban scenario. We observe that our proposed ADR-OWA algorithm achieves the higher packet delivery ratio than the other schemes in all channel conditions, i.e., all different values of σ. The reason is that as the NoADR scheme configures the transmit power and spreading factor randomly, its performance is not affected by varying σ and its achieved packet delivery ratio is about 40% for all channel conditions which is lower than that in ADR-OWA. Also, as ADR-MAX has an optimistic approach to predict the channel condition, it does not have a good performance in noisy channels and so it experiences the packet delivery ratio reduction when $\sigma = 0.89$ which will be worse when σ is increasing. Although ADR-AVG has the same performance as our ADR-OWA for $0 \leq \sigma \leq 2.67$, i.e., channels with low noise, its packet delivery ratio starts to decrease for $\sigma \geq 2.67$. However, since our ADR-OWA has a dynamic approach, it configures the transmit power and spreading factor of the nodes according to the channel condition, and so the increase in σ cannot affect its performance. As we see from Fig. 2, our ADR-OWA performs 1.5 and 4 times better than NoADR and ADR-AVG, and ADR-MAX, respectively, in channels with high noise, i.e., when σ has the highest value ($\sigma = 7.13$).

From Fig. 2, we observe that our ADR-OWA has a lower energy consumption than the NoADR for all channel conditions. We also see that the energy consumption of ADR-OWA is slightly more than ADR-MAX for $\sigma < 1.78$, i.e., channels with low noise. The reason is that as ADR-OWA has a pessimistic approach, it configures the transmit power of nodes a bit higher than ADR-MAX in channels with low noise which leads to higher energy consumption. However, as σ increases, the energy consumption of ADR-MAX largely increases for $\sigma \geq 1.78$ which is much more than the ADR-OWA. The reason is that as the packet delivery ratio of ADR-MAX is decreased with increasing σ (see Fig. 2), the nodes have to transmit with a higher power which results in increased energy consumption. From Fig. 2, we also see that the energy consumption of ADR-OWA is the same as that in ADR-AVG for $\sigma \leq 0.89$. However, ADR-OWA consumes more energy than ADR-AVG when $0.89 < \sigma < 6.24$. The reason is that although our ADR-OWA has a higher packet delivery ratio than ADR-AVG (see Fig. 2), since it configures the transmit power of nodes based on the channel condition, so it assigns higher power to the nodes in noisy channels leading to higher energy consumption. On the other hand, the ADR-AVG has higher energy consumption than ADR-OWA when $\sigma \geq 6.24$, due to the better performance of ADR-OWA in channels with high noise which results in much higher packet delivery ratio and lower power consumption. As seen in Fig. 2, ADR-OWA consumes the least energy compared to other algorithms in channels with high noise, i.e., when $\sigma = 7.13$.

Now, we investigate the scalability of our ADR-OWA for typical channels in the sub-urban scenario. Fig. 3 shows the packet delivery ratio and energy consumption of different algorithms versus the number of nodes for typical channels, i.e., $\sigma = 7.08$ in the sub-urban scenario. As seen, the increase in the number of nodes results in a decreased packet delivery ratio. However, the packet delivery ratio of ADR-OWA is higher than other algorithms for all number of nodes. Indeed, ADR-OWA achieves a 37% to 50% increase in packet delivery ratio compared to NoADR and ADR-AVG while this value is 3.6 to 4 times that of ADR-MAX in typical channels. From Fig. 3, the higher number of nodes results in increased energy consumption. However, the energy consumption of ADR-OWA is lower than the other algorithms when there are less than 500 nodes in the network. When $500 - 600$ nodes are in the network, ADR-OWA consumes the same amount of energy as ADR-AVG while its energy consumption is slightly higher than ADR-AVG for 700 nodes which is due to its pessimistic approach to configure the transmit power of nodes.

B. The Urban Scenario

In this section, we investigate the performance of our ADR-OWA algorithm in the urban scenario. Fig. 4 shows the packet delivery ratio and energy consumption of different algorithms versus σ in the path loss model when there are 100 nodes in the

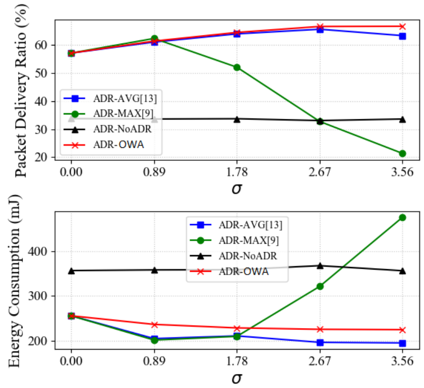

Fig. 4. Packet delivery ratio and energy consumption of different algorithms versus σ in the urban scenario (100 nodes).

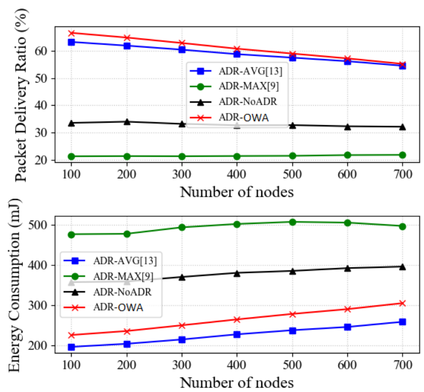

Fig. 5. Packet delivery ratio and energy consumption of different algorithms versus the number of nodes for typical channels in the urban scenario.

urban scenario. As seen, our ADR-OWA algorithm achieves the higher packet delivery ratio than ADR-MAX and NOADR in all ideal, moderate, and typical channel conditions, i.e., all values of σ. Also, the packet delivery ratio of ADR-OWA is the same as ADR-AVG for $\sigma \leq 1.78$, i.e., ideal and moderate channels, while ADR-OWA attains higher packet delivery ratio than ADR-AVG for $\sigma > 1.78$, i.e., typical channels.

From Fig. 4, we see that the energy consumption of ADR-OWA is always lower than NoADR. Also, ADR-OWA consumes the same energy as ADR-AVG and ADR-MAX in ideal channels, i.e., $\sigma = 0$. Although the energy consumption of ADR-OWA is slightly higher than ADR-MAX in moderate channels, i.e., $\sigma = 1.78$, it consumes much less energy than ADR-MAX in typical channels, i.e., $\sigma = 3.56$. Also, the energy consumption of ADR-OWA is slightly more than ADR-AVG in moderate and typical channels due to its pessimistic approach leading to the higher transmit power of nodes.

Finally, we investigate the scalability of our ADR-OWA for typical channels in the urban scenario. Fig. 5 shows the packet delivery ratio and energy consumption of different algorithms versus the number of nodes for typical channels, i.e., $\sigma = 3.57$ in the urban scenario. We see that the packet delivery ratio of ADR-OWA is higher than other algorithms for all number of nodes. We also observe that ADR-OWA always consumes less energy than ADR-Max and NoADR. However, the energy consumption of ADR-OWA is higher than ADR-AVG. The reason is that ADR-OWA has a pessimistic approach and it configures the transmit power of nodes a bit higher than ADR-AVG which results in higher energy consumption.

V. Conclusion

In this paper, we proposed a dynamic ADR algorithm for the central platform of LoRa networks which configures the transmission parameters including the spreading factor and transmit power of nodes. The proposed algorithm uses the OWA operator for dynamically configuring parameters based on the channel condition such that it performs well in all channel conditions. Through the simulation results, we evaluated the capability of the proposed algorithm in the LoRa network which demonstrated that our proposed ADR algorithm has the same performance as other algorithms in channels with low noise and outperforms the others in channels with high noise. As future work, we will be evaluating the effect of the number of gateways on the ADR algorithm performance. Also, considering the delivery time of the last packet as a decision making parameter is an interesting future work.

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