Feasibility Study of the LoRaWAN Blind Adaptive Data Rate

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***Abstract*—LoRaWAN is widely adopted as an alternate solution for the Internet of Things applications due to its long-range, low-cost, ultra-low energy consumption and support for a large number of end devices (EDs). To allocate resources to EDs, LoRaWAN utilizes an energy-efficient adaptive data rate (ADR), which is recommended for static applications. Recently, Semtech suggests using a blind ADR (BADR) to increase geographical coverage with enhanced battery life for mobile applications, such as pet-tracking. The BADR utilizes three spreading factors (SFs): SF 12 (one time), SF 10 (twice), and SF 7 (three times) every hour. This study aims to analyze and provide insights into the potential and limits of the BADR. Simulation results show that both ADRs suffer from high packet loss and excessive energy consumption in confirmed and unconfirmed modes. However, BADR is observed outperforming the ADR.**

***Index Terms*—Internet of Things (IoT), adaptive data rate (ADR), Long-range wide area network (LoRaWAN), blind ADR, mobile applications**

I. Introduction

Long range wide area network (LoRaWAN) consists of a large number of end devices (EDs), a gateway (GW), a network server (NS), and an application server, forming a star-of-stars topology, as shown in Fig.1. LoRaWAN employs a key adaptive data rate (ADR) at ED and NS sides for resource assignment (e.g., spreading factor (SF) and transmit power). The ADR at the ED side is straightforward: if retransmission is a multiple of two, the SF is increased. While the ADR at the NS reduces SF and changes transmit power (TP) depending on the 20 uplink packets history [1].

Once the ADR is adjusted, the link is periodically maintained. Thus, it is suitable for high capacity and static applications such as metering. The channel situation for mobile Internet of Things (IoT) applications, on the other hand, changes dramatically between an ED and a GW [2]. Therefore, in such situations, the use of typical ADR is not recommended [3]. Besides, LoRa has a direct trade-off between link budget and time-on-air (ToA). As a result, more in-depth coverage comes at the expense of increased energy consumption. Therefore,

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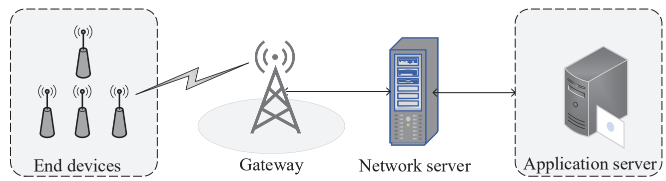

Fig. 1. A simple LoRa architecture comprised of end devices, gateway, network server, and application server.

to address the fixed range-communication trade-off using a single SF, Semtech recommends using a blind ADR (BADR) by targeting mobile applications (e.g., pet-tracking) to gain good coverage with a better battery lifetime [3]. The BADR uses three SFs: SF 12 (once), SF 10 (twice), and SF 7 (three times) every hour, as shown in Fig. 2 [3]. The primary aims of this study are to examine, highlight limitations, and provide insights into BADR.

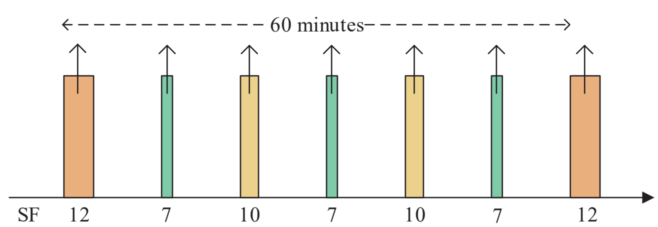

Fig. 2. Uplink SF utilization mechanism of blind adaptive data rate (BADR) [3].

The remaining of this paper is structured as follows: Section II discusses experimental results and feasibility study of the BADR while concluding remarks are provided in Section III.

II. Experimental Results

This section evaluates the BADR compared with ADR for mobile IoT applications in terms of packet success ratio (PSR) and energy consumption. Later, in this section, a feasibility study of the BADR is discussed. The requirements of mobile IoT applications are highlighted in Table I and the ToA for the packet sizes are shown in Table II.

TABLE I
REQUIREMENTS OF THE TWO PET-TRACKING APPLICATIONS.

Application	Conditions		
	UL packets/h	*Packet size*	*Mobility*
Pet-tracking1 [3]	6	30 [bytes]	Yes
Pet-tracking2* [5]	2	50 [bytes]	Yes

*3GPP has set different requirements for a pet-tracking application.

TABLE II
TIME-ON-AIR (TOA) IN MILLISECONDS FOR THE TWO PET-TRACKING APPLICATIONS WITH PACKET SIZE = 30 AND 50 [BYTES].

SF	7	8	9	10	11	12
30 [bytes]	71.94	123.39	226.30	452.61	905.22	1646.59
50 [bytes]	97.54	174.59	328.70	616.45	1314.82	2301.95

A. Preliminaries

The mode of communication for the BADR is not explicitly defined by the Semtech [3]; therefore, we analyze the BADR in both confirmed (CON) and unconfirmed (UNC) modes. In the CON mode, for an uplink packet, every ED requires an acknowledgment (ACK) from NS, where the uplink transmission limit (Tx_{limit}) is set to 8. On the other hand, the UNC mode of LoRaWAN is termed as "unreliable", where EDs do not require ACK from NS (Tx_{limit} is set to 1) [4].

In addition, we modify the optional medium access control (MAC) command ($Fopts$) of the LoRa frame header ($FHDR$) to transmit the coordinates (x- and y-positions) of the ED, suggested by the BADR in [3] and shown in Fig. 3. Thus, in the case of BADR, the packet size shown in Table I includes 8 bytes of ED positions (it is set to 17 bytes in BADR [3]) and 9 bytes of PHY/MAC headers (header size is also included in the case of ADR).

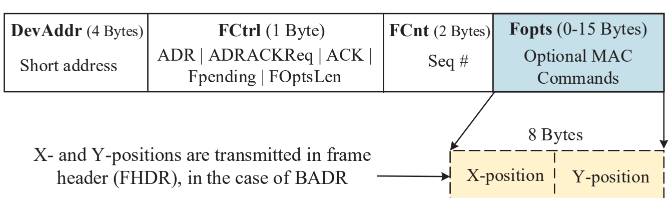

Fig. 3. Modified frame header (FHDR) of the LoRa message for the BADR [3].

B. Simulation Setup

We utilize ns-3 to conduct the experiments, where EDs with a random walk 2-D mobility model are deployed in a 6-km radius around a single GW with a random speed of 2-5 m/s. The height of the antennas for the GW and ED is set to 15 and 1.5 meters, respectively [6]. In addition, we consider log-distance propagation and shadowing models, similar to [7]. The simulation also takes into account both intra- and inter-SF interferences [8]. In the case of intra-SF interference, a collision between the two packets occurs when EDs transmit an uplink packet with the same SF on the same channel. On the other hand, inter-SF interference is described as a collision between two uplink packets sent with different SF on the same channel.

TABLE III
PARAMETERS FOR SIMULATION.

Parameter	Value
Simulation time [h]	24
Gateway	1
End devices	Class A
Path loss exponent	3.76 [6]
Frequency region	EU-868
Number of channels utilized	3 [868.1, 868.3, 868.5] MHz

Furthermore, during the initial deployment, BADR follows the SF assignment pattern shown in Fig. 2. Conversely, ADR utilizes SF 12 with TP of 14 dBm (BADR continuously sends packets with TP of 14 dBm). The rest of the parameters for the simulation is shown in Table III.

C. Analysis of Blind and Typical Adaptive Data Rates

1) Analysis of BADR and ADR in Confirmed Mode: The PSR in the CON mode is termed as when the NS and corresponding ED receive an uplink and downlink packets, respectively.

Figure 4 presents the average PSR of both typical and blind ADRs. In general, as the number of EDs grows, the PSR in the CON mode decreases for both ADRs. However, in ADR, the propagation environment around ED may have been dramatically altered when ED receives a downlink $LinkADRReq$ medium access control command from the NS containing new resource parameters (i.e., SF and TP). As a result, these parameters are no longer suitable because they can fail to successfully deliver a packet to the GW, resulting in significant packet loss. Furthermore, as seen in Fig. 5, extensive packet loss causes EDs to retransmit a packet several times, resulting in unnecessary energy consumption (in the case of ADR). In this paper, the energy consumption is determined by dividing the overall energy consumption of EDs by the number of successfully received packets, where the energy consumption module is adopted from [9].

The PSR of BADR in Fig. 4 is higher than ADR and the energy consumption in Fig. 5 is much lower than ADR owing to a low number of retransmissions. Therefore, the BADR achieves its primary aim of enhancing the battery life of mobile applications.

2) Analysis of BADR and ADR in Unconfirmed Mode: The PSR in the UNC mode is termed as when a UL packet is received by the NS only. In Fig. 4, PSR in UNC mode for both ADRs is much higher than CON mode. This is because, in both ADRs, ACK is not expected by the ED after every uplink transmission, reducing collision. However, the PSR of ADR is much lower than BADR because the packets are initially transmitted with SF = 12 and TP = 14, resulting in increased interference (due to high ToA). Furthermore, due to the use of high SF (e.g., SF 12) in the case of ADR, the

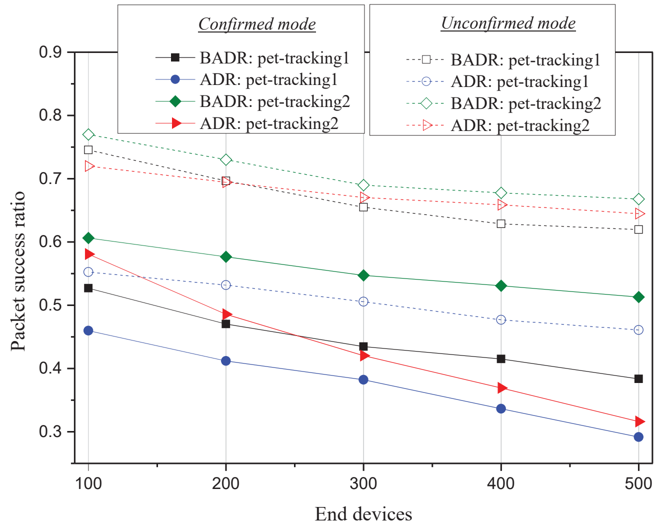

Fig. 4. Packet success ratio (PSR) analysis of BADR and ADR.

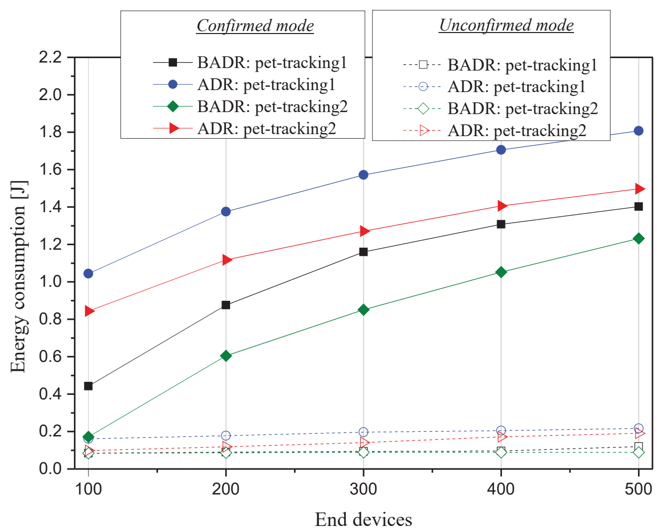

Fig. 5. Energy consumption analysis of BADR and ADR in joules [J].

energy consumption is high due to high ToA, as shown in Fig. 5.

Conversely, the PSR of BADR is much higher, and the energy consumption is low in the UNC mode compared to ADR due to the use of lower SF (except SF 12).

D. Feasibility Study

Generally, collision in a LoRaWAN network occurs from both intra- and inter-SF interferences [10], [11]. Initially, the EDs utilize higher SF in ADR (e.g., SF 12) during the deployment phase. Thereby affecting the channel capacity, which in turn increases interference [11]. Thus, the results presented in this study confirm that ADR is not feasible for mobile IoT applications (similar findings regarding ADR are shown in [9]). On the other hand, BADR is observed outperforming ADR in PSR and energy consumption.

TABLE IV
PERFORMANCE COMPARISON OF THE ADR AND BADR.

Application	Algorithm	Mode	PSR	Energy
Pet-tracking1 & 2	BADR ADR	CON & UNC	high low	low high

Furthermore, a considerable impact of the uplink interval was observed in Fig. 4 and Fig. 5, which show that a low uplink interval of 2 packets/h has higher performance in terms of PSR and energy consumption for both ADRs. Therefore, in general, it is recommended to use the low uplink interval to improve network performance.

Finally, Table IV shows that BADR has significantly improved the performance of mobile applications in both confirmed and unconfirmed modes. Thereby, BADR is recommended for mobile applications (e.g., pet-tracking) over ADR.

III. CONCLUSION

This paper evaluated both typical and blind adaptive data rates in the confirmed and unconfirmed modes for pet-tracking applications. Through simulation results, we observed that typical ADR is not ideal for mobile applications since it failed to adapt itself to the changing channel conditions. However, the BADR outperformed the ADR in PSR and energy consumption in the confirmed and unconfirmed modes.

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