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The Impact of LoRa Transmission Parameters on Packet Delivery and Dissipation Power

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***Abstract*—In this paper we present results of the simulation analysis of the impact of transmission parameters and distance between LoRa node and gateway on communication performance (packet loss rate and energy consumed by nodes). FLoRa simulation framework based on Omnet++ was used to vary spreading factor, bandwidth, coding rate and transmission power. For given distance of 100 m, Lora gateway successfully received the packets in 80 configurations. In particular case, when the distance between node and gateway was doubled, just 8 configurations were able to deliver the packets. Finally, we used 5 values of path loss variance in range from 0 to 7.08 dB with a distance of 400 m, and the success rate of data transmission from node to the gateway decreased to 48.83%.**

Keywords— FLoRA, LoRa. Low-Power Wide-Area Networks, transmission parameters, reliability, energy efficiency.

I. Introduction

Among various Low-Power Wide-Area Network (LPWAN) technologies (LoRa, LoRaWAN, Sigfox, Ingenu, Telensa, Weightless, NB-IoT), a Long Range (LoRa) is widely used in many applications [1]-[5]. For example, solid waste management system based on LoRa radio modules with ultrasound sensors was deployed to monitor the filling level of the bins [1]. Moreover, LoRa technology was used for accurate determination of load profiles of dwellings [2]. When applied to smart grids, the developed systems can perform demand-driven forecasting studies, analysis of home consumption, and optimization of electricity tariffs [2]. A system for faster and more efficient responses (called LoRaMoto) of emergency units after natural disasters, such as earthquakes, was presented in [3]. Application of LoRa modules in agriculture with increased level of data security was considered in [4]. Moreover, Industrial Internet of Things (IIoT) applications are very important target for LoRa deployments, but a medium access strategy that provides support for real-time flows is required [5].

LoRa transmission configuration can be defined with various parameters (spreading factor, bandwidth, coding rate, center frequency, transmission power) as it will be discussed in Section II, resulting in over 6720 possible parameter settings [6]. Numerous configurations of LoRa parameters can provide acceptable link quality, but energy consumption may be very different, even by factors of more than 100 [6]. Thus, the lifetime of battery powered sensor nodes can be significantly changed if transmission parameters are configured properly. Therefore, optimal configuration of the transmissions parameters requires clear understanding of impact of different LoRa configuration settings on communication performance and energy consumption.

Experimental configuration of LoRa transmission parameters on hardware of sensor nodes is time consuming and an inefficient process, as finding of optimal configuration requires huge number of tests. Because of that, various LoRa simulators have been developed to speed up process of design and estimation of network performance prior to the real deployment [7], i.e. PhySimulator [8], FLoRa [9], Ns-3 module [10], LoRaSim [11]. In this study, we choose FLoRa framework which is based on OMNeT++ simulator [12] and modules from INET framework [13]. Using the described simulation platform, we presented analysis of the impact of the transmission parameters values (spreading factor, bandwidth, coding rate and transmission power), distance between LoRa sensor node and LoRa gateway on communication performance (packet delivery), and energy consumed by sensor nodes.

This paper is organized as follows: in Section II, an overview of the LoRa technology is given. The focus is on the theoretical analysis of the transmission parameters on the communication performance and energy consumption. Moreover, metrics for the evaluation of transmission parameters selection on communication performance and energy consumption in LoRa networks is given. The main components of the simulation environment (OMNeT++, INET and FLoRa) are described in Section III. Results and discussion are given in Section IV. Section V concludes this work with an overview of the main contributions and directions of future works.

II. Overview of LoRa

A. Basics of LoRa

LoRa is the physical layer specification based on Chirp Spread Spectrum modulation that enables long-range and low-power transmissions of small amounts of data. Typical LoRa network topology is star of stars with nodes, also called end devices (ED), one or more gateways (GW) and network server (NS), as it shown in Fig. 1. Communication between ED and GW is based on LoRa radio, while Internet Protocol (IP) communication is common between GW and ED.

LoRa transmissions are implemented in industrial, scientific and medical (ISM) applications of the unlicensed radio spectrum of the sub-GHz range (0.4 GHz - 1.1 GHz), with actual frequency band defined according to the region (i.e. in Europe, the 433 MHz and 868 MHz are adopted). In addition to the frequency band, there are multiple parameters that define LoRa communication: spreading factor (SF),

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transmission power (TP), center frequency (CF), code rate (CR) and bandwidth (BW).

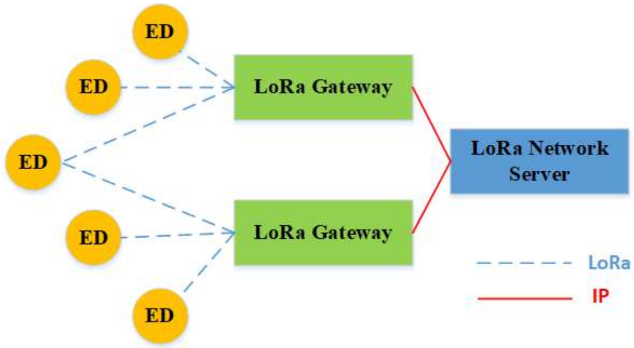

Fig. 1 Typical LoRa network topology.

SF defines how many chirps are sent per symbol. The possible values for SF are from 7 to 12.

TP on a LoRa radio can be adjusted from −4 dBm to 20 dBm. However, TP range is often limited from 2 dBm to 20 dBm, while power levels higher than 17 dBm are only allowed on a 1% duty cycle [6].

CR defines forward error correction (FEC) by encoding the 4-bit data with n=1,2,3,4 redundant bits. CR is expressed with following equation:

$$CR = \frac{4}{4+n} \tag{1}$$

Therefore, common notations of CR are: 4/5 (n=1), 4/6 (n=2), 4/7 (n=3) and 4/8 (n=4).

CF can be defined in the range between 137 MHz and 1020 MHz (with steps of 61 Hz) and it depends on the particular region and LoRa chip [6].

BW is the range of frequencies over which LoRa's chirps are spread with possible values: 125 kHz, 250 kHz or 500 kHz.

B. *The Impact of the Transmission Parameters Selection on Communication Performance and Energy Consumption*

Selection of transmission parameters has a huge impact on the communication performance and energy consumption of the device. Usually, it is necessary to have a balance between these two parameters.

For example, a high SF means lower data rate, higher sensitivity and longer range, but it increases the length of the packets [6,14]. A larger CR decreases decoding errors, but increases the length of packets [6,14]. A higher BW implies a higher data rate, but also reduces the receiver sensitivity and communication range [6,14].

Moreover, the required time for transmission of one symbol (also called and symbol duration- TS) is a function of SF and BW:

$$TS = \frac{2^{SF}}{BW} \tag{2}$$

In addition to this, the bit rate (R_{bit}) of LoRa radio is a function of SF, BW and CR:

$$R_{bit} = \frac{SF \cdot BW}{2^{SF} \cdot CR} \tag{3}$$

Time on Air (ToA), a parameter that shows air time of the LoRa frame, is impacted by CF, BW, SF and packet size. LoRa packet structure is shown in Fig. 2.

Preamble	Header (Optional)	Payload	CRC

Fig. 2 Structure of the LoRa packet.

The preamble consists of a few symbols (usually 8) to synchronize the radios. Payload size and LoRa configuration are stored in the Header (with CR=4/8), while the payload is encoded with a defined CR. At the end of the frame, the Cyclic Redundancy Check (CRC) is also encoded with defined CR. However, the symbol size of a LoRa packet is not only dependent on the payload, but also on SF, BW, and CR. For example, a 32-byte packet at CR=4/5, SF=12, BW=500 kHz is 38 symbols large, while at CR=4/5, SF=7, BW=125 it is 58 symbols large. However, a 32-byte packet at CR=4/8, SF=12, BW=500 kHz is only 56 symbols large [15].

C. *Evaluation of the Transmission Parameters Selection on Communication Performance and Energy Consumption in LoRa Networks*

The main hypothesis of this work is that investing more energy will not necessarily result in better LoRa radio communication performance. An example that motivated this work was that increasing the CR value would increase packet size and energy consumption with a better performance only in areas with strong interference. In many applications, where that is not the case, higher energy will be consumed without need or reason. Furthermore, different configurations of LoRa parameters (SF, BW, CF and CR) can lead to very similar energy consumption per transmission but with totally different communication performance.

III. Simulation Environment

A. *OMNeT++*

OMNeT++ is a modular, component-based C++ simulation library and framework for building network simulators [12]. OMNeT++ Integrated Development Environment (IDE) is based on Eclipse. In OMNeT++ IDE, new models can be created or existing models can be edited with Network Description (NED) language, and configuration files (.ini). Also, the creation of modules, channels and classes is possible. In this study we used the version 5.2.1.

B. *The INET Framework*

The INET framework provides additional features to the OMNeT++ simulator, such as agent, protocols with support for physical, link, network, transport, and application communication layers for different types of communication networks [13]. In this study, the employed version was INET 3.6.1.

C. *FloRa Framework*

FLoRa is a specific framework to test LoRa/LoRaWAN networks within the OMNeT++. It enables physical and link layer evaluation, defining networks server, gateways in the network and end-nodes. FLoRA supports bi-directional communication, defining the path for messages from the source to the destination (LoRa end-nodes to Network Server), and estimating the energy consumed by LoRa end-devices. FLoRa module sets the main LoRa/LoRaWAN parameters: SF, CF, BW, CR, and TP, which influence the communication coverage and the probability of data frames collision. The FLoRa framework includes an Okumura-Hata radio propagation model [16]. In our study, the used version of FLoRa was 0.8.

Energy consumption module in FLoRa includes a state-based energy estimation, therefore the energy consumed depends on the amount of time spent by the LoRa radio in transmitting, receiving and in a sleep state. Current values for each transmission power level (2 dBm-14dBm) are taken from [17]. The current drawn during the receiving and sleep modes are derived from the Semtech SX1272/73 datasheet [18] with a supply voltage of 3.3 V [16].

Packets sent from the LoRa node will not be delivered to the gateway if the transmission power is insufficient for the distance between ED and GW and actual path loss variance (σ) on the channel. FLoRA framework includes possibilities to vary values for σ and to create more realistic conditions. For example, σ=1.785 dB or σ=3.57 dB are moderate and typical variability of urban areas, respectively [16]. Values of σ=3.54 dB or σ=7.08 dB are moderate and typical variability of sub-urban areas, respectively [16]. Ideal scenario without losses is when σ=0.

IV. Results and Discussion

A. Simulation configuration

The network LoRa topology used in this simulation consists of one LoRa node, LoRa gateway, gateway router, the Internet cloud, network server router and a network server as shown in Fig. 3. Additional simulation modules that define LoRa framework module are LoRa medium and configurator.

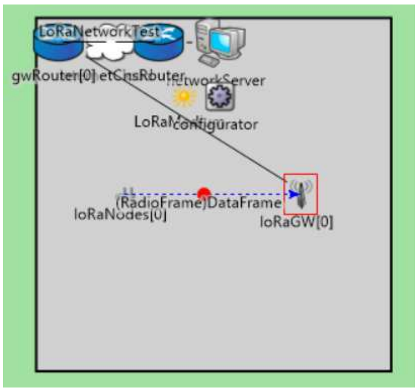

Fig. 3 Deployed LoRa network in FLoRa framework.

Network size was defined as 1 000 m × 1 000 m. After warm up, the node sent a packet (16 Bytes) using LoRa radio to gateway. The time interval between transmissions was defined as 1 hour (3600 seconds). Total simulation time was 1 day. Therefore, 24 packets were sent in total from the node to the gateway.

Numerical simulation examining the packet delivery and dissipation were performed. Firstly, the distance between node (100 m, 200 m) and gateway (300 m, 200 m) was 200 m. In the second part of the experiment, distance between node (50 m, 200 m) and gateway (450 m, 200 m) was doubled (400 m). The final part of the experiment included variation of 5 path loss variance values. Simulations were performed in "fast" mode.

Baseline simulation scenario was as follows: SF was set to 12, CR=4/5, BW=125 kHz and TP=14 dBm. Then, all parameters remained constant, while TP was gradually decreased until the message was not delivered to the gateway. After that, configuration was changed by changing either SF={12, 11, 10, 9, 8, 7}, CR={4/5, 4/6, 4/7, 4/8} or BW={125 kHz, 250 kHz, 500 kHz} and the simulation was repeated with decreasing TP from the starting 14 dBm.

Monitoring of received messages on gateway was proposed with a variable LoRa_GWPacketReceived count in the LoRaNetworkTest.loRaGW[0].packetForwarder module (Fig. 4).

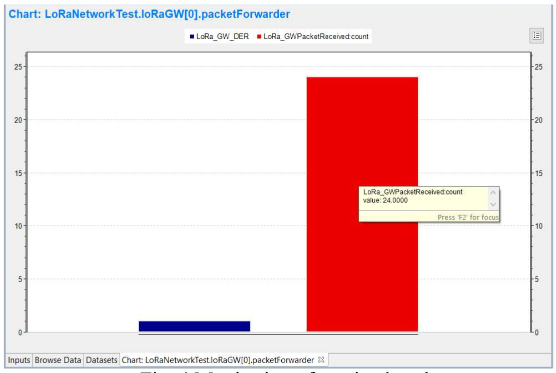

Fig. 4 Monitoring of received packets

Monitoring of the LoRa node consumed energy is proposed with LoRaNic.radio.energyConsumer module as shown in Fig. 5 and discussed in Section III.C.

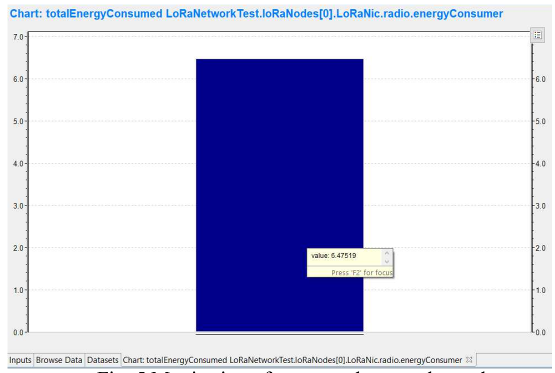

Fig. 5 Monitoring of consumed energy by node.

B. Obtained results and discussion

As described in the previous section, the energy consumed by nodes was monitored with the success of packets delivered. The simulation covered in total 936 configurations, and in this paper we will focus on the consumed energy of cases when packet delivery was successful. Path loss variance was initially set to zero.

In communication scenario with SF=12, consumed energy of LoRa node decreased with decreasing TP. According to simulations, the lowest TP level with successful packet delivery was 9 dBm. If TP and BW are constant, consumed energy increased with increasing CR. When TP and CR are constant, consumed energy decreased with increasing BW. Configurations with TP<11 dBm and BW=250 kHz were unsuccessful. However, all configurations with BW=500 kHz were unable to deliver package. Graphical presentation of all results for SF=12 are shown in Fig. 6.

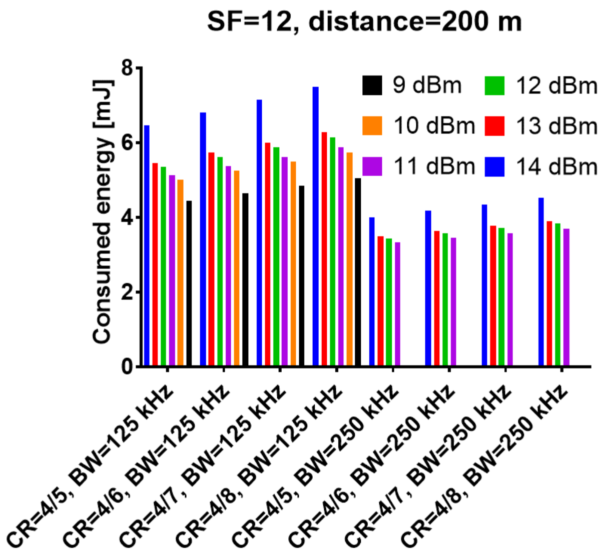

Fig. 6 Consumed energy for SF=12 and different CR, BW and TP configurations.

Further, spreading factor was decreased to 11. A consumed energy of LoRa node decreased with decreasing TP. The lowest TP level with successful packet delivery was increased to 11 dBm. If TP and BW are constant, consumed energy increased with increasing CR. When TP and CR are constant, consumed energy decreased with increasing BW. Configurations with TP<14 dBm and BW=250 kHz were unsuccessful. However, all configurations with BW=500 kHz were unable to deliver package. Graphical presentation of all results for SF=11 are shown in Fig. 7.

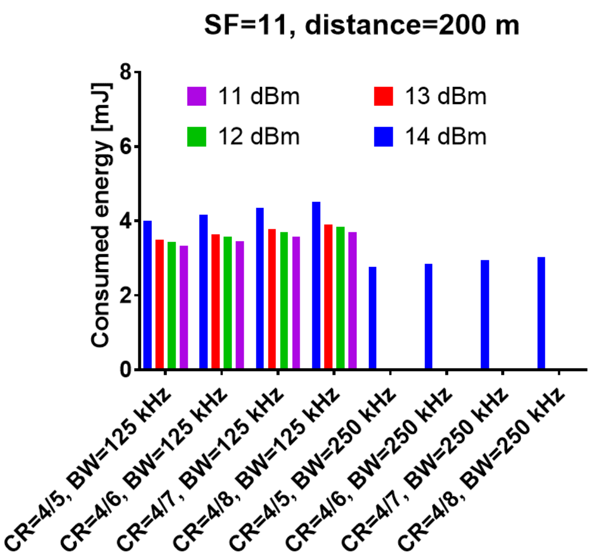

Fig. 7 Consumed energy for SF=11 and different CR, BW and TP configurations.

When SF was set to 10, consumed energy decreased with decreasing TP. The lowest TP level with successful packet delivery was 13 dBm. If TP and BW are constant, consumed energy increased with increasing CR. When TP and CR are constant, consumed energy decreased with increasing BW. Note that all configurations with BW=250 kHz and BW=500 kHz were unable to deliver package. Graphical presentation of all results for SF=10 are shown in Fig. 8.

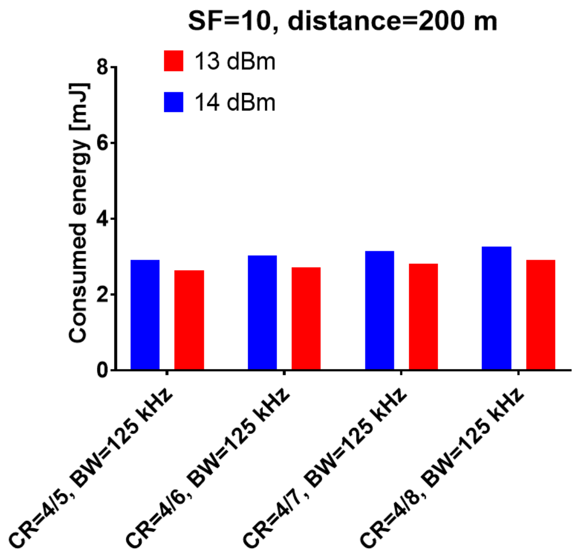

Fig. 8 Consumed energy for SF=10 and different CR, BW and TP configurations.

Simulation results showed the highest energy consumption (7.502900 mJ) for configuration SF=12, TP=14 dBm, CR=4/8 and BW=125 kHz, while the lowest energy consumption (2.63215 mJ) was obtained for configuration SF=10, TP=13 dBm, CR=4/5 and BW=125 kHz.

In addition, if BW=125 kHz, CR=4/5 and TP=14 dBm were constant, configuration with SF=12 consumed 6.47519 mJ which is more than double higher when compared to 2.9139 mJ (BW=125 kHz, CR=4/5, TP=14 dBm and SF=10). Nevertheless, both configurations successfully delivered all packets. Furthermore, time on air (T_{packet}) for SF=12 h was more than 3.5 times higher when compared to SF=10 (BW=125 kHz and CR=4/5) [1].

For the second part of the study, distance between LoRa node and gateway was doubled. Path loss variance was set to zero. Only the configurations with SF=12, BW=125 kHz, CR={4/5, 4/6, 4/7, 4/8} and TP={14 dBm and 13 dBm}were able to deliver packets. Energy consumptions are shown in Fig. 9.

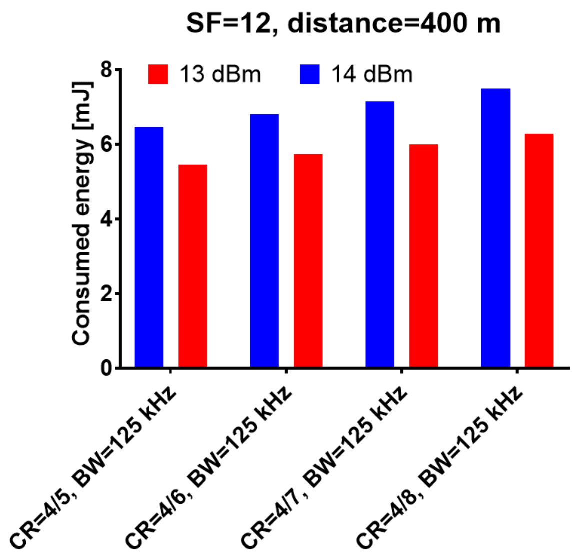

Fig. 9 Consumed energy for SF=12 and different CR, BW and TP configurations.

To identify the influence of physical obstacles in an urban area it was conducted a comparative parametric simulation on path loss variance of LoRa communication module. Thus, configuration SF=12, BW=125 kHz, CR=4/5 and TP=14 dBm was simulated with different values of path loss variance when distance between node and gateway was increased to 400 m. As expected, increased path loss variance increased number of lost packets. The results reveal a significant increase of PLR due to increased value of path loss variance. A comparison of success rate for different values of σ (path loss) is shown in Table I.

TABLE I. COMPARISON OF SUCCESS RATE IN PACKET DELIVERY FOR DIFFERENT VALUES OF PATH LOSS VARIANCE.

Path loss variance	**Sent packets**	**Received packets**	**Percentage**
0 dB	24	24	100%
1.785 dB	24	20	83.33%
3.54 dB	24	14	58.33%
3.57 dB	24	14	58.33%
7.08 dB	24	11	48.83%

V. CONCLUSION

In this paper we investigated the impact of transmission parameters values (spreading factor, bandwidth, coding rate and transmission power) in a FLoRA simulation analysis and the influence of the distance between LoRa sensor node and LoRa gateway on the communication performance (packet delivery) and consumed energy by sensor nodes. Obtained results are in compliance with theoretical expectations. Based on this results, it can be said that the assumed that the simulation platform is promising for further use in terms of better understanding of LoRa technology and, consequently, to find the energy optimized configurations for parameters transmissions with maximum efficiency in packet delivery.

Future work will be primarily directed towards hardware-based experiments and verification of the presented simulation. Moreover, estimation of path loss variance values for different geographical regions can be very useful for further improvements of IIoT concept [19].

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