Evaluation of Low-Power Long Distance Radio Communication in Urban Areas: LoRa and Impact of Spreading Factor

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***Abstract*— LoRa is a wireless communication technology for long-range applications such as; smart city, smart industry, product monitoring and control. Throughout this article, the performance of LoRa technology in terms of coverage area has been reviewed. LoRa technology allows long-distance connections thanks to chirp spread-spectrum modulation. Spreading factor is another component for LoRa that contributes to the coverage area. For that reason, spreading factor and its effect on the coverage are examined in real environment. The LoRa radio has been experimented in different spreading factors, in order to verify the theoretical limits obtaining the practical performance profile of the radio. Thus, in a dense urban areas the radio is tested and performance profiles are given in the end of paper. Theoretically presented RSSI and SNR values have been observed and their evaluations have been experimented under real conditions. Experiments were carried out in a crowded residential area in the centre of Trabzon. In the scenario, line of sight connections were avoided and the transmitter was placed inside the building and measurements were taken in this condition. The outcome of the article may vary under different circumstances but would provide an general assessment.**

Keywords — Internet of Things, LoRa, ZigBee, 802.15.4, wireless communication, spreading factor, wireless sensor networks

I. INTRODUCTION

In recent years, the traffic provided by the wireless technologies and mobile technologies covers a large part of the total internet, while the Internet of Things in the future is expected to grow much faster [1]. Among these technologies, the usage of LoRa is rapidly increasing. According to the purpose of use, LoRa works in a condition that other technologies cannot fit. Here, Wi-Fi, Bluetooth or cellular technologies require high power and wider bandwidth, they also have quite limited coverage area. For that reason, the use of LoRa happens to be increasing dramatically in particular for the Internet of Things applications such as smart cities, smart agriculture, remote meter measures or indoor usages. As a result of this estimation, LoRa could be considered complement of Wi-Fi, Bluetooth and Cellular[5].

In the study by Widianto [6], the coverage of LoRA is subjected. The similarity of this study with the mentioned article was explained in the article that our concerns on the effect of different spreading factors are more exclusive. Indeed, both articles show that theoretical values vary from due to reasons such as signal reflection or multipath nature of the channel are causing significant performance degradation. In our study, these influences have more impact due to a densely populated city conditions.

In our study, the impact of spreading factor to communication is examined in terms of distance. This could provide an insight into LoRa technology for real applications in urban areas where channel is having high elevation paths.

II. PROTOCOLS

A. LoRa ve LoRaWaN

LoRa is a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technology. The technique is suitable for long range communications since it can reach 15-20 kilometers distances [2]. LoRa is often used in sensor readings, agricultural monitoring, meter reading or smart cities. LoRa and LoRaWaN are sometimes used in the same sense, but this is a misconception. LoRa presents the physical layer for the long distance connections, while LoRaWaN is defined as the connection protocol and the system architecture. As a trademark registered by Semtech, LoRa transfers data from one point to another for the LPWAN (Low Power Wide Area Network) using the chirp spread spectrum. Due to sub-GHz radio spectrum, LoRa has better immunity to interference.

LoRa has the ability to change the spreading factor during communication. with (Adaptive Data Rate)ADD, it selects the best spreading factor according to the environment or the distance between the gateway and the device [7]. Thus, the data rate varies between 0.3kbps and 50kbps. This way, the battery life is used in the most efficient way.

Depending on the country, LoRa can be used in 3 different ISM bands; 433MHz in Asia, 868MHz in Europe and 915MHz

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in America. Using low ISM band frequencies, enables communication over long distances.

LoRaWAN has three different endpoint device classes to meet different conditions due to wide range of applications. These classes are Class A, Class B and Class C.

- Class A has dual communication capability. The class A, which is the default class, is supported by all LoRaWaN devices. The end device can initiate communication. Power consumption for this class is low.
- Class B implements the reception of messages at designated times in addition to class A and can send messages at the same time. Server can initiate communication at fixed intervals. Therefore the delay is quite small in Class B mode[3].
- Class C has more power consumption than other classes. There is no delay in communication. Communication can be started at any time.

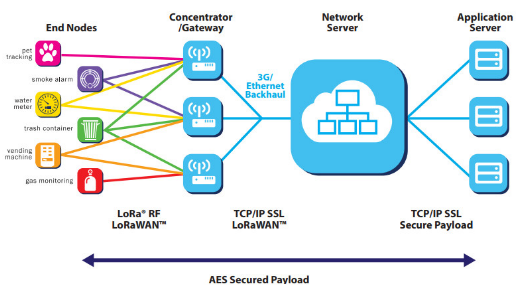

Figure. 1. LoRaWaN architecture [4].

B. *Packet Format*

LoRa use two type of packet formats which are called explicit and implicit. The explicit packet includes a short header that contains information about the number of bytes, coding rate and whether a CRC is used in the packet.

The LoRa packet encompasses three parts; a preamble, optional header and data payload as shown in Figure 2 [3].

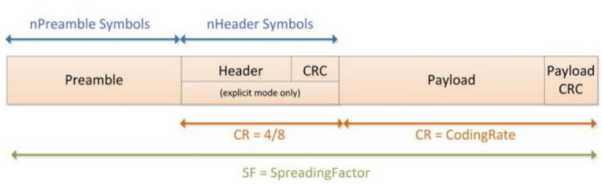

Figure. 2. LoRa packet format.

C. *Comparison With Other Technologies*

With the development of Internet of Things the industrialisation of different technologies were aimed at this field. The technologies such as; Bluetooth, Bluetooth LE, ZigBee, 6LoWPAN as well as LoRa are widely known. Furthermore, the number of connected devices is constantly increasing. However, ability to connect and communicate over a long distance is a persisting difficulty.

Bluetooth initially considered as wireless replacement of device connection by a cable is a useful solution for short-range communications. It employs licensed free 2.4 GHz frequency band with up to 1MHz channel frequency band. Bluetooth embraces frequency hopping spread spectrum (FHSS) transmission technique and offers maximum data rate up to 1Mb/s. It is widely used for technologies such as wireless speakers, wireless headsets, device-to-device data transfers [13].

BLE is a low power version of Bluetooth. It also use free ISM band as well as 40 channels. It is ideal for wireless-enabled wearable technology devices, beacons or health monitoring. Also short-distance like former technology which is Bluetooth.

IEEE 802.15.4 standard which is the base standard for the -well known- ZigBee industrial standards , is widely used for IoT applications due to low cost and low power consumption. Nevertheless, low-range communication is a limitation compared with LoRa. In the same way, Bluetooth and BLE have same obstacle too. ZigBee is capable of approximately 100 meters of communication [14]. In the next section, it will be considered that LoRa is able to communicate far beyond this distance. This advantage also applies over Bluetooth and BLE technology.

III. Implementation of Protocols in Urban Areas

A. *Measurement Scenarios*

In order to measure the effect of the spreading factor on the distance, the ST-brand B-L072Z-LRWAN1 Discovery Kit, which contains the Semtech SX1276 chip, was used. The kit is capable of both the receiving and transmitting data. Thanks to the built-in structure, GPS information can be read with the help of the screen. RSSI and SNR values reachable via a PC monitoring the serial port (UART). The ST LoRa kit and accompanied GPS system is shown in Figure 3. The external pins are programmed to choose different spreading factor values externally. Therefore during the communication changing the external pin inputs allow to choose different spreading factors such as SF-7, 10 or 12.

Figure. 3. The B-L072Z-LRWAN1 kit is connected to the display and GPS.

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Karadeniz Technical University and its surrounding urban buildings shown in Figure 4 were used for the measurements. In the aforementioned urban conditions, there are crowded buildings as well as dense trees. Due to the natural conditions of the region, there is a difference in height between the transmitter and receiver.

The red dot on the map in the Figure. 4. picture represents the base transceiver in the university building. The yellow spots seen in different places show the recipients. For the measurement points shown in Figure 4 by the numbers from 1 to 6, only on the measurement point 1, the transmitter and receiver was in the same elevation while all other measurement points are located in significantly different elevations than the base transceiver.

Figure. 4. Measurement points which are yellow dots and base transceiver which is red dot

By the increasing distances, it happens to increase this height difference significantly. Therefore, the elevation profile should be taken into consideration as well as the different distances between transmitters. The elevation profiles for the measurement points are showed in Fig.5.

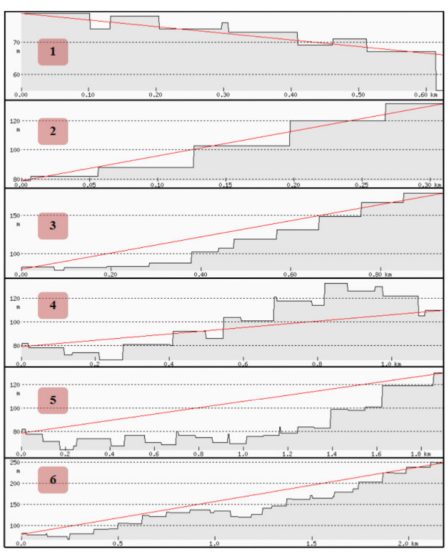

Figure 5. The path profiles of measurement points

B. Receiver and Transmitter

The measurements for LoRa were executed at different distances and in different urban conditions. Distances that can be communicated range from 300 meters to 2.2 km. Urban conditions can be considered as dense and medium dense urban structures. There is no line of sight (LOS) between the transceiver for the duration of measurements. The transmitter is placed in Telekom Lab in The Electrical and Electronics Engineering building. On the other hand, the receiver was found both inside and outside the building while measurements were carried out.

On the LoRa radio, the spreading factor values were changed to 7, 10 and 12 and measurements were made at the same distances. The values that are fixed in the application are as follows:

- Power transmission: 20dBm,
- Bandwidth: 125kHz,
- Coding rate:4/8.
- Radio frequency: 868 MHz

IV. OUTCOMES

A. Results for measurement of RSSI

Receiver sensitivity is defined as the minimum signal power level with an acceptable Bit Error Rate (in dBm or mW) that is necessary for the receiver to accurately decode the given signal [11].

In the course of the study, RSSI and SNR values were observed for each spreading factor. LoRa modulation and spreading factor have a significant impact on coverage [8]. High spreading factor values during communication, while promising greater distances, have a significant disadvantage, data rate. Following formula can be used to calculate Lora data rate which is appeared with Rb in bps;

$$R_b = SF * \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}} * 100 \qquad (1)$$

At the formula (1) SF is symbolize to spreading factor, CR is code rate and BW is bandwidth in kHz. As can be seen, the spreading factor, as well as bandwidth and coding rate, also affect Rb [6].

The spreading factor is critical for long distances. This was clearly observed in the experiments. While spreading factor 12 is maintains communications for long distances, the radio could not connect with spreading factors of 7 or 10. Of course, this situation dramatically degrades the data rate values. As seen in Table 1. spreading factor has a significant effect on bit rate. These values should be considered for the applications.

TABLE I. LORA DATA RATES

Spreading Factor	Bit rate (bit/s)
7	5469
8	3125
9	1758
10	977
11	537
12	293

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LoRa -136dBm provides the sensitivity in the settings used for the further distance [9]. As it is seen in Table 2. this value is very similar to in the long range where communication is in difficulty. Gray areas indicate no communication.

TABLE II. RSSI RESULTS(DBM)

SF/Places(meter)	**1** (651)	**2** (371)	**3** (944)	**4** (1120)	**5** (1910)	**6** (2200)
7		-105	-105	-112		
10	-113	-113	-125	-122		
12	-126y	-109	-125	-129	-133	-126

Low Spreading factor provides an advantage when shorter distances are considered. Especially in applications where high data rate is required, the lower values for spreading factor should be preferred. As can be seen from the measurements, 7 or 10 spreading factor values could not be reached at long distances. Therefore, when a long distance is the case the spreading factor 12 might be the only choice.

The geographic conditions tested do not provide direct visibility. Like fourth illustration in Figure. 5. There is tough elevation paths in the measurements. This greatly affects inter-device communications. However, in case of direct visibility, communication can be made at far longer distances. At the same time, compared to urban conditions, higher RSSI values can be achieved when the same distances are evaluated [10].

B. Results for measurement of SNR

Noise is any signal that interferes with your signal. Signal-to-Noise Ratio (SNR) is the ratio between the received power signal and the noise floor power level. In general, noise floor is the limit of sensitivity, on the other hand noise power level is not the limit for LoRa. Because LoRa have ability to work beneath of the noise floor, therefore it can demodulate the signal in an SNR value of up to -20 dB as it is shown in Table III.

TABLE III. SNR VALUES FOR EACH SPREADING FACTOR[12].

Spreading Factor	**Chips / symbol**	**SNR Limit(dB)**
7	128	-7.5
8	256	-10
9	512	-12.5
10	1024	-15
11	2048	-17.5
12	4096	-20

Table 3. demonstrates the SNR limits for each spreading factor. With the spreading factor increase, SNR changes -2.5dB for each SF.

TABLE IV. SNR RESULTS

SF/Places(meter)	**1** (651)	**2** (371)	**3** (944)	**4** (1120)	**5** (1910)	**6** (2200)
7		-4	-5	-9		
10	-7	-9	-16	-16		
12	-8	0	-12	-17	-15	-13

Given SNR values Table 4. spreading factor 7 have better values than higher ones. Although we have the SNR values given by datasheet in the previous table, lower values were reached during the application. This difference is a worthy example for purpose of this application.

V. CONCLUSION

In this study, the communication performances of a LoRa radio is studied in dens urban environment. The obtained performances in some areas were better than it supposed to be referring the data sheet of LoRa radio. However, the communication is significantly limited capacity in a densely populated areas in a city, providing that there is no line of sight between transmitter and receiver. So, the results presented in several paper some time overlooks the technology by concerning its performances in well behaving channels such as if there is a line of sight path. This paper checks the performance profile that while practical distance is found quite shorter than as it is presented [5], the noise performance is found better than some publications as in [9,10].

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