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Performance Exploration of LoRa Network in Indoor Environment

Gagandeep Kaur
Amity School of Engineering and Technology
Amity University
Sec-125, Noida
India
gkaur@gn.amity.edu

Sindhu Hak Gupta
Amity School of Engineering and Technology
Amity University
Sec-125, Noida
India
shak@gn.amity.edu

Harleen Kaur
Department of Computer Science
Jamia Hamdard
New Delhi
India
harleen.unu@gmail.com

***Abstract*- Long Range (LoRa) technology has been most adopted in the IoT domain due to its configurable transmission parameters which can be adjusted to enhance the network performance. To deploy a LoRa device in a real field application, it is critical to configure these parameters based on the scenario the LoRa device is deployed in. The current work experimentally evaluates the link-level performance of the LoRa network. Measurements are carried out in an indoor area considering both line of site (LoS) and highly obstructive environment. The network performance is investigated in terms of received signal strength indicator (RSSI), signal to noise ratio (SNR) and packet reception rate (PRR). The impact of various spreading factors on the performance of the deployed LoRa setup is also analyzed. Measurements indicate that RSSI and SNR increases with increase in SF and offers maximum values in an LoS environment corresponding to same SF. Further, the bit error rate (BER) of the link set up has been evaluated using the received values of the SNR at the gateway and it has been observed that BER decreases with increase in SF and is lesser for LoS scenario.**

Index Terms*- *IoT, LoRa, link-level, indoor area

I. INTRODUCTION

We are living in an era where objects of every day's life are equipped with sensors which are connected and exchanging information through internet. The IoT paradigm has heterogeneous field of applications such as business, industry, agriculture, consumer electronics, Health care, automotive and so on. The data access between the devices in an IoT system needs a wireless technology based on the application requirement and usage, by scrutinizing requisite data rate, power consumption and communication range [1]. IoT is a concept of connecting devices through internet so the main requirement is the technology which consumes less power and covers larger distances.

LPWAN technologies ensures extended coverage area, low power requirement, lower latency and lowest possible cost which complements them from cellular and short range wireless technologies. A comparative analysis of various IoT technologies has been tabulated in Table I. LoRa technology developed by Semtech is the most popular LPWAN technology working in unlicensed frequency band as it has the potential to resolve the necessities of diverse IoT applications. Lora features low energy consumption, low cost and operation expenses, low data rate, long transmission range and high capacity [2]. It is physical layer protocol that utilizes chirp spread spectrum modulation technique making it robustness against interference and resistance to multipath fading and Doppler shift [3]. It utilizes unlicensed ISM band of 433 MHz, 868 MHz and 915 MHz subject to the geographical section they are deployed in [4]. Based on the application and requirement, the LoRa end device can be deployed in any environment at a chosen location. LoRa has transmission parameters that can be adjusted at the device level. These customizable factors are coding rate (CR), bandwidth (BW), transmission power, spreading factor (SF) and carrier frequency [5]. Lora services spreading factors in the range of 7-12 which are orthogonal in nature. Carrier frequency defines the frequency used for the transmission which ranges from 860 MHz to 1020 MHz depending upon the specific LoRa chip used. Lora network operates in three scalable bandwidths of 125kHz, 250 kHz and 500 kHz [6]. To improve the receiver sensitivity LoRa integrates forward error correcting code (FEC) and thus the number of FECs used are defined in terms of Coding rate ($CR=4/4+m$). The value of m which define the code rate ranges from 0-4 with $m=0$ means that no FEC is used. Transmission power of the LoRa device is limited in the range of 2dBm to 20 dBm due to hardware operation restrictions.

In LoRa, transmission parameter adjustment has a great relationship with the network performance. Therefore, we can test the network performance in the deployed environment by adjusting the parameter combination.

The current work experimentally assesses the link quality of the LoRa network in an indoor area considering line of sight (LoS) and highly obstructive environment. The link performance of the LoRa network is experimentally analyzed in terms of received signal strength indicator (RSSI), signal to noise ratio (SNR) and packet reception rate (PRR). Using the SNR values collected from the experimental observations, bit error rate (BER) is further evaluated for both LoS and obstructive environment to estimate the link performance of the LoRa network. This work also analyzes the relationship between different spreading factors and the link performance of the considered LoRa network setup.

Further the flow of the current work is systematized as: Section II offers the summary of the work related to experimental evaluation of LoRa network. Section III highlights the measurement setup to estimate the performance of the deployed LoRa network setup. Section IV depicts the experimental outcomes and section V determines the experimental exploration.

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TABLE I
COMPARATIVE ANALYSIS OF VARIOUS IOT TECHNOLOGIES [7]

	Cellular	Wi-Fi	Bluetooth	ZigBee	LoRa	Sigfox	NB-IoT	Weightless	LTE-M
Data Rate	10 Mbps	54 – 1300 Mbps	1 – 3 Mbps	250 kbps	300 bps – 50 kbps	200 bps – 100 kbps	0.1 – 1 Mbps	200 bps – 100 kbps	1 – 10 Mbps
Frequency	Cellular bands	2.4 GHz, 5 GHz	2.4GHz	2.4GHz	subGHz	subGHz	Cellular bands	subGHz	Cellular bands
Range	35 km	15-50 m	30 m	30-100 m	3- 15 km	5-25 km	10 km	2-5 km	10 km
Frequency Band	Licensed	Licensed	Unlicensed	Unlicensed	Unlicensed	Unlicensed	Licensed	Unlicensed	Licensed
Max. Payload	-	1492 bytes	258 bytes	127 bytes	256 bytes	12 bytes	1600 bytes	10 bytes	256 bytes
Power Consumption	High	High	Medium	Low	Low	Low	Medium	Low	Medium
Standard	GSM, EDGE, LTE	IEEE 802.11	IEEE 802.15.1	IEEE 802.15.4	LoRaWAN	Sigfox Proprietary	3GPP	Weightless-SIG	LTE

II. RELATED WORK

Significant amount of work has been done by the research communal to compute the link quality of the LoRa network which majorly depends upon its configured transmission metrics. These constraints can be adjusted at the device side to test the LoRa performance. There has been a substantial extent of work on the experimental evaluation of the Lora network performance. Authors in [8] developed the path loss models and experimentally evaluated to analyse the coverage area of LoRa network and its performance in urban and rural areas sites. The results reveal the consistency of LoRa technology of IoT applications. In [9], through field test, link level and system level performance of LoRa network is analysed to estimate the capability of LoRa gateway and multi-gateway network over large communication range. Authors in [10], evaluated transmission and link level performance of the LoRa network based on different transmission parameters for different radio propagation channels. Authors in [11] evaluated the influence of diverse SFs on the LoRa network performance in the application of vehicular communication in terms of RSSI, SNR and PRR. The impact of coding rate on the packet error rate (PER) of the communication link having single LoRa device has been analysed in [12]. The authors in [13], the link quality of LoRa based underground wireless sensor networks has been evaluated. The influence of different propagation paths on the LoRa network performance is analysed in relations of RSSI, SNR and PRR. A comparison of the described related work is depicted in Table II.

In contrast to the above summarised related works, the current work analysis the impact of spreading factor on the link quality of the LoRa network set up in an indoor area considering LoS and obstructive scenarios. The obstructive condition in an indoor area includes the attenuation losses that occurs when signal penetrates through walls and floors.

In the next section the experimental setup and the link performance analysis of the LoRa network has been described

III. EXPERIMENTAL SET UP

A. Hardware Setup

The hardware set for the experimental analysis is divided into two parts- the transmitter node and the gateway node. The transmitter node consists of Semtech SX1278 LoRa module attached to an 8 bit Arduino Uno microcontroller and a DHT11 sensor. DHT11 sensor is a composite sensor used to measure temperature and humidity. The gateway node also consists of a SX1278 LoRa module along with ESP32 microcontroller which has a built-in Wi-Fi module to transmit the data received from the transmitter to the cloud server using internet. Measurements are done on a single uplink channel with the gateway communicating with a single transmitter node. All the data provided to the gateway is published to the ThingSpeak cloud for further analysis.

TABLE II
COMPARISON OF THE RELATED WORK

Reference	Performance metrics	Environmental scenario	Range Covered	Approach Employed
[8]	PDR, SNR	Indoor, Rural and Urban	8km, 45 km	Developed path loss models
[9]	Success rate, throughput	Rural	10.8 km	Investigated single gateway and multi-gateway LoRa network
[10]	RSSI, PDR	Indoor and Outdoor	80 m- 490 m	Impact of different transmission parameters
[11]	RSSI, SNR	Outdoor	800m	Analysed vehicular LoRa communication
[12]	RSSI, SNR, PER	Urban, Suburban and Open Area	1km- 3.8 km	Impact of coding rate
[13]	RSSI, SNR, PRR	Underground	20 cm - 80 cm	Impact of different propagation paths
Current work	RSI, SNR, PRR, BER	Indoor (LoS and obstructive)	70 m	Impact of different Spreading Factors

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TABLE III
LINK QUALITY PERFORMANCE OF LORA NETWORK

SF	RSSI (dBm)		SNR (dB)		PRR (%)		BER	
	LoS	Obstr	LoS	Obstr	LoS	Obstr	LoS	Obstr
7	-77.54	-113.10	8.01	2.45	98	98	10^{-30}	10^{-17}
8	-73.74	-111.14	8.42	2.58	98	97	10^{-44}	10^{-26}
9	-71.36	-109.35	8.96	3.01	99	98	10^{-62}	10^{-38}
10	-69	-106.95	9.72	3.42	97	96	10^{-85}	10^{-54}
11	-68	-105.15	10.29	4.08	97	96	10^{-112}	10^{-75}
12	-67.39	-104.32	10.88	5.03	96	95	10^{-145}	10^{-102}

B. *Measurement Setup*

In this work SX1272 LoRa module operating at 433 MHz frequency band is considered. The gateway node is deployed fixed in a room and the transmitter node is moved at different locations aiming to cover both the considered environmental conditions. Indoor measurements are performed inside a multi-storey building considering two environmental scenarios that are LoS and highly obstructive. The highly obstructive environment is affected by obstructions resulting from 3 concrete walls and 2 floors. Measurement is done over a fixed communication range of 70meters for both the environmental scenarios. To achieve LoS condition, the transmitter node and the gateway node are deployed in single empty room wherein transmitter node and the gateway node can be seen from each other's place.

The transmitter node and the gateway node are configured with identical transmission parameters to measure the link performance for both scenarios. The impact of varying spreading factor (7-12) is taken in to account maintaining other transmission parameters like coding rate, bandwidth, carrier frequency and transmission power to be constant for all the measurements. During the experiment the transmitter node is configured to send 100 packets to LoRa gateway for each SF. The performance metrics analysed are RSSI, SNR and PRR which can be observed at the gateway node for each packet. PRR is measured as the ratio of effectually packets received at the LoRa gateway to the total number of packets transmitted for each LoRa transmission configuration. Further utilizing the logged SNR values at the gateway, BER is also estimated to investigate the link quality performance for both the environmental conditions. In addition, the influence of diverse spreading factors on the link performance for the considered scenarios has also been evaluated.

For an indoor area, the long distance propagation model has been considered. In order the calculate the path loss for a highly obstructive environment in an indoor area, the additional attenuation losses due to walls and floors which are described as wall attenuation factor (WAF) and floor attenuation factor (FAF) are taken into consideration.

C. *Link Performance Analysis*

To estimate the link performance of the LoRa network setup under the considered scenarios, the measured value of SNR is take into account to further calculate the BER.

The SNR of the LoRa system in the AWGN channel is directly related to normalised SNR or SNR per bit defined as the ratio of energy per bit to noise power $\left(\frac{E_b}{N_o}\right)$, and as stated in [14] can be expressed as

$$SNR = \frac{E_b}{N_o} \times \frac{SF}{2^{SF}} \quad (1)$$

The analytical expression of BER for the LoRa modulation using $\frac{E_b}{N_o}$ and Q function as stated in [12] is stated as

$$BER = Q\left(\frac{log_{12}(SF)}{\sqrt{2}} \times \frac{E_b}{N_o}\right) \quad (2)$$

The effect of SNR and spreading factor on the BER of the LoRa network can be computed using equation (1) and (2) as

$$BER = Q\left(\frac{log_{12}(SF) \times 2^{SF} \times SNR}{\sqrt{2} \times SF}\right) \quad (3)$$

where SNR depicts the received SNR value of the packet received at the gateway corresponding to configured SF.

The next section explains the simulation results of the indoor measurement setup in the considered scenarios.

IV. SIMULATION RESULTS

The link quality performance of the LoRa network setup is evaluated using the varying value of spreading factor in its permissible range of 7-12. The code rate and bandwidth are fixed at 4/5 and 250 kHz respectively. Transmission power is plugged at 13dBm since maximum authorised emitted power in most of the countries is fixed at 13dBm. The carrier frequency is taken to be 433MHz as allowed for the LoRa chip used. The transmitter node and the gateway are placed indoors at 70 meters apart for both LoS and obstructive environment. To analyse the performance of link setup, RSSI and SNR values for all the successfully received packets are recorded at the gateway. Table III presents the logged and the evaluated values of RSSI, SNR, PRR and BER corresponding to various SFs for LoS and highly obstructive (Obstr) environment.

Fig. 1 shows the average value of RSSI recorded at the gateway corresponding to various SF considering both the scenarios. It can be observed that RSSI increases with increase in SF. The result also depicts that the RSSI of the signal received at the gateway in LoS environment is higher than that of RSSI value of the received signal in highly obstructive environment.

Fig. 2 shows the average SNR value corresponding to different spreading factors. Result shows that average SNR of the packets received at the gateway increases with rise in SF but accounts lower within a highly obstructive environment. Lower value of SNR indicates the higher noise interference due to obstructions in the path of the signal.

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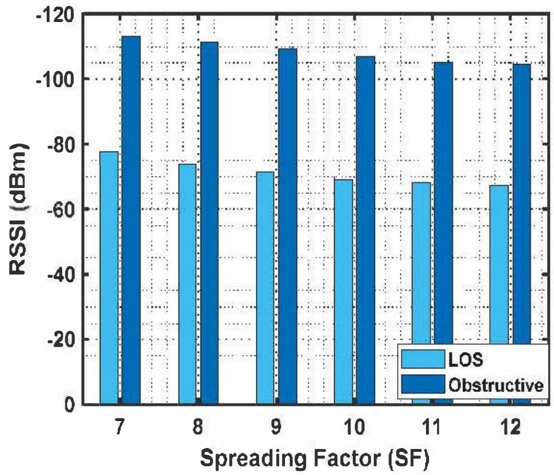

Fig. 1. RSSI vs Spreading Factors

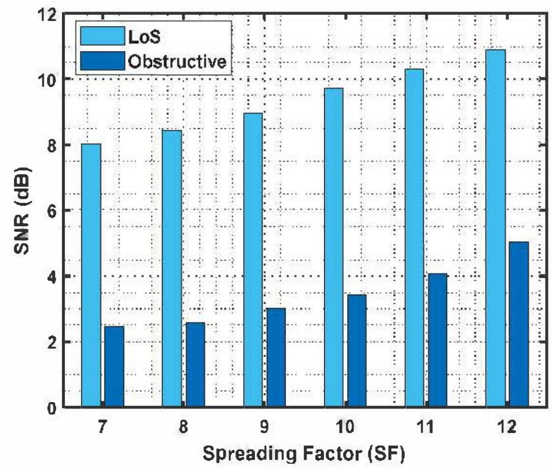

Fig. 2. SNR vs Spreading Factors

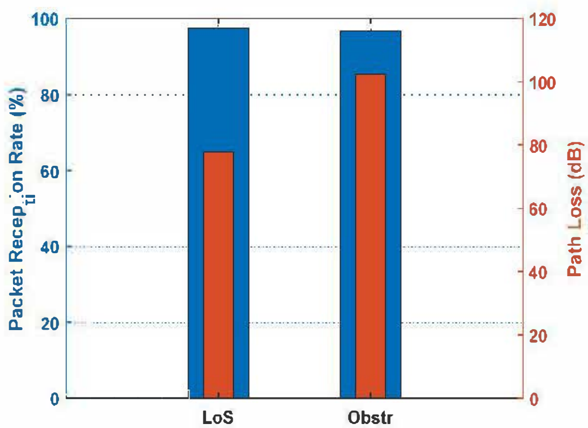

Fig. 3. Comparative analysis of PRR and Path Loss ofLoS and obstructive scenarios

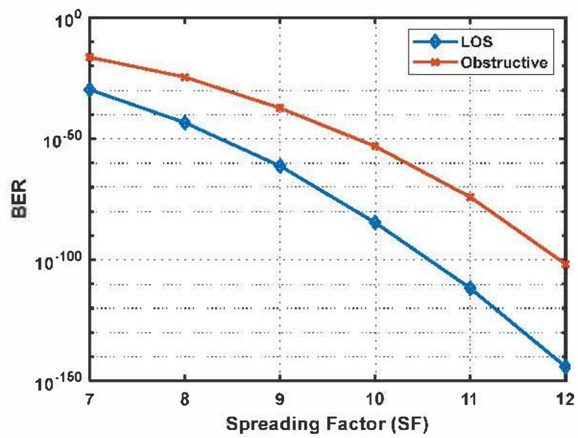

Fig. 4. BER vs Spreading Factors

The performance of the deployed LoRa network setup is also assessed in terms of Packet Reception Rate (PRR) and path loss (PL) during the indoor measurements for both the environmental scenarios. Fig. 3 shows the average calculated PRR value and PL value for both LoS and highly obstructive (Obstr) conditions. The result depicts an average PRR of 97% for LoS and 95% for highly obstructive condition. The impact of WAF and FAF on the received signal at the gateway is taken into consideration for an obstructive scenario. The result shows a PL of 77.5 dB for LoS and 91.98 dB in case of highly obstructive condition.

SNR is a good measure to determine the link quality of the LoRa network. Thus the average value of SNR logged at the gateway is further utilized to compute the BER to analyse the link level performance of the deployed LoRa setup. Fig. 4 shows the BER performance for different SFs considering both scenarios. It is observed that BER decreases with increase in SF and accounts better for LoS condition. At SF = 12, a BER = 10^{-145} is achieved forLoS condition and BER = 10^{-102} for highly obstructive environment. Such a lower value of BER is due to the fact that the measurement is done over a short communication range which is less than 100 meters.

V. CONCLUSION

LoRa is the most adopted LPWAN technology that fulfils all the requirements of low power IoT applications. The current work experimentally estimates the link quality performance of the LoRa network. Measurements has been conducted in an indoor area considering both LoS as well as highly obstructive environment. Experimental setup has been prepared to validate the achievability of LoRa technology in a short range coverage and impact of SF on link quality of the LoRa network. The performance metrics utilized to estimate the link performance of the setup network are- RSSI, SNR, PRR and BER. Measurements indicate that RSSI and SNR increases with increase in SF and offers maximum values in an LoS environment corresponding to same SF. The measured SNR values are further utilized to calculate and analyse the effect of SF on system BER. BER of the setup LoRa network decreases with increase in SF and is lower for LoS scenario with minimum BER of 10^{-145} achieved for SF=12.

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