Study of LoRa Performance at 433 MHz and 868 MHz Bands Inside a Multistory Building

Ivan Bobkov
National Research University Higher School of Economics
Moscow, Russia
ivbobkov@miem.hse.ru

Alexey Rolich
National Research University Higher School of Economics
Moscow, Russia
arolich@hse.ru

Maria Denisova
National Research University Higher School of Economics
Moscow, Russia
madenisova_1@miem.hse.ru

Leonid Voskov
National Research University Higher School of Economics
Moscow, Russia
lvoskov@hse.ru

***Abstract*—Owing to its energy efficiency and long range, LoRa wireless network has become a widely spread technology among IoT systems recently. LoRa allows to use various ISM bands such as 433 MHz, 868 MHz and 915 MHz. During this study 433 MHz and 868 MHz frequencies have been compared. Parameters such as SNR and RSSI were measured at different floors and visualized. A comparative table of packet delivery ratio at various spreading factors can be found in this paper. A series of range experiments at different spreading factors showed that 433 MHz LoRa module gains a stronger signal. However, 868 MHz LoRa module shows higher percentage of received packets. It has been concluded that for nine-story building with concrete floors it is better to deploy 868 MHz LoRa network at 10th spreading factor.**

Keywords—IoT, Internet of things, LoRa, indoor performance, signal propagation, ISM band comparison, SNR, RSSI, PDR, packet loss, spreading factor.

I. Introduction

Due to Internet of Things (IoT) constant development, wireless technologies are actively infiltrating into our everyday life. As well as personal IoT devices, complicated IoT systems such as smart buildings are becoming more spread nowadays. Increasing smart buildings demand requires innovative and more energy efficient solutions for information transmission. One of the most common network solutions for IoT systems is LoRa wireless communication technology [1]. Compared with Wi-Fi and Bluetooth Low Energy (BLE), LoRa is considered as a better choice for indoor deployment in multi-story buildings [2].

The subject of LoRa indoor placement is an important issue for IoT in smart buildings. There are several studies where various LoRa indoor experiments were conducted such as a research of LoRa technologies possibility in the indoor environment in the context of human-centric applications [3–4] or a study of LoRa deployment specificity inside a flower auction warehouse [5]. Mainly, LoRa indoor articles concentrate on the measurement of received signal strength indicator (RSSI) [6–7], packet delivery ratio (PDR) [8–9] and on the comparison of different spreading factors [10–11]. However, there are only a few papers where these significant parameters are compared at different frequencies.

This paper describes an architecture of a LoRa indoor network experimental stand for carrying out experiments with the transfer of packets indoors under various transmission conditions and the results of experimental studies of the received signal level indicator for 433 MHz and 868 MHz at various spreading factors.

Results are presented in the following order: Section II contains an overview of related works. The rest of the paper is organized as follows: section III briefly describes LoRa network experimental stand architecture. Furthermore, the conducted experiments are presented and described in section IV. Section V contains the received data and its analysis. Finally, the obtained results of the study are concluded in section VI.

II. Literature Review

Islam, B. et al. [2] analyzed the feasibility of using LoRa, an emerging low-power wide-area networking technology, in indoor localization. Considering the coverage, stability and regularity of signals, accuracy of localization, responsiveness, power, and cost – authors concluded that LoRa is a feasible choice for indoor localization, especially in wide and tall indoor environments like warehouses and multi-storied buildings.

In [5], authors present the indoor performance of LoRa by the means of real-life measurements. The measurements were conducted using the commercially available equipment in the main campus of the University of Oulu, Finland. The paper [6] consider data collection in the Hanover building at Glasgow Caledonian University using the LoRa transceivers. This paper facilitates the link budget design, network implementation and coverage diagnosis in similar indoor scenarios.

Erbati, Schieli and Batke [10] present behavior analyzes of LoRaWAN technology in urban settings in both an indoor and an outdoor scenario, with respect to parameters such as RSSI, SNR, PDR, Coverage, and Deep Indoor Penetration (DIP).

LoRa modules mainly use non-licensed 433 MHz, 868 MHz and 915 MHz industrial, scientific and medical (ISM) radio bands [11]. In this study 433 MHz and 868 MHz

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frequencies are compared indoors. To our knowledge, there is only one research where these two ISM bands have opposed each other inside a modern multi-story construction. Based on the signal-to-noise ratio (SNR) measurements through two thick concrete cores the article claims that 434 MHz frequency is more preferable for LoRa indoor communication [13] which this study partly proves.

Each standard LoRa module includes a spreading factor (SF) – a customizable parameter which can be changed from 7 to 12 conventional units. Recent study shows that the greater the distance outdoors from transmitter to receiver is, the greater SF value should be. The article [14] compares different spreading factors indoors and illustrates the best solution for multi-story buildings, depending on the number of floors between LoRa modules.

In summary, all of the aforementioned works study the feasibility of LoRa for indoor communication, formulating many open issues and addressing some of them. Thus a potential gap in study of LoRa indoor communication using 433 MHz and 868 MHz with different spreading factors can be observed.

III. EXPERIMENTAL STAND ARCHITECTURE

A complete architecture of the provided experimental stand is presented in Figure 1. Stand includes the following elements:

1. End-point data collection devices (nodes) using 433 or 868 MHz frequencies (one or several sensors can be connected to these devices; data transmission is performed according to the LoRa specification).
2. LoRa base station (consists of Heltec LoRa module and Raspberry Pi 3).

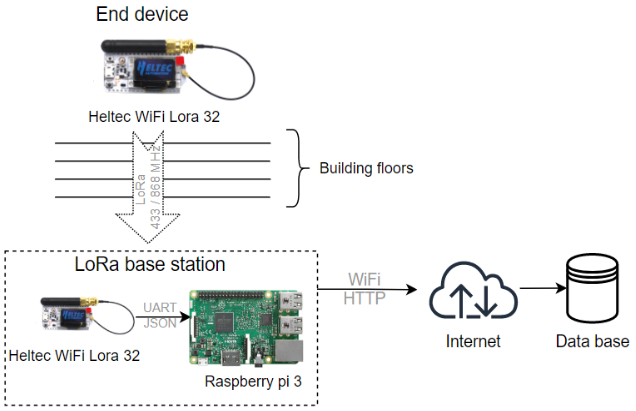


Fig. 1: LoRa network experimental stand architecture

Each LoRa node for signal transmission consists of a LoRa module based on ESP32 microcontroller and SX1276 transceiver. These modules are provided by Heltec Automation [15]: Wi-Fi LoRa 32 module for 433 MHz and Wi-Fi LoRa 32 (v2) module for 868 MHz experiments respectively.

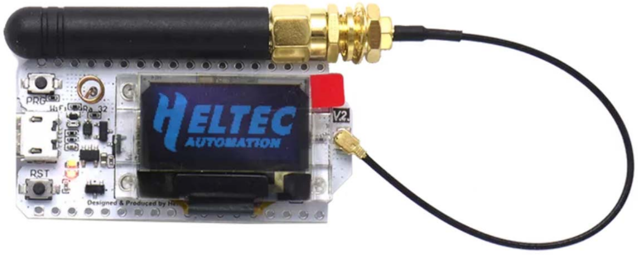


Fig. 2: Heltec Wi-Fi LoRa 32 (v2) module

Transmission nodes also include one battery holder for 4 AA batteries and are placed inside a plastic case with antenna on the outside.

Fig. 3: LoRa transmission node

During each experiment LoRa transmitter is continuously sending packets which contain their identification number, spreading factor and number of floors between the transmitter and the base station. In total, transmitter sends 3000 packets per experiment (500 packets for each of 6 SF). Switching between spreading factors happens automatically.

Packet reception takes place at LoRa base station which consists of Heltec LoRa module described in subsection A (v1 or v2 depending on the experiment frequency) and a single-board computer Raspberry Pi 3 [16] which sends collected (packet id, SF, floor difference) and calculated (SNR, RSSI) data to server. LoRa receiver listens to the broadcast from 7 to 12 SF consequentially.

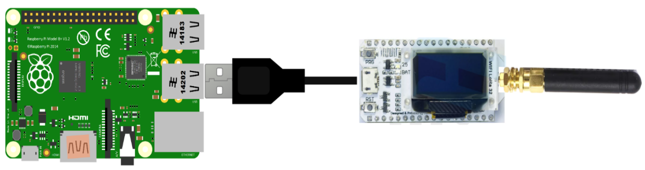


Fig. 4: LoRa base station

IV. CONDUCTED EXPERIMENTS

A. *Nodes placement*

Experiments took place in a nine-story building of HSE Electronics and Mathematics Faculty. LoRa base station was permanently placed on the ground floor, while LoRa transmitter was being moved from the second to the ninth floor consequentially. The transmitter was placed on the concrete floor above the receiver as vertically as possible to minimize deviations from a straight path.

B. Experiments description

The goal of the study was to find out which one of the two frequencies is more suitable for LoRa indoor communication: 433 MHz or 868 MHz. Firstly, LoRa 433 MHz transmitter sent 3000 packets (500 packets for each SF) from every floor to the base station. Secondly, LoRa 868 MHz transmitter has done the same. Calculated SNR, RSSI and packet loss have been analyzed for every SF of each ISM bands and presented as comparative diagrams in section V.

Fig. 5: Nodes placement

V. RESULTS AND ANALYSIS

A. 433 MHz and 868 MHz comparison

TABLE I. AVERAGE SNR FOR 433 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	12.47	12.40	12.44	12.43	12.56	12.47
2	12.30	12.39	12.40	12.49	12.38	12.39
3	12.28	12.37	12.33	12.35	12.35	12.33
4	12.30	12.36	12.37	12.36	12.38	12.38
5	12.80	12.66	12.70	12.79	12.79	12.82
6	12.67	12.72	12.74	12.73	12.73	12.71
7	12.64	12.69	12.69	12.68	12.72	12.69
8	12.27	12.44	12.45	12.46	12.57	12.85

TABLE II. AVERAGE RSSI FOR 433 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	-75.39	-76.50	-77.36	-80.96	-82.21	-80.48
2	-96.77	-97.35	-97.39	-99.53	-101.15	-101.45
3	-117.23	-118.91	-119.20	-120.04	-119.89	-119.90
4	-114.80	-115.72	-116.17	-117.80	-118.84	-118.41
5	-116.73	-117.76	-118.26	-119.34	-119.80	-119.69
6	-115.89	-116.50	-117.07	-118.44	-119.18	-119.36
7	-117.71	-118.50	-119.01	-120.77	-120.63	-120.63
8	-120.35	-121.19	-121.54	-123.10	-122.21	-119.51

TABLE III. AVERAGE SNR FOR 868 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	9.55	9.05	9.20	9.16	9.15	9.15
2	8.88	8.97	8.96	8.96	8.97	8.98
3	8.92	8.95	9.00	8.96	8.99	9.00
4	9.01	9.08	9.10	9.05	9.04	8.95
5	9.11	9.13	9.17	9.21	9.22	9.21
6	9.02	9.06	9.11	9.10	9.08	9.16
7	9.00	9.07	9.08	9.08	9.06	9.10
8	9.07	9.09	9.13	9.05	9.09	9.13

TABLE IV. AVERAGE RSSI FOR 868 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	-77.83	-81.12	-80.18	-85.30	-86.51	-86.20
2	-109.54	-112.03	-108.99	-109.47	-110.91	-110.78
3	-117.66	-118.22	-120.22	-120.07	-120.96	-121.50
4	-127.27	-127.50	-127.67	-129.22	-129.86	-129.77
5	-128.98	-129.45	-130.07	-130.91	-131.11	-130.91
6	-128.89	-129.54	-129.76	-130.89	-131.29	-131.10
7	-127.63	-128.13	-128.59	-130.26	-130.66	-130.63
8	-128.91	-129.29	-129.78	-131.08	-131.23	-131.13

TABLE VI. AVERAGE PDR FOR 433 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	99.8	99.8	100	100	87	99.8
2	100	100	99.8	100	100	100
3	77.2	75	94	99.2	99.6	100
4	99.4	99.6	100	100	99.4	100
5	37.2	97	98	98.8	98.4	99.2
6	99.8	99.8	99.4	100	100	98.8

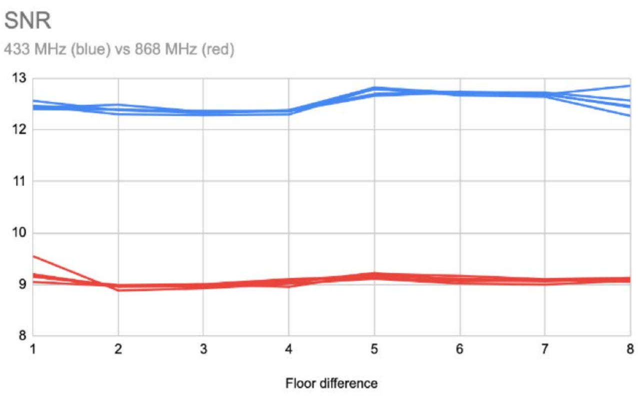
7	82	92.2	95	93.2	99.8	100
8	32.2	79	88.2	98	99.2	99.2

Arithmetical mean values of all gathered SNR and RSSI have been calculated for each floor and SF, then put on the line graph. According to the provided comparison, it can be concluded that LoRa shows better SNR and RSSI values at 433 MHz than at 868 MHz ISM band.

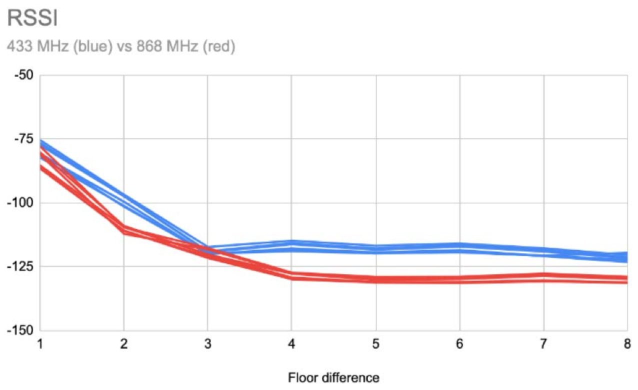
TABLE VI. AVERAGE PDR FOR 868 MHZ

SF / *Floor*	**7**	**8**	**9**	**10**	**11**	**12**
1	99.8	99.8	99	100	99.8	100
2	99.2	100	93.6	100	100	99.8
3	100	99.8	97.6	100	100	100
4	98.6	99.8	99	100	99.8	99.6
5	79.4	87.4	92.8	99.6	99.4	99.4
6	97.4	99.4	100	99.4	99.6	99.8
7	98.8	100	100	100	100	99.4
8	97.60	99.6	99.8	100	100	99.4

However, comparison of packet delivery ratio (PDR) illustrates more serious packet loss at 433 MHz frequency. It can be observed that the lowest point of 433 MHz at the 5th floor is much deeper than the bottom point of 868 MHz ISM band (37.2% of packets were received at 7 SF against 79.4% respectively). The same situation occurs at the 8th floor (32.2% against 97.6%). Moreover, 433 MHz percentage fluctuates more dramatically, while 868 MHz percentage remains stable most part of the floors.



(a)



(b)

Fig. 6: Comparison of 433 MHz and 868 MHz SNR (a) and RSSI (b)

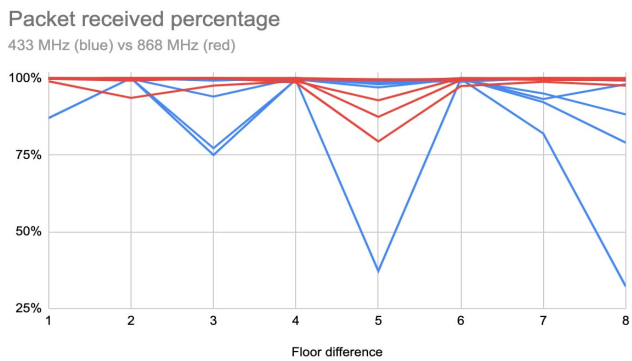
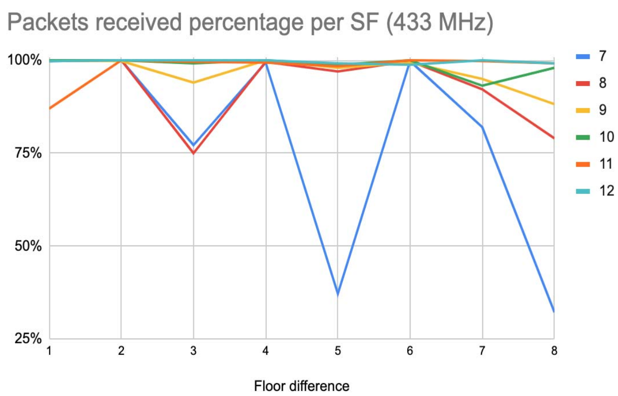


Fig. 7: Comparison of 433 MHz and 868 MHz packet delivery ratio

B. Spreading factor analysis



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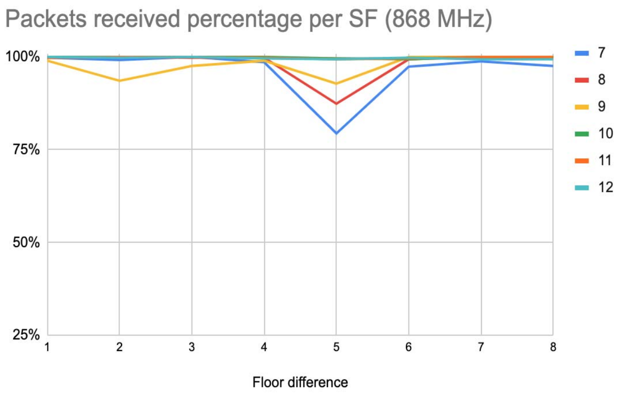

(b)

Fig. 8: Percentage of received packets per SF at 433 MHz (a) and 868 MHz (b)

Packet received percentage line graphs reflect that signal becomes more unstable at low spreading factors. Transmission stability can be classified according to the following rules: more than 95 % of packets received means a stable signal, less than 95 % but more than 80 % of packets received means a partly stable signal, while less than 80 % of packets received means an unstable signal.

TABLE VII. CLASSIFICATION OF TRANSMISSION AT DIFFERENT SF AND FREQUENCIES

ISM band	SF	Lowest percent	Classification
433 MHz	7	32.2%	Unstable
	8	75.1%	Unstable
	9	88.2%	Partly stable
	10	93.2%	Partly Stable
	11	98.4%	Stable
	12	98.8%	Stable
868 MHz	7	79.4%	Unstable
	8	87.4%	Partly stable
	9	92.8%	Partly Stable
	10	99.2%	Stable
	11	99.4%	Stable
	12	99.4%	Stable

Signal stability classification illustrates that, firstly, the best packet reception occurs at higher spreading factors (from 10 to 12). Secondly, 868 MHz frequency provides, in total, more stable transmission than 433 MHz ISM band (3 stable SF against 2, 1 unstable SF against 2).

VI. CONCLUSION

This paper proposed an architecture of a LoRa indoor network experimental stand for carrying out experiments with the transfer of packets indoors under various transmission conditions and the results of experimental studies of the received signal level indicator for 433 MHz and 868 MHz at various spreading factors.

The study results show that 433 MHz frequency provides a stronger LoRa signal due to greater SNR and RSSI values. Nevertheless, 868 MHz ISM band shows more stable packet reception at every spreading factor. Considering that the less the SF value is the less energy is being consumed [17], it can be recommended to use 868 MHz LoRa modules at 10th spreading factor in nine-story buildings. With greater floor difference between modules it would be better to use higher values of spreading factor. In future studies 915 MHz frequency can be explored and all three LoRa ISM bands can be compared with each other indoors and outdoors.

The results can be useful in development and configuring LoRa indoor networks. These results were used to deploy a research infrastructure of the Internet of Things based on LoRa at the National Research University Higher School of Economics.

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