

Planning and Research of Long-Range LoRaWAN Radio Coverage for Large Areas with Complex Terrain [†]

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Abstract: When building energy-efficient communication platforms for IoT, it is necessary to plan in advance a number of actions related to radio coverage and to anticipate possible problems to be solved before building the platform. Since all data traffic is transmitted wirelessly, it should provide reliable and quality radio coverage. Designing long-range LoRaWAN communications in outdoor environments with complex terrain is a challenging task that involves determining the correct location and height of the gateway to provide the necessary line-of-sight and minimize communication with reflected signals, as well as the appropriate equipment (e.g., transceiver antennas and radio modules). This article discusses the planning and research of such a type of radio coverage. For evaluation, the following were used: determining the coverage range and measuring the signal parameters, taking into account the receiver sensitivity; control of communication parameters; measurements and analysis in order to detect and eliminate existing disturbances and issues; and assessment of the quality of the service through survey and continuous monitoring in the coverage area.

Keywords: LoRaWAN; radio coverage; quality of service



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1. Introduction

The task of transmitting data over long-distance wireless telecommunication networks in complex terrain is an important and complex challenge to solve [1–3]. Transmission and protection of messages (bundled into packets) over long distances with low-power consumption devices (used for IoT applications) is proving to be a difficult task [4–6].

The concept of low-power communications is based on a number of different end devices with their own low power consumption and the ability to be powered autonomously for large periods in hard-to-reach locations [7,8]. Renewable energy sources are used to charge rechargeable batteries as well as suitable batteries depending on the climate at the point of placement of the end device [7]. The low power consumption of the end device is achieved using modern information transmission protocols [9,10]. The encoding and modulation that takes place during the transmission and reception of the information packets allows the information to be sent over the air in a short moment of time by means of the transceiver integrated into the end device, thus contributing to the low power consumption of the end device [7,9,11,12].

Low-power networks are composed of devices with various sensors, with switching and control modules additional to them, with low energy consumption, and the ability to aggregate and analyze a large volume of small data packets (processing is performed in the server with the stored data) to improve the organization of a particular activity, optimize a process or operation, ensuring constant monitoring of network devices, at low financial cost [5,6,12,13]. One of the standards and specifications emphasized in this paper is the LoRaWAN standard; this is a standard for low-power broadband wireless networks

(LPWANs), and it is based on LoRa transceiver modules used to build increasingly large low-energy smart wireless networks [7,14].

The development and growth of the application of the Internet of Things in various fields is leading to an increased interest in wireless networks of the LPWAN (Low Power Wide Area Network) type. Solutions are being sought for the deployment of wide area networks that provide extremely reliable communication at low transmitted power and low energy consumption to ensure high autonomy of end devices and, at the same time, achieve a large network range. One of the technologies that meets these criteria is LoRa/LoRaWAN. Meeting these requirements involves solving a number of challenges. These are related to the specifics of the geographical area in which the network is to be built, which affects the correct placement of the communication equipment (gateways, concentrators, etc.). Numerous LoRaWAN-based networks are being deployed in a number of cities and countries [15–17]. In this type of network, a common platform is built with a central device—a concentrator, which is part of the gateway. The concentrator receives a variety of sensor data from different sources, depending on the network application. These data are forwarded from the gateway to a cloud/network server where they can be used for analysis, visualization, prediction and optimization, and intelligent management of processes and services. In Bulgaria and worldwide, this type of LoRaWAN technology is just emerging and is the subject of interest and research into its various applications and challenges.

In this paper, an experimental setup is proposed to evaluate the quality of radio coverage in complex terrain conditions for long-range communication. The obtained results are presented graphically and tabularly, giving information about the capabilities and applicability of LoRaWAN technology in relevant scenarios and conditions of large coverage areas and complex terrain.

2. Development of Experimental Setup and Evaluation Methods

When building this type of platform, a number of actions need to be planned in advance, and possible problems need to be anticipated and solved before the platform is built. Since all data traffic is transmitted wirelessly, serious consideration must be given to the antenna–feeder complex as well as the location and height of the gateway deployment [10,16–19].

The research and analysis of the range and process of signal propagation in outdoor environments and the reliable data transmission in the LoRaWAN network require the development of a flexible experimental setup with extensive modification and customization capabilities. For these purposes, a test experimental model was developed, as shown in Figure 1.

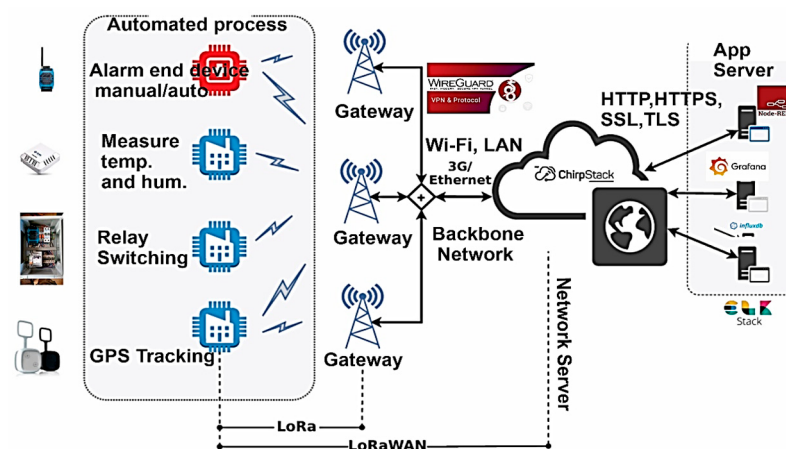


Figure 1. Block diagram of LoRaWAN network experimental setup.

2.1. Design and Implementation of LoRaWAN Gateway

A specialized LoRaWAN gateway has been developed, which includes the following:

- Control unit based on a Raspberry Pi model 3B+ single-board computer;
- Concentrator based on RAK2245 radio module.

The two main blocks of the gateway are powered by 5VDC and 3A (high mast mounting heights result in large losses in the power supply lines). Power is supplied by a dedicated POE unit. This power supply provides 24VDC, which is fed to a DC/DC converter to adjust the voltage to the required 5VDC. The block diagram of the implemented power supply unit is shown in Figure 2.

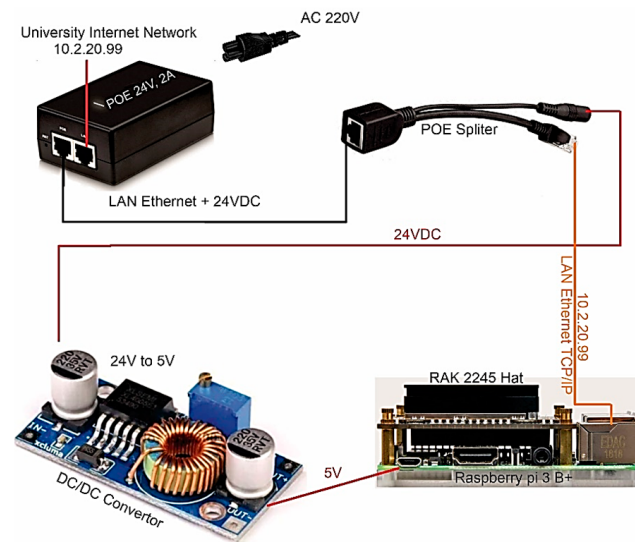


Figure 2. LoRaWAN gateway power supply implementation.

Figure 3 shows the experimental implementation of the developed LoRaWAN gateway.

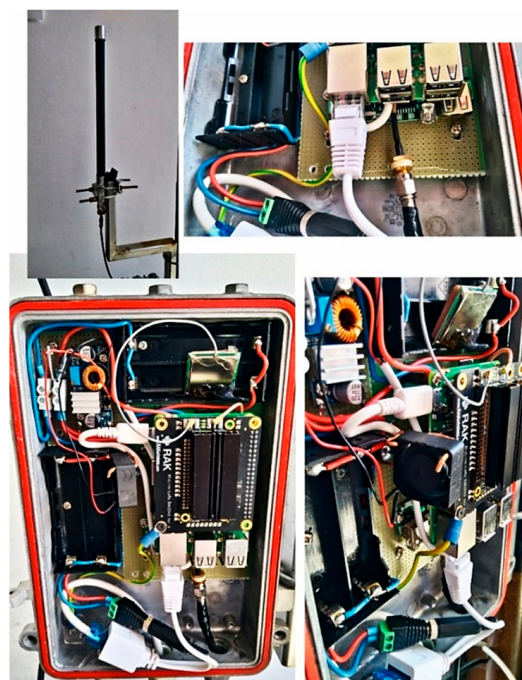


Figure 3. Component modules of the LoRaWAN gateway.

Battery power mode is available when the POE injector power fails. An active cooler has been added to the enclosed volume of the aluminum enclosure to prevent the modules from overheating when the unit is mounted in an open area.

To the LoRaWAN gateway, in addition to the transceiver antenna for LoRaWAN communication at a frequency of 868MHz, a GPS antenna is also included to allow time synchronization of data traffic with both the receiver and the network and application servers. The GPS antenna is connected to the RAK2245 concentrator connector. A mounting structure is attached to the aluminum box for both mounting the LoRaWAN antenna and attaching the box to a supporting vertical pipe or other structure.

The experimental studies were carried out in two stages:

- Stage 1—experimental studies in an urban environment in the presence of nearby buildings—the area of the University Campus 2 of the TU-Gabrovo was used for this purpose.
- Stage 2—experimental studies outside the populated area—the surroundings of the town of Pavel Banya were used for this purpose.

2.2. Implementation of the Experimental Setup—Algorithm and Methodology

Figure 4 shows the implementation sequence of the experimental setup for conducting planning and research of long-range LoRaWAN radio coverage for large areas with complex terrain.

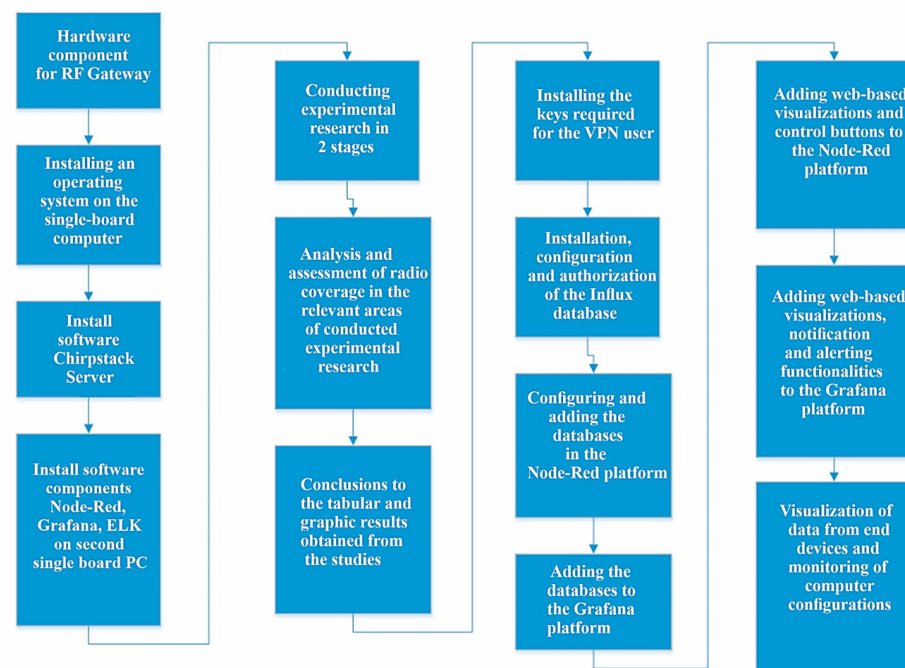


Figure 4. Methodology algorithm for experimental setup design.

The control unit is based on a Raspberry Pi platform, which is very suitable and flexible for wireless IoT network development [20,21]. In particular, the control unit is based on the Raspberry Pi model 3B+ single-board computer and implements a server based on three software components—gateway bridge, network server, and application server—that are part of a common software stack as follows:

- The Gateway Bridge is implemented by the ChirpStack Gateway software service. The purpose of the bridge is to convert the LoRa packets (received from the LoRa end devices in the network) into a common data format (JSON and Protobuf) used by the ChirpStack network server;

- ChirpStack Network Server—the purpose of this component is complex and includes processing the packets received from the LoRa gateways, performing authentication and ensuring network security, communicating with the application server, etc.;
- ChirpStack Application Server—the purpose of this server is to perform an “inventory” of the end devices connected to the LoRaWAN infrastructure: handling of received application payloads and the downlink application payload queue. It provides a web interface and API (RESTful JSON and gRPC) for integration with external services. Received payloads are published over MQTT and payloads can be enqueued by using MQTT or the API.

Data received from and sent to the end devices over MQTT or HTTP can be written directly to a database—in this case, InfluxDB.

3. Results and Discussion

The experimental studies on Stage 1 were conducted in an urban environment in the presence of nearby buildings—the area of the University Campus 2 of the TU-Gabrovo. A large number of measurements were taken at each control point and then averaged to obtain an arithmetic mean of the signal parameters. The following signal parameters are measured at the control points:

- RSSI;
- LoRaSNR.

Control points are provided both inside and outside the building—Figure 5 [22]. A total of about thirty control points were measured. Sending messages in this scenario is configured to be performed manually, with the press of a button from the web-based interface panel of the ChirpStack network server. Through the applications and their registered devices and Web-based buttons and features, end devices can be controlled by sending a combination of symbols, numbers, and alphabetic characters.



Figure 5. Control points in the test area of University Campus 2.

Figure 6 presents the graphical results of the comparison of the RSSI parameter value at different control points as the LoRaSNR parameter is varied. The reported values for each control point are the arithmetic mean of 10 measurements of the RSSI parameter.

It can be seen from Figure 6 that the largest negative value of the RSSI parameter was recorded at control points located inside the building. Nevertheless, successful data reception and decoding are achieved even at very low LoRaSNR parameter values.

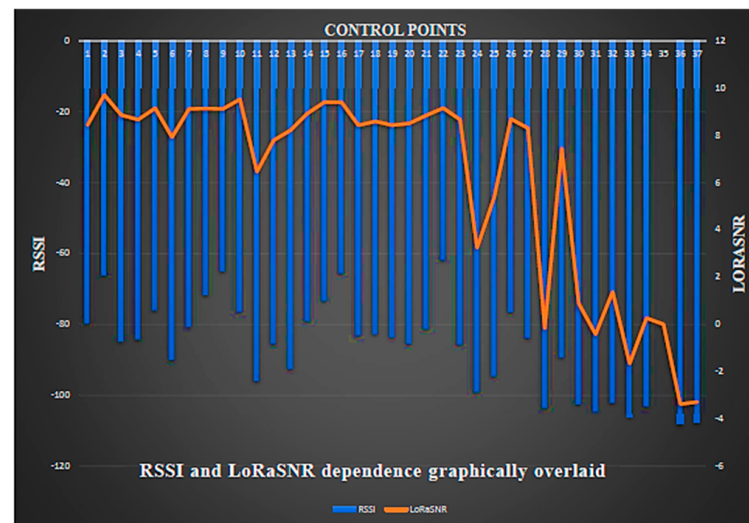


Figure 6. Graphical representation of the measured RSSI and LoRaSNR values at the given control points.

Stage 2 of the research examines the quality of radio coverage in a large open area with complex terrain. A series of measurements were taken and analyzed for a large number of covered control points on the territory of the town of Pavel Banya and its surroundings.

The territory of the town of Pavel Banya and the surrounding area includes a large percentage of forested area, a serious elevation between the transmitter and the receiver, and numerous buildings; these conditions seriously test the robustness of the LoRaWAN protocol. The LoRaWAN Gateway is installed on the roof of a 4-storey block, which is located at an altitude of 427 m above sea level—Figure 7.



Figure 7. Installation site of the experimental LoRaWAN gateway.

The routes covered are several in number and were covered at different times, in different weather conditions, and on different days and times. To document the measurements, the software tool TTN Mapper [23] was used to plot control points from the measurements on a map of the area around the LoRaWAN Gateway. The color of the vectors indicates the

value of the RSSI parameter: red indicates a strong signal, and blue indicates a weak signal. The results are presented in Figure 8 [23].

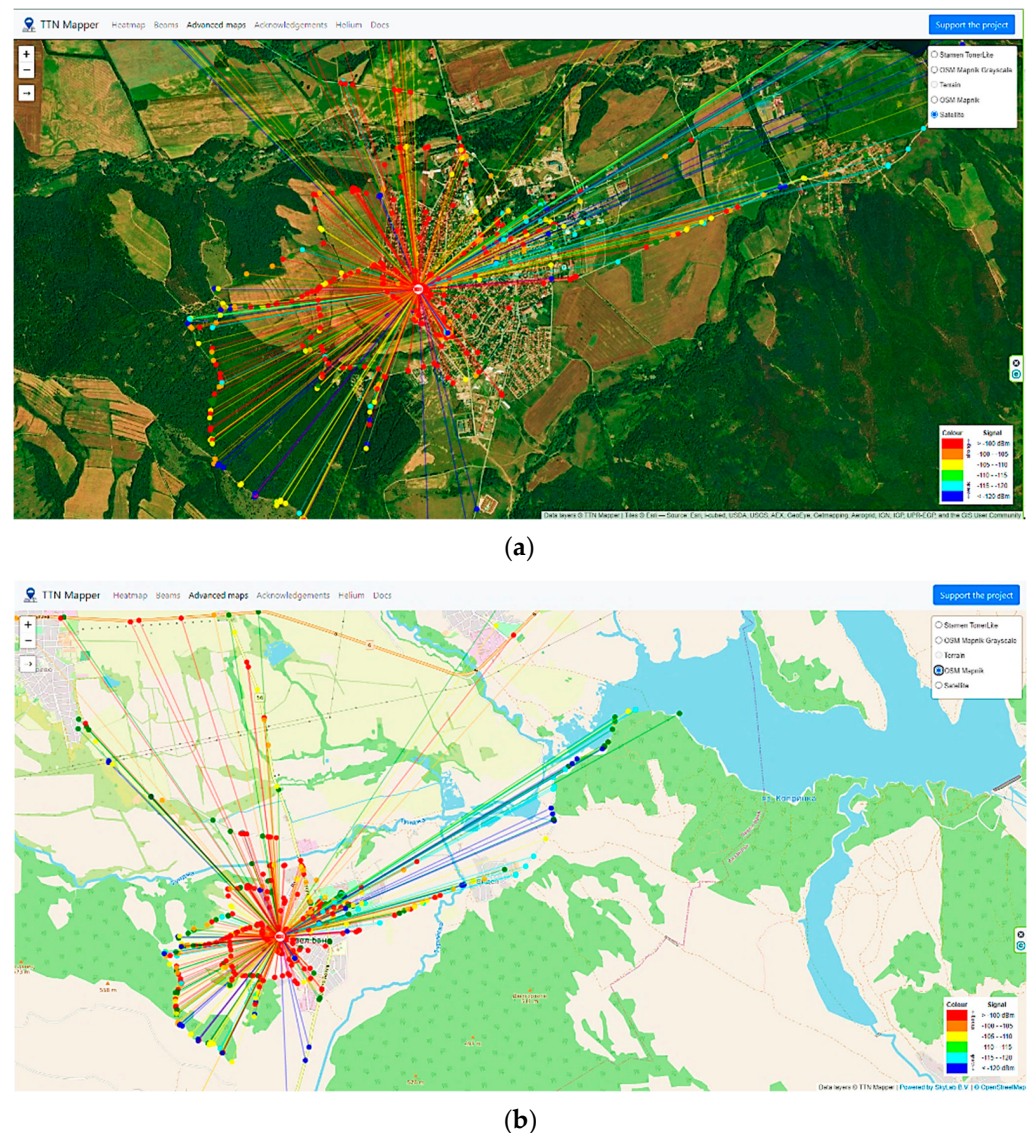


Figure 8. Signal strength at different control points inside and outside the populated area of the town of Pavel Banya and near the Koprinka dam: (a) satellite image, (b) simple mapping processed by TTN Mapper Tool.

The total number of control points made in the measurement is 1483, and for each of them, the TTN Mapper application records the RSSI, LoRaSNR, and GPS coordinates of the position from which the message was transmitted. The measurements were performed over a period of 10 days, with some of the routes overlapping.

The control points shown on the map in Figure 8 show reliably received packets. The coverage area can be divided into three parts as follows:

- distant non-urban area—up to 6 km, where the RSSI level of the received packets is in the range of -115 to -130 dBm; in this remote area, the terrain includes open fields with well-received signal levels, but also forest passages, valleys and high hills where the received signal level is degraded;
- near suburban area—up to 2.5 km, where the RSSI level of the received packets is in the range of -110 to -130 dBm; regardless of the shorter distance, in this area,

the strong attenuation of the signals is due to the nearby dense forest massifs and high hills;

- near urban area—up to 1 km, where the RSSI level of the received packets is high and is in the range of -100 to -110 dBm; signal attenuation is mainly due to buildings.

An SDR-based analyzer (RTL2838UHID receiver and HDSDR software tool) was used to monitor the signal spectrum and sideband emissions [21]. The measurement made is for one frequency channel for one end device sideband emission—Figure 9.

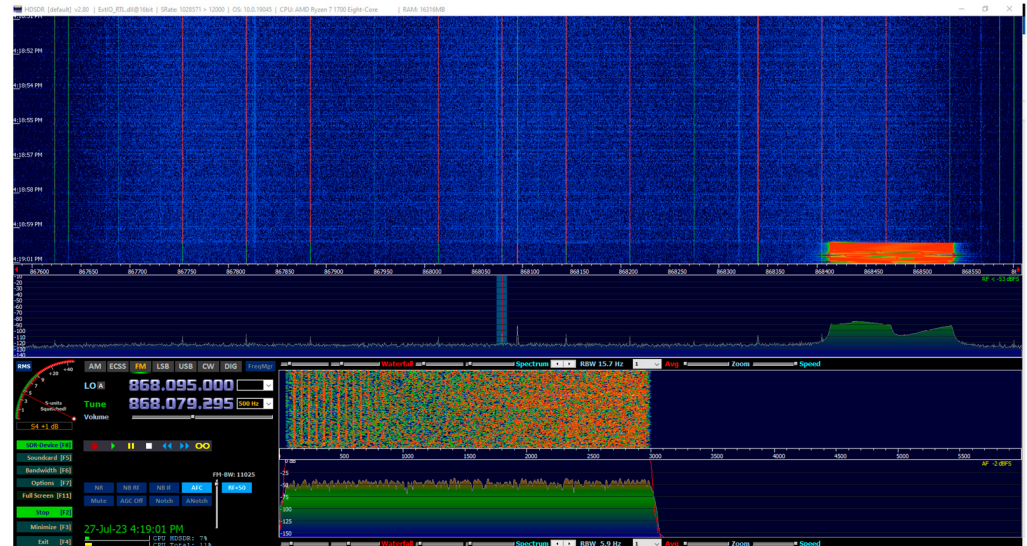


Figure 9. Monitoring the spectrum of the LoRa signal for one transmitted message.

As can be seen from the waterfall diagram of the signal spectrum shown in Figure 9, no spurious side emissions are observed when transmitting at the end device, and the main signal energy is concentrated in the transmission frequency band from 868.1 to 868.9 MHz.

4. Conclusions

The experimental results of the studies conducted with the implemented LoRaWAN gateway show that LoRaWAN technology can provide reliable communications both indoors and outdoors in a populated urban area (Stage 1), depending on the urban architecture and building layout. This also determines the long range of the network and the required quality of radio coverage in such an area. Studies conducted in an urban environment in the presence of nearby buildings—the area of the University Campus 2 of the TU-Gabrovo prove that the signal level at all measurement control points is above the receiver sensitivity threshold, and to create more severe conditions, the LoRaWAN gateway is located indoors on floor 2 of the building.

The studies carried out in the conditions of complex terrain in and around the town of Pavel Banya show the successful applicability and effectiveness of the technology in both urban and non-urban conditions. The results are experimentally proven and take into account the influence of the parameters of the end device, LoRaWAN gateway, feeder lines, transceiver antennas, etc.

The software and hardware components and tools used enable the construction of a low-power wireless communication platform that is scalable, flexible, and versatile with respect to the variety of different applications and end devices that can be integrated into it.

The specific signal processing and modulation used in LoRaWAN networks ensures error-free and robust data transmission for both indoor and outdoor scenarios. Nevertheless, the possibility of improving, optimizing, and extending the range of applications by further modifying the modulation parameters, especially in fixed and mobile end device scenarios, can be explored as future work.

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