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LORA AND LORAWAN TESTS IN THE ASPECT OF CRITICAL INFRASTRUCTURES

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Research article

Abstract: IoT technologies are also increasingly used in critical infrastructures. One of the most used Internet of Things (IoT) communication technologies is LoRaWAN. This communication protocol provides an opportunity to design large-scale, low-power systems. Due to the robustness of the communication, it is especially suitable for ensuring stable data connections in extreme terrain and environmental parameters. Our research aims to determine the data transmission distance under different, extreme environments, as well as the radio parameters that characterize data transmission. Based on the measurement results, it is possible to indicate in which cases and in what way the LoRaWAN can be applied in the aspect of critical infrastructures.

Keywords: LoRa, LoRaWAN, CIP, Network Test, Interference Measurement.

Introduction

Critical infrastructure (CI) is a system component of any service, device, facility, or system and its services, which are essential for performing vital social tasks, national security, the maintenance of the economy, and public safety and health. These infrastructures are essential for health care, the security of the population and property, the provision of economic and social public services, and the country's defence, and the failure of which would have significant consequences due to the lack of continuous performance of these tasks (Wolters Kluwer, 2012; CISA, 2019; European Commission, 2006).

In Hungary, ten sectors have been separated in the critical infrastructure category (NDGDM Hungary, 2020). The U.S. Guide to Critical Infrastructure Security and Resilience 2019 identifies 16 critical infrastructure sectors (CISA, 2019). The sectors covered by the Hungarian and American critical infrastructures are shown in Fig. 1. Similar and identical sectors can be found in both cases. It can be seen that the U.S. contains a more detailed classification.

Critical Infrastructure Protection (CIP) refers to activities designed to mitigate or neutralize a threat, risk, or vulnerability to ensure a critical system's function, continuous operation, and integrity (Wolters Kluwer, 2012; Vertos, M. et al., 2018; CISA, 2019). The importance of CIP is gaining prominence due to the effects of global warming and increased cyber-attacks (Salimi and Al-Ghamdi, 2020; Bruijn and Janssen, 2017). However, the effects of the 2020 COVID-19 pandemic, which has brought health to the forefront, must not be forgotten either (Franchina, 2021).

What is the relationship between IoT technologies and CIP? Looking at the applications of IoT solutions, it can be seen that they are found in the critical infrastructure sectors and industry or everyday life. LPWAN (Low-Power Wide Area Network) solutions are a significant part of IoT technologies. Essential LPWAN communications are NB-IoT, LoRaWAN, Sigfox, and LTE-M; 40 % of the market is dominated by LoRaWAN technology (IoT Analytics, 2020a). Therefore, our research focuses on examining LoRaWAN technology from different aspects. The main application areas of IoT: manufacturing, transport, energy, healthcare, agriculture (IoT Analytics, 2020b).

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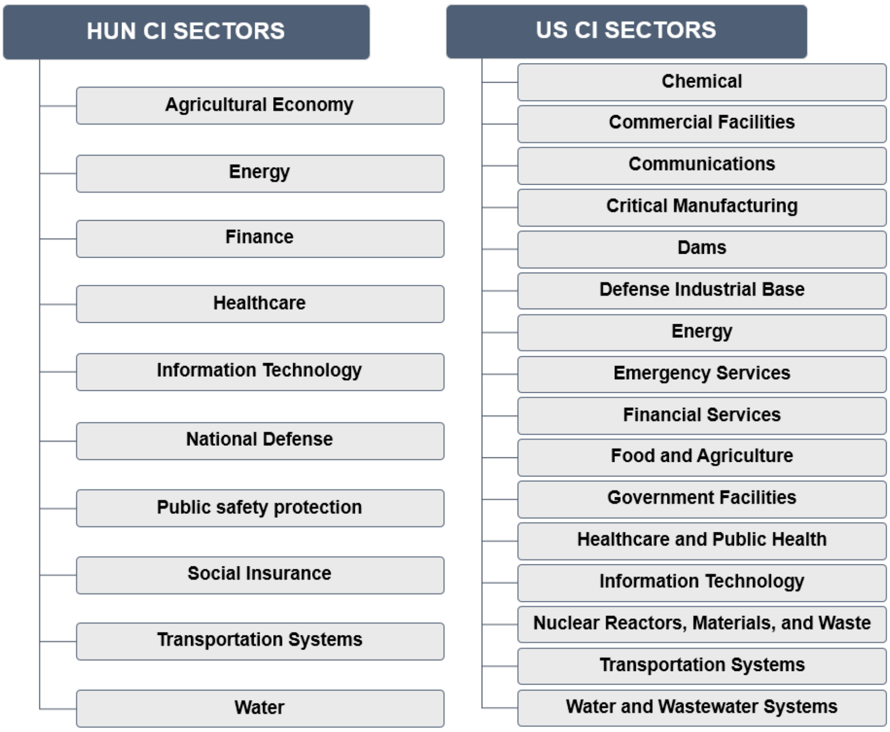

Fig. 1 Hungarian and American CI sectors

At the beginning of our paper, we provide a brief overview of LoRaWAN technology, highlighting the relevant features. The technical basics are needed to understand the measurements and evaluate them. The results of other research on LoRaWAN measurements were also examined. The methods follow the Introduction and a short technology summary.

For utilities, the benefits of IoT assets do not need to be presented. There are also several solutions for sensors and actuators that increase the quality and stability of care. Outages can be prevented; processes can be automated and promptly detect errors. IoT solutions require fewer human resources, reducing the number of people and saving organizations costs. The use of IoT technologies is also a considerable advantage in CIP. However, it should be added that in addition to the benefits, it also carries risks that, in some cases, call into question applicability and require regulation.

Our measurements cover different areas. The paper describes the results of the measurements made in the built-up urban area with LoRaWAN. Part of the research was preparing and evaluating the measurement performed on the Hungarian LoRaWAN service provider network. The study includes a description of the test environment designed to interfere with LoRa communication and the measurement results. The results and evaluation of two unique measurements are also presented. One such measurement deals with the communication of a LoRa device placed underwater. The other measurement examined the communication of a LoRa device placed in a safe. The measurements were checked several times and in case of doubtful results. In the case of measurements, we tried to get as many measurement points as possible and send a message so that the measurements could be repeated as much as possible. Based on the results of the measurements, the paper also contains recommendations. The study concludes and provides suggestions for possible further research.

Overview of LoRa and LoRaWAN

Various IoT technologies are used in many fields today. One of the most commonly used communication is LoRaWAN. Its popularity is due to the fact that it enables long-range connections with low-energy consumption, as the name implies. LoRa and LoRaWAN do not mean the same thing. LoRa is practically the modulation method that devices use to communicate wirelessly. Semtech developed this protocol. LoRaWAN is based on LoRa, which enables network communication.

There are some rules to follow when using LoRa. In Hungary and Europe, the devices can be used in the 433 MHz and 868 MHz industrial (EU433 and EU868), scientific, and medical (ISM) frequency

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bands, but the 868 MHz band is most often used. Other continents and areas use a different frequency band defined by the LoRa Alliance. The great advantage of ISM bands is that they can be used freely, but it is determined how often and with what fill factor the devices can communicate on them. Devices can transmit up to 14 dBm (~ 25 mW) of power and operate at 125 kHz or 250 kHz bandwidth (BW). In this case, this means a fill factor of 1 %. For LoRaWAN, private networks can be set up, but some rules to follow.

The network topology of LoRaWAN is star-of-stars. Any end node can connect to any nearby gateway that transmits the data to the server. If multiple gateways receive the packet, it will not be added to the database more than once. Avoiding packet duplication on the server-side is solved. The classic network consists of the following elements: node(s), gateway(s), a network server(s), application server(s).

The Spreading Factor (SF) indicates the Over-the-Air (OTA) time of the data. The fastest-sending speed is SF 7 and the slowest is SF 12. A greater distance can be achieved with the same environmental parameters if we increase the value. Bandwidth allows specifying the wide frequency spectrum along which the device transmits. This value can be selected from 125-250 kHz. Sensitivity increases with a higher value. SF12 at 250 kHz results in 250 bps, but SF7 at 125 kHz results in 5470 bps. The coding rate is also settable: it expresses the size of the error correction code at the end of the packet relative to the rest of the packet. The LoRaWAN data rate depends on the spreading factor, bandwidth, and code rate.

LoRaWAN devices can be divided into classes like Class A, Class B, and Class C. Class A consumes the least power because the device can only receive data after sending a message. The rest of the time, it is in low power mode. Class A devices are most commonly used. Devices in Classes B and C consume more energy than those in Class A, and more (or continuous) receiving windows are available. Therefore, devices in this class are already used by actuators.

The technology overview is based on the LoRaWAN specifications (LoRaWAN Specification V1.0, 2015; LoRaWAN Specification V1.0.3, 2018, LoRaWAN Specification V1.1, 2017).

Related work

The research community has published several review studies of LoRaWAN, most of which summarize technical information (Noura et al., 2020; Sinha, 2017) regarding LoRa and LoRaWAN (first group). A small number of measurements appeared in the second group, which examined communication disturbance, primarily by shielding techniques or jamming overload. The second group of publications examines information security issues and reliability but focuses primarily on information security (Eldefrawy et al., 2019). The third group includes studies describing applications and associated functional measurements. The third group includes measurements that examine the data transmission distance for the application or different environmental parameters. Publications in the first group usually do not contain independent measurement results.

The record for the furthest data transmission was set at 766 m on 13 July 2019 (The Things Network, 2019; LoRa Alliance, 2019). The peculiarity of the result is that the node was lifted by a balloon into the air to a height of several kilometres. By contrast, our measurements are made on the ground, not in the air.

The number of papers for underwater measurements is relatively low. Measurements were made with an end node placed 30 cm underwater in a garden pond (Cappelli et al., 2020). The SF value was changed in the measurement setup, and the ratio of SNR, RSSI, and lost packets was examined (Dala et al., 2021). Another study deals with underwater- and surface-communication-antenna design. Six metres of distance is reported for underwater measurements and 160 m and 300 m for water-surface measurements.

No paper describing measurements in a safe box was found during the literature review.

The French company Kerlink, whose main activity is the production of LoRaWAN gateways, describes three main areas in which the technology is applied to protect critical infrastructures (Kerlink, 2021). Each is related to the infrastructure engineering area. The first area is smart airports, the second is smart railways, and the third is smart ports. Examples of typical applications include the monitoring of ageing materials and constructions, mechanical and chemical parameters, environmental factors, and accidental environmental and human damage. In summary, application examples are highlighted for the three areas centred around monitoring tasks.

Our measurements were determined based on a review of related work and case studies. A description of the measurements and evaluation of the results are provided in the next section.

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Results and discussions

Coverage measurement in a housing estate

Nowadays, many elements of big cities can be considered critical infrastructures in which LoRaWAN devices and systems are mainly used for monitoring purposes. A private LoRaWAN network has been set up to perform metropolitan environmental measurements. There were different gateways in the established network during the measurement to make comparisons based on the measurement results.

The measurement aimed to examine networks' coverage between reinforced concrete buildings and the radio parameters of the communication. The measurement examines the communication between a gateway and an end node. The gateways were on the balcony of the second floor of a panel house. The transmitter was a Chipcad Micromite LoRaWAN + GPS device. The transmitter moved continuously around the panel house and in the nearby forest while sending GPS coordinates.

- Microtik wAP + R11e-LR8 LoRa Gateway module (A):
  - Outdoor gateway;
  - Antenna: Collinear antenna, 10 dBi;
  - Maximum reception sensitivity: -137 dB SF12 (MikroTik, 2020).
- Tracknet TBGW10 (B):
  - Indoor gateway;
  - Antenna: internal PCB antenna;
  - Maximum receive sensitivity: -140 dB SF12.
- Kerlink WirnetTM iFemtoCell (C):
  - Indoor gateway;
  - Antenna: LoRa® swivel antenna, 3 dBi;
  - Maximum receive sensitivity: -140 dB SF12.

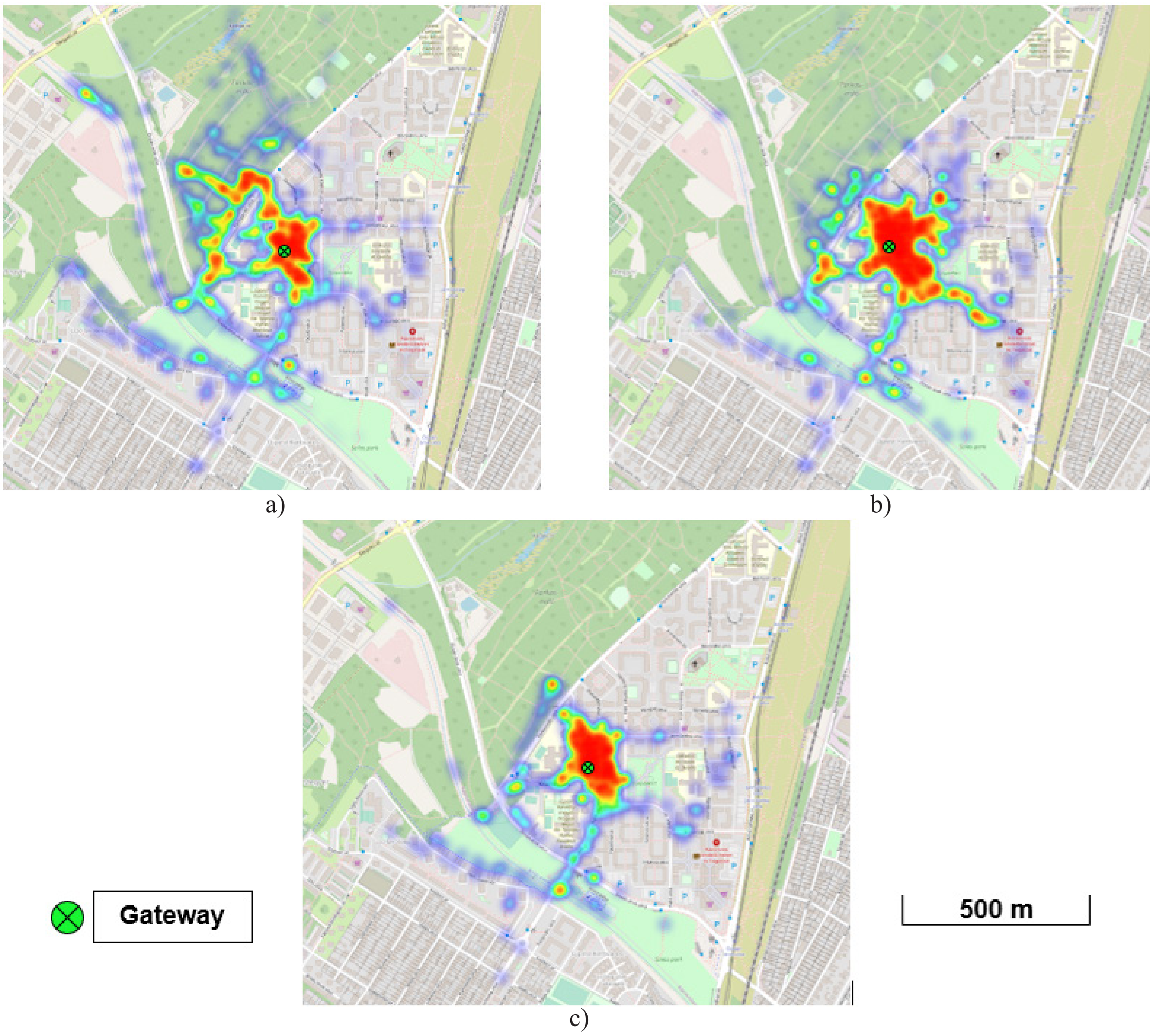

Fig. 2 Mikrotik Gateway; a), Tracknet Gateway; b) and Kerlink Gateway; c) RSSI heat map

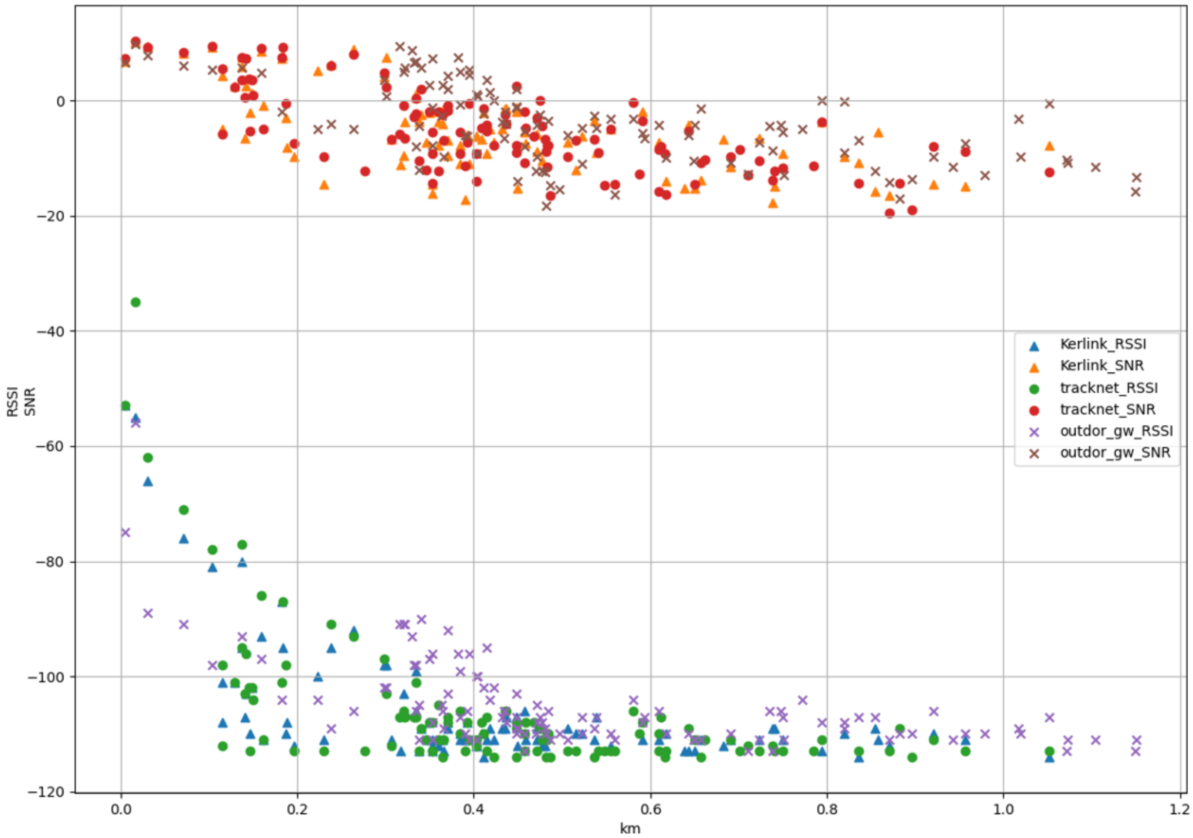

Fig. 3 Representation of RSSI and SNR values per gateway as a function of distance

Three different gateways were tested during the measurement. Messages sent were received by all three gateways. The heat map shows the number of different gateways that could receive the same messages. Red-blue spots indicate areas covered and the number of messages received (the more messages received, the redder the color). Fig. 2 shows the results of the three gateway measurements in a heat map. Red colour indicates more frequent data transmission, while bluish shades indicate less frequent data transmission. In the 0-400 m environment of the gateways, despite the reinforced concrete building blocks, the number of lost packets was deficient, and the communication took place within radio parameters that could be considered adequate (Fig. 2). Moving away from the gateways, the number of incoming messages decreases and RSSI and SNR values deteriorate, as Fig. 3. shows. The outdoor (Microtik wAP) device proved the most reliable of the three gateways. The properties of the two indoor gateways can be improved if the factory antenna is replaced. The measurement results show that the LoRaWAN communication can be used with high efficiency at a distance of 1 km in a densely populated urban environment.

Measurements on the Hungarian LoRaWAN service provider network

Antenna Hungária has the largest LoraWAN network in Hungary. The advantage of their system is that it can be used free of charge for up to 10 devices for research and development purposes. Setting up a private network can be costly, so using a provider's LoRaWAN network can be effective. The measurement aimed to determine the network coverage in our country, in the Budapest area and in general. The measurement requires at least one LoRaWAN end-node with which the appropriate registration and activation steps have been performed in the service provider system. Two GPS-LoRaWAN transmitters were also used to measure Chipcad Micromite GPS LoRa MOTE, ACSIP EK-S76GXB.

Fig. 4 shows the areas traversed by GPS devices. The measurements affected several critical locations in the Hungarian capital. The measurements locations were Budapest University of Technology and Economics, Petőfi Bridge, Óbuda University, Keleti Railway Station, Városliget, Nyugati Railway Station, Árpád Bridge, and priority public

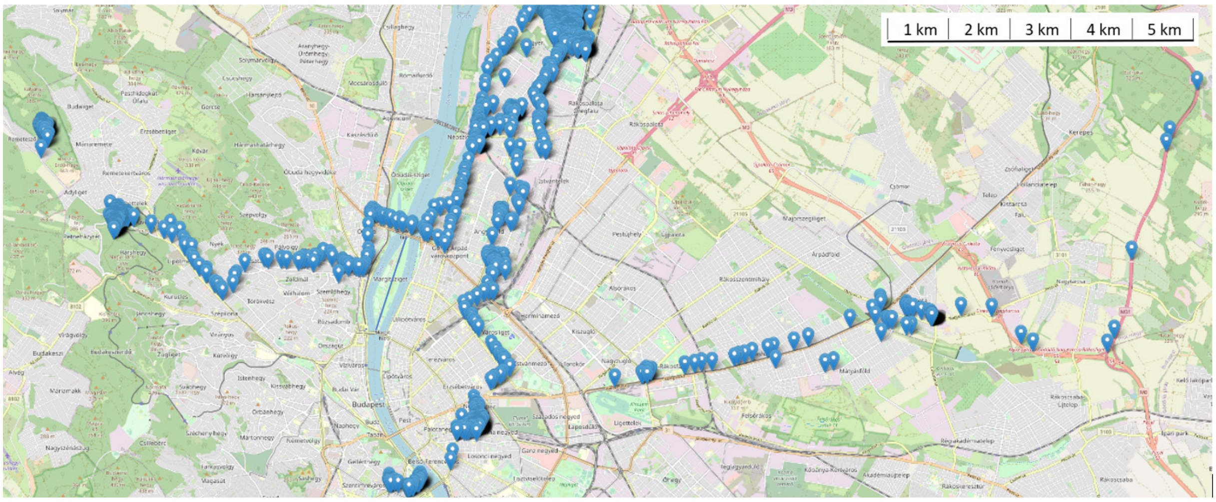

Fig. 4 Areas visited in Budapest during the measurement

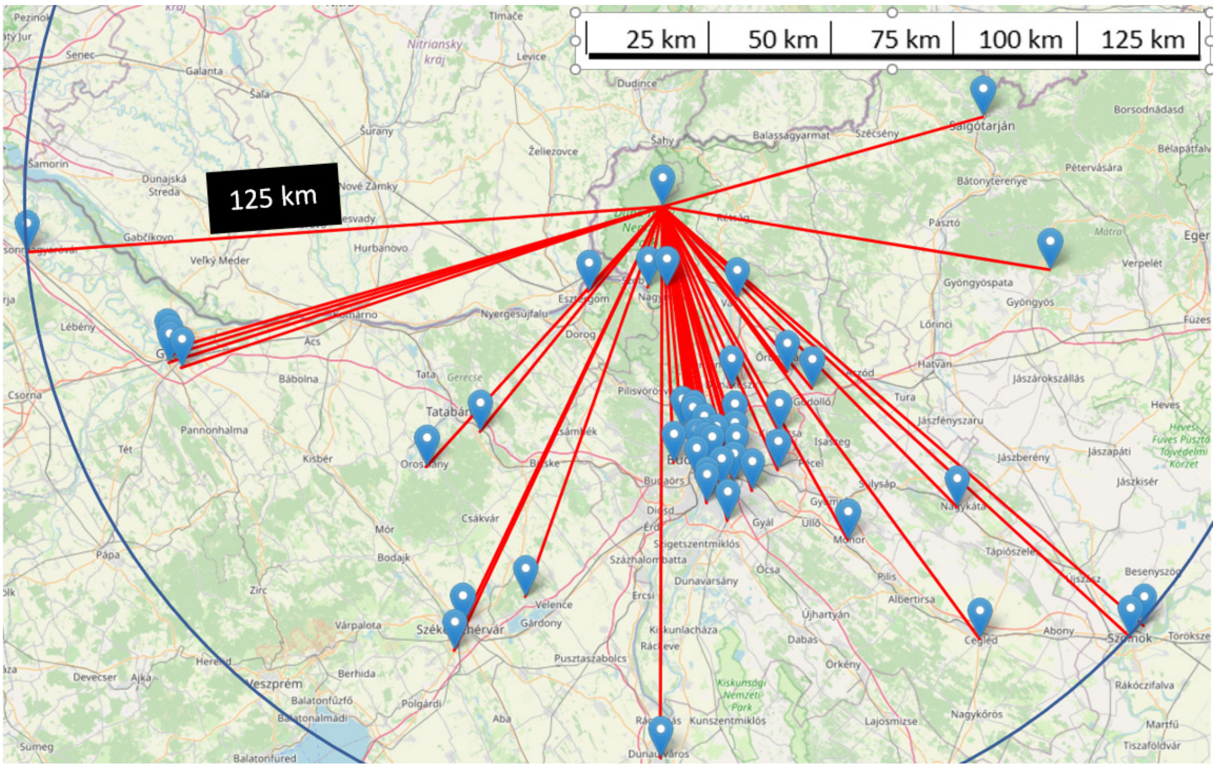

Fig. 5 Measurement from Csóványos

transport lines. Communication was stable at key traffic locations. Unfortunately, during Budapest's measurement, it was impossible to determine the quality of the communication from the metro underpass to the ground because GPS data is not available underground.

Csóványos is the highest point of Pest County, 939 m high, a popular hiking destination. The results of the Csóványos measurements are shown in Fig. 5. Pins indicate the gateways that received the sent messages. Service gateways located in the surrounding big cities were available up to 50 km away. In the case of Budapest, it can be observed that several gateways were available.

During the service provider measurements, the most significant data transmission distance between Abasár and Debrecen was measured; it was 125 km. 125 km is ten times the data transmission distance of 10-15 km, which is typical of a less populated area with LoRaWAN communication protocol. The topographic conditions between Debrecen and Abasár are shown in Fig. 6.

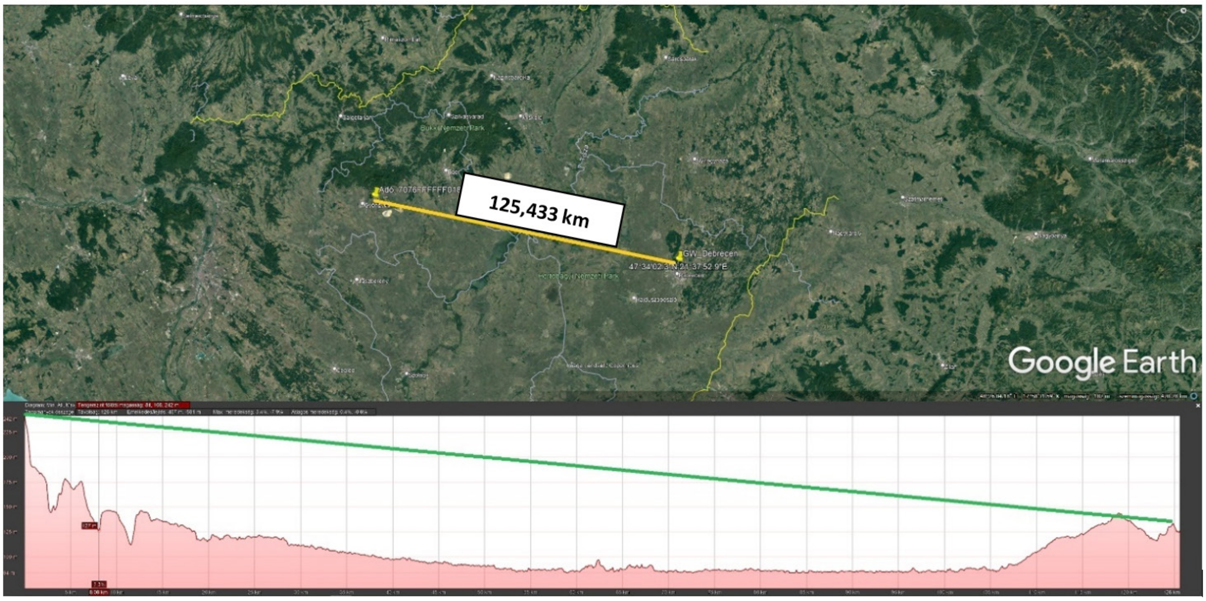

Fig. 6 125 km data transmission distance on the Hungarian LoRaWAN service provider network

Interference measurement

The purpose of the interference measurement was to examine the extent to which LoRa communication could be interfered with and whether data transmission between the two devices could be blocked. The measurement was performed at three different Spreading Factors to determine precisely at what speed and how much the communication could be disturbed. The first step was to set the SF value, place the transmitter next to the receiver and the jamming device, and send 25 packets. The transmitter was then placed farther and farther away from the receiver by repeating the data transfers. The chirp signal that was used as the interference signal was emitted with a power of ~20 dBm and at speeds of 1 Hz and 1 kHz. The distance between the receiver and the jammer was 0.06 m, and the distance between the transmitter and receiver varied from 0 to 4 m. Meanwhile, the average RSSI and SNR of the reception and the Packet Error Rate (PER) can be stored. The measurement set-up is shown in Fig. 7. The devices that were used during the measurement are as follows:

- Receiver (B-L072-LoRaWAN Discovery board);
- Transmitter (Nucleo STM32WL55J);
- Jammer (HackRFOne with SAW filter and ADL5611 LNA).

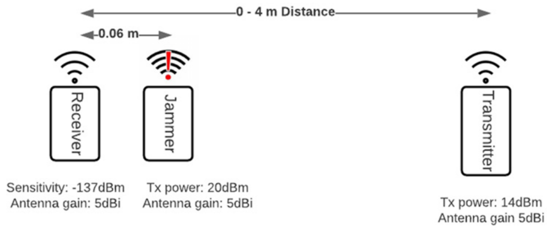

Fig. 7 Interference measurement set-up

The measurement results are shown in Fig. 8. Increasing the distance during data transmission without interference decreases the RSSI value for all three SFs, whereas the SNR value remained nearly the same for different spaces. Without interference, the packet loss rate on the property image was 0 % regardless of the (examined) span. During the measurement, it was found that if the data transmission was disturbed by interfering with the data transmission with a slower (1 Hz) chirp signal, the slower (SF12) data rate mode proved to be more sensitive. In the case of a faster (1 kHz) chirp signal, the reverse was observed. The communication proved to be more sensitive to interference at the faster (SF7) data rate. In any case, it can be said that the data transfer speed will slow down to some extent, and it will be more challenging to transfer the data stably.

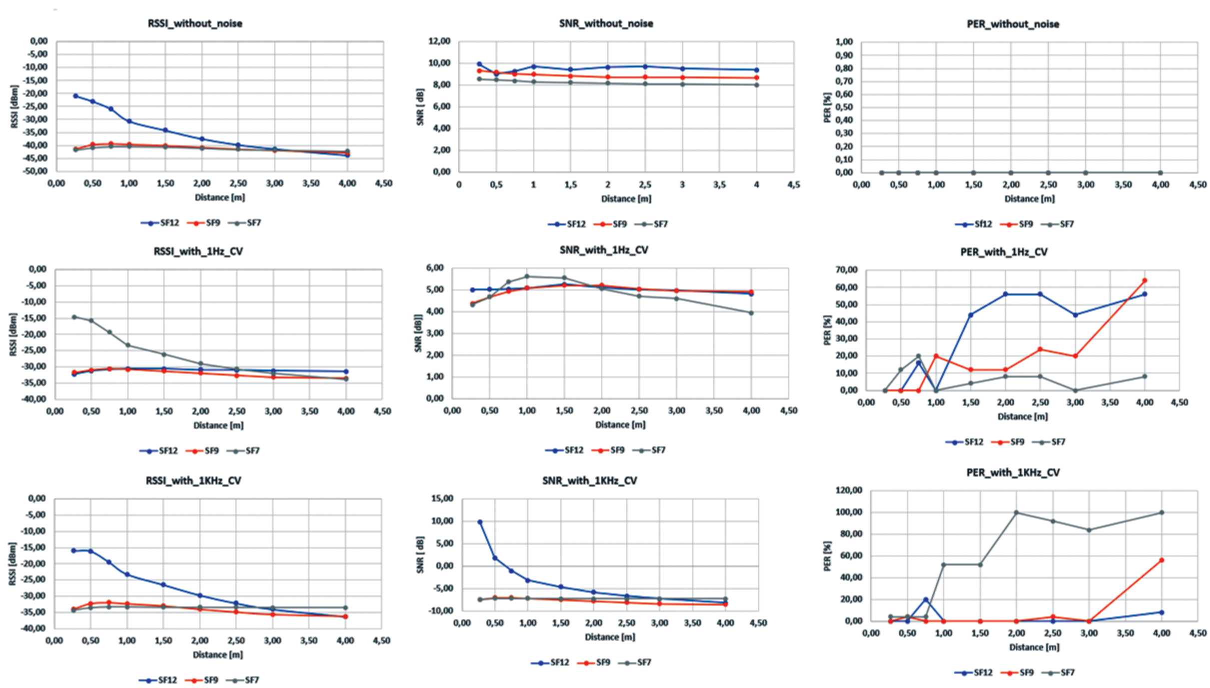

Fig. 8 Interference measurement results

There was also a 100 % packet loss during the measurements, which in the case of 1 kHz interference, with the transmitter set to SF7. The distance used between the jammer and the receiver is relatively tiny, placed right next to it. In an actual application, this would mean that physical access to the immediate environment of the receiver is required. In a well-designed application, close interference to receivers is challenging to implement. In conclusion, LoRa as a modulation technology can be used with high reliability for point-to-point transmission in critical infrastructures because it is difficult to disrupt.

Safe measurements

Safes may also require wireless communication due to parameter monitoring. Therefore, our research also examined the use of LoRaWAN devices in a safe box. The measurements were performed in an old stainless steel safe with walls approximately 10 cm thick. The transmitter was placed in the safe. Measurements were performed both with the safe door open and with the safe door closed. From the results of the two measurements, the effect of the structure on the data transmission of LoRa communication can be determined. The Nucleo STM32WL55J served as a transmitter with a power of 14 dBm, and the receiver was a B-L072-LoRaWAN Discovery board. The measurement setup is shown in Fig. 9.

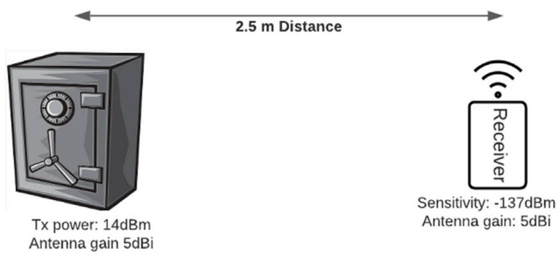

Fig. 9 Safe measurement set-up

The measurement results are shown in Fig. 10. The results show that for SF7 and SF8, the rate of lost packets when the safe door is closed is 100 %. In the case of SF9-10, the proportion of lost packets is 20-30 %. Using SF11 and 12, almost all sent messages arrive successfully.

SF11 and SF12 are recommended for applying LoRa and LoRaWAN communications in safes based on the measurement results. The safe has a metal construction and acts as an excellent RF insulator, so choosing a low data rate is highly recommended. In a similar environment, a distance of more than a few meters between the transmitter and receiver is not recommended.

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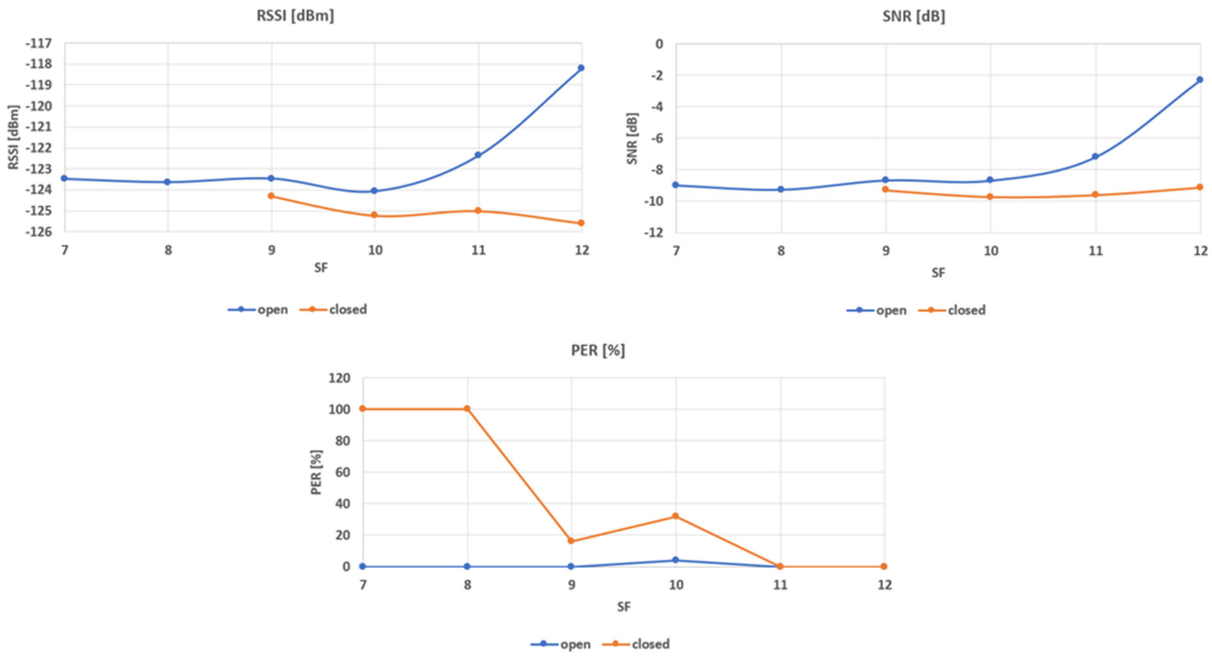

Fig. 10 Safe measurement results

Underwater measurement

Research has also looked at how water affects LoRaWAN communication. The findings can be important for applications where we want to place devices underwater and transmit data that way. Water is a denser medium than air, so it may be essential to consider the radio parameters under which data can be sent with LoRa. Such an application can be a water-quality monitoring system for natural stagnant and running water or even a reservoir.

The measurement was carried out by immersing the transmitter in water (pond) and observing how many packets could be received from different depths and transmission speeds. The receiver was on the waterfront. We used the STM32WL55j Nucleo board during the measurement, which was used with maximum transmitter power (~14 dBm). The receiver was a B-L072-LoRa Discovery board with a sensitivity of -134 dBm. The two devices' energy balance was around 148 dBm.

Fig. 11 above shows the measurement results. The y-axis shows the attenuation in dB. The distance between the transmitter and receiver is 45 cm for blue columns, while for the orange column, this distance is 60 cm. The first two columns show the calculated value, which gives the amount of air attenuation in the free space at a given distance. The other columns show the measured attenuation of the water at different spreading factors.

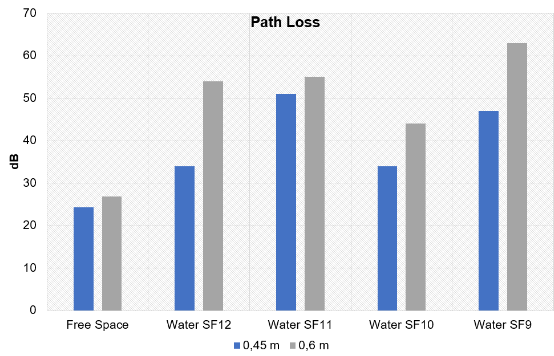

Fig. 11 Underwater measurement results

The expected results were observed during the measurement, and it can also be stated that communication can be ensured up to a certain depth. It was not possible to test a deeper dive due to the lake's depth during the measurement. On the other hand, it can be stated that the device can be used for the applications, as mentioned earlier, but higher attenuation must be taken into account.

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Conclusion

The results of a comparative measurement of the gateway in an urban, prefabricated environment demonstrated that LoRaWAN communication could be used with high reliability in the setup test environment. Reinforced concrete buildings are residential areas and industrial plants, factories, sewage treatment plants, and hospitals that can be built in similar constructions, are classified as critical infrastructures. The coverage measurement results show that the service provider network in Budapest has sufficient coverage to implement CIP applications. As the measurements were also examined from a moving vehicle, LoRaWAN can be used even on public transport: bus, tram, train, trolley. The results of the jammer interference measurement showed that if a well-designed application or network is established, the communication can interfere only to a minimal extent, which proves the stability of LoRa communication. It can also be pointed out here that further measurements related to interference could be made, but there are already many examples in the research papers. The results of the safe box measurement show a positive direction, even though it has an exceptionally high shielding capacity due to the physical design of the box. Other widespread wireless communications would not have worked in such an environment. In terms of application, the directive is appropriate for safe-keepers and similar structures, such as a container or a safety deposit box designed to protect medicines. During the water measurements, data transmission was achieved at a depth of 0.6 m, with a point-to-point LoRa connection. The results predict that communication can be used to monitor reservoirs, but further measurements are recommended for more accurate findings.

Several areas can be highlighted for future work. It is recommended to take measurements in subway underground and underground metro sections that are not GPS based. From the measurement results, it would be possible to outline the LoRaWAN coverage of the Budapest metro line from the service provider's point of view. Because several previous measurements have been made that examine LoRaWAN communication with balloon-released nodes, this is not considered a new direction. Safe measurements should be supplemented with cases where the distance between the safe and the receiver unit is more extended than was in our current measurements, and LoRaWAN should be used instead of point-to-point LoRa communication. The former is similarly valid for water measurements. Other valuable results can be obtained for water measurements by placing the end-node deeper below the water surface or in a large natural lake. In addition to our test areas, in connection with the protection of critical infrastructures, the examination of coverage and signal propagation in the field of stadiums and stations can be highlighted, among other measurement areas.

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