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LORAWAN SOLUTIONS IN THE COVID-19 ASPECT

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Review article

Abstract: The rapid growth in the number of solutions using the Internet of Things (IoT) technologies is not new. The number of products using LoRaWAN technology is also growing. The spread of COVID-19 has, among other things, led to the evolution of IoT devices related to virus control. Several LoRaWAN products related to COVID-19 are being developed. LoRaWAN COVID-19 solutions are mainly grouped around the following topics: contact tracing/proximity detection, health equipment or device data transmission, and signalling/calling systems. Contact tracing has a crucial role in healthcare institutions, government agencies, and vital factories and among these institutions' workers. In the case of a medical device, data transmission simplifies administration, reduces the volume of contact, and allows contactless monitoring. In critical situations, healthcare institutions need to create temporary nursing areas. Mobile signalling or call systems may be required in these areas. The research examines LoRaWAN COVID-19 solutions and their relationship to critical infrastructures.

Keywords: LoRaWAN, COVID-19, Data Collection, Tracking, Signalling.

Introduction

As is well known, unfortunately, the whole world is experiencing a period in which a pandemic is hampering our daily lives. This epidemic is caused by a coronavirus called COVID-19. The WHO declared a pandemic situation on 11 March 2020 (WHO, 2020). The coronavirus affects the lives of all of us. We need to change our general habits and daily routines and follow new rules. The change has been not just in behaviours. New methods and technological solutions have also come to the fore to prevent the spread of the virus (Singh et al., 2020; Swayamsiddha and Mohanty, 2020).

Technological solutions such as IoT technologies have mainly served convenience, but this seems to be changing today. The applied solutions can now play an additional, complementary role and have also become necessary. Authorities, companies, healthcare institutions, and educational institutions have begun to apply technological solutions to control the virus. There are situations when the rules and their observance alone are not enough; technical help and support is needed in some cases. In these cases, IoT technologies come to the fore. Several COVID-19-related IoT applications have been born, and numerous developments are ongoing (Kamal et al., 2020; Shubina and Ometov, 2020). This is especially true for LoRaWAN technology (LoRa Alliance, 2020a).

What LoRaWAN solutions for COVID-19 have come to the fore in the market? What challenges does this technology face? This research seeks to answer these questions, focusing on LoRaWAN products and solutions developed for the coronavirus and collecting these products and systems. Following the introduction, the basic features of LoRaWAN technology are described, followed by some typical application examples. Then, the issues that can be resolved with LoRaWAN technology are summarised, and applications have been developed for this purpose. With all this in mind, the paper groups the LoRaWAN solutions for coronavirus. The study closes with conclusions and a summary of possible future research directions.

Materials and methods

The paper starts with an overview of the essential characteristics and parameters of the LoRaWAN technology based on the LoRaWAN specifications, and then the competitors of the technology are examined and compared based on statistical and literature data. Following this, the main areas of application of LoRaWAN technology are gathered through a literature review and examination of

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specific products. A summary of LoRaWAN COVID-19 solutions is based on the rules to be followed, prevention and protection measures, and divided into three groups. In determining the application areas, the properties of the published products and the manufacturer's recommendations were considered.

The following measurements were made to verify the viability of the LoRaWAN technology (protection against COVID-19). An application designed to measure coverage and network parameters. Respectively, a simple application for measuring environmental parameters, based on the feedback of which ventilation events can be controlled and scheduled. The measurements were performed at Obuda University[1] in Building B of the Tavaszmező site, affecting rooms and rooms that function as an office, practice room, or laboratory. The application, the tools used, the conditions and parameters of the measurement, and the results will be explained later.

Background

Technology background

LoRaWAN technology is increasingly widely used IoT, specifically LPWAN (low-power wide-area network) technology (Noura et al., 2020). LoRaWAN products and solutions have also appeared in everyday life. The technology's popularity is mainly due to its properties; it makes it possible to build long-range networks. Large-scale in an urban environment should be understood as a few kilometres; in less populated areas, the data transmission can cover up to more than 10 kilometres. Communication in Europe takes place mainly on the 848 MHz frequency band, which belongs to the ISM (industrial, scientific and medical) band, free-to-use frequency (LoRaWAN Specification V1.0, 2015; LoRaWAN Specification V1.0.3, 2018). It should also be emphasised that the technology provides an opportunity to set up private networks (Penã Queralta et al., 2019), but network providers are still available (LoRa Alliance, 2020b). In addition to the considerable data transmission distance, the end-nodes' low power consumption should be emphasised, which results in up to 10 years of operation from a single battery (Borsos, 2020). LoRaWAN is a network communication based on LoRa radio communication. Its advantageous properties include high interference immunity, which makes it suitable for use in adverse environmental conditions, such as reinforced concrete buildings, underground garages, and hilly areas, both outdoors and indoors (Borsos, 2020). The data transfer rate and the maximum size of the payload are relatively low, so they are mostly used in measurement data acquisition solutions. The maximum data transfer rate is around 50 kbit/s, and the maximum size of the payload is just over 200 bytes (LoRaWAN Specification V1.0, 2015; LoRaWAN Specification V1.0.3, 2018).

Communication is bi-directional, and it is also possible to send confirmed or unconfirmed data messages (LoRaWAN Specification V1.0, 2015; LoRaWAN Specification V1.0.3, 2018). In a classic LoRaWAN network, the end nodes are connected to gateways that communicate with the network server, which is connected to the application servers (LoRaWAN Specification V1.0, 2015; LoRaWAN Specification V1.1, 2017; LoRaWAN Specification V1.0.3, 2018). As mentioned earlier, a LoRaWAN network can be built privately, independent of service providers. Finally, it should be mentioned that identifiers and keys are used in communication; communication is encrypted. The LoRa Alliance is responsible for the elaboration and development of the LoRaWAN specification (LoRa Alliance, 2020b).

Looking at IoT Analytics 2020 data around LPWAN technologies, LoRaWAN and NB-IoT can be highlighted (IoT Analytics, 2020). Both technologies are present in over 40 % of the market.[2] A third technology, Sigfox, is also worth highlighting, with a 6 % market share. A summary of the characteristics of the three technologies is shown in Tab. 1 (Abbas et al., 2020.; Lavric et al., 2019; Mekki et al., 2019; Sinha et al., 2017).

NB-IoT is the only one of the three that does not use a free-to-use frequency. In terms of data rate, Sigfox has a very low bit rate of only 100 bps. For all three technologies, bidirectional communication is implemented in a half-duplex way. The NB-IoT's interference immunity is the lowest, so it is the most sensitive to disturbances and noises. The data given for coverage are maximum values calculated under ideal conditions. With its 50 km high, Sigfox stands out compared to the other two technologies. In terms of encryption and authentication, it already stands out negatively, as the feature is not currently implemented. Of the three technologies, only LoRaWAN allows the deployment of private networks. The cost of setting up an NB-IoT network is the highest, considering all network participants; the second most expensive is the Sigfox network, and the cheapest is the LoRaWAN.

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[2] NB-IoT 44 %, LoRaWAN 41 % market share.

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Tab. 1 Features of NB-IoT, LoRaWAN and Sigfox

Aspect	NB-IoT	LoRaWAN	Sigfox
Market (2020)	44 %	41 %	6 %
Frequency (Europe)	LTE licensed	868 MHz (unlicensed ISM)	868 MHz (licensed ISM)
Bandwidth	200 kHz	125 kHz, 250 kHz	100 kHz
Data rate (maximum)	250 kbps	50 kbps	100 bps,
Data direction	Half-duplex	Half-duplex	Half-duplex
Payload (maximum)	1600 bytes	222 bytes	12 bytes
Interference immunity	Low	Very high	Very high
Range (maximum)	10 km	15 km	50 km
Encryption, authentication	Yes (LTE encryption)	Yes (AES128)	Not implemented
Private network	Not allow	Allow	Not allow
Module Cost	~5 $	~10 $	~2 $
Gateway/Station cost	15000 $	100-2000 $	5000 $
Spectrum cost	>500 $ million	Free	Free

Given all these qualities, the three technologies have their advantages and disadvantages. On the other hand, low deployment and maintenance costs, high interference immunity, proper encryption and authentication, data transmission distances of up to 15 km, relatively high data rates, and payload size support the use of LoRaWAN technology.

Applications

In the previous subsection, the basic features of LoRaWAN technology are described without claiming completeness. Features that are relevant to the topic have been highlighted, and the application areas will be brought closer. The technology is mainly used in cases where relatively small data need to be frequently transmitted over distances of kilometres, or frequent access to the collector may be problematic.

Four well-separable but interrelated application areas are environmental monitoring, tracking, utility monitoring and metering, and city management (Khutsoane et al., 2017; Adelantado et al., 2017; Luvisotto et al., 2018; Miles et al., 2020; LoRa Alliance, 2020c). It should be noted that other types of grouping are also possible. The paper highlights examples that may be related to critical infrastructures. Environmental monitoring includes solutions that perform some environmental parameter measurement: temperature-humidity measurement, air pollution measurement, forest fire detection, earthquake detection, avalanche detection, stone explosion detection, and critical downtime detection. Tracking solutions are made for vehicles, people, containers, and animals in different designs; their application can also be related to protecting critical infrastructures. The area of utility monitoring and consumption measurement has also been highlighted, which is essential for maintaining vital social tasks' smooth performance. The fourth priority area is LoRaWAN applications related to urban management. City management applications can include public lighting monitoring, control, traffic monitoring, counting, parking monitoring, waste, and sewerage management.

In the previous areas, areas for which LoRaWAN solutions and systems were all developed have been highlighted. These solutions are all related to critical infrastructures or their protection. These applications were already present in pre-coronavirus times. However, the coronavirus has created new issues and challenges, which have been addressed using LoRaWAN technology (LoRa Alliance, 2020a; LoRa Alliance, 2020c; Semtech, 2020a). The next section discusses these. It should be emphasized that these are not necessarily new technological developments, but the placement of existing ones in a new context.

LoRaWAN COVID-19 solutions

Issues, challenges

This section's central question is the following: what new challenges and issues have come to the forefront concerning the coronavirus? The first primary area is the proper distance. People should keep a safe distance from each other and avoid social contacts to prevent and reduce the spread of the virus (Thu et al., 2020; Nguyen et al., 2020). It is essential to track and investigate the contacts. It is essential to monitor and follow how many people are in each building, room, area, and possibly to know who they are. Unfortunately, the number of coronavirus patients treated in the hospital increases, so it has become necessary to monitor patients and medical devices remotely. More frequent and operational cleaning is also essential in the fight against the virus and providing appropriate environmental parameters such as adequate air quality. How can LoRaWAN technology help solve these challenges? What new uses have emerged, and which groups of areas do they affect? These application examples are described below.

Healthcare

The first studied area is healthcare. IoT technologies to increase the efficiency and quality of care are not a novelty in healthcare. It was also named after IoMT, meaning the Internet of Medical Things. The IoMT systems' architecture typically consists of installed, mobile or wearable devices, gateways/collectors, a cloud-based service, and display/application components. The devices can be sensors, actuators worn by the patients or can be made in an installable version or in a form that can be fitted to some equipment. The data sent by them is collected, processed, evaluated, and then displayed. It is then possible to perform interventions either automatically by interveners or in person by the nursing staff. (Nguyen et al., 2020)

The spread of COVID-19 has changed a few things. Healthcare workers fighting on the front lines of care are exposed to extremely high stress, and the number of tasks has also increased; in addition, their physical exertion has increased as a result of wearing protective equipment. There are several tasks that can be easily automated and monitored remotely, even without a personal presence. These solutions have become necessary for healthcare professionals in order to focus on critical tasks that require a personal presence.

In connection with the protection against the coronavirus, several health improvements have been made, which are related to remote monitoring and help doctors and nurses' work. A gas valve monitoring and respiratory sensor (LoRa Alliance, 2020a) have been developed specifically for this purpose, with the help of which a coronavirus patient's respiratory parameters can be monitored remotely, and body temperature measurements can also be monitored (Semtech, 2020c) for viral patients.

In healthcare, not only is it essential to monitor and maintain a patients' body temperatures regularly, but this is also true for a variety of assets; blood, vaccines, and medicines (SimplySense, 2020) must be stored at the right temperature and humidity. In cases where healthcare workers are exposed to constant, extreme stress to reduce the burden, automatic monitoring of the temperature of these assets can also be of great help. LoRaWAN applications have also appeared for such purposes, specifically to the coronavirus. Another pivotal point is the management of oxygen cylinders. They created a solution for two tasks using LoRaWAN technology to track the bottles and the other to monitor their fill level and indicate depletion (Cavagna Group, 2020).

Due to the viral situation, temporary hospitals and nursing areas are being set up. Portable nurse call devices have been developed for these situations with LoRaWAN communication. Nurse callers are devices that can signal to the nurses when the patient has a problem or needs something. There are several alternatives to this, from a simple "one-touch" solution that can only give one type of signal to complex designs that can even be used to specify a call's urgency or intent (Klemets and Toussaint, 2016). These nurse callers can be found in most average wards; however, they are not provided in temporarily established care areas. Mobile nurse call devices with LoRaWAN technology have been developed for these cases (LoRa Alliance, 2020a; Semtech, 2020a; CareBand, 2020). Thanks to technology, the devices can communicate wirelessly, allowing them to be easily placed in the right places temporarily. Additional solutions also have been implemented that can provide additional assistance to providers. Such additional functions include body temperature measurement, local light, and sound signalling. In addition to the basic functions, bed occupancy signalling and monitoring are also possible at the application level. There are also system-level solutions in which healthcare workers wear wearable devices that can also be used to send an alert, receive an alert, or track a contact. In Spain, a similar solution is used in an institution designated for care for coronavirus patients (Actility, 2020a).

Industry

The paper addresses the industry issue, solutions designed to protect workers and maintain business continuity. These applications and products are mainly grouped around tracking. Even before the virus, LoRaWAN technology had been widely used in tracking solutions for data transfer tasks (LoRa Alliance, 2020c). Solutions are grouped around the following areas: contact tracing, person tracking, proximity detection, signalling, zone indication, presence monitoring, cleaning monitoring and scheduling, and maintenance monitoring and scheduling (LoRa Alliance, 2020a).

Does the question arise as to why the mobile phone application proposed by governments is not appropriate to perform contact tracing tasks? Why is it necessary to develop alternative solutions when most people have smartphones and those different communication options? The answer is simple: There are areas and buildings where the use of smartphones is prohibited or not possible or otherwise challenging. Such an area could be a construction site, a factory site, a research centre, an infection or explosive area, or other places subject to special, strict regulations.

These solutions usually include not only LoRa communication but also BLE (Bluetooth Low Energy). These are usually integrated solutions that offer a complex system for tracking, contact monitoring, and presence detection. With other solutions, it is possible to indicate if two people are too close to each other or have left the designated area for their work or if more than one person is within a virtually designated area. In terms of application, it can also be used for presence cleaning scheduling, although this may also be true for maintenance scheduling. Such systems' general structure is the LoRa nodes of the LoRaWAN network alternately with BLE + LoRa gateways to which BLE devices are connected. These BLE devices are usually small in size and wearable in design. BLE beacons may have a panic button and a light source for signalling or a speaker or vibrator motor. (CareBand, 2020; NNNCo and Microshare, 2020; Actility, 2020b)

Solutions are characterized by complexity and inversion based on their application properties. Many manufacturers offer multi-technology (devices or systems that integrate multiple communication technologies) end-to-end solutions. It should be noted that similar systems existed in the past, but the coronavirus has accelerated their development and increased their markets (LoRa Alliance, 2020c).

Community

The third group is the community LoRaWAN coronavirus solutions, but it should be noted that all the solutions described so far are of some interest to the community. These solutions are used in public, communal places, and buildings such as schools, stations, plazas, squares, and offices. These products are related to measuring body temperature (Semtech, 2020c), counting pedestrians (LoRa Alliance, 2020d), and monitoring the environment (Semtech, 2020b; Eleven-x, 2020).

Standalone outdoor and indoor body temperature meters have been developed specifically for use in communal areas that transmit measured values via LoRaWAN networks. The benefit of this is that body temperature data is available in real-time without human intervention and presence; interventions can be made based on these.

Pedestrian counter solutions serve several purposes. One goal is to monitor attendance and headcount. The other goal is to determine the change in people's habits due to the virus. This is also true for monitoring paths, visiting individual areas, or monitoring time and activity in that area (RS-Online, 2020). In addition to LoRa, these solutions often use Wi-Fi communication for the task (Kerlink, 2020), taking advantage of Wi-Fi-enabled smartphones, tablets, and laptops on people.

Also, LoRaWAN environmental and air monitoring solutions have been developed for community and residential use to protect against coronavirus. These are very similar in design to the solutions described earlier. Here, too, the goal is to ensure clean air of the right quality and schedule cleanings and disinfection.

Measurements and results

One of the buildings of the University of Óbuda was selected as the testing site, as mentioned earlier. An educational institution is involved in both the community and the workplace with the coronavirus. One measurement group is whether the local service provider LoRaWAN network is available in the building since further developments do not make sense. It could have been measured with a private gateway, but measurements have been made for it before. A local service provider was chosen because access is provided free of charge for development and research purposes, thus reducing costs. More complex measurements were performed in two rooms, and additional rooms were tested for network coverage. The test also implements a simple air quality monitoring that can be used later when students return to the educational institution.

Measurement conditions

End node

The end node consists of four central units: microcontroller STM32L0+, sensors (temperature, humidity, CO_2), LoRaWAN module, and battery. This setup was applied to each measurement. The block diagram and photo of the prototype are shown in Fig. 1.

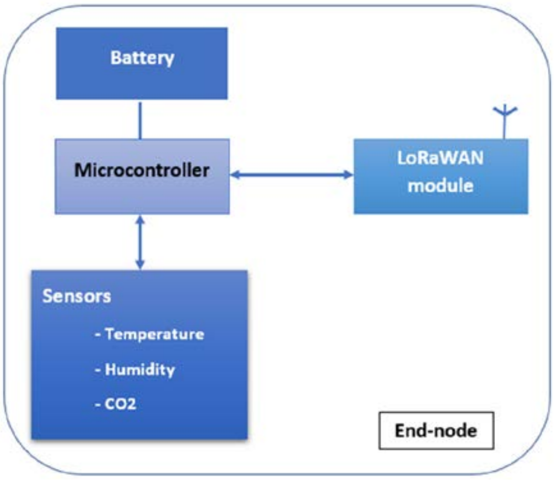

Fig. 1 End-node block diagram

The microcontroller is an extra-low-power STM32L0+ type. The LoRaWAN module is a Microchip RN2483 device. Temperature and humidity were measured with the common DH22 sensor module. The CO_2 sensor is an MQ-135 integrated air quality meter.

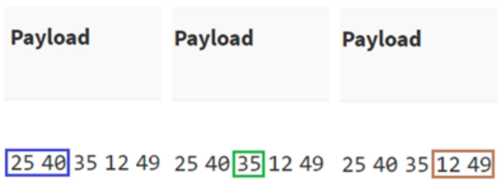

Fig. 2 Message payload

The software running on the microcontroller was written in embedded C language. After the peripherals are initialized, the LoRaWAN network parameters are configured, and then periodically, the sensor data is retrieved, processed, and transmitted. During the tests, small messages were sent, precisely 5 bytes. An example of the message structure message is shown in Fig. 2.

The temperature is framed in blue. The first byte is the whole part, and the second byte is the fraction. Humidity is indicated in green by 1 byte. The CO_2 value is displayed in 2 bytes framed in brown. In addition, it should be noted that the payload can be sent in hexadecimal, but the values were transmitted in decimal during the tests.

Network

The structure of the network used during the measurement is shown in Fig. 3. A local service provider network has been used, which includes a network registration on loriot.io. The site allows configuring network parameters (as far as free developer registration allows) and monitoring network communication. Another helpful option is to set the output where the WebSocket is set.

Application, user interface

The application is made in Node-RED. The created program includes a graphical user interface and the storage of data needed to evaluate the measurements (RSSI[3] and SNR[4] values with date and frame counter). The prepared program is shown in Fig. 4.

[3] Received signal strength indication.

[4] Signal-to-noise ratio.

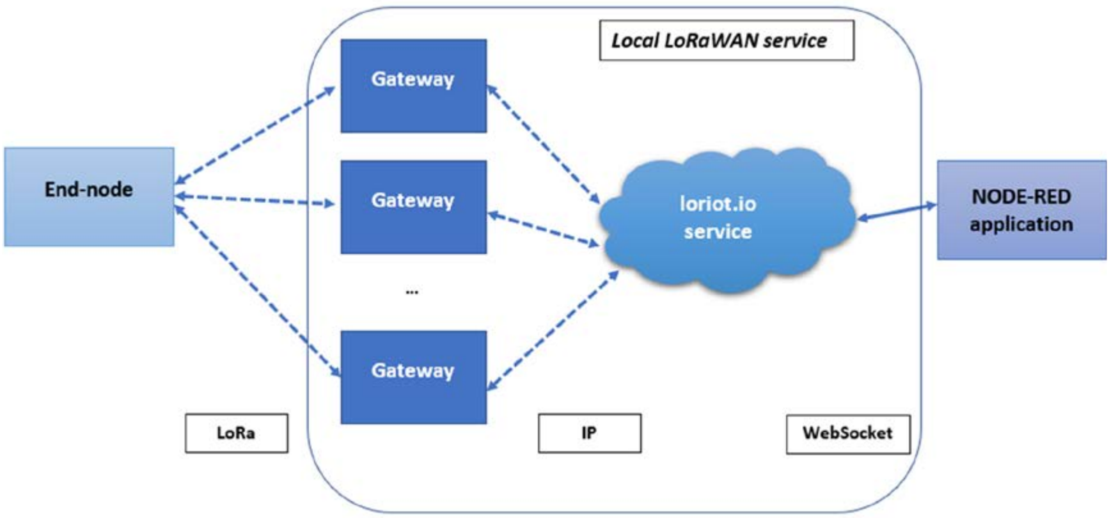

Fig. 3 Network

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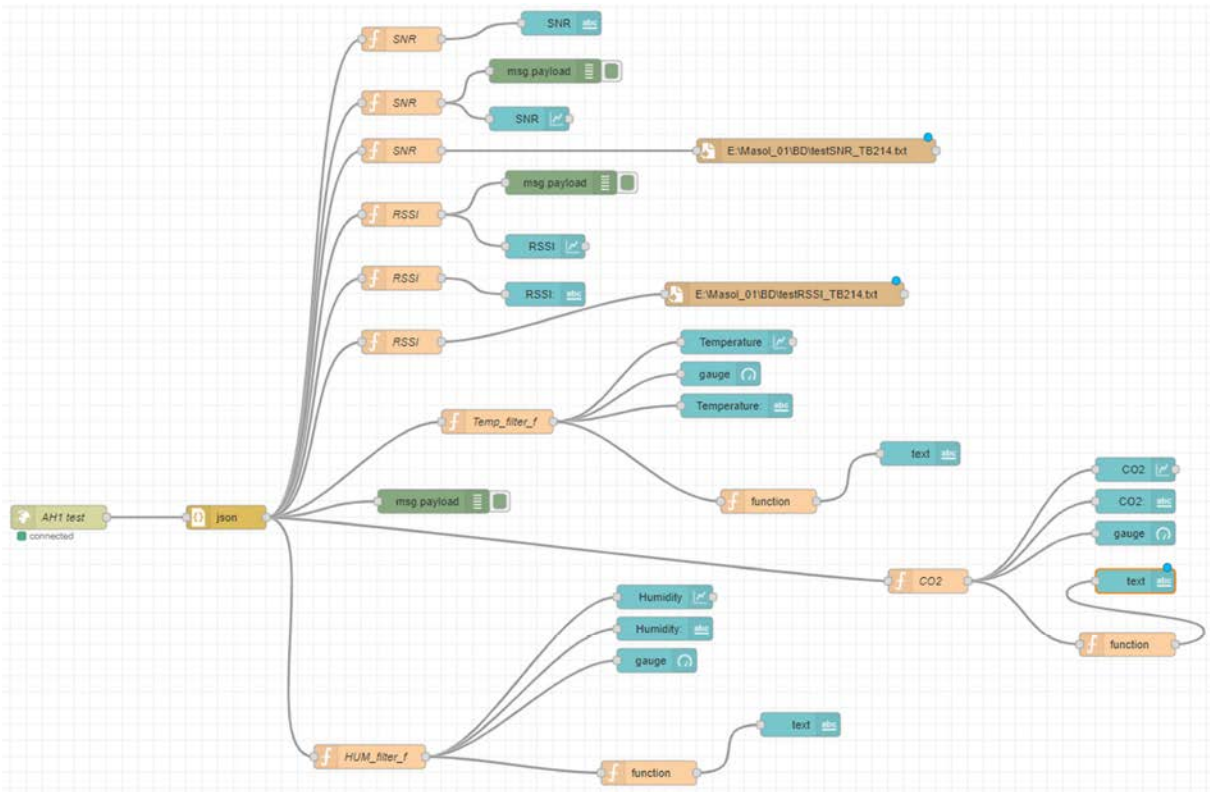

Fig. 4 Node-RED program

The RSSI, SNR, temperature, humidity, and CO_2 values are displayed graphically in the user interface, and the latest values are also displayed separately. Temperature, humidity, and CO_2 values are also displayed in a gauge. In the case of the gauge display, colour scales have been set to distinguish between optimal, too low, or high values. Values that are too high are displayed in red; it is also displayed in the form of a text message whether the data is appropriate from a health point of view. The limits were set based on the 2018 National Indoor Air Quality Action Plan (InAirQ, 2018). The user interface display is summarized in Tab. 2 and the dashboard is shown in Fig. 5.

Coverage tests

During the test, the data transfer was set to 980 bps, which is the 3rd lowest setting option. This option was chosen because the purpose of the study was not to determine the best communication parameters. The purpose of the measurement was only to see if the network was available in the designated rooms. In addition, it should be noted that the measurements were made specifically in areas where a university Wi-Fi network is not available. An obvious solution could be to build future systems on an existing Wi-Fi network, but LoRaWAN technology could be an alternative solution since it is not available.

Tab. 2 User Interface parameters

	Graph			**Gauge**					**Unit**
	Min.	**Max.**	**Period**	**Min.**	**Max.**	**Colors**			
RSSI	-200	0	24 h	-	-	-	-	-	dBm
SNR	-50	50	24 h	-	-	-	-	-	dB
Temperature	0	40	1 h	0	40	< 18.5	18.5-25.5	> 25.5	°C
Humidity	0	100	1 h	0	100	< 43	43-67	> 67	%
CO_2	0	2000	1 h	0	2000	< 1200	1200-1800	> 1800	ppm

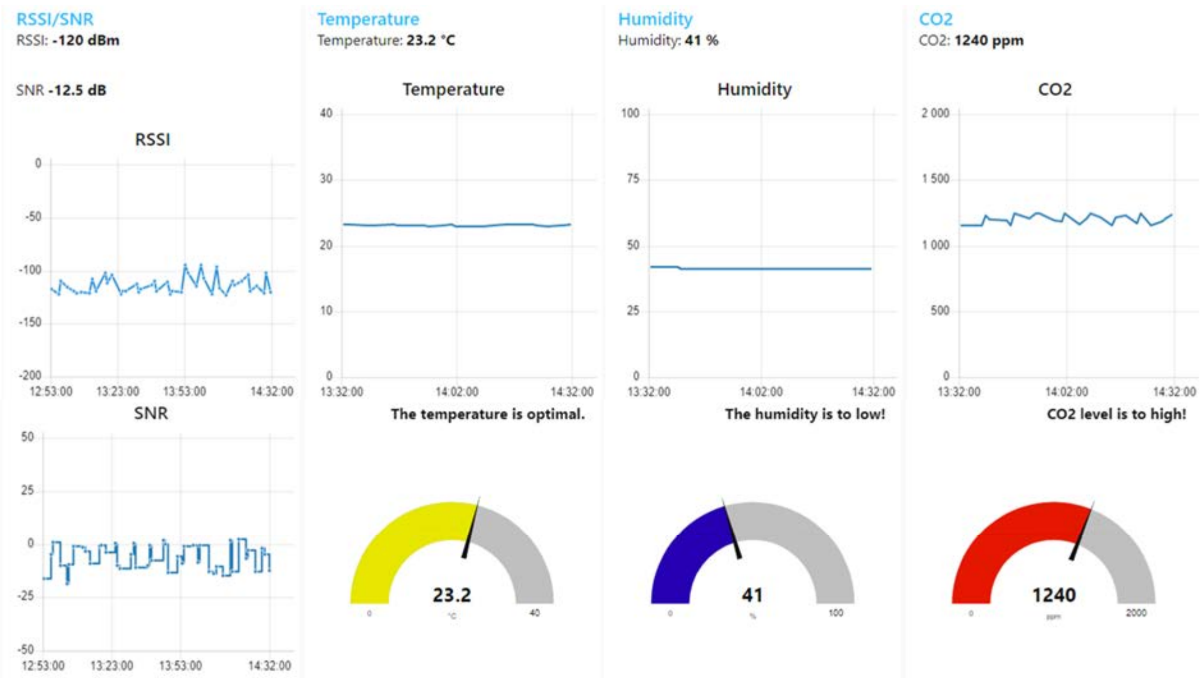

Fig. 5 Graphical User Interface

The measurement affected four building levels (upper floor, 1st floor, 2nd floor, 2nd floor gallery level), corridors, ten rooms (workshop, office, laboratory). Before summarizing the measurement results, it should be noted that a successful message was sent from each area examined. The results of the measurements in two rooms are highlighted: TB.2.214., TB.2.216.G. Room TB.2.214 is a computer laboratory located on the 2nd floor, where 12 + 4 students can be accommodated and one or two lecturers. Room TB2.216.G functions as a measuring room and office with seating for six people. 100-100 messages were sent from both rooms. The measurement results are summarized in Tab. 3 and Fig. 6.

From the summarized results, in both rooms, one hundred messages were successfully sent out of a hundred messages. This is probably due to good network coverage, a properly chosen antenna, small data, and low data rates. For room TB.2.216.G, the average RSSI value is higher compared to another room, which means that the signal was stronger than the Room TB.2.214's signal. The difference is minimal, and we can still talk about relatively weak signal strength. Also, in the case of the SNR values, the values were higher in room TB.2.216.G, i.e., the signal was less damaged there. These values can be corrected by further adjusting the network parameters.

Both highlight rooms were locations where the university Wi-Fi network was not available. The application of LoRaWAN technology to prevent the spread of COVID-19, such as the monitoring of environmental parameters and the controlled scheduling of ventilation, can be implemented in the studied university environment.

Tab. 3 Coverage test result in two room

TB.2.216.G	
Bitrate	980 bps
Successful transmission	100
RSSI minimum	-123 dBm
RSSI maximum	-95 dBm
RSSI average	-111.17 dBm
SNR minimum	-20 dB
SNR maximum	-2.2 dB
SNR average	-8.287 dB

TB.2.214.	
Bitrate	980 bps
Successful transmission	100
RSSI minimum	-127 dBm
RSSI maximum	-103 dBm
RSSI average	-117.23 dBm
SNR maximum	-16 dB
SNR minimum	-8 dB
SNR average	-11.93 dB

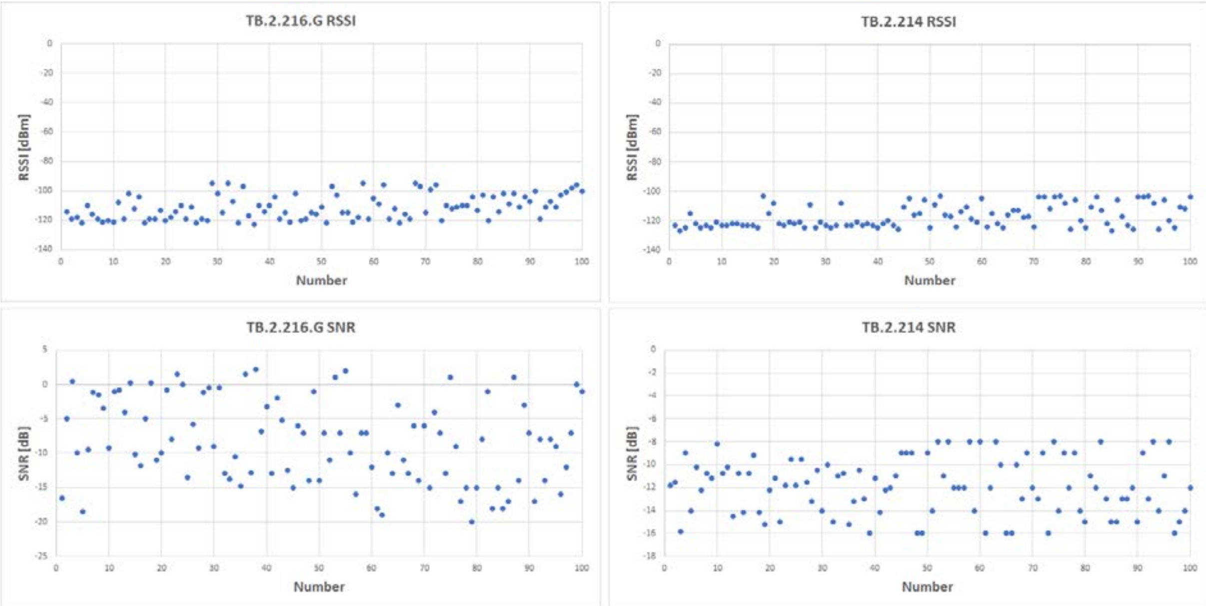

Fig. 6 RSSI and SNR values in the two room

Conclusion

Due to the new challenges posed by the coronavirus, new use cases have emerged. These solutions are mainly grouped around tracking and monitoring. The focus is on the following challenges: workers' health and safety protection, maintaining business continuity, healthcare workers and patient's health and safety protection, reducing pressure on healthcare workers, optimising patient care, and protection of persons in community territories. In short, the protection of human life is paramount.

The described solutions have been present so far; only the field of application has been re-evaluated. The range of LoRaWAN products for tracking and monitoring was quite wide even before the coronavirus. The emergence of COVID-19 LoRaWAN solutions can be traced back to three main reasons (LoRa Alliance, 2020a). The first reason is that it is possible to set up private networks so that systems can be easily installed anywhere, even at low maintenance costs. The second reason is that it is relatively easy and quick to develop new applications or possibly transform existing ones with LoRaWAN technology. The third reason is to be found in the fact that in several countries, LoRaWAN providers have made their network available free of charge, thus supporting the fight against the coronavirus.

Measurements were carried out in the university area, which confirms that it is possible to use systems using LoRaWAN communication in the affected areas. All this was confirmed by the measurement results of coverage tests. This is especially important because there is no university Wi-Fi network available in the examined rooms, which would provide a relatively simple solution. A system for monitoring demo environmental parameters with a graphical user interface has been implemented to support the measurements through the application area. In the future, the tests can be expanded by finding the optimal setting of the network parameters. Another possible direction is to develop a demo tool.

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