ICT-777137

5G-RANGE

5G-RANGE: Remote Area Access Network for the 5th Generation

Research and Innovation Action

H2020-EUB-2017 – EU-BRAZIL Joint Call

D6.4: 5G-RANGE operation for the remote area Internet access use-case

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Abstract

The 5G-RANGE network has been designed to cover different use cases, including voice connectivity, backhauling, smart farms and e-health. Although the protocol stack can be dynamically configured to cover all these different applications, the 5G-RANGE proof-of-concept has been developed to demonstrate the key requirements for voice connectivity, backhauling and smart farms applications. The demonstration of the other application scenarios would require resources that are not available in the project. This deliverable presents the description of the field test demonstration based on the proof-of-concept developed to provide Internet access and integrated Internet of Things services in remote and rural areas via the 5G-RANGE network. The developed demonstration covers an end-to-end application for providing voice and data connectivity at distances up to 50 km and Internet of Things applied to agribusiness, including a dashboard where the farmers can have access to all information collected from the fields. This deliverable describes the details of these applications.

Target audience

The primary target audience for this document is the radio access network research and development community, particularly those with an interest in mobile communication physical and MAC layers. This material can be fully understood by readers with a background in mobile wireless cellular systems, especially those familiar with 3GPP standards for 4G and 5G.

Impressum

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Executive Summary

The mobile communication networks in remote and rural areas must support a miscellanea of different applications, covering from broadband communication to remote operation of machinery in farms and mines. The mobile network must be flexible to cover long-distances, provide robust communications for control systems, tackle doubly dispersive channels at high speeds, provide low out-of-band emissions and spectrum agility for the cognitive radio operation in remote areas.

The main aim of this deliverable is to present the applications developed to demonstrate the main features of the 5G-RANGE network in field. The prototypes of the 5G-RANGE base station and consumer premise equipment have been developed to provide real-time operation and demonstrate that the main features proposed in the 5G-RANGE project can be implemented with today's technology.

The main features of the 5G-RANGE network that will be exploited in this deliverable are:

- achieving up to 100 Mbps at 50 km distance from the base station;
- fragmented and dynamic spectrum allocation;
- incumbent protection based on cognitive radio approach and precise spectrum sensing.

The setup consisting of a base station and at least two user equipment will be deployed in Santa Rita do Sapucaí, Brazil. The user equipment will be installed in different geographic locations and the key performance indicators will be evaluated, with special attention to the overall throughput for the terminal in the edge of the cell. A dummy TV station will also be used to simulate the presence of incumbent signals and the operation of the sensing and protection mechanisms. The out-of-band emissions will be measured at the input and at the output of the power amplifier.

This deliverable will also describe the solutions developed for the smart farm applications, including the integration with other technologies, such as LoRa and Sigfox. All the data collected from the sensors for different measurements in a farm environment will be processed and displayed in a dashboard developed for the 5G-RANGE demonstration. The results from the field test show that the 5G-RANGE network is an interesting and feasible solution for providing Internet communication and Internet of Things services in remote and rural areas.

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Definitions and Abbreviations

API	Application Programming Interface
BER	Bit Error Rate
BS	Base Station
CAPEX	Capital Expenditure
CQI	Channel Quality Indicator
CSI	Channel State Information
DSA	Dynamic Spectrum Allocation
DSS	Decision Support System
FSA	Fragmented Spectrum Allocation
GFDM	Generalized Frequency Division Multiplexing
GPS	Global Positioning System
IDSS	Intelligent Decision Support System
ISDB-T	Integrated Services of Digital Broadcasting – Terrestrial
ISM	Industrial, Scientific, and Medical (service band)
KPI	Key Performance Indicator
LoRa	Long Range
LOS	Line of Sight
LPWAN	Low Power Wide Area Network
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MER	Modulation Error Rate
MIMO	Multiple Input Multiple Output
MQTT	Message Queueing Telemetry Transport
OFDM	Orthogonal Frequency Division Multiplexing
OOBE	Out-of-Band Emissions
OPEX	Operating Expenses
PC	Programmable Computer
PHY	Physical Layer
PoC	Proof-of-Concept
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RA	Resource Allocation
ROC	Receiver Operating Characteristic
RTMP	Real-Time Messaging Protocol
SDR	Software-Defined Radio
SDU	Service Data Unit
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
SS	Spectrum Sensing
SUAV	Small Unmanned Aerial Vehicle
TVWS	TV White Space
UAV	Unmanned Aerial Vehicle
UE	User Equipment
USRP	Universal Software Radio Peripheral
Wi-Fi	Wireless Fidelity

1 Introduction

The 5G-RANGE network has been designed to cover different application scenarios for remote and rural areas. Two main requirements for the feasibility of a remote area mobile network are the large coverage of each cell, assuring a high number of potential users within the one cell, and the capability to exploit the vacant TV channels in a opportunistic fashion, reducing the cost of spectrum licences. These two requirements result in several KPIs (Key Performance Indicators), such as low OOBE (out-of-band emissions) without RF filter, spectrum sensing capability, DSA (Dynamic Spectrum Allocation and FSA (Fragmented Spectrum Allocation), high robustness against doubly dispersive channels and flexibility to cover different use cases.

The design of the PHY (Physical), MAC (Medium Access Control) and Network layers has considered these KPIs. Nevertheless, these requirements must be evaluated in a field test to assure that today's technology can be used to implement this challenging network. The PoC (Proof-of-Concept) developed for this performance evaluation and for the field demonstrations can cover different use cases defined for the 5G-RANGE networks. The PoC can be dynamically configured to provide Voice and Data Connectivity, Backhauling and Smart Farms applications.

The aim of this deliverable is to present the results obtained in the field tests and also describe the solution developed to demonstrate the potential of the 5G-RANGE network. This report brings details about the deployment of the network in Santa Rita do Sapucaí, the results obtained in the measurement campaign and the solutions that have been developed to demonstrate the benefits of the connectivity in a smart farm scenario.

The remaining of this document is organized as follow: Section 2 describes the methodology used for the field test demonstration, while Section 3 presents the field test setup. Section 4 shows the details about the procedures to perform the field tests, Section 5 evaluate the results obtained in the field test and Section 6 concludes this document.

2 Methodology for the Field Test Demonstration

This section presents the methodology used to test and evaluate the 5G-RANGE network system. This methodology is based on evaluating the coverage and throughput, the spectrum sensing algorithm, and the integration of the 5G-RANGE network with other technologies to provide IoT (Internet of Things) services in rural areas. Each one of these topics are described following.

2.1 Methodology for Coverage and Throughput Test

The 5G-RANGE network was specified and designed to provide connectivity to UEs in remote areas within a radius of up to 50 km, while providing data rate up to 100 Mbps at the cell edge. Trial tests were performed to verify the network operation according to these conditions. The methodology for this case consists on measuring the maximum data rate possible at a given distance from the 5G-RANGE BS, while measuring the received power level and the BER (bit error rate) at a given position. The measurement was classified as success if there was a configuration for the 5G-RANGE network that provided at least 100 Mbps with BER zeroed at the given location. The maximum distance where 100 Mbps at BER zeroed was defined as the result of this measurement campaign.

2.2 Methodology for Spectrum Sensing Test

The SS (spectrum sensing) algorithm is a key feature of the 5G-RANGE network, since it will be responsible for assuring that a given TVWS (TV White Space) can be exploited without harming TV users. The methodology used in this case consists of measuring the ISDB-T (Integrated Services of Digital Broadcasting - Terrestrial) signal, which is the digital TV standard used in Brazil, provided by a modulator. The power level of the TV signal is controlled by a continuous variable attenuator. The UEs perform the SS algorithms in 4 UHF channels and report the individual decision to the BS. A fusion algorithm is responsible to provide the final allocation decision based on the OR rule.

2.3 Methodology for Smart Farm Test

In addition to providing a low-cost network solution for rural and remote areas, the 5G-RANGE system can enable the communication of LPWAN (Low Power Wide Area Network) networks, for standard technologies like LoRa (Long Range), Sigfox, ZigBee, and other IoT technologies. The integration of these technologies to the 5G-RANGE network increases the flexibility of the solution proposed in this research project and increases its flexibility to provide other services in remote and rural areas. Several different use cases can benefit from this integration and the smart farm scenario will be exploited in more details in this report. The methodology, in this case, consisting on integrating the 5G-RANGE UE with a Wi-Fi (Wireless Fidelity) router, a LoRa BS and a Sigfox BS. Mobile terminals and IoT device compatible with these technologies will be used to demonstrate that data generate for these devices can de depicted in a dashboard, supporting farmers' decisions about the agribusiness processes. Figure 1 depicts the scenario developed for the smart farm field test.

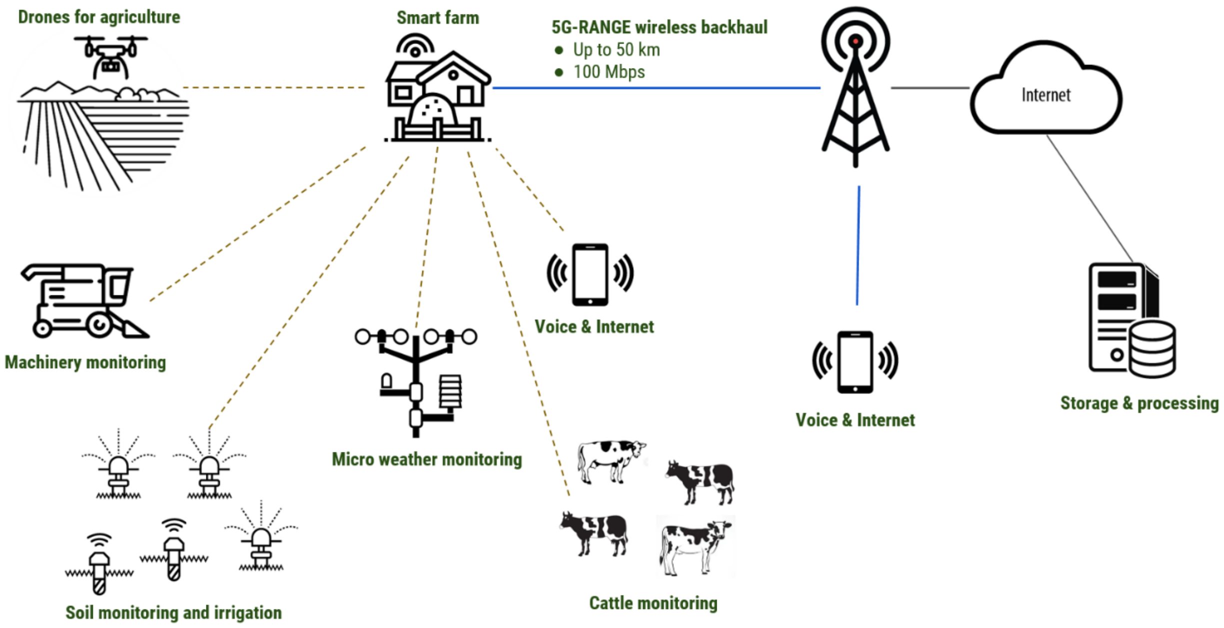

Figure 1. Description of the Smart Farm use case.

3 Description of the Field Test Setup

This section presents description of the tests and demonstrations performed in the field. Details about configurations, installations conditions, and infrastructure are shown accordingly to the topics reported in the previous section.

3.1 Numerologies for the Different User Cases

5G-RANGE is a flexible network that allows the PHY and MAC layers to be configured to cover the main requirements of different uses. Table 1 shows the different numerologies that can be applied in the 5G-RANGE PHY. There is trade-off among subcarrier spacing, cyclic prefix duration and symbol duration for achieving long-range or support high mobility can be adjusted for each use case.

Table 1. 5G-RANGE numerologies.

Num. ID	Subcarrier spacing [kHz]	Cyclic Prefix [µs]	Symbol duration [µs]	Target Range [km]	Target Speed [km/h]
0	1.875	141.7	2133.3	236,11	7
1	3.75	70.8	1066.7	118,06	15
2	7.5	35.4	533.3	59,03	30
3	15	17.7	266.7	29,51	60
4	30	8.9	133.7	14,76	120
5	30	4.4	66.7	7,38	240

From the PHY and MAC layers point-of-view, the integration among the different use cases is seamless, since the 5G-RANGE can be configured to support the different requirements at each frame. As presented in the deliverables from work packages 3, each application scenario can exploit a specific configuration in terms of subcarrier spacing, modulation order, cyclic prefix sizes, number of subcarriers and coding rate. This configuration can be done for one specific resource block, or for a set of resources blocks and it can vary from one frame to other. Wireless backhauling uses numerology 0 since mobility is not a concern in this case and high spectrum efficiency is required. For e-Health monitoring, two modes can be used. The low mobility mode, which employs numerology 1, is used for doctors to perform exams and collect data from patients in the field. The second mode uses numerologies 4 or 5 for allowing high speed ambulances to be connected to the Internet. Real-time data from the patient can then be sent to the hospital. Agribusiness application can exploit numerology 2 to provide coverage in the field where sensors installed in animals or machinery that move with low speeds. Finally, voice and data connectivity can use numerology 3 to provide Internet and voice connection for people living in rural and remote areas.

3.2 Coverage and Throughput Test

This topic provides details about the field test realized to define the maximum coverage and maximum throughput achieved with the 5G-RANGE PoC. Information about the geographical conditions and the system configuration are provided. The largest distance among the BS and the UE where a zeroed BER was measured with throughput of at least 100 Mbps was 50.5 km from each other. The 5G-RANGE PHY configuration, details of the selected location for the BS installation, and for the UE location, including their respective geographic coordinates, are shown in Table 2.

Table 2. Parameters used in the coverage and throughput field test.

Parameter	Value/specification
Operation Frequency	545 MHz
Transmission Power	12 W
Number of antennas	2
Antenna gain	9 dBi
Bandwidth	24 MHz
Modulation	256-QAM
Channel Code	Polar Code
Code rate	2/3
BS location	City: Santa Rita do Sapucaí - MG - Brazil Latitude: -22.1975366 Longitude: -45.742908
UE location	City: Campos do Jordão - SP- Brazil Latitude: -22.641398 Longitude:-45.63803

Figure 2 shows a Google Maps image with the BS location (identified as TX) and the UE location (identified as RX). This figure also shows the terrain profile of the link, along with the first Fresnell ellipsoid between the BS and the UE. It is possible to verify in the superimposed chart that the selected locations allow for LOS (Line-of-Sight) between the nodes.

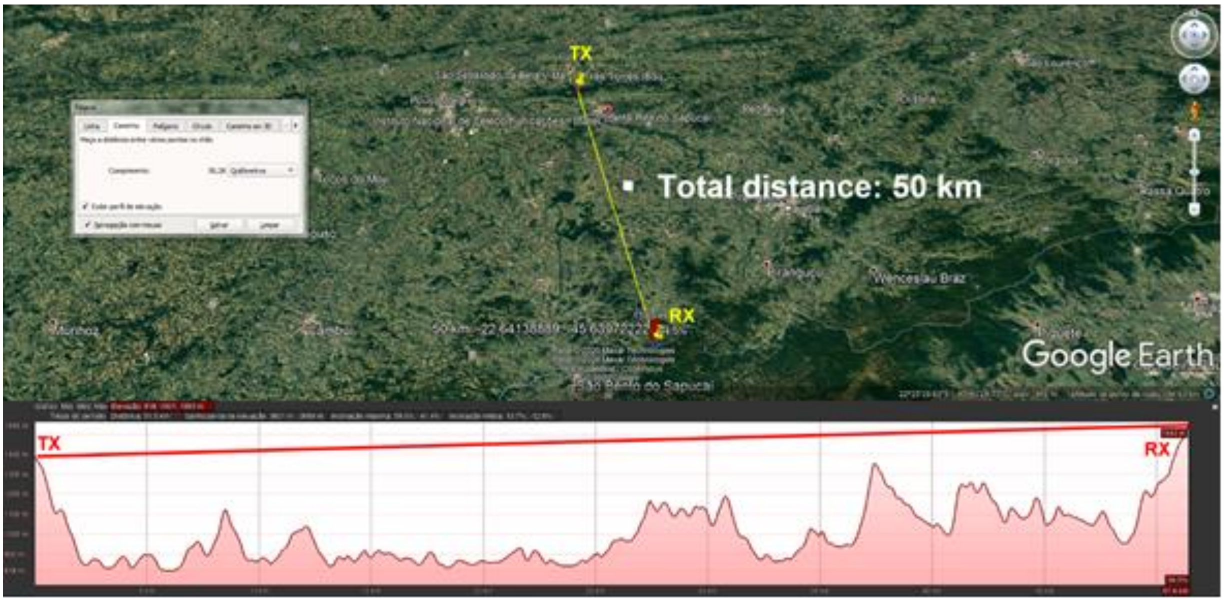

Figure 2. Location of the 5G-RANGE nodes and terrain profile of the 50 km link.

3.3 Spectrum Sensing

Figure 3 shows the block diagram of the setup used to evaluate the SS algorithm. This setup allows the evaluation of the threshold detection and TVWS allocation.

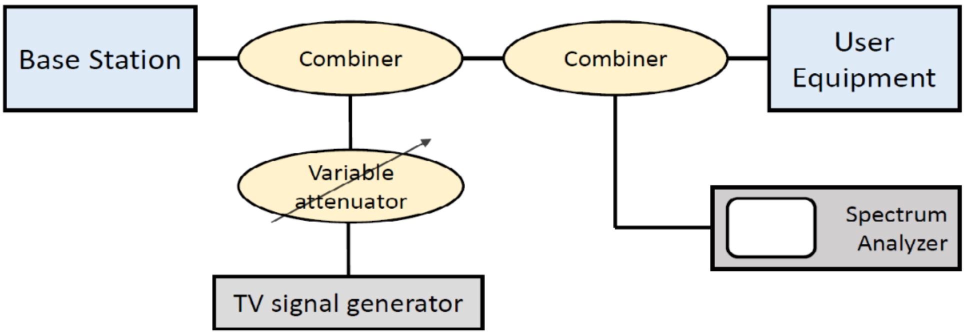

Figure 3. Block Diagram: Spectrum Sensing test setup.

The TV signal generator provides a ISDB-T signal, which is combined with the signal from the 5G-RANGE equipment through a combiner and a continuous variable attenuator. The attenuator controls the power of the TV signals, allowing for evaluation of detection threshold. A combiner on the UE side allows the signal to be applied in a spectrum analyzer, where the functionalities of the SS algorithms can be verified in the spectrum domain.

3.4 Smart Farm Edge System

Figure 4 shows the block diagram of the 5G-RANGE setup used to implement the smart farm scenario. One UE is placed at the farm headquarters where the IoT applications will be installed. The BS can be located at 50 km from the farm with data rate up to 100 Mbps. The farm UE has an Ethernet interface to supply a network infrastructure. As shown in Figure 4, this interface is attached to a network switch, allowing all IoT services to transfer data to the Internet servers.

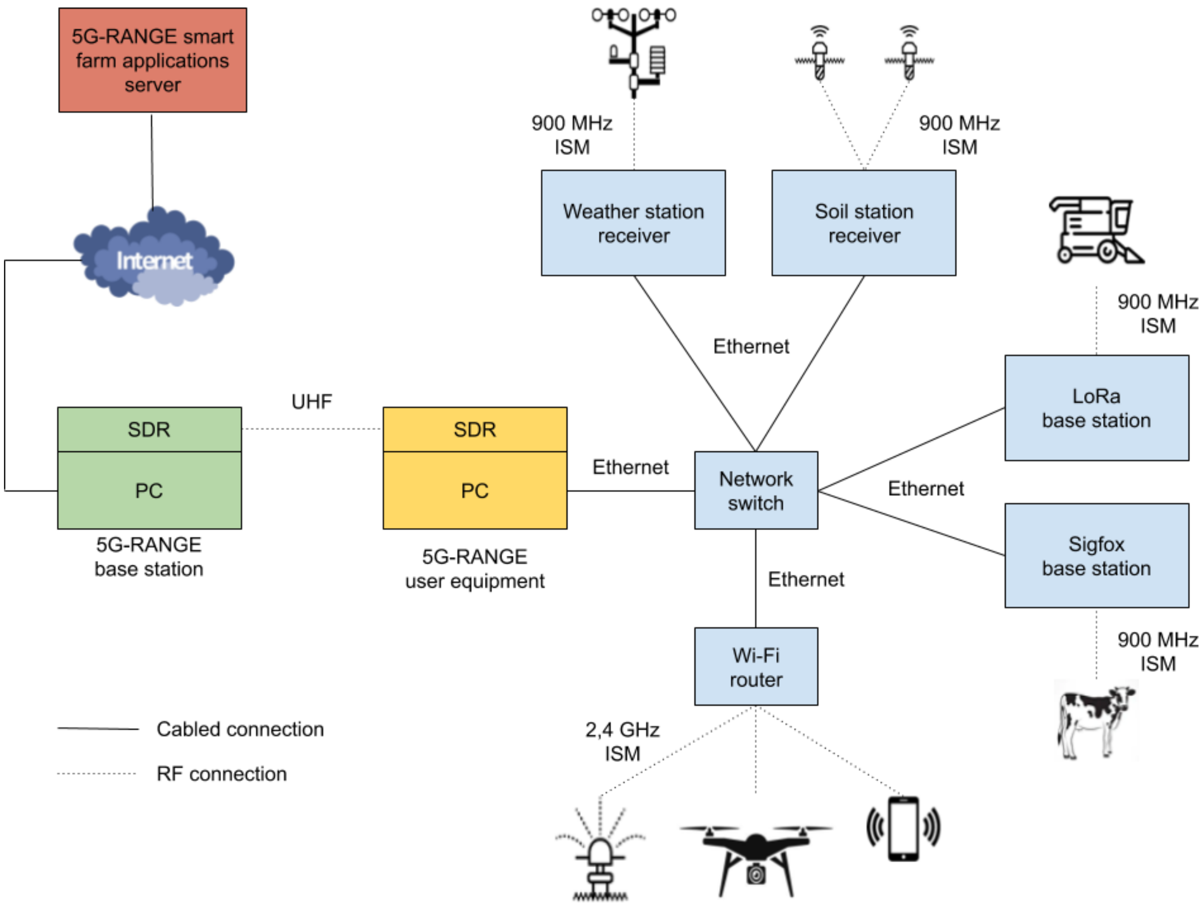

Figure 4. Block diagram: smart farm applications system installed in the User Equipment (UE).

The implemented applications include a micro-weather monitor, crop soil sensors (humidity, temperature, and leaf moisture) whose receivers are connected directly to the network switch. A LoRa BS is also connected to the switch. LoRa IoT devices are installed in agribusiness machinery for monitoring the location, speed, and status of the vehicles. The data collected from the LoRa IoT devices are sent to the application server for processing and exhibition to the users.

The farm cattle are monitored employing smart collars. These devices have the capability of acquiring data from the animals like positioning, body temperature, heat state and behaviour. The wireless technology used by collars communication is Sigfox.

Drones are also used in the smart farm scenario, where they are used for image collection and for precise agriculture. A drone with high definition camera is used to acquire videos from crops, which are transmitted in real-time to a streaming platform, allowing the users to watch the images during the drone flight. The drone is connected to the network using the Wi-Fi router. A drone for agriculture application can be used to deploy pesticides or fertilizers in precise locations where the presence of insects or stressed plants are detected.

The Wi-Fi router can also be used to connect mobile devices and computers. This is an interesting solution to provide broadband connectivity in rural and remote areas. LoRa and Sigfox can be used for activating watering system, temperature control, lights and other actuators necessary in agriculture processes.

3.4.1 Weather and soil monitoring

Information about the local micro weather and soil conditions in rural properties is essential for farmers. From this real-time data and history, agricultural production can be better managed and decisions can be made based on realistic conditions. Decisions about irrigation and the best moment for fertilizing, for example, need a precise mapping of these parameters.

Figure 5 depicts the weather and soil monitoring system integrated with the 5G-RANGE network. A Davis Instruments Weather Station and Wireless Leaf & Soil Moisture/Temperature Station, from the same company, were used to collect the data. All stations are linked on a mesh network, and the devices can send the data to each other, covering large distances. The weather station radio model is Vantage Pro2 and it was employed as the gateway for the sensors.

The devices utilize ZigBee technology set to 900 MHz bands reserved for ISM (Industrial, Scientific and Medical) services (915-928 MHz). A proprietary protocol, provided by Davis Instruments, is responsible for the communication execution. All measures and data from the stations are stored and made available via web servers. An API (Application Programming Interface) is used to recover the data from the servers and display the information in a web-based dashboard, specially designed for the 5G-RANGE demonstration. The monitored parameters are temperature, humidity, atmospheric pressure, leaf wetness, precipitation concentration index, wind speed, wind direction, soil temperature, soil humidity and amount of water on the leaves.

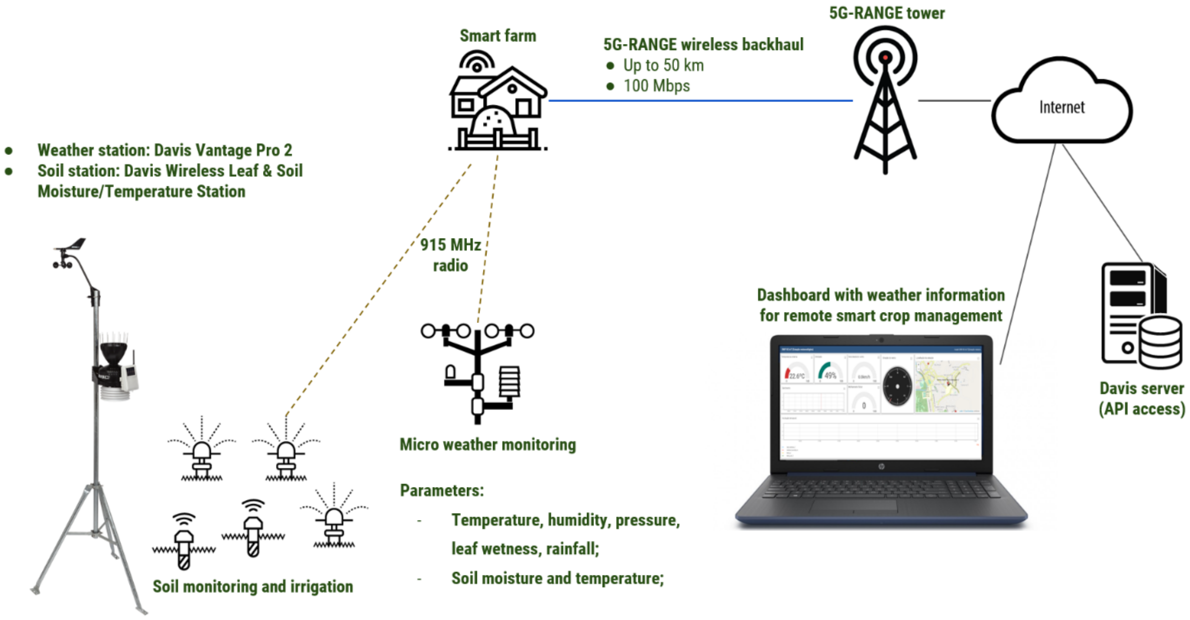

Figure 5. Diagram for applications in micro weather and soil monitoring for precision agriculture.

3.4.2 Cattle monitoring

Individual animal monitoring can provide important information about cattle health and behaviour. Actions can be promptly taken to treat sick animals and to avoid disease proliferation. Figure 6 shows the 5G-RANGE application for cattle monitoring. Smart collars are used to acquire the animal’s position and embedded sensors can measure the body temperature and movements

The data can be also analysed by algorithms based on artificial intelligence to detect anomalous behaviour. Sickness and cow fever, for example, can be identified via this analysis, or even cattle rustling can be precisely detected. All collected information is sent to the gateway employing Sigfox technology, while the 5G-RANGE network is used to deliver the data to the servers. Once again, an API is used to display the cattle information in the 5G-RANGE dashboard.

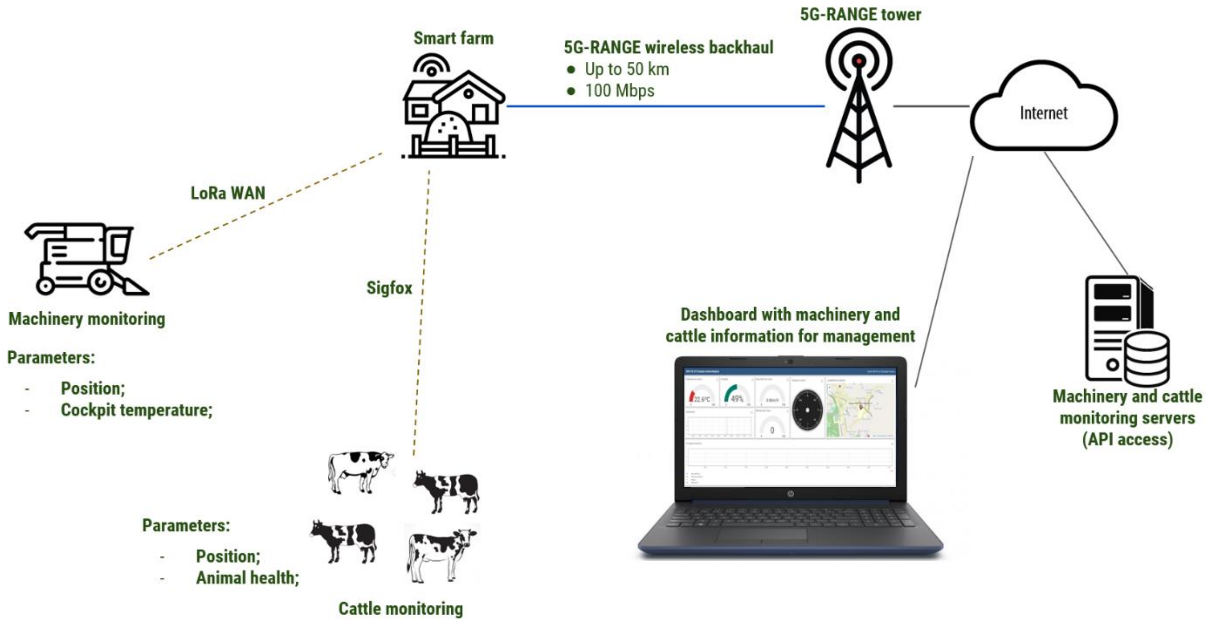

Figure 6. Diagram for applications in machinery (LoRa) and cattle (Sigfox) monitoring.

3.4.3 Machinery monitoring

Real-time information about active machinery is a powerful tool to assist farm production. Details about position, route tracking, load level and consumed agricultural products per unit area can be collected and analysed to avoid wasting and mistakes.

Another useful data that can be provided is the engine state. Mechanical or electronic fails can be predicted and corrected, avoiding maintenance issues, and reducing the time of inoperability of the monitored machines. Since LoRa network allows commands to be sent, remote control or even autonomous operation using artificial intelligence can be implemented. LoRa data from all nodes are concentrated on the 5G-RANGE BS and sent to the applications server. The dashboard can be used to display all information from the machines and to input commands to be sent to the machines.

Figure 6 depictures the integration of the machine monitoring service to the 5G-RANGE network. The vehicle to be monitored has a positioning device (GPS), a temperature sensor and a moisture sensor installed into the cabin. These sensors send the data to a Raspberry Pi 3 mini-computer. After that, the data is transmitted to the gateway using LoRa. The LoRa gateway is another Raspberry Pi 3 mini-computer that gathers all information from the nodes and forward the data to a web server via the 5G-RANGE network.

3.4.4 Agricultural drone image

The use of UAVs (Unmanned Aerial Vehicles), known as drones, has become a frequent procedure in agribusiness. The aerial images captured by drones provide a fast and efficient inspection of land and crops. The images can be transmitted to a technician for analysis, avoid the presence of this professional at the crop site. Processing of these images enables plant counting and classification. Special multispectral cameras and software can identify plant diseases, insects, plagues and portions of land with hydric stress. Another possible application using drones is the topographic profile analysis of the farm.

Figure 7 shows the application diagram deployed in the 5G-RANGE network. The drone used to capture images is a Mavic 2 Zoom model from DJI manufacturer. The video captured by the drone is sent in real-time through the 5G-RANGE network to a server using RTMP (Real Time Messaging Protocol). The real-time video stream can be accessed by any device connected to the Internet that has access to the 5G-RANGE applications server.

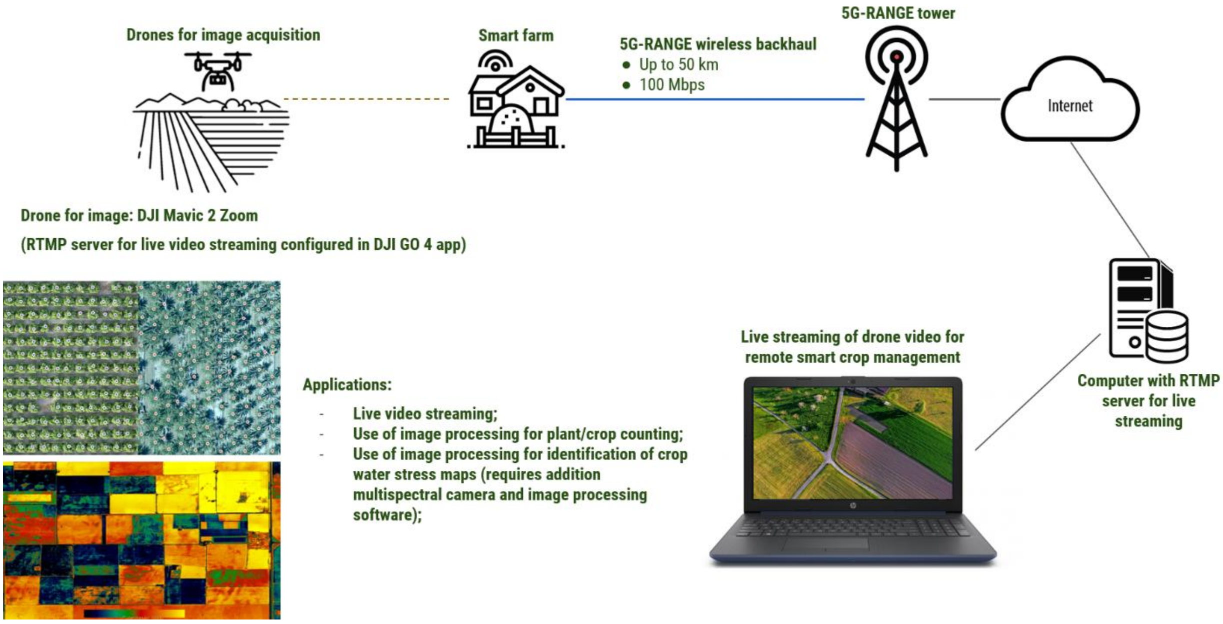

Figure 7. Use of drones for image acquisition in the smart farm scenario.

3.4.5 Crop spraying drones

Application of fertilizers and pesticides in agriculture is a very important procedure to ensure high production efficiency in farms. At the same time, it is a costly process. Good management of these agricultural chemicals is essential to increase the profit margin for the farmers. The reduction of applied chemicals also has a positive impact in the health of those living nearby the fields, since the contamination levels are reduced. Nowadays, the demand for crop-spraying drones has grown significantly. This category of drones can apply fertilizers or pesticides precisely, reducing the cost and risk of environment and food contamination.

Figure 8 shows a diagram of the precise agriculture application integrated to the 5G-RANGE network. The crop-spraying drone is an Agras MG-1P model from DJI company. It is possible to create a flight plan according to a specific crop to proceed a confined and well-dosed pulverization. The previous flight plan mapping can be executed based on image capture drones guided remotely, and it can be sent to the crop-spray drone operator via an Internet connection. This entire infrastructure is provided by the 5G-RANGE network.

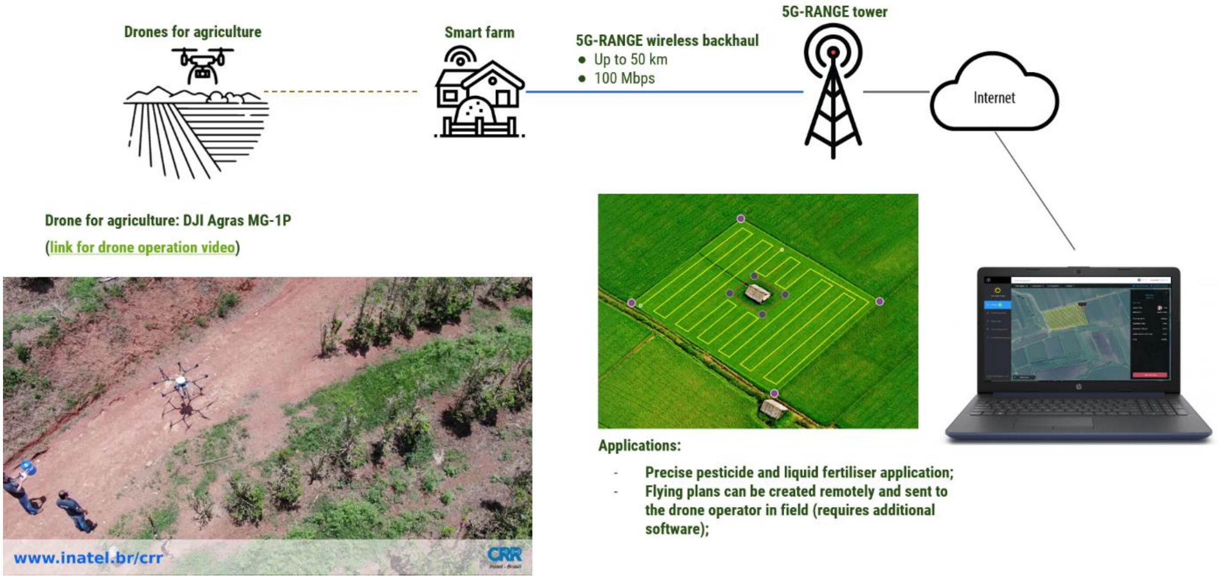

Figure 8. Diagram for use of drones (crop spraying) in precision agriculture.

3.4.6 Voice and Internet access

IoT applications have the potential to improve the agriculture productivity. Significant results can be achieved with the comprehensive spread of this technology. A close-fitting control over crops, cattle and farm processes will allow considerable production increment and cost reduction. However, more than the automation itself, other requirements must be addressed to fulfil the needs of those living in rural areas. Today, most rural areas have poor or no coverage at all. Services like voice and data connectivity are unavailable for most people living in farms and rural areas. 5G-RANGE can be used to provide broadband Internet access and allow those living in currently uncovered areas to experience the benefits of the Information age.

Figure 9 shows a diagram of the 5G-RANGE network used to provide voice and data connectivity. A 5G-RANGE UE can be integrated with a Wi-Fi router to allow any smartphone or computer to connect to the Internet. The high data rate provided by the 5G-RANGE network allows the users to access several services, from video streaming, voice over IP communication, Internet browsing and social network services.

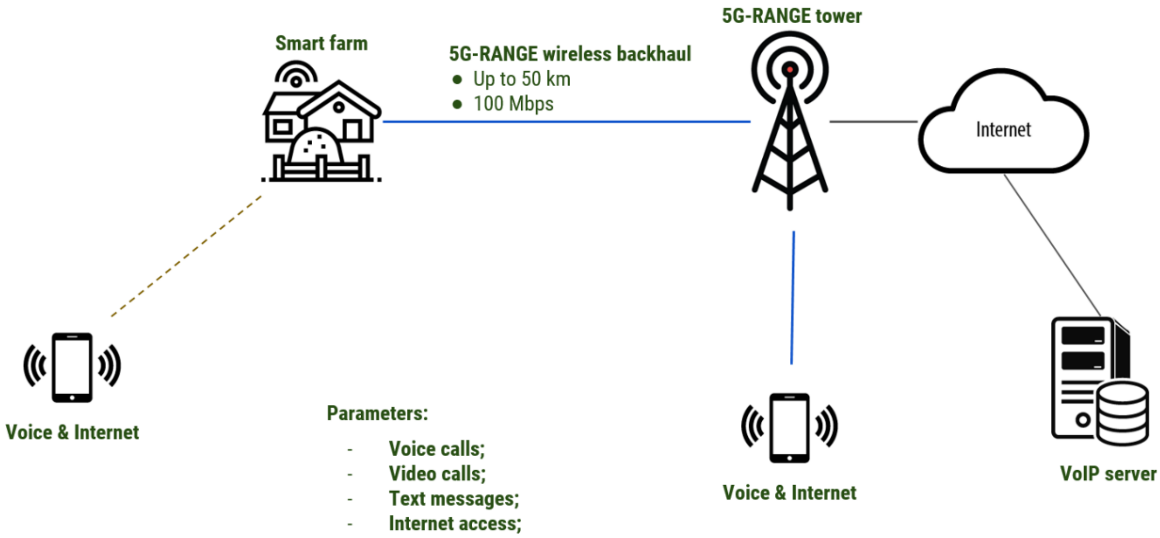

Figure 9. 5G-RANGE for voice and data connectivity.

4 Test Execution Description

The main aim of this section is to provide a detailed description about how the tests and demonstrations described in Section 3 have been performed.

4.1 Coverage and Throughput Test Execution

For the coverage and throughput test, the 5G-RANGE BS was installed in a telecommunication site named Serra do Paredão, located in Santa Rita do Sapucaí, MG, Brazil. The equipment was installed in a local FM broadcast radio site and the backhaul was provided by a local ISP (Internet Service Provider) via fiber optic connection.

Figure 10 shows the tower where two antennas of the 5G-RANGE BS were installed. Both antennas (the red ones visible in the same figure) were positioned for vertical polarization. Since the TV broadcasters employ horizontal polarization, this procedure increase the robustness of the 5G-RANGE network against OOBE from digital TV transmitters.

Figure 10. 5G-RANGE BS antennas.

The UE was placed into a vehicle trunk. A high-capacity stationary battery connected to a power inverter provided the energy for the UE operation. Measurements were taken at several locations and the most distant place where the 100 Mbps was measured with zeroed BER was a rural road in Campos do Jordão - SP. Figure 11 shows a photograph taken in this location. The measurement equipment was arranged next to the vehicle, allowing the researchers to evaluate the received power, path loss and channel response. The antennas, similar to those used in the BS, were installed next to the UE, emulation a roof-top reception.

Figure 11. 5G-RANGE UE spot.

Figure 12 shows the UE antennas correctly pointed to the direction where the base radio station was installed. It is important to observe that two antennas were used, leading to a 2×2 MIMO (Multiple Input Multiple Output) system. In this case, the MIMO system is providing a diversity gain of order 4, increasing the overall system robustness and improving the SNR (Signal to Noise Ratio).

Figure 12. Antennas alignment for the UE during the field test.

4.2 Spectrum Sensing Setup

A laboratorial setup was developed in order to evaluate the SS functionality of the 5G-RANGE UEs, as described in subsection 3.2. Figure 13 shows a picture of the setup.

The 5G-RANGE signal can occupy up to 24 MHz, consisting of 4 TV channels. If no TV signal is detected, the 5G-RANGE BS will allocate all channels for the secondary network. Once a TV signal is detected in a given channel, the 5G-RANGE UEs will detect this signal and inform the BS about the presence of a primary user. The BS will remove the channel from the allocation table and all subcarriers within this channel will be turned off. The excellent spectrum localization of the 5G-RANGE waveform will assure that no interference will harm the primary user, besides the fact that no RF filtering is employed.

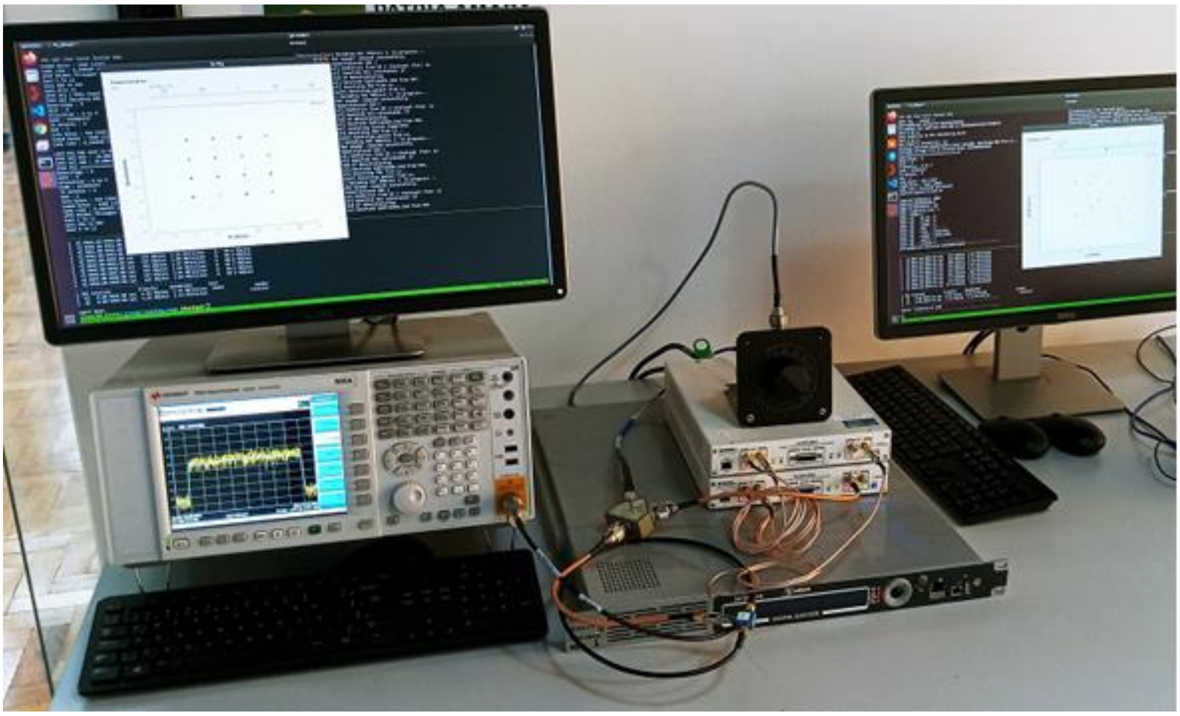

Figure 13. Setup for the SS evaluation.

4.3 Smart Farm Integrated System

A 5G-RANGE network small-scale setup was implemented to illustrate its characteristics for connectivity in remote and rural areas. The objective is to demonstrate that the system can support a set of IoT applications for the agribusiness environment. The 5G-RANGE demonstration was implemented at the Inatel premises, considering the limitations imposed by the period of COVID-19 pandemic. The application scenario planned for this demo is similar to one shown in Figure 1. A BS is used to provide the backhaul connection for the UE. The UE is connected to other equipment allowing IoT applications to be implemented. Figures 14 and 15 shows the devices used in the setup. Figure 14 shows the BS connected to an Internet provider through a cable. Figure 15 shows the UE connected to the Internet through an RF link with the BS and additional equipment to support IoT applications.

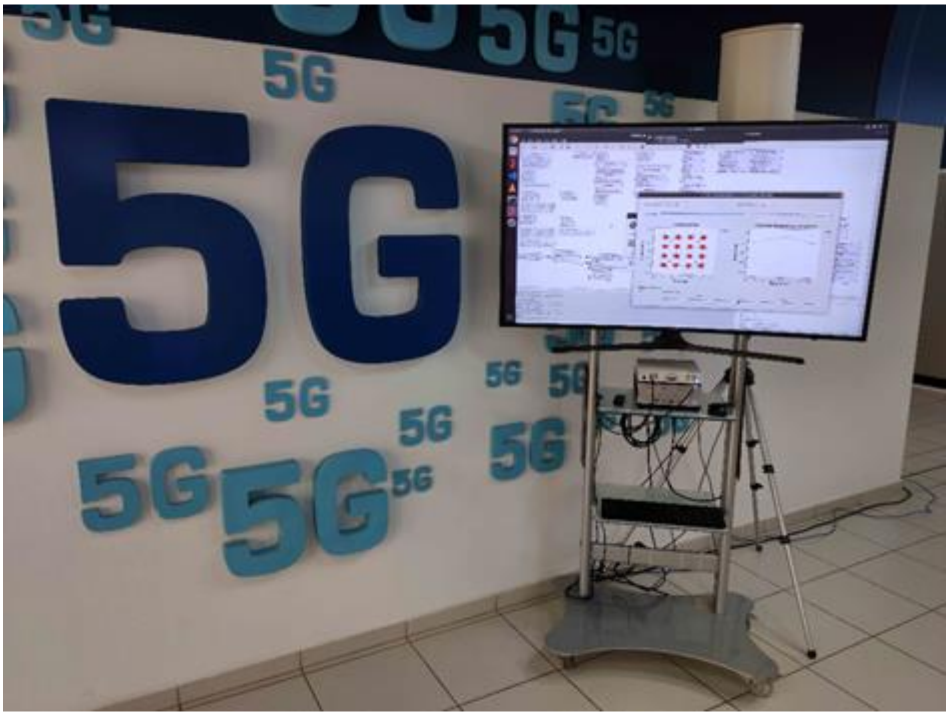

Figure 14. The 5G-RANGE BS used in the Smart Farm demonstration.

Figure 15. The 5G-RANGE UE for the smart farm demonstration.

Figure 16 shows all the additional equipment connected to the UE, providing support to the IoT applications in the smart farm use case. The Internet connection is distributed to the additional equipment using a network switch. A weather/ground station receiver, a LoRa gateway, a Sigfox base station and a Wi-Fi router (not shown in the Figure 16) are connected to the UE to increase the connectivity of the network.

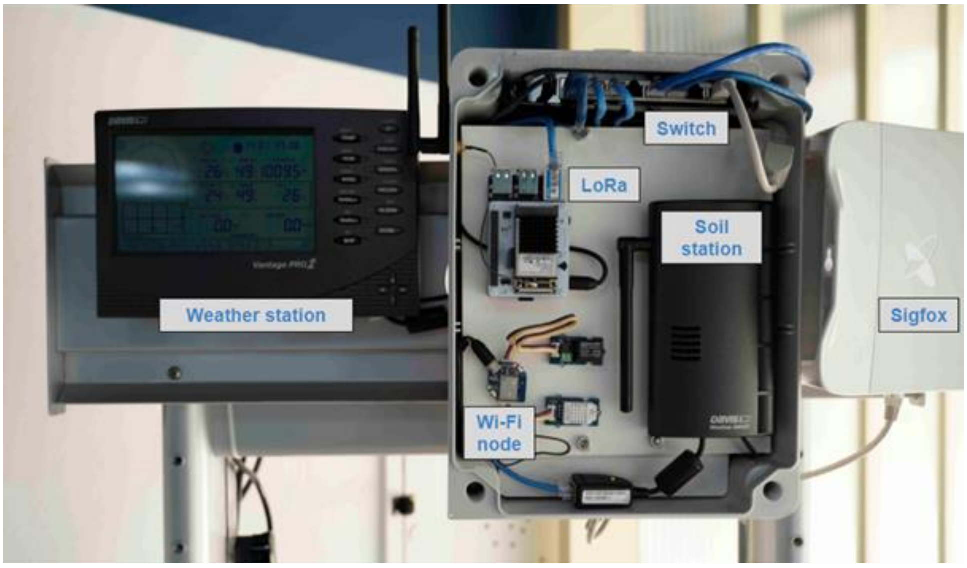

Figure 16. UE setup for the smart farm applications.

In Figure 17 we can see, on the left side, the weather station. In the right side, there is the soil station with stimulation of moisture in the leaf wetting sensor. A water spray was used to simulate the presence of dew or rain in the monitored crop. This same station has soil, temperature, and humidity sensors installed in the plant pot to be monitored.

Figure 17. Weather and soil station used for the micro weather and soil monitoring applications.

A pair of drones for precision agriculture had also been used. Figure 18 shows, on the left side, the crop-spraying drone model AGRAS MG-1P, and, on the right side, the image capture drone, model MAVIC 2 Zoom. Both models are manufactured by DJI.

Figure 18. Drones used for image and crop-spraying applications in precise agriculture.

For the presentation of precision agriculture, the crop-spraying drone was used to simulate an application of pesticide in a plant pot. It illustrates the precise application of products only in areas where they are required. For the demonstration case, just water had been used instead of pesticide. During the pesticide application simulation, the image drone filmed the entire process and transmitted the scenes in real-time to the drone's remote control. Through a remote-control feature, the image stream was transmitted to the Wi-Fi router installed on the UE and directed to a RTMP server. In this way, any Internet user could access the RTMP server and monitor the spraying operation in real-time. This mechanism can be used for visual monitoring of crops using just the image drone.

The photographs of this precision agriculture demonstration using the crop-spraying drone and the image drone is presented in Figure 19. The left image shows the drone's real-time video transmission through the RTMP stream and decoded by the VLC software. The right side picture shows a superimposed image with the video recorded by the drone and stored on its internal memory card. The constellation of the signal received by the UE and the channel frequency response is also visible in Figure 19.

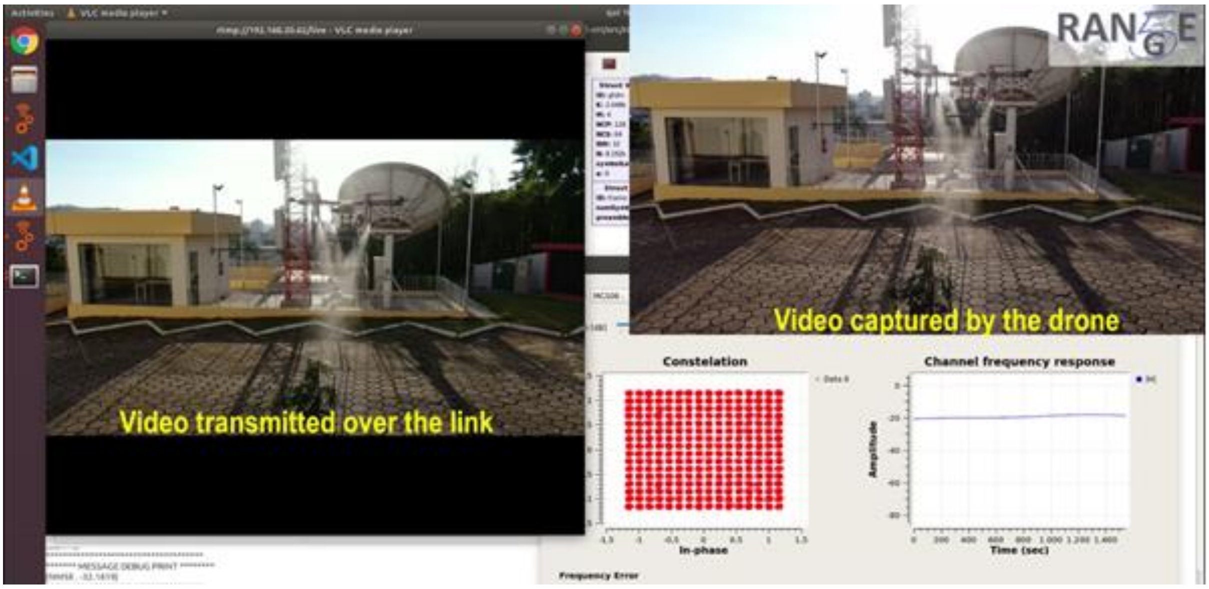

Figure 19. Picture of the precision agriculture application using drones.

Figure 20 shows the collar devices used for cattle monitoring. This collar model uses Sigfox for RF communication and monitors the animal localization, temperature, and behaviour. Figure 21 shows the machinery-monitoring device, which uses LoRa technology for RF communication and monitors the machinery position, speed, and altitude. For the demonstration, the devices were spread in different locations around the Inatel campus.

Figure 20. The Sigfox collars used for the cattle monitoring application.

Figure 21. The LoRa nodes used for the machinery monitoring application.

5 Results and Evaluation

The following subsections show the outcome of the tests performed during the demonstrations and evaluation of the 5G-RANGE network.

5.1 Coverage and Throughput Results

During the coverage and throughput test, measurements were made to verify the system performance. The results are presented in Figure 22, where Figure 22 (a) shows the constellation received by the UE at 50.5 km from the BS. It is possible to visualize the dispersion of the 256-QAM (Quadrature Amplitude Modulation) symbols. Figure 22 (b) shows the MER (Modulation Error Rate) and the SNR (Signal-to-Noise Ratio) of the signal received for each antenna. The minimal MER measurements that allowed the proper error-free reception of the signal were around 28.6 dB. The measured SNR was around 27 dB and 24 dB on each antenna. The red square in Figure 22 (b) highlights the zeroed BER, indicating an error-free communication link.

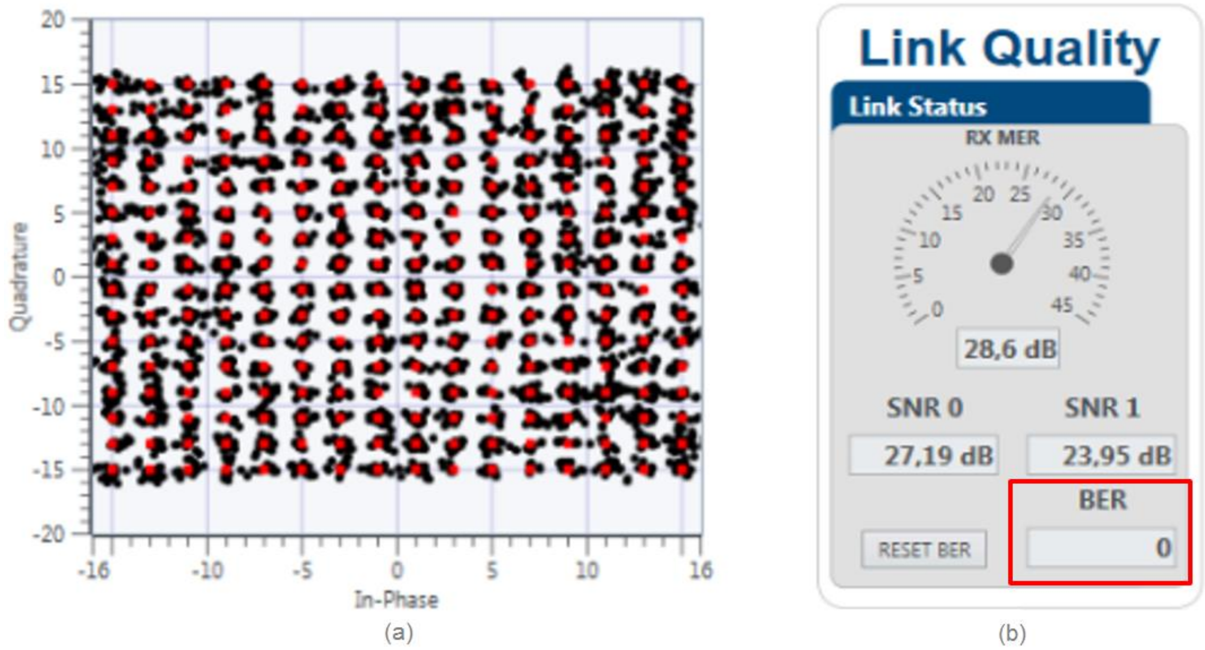

Figure 22. UE received signal at 50.5 km from the BS. (a) 256-QAM constellation. (b) SNR and BER.

Measurements related to the communication channel at the UE side were also collected. The channel delay profile is shown in Figure 23 (a). Figure 23 (b) shows the magnitude of the channel frequency response.

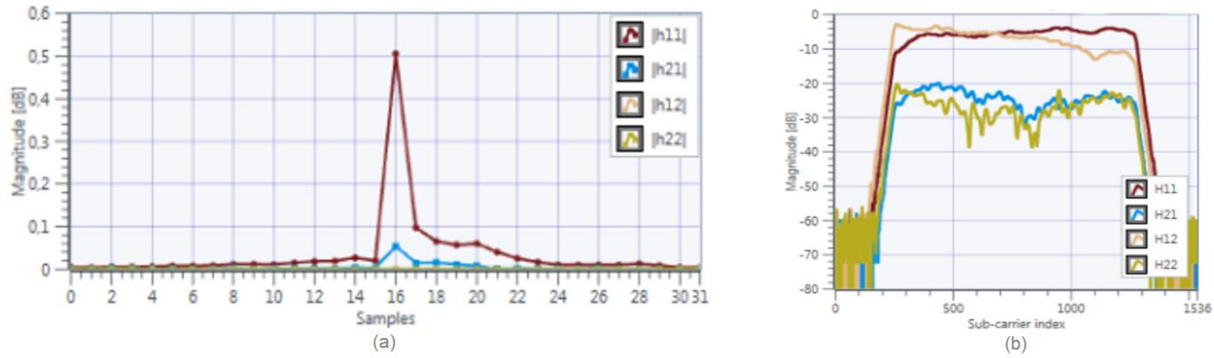

Figure 23. UE channel measures: (a) Channel impulse response. (b) Channel frequency response.

Figure 24 displays the data throughput at the BS during the field trial test. The measurement indicates a data rate of 102 Mbps, showing that the PoC was able to achieve data rate requirement of 100 Mbps at 50 km from the BS.

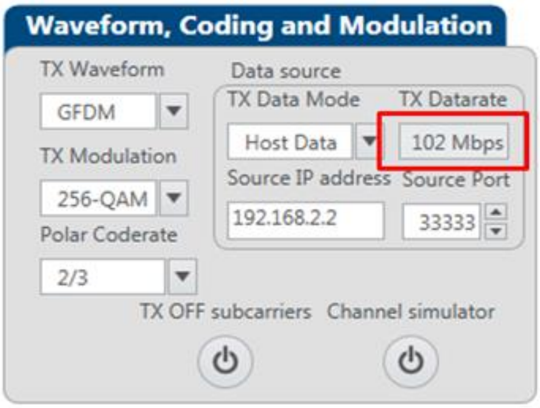

Figure 24. System throughput during the 5G-RANGE field trial test.

5.2 Spectrum Sensing

The detection and reallocation procedure could be effectively verified during the spectrum sensing test. Figure 12 shows a Digital TV transmitter equipment that provides a TV station simulation and the spectrum analyzer used to verify the SS functionality. As we can see in the signal captured by the spectrum analyzer, the cognitive radio feature disabled all subcarriers of the channel where the TV signal was detected.

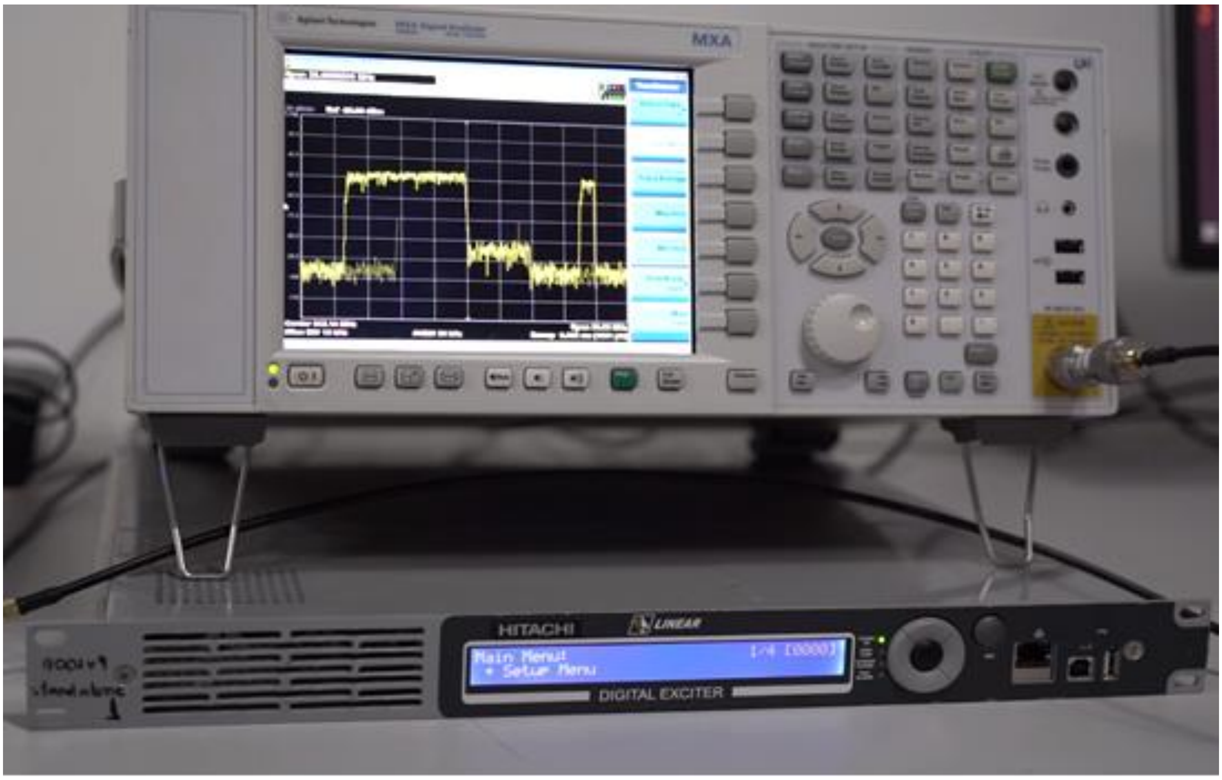

Figure 25. Spectrum sensing detection. The primary user triggers a dynamic spectrum allocation.

5.3 Smart Farm Integrated System

In the smart scenario developed to demonstrate the 5G-RANGE capabilities to provide IoT services in rural areas, all data collected from the sensor where displayed in a web-based dashboard, allowing any authorized user to monitor the information acquired from the demonstration.

Each application and service have its own cloud server to gather the data from sensors and controllers. A Python script was developed to act as a gateway, concentrating all the information. It accesses the servers regularly using the APIs provided by the vendors and generating a unified database that is accessed by the dashboard application. All data can be conveniently organized and shown in a featured panel. The script publishes the info via the dashboard using the MQTT (Message Queueing Telemetry Transport) protocol. ThingsBoard server hosts the dashboard developed for this demonstration.

Figure 26. Parameters monitored by the smart farm applications over the 5G-RANGE network. shows a general view of the information available in the dashboard. The ThingsBoard service library provides a variety of widgets components as the examples shown in Figure 27. Some of the widgets are ready for use, as the simple digital temperature widget in Figure 27(b). The widget in Figure 27(a), used to monitor the soil moisture sensor, needed to be customized to represent the measures taken from the sensor.

The Sigfox and LoRa data were monitored through a map that also composes the web dashboard. The map allows for obtaining the location of the following devices: weather station, cattle collars, and machinery monitoring nodes. In addition to the location data, more information is available throughout the icons of the monitored devices. In the most left part of Figure 28, the weather station displays latitude, longitude, temperature, relative humidity, wind speed, and atmospheric pressure. In the central figure, the smart collar’s latitude, longitude, and temperature are displayed. At last, the right figure shows the information of a LoRa node (latitude, longitude, altitude, and speed for the monitored machinery).

Other useful widgets available in the ThingsBoard library are the charts. The time series charts are used in the 5G-RANGE dashboard to monitor the time evolution of different sensors for a specific period. The weather station and the soil station have many of their sensors monitored using these charts, as can be seen in Figure 29.

Figure 26. Parameters monitored by the smart farm applications over the 5G-RANGE network.

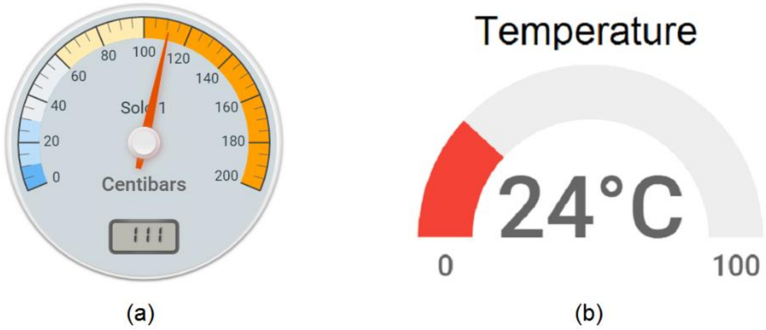

Figure 27. (a) Analog customized gauge for soil moisture. (b) Digital gauge for temperature.

Figure 28. Parameters monitored for each device type: weather station (left), cattle collars (central) and Lora nodes (right).

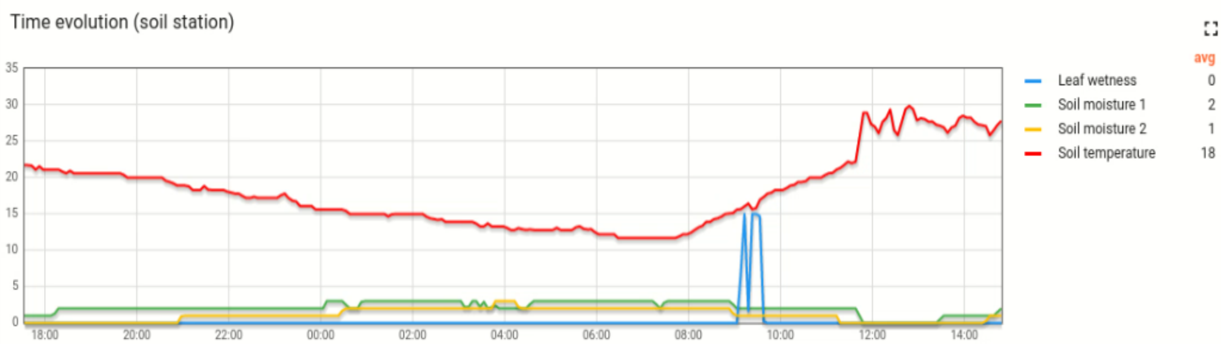

Figure 29. Time series chart used to monitor the soil sensors in the soil station.

The online exhibition of metrics and status is a friendly tool to monitor all the applications in use. This analysis can be complemented by cross-correlation processing of the available data, which provides many new information for the users. Multispectral image mapping of crops can point to regions where the action is locally needed, generating an important reduction in pesticide and fertilizer cost application. This inspection info map integrated with soil moisture and topographic data leads the irrigation procedures and indicates the proper actions to control hydric stress.

Cattle health can be monitored accordingly to vital signs and behaviour. Cow heat monitoring improves the reproduction rate. Stress management avoids treatment costs and increases milk production. Feed optimization is also possible comparing cow’s rumination activity, detected by smart collars, with feed intake information being served to them. Animal tracking is a crucial support for surveillance. Cattle rustling and scape are immediately detected with an operational cost reduction.

Machinery supervision, maintenance issues, remote operation, autonomous harvesting, and many other machinery operation enhancements are carried out when a reliable network system infrastructure is provided.

Artificial intelligence is an important technology that can be integrated to this data analysis, allowing automatic actions to be taken or provided more detailed information to support the user’s decisions. This is the baseline for IDSS (Intelligent Decision Support System) applied to the smart farm environment.

6 Conclusion

The 5G-RANGE demonstration showed that the 5G-RANGE network can be implemented with current technology and that the challenging requirement of achieving 100 Mbps at 50 km from the BS is feasible. The integration of the 5G-RANGE with complementary technologies has shown that the proposed network is able to support several IoT applications for rural areas. Services for crop, cattle and machinery monitoring where supported by different technologies integrated to the 5G-RANGE network. A dashboard, created to concentrate all information collected from the farm, provided valuable information for farmers. The spectrum sensing test demonstration showed that the dynamic spectrum allocation operated properly, protecting the incumbents while exploiting the vacant channels.

The concepts of precision agriculture and smart farm established a combination of features, services and IoT standard interfaces aggregated into the 5G-RANGE network system. All connected technologies and devices used to demonstrate the functionality of this infrastructure worked faultlessly, as expected.

Even though the integrated system demonstration was somewhat different from the initial plan due to the limitations imposed by the COVID-19 pandemic, this implemented demonstration showed that the 5G-RANGE is an interesting solution to provide a reliable and feasible mobile coverage in remote and rural areas.

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