Smart City in Action: a Case Study of the City of Santa Rosa, Brazil

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Abstract: The concept of smart cities has been largely explored in recent years, and consequently, several researchers, universities, and public administrations have invested their efforts in an attempt to create infrastructures for their cities providing smart services to the population. Motivated by this context, a project proposed by Unijuí University was selected by notice SICT-RS nº 04/2021 TEC4B that granted BRL 1.321.568,22 to create a large development laboratory, called Smart LiveLab, and in partnership with the municipal government and IT companies in the city aim to create an infrastructure for providing smart services in the city of Santa Rosa. In the planned infrastructure, it intends to use the LoRA Gateways to coverage totally Santa Rosa city, capturing data from different sensors compatible with the LoRaWAN protocol. Therefore, new intelligent services can be developed to attend to the demands of Santa Rosa, mainly those related to the health and safety of the city. It is important to highlight that this project is open to the whole society that has a clear roadmap of new services that will be added in the future to make the city more dynamic in terms of the use of available resources.

1. Introduction

The concept of smart cities is not new, but it has been changing in recent years, seeking to expand the conceptual characteristics of new cities and the behavior of the citizens. One of the first definitions was proposed in 2010 by Harrison et al. (2010) who consider that a smart city has its "physical infrastructure connected to IT infrastructure, social infrastructure and business infrastructure to leverage the collective intelligence of the city". The study by Sharifi et al., (2021) analyzed articles published in the last 30 years approaching the topic of smart cities. The first ideas on the topic date to the 1970s (precisely, at 1974) and have been expanding rapidly in recent years, gaining significant momentum in science and politics. Although there is no single concept, the authors emphasize that: intelligence (of cities) is a multidimensional concept that combines physical infrastructure (based on technology) and soft infrastructure (regulations, knowledge economy, participation, innovation social and institutional, data management, etc.). This combination establishes the foundation for building smart cities. In work proposed by E. Ismagilova et al. (2019), the authors group relevant studies by areas associated with the topic of smart cities. In this review, the following applications were found: Smart Mobility (traffic management, vehicle tracking, route stability, smart metro, and internet of vehicles), smart living (public safety, healthcare, smart education, smart tourism, and smart buildings), smart environment (monitoring of city trees, air pollution quality, water quality, green spaces, weather mone, emission monitoring, waste collection, management energy efficiency), smart citizens (adoption of technology, privacy and security, citizens engagement, crowdsourcing, social interactions, and communications), smart government (social media, planning process of developing smart cities, open data, open government, smart governance–public services, dimensions of smart government, sustainable governance, and smart collaboration), smart economy (smart business and m-commerce), smart architecture and technologies (data exchange, improving cybersecurity and privacy of data, data processing, data storage, and technologies for smart cities).

In fact, many cities around the world have developed and/or are planning to develop smart city programs. They hope to improve the quality of life of their citizens, increase the efficiency and effectiveness of urban operations and develop solutions to overcome challenges, whether social, environmental.

The planning described in this chapter is applied to the city of Santa Rosa. It is a Brazilian municipality located in the northwest region of the state of Rio Grande do Sul, southern Brazil. Figure 1.1 shows the geographical location of the Santa Rosa city in the country. The municipality was created as a colony of European immigrants, mainly Italians, Germans, and Russians in 1915. According to the Brazilian Institute of Geography and Statistics (IBGE), the estimated population in 2022 is 73,882 people, with a territorial area of 489,380km², and a population density of 140.03 inhabitants per km². Its Municipal Human Development Index (IDHM) is considered high, with a value of 0.769 in 2022. The city's GDP per capita in 2022 reached BRL 43,564.15.

The city was traditionally known as "The National Cradle of Soy", as it was in this city that the first seedlings of the cereal were planted in Brazil. This title was made official by the Brazilian Congress in 2022.

Figure 1.1: Santa Rosa Geographical location in Brazil. (Adapted from Google Earth Pro)

The objective of this chapter is to present the infrastructure being developed by the authors at the University, in collaboration with the public administration of Santa Rosa. This project uses the LoRa communication network and provides global coverage for the urban and rural areas of the city. The public-use network will allow the interconnection of IoT devices and various sensors, storing the information collected in the local cloud. The rest of this chapter is organized as follows: in Section 2, we present a brief review of the state of the art in developing smart cities in Brazil. Section 3 introduces the several laboratories which were created as open spaces for students, companies, and any other citizen interested in accessing the infrastructure to develop his/her idea as a smart service for the city. Section 4 details the hardware infrastructure and the coverage area of the deployed antennas. Section 5 provides an overview of the smart services under development to tackle problems in urban areas such as flooding caused by the rains and air quality monitoring, and in rural areas monitoring soil temperature and humidity. Section 6 introduces nine smart services that integrate the project roadmap, and we expect to develop and deploy them in the near future. Section 7, summarizes and concludes this chapter.

2. Smart cities in Brazil

Smart Cities are today an important policy for modeling sustainable urban development. The concept associates the opportunities of the digital world with the increasing advance of recent technologies, which can help in social inclusion, quality of life, integration of mechanisms and actions of management and planning of urban spaces.

The project known as Connected Smart Cities Ranking (Ranking, 2022) determined 75 indicators in eleven thematic axes to establish which are the potential smartest cities in Brazil. This project was conceived by technology companies and presents the real configurations of cities and works as one of the starting points to understand their indicators and levels of development. The evaluation methodology was distributed in the following themes: (1) Urbanism, (2) Economics, (3) Education, (4) Entrepreneurship, (5) Energy, (6) Governance, (7) Mobility, (8) Security, (9) Environment, (10) Technology & Innovation, and (11) Health. The methodology for calculating the ranking used values with three different weights: (a) Weight 0.5 for dichotomous indicators, that is, there is or is not a certain type of service. For example, services such as smart traffic lights, smart lighting system, electronic public transport ticket, risk area monitoring, appointment scheduling in the public health network were considered; (b) Weight 0.8 for indicators with a rating or rating scale. This criterion mainly covers municipal legislation, computerized or georeferenced registration of properties, citizen service via smartphone application, among others; and Weight 1.0 as a scale based on indicators of economic growth, employability rate and others.

According to the study, in 2022 the general ranking for the top 10 was as follows: (1) Curitiba, (2) Florianópolis, (3) São Paulo, (4) São Caetano do Sul, (5) Campinas, (6) Brasília, (7) Vitória, (8) Niterói, (9) Salvador and (10) Rio de Janeiro. This evaluation methodology also considered the five regions of Brazil (North, South, Midwest, Northeast and Southeast). It is also necessary to highlight the prevalence of the Southeast Region in the ranking, which concentrates 58 of the 100 smartest cities in Brazil. Considering the top ten, 6 are from the Southeast Region, 3 from the South Region, 1 from the Midwest Region and 1 from the Northeast Region. Another interesting data is the classification of cities considering population size. Of the 100 ranked cities, 11 have less than 100,000 inhabitants, 55 cities have a population between 100,000 and 500,000 inhabitants and 34 cities have more than 500,000 inhabitants. Of the top 10 Brazilian cities, 8 have more than 500,000 inhabitants.

When the health axis is analyzed, it is possible to highlight the predominance of the south and southeast regions. Of the first 10 cities, 5 are from the south region, 4 from the southeast region and only 1 from the northeast region. The classification is as follows: (1) Belo Horizonte, (2) Balneário Camboriú, (3) Barueri, (4) Vitória, (5) Barretos, (6) Florianópolis, (7) Foz do Iguaçu, (8) Porto Alegre , (9) Jaraguá do Sul and (10) Sobral. It is possible to verify that only Florianópolis and Vitória are ranked among the 10 smartest cities in the general classification considering all other evaluation criteria. It is also possible to highlight that 7 cities have a population between 100,000 and 500,000 inhabitants and 3 have more than 500,000 inhabitants.

The analysis of the mobility axis again shows the predominance of the South and Southeast regions of Brazil. Of the first 10 cities, 5 are in the South region, 4 in the Southeast region and only 1 in the Midwest region. The top 10 cities are: (1) São Paulo, (2) Balneário Camboriú, (3) Itajaí, (4) Florianópolis, (5) Rio de Janeiro, (6) Santana do Parnaíba, (7) Joinville, (8) Barueri, (9) Blumenau and (10) Brasília, which 5 cities with a population between 100,000 inhabitants and 5 cities with more than 500,000 inhabitants.

The technology & innovation axis shows a balance between the South, Northeast and Southeast regions. Of the first 10 cities, 4 are from the South region, 3 from the Northeast region and 3 from the Southeast region of Brazil. The top 10 cities are: (1) Fortaleza, (2) Curitiba, (3) Belo Horizonte, (4) Rio de Janeiro, (5) Campinas, (6) Florianópolis, (7) Recife, (8) Salvador, (9) Porto Alegre and (10) Jaraguá do Sul. It is possible to highlight that 9 cities have more than 500,000 inhabitants, only the city of Jaraguá do Sul has a population between 100,000 and 500,000 inhabitants.

In the economic axis, cities in the South (3) and Southeast (7) regions predominate in the top 10 positions. It is possible to highlight that of the first 100 cities ranked, 56 are from the Southeast region, 33 from the South region, 2 from the North region, 5 from the Northeast region and 4 from the Midwest region of Brazil. The first 10 are: (1) São Paulo, (2) Barueri, (3) Campinas, (4) Jaguariúna, (5) Cajamar, (6) Itajaí, (7) Jaraguá do Sul, (8) São Caetano do Sul and (10) Florianopolis. Of the 10 cities, 2 cities have a population of less than 100,000 inhabitants, 4 cities have a population between 100,000 and 500,000 inhabitants and 4 cities have a population of over 500,000 inhabitants.

In a general analysis, it is possible to see that the South and Southeast regions of Brazil concentrate the largest number of potentially smart cities. Of the 100 first cities ranked in the general classification, two regions (South and Southeast) concentrate 81 cities, only remaining 19 cities in the North (2), Northeast (10) and Midwest (7) regions. These data also reflect the social inequality that exists, mainly, in the North and Northeast regions of Brazil.

3. Building Living Labs

The starting process of making the city of Santa Rosa smart began as a public notice issued by the Secretary of Innovation, Science and Technology of Rio Grande do Sul State. The notice SICT nº 04/2021 TEC4B selected three proposals for the development of large experimentation laboratories contemplating IoT and smart cities.

The proposal, led by Unijuí University in partnership with the municipal government and IT companies in the city, was granted BRL 1.321.568,22 to create a large development laboratory, called **Smart LiveLab**. Characterized by being a collaborative space for technological innovation to generate the social economic development of the Northwest and Missions Macro region of the state of Rio Grande do Sul. The Smart LiveLab laboratory is composed of a set of environments that allow the partners that make up the quadruple helix of innovation (Society, Business, Government, and University) to appropriate associated intelligent technologies and the Internet of Things (IoT) to facilitate the development innovative, scalable, and sustainable solutions, which directly impact the development of the macro-region. The Smart LiveLab project consists of six environments, namely: Make LiveLab, Idea LiveLab, Storage LiveLab, Front LiveLab, Collab LiveLab, and City LiveLab. Table 1 presents all spaces and their characteristics defined in the **Smart Livelab** project.

Table 1: Smart LiveLab environments

Name	Description
Make LiveLab	In this environment, partners can carry out the prototyping process, pilot production and component tests. The function of the space is to assist in the validation of the generated ideas. In addition, this space can be used for team training in recent technologies.
Idea LiveLab	Aimed at stimulating creativity and innovation. A pleasant environment associated with a set of technologies that include creative tools, computer equipment and software to stimulate creativity and generate solutions that are in accordance with the context of the subject worked. The ideal place to make innovative ideas.
Storage LiveLab	Consists of a set of high-performance and high-capacity servers that allow the storage and retrieval of data collected by the sensors. Data is stored independently for each partner or test, ensuring the security and confidentiality of the information collected.
Front LiveLab	Destined to the reception of the partners and users of the laboratory, also constituting in a control and accounting of access of the users.
Collab LiveLab	Used for prospecting meetings for new partners and investments. Its composition is formed by the project coordinator, a representative from the private sector, a representative from universities, a representative from civil society and another from the government. Its function is to create a network of partners around Smart LiveLab with a view to planning and prospecting the sustainable continuity of this project.
City LiveLab	The largest and broadest project activity includes the set of communication devices for IoT in an actual city environment. These devices, in addition to collecting and making public data from sensors available, allow partners to test and evaluate their products on communication issues, including distance, coverage area, security, QoS, among others.

Among the environments listed in Table 1, one of them stands out as it is inseparable from the city itself. **City LiveLab** is intended to make the entire city a great laboratory for experimentation and testing in smart cities. This environment will be implemented in the city of Santa Rosa in partnership with the City Hall and the city's Secretariat for Economic and Social Development.

We cannot talk about smart cities without mentioning the two main technologies involved, which are IoT and LoRa. The Internet of Things (IoT) characterizes any device that can be connected to the Internet through one of several types of connection. Sensor-like devices can use connections such as RFID, NFC, Wi-Fi, Bluetooth and Zigbee or long-distance connections such as GSM, GPRS, 3G, LoRa. Simply put, LoRa is a type of wireless network like Wireless and Bluetooth, which makes use of radio frequency waves to transmit small data rates over long distances. The exchange of information is done through a Gateway or between the devices themselves.

> "LoRa is an RF modulation technology for low-power, wide area networks (LPWANs). The name, LoRa, is a reference to the extremely long-range data links that this technology enables. Created by Semtech to standardize LPWANs, LoRa provides for long-range communications: up to three miles (five kilometers) in urban areas, and up to 10 miles (15 kilometers) or more in rural areas (line of sight). A key characteristic of the LoRa-based solutions is ultra-low power requirements, which allows for the creation of battery-operated devices that can last for up to 10 years. Deployed in a star topology, a network based on the open LoRaWAN protocol is perfect for applications that require long-range or deep in-building communication among a large number of devices that have low power requirements and that collect small amounts of data." (SEMTECH, 2022)

Figure 3.1 presents a typical standard architecture for LoRaWan. This figure demonstrates the integration between the main components involved in the configuration, which are: end devices, gateways, network server, join server, application server, and dashboards. Table 2 details each of these components by exploring their functions (SEMTECH, 2022)

Figure 3.1: Typical LoRaWAN infrastructure and architecture.

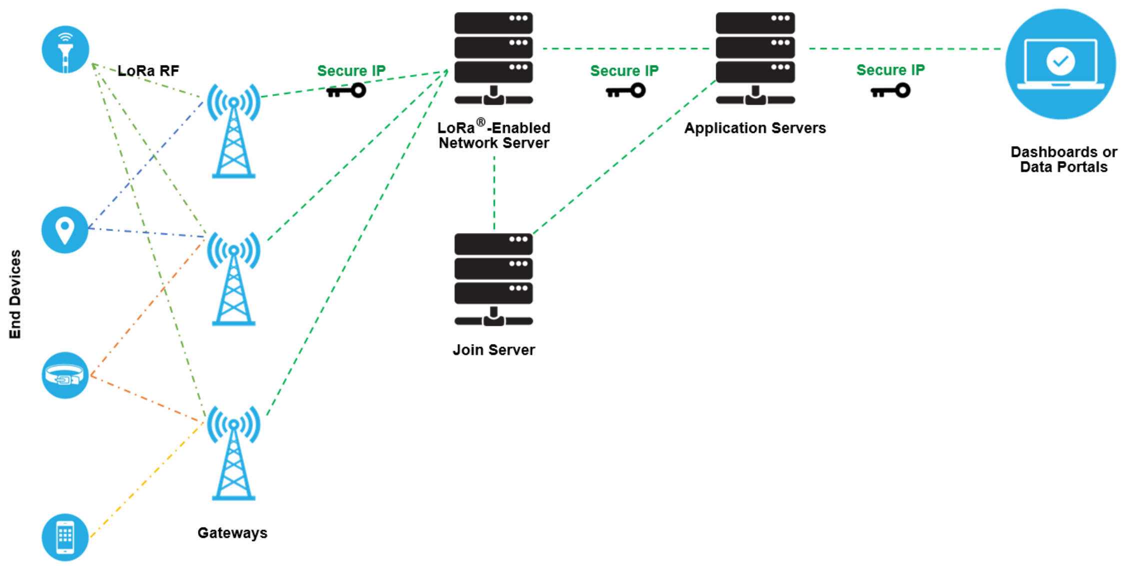


Table 2: Typical LoRaWAN architecture component (Adapted Semtech, 2022)

LoRaWAN Architecture Component	**Description**
End Devices	A LoRaWAN-enabled end device is the basic elements or modules of the network. They represent sensors or actuators that are connected by radio frequency signals to a network LoRaWAN through Radio Gateways using LoRa modulation. In the majority of applications, an end device is an autonomous and can be sensor like temperature, motion, energy consumption, water, gas or actuators like panic buttons, street lighting, irrigation controllers, among others.
Gateways	A LoRaWAN gateway is the receiver of the signals sent by radios, a LoRa modulated RF message from any end device. A gateway can receive data from thousands of devices and forward them to a network server. In some models, the network server is integrated into the gateway. An external gateway, depending on the conditions of the site's topology and its antenna can cover from 2 to 15 Km.
Network Server	The LoRaWAN network server guarantees authenticity of each sensor on the network and the integrity of each message. It is software running on a server, responsible for managing the information sent by gateways. How is there the possibility of two or more gateways receiving the same packet from a certain module, the network server validates the authenticity and integrity of devices, deduplicates uplinks, selects the gateways used for downlinks and performs adjustments to adapt the rates of data (Data Rate - DR) to manage the times between communications and the energy consumption.
Join Server	The Join Server manage the activation process during transmission to add End Devices to the network server. For that purpose, the join server must contain device information like: DevEUI (End Device Serial Unique Identifier), AppKey (Encryption Key Application), NwkKey (Network Encryption Key), Application Server identifier (Application Server Identifier), End-Device Service Profile End Device).

Application Server	Application servers are responsible for securely handling, managing, and interpreting sensor application data. They also generate all the application-layer downlink payloads to the connected end devices.
Dashboard or Data Portal	They are the means of displaying the data already processed and interpreted. Data can be viewed on mobile phones, web pages, industry internal control panels, among others.

The principal component, LoRaWAN is the name given to the protocol that defines the system architecture as well as the communication parameters using LoRa technology. Thus, this protocol was developed by the LoRa Alliance, a non-profit organization founded in 2015.

> "The members of the LoRa Alliance® believe that the time of the Internet of Things is now and that standardization and a strong, growing ecosystem is the only way drive volume deployments for low power wide area (LPWA) networks. These LPWA networks are projected to connect 50% of the predicted IoT volumes. The LoRa Alliance® is standardizing LPWA with the LoRaWAN® specification and has created a certification and compliance program to ensure interoperability. LoRaWAN® end-devices will be able to be deployed in multiple networks and roam from one network to another irrespective of network infrastructure or operator. The LoRa Alliance® is the fastest growing technology Alliance; we already more than 500 members and have been operational since the end of March 2015. The members include technology leaders such as IBM, Cisco, HP, Foxconn, Semtech and Sagemcom as well as the leading product companies such as Schneider, Bosch, Diehl, and Mueller and many SME's and Startup companies all adding significant value to the fast growing LoRaWAN® ecosystem. Our members also include the largest mobile network operators who are deploying public networks using the technology." (LoRa Alliance, 2022)

The project to make the city of Santa Rosa a Smart City considers the need to use the LoRaWAN architecture, for reasons of compatibility and must be integrated into the spaces defined by the Smart LiveLab project.

4. Making the city smart

The city coverage project with LoRa technology, contemplated by City Livelab, provided for the installation of LoRa Gateways scattered throughout the city in sufficient quantity for total coverage. After analyzing the equipment available on the market, RAK brand equipment was chosen. Still seeking greater compatibility between the equipment, a set of other equipment, including sensors, were acquired from the same brand. The main components for LoRa network coverage in the city are the external gateways, in this case the RAK 7240 model was purchased (Figure 4.1) with the following key features: 8 Channels with 4G, GPS Antenna, 2.4G Wi-Fi Antenna, and power via PoE injector.

Figure 4.1: External Gateway - RAK 7240

The RAK7240 WisGate Edge Prime is an outdoor LoRaWAN Gateway for LPWAN deployment. It is based on the SX1301 LoRa core.

The main hardware and software characteristics are presented in the Table 3 below.

Table 3: RAK7240 Hardware e Software Features

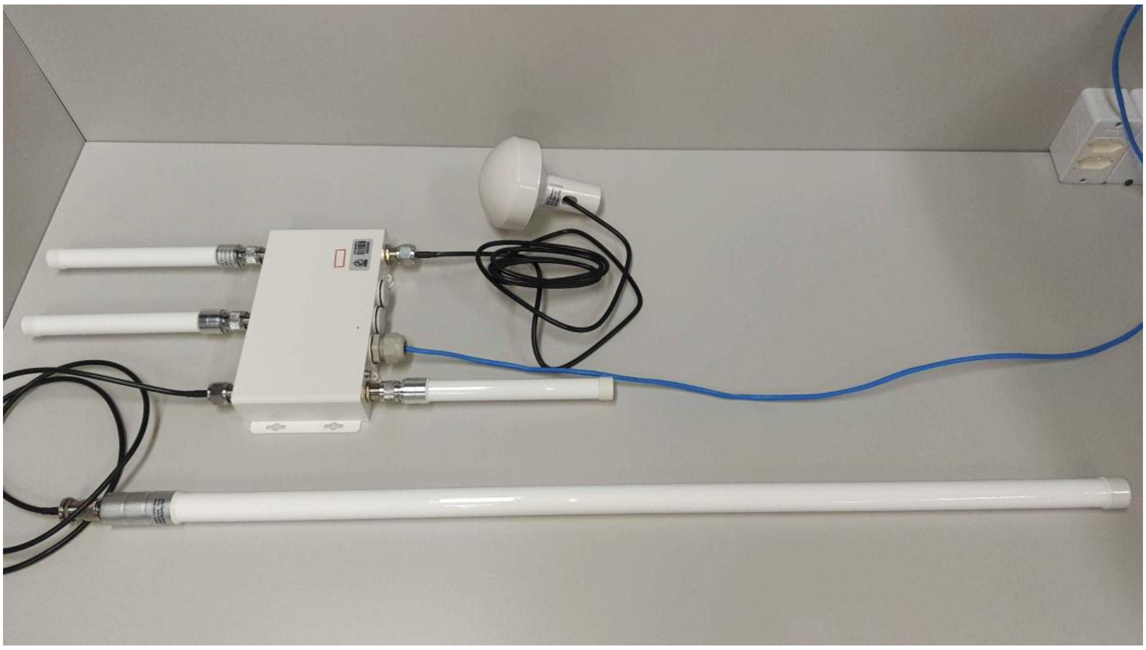
Hardware Features	**Software Features**
IP65 industrial-grade enclosure with cable glands	Built-in LoRa® Server
	OpenVPN
PoE + Surge Protection	Software and UI sit on top of OpenWRT
Dual LoRa® Concentrators for up to 16 channels	LoRaWAN® 1.0.2
	LoRa® Frame filtering (node whitelisting)
Backhaul: Wi-Fi, LTE, and Ethernet	MQTT v3.1 Bridging with TLS encryption
GPS	Buffering of LoRa® frames in case of NS outage (no data loss)
SD card slot	

An important item in the entire city-wide LoRa signal coverage process is signal range. The option was to use antennas with greater power and with overlapping signals. To work with the gateway, the 8dBi Fiberglass Antenna was chosen, shown in Figure 4.2.

Figure 4.2: 8dBi Fiberglass Antenna

The 8dBi Fiberglass Antenna is a high-quality outdoor antenna designed to be deployed outdoors, for better range. The antenna connector is one with the antenna body, because this design increases the resistance of the antenna to external conditions further. It is IP67 rated, making it waterproof. The first configuration and installation step was done in the laboratory, in Figure 4.3 we see the first external gateway being tested.

Figure 4.3: External Gateway Laboratory Test



The first external gateway of the LoRaWAN network that should cover the entire city of Santa Rosa is already in operation at the university. Figure 4.4 shows the antenna installed on top of the building.

Figure 4.4: First External Gateway Installed at UNIJUÍ

To store the values collected from the sensors, a Dell server will be used, more specifically the PowerEdge R550 model (Table 4). The VMs to receive data will be installed on this server. The basis of the system is Microsoft Hyper-V Server.

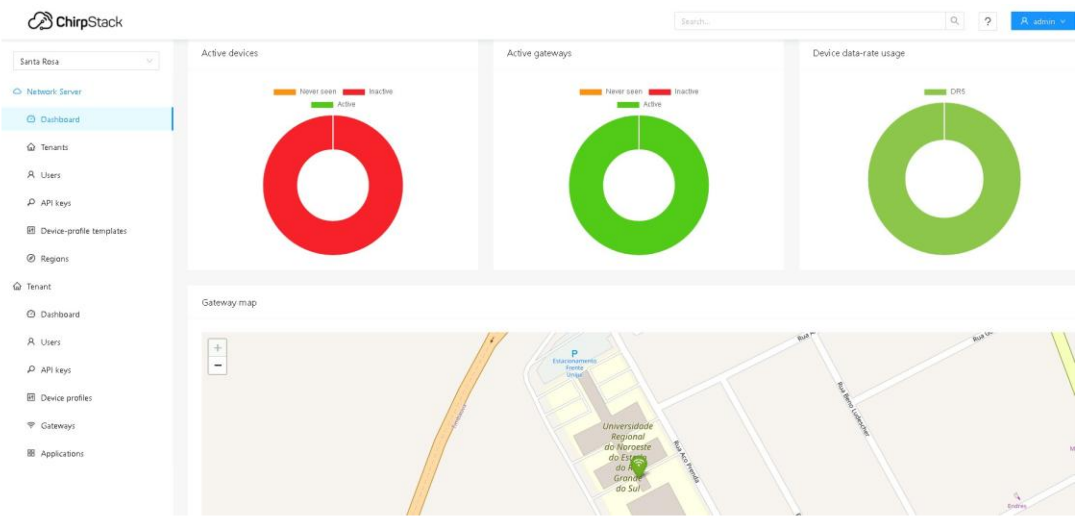
For the management of the various gateways and sensors, the ChirpStack software was defined. It is an open-source LoRaWAN Network Server, Join Server and Application Server which can be used to build and manage private or public LoRaWAN networks. Figure 4.5 presents Chirpstack and a real-time view of the status of gateways and sensors. The dashboard presented is the beginning of the configuration of the LoRaWAN network covering the city.

Table 4: Server Hardware Specification

Hardware Features	Description
Model	PowerEdge R550
Processor 01	Intel(R) Xeon(R) Silver 4314 CPU @ 2.40GHz
Processor 01	Intel(R) Xeon(R) Silver 4314 CPU @ 2.40GHz
RAM Memory	256 Gb

SSD	1.77TB Raid 5 + HotSpare
HDD	7.28TB Raid 5 + HotSpare

Figure 4.5: ChirpStack Software for Santa Rosa LoRaWAN



4.1 Coverage area

One of the most crucial factors to make the city completely smart is to provide an infrastructure that reaches all locations, that is, the total coverage of the geographic area of the city by the LoRaWAN network signal. The process of choosing the locations considers the participation of the government entity (city hall), which made the Basic Health Units (UBS) available for the installation of gateways. The UBS are basic health care units distributed throughout the city, despite having more units in the central region, they exist in the rural area, totaling eighteen units.

The gateways and antennas to be used were presented in the previous section and, according to some experiments, they report that they have a range of up to fifteen kilometers in radius. The range of the antennas may change depending on the topography, barriers, trees, and among others. Considering the interference factors in the signal range, the distribution of the gateways considered the range of 7 km in rural areas and 3 km for the gateways positioned in the urban area of the city.

In the initial distribution, ten gateways will be installed with the approximate coverage shown in Figure 4.6. The largest circles represent installations with a coverage of 7km and the smallest, installations with a signal coverage of 3km. The other lines represent the geographic limits of the municipality. The possible overlapping of signal coverage is beneficial as it allows the sensor to send information to the gateway with the best signal, thus avoiding excessive energy consumption. Table 5 presents the gateways installation locations and the expected range for each one of them.

Figure 4.6: Gateway distribution map

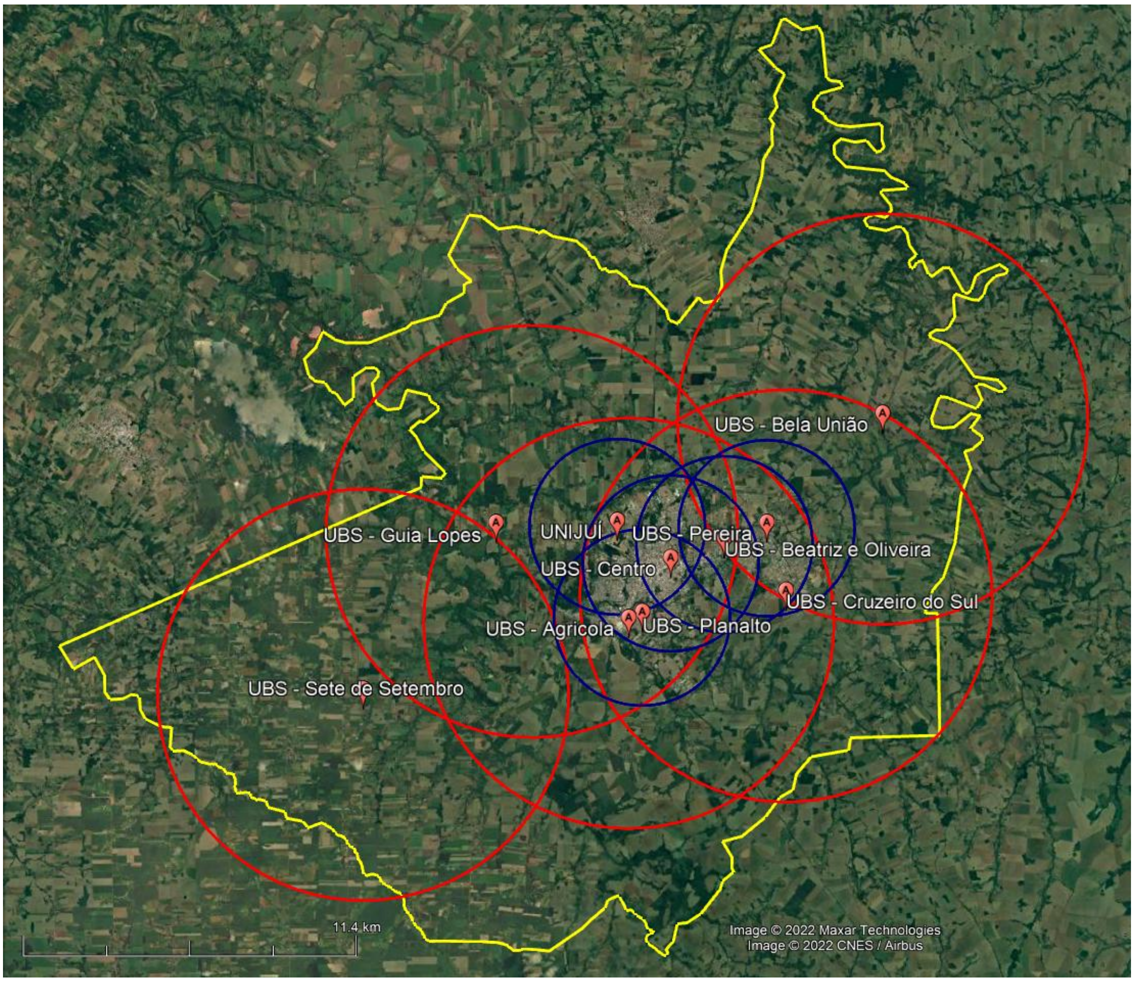


Table 5: Installation point and range

Installation Point	**Range**
UBS Agrícola	7 Km
UBS Bela União	7 Km
UBS Cruzeiro do Sul	7 Km
UBS Guia Lopes	7 Km
UBS Sete de Setembro	7 Km
University Campus	3 Km
UBS Beatriz e Oliveira	3 Km
UBS Centro	3 Km
UBS Pereira	3 Km
UBS Planalto	3 Km

This structure will allow the collection, transfer, and storage of information from sensors scattered throughout the city. Following the text, proposals for the use of different sensors in local scenarios within the concept of smart cities will be presented.

5. Smart services under development

The LoRa infrastructure proposed for the city of Santa Rosa consists of capturing data from different sensors compatible with the LoRaWAN protocol and transmitting the data through LoRa Gateways that cover the entire city (urban and rural) to the server (Storage), which is located at Unijuí University campus of Santa Rosa. This session presents four smart services that are in progress in partnership with the municipal government, undergraduate students in Computer Science and Software Engineering graduation courses, and, master and doctoral students in the Postgraduate Program in Mathematical and Computational Modeling at Unijuí.

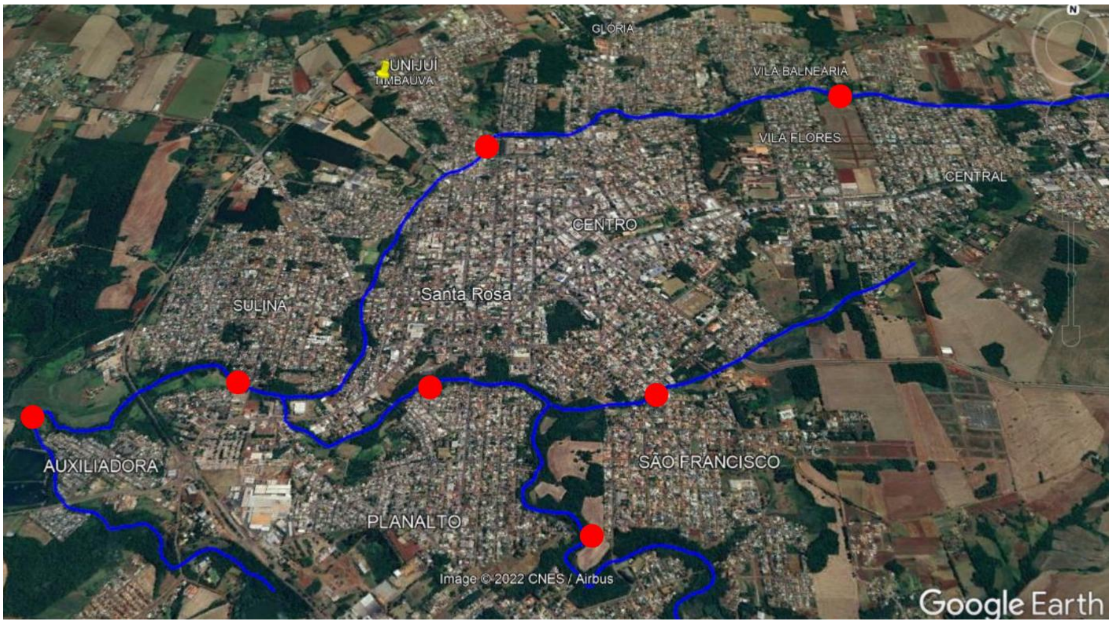
5.1 River Water Level Monitoring

The city of Santa Rosa is cut by a set of small rivers that recurrently cause disturbances due to flooding caused by the rains. These floods cause inconvenience to residents of areas close to rivers, damage to merchants, damage to public roads and risk to people's lives and physical integrity.

In one of the incidents, according to the Civil Defense, more than a hundred families had to leave their homes due to the volume of rain that caused flooding in the Pessegueiro and Pessegueirinho rivers. In periods of heavy rains, flooding occurs in several neighborhoods, the most affected being Vila Santa Inês, Sulina, Aliança and Auxiliadora.

The real-time measurement, transmission, and storage of river levels at strategically defined points will be a source of consultation and issue of alerts for the municipal government and the population residing in areas most prone to flooding. In addition, data is stored to compose a history of water levels throughout the year.

Figure 5.1: River Water Level Monitoring map



For monitoring the level of small rivers that cut through the city, Khomp brand sensors will be used. Figure 5.1 presents the suggested points for monitoring the elevation of rivers. The Liquid Level Sensor accurately measures the static pressure of the liquid proportional to its depth. It uses a high-performance piezoresistive diffuse silicon pressure sensor as the measurement. Figure 5.2 presents the Level Sensor for liquids up to twenty meters.

Figure 5.2: Level Sensor for Liquids

5.2 Monitoring of air and soil temperature and humidity

According to the report on the 2021 Conjuncture of Water Resources in Brazil (CRHB) by the National Water Agency (ANA) the demand for water in Brazil has been growing continuously over the years, with emphasis on the supply of cities, industry, and irrigated agriculture. The use for irrigation has increased from 640 to 965 m3/s in the last two decades and represents approximately 50% of total withdrawal by sectoral consumptive uses of water in 2020. There is estimated a 42% increase in water withdrawals over the next 20 years (up to 2040), going from 1,947 m3/s to 2,770 m3/s, an increase of 26 trillion liters per year extracted (ANA, 2022).

In the same report presented by ANA, the need to plan the use of water to avoid supply crises is reinforced. If, on the one hand, we know that one of the main factors for the good development of agricultural plants is the amount of water in the soil, on the other hand, we need to avoid wasting water resources.

For this, a comprehensive monitoring system can provide subsidies for farmers to decide when irrigation is actually necessary or when the process can wait. This system collects the values of soil humidity sensors and atmospheric sensors (temperature and relative humidity), continuously, consolidating them on a daily basis.

Seeking uniformity in the data within the municipal territory, the sensors will be distributed equidistantly, making it possible to generate a map of soil temperature across the entire area of the municipality. It is planned to install 40 sensors in the rural area, spaced approximately 4 km. Figure 5.3 presents the sensor distribution map.

In the urban area, the same system provides information for the maintenance of squares and parks in the city, drawing attention to the need for irrigation of trees or flowers. Figure 5.4 represents the soil temperature and humidity sensor.

Figure 5.3 - Map of Air and Soil Temperature and Humidity Sensors

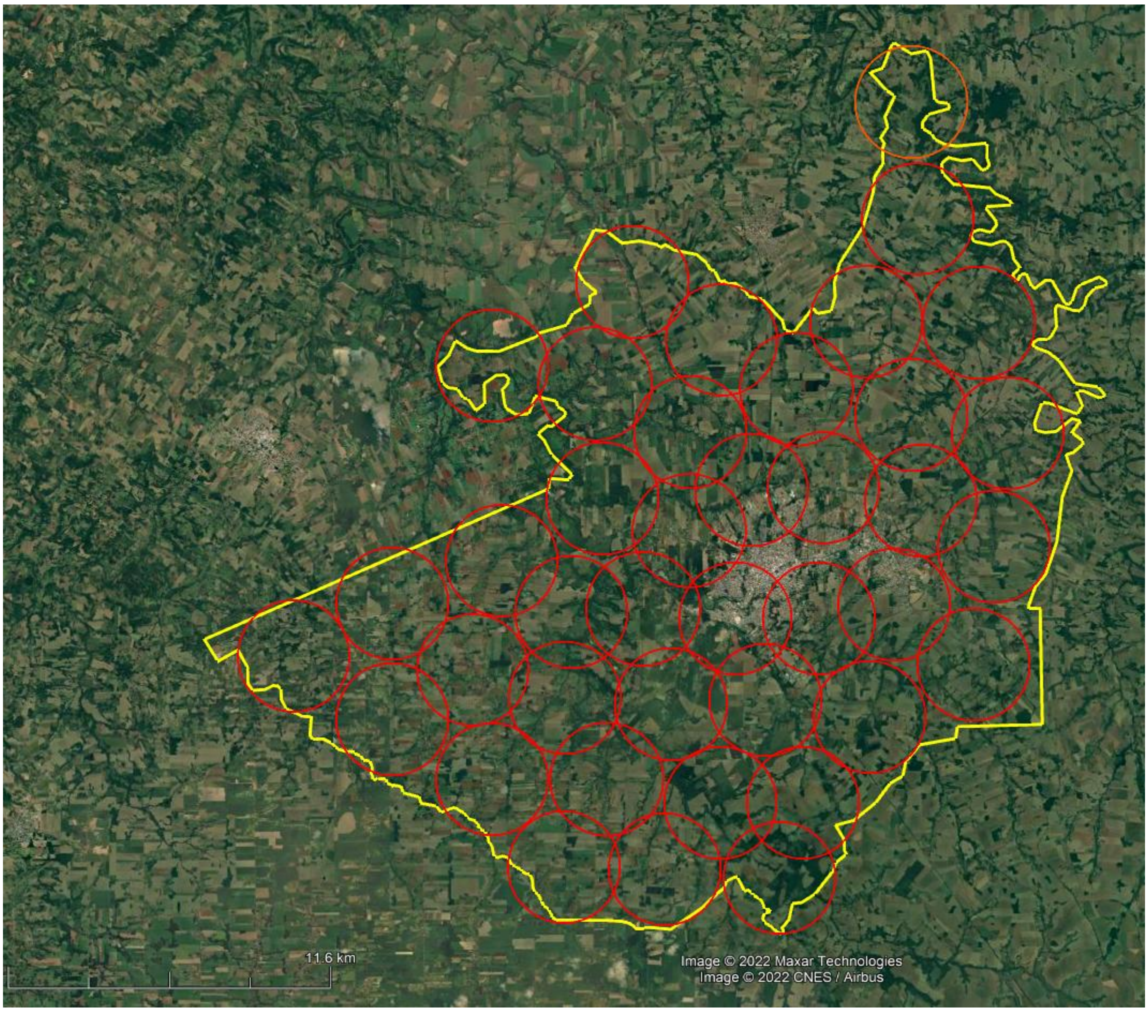


Figure 5.4 - Soil Humidity Sensor Module

5.3 Climate Monitoring

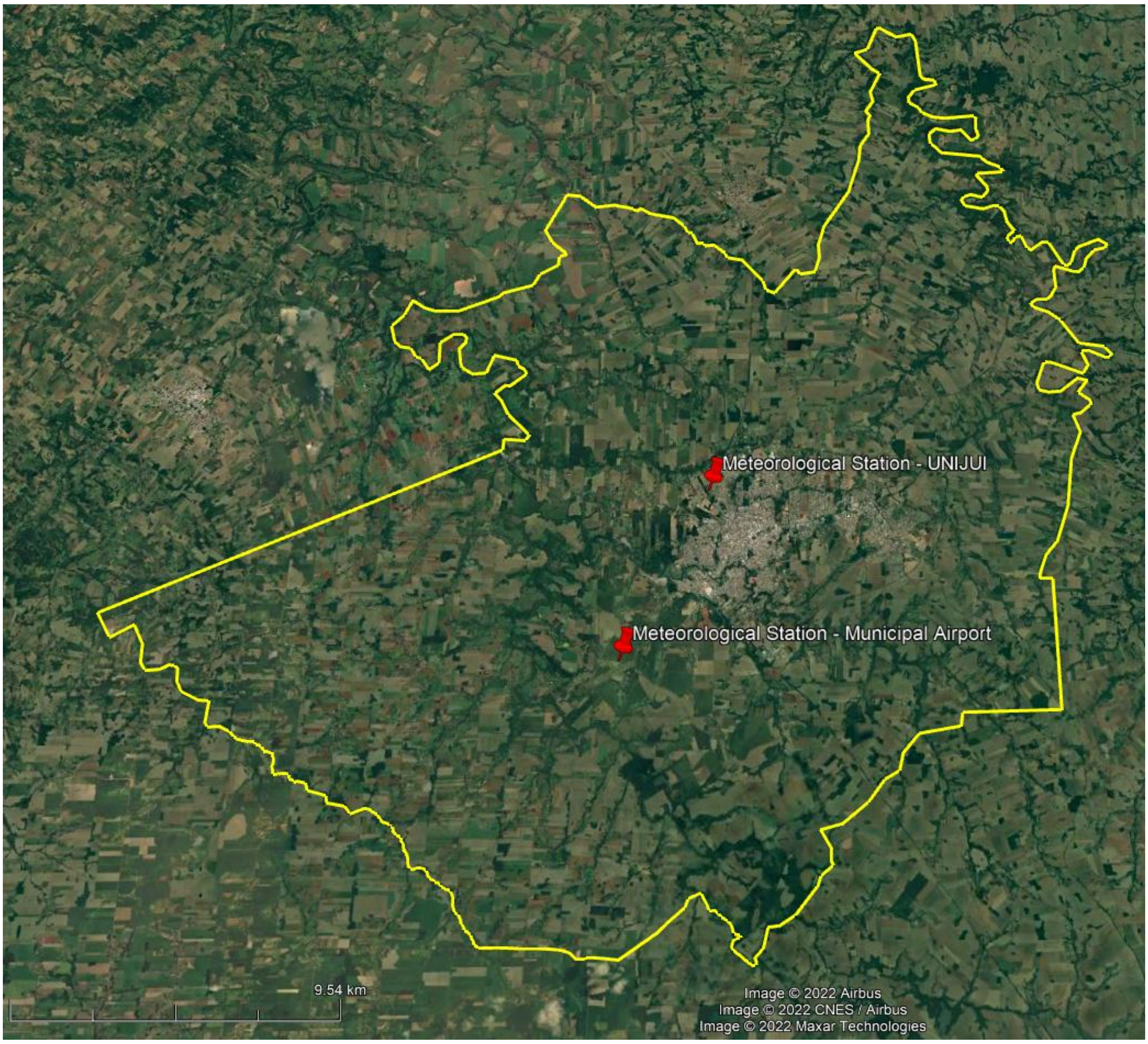
Climate monitoring is important for various sectors of society, especially for the agricultural field, indispensable for planting and fertilization decisions, in addition to assisting in the rational use of water for irrigation. In addition, the city's civil defense can benefit from information that helps in its planning.

To monitor the climate in the city of Santa Rosa, two meteorological stations will be installed. Figure 5.5 presents the meteorological stations with sensors that capture data about wind direction, wind speed, pluviometer, temperature, moisture, UV radiation and atmospheric pressure.

Figure 5.5 - Khomp Meteorological Station

Due to the characteristics of the sensors present in this meteorological station, their installation requires an appropriate location, so that they do not suffer interference. The intended locations are the municipal airport and the university campus, which also make it possible to distinguish between monitoring in urban areas (university) and monitoring in rural areas (airport) (Figure 5.6).

Figure 5.6 - Meteorological Station Map



5.4 Air Quality Monitoring

When we talk about air pollution, we immediately associate it with respiratory and cardiovascular diseases, but the effects on the health of people and animals may not yet be fully known. According to Costa et al. (2020) pollution can negatively affect the brain and contribute to central nervous system diseases. The authors list several studies where exposure to air pollution appears to be associated with markers of neurodegenerative diseases such as Alzheimer's and Parkinson's and/or relating pollution to neurodevelopmental disorders, including autism spectrum disorder.

Air pollution is composed of particulate matter (PM) which is a mixture of solid and liquid particles that are suspended in the environment. An important contributor to PM is traffic-related air pollution, mainly attributed to diesel exhaust. Particulate matter (PM) is classified into coarse, fine and ultrafine, with PM2.5 being a method used to describe pollutant levels both in outdoor and indoor environments. PM2.5 are fine particles that have a diameter of less than 2.5 micrometers and remain suspended in the air for a longer time. Due to their size they can travel deep into the respiratory tract, reaching the lungs and entering the bloodstream.

To monitor pollution in the city of Santa Rosa, a Khomp brand sensor (NIT K72623-LO) with micro particle measurement capabilities (PM2.5) will be installed. This same sensor allows the monitoring of noise, temperature, and air humidity. Figure 5.7 shows the pollution monitoring sensor being adjusted in the laboratory prior to installation in the final location. Power is via battery and has a solar panel to maintain the charge

Figure 5.7 - PM2.5 Sensor

As the burning of fossil fuels by automobiles is one of the main causes of air pollution, the sensor will be installed in the central area of the city, next to the police station (Figure 5.8).

Figure 5.8 - Air Quality Monitoring Sensor Map

6. Expected Smart Services for the near future

The implementation of a LoRa infrastructure in the city of Santa Rosa provides the planning of new intelligent services to be developed for the near future. This section describes 9 possible smart services that can be implemented in the municipality of Santa Rosa using the LoRa technology and sensors compatible with the LoRaWAN protocol.

6.1 Smart bus tracking system

There are several applications for monitoring public bus transport using LoRa technology. For example, in Nagoya, Japan, it was possible to find the location of buses using Arduino and GPS modules combined with LoRa at bus stops (Boshita, et. al, 2018). Buenos Aires and Córdoba, both in Argentina are cities that already have LoRa networks implemented with GPS and LoRa modules (Gríon, et al., 2017). The work of James and Nair, 2018 propose a public transport tracking in India using the LoRa network and GPS. The authors use LoRa wireless transmission for communication between bus stops and a base station. RF Receivers are placed at the bus stop and relay this information to the server via LoRa communication.

The movement of buses can be affected by unknown conditions as the day progresses, such as heavy traffic, weather, traffic jams, mechanical problems, among others. If people traveling by bus get the exact location of the bus and approximate arrival time based on normal traffic conditions, it will increase reliability in public transport.

Public transport in Santa Rosa is provided by bus only. The buses travel through the city's neighborhoods on 60 predefined routes. The transport company travels on all routes using a fleet of 43 buses. Routes and timetables are available on the company's website. The proposed infrastructure for the city of Santa Rosa is to cover the entire city (urban and rural) with LoRa

Gateways. This allows the buses to be equipped with integrated GPS and LoRa modules to capture their position in real time. The positions are transmitted through the LoRa Gateways to the data server located on the Unijuí campus, Santa Rosa.

The implementation of a bus tracking system in Santa Rosa allows monitoring the location of buses in real time from smartphones, computers and mobile devices in general. This service can optimize the waiting time at bus stops and can improve the organization of citizens' daily activities.

6.2 Smart school bus monitoring system

Infrastructure for monitoring school buses and public transport are similar. In addition to the applications that use LoRa technology already mentioned in this section, there are several works that specifically focus on tracking school buses. An example can be seen in the work of Kanaan, et al., 2018 which propose an integrated system for tracking and monitoring school buses using LoRa technology at the Islamic University of Lebanon (IUL). The goal is to optimize student waiting time at bus stops. Among the services, the authors propose an estimate of the arrival time of buses to the university. Kadam, et al., 2018 proposes a system to track public buses using GPS (Global Positioning System) to inform the user of the estimated time of arrival. The location of the bus can be tracked by the public using the Android app which contains the number of buses, bus routes, bus stops and bus timetables.

In Santa Rosa there are 68 schools divided into 4 categories: private, municipal, state and federal. In this distribution, 11 schools are private, 23 are municipal schools, 32 are state schools, and 02 federal schools. The municipal hall of Santa Rosa only provides free public transport for students at the municipal schools through 11 buses. The buses travel through 14 Routes that take students from rural and urban areas to schools. After classes are over, buses take students to their homes.

The implementation of a school bus tracking system in Santa Rosa can help parents and students who live in rural areas and away from bus stops to reduce waiting time, especially on rainy and cold days. In addition, parents can monitor their children's return home, increasing family security. School bus tracking can use all proposed LoRa infrastructure for public bus transport monitoring.

6.3 Intelligent IoT systems for traffic management

Traffic congestion is one of the problems that occur in urban cities with the number of vehicles increasing every year. Using multiple sensors, the number of vehicles along the road can be monitored and the level of congestion can be estimated. There are many technologies and methods that are being tested and used around the world in the effort to track or detect vehicles at an intersection. An example is the LoRa technology which can serve as an infrastructure to monitor the traffic light congestion area. LoRaWAN protocol compatible sensors can be accessed over long distances using low operating power. In this way, Nor et. al, 2017 propose a congestion model based on readings from sensors compatible with the

LoRaWAN protocol in order to detect the presence of the vehicle and increase the accuracy of data collection. The collected data is transmitted through the LoRa network to the server.

In 2022, Santa Rosa has approximately 60,000 vehicles registered with the traffic department of the state of Rio Grande do Sul. In addition to the high number of vehicles, compared to the number of inhabitants, the city of Santa Rosa has numerous intersections, traffic lights and roundabouts. Congestion at peak times is inevitable, as there is no real-time monitoring of vehicle flow. Our proposal is to monitor the flow of vehicles through LoRaWAN sensors with the objective of informing in real time the places of congestion. With this information, it is possible to synchronize traffic lights and the flow of vehicles in order to avoid congestion. In addition, the driver can be informed in real time which are the most congested places.

6.4 Public Garden and Park

Climate change turns to smart city concepts, as they can harness the potential of advanced information technologies to conserve scarce natural resources and to maintain irrigated parks and gardens. For example, in Frankfurt, Germany, a scientific research approach was taken to develop an intelligent irrigation system for urban trees. It was described how IoT and data analytics can contribute to sustainable and smart irrigation. Several specialists participated in this project, including representatives of the municipal administration, IoT specialists and botanists. LoRa technology was used for the transmission of sensor data, initially 18 sensors were installed in eight trees (Gimpel et. al, 2021).

Santa Rosa is characterized by a tropical climate where, especially in summer, the heat is intense, reaching the mark of 45 degrees Celsius. This effect causes the vegetation in the city's parks, including flowers, lawn and trees, to dry up or even die from lack of water. There are currently 44 parks that can be monitored in real time. The idea is to insert soil moisture and temperature sensors, so that city managers can be notified of the need to irrigate the place. Another possibility is to automatically trigger a controlled and intelligent irrigation system, based on information on soil temperature and moisture. With this, the amount of water can be controlled.

6.5 Noise monitoring systems

Noise mapping is a strategic action plan that visualizes noise pollution in real time in our cities The work by Liu et al, (2020) discusses in detail the benefits of a noise map for cities, as well as describing technical challenges using mobile sensors and acoustic sensors. The use of noise sensors can help municipal managers to identify different types of sound. For example, the noise of an accident between vehicles, gunshots, calls for help, sound limits in cars, among others.

The installation of noise sensors in buildings, schools and offices, can increase the security of the places. In addition, when noise sensors are combined with temperature and brightness sensors, it is possible to detect whether a lamp has been turned on or even an air conditioner, which can help reduce costs. On the Unijuí campus in Santa Rosa, a combination of noise, temperature and light sensors compatible with the LoRaWAN protocol will initially be installed in the classrooms in order to help university managers monitor the environments.

6.6 Smart Bike sharing

Changing mobility behavior in cities can help reduce CO2 emissions, as it minimizes the use of motor vehicles such as cars and motorcycles. In addition, healthy habits such as walking and cycling improve the population's quality of life.

The work of Torres, et al., 2021 propose a bicycle tracking system based on LoRa technology with the objective of promoting the use of this type of transport at the Polytechnic Institute of Viana do Castelo, Portugal.

Our proposal is similar to the one implemented in Viana do Castelo, however we aim to use the bicycle path in the municipality of Santa Rosa, which has about ??? Km, inserting low-cost GPS sensors into bicycles made available by the municipal government, the private sectors or social entities. Bicycles monitoring can use the LoRa Gateways infrastructure to transmit data to the server. With this, it will be possible to monitor in real time various information, such as bicycle location, usage time, route and speed.

6.7 Smart parking system

One of the significant problems faced in today's society is the increase in the number of vehicles and traffic congestion, mainly due to the unavailability of sufficient parking lots. This has become a big problem in medium and large urban cities where there is commerce in the city center. According to the Rio Grande do Sul State Department of Transit, Santa Rosa has approximately 60,000 vehicles. At peak times, parking spaces are not available for all cars.

An intelligent parking system helps to optimize waiting time and organize citizens' daily lives. With a heat map indicating the number of available parking spaces, it can help in the decision to leave the house with the vehicle or through another type of transport. This reduces the emission of polluting gasses and can also reduce the probability of traffic accidents. It is possible to implement this system through the use of LoRaWAN ultrasonic sensors as shown in the works of Kodali et al., 2018 and Tung, et al., 2019. The smart parking system in Santa Rosa can utilize the transmission infrastructure provided by covering the entire city through LoRa Gateways.

6.8 Smart public lighting monitoring

The installation of smart meters and luminosity sensors for monitoring public lighting provides easy access to measurements of electrical variables and lighting levels, which helps the public manager to control public spending (Sánchez, et al, 2020; Tung et al., 2019; Muthanna et al, 2018).

In the city of Santa Rosa are 10,000 streetlights distributed on the streets. Currently, traditional streetlamps are automatically turned on or off based on the timer or day/night sensor. The considerable number of lamps requires attention from the maintenance team. However, it is difficult to locate and replace damaged lamps, because often the maintenance team is not notified. As a result, many streets become dark, causing inconvenience to citizens. The challenge of this project is to identify in real time which street lighting lamps are damaged to optimize the waiting time of maintenance teams and improve the quality of service.

6.9 Smart public waste container monitor

Cleanliness is a key issue for modern cities. The overflow of waste containers (bins) in public areas creates unhygienic conditions and can induce numerous diseases in the population. To avoid this problem, recycle bins and residues management can be modernized using the Internet of Things (IoT). An example is the work of Ziouzios & Dasygenis (2019) who proposed the use of ultrasonic sensors and LoRa technology to estimate the level of residues in each public bin.

In Santa Rosa, there are 400 public bins distributed by 9 Neighborhoods of the city for the collection of dry residues and organic residues. The location of the container is also valuable information for the public manager. The proposal of our project is to distribute ultrasonic sensors with GPS compatible with the LoRaWAN protocol with real-time transmission through the LoRa network. The notifications aim to help the manager to increase the efficiency of garbage collection.

7. Final Remarks

This chapter presented a smart city infrastructure being developed by Unijuí University in partnership with the public administration of Santa Rosa. This infrastructure is the result of the project that was granted BRL 1.321.568,22 to create a large development laboratory, called Smart LiveLab, through notice SICT nº 04/2021 TEC4B. The city of Santa Rosa was covered with LoRa technology provided for the installation of LoRa Gateways. In short, the LoRa infrastructure consists in capturing data from different sensors compatible with the LoRaWAN protocol and transmitting the data through LoRa Gateways that cover the entire city to the server (Storage).

After the implementation of LoRa infrastructure in the city of Santa Rosa, new services can be planned and developed to attend to the demands of society. In this sense, this chapter proposed nine possible services to be developed, such as smart bus tracking system, smart school bus monitoring system, intelligent IoT systems for traffic management, monitoring system of temperatures for public gardens and parks, noise monitoring systems, smart bike sharing, smart parking system, smart public lighting monitoring, smart public waste container monitor. Other services can also be implanted using the LoRa infrastructure of the city.

Motivated by the technological advances of recent years, mainly in relation to sensors, the internet, and artificial intelligence, it is possible to observe a tendency of cities to join the movement of becoming smart cities, receiving public and private investments to build such infrastructures. In this context, the city of Santa Rosa becomes another Brazilian city to have a LoRaWAN infrastructure, making it possible to provide smart services to the population both in rural and urban areas. It is important to emphasize that this chapter described an inclusive project open to the whole society that has a clear roadmap of new services that will be added in the future to increase citizen participation, make the city more dynamic in terms of the use of resources, and improve aspects of health and safety of the city.

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