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RSSI performance of LoRa, BLE, and WiFi sensor nodes in an interoperable IoT system.

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***Abstract*—** This paper shows the process of designing and implementing an interoperability system for the Internet of Things (IoT). It integrates into a processor (embedded system Raspberry Pi3), the access interconnection to the standards IEEE 802.15.4 - LoRa, IEEE 802.15.1 - Bluetooth LE (BLE), and IEEE 802.11.a, b, g - WiFi. This set of standards corresponds to the most used in IoT systems. The embedded system is configured as an IoT hub device on the Azure platform. It handles a model view controller architecture; the storage and display system is of the web type. The response of each sensor node variable is displayed under the concept of real-time, together with the location and the received signal strength indicator (RSSI). The results of the coverage tests in external and internal environments are displayed. The maximum range is 313 meters in LTE and LoRa interoperability, LTE and BLE 22 meters, LTE and WiFi 44 meters. The maximum coverage perimeter is 979 meters, BLE 70 meters, WiFi 136 meters.

Keywords: IOT, Azure, coverage, interoperability, interconnection, RSSI.

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I. INTRODUCTION

In IoT, the message from the sensor nodes must be delivered instantaneously between neighboring nodes in the IoT-enabled network. For this to happen, the sensor nodes must be in a suitable transmission range generally determined by the Received Signal Strength Indicator (RSSI) level. A literature review reveals that not much work has been done on the concept of IoT and the exploration of its applications. The main idea of the Internet of Things is to interconnect multiple analog and digital electronic devices of homogeneous and heterogeneous nature so that they can efficiently deliver information. IoT is considered a rapidly evolving concept. [1]. The Internet of Things is becoming increasingly relevant and refers to the interconnection of billions of smart devices. The increasing number of IoT devices with heterogeneous characteristics requires future networks to evolve to provide a new architecture to support the expected increase in data generation and storage. The performance of architecture could focus on two parameters latency and network traffic. [2]

The concept of interoperability has been defined as "the ability of two or more systems or components to exchange information and use the information that has been exchanged" [3]. In the last decade, Internet of Things (IoT) technologies have matured in both hardware and software for large-scale implementation, and so has the concept of smart cities. Active IoT elements are essential for Smart City implementations. One framework for functional real-time Smart City ICT is the powerful application program interfaces (APIs) used to interact between applications, services, and devices. APIs help build functional interoperability between many systems. Data visualization and storage can be collected from various platforms, cloud services, and end-user applications. [4]

JavaScript is one of the most widely used programming languages for API development. It allows us to create multiple interactivities as in [5] to achieve inline comments translation and real-time feedback. Because JavaScript is a decision-making programming language, we can control the attributes of HTML and CSS to make a flexible and intelligent web page. Incorporating responsive web in web-like environments provides users with an environment that supports distributed interactions using web platforms on mobile devices. [6] JavaScript applications are widely used in various scenarios, including client web applications, mobile applications, and server-side applications. Due to its cross-platform support, JavaScript has become the core technology for web platforms such as social networks. [7]

PostgreSQL is an open-source database system developed by the University of California, Berkeley. PostgreSQL is one of the world's leading relational databases and is widely used in many fields. PostgreSQL is based on a relational data model that follows the international SQL standard. PostgreSQL combines the operational capabilities of structured query languages with the data processing capabilities of procedural languages to efficiently support large-scale data access and storage. PostgreSQL is written in C and uses a multiprocess model to support high concurrent and efficient access. A big data service platform can be applied to the network system to solve better the problems of storing, computing, and analyzing massive data in near real-time. [8] The cloud-as-a-service model allows the user to utilize the provider's resources. We also know it as a distribution model Service Delivery Model of cloud computing. It comprises the three basic pillars SaaS, PaaS, and IaaS. For this case (PaaS), Platform as a Service is mainly for developers implementing their software solutions. The main goal of preconfigured environments is to facilitate the creation of new applications and simplify their deployment in production and runtime maintenance. These environments help eliminate purchasing middleware or service delivery software [9] separately. An example of a cloud platform as a service (PaaS) is Heroku. Heroku is characterized by supporting multiple programming languages used for the web application deployment model. It is based on a managed container system with integrated data services and an ecosystem for deploying and running modern applications. [10]

The largest Internet of Things (IoT) cloud platform providers are Microsoft Azure, Amazon Web Services, and Google Cloud. These three companies are recognized as the most important companies that agreed to join the IoT domain and focus on improving services on their IoT platforms. Microsoft Azure has many tools, especially data visualization tools. The study described in [11] argued that Microsoft Azure and AWS were the leading platforms in the market, and in a situation where the user was interested in analytics, visualization, data storage, and monitoring in addition to messaging in the device cloud, Microsoft Azure was the best choice as it had more options than the other two.

WebSocket is a lightweight real-time protocol that enables reliable and fast communication between two clients. The work [12] showed a method to play a remote video with less than 2 seconds delay in a 4G / LTE network, using reliable web connectors or WebSocket connection between the two parties. However, if the network quality conditions are reduced, the latency increases.

This article describes the implementation of an interoperability system between cellular networks and wireless technologies used in IoT environments, initially presenting the theoretical framework followed by the methodology or procedures, the results, analysis and interpretation, and finally, the proposed solution and improvements, conclusions and recommendations.

II. THEORETICAL FRAMEWORK

The deployment of the second and third generation, 2G and 3G, mobile communications systems in the country is very high. However, the interest of many research organizations is focused on future standalone systems such as 5G and LTE. With 4G technology, a range of new services and models are available. These service interfaces and models need to be analyzed and evaluated with existing cellular communication systems which are classified according to generation. [13]. The first-generation cellular networks were basic analog systems designed for voice communications. Subsequently, a shift was made to the first data services, and spectral efficiency was improved in 2G systems using digital modulations and time division or code division multiple access. Third-generation networks (3G) introduced high-speed internet access and highly enhanced video and audio transmission capabilities through the use of technologies such as wideband code division multiple access (W-CDMA) and high-speed packet access (HSPA) that are intended to extend and improve the performance of conventional 3G mobile telecommunications networks using WCDMA protocols. An enhanced 3GPP (3G Partnership Project) standard, HSPA+, was launched in late 2008, with subsequent worldwide deployment starting in 2010. HSPA has been deployed in over 150 countries by more than 350 communications service providers in multiple frequency bands. New applications and new systems are implemented to improve the characteristics of current methods and thus replace existing techniques, but without losing compatibility with previous generation systems, such as those originating after the third generation called B3G or 4G. [14]. Technically, 4G means a single integrated, IP-based environment for all telecommunication needs, including voice, video, broadcast media, internet, and IoT-oriented applications using wired networks. Users are the central focus of 4G, and as a central focus users via smart terminals can get simple broadband access to a range of services that take into account their personal preferences [15].

a. Wireless communications

I. WiFi 802.11B/G/N

With the continuous development of IP applications, WiFi networks are becoming more and more common. So-called WiFi access points (AP) have become key nodes for strengthening data security and user access control. The WiFi access point is initially an intermediate forwarding node, and it can acquire all data for user interaction. On the other hand, WiFi access points connect to the ISP, allowing users to access or not access the network. Thus they are the first barrier to controlling malicious user access to the network and are an important basis for access control [16]. The IoT concept requires devices to be connected to the internet. The new era of the Internet of Things (IoT), referred to as uniquely identifiable objects and represented in an "Internet-like" structure, has played an important role in our daily lives in terms of intelligence and automation as convenient ways. Establishing IoT connectivity as an intelligent system to link objects to the internet network generates a large volume of data that needs management and control. As technology advances, IoT management and automation system presents new applications and is applied in many basic infrastructures such as sensor metering systems, electricity, gas, and water management according to the convenience of individuals and organizations. [17].

II. Bluetooth ble IEEE 802.15.1

Bluetooth Low Energy (BLE) devices have been included in the Bluetooth standard since the Bluetooth 4.0 specification and define two different network topologies for transmitting data: tethering and broadcasting. Due to their characteristics, each topology is appropriate to determine use cases with different strengths and weaknesses. Later versions of BLE (4.1, 4.2, and 5.0) maintain these topologies and enhance them by allowing the combination of different roles. However, these latest improved versions are not implemented in most IoT devices, so if you intend to work with IoT applications, it is advisable to use BLE 4.0 devices. The topologies available in the BLE standard are Connection topology and Broadcast topology. [18].

III. LoRa IEEE 802.15.4

With the growing interest in IoT, various technologies are being developed to address the requirements for the integration of smart devices for low power consumption and wide area signal coverage. Some of the LPWAN technologies are still under development; however, technologies such as LoRa and SigFox are already widely available in the market. Regarding low-cost operation, LoRa-based networks present an advantage over SigFox-based networks, considering the need for a SigFox subscription for each device, resulting in operating expenses for each connected device. However, LoRa networks need to configure a proprietary network, as suggested by [19], in a solution for evaluating a Smart City network. A great deal of work has been done since the 1960s to understand radio wave propagation in the forest and urban environment. It is possible to witness the total breakdown of the communication link due to external factors. Much more research is needed, especially for site-specific empirical work and those limiting the practical application of existing research work, as described in [20], oriented to transmission in forest environment areas.

b. Interconnectivity between networks

With the widespread use of smartphones, mobile data traffic is growing exponentially. This fact poses a major challenge to mobile operators' capacity, whose infrastructures cannot support all the additional traffic generated by users of this type of IP device. Emerging alternatives currently being considered as part of the 5G (fifth generation) network evolution include migrating mobile data traffic from the operator's infrastructure to users' offloading devices, leveraging the connectivity capabilities of today's smartphones to transmit data via device-to-device (D2D) communications, machine-to-machine (M2M) communications and the integration of cellular, WiFi and ad-hoc communications. Wireless access must include services to any object linked to a connection. This concept is often referred to as the Internet of Things (IoT). Devices such as smart utility meters, digital signage, in-vehicle infotainment systems, WSN (Wireless Sensor Network) sensor networks, mobile networks (LTE), 5G migrations, and protocols must analyze the compatibility of IoT-oriented technologies. [21]. The paper [22] presents the basic structure of an IoT system. It describes a large number of sensor types and possible interconnectivity applications, and the article allows us to analyze the great potential of IoT-type applications. It describes different sensor applications and suggests which type of IoT application is recommended for each type of sensor.

III. METHODOLOGY OR PROCEDURES

This work consists of designing, constructing, and evaluating an interoperability system between cellular and wireless IoT networks. The methodology consists of four phases. Initially, a conceptual design, a second phase with the functional design, phase three comprises the system's implementation and configuration, and finally, the validation and testing phase. Figure 1 describes the methodological phases used for the proposed interoperability system.

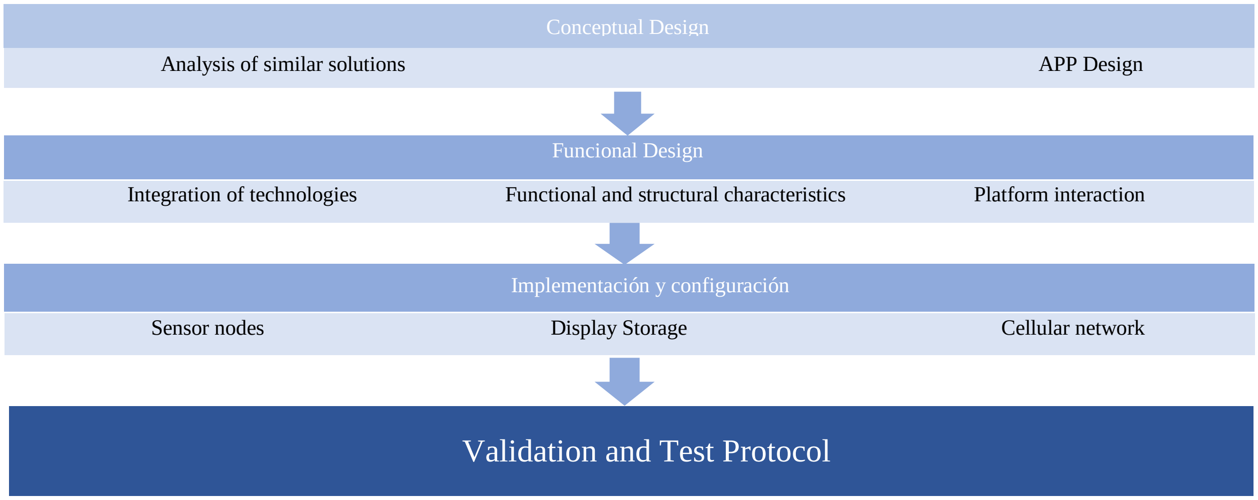

Figure 1: From top to bottom, phases of the proposed methodology for developing the system and interoperability study.
Source: Prepared by the authors.

a. Conceptual design

The functional prototype is a technological development that aims to generate new research ideas in the IoT area. It should enable emerging technologies to interoperate, solve specific needs, and help guide technological developments requiring wireless telecommunications in home and business end-user environments.

1. Analysis of similar solutions

The design process should involve the search for similar developments aimed at developing technological surveillance of the solution. In the article [23], the simulation necessary for implementing an IoT wireless sensor network using 6LoWPAN technology is presented. The sensor node of the WSN is composed of a sensing module, processing algorithms, and communication elements. Wireless Sensor Networks (WSNs) tend to integrate with IoT to interoperate with heterogeneous communication technologies. Currently, the Internet access by WSN has two ways to integrate an IoT network. The first is a connection of an independent WSN and Internet access through a single gateway, commonly called Gateway, that generally uses cellular technology. The second form is based on a hybrid network formed by independent networks, where each sensor node can access the internet.

The concept of smart sensors is needed in real-time variable sensing for IoT applications, e.g., pollutant index. The work [24] is proposed in Bangkok city. This design proposes the adoption of LPWAN sensors to monitor air pollution through the NB-IoT network.

Interoperability in a LoRa WAN and BLE network is addressed in the work of [25]. This work proposes a new dual-radio network architecture for IoT used in wildlife monitoring, and more extensive control over the trade-off between power consumption and range is achieved. Evaluation results indicate that the proposed dual network outperforms traditional systems using a single type of transceiver radio, i.e., LoRa or BLE. On average, LPWAN (LoRa WAN) power consumption was reduced by 97%. The architecture improved network lifetime by up to 99% for various packet traffic rates in the network. Interoperability between wireless technologies is necessary for IoT-type applications in work [26], and the implementation of wireless technologies (BLE) Bluetooth Low Energy and ZigBee is described. A Gateway or gateway developed for the interconnection of these two technologies oriented to an IoT type application is proposed to reduce costs, energy, and latency; interoperability is important for large-scale adoption of IoT. The main task of IoT is to collect sensing data from connected devices and send it to the webserver. ZigBee protocols are used to create a network environment with sensor nodes with low data rates, and BLE protocols are used to collect this information and transmit it at higher data rates.

The results of the implementation of LoRa wireless technology are presented in work [27], which analyzes the performance of the technology, taking into account the coverage in closed and open environments by modifying the configuration parameters according to each condition. The results conclude that in closed environments, the performance depends on the Gateway's distance and the structure of the enclosure elements; in open spaces, the distance is from 12 to 330 meters, having the Gateway in an enclosed space.

A modified LoRa WAN based on mesh networking and TEDS is proposed in [28]. Mesh networking improves coverage and facilitates deployment. With TEDS, the network collision rate is reduced especially for systems with many end nodes and need to collect event-driven data. In particular, it is suitable for battery-powered remote water and gas metering systems, simulated systems that require near-real-time capabilities, and street lighting control systems that require fast response from many nodes.

A solution for wearable environmental monitoring is described in [29]. A wearable IoT sensor node for security applications is called WE-Safe, and its goal is to provide early warnings for people working in extreme and hostile environments. The paper [30] presents a development based on air pollution detection sensors which are processed by a microcontroller and sent to a website via NB-IoT wireless communication. The system was designed for smart cities in Thailand; the website visualizes the air quality index graph and presents variables' results by configured sensors. The paper [31] describes implementing a microprocessor system, specifically the STM32F103RCT6; the microprocessor interacts with the serial port in which the electrochemical gas sensor is connected, performing a constant sending of data. The system can provide temperature, humidity, and PM2.5 particulate matter data. The NB-IoT module or GPRS module implements the connectivity, and the time-stamped data can be uploaded in real-time. In the paper [32], RSSI measurement is performed on a LoRa GW for indoor, suburban, and urban areas when the LoRa transmitter is in an indoor location or on an unmanned aerial vehicle (UAV). For an indoor environment, LoRa GW can receive packets if it is placed in the line of sight in the building. Drone height and antenna orientation play a crucial role in RSSI for the suburban environment.

Chapter 6 of the book [33] presents a wireless zigbee solution applied to a SCADA type solar energy system to monitor variables of interest. It comprises a storage system, a visualization system, and a network of sensors and actuators. The interconnection process between the wireless network and the server makes possible the acquisition, processing, and characterization of signals delivered to the server.

In [34], a system that proposes information traceability and an automatic collection system based on IoT is described. The acquisition is mainly composed of RFID sensing terminals, a bus-type structure, and a computer system for management. The results indicate that IoT-type systems significantly improve product quality and safety management capabilities.

Chapter 4 of the book [35] proposes an IoT type system for monitoring variables of interest based on a GHI microprocessor, reference G120, 32 bits, ARM Cortex-M3 type. The solution contains storage, reporting, and visualization system based on the interoperability between sensors connected directly to the electronic card and three technologies; satellite, third-generation cellular, and WiFi. The system only provides a backend to enable the creation of multiple frontends. Interoperable systems should be oriented to provide support services between them. Connectivity and compatibility are more basic concepts than interoperability. This deduction is based on the work of [36], which performs a comparative analysis of state of the art in the models found and existing architectural frameworks and describes the interoperability requirements for electric mobility. Its structure originates from the Smart Grid architecture model.

Body area sensor network (BASN) under the IoT framework has been widely applied for ubiquitous health monitoring; the paper [37] presents the WISE (IoT cloud-based health monitoring system) system for real-time health monitoring. WISE adopts the BASN (body area sensor network) framework. Most health monitoring systems require a smartphone as a gateway for data processing, visualization, and transmission. While in WISE, the data collected from BASN is transmitted directly to the cloud.

2. APP design

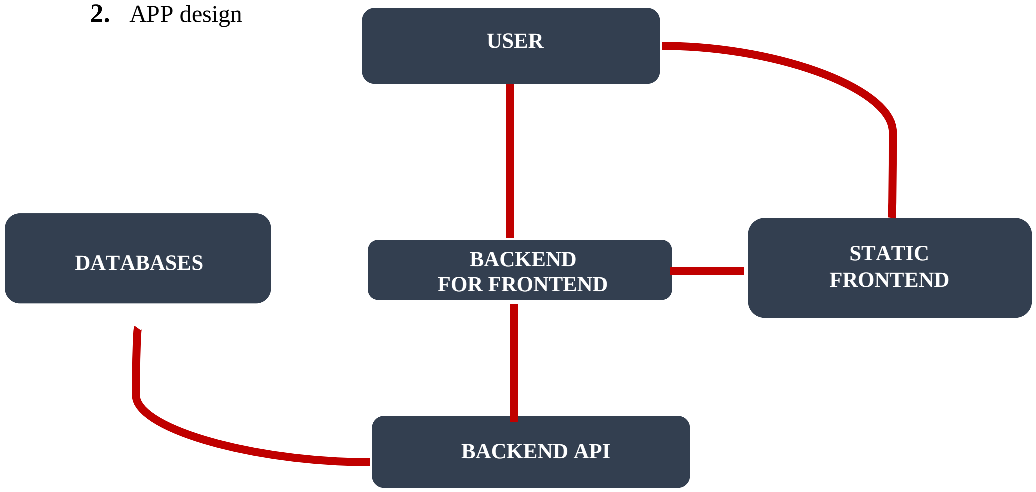

Figure 2: APP design based on the trend of modern web apps.
Source: Prepared by the authors.

The proposed conceptual design is based on modern apps. Modern PPPs tend to modify the system's components to find the best performance in their platforms. For the development of the system, the proposed conceptual design can be seen in Figure 2. The proposed design for the implementation is composed of the backend, which manages the processing unit and the storage unit of collected data. An API that allows interfacing with other applications and the frontend facing the browser. The most difficult challenge of IoT systems is to address the concept of "real-time" management coupled with the implementation required for the interoperability of multiple technologies.

For the development of the system, the data traffic coming from the hardware must be focused in real-time. Figure 3 shows the proposed design for the data flow to the implemented server. The server was developed in node.js, so the concept of websocket (web connector) must be incorporated through the javascript library called socket.io, which is selected for targeting real-time web applications and because it allows bidirectional communication between the client running in the browser and a server in the cloud.

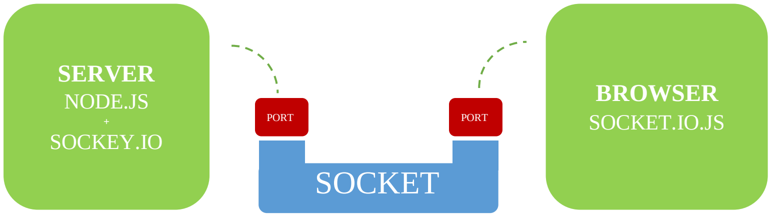

Figure 3: Data traffic to the web via web connectors.
Source: Prepared by the authors.

b. Functional design

Considering that this system intends to integrate emerging technologies aimed at IoT, it is proposed to develop the main processing from an embedded system based on microprocessor architecture for interaction with the user through an operating system.

1. Analysis of functional and structural characteristics.

- Architecture and platform evaluation and selection
- Incorporation of compatibility with mobile devices.
- The system must capture and interpret the necessary data
- Implementation of cloud storage function.
- Real-time graphical display of variables.

2. Technology integration design.

The design used is based on a Linux operating system operating on a raspberry embedded device, where the backend and frontend were implemented to facilitate visualization and communication with wireless systems, as shown in Figure 4. However, although the performance is better in the visualization, the web application presented instability and overheating in the storage process from the seventh minute of operation, performing management of readings every second in each technology.

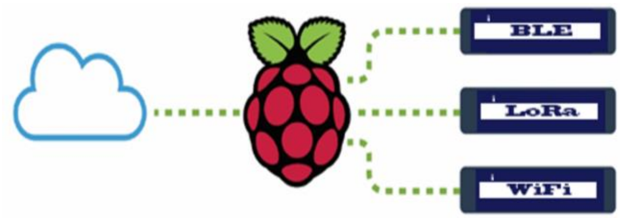

Figure 4: IoT wireless technologies.
Source: Prepared by the authors.

3. Platform interaction design.

The proposed prototype must interconnect the cellular technologies that provide access to the WEB platform and the wireless technologies WiFi, LoRa, and BLE. The proposed design is visualized from the process of interconnection and interoperability of both technologies and applications. The proposed design is visualized in Figure 5. The embedded system's interfaces do the interaction with the sensor nodes for the IEEE 802. 15.1 communication is established from the BlueTooth interface of the control system and the sensor node that implements Bluetooth low energy 4.0 (BLE). The IEEE 802.15.4 standard interacts from the USB port of the raspberry to a module that implements LoRa technology. Finally, the IEEE 802.11 standard is interconnected from the WiFi interface of the embedded system and a module that implements the IEEE 802.11 b/g/n standard.

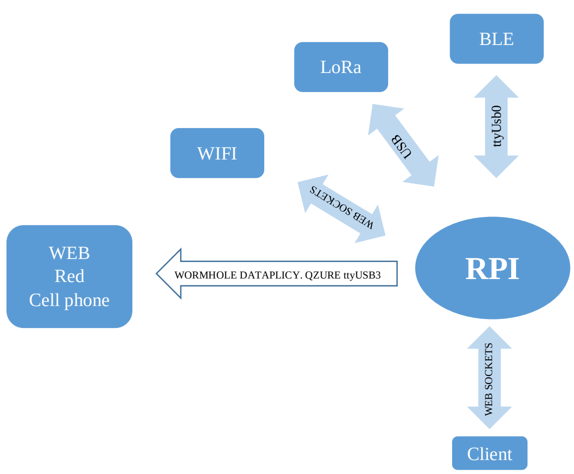

Figure 5: Functional design for platform interconnection.
Source: Prepared by the authors.

c. Implementation and configuration

The first step for the implementation is the selection of the hardware control system, microcontrollers, and embedded systems of 8, 16, and 32 bits were evaluated, on which web services were implemented for interaction through the post and get methods with HTML and CSS, looking for the management and reading of ports in this first step of evaluation, a Raspberry PI3 embedded system with the Raspbian operating system was validated as the best option.

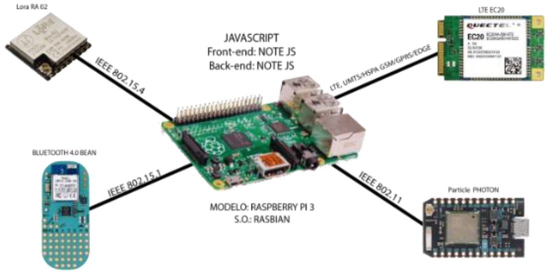

Figure 6: Projection for interconnection of IoT technologies.
Source: Prepared by the authors.

The hardware interaction for the LoRa interoperability system, Bluetooth LE 4.0 BLE, WiFi, and LTE, can be seen in Figure 6. This visualizes the Raspberry PI 3 as the main hardware management and control module that exchanges data with the selected devices for each standard.

Figure 7: Implemented interoperability system hardware.
Source: Prepared by the authors.

1. Cellular network

Connection to long-range networks is necessary to interact with devices and data servers for monitoring and analysis purposes [38]. The EC20 reference integrated circuit from Quectel Wireless Solutions implements GSM, GPRS, UMTS, HSPA, LTE, and GNSS of multiple constellations [39]. The implemented system operates via USB over the ttyUSB3 interface, and the console manages it by sending AT commands. The quectel module configuration provides an IP address when connected to the internet. The current peaks for the operation of the cellular module make necessary an additional 500 mA source and requires a cellular type antenna to improve the CSQ indicator, stabilize the reception and delivery of data, and incorporate an RGB led, which changes color to green when the network is available to establish a connection, as shown in Figure 8.

Figure 8: Cellular module for Gateway link.
Source: Prepared by the authors.

The interface to cellular networks is part of the operation of the gateway, the power supply system is autonomous, based on solar panels and rechargeable batteries. The control system's touch screen for monitoring and commissioning the system is shown in Figure 7. The GNNS module provides the geopositioning coordinates, and with the Google Maps API, the system's location can be displayed, as shown in Figure 9.

Figure 9: Google Maps API consumption view.
Source: Prepared by the authors.

2. BLE IEEE 802.15.1 sensor node

BLE (Bluetooth Low Energy) devices are included in the IEEE 802.15.1 Bluetooth standard since the Bluetooth 4.0 specification and can have two connection topologies. In the first connection topology, two BLE devices can establish a connection to exchange data permanently and periodically, and two roles are used in this topology: master and slave. Connecting a master device with up to 8 slave devices in a star topology is possible. This topology allows data flow in both directions; the slave devices provide notification and indication features to send data to the master. The second topology is called broadcast. A BLE device can use advertisement packets to transmit data to any BLE device in scanning mode located within its coverage range. In this topology, two roles are defined: sender and receiver. Due to the nature of this topology, the data exchange is unidirectional [18]. In the development of the system, the Bluetooth communication peripheral integrated into the raspberry is configured as the master device, connectivity was established, bidirectional data traffic, control and reading of devices, the module implemented as a slave is the LightBlue Been LBM 313, manufactured in Minneapolis by the company punch through during testing was shown robust, stable and very low power consumption, its power supply is made from 2.1v to 3. 3v, a 3.7v LiPo battery is incorporated, regulated to 2.8v and a 300mA - 5V solar cell charging system. A node.js library called been.js is used to control the device.

3. WiFi 802.11B/G/N sensor node

The WiFi access point serves as an intermediate forwarding node. Initially, it can acquire all the data for user interaction. On the other hand, the WiFi access points connect to the ISP, allowing users to access the network [16]. In the development, the integrated WiFi wireless connection interface in the raspberry performs as a router for data traffic and is configured using the routing tables to establish a connection between devices connected to a local LAN and the WAN network. The particle platform supports the selected WiFi device. It offers an integrated circuit based on the Cypress WICED architecture. It is commercially called Photon, framed in the Particle Photon family, and combines an STM32 ARM Cortex M3 microcontroller with the BCM43362 WiFi chip. The implementation of communication with this device requires the configuration of the features of the IEEE 802.11 standard and the routing tables iptables in the operating system for this preparation based on the work [40].

4. LoRa IEEE 802.15.1 sensor node

The propagation of the LoRa standard at 433MHz is located in the Ultra High Frequency (UHF) band and is detailed in the IEEE 802.15.1 standard [20]. LoRa technology was implemented using SX1278 transceivers, considering that they operate in a free spectral range, handle low power consumption and low cost, and feature the LoRa® long range modem that provides ultra-long range spread spectrum communication and immunity to interference. The technology is driven by the use of Semtech's patented LoRa modulation technique, which can achieve a sensitivity of more than -148dBm using a crystal and other complementary components such as propagation antennas, the propagation antennas used in the development are molex flex type for 433 Mhz.

5. Visualization and storage

The growing interest in using the Web as a platform for data sharing has motivated research on data publishing and consumption. [41] The main programming language implemented is node.js, inspired by javascript. The operating system installed is Linux Raspbian, and hardware interaction is achieved by using web sockets for communication through peripherals using the sockets.io library, as in the paper [42]. JavaScript applications rely on a JavaScript engine to execute their core logic and user interface (UI) modules. Bridging modules provide JavaScript APIs with system resources; thus, JavaScript code can invoke code from other native languages to access resources from other systems [7]. The particle API for WiFi and Google maps technology are consumed in the developed system. Initially, a solution was chosen in which the backend and frontend are continuously connected, and implementation of the requirement of a single-threaded concurrent model runs on embedded systems. The concurrent client-server model in the visualization process showed positive results in terms of latency. However, performing the data storage process presented overheating in the processor and instability in the web application after approximately seven minutes of operation, visualizing and storing data from the three sensor nodes every second. The final configuration of better performance was achieved on the Azure platform with the control device configured as an IoT hub, the storage was performed in the cloud, and stability was obtained in the application. The architecture is visualized in Figure 10.

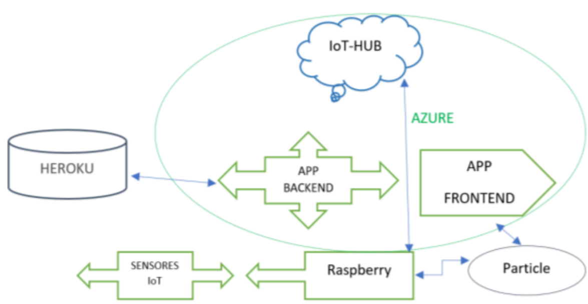

Figure 10: General architecture of the implemented application.
Source: Prepared by the authors.

IV. RESULTS ANALYSIS AND INTERPRETATION

A website can be hosted on a server and provide services requested by clients. Web servers consist of an operating system, a web page, and a memory space, clients can access a web server through an output to the internet [43], and several frontend clients can connect to the backend server at the same time, with many integrated and linked systems [44]. The system's frontend view on a mobile device and a computer is visualized in Figure 11.

To verify the operation, enter the browser and locate the web application located in the domain (https://interopview.azurewebsites.net/). The application shows the illumination levels measured in parallel in the three technologies and the RSSI and CSQ values.

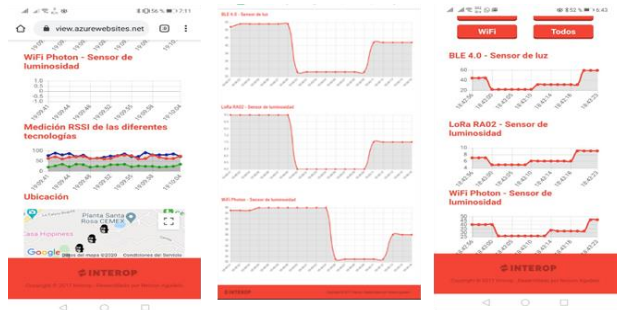

Figure 11: Frontend view of the developed WEB application.
Source: Prepared by the authors.

During the validation of the prototype, it was observed that cloud computing platforms such as Azure allow efficient management of IoT architectures and interconnection with web services, representing the concept of interoperability in applications. LoRa networks offer flexibility in a free spectrum, low cost (5 USD) approximately each radio device, and low energy consumption. The developed system allows its implementation in rural-urban areas and difficult access due to its energy autonomy and the future adoption of new technologies, services, and platforms.

a. Test protocol

1. Performance outdoor urban environment

A test run in an open space in an urban area is proposed to analyze the performance of the RSSI indicator, taking into account an urban scenario with obstacles to analyze the coverage of each solution. The gateway is elevated at 7.7 meters indoors, separated from the open space by a 7-millimeter glass to the north of the data acquisition. The sensor nodes are elevated from the ground by approximately one meter. Figure 12 shows the RSSI levels in dBm for each technology at the starting point of the test (RSSI: WiFi: -53 dBm, LoRa: -78 dBm, BLE: -67 dBm) separated by 0.3 meters for each node from the gateway.

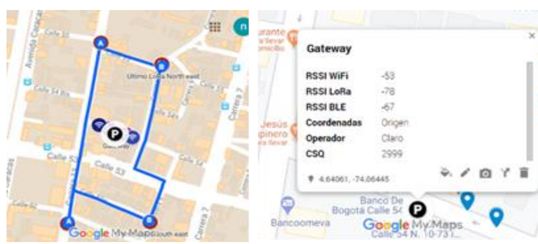

Figure 12: Node system location and gateway conditions.
Source: Prepared by the authors.

The proposed test route is described in Figure 12 at points A and B with the sensor nodes of each technology. The Gateway signal quality conditions are CSQ: 29.99 dBm, operator: claro, connected cellular network: LTE, the longitude and latitude coordinates detailing the geographical location of the point can be visualized in Figure 12. For this test, 176 data were taken. The relevant information for the analysis is the one describing the location of each sensor node in addition to the RSSI signal strength indicator of each one at each point.

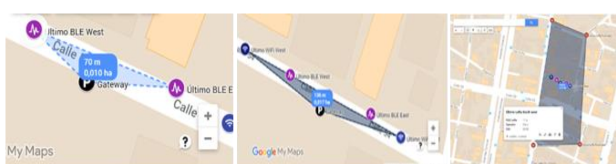

Figure 13: Coverage of each technology calculated with coordinates.
Source: Prepared by the authors.

The test consists of locating the furthest information sending points; in the case of BLE technology, two points of maximum data transmission distance were found with the sensor node displaced to the east 20 meters and then to the west 16 meters; the points of the maximum range were located on the map in Figure 13, with the markers "Last BLE". The RSSI data for the last data delivery point to the east are: (RSSI: WiFi: -66 dBm, LoRa: -94 dBm, BLE: -91 dBm). The related distances on the map require an adjustment due to the elevation of the Gateway. The difference in the z-axis corresponds to 6.7 meters, and this adjustment can be made with Equation 1.

$$h^2 = a^2 + b^2$$

Equation 1 Calculation of BLE maximum distance.

For the calculation of the maximum distance of the BLE device, a represents the elevation of the Gateway, b represents the calculated distance from the satellite coordinates, and h is the approximate distance from the sensor node to the gateway; thus, in the equation $h^2 = (6.7m)^2 + (20m)^2$ for the eastern distance, the result of the equation h = 21.09 m and $h^2 = (6.7m)^2 + (16m)^2$ for the western distance, the result of the equation h = 17.33 m. The angles can be calculated with Equations 2 and 3.

$$\varphi = \arcsin(a/h)$$

Equation 2 Calculation of angle of formed triangle.

$$\beta = \arcsin(b/h)$$

Equation 3 Calculation of angle of formed triangle.

For the specific case, the angles correspond to φ=18.52°, and β=71.50° Eastern BLE and φ=22.72° and β=67.52° Western BLE. The perimeter calculation for BLE technology is performed with Equation 4. Equation 5 can calculate the coverage area, and Equation 6 can determine the angles formed.

$$P = a + b + c$$

Equation 4 Calculation of maximum coverage perimeter

$$A = \frac{ah}{2}$$

Equation 5 Calculation of maximum coverage area

$$h = b\sin\varphi = c\sin\beta$$

Equation 6 Calculation of BLE maximum coverage area angles

The calculated perimeter and area for the BLE technology correspond to P=70 m, $A = 99.87\ m^2$ and the calculated angles of the coverage area corresponding to $\alpha = 141{,}3752°$, $\beta = 21.5422°$, and $\varphi = 17.0826°$. Making the corresponding adjustments to the lengths calculated by the Gateway elevation according to Equation 1 and Equation 2, the perimeter, area, and angles are obtained: P = 72.42 m, $A = 151.14\ m^2$And angles $\alpha = 124.2011°$, $\beta = 30.8656°, \varphi = 24.9333°$. For WiFi technology, the maximum point to the east was 33 meters; to the west, 35 meters are identified with the blue markers in Figure 13, the RSSI values correspond to WiFi: -74 dBm and LoRa: - 101 dBm, and to the west, WiFi: -76 dBm and LoRa: -102 dBm, the coverage is 136 meters.

Table 1: Calculated distances and angles for each maximum point.

Point	RSSI dBm	Distance (m)	Adjustment (m)	Area (m^2)	Perimeter (m)	α°	B°
Northwest	-113	189	189.12	633.15	384.82	2.03	87.96
Northeast	-112	168	168.13	562.8	342.83	2.28	87.75
Southeast	-113	193	193.12	646.55	392.82	1.99	87.98
Southwest	-114	205	205.11	686.75	416.81	1.87	88.12

Source: Prepared by the authors.

From Equations 1 to 6, it is solved that $h^2 = (6.7m)^2 + (33m)^2$ for the eastern distance, the value is h = 33.67 meters, and $h^2 = (6.7m)^2 + (35m)^2$ for the western distance is h = 35.64 meters. The perimeter and area correspond to P = 135 m, $A = 194{,}53m^2$. The calculated angles correspond to $\alpha = 160.3149°, \beta = 10.1349°, \varphi = 9.5502°$. Making adjustments for perimeter and area: P = 136.31m, $A = 297.10m^2$ and angles $\alpha = 14.4087°$ $\beta = 15.2717°$ $\varphi = 150.3197°$. To include the difference in heights between the sensor node and the walkway, separating the shape into four triangles distributed from the origin to the north, south, east, and west is necessary. From Equations 1 to 5, we have the adjustment calculation for each shape and the angles for each triangle; the results are shown in Table 1. Equations 1 and 6 are used to make the adjustments for calculating area, perimeter, and angles. The results are presented in Table 2.

Tabla 2: Calculated distances and angles for each coverage area.

Point	Base (m)	A (m)	b (m)	Perimeter (m)	Area (m^2)	α°	B°	γ°
North	122	189.12	168.13	479.25	10088.37	39.3869	79.6287	60.9844
South	155	193.12	205.11	553.23	14171.96	45.6891	63.0675	71.2434
East	325	193.12	168.13	686.25	12777.06	128.0917	24.0257	27.8827
West	377	205.11	189.12	771.23	10854.88	145.9671	17.7276	16.3052

Source: Prepared by the authors.

The LoRa technology presented four points of maximum transmission from the gateway. The first point is located to the northwest at 189 meters, the second point to the northeast at 168 meters, the third point at 193 meters to the southeast, and the fourth at 205 meters to the southwest. The RSSI data for the LoRa technology last data delivery points are northwest RSSI -113 dBm, northeast RSSI -112 dBm, and southeast RSSI -113 dBm, and southwest RSSI -114 dBm.

The coverage figure obtained for LoRa technology is 979 meters and is a rectangle with non-uniform sides identified and measured by satellite coordinates, as shown in Figure 13. In addition, indeterminate records from the LoRa technology sensor node were stored in the database, equivalent to 20.59%, as shown in Table 3.

Table 3: Percentage of undetermined data in LoRa technology.

RSSI	False	True	Total
-113\r	4	15	19
-114\r	2	6	8
-115\r	1	6	7
Total	**7**	**27**	**34**
Percentage	**20.59%**	**79.41%**	**100.00%**

Source: Prepared by the authors.

2. Indoor performance.

For testing in closed environments, locating a 5-story building with a common physical point on each floor is proposed. This common physical point must have the possibility of locating the sensor nodes of the proposed technologies to observe the RSSI value against vertical and horizontal obstacles in closed environments. The selected test space is not totally closed. It presents vertical obstacles, but it has windows to the outside, representing horizontal obstacles of 0.8 mm thick glass, except for level 1, where the horizontal obstacles are 10-centimeter walls. Initially, the sensor nodes are placed 0.6 meters apart from the gateway, and the system is put into operation.

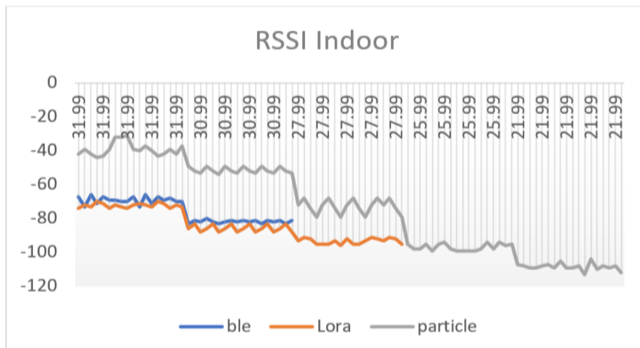

Figure 14: RSSI and CSQ performance of wireless technologies in enclosed spaces.
Source: Prepared by the authors.

The storage is done in real-time and is available in a web-database for subsequent analysis. For the particular case of the indoor range tests, 484 records containing the information of each technology were used. For each level, an average of 18 records were taken; the height of each level is 215 cm, each horizontal obstacle is 21 centimeters represented in a concrete plate separating the levels, the total distance corresponds to 236 cm, and the behavior of the signals is shown in Figure 14. The information acquired during the LTE technology test of the CSQ indicator is shown in Figure15.

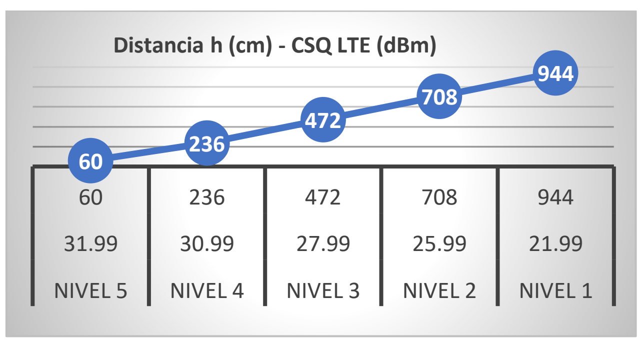

Figure 15: RSSI and CSQ performance of wireless technologies in enclosed spaces against obstacles and distance.
Source: Prepared by the authors.

V. SOLUTION PROPOSALS OR IMPROVEMENTS

In the data stored during the range test for LoRa technology, records with invalid (indeterminate) values were received at RSSI values above 113 dBm. There are two options for the records with indeterminate values: delete the record or correct the record. The first proposal is to locate a maximum data sending and receiving point of RSSI = -110 dBm. The second proposal is based on the percentage found equivalent to 20.59% of data that were received as invalid characters. It is then proposed to develop a validation algorithm in the data processing system before sending messages to the cloud, complemented with an algorithm for retransmission of lost data in a time stamp of at least □ = To/5, when the RSSI level is below -110 dBm, based on the fact that the invalid character corresponds to approximately 21% of the data, seeking to consolidate the messages with valid data in the time required by the system. This solution would imply increasing the processing in the sensor node and the gateway, thus increasing the energy consumption in the nodes and the gateway. The third proposal is to perform the record correction treatment on a large amount of data using machine learning techniques for clean data on the Web platform.

The most representative programming language in the implementation is node.js, a modular language that allows easy scaling and reuse of code. Additionally, it has the features of other programming languages such as PHP for database management. During development, the client, server, and storage were implemented locally, and the application was unstable after 7 minutes of operation when it was necessary to migrate all services to the cloud. Thus, it is recommended for similar applications the use contracted services in the cloud and improve the characteristics of the contracted servers according to the need for scalability of the system.

BLE technology is limited by the number of ports available in the gateway, so it is proposed to design and implement network topologies that improve the scalability of this technology.

For the development of networks over LoRa 433Mhz technology, it is proposed to work on designing or adopting a network topology, addressing schemes to improve the behavior of the technology in multi-node sensor networks and information security.

VI. CONCLUSIONS

The perimeter that can be covered by LoRa technology with four sensor nodes is approximately 979 meters, calculated using georeferencing coordinates. There are two BLE receivers maximum of 70 meters and two WiFi sensor nodes of 136 meters.

BLE technology allows a maximum range from the gateway of 22 meters, WiFi 44 meters, and LoRa 313 meters in an urban, open environment, storing and visualizing every second.

Cloud computing-type solutions are the most appropriate for this development. The choice of architecture was efficiency, scalability, and cost-benefit ratio. The cost of implementing all the services had a value of 17 USD being an application for academic purposes.

The client-server architecture on an embedded control device "Raspberry PI3" reduces delivery times and packet loss, which represents a better performance in visualization; however, in this case, it did not have a good response in storage processes because the web application presented instability and overheating from the seventh minute of operation, managing readings every second in each sensor node.

IoT-type systems are solutions that evolve according to the end user's needs. According to the results, it is concluded that there is no one technology better than another; the most appropriate one should be used according to the specific need in terms of distance, quality, and quantity of information.

The business models of companies that design and implement IoT systems, together with software companies, are oriented towards providing visualization, storage, and data analysis services in the cloud.

Web services allow the user to develop consumer web applications using their own frontend and contracted backend and their own backend and contracted frontend.

The implemented WiFi technology has the highest latency because it requires an additional route to the particle server (manufacturer). It is worth this additional route because, although the latency increases, the security for the node also increases, as well as the versatility in cloud applications, which is why it is shown as the safest. Besides being on the IP protocol, the number of sensor nodes depends on the addressing proposed by the administrator of the IoT solution.

VII. RECOMMENDATIONS

In this work, an interoperability system for wireless networks was designed and implemented for IoT developments. The devices involved have the security offered by the manufacturer, but in deployments that require a large number of sensor nodes and a combination of large networks of different technologies, the development of malware detection methods should be analyzed, as stated in the work of [45], which indicates that IoT devices are based on CPU architectures, even on hardware with limited resources, such as Unix-based operating systems. With this change, IoT devices are becoming a favorite target for attackers due to the lack of security design or implementation, so it is recommended to work on security for IoT systems.

In the book [35] chapter 4, an IoT system for monitoring variables of interest is proposed; however, real-time visualization is not as effective, especially if the satellite network is chosen, which delivers its variables to the backend web platform in an XML format that is defragmented and delivered to the frontend, this process increases latency but improves coverage by incorporating two long-range technologies. It could be a more recommended solution in rural and difficult access environments. Still, for a reduced amount of transmitted data, it is recommended to implement a technology according to the project's specific needs.

In developing the coverage tests, the work [27] was taken into account. But it was complemented by performing tests with the Gateway in internal and external environments, providing the Gateway with autonomy to move and compare the performance of technologies. It is recommended to analyze existing solutions to develop applications with new features or combine several technologies and different manufacturers; adopting a single technology generally does not allow the creation of differentiated concepts.

The Internet of Things (IoT) infrastructure has been steadily expanding to include more intelligent and effective user interactions. Individual IoT data sets can be combined with additional content in a distributed and efficient manner for use in end-user applications. The paper by [46] proposes an architecture to combine AR augmented reality interface with IoT, aiming for an enhanced shopping experience. In this way, it is possible to generate new applications on IoT combining new concepts, and it is recommended to propose future works oriented to virtual, augmented, and mixed reality on IoT.

During the development of the system, the importance of radiators for IoT systems was observed in [47], which proposes an efficient design of compact antennas that operate in multiple bands suitable for the Internet of Things (IoT). According to the need for interconnection of technologies proposed by interoperable systems, it is interesting to work on the design and implementation of antennas that resonate in several bands aiming at the versatility of IoT systems.

The Internet of Things (IoT) has been widely deployed in recent years, which makes the generation of information increase exponentially, causing the data storage systems of IoT systems to collapse. The paper [48] mentions the need to solve IoT systems' data processing and storage problems. For this reason, it is recommended to explore solutions aimed at data cleaning and data mining concepts implemented on IoT systems and devices.

The next generation of 5G cellular communications, coupled with the massive Internet of Things (IoT) deployment, requires data filtering before storing in the cloud. It also starts to be vulnerable to routing attacks due to its dynamic infrastructure. New computing resources and the heterogeneity of mobile sensors will be necessary, so it is recommended to work on the concept of cognitive IoT.

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