Smart Building Internet of Things Deployment Using Low Power Wide Area Networks

Long Range (LoRa) Wireless RF Technology

An Operational Practice prepared for SCTE by

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1. Introduction

Charter Communications designed and deployed a Low Power Wide Area Network (LPWAN) and smart building solution at one of its offices located in North Carolina (location 2), with the goal of enhancing employee comfort and improving operational efficiencies. The solution includes environmental monitoring and room occupancy sensors across four floors. In this paper, we describe the methodology used to deploy the end-to-end solution, therefore, we outline the goals and various components of a smart building solution. Second, we describe the radio frequency (RF) design and dimensioning for network deployment. Third, we show the parameters of the propagation model which were utilized to calibrate the design tool. Fourth, we explain the method of optimization and monitoring the live solution. The entire process is shown in Figure 1. Last, our experimental results also describe the network performance testing (coverage and quality) and best practices to deploy in a high-rise building based on Charter's experience. As Charter evaluates emerging technologies to expand our wireless network portfolio, LoRa technology has been selected to enable many use cases for Internet of Things (IoT) solutions.

2. LoRa and LoRaWAN Technical Overview

One of the prominent wireless technologies of LPWAN for IoT is Long Range, commonly known as LoRa. Specifically, LoRa is purely the radio signal that carries the data into the physical (PHY) layer which is based on a Chirp Spread Spectrum (CSS) modulation technique that was developed by the vendor Semtech [1]. LoRa chip sets are built into LoRa gateways and sensors. Medium Access Control (MAC) is the following layer, commonly known as LoRaWAN, which is managed by LoRa Alliance. LoRaWAN is the communication protocol that controls how data is communicated across the network for the upper layer [2].

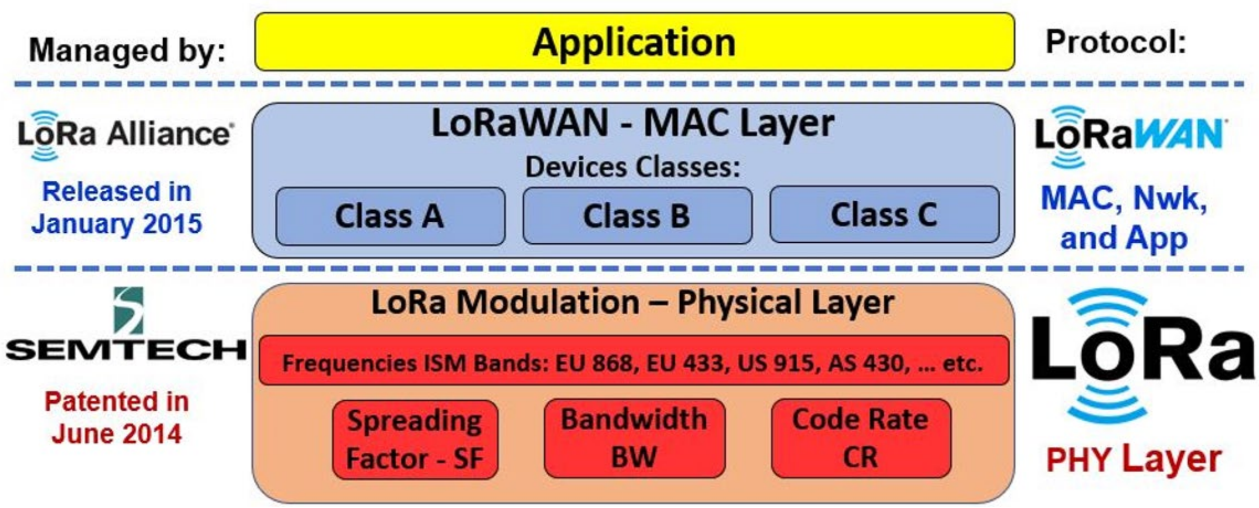


Figure 1 – LoRa and LoRaWAN Technology Stack [2]

In addition, LoRaWAN defines multiple Data Rates (DR) which are a combination of Spread Factor (SF), channel Bandwidth (BW), and Coding Rate (CR) [3]. These parameters together are used to compute the DR also known as LoRa Modulation Bit Rate (Rb) and is given in Figure 2.

Data Rate Formula

$$R_b = SF * \frac{\left[\frac{4}{4+CR}\right]}{\left[\frac{2^{SF}}{BW}\right]} * 1000$$

SF = Spreading Factor (6,7,8,9,10,11,12)
CR = Code Rate (1,2,3,4)
BW = Bandwidth in KHz (10.4,15.6,20.8,31.25,41.7,62.5,125,250,500)
Rb = Data rate or Bit Rate in bps

Figure 2 – Data Rate Formula For LoRa Transmission [4]

Figure 3 details a typical LoRaWAN architecture, which includes LoRa sensors or end devices, LoRa Gateways (GW), and a network server called LoRaWAN Network Server (LNS). Sensors are connected to one or more gateways via LoRa CSS modulation technique which encodes data on radio waves using chirp (also known as sweep signal which defines the tone in which the frequency changes in a period of time) [2]. It can be of two types, up-chirp (connoting an increase in frequency) and down-chirp (frequency decrease). Gateways are connected to the LNS through standard IP connectivity. The LNS routes data information from the sensor to the associated Application Server (App Server), provides authentication for sensors, and manages security for the entire network using keys such as the DevEUI, the Network Session Key (NwkSKey), and the Application Session Key (AppSKey). LoRaWAN provides end-to-end security services through the use of Advanced Encryption Standard (AES) cryptography.

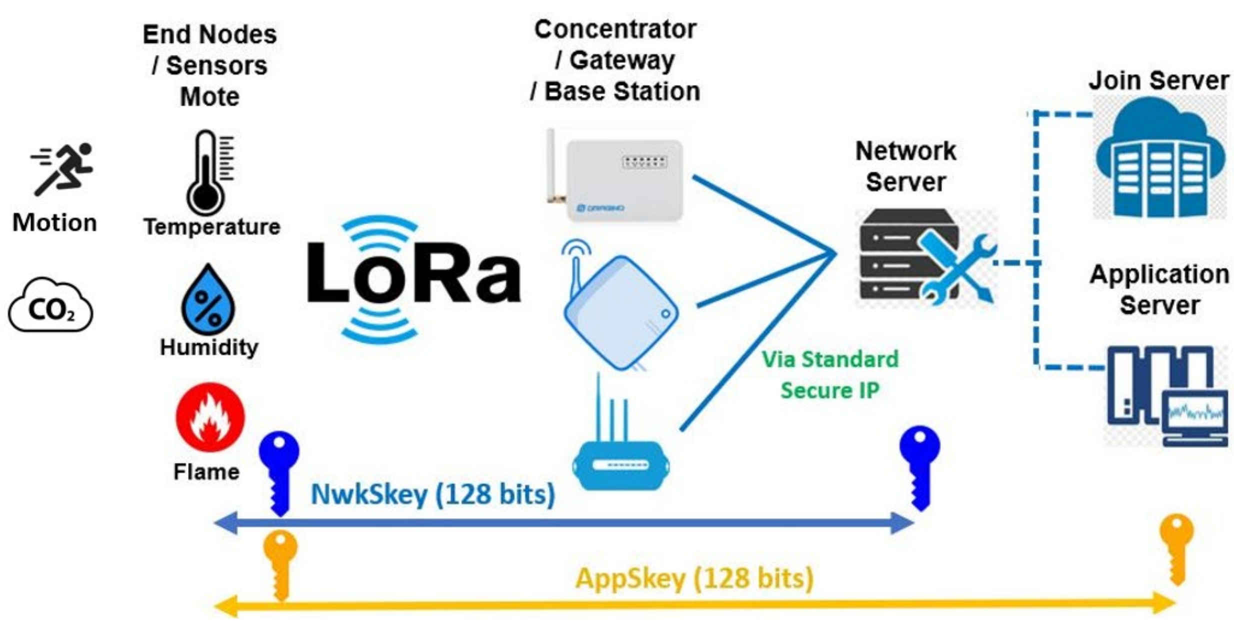


Figure 3 – LoRa Architecture [2]

In the United States, the LoRa technology works on the unlicensed Industrial, Scientific, and Medical (ISM) bands from 902 to 928 MHz, therefore, there is no Federal Communications Commission (FCC) licensing required. The LoRa gateway's backhaul can be Ethernet, cellular, or both, depending on the GW model. The red outlined sections shown in Figure 4 are part of Charter LoRa Network as a Service (NaaS).

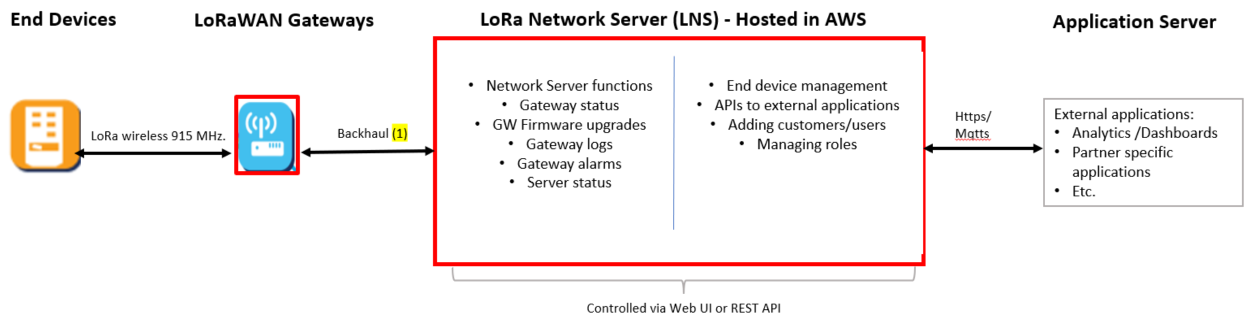


Figure 4 – Charter's LoRaWAN Architecture (High Level)

In this deployment, Browan and Tektelic brand gateways have been used along with multiple LoRa sensors (e.g., temperature, humidity, CO_2, and motion). In addition, a Multitech brand Field Test Device (FTD) has also been used to measure the strength and quality of the received signal – or, in technical terms, the Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR). The sensors' information is pushed from the LNS to the App Server using an HTTP connection. The LNS gathers all the sensors' raw data and transforms it (by decoders sent to the App Server) into actionable insight for optimizing workflow process, improving the efficiency of room occupancy, and reducing operating costs. Therefore, all the data analytics are managed by the App Server, allowing for user-friendly data visualizations to be displayed through dashboards (Figure 5).

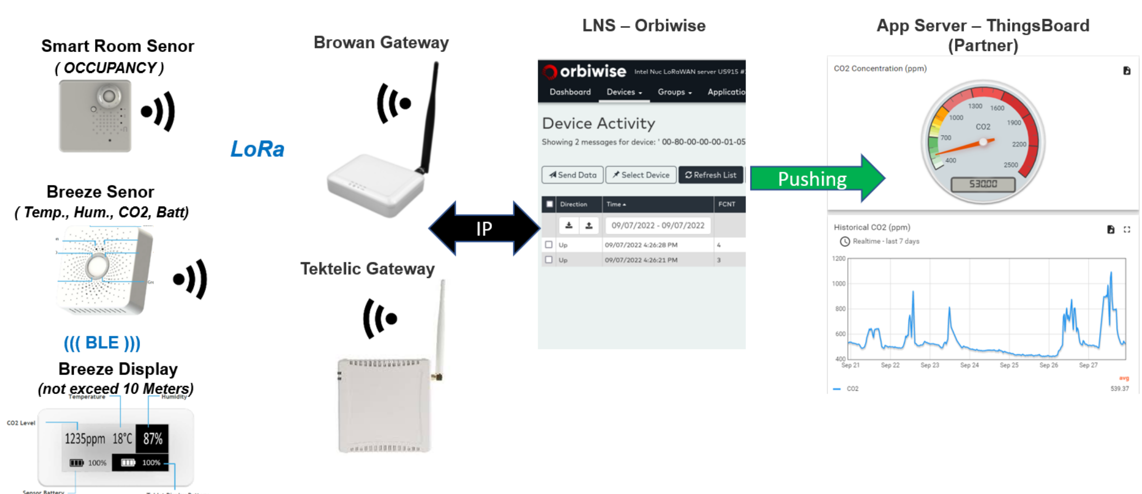


Figure 5 – Charter's LoRaWAN Architecture & (High Level)

The LoRa's transmission based on the spread spectrum technique is carried out by low-power transmitters to send small amounts of data to receivers placed at long distances (Figure 6).

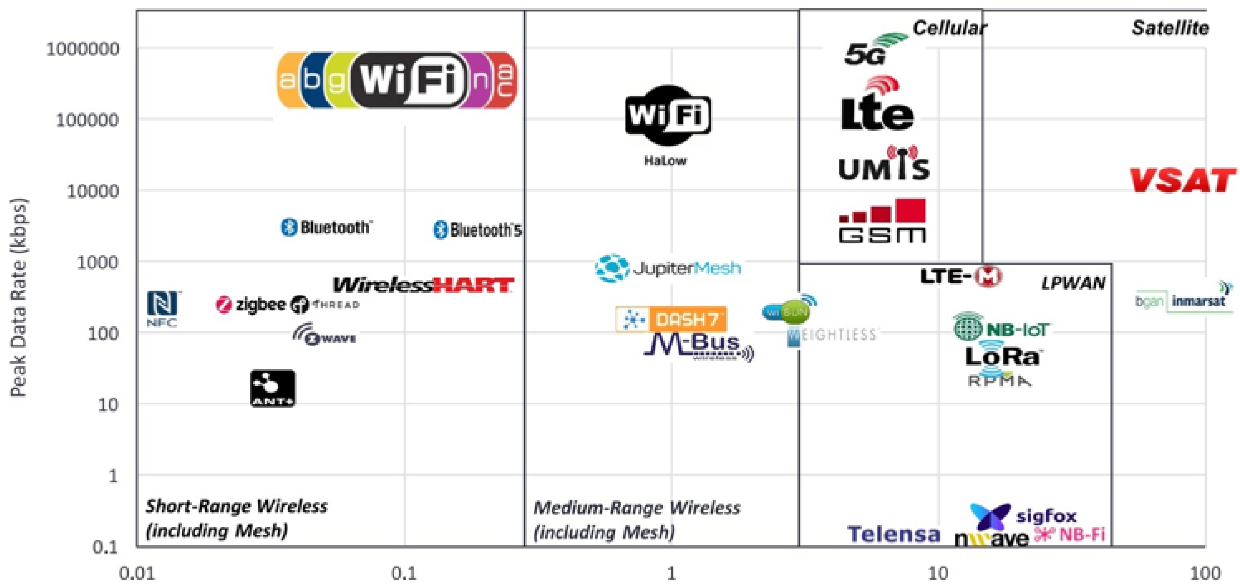


Figure 6 – Comparison of Wireless Technologies [5]

LoRa's key features are detailed below.

- **LoRa is specially designed for:**
  - ✓ Multiple low data rates ranging from 0.3 kbit/s to 50 kbit/s per channel.
  - ✓ Long-Range wireless communication.
    - ➢ Three miles in urban areas.
    - ➢ 10 miles or more in rural areas (depending on the line of sight).

- **Strengths:**
  - ✓ The best link budget of any other standardized wireless communication technology.
  - ✓ Operates under unlicensed frequency ISM bands 915MHz - FCC Part 15.
  - ✓ Deep penetration inside homes/buildings – low freq.
  - ✓ Low-power consumption / long battery life (~ 10 years).
  - ✓ Cost efficiency (infrastructure implementation).
  - ✓ High capacity - multi-tenant interoperability.
  - ✓ Scalability - easy to add sensors and gateways.
  - ✓ Security - embedded end-to-end AES-128 bits encryption.
  - ✓ Allows FUOTA (Firmware Updates Over-The-Air).
  - ✓ Resilience - multiple spreading factors result in interference protection.

- **Weaknesses:**
  - ✓ Not good for high data-rate transmissions.

The LoRaWAN Channels for North America follow the entire FCC Part 15 regulations for the 902 - 928 MHz ISM band, which is better known as the 915 MHz Band. This frequency plan is detailed in Figure 7, Table 1 and Table 2.

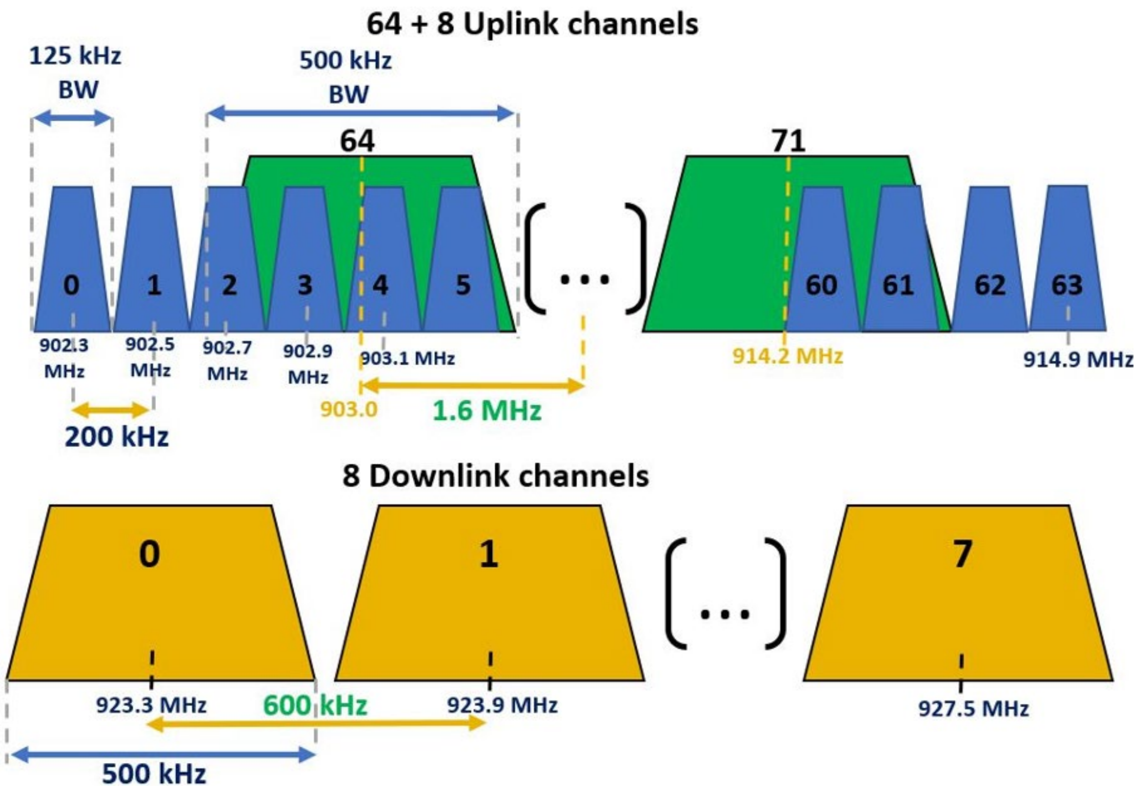


Figure 7 – LoRaWAN Channels for North America [2]

Table 1 – US 902-928 MHz Frequencies Plan [6]

Description	Upstream – 64	Upstream – 8	Downstream – 8
Channels numbered	0 to 63	64 to 71	0 to 7
Number of channels	64	8	8
Frequency starting at	902.3 MHz	903.0 MHz	923.3 MHz
Linearly increment	200 kHz	1.6 MHz	600 kHz
Frequency ending at	914.9 MHz	914.2 MHz	927.5 MHz
Bandwidth	125 kHz	500 kHz	500 kHz
SF varying	SF7 - SF10	SF8	SF7 - SF12
Coding rate	4/5	4/5 - 4/8	4/5 - 4/8

Table 2 – LoRaWAN Regulation for North America [6]

Description	LoRaWAN specification for North America
Frequency Band	902 - 928 MHz
Max. Tx Power Uplink	(30 dBm allowed) 20 dBm is typical
Max. Tx Power Downlink	27dBm
Max. dwell time	400 milliseconds on Up-Links

3. Methodology and Equipment Setup

This section details the methodology and equipment setup for the entire LoRa solution deployment process. First, the LoRA network was deployed on the 3rd floor of the Charter Colorado office lab (location 1) in which RSSI and SNR were measured on each floor through the field test device (FTD). Second, using the experimental results of RSSI and SNR, the propagation model was calibrated on the design tool to adjust the theoretical results. Third, once the propagation model was calibrated, the Radio Frequency (RF) and networking design was carried out for the Charter premises in North Carolina (location 2). Fourth, gateways and sensors had been pre-commissioned in our laboratory, as well as the HTTP connection between the LNS and the App Server. In addition, all the dashboards, triggers and alarms need to be tested prior to the actual installation. Fifth, when all the components are working properly, the next step is to mount all gateways and sensors in the planned place. Finally, we validate all the gateways and sensors are up, running, and sending data. Moreover, all the action points were tested. This process is illustrated on Figure 8.

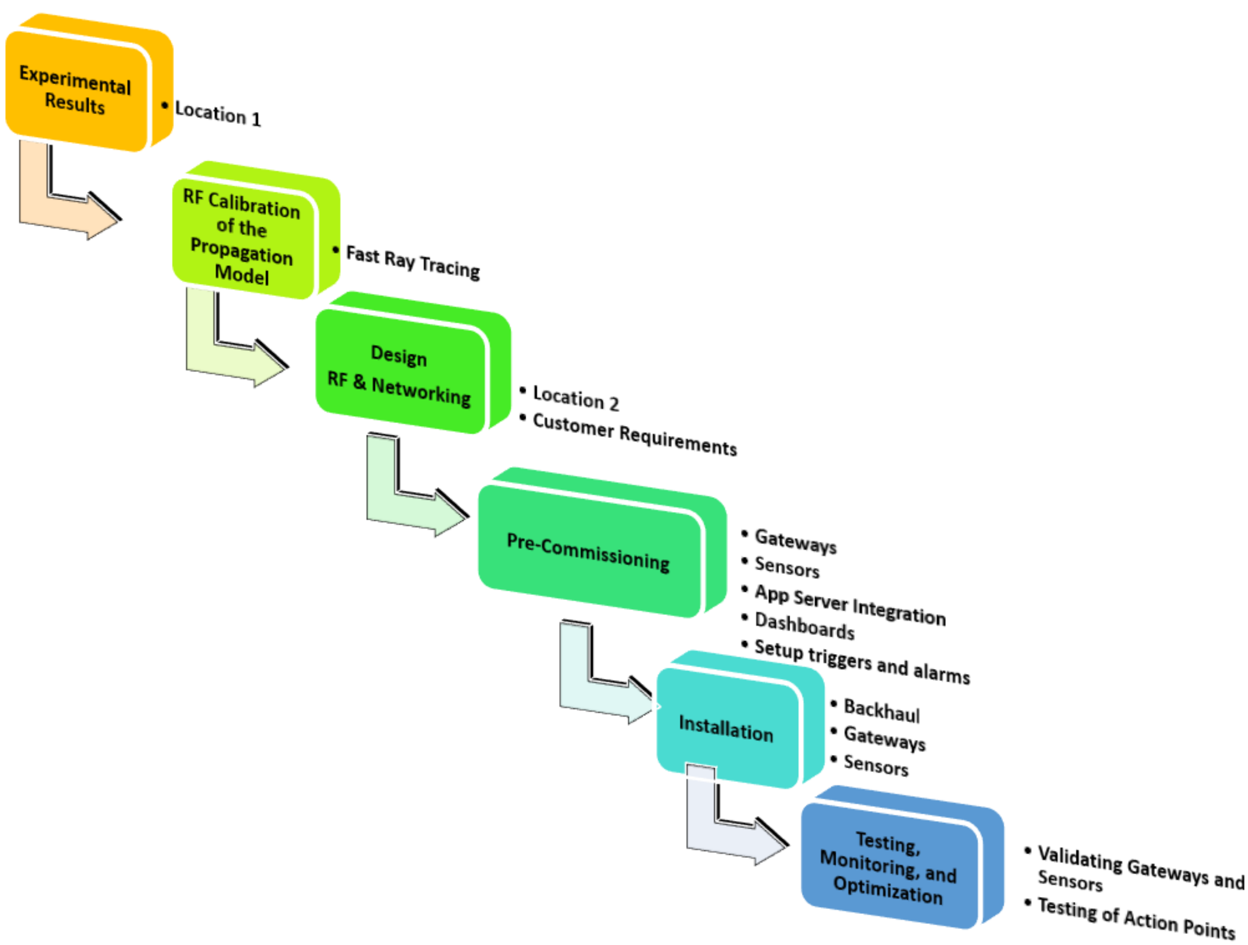


Figure 8 – Deployment Process

3.1. Experimental Results at Location 1

Figure 9 shows the five points of interest where the FTD was used to capture the RSSI and SNR values on each floor at the location 1. In the same way, one gateway was located on the corner of the building on the third floor (green section in the southeast). The legend shows the gateway setup used on the design tool.

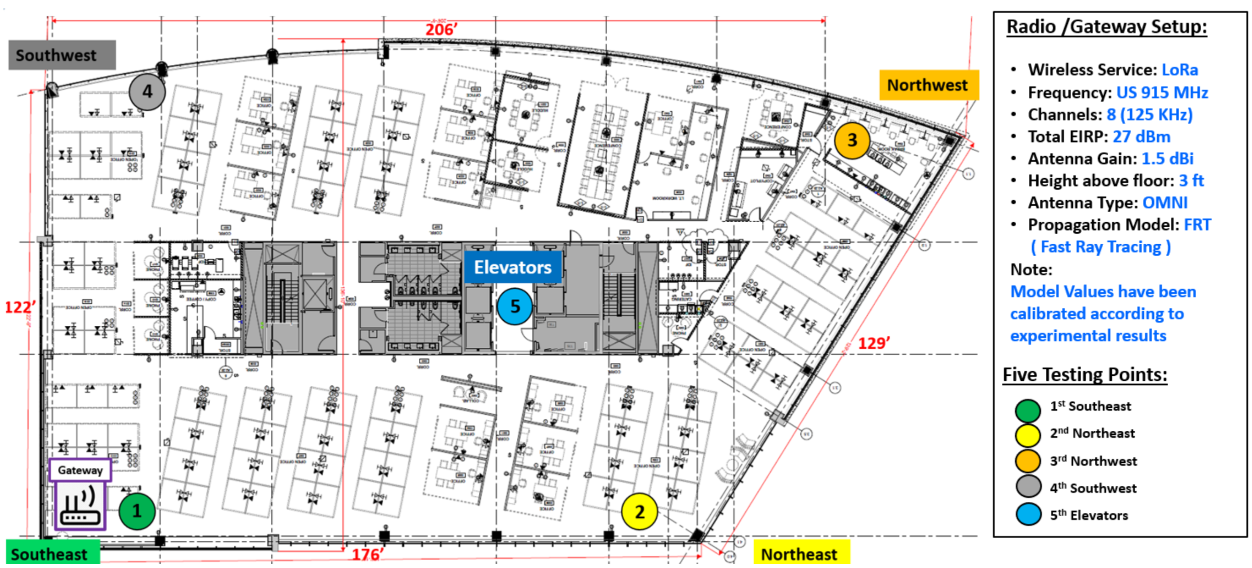


Figure 9 – Location 1 Setup and RF Specifications

Figures 10-13 show the result obtained using the FTD to measure the RSSI and SNR on each floor. The gateway located on the third floor was able to cover the entire floor, as well as one floor below and above, with optimal levels of RSSI and SNR, covering 25,000 sq. ft.

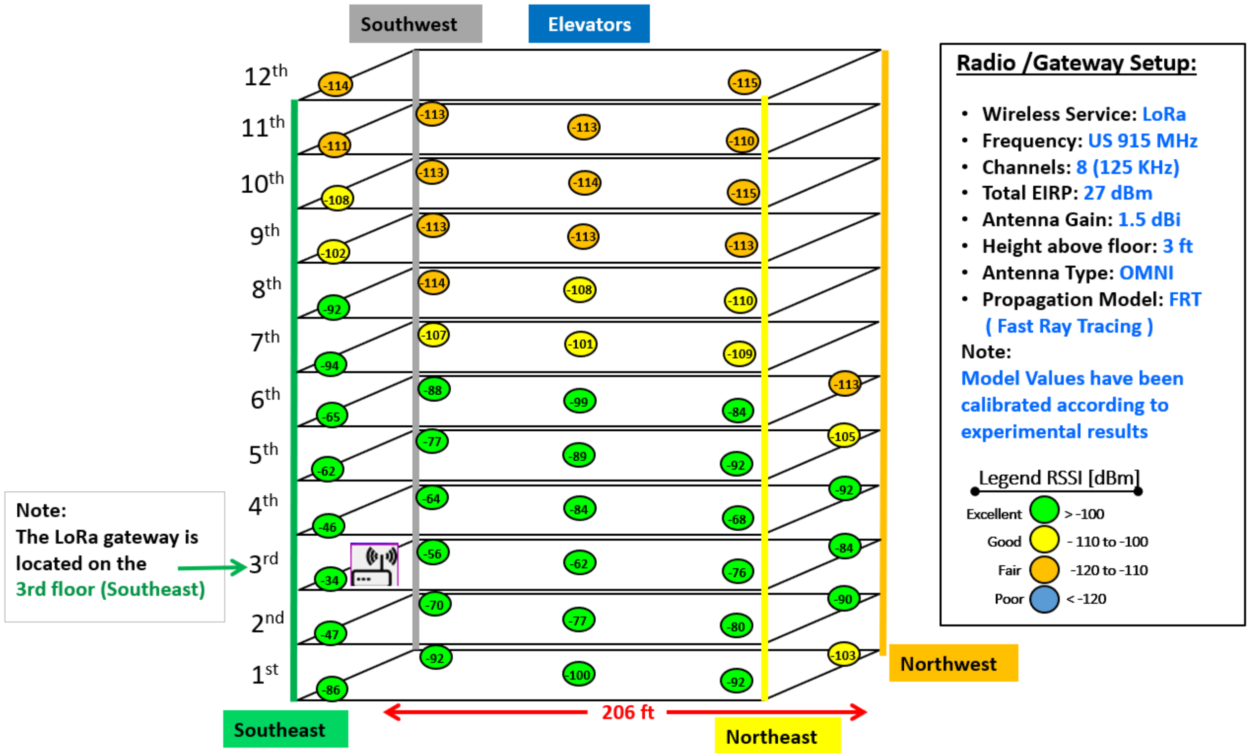


Figure 10 – Location 1 Walk Test Results Signal Strength RSSI

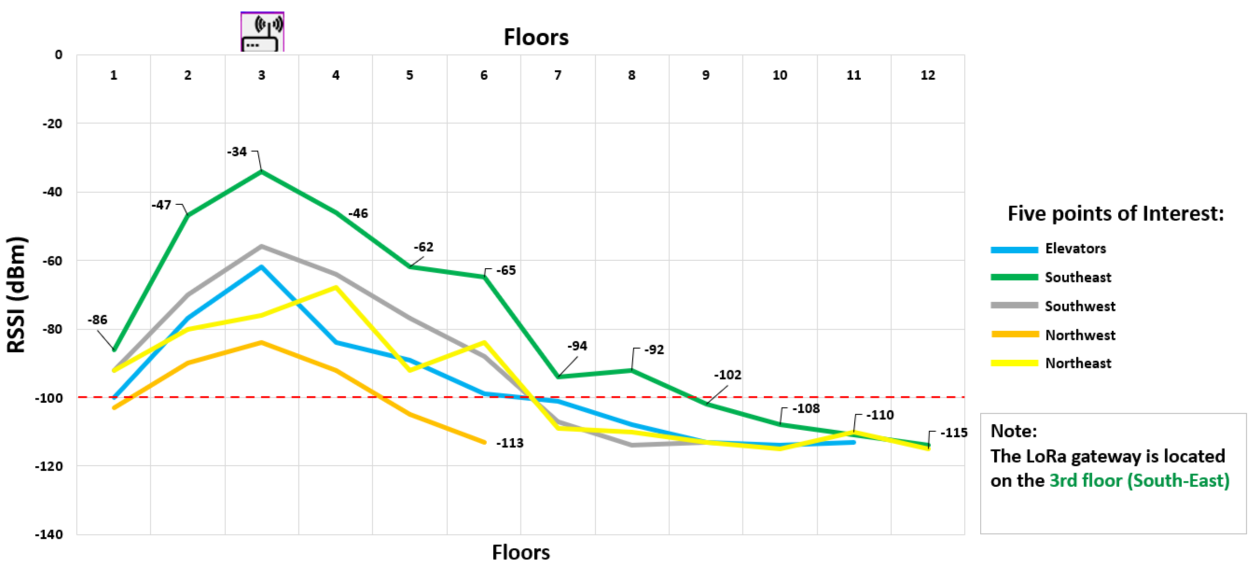


Figure 11 – Location 1 Summary Results Signal Strength RSSI

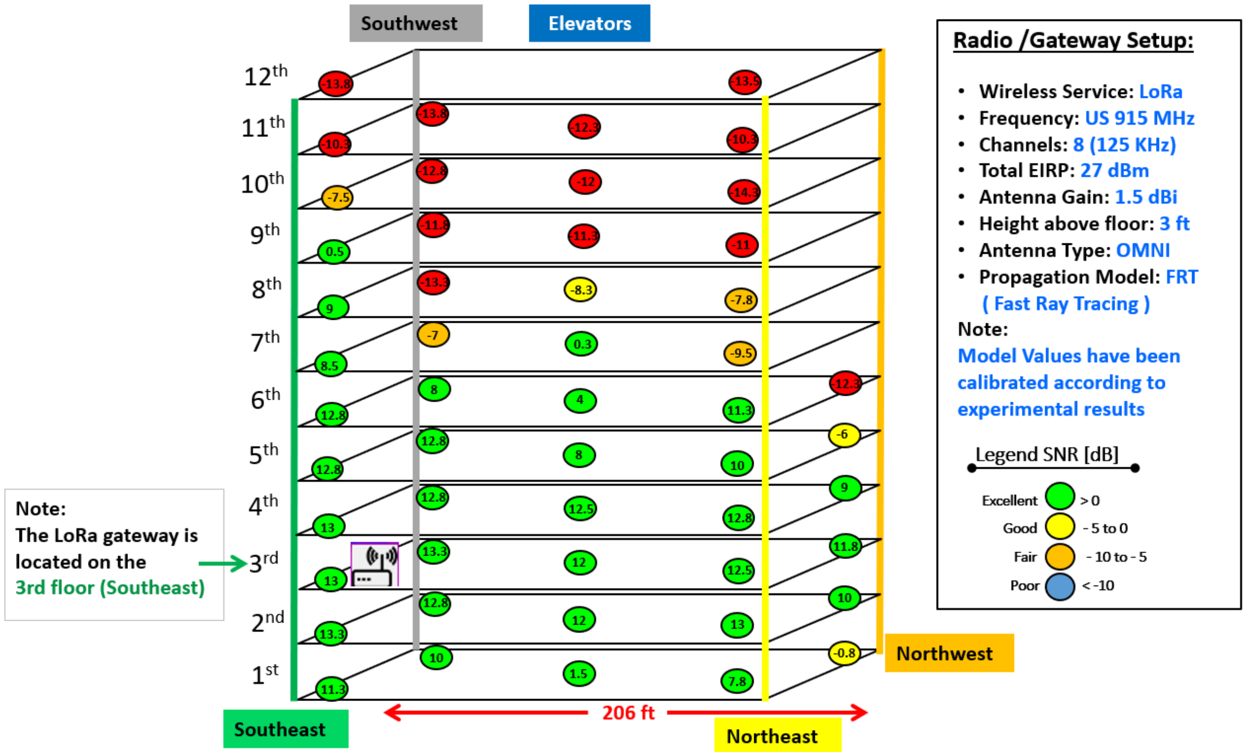


Figure 12 – Location 1 Walk Test Results Signal Quality SNR

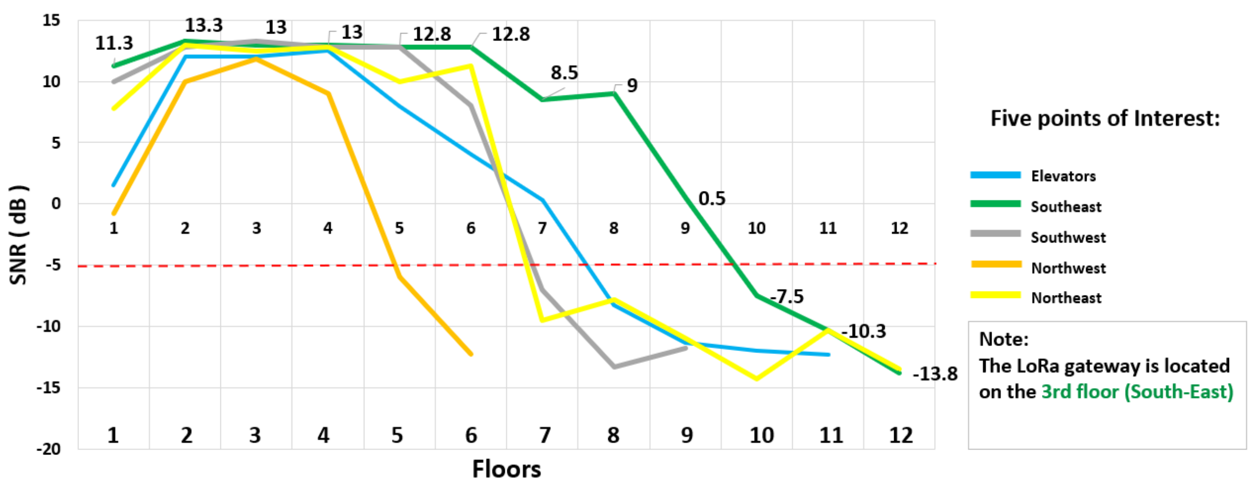


Figure 13 – Location 1 Summary Results Signal Quality SNR

3.2. Propagation Model Calibration at Location 1

All these data surveys were utilized to calibrate the propagation model on the design tool. The path loss parameters and the physical properties of the materials have been calibrated (transmission and reflection losses), as well as model coefficients of the Fast Ray Tracing (FRT). Table 3 details the transmission loss values for different materials and the FRT model coefficients which have been calibrated on the 917 MHz band for LoRa technology. Using the calibrated model, one example of signal strength RSSI is shown on Figure 15.

Table 3 – Calibration of the Model Propagation

Parameters of the Materials (Band 900MHz)		Model Coefficients of FRT (Band 915MHz LoRa)
Type of Material	**Transmission Loss [dB]**	Wall loss factor 1 (p1): 4
Drywall	1.75	Wall loss factor 2 (p2): 2
Glass Indoor	2	DLOS (y1): 4.70
Glass Outdoor	7	RP (y2): 3.77
Drywall individual workstation	0.15	DNLOS (y3): 4.27
Concrete Heavy	27	Body loss (Δy1): 4
Elevators (Metal)	75	

- DLOS (y1): Direct line of sight path only.
- RP (y2): Reflected path only.
- DNLOS(y3): Direct non-line of sight path.

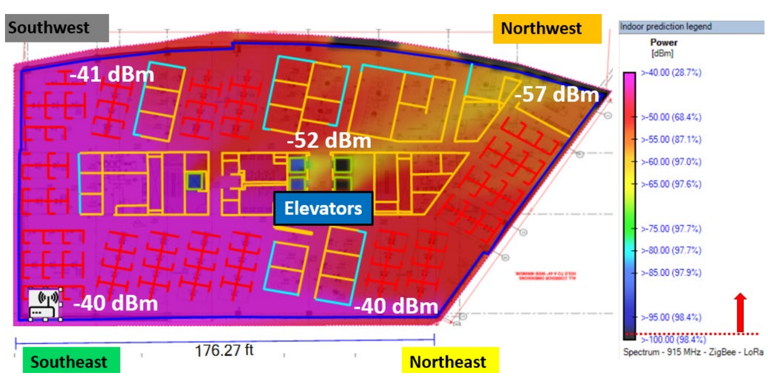


Figure 14 – Before Calibration of RSSI (Theoretical ≠ Experimental)

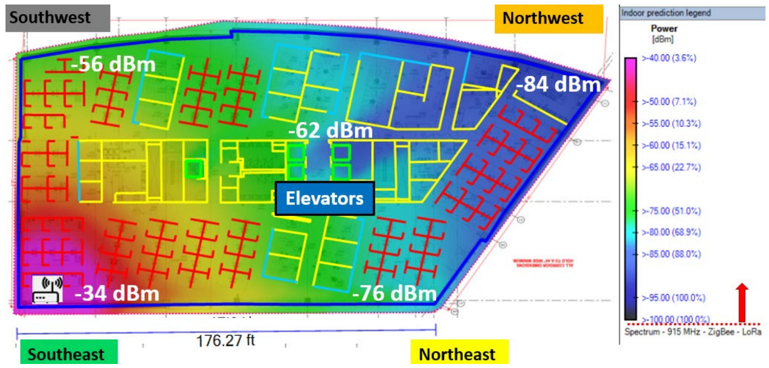


Figure 15 – After Calibration of RSSI (Theoretical ≈ Experimental)

4. Results

Determined by the building size, shape and design, the placement of gateways were strategically located at the location 2 premises to cover the entire building. Four gateways were needed to cover the entire building, and their locations will warrant appropriate signal strength and quality levels.

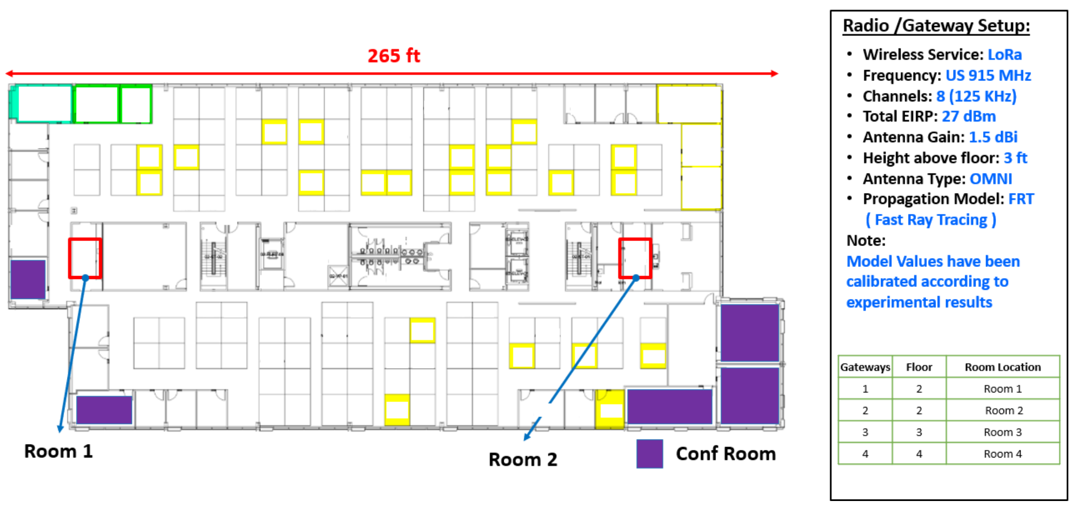


Figure 16 – Location 2 Setup and Specifications

4.1. Design / Planning

4.1.1. RF Design for Location 2

Once the propagation model was finally calibrated, the heatmaps for RSSI, SNR and best server were made for each floor. The results are shown on Figures 17-20. The criterion for the design is focused on RSSI > 97 dBms and SNR > 2 dB, based on the experimental results.

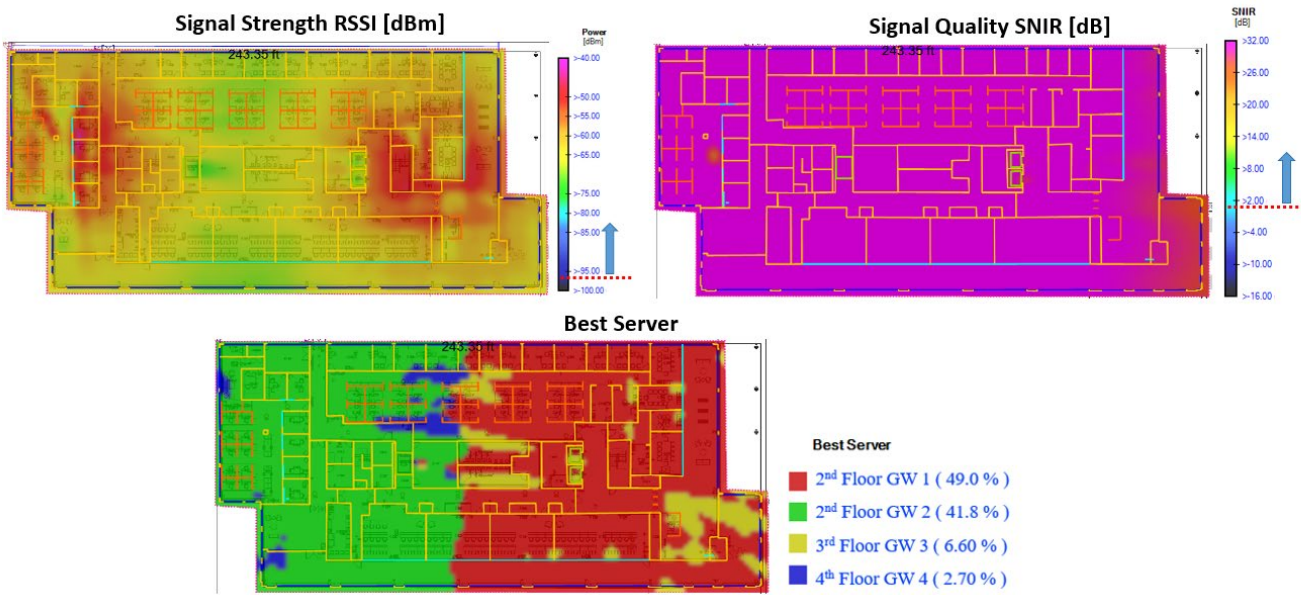


Figure 17 – Location 2 Design 1st Floor

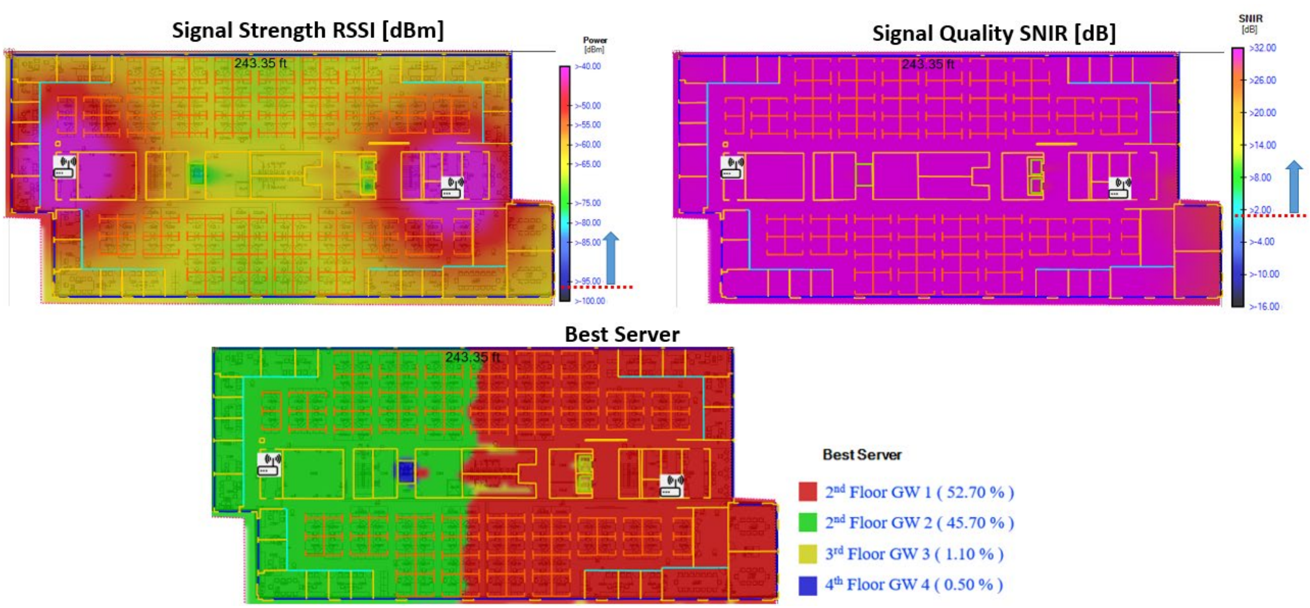


Figure 18 – Location 2 Design 2nd Floor

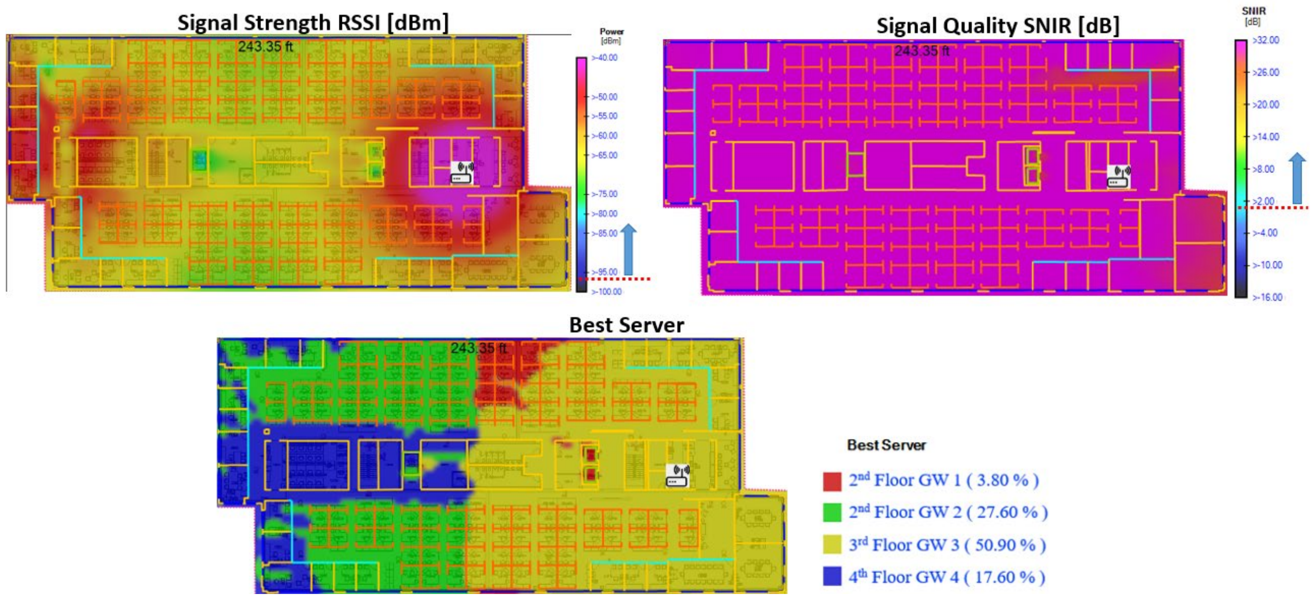


Figure 19 – Location 2 Design 3rd Floor

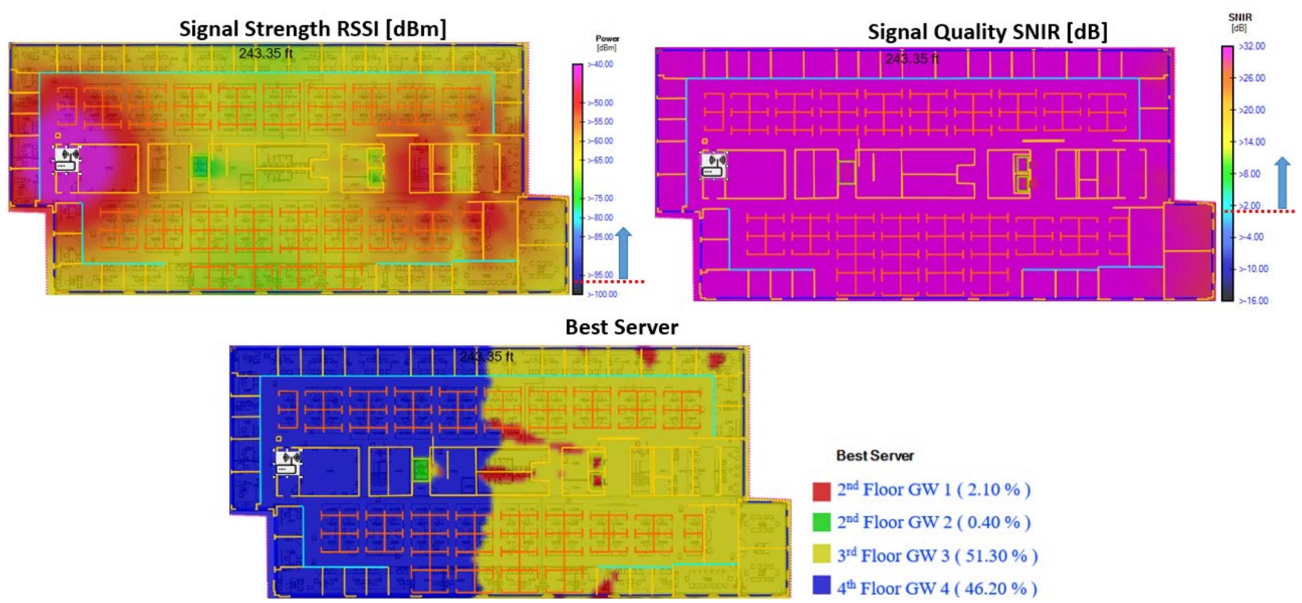


Figure 20 – Location 2 Design 4th Floor

4.1.2. Networking Design

The networking design is based on how many gateways were needed and their respective locations. Therefore, this design required three PoE (Power over Ethernet) switches and one router (Figure 21).

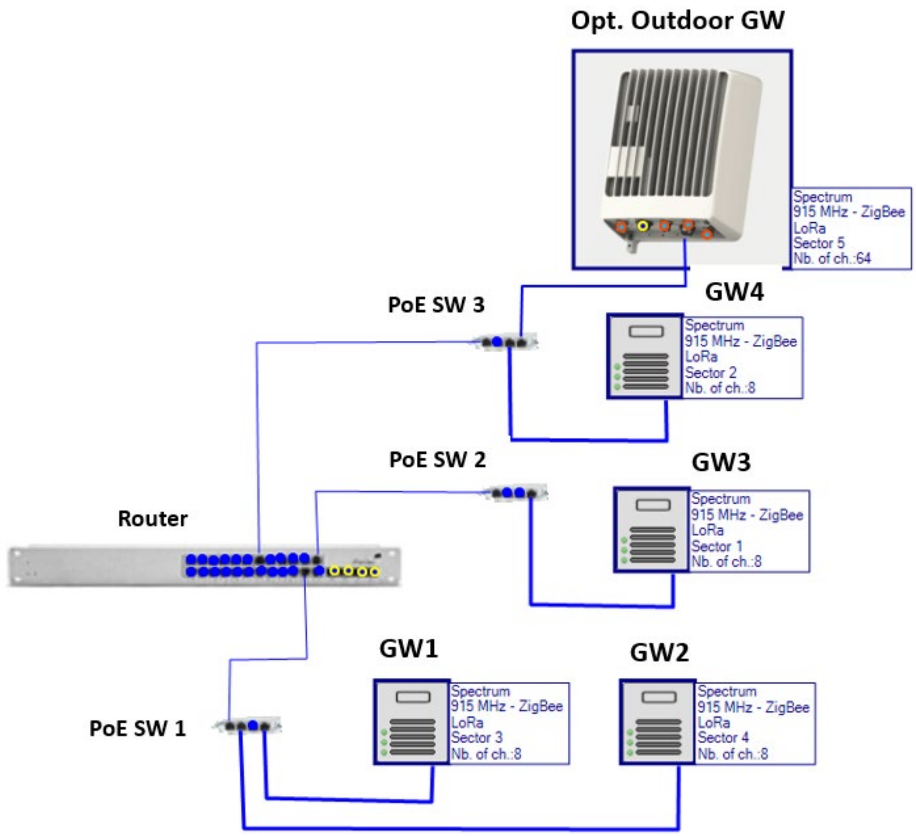


Figure 21 – Networking Design

4.2. Pre-commissioning on LNS and App Server integration

All the gateways and sensors were pre-commissioned, which means the gateways are up and running on the Network Supervision Tool (NST) and the sensors are sending data on the Data Access Sub System (DASS) platform through the GWs (Figure 22). The sensors' information is decoded on the LNS and then sent to the App Server for user-friendly data visualization via dashboards (Figure 23). Finally, all the components (sensors, GW, LNS and App Server) were working together and the next step was to mount all equipment in its planned location at the location 2 premises.

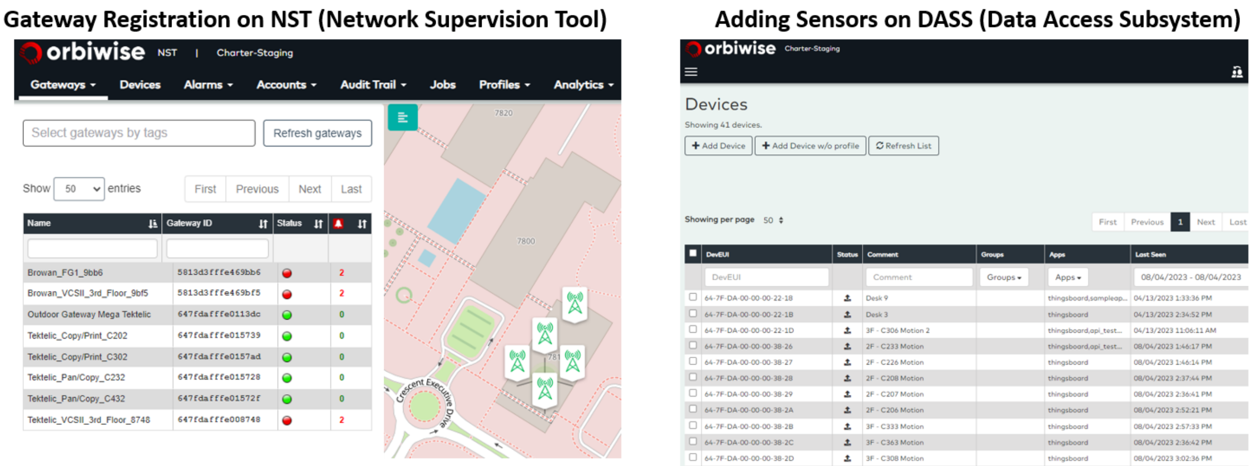


Figure 22 – LoRaWAN Network Server

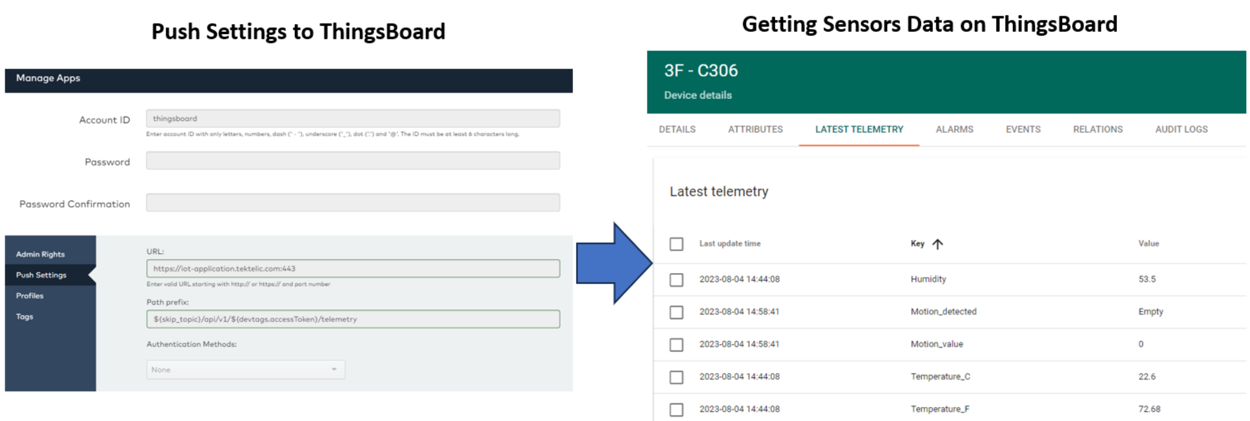


Figure 23 – LNS and App Server Integration

4.3. Walk Test at Location 2

Once all the components are in place and operating properly, the FTD was used to characterize the GWs' signal on each floor at the location 2 premises. Figures 24 - 27 show the actual results of signal strength RSSI (measurement of how strong the sensor can hear a signal from a GW), signal quality SNR and best server. On each floor, several measurements were obtained, and the results show that all the samples are above -100 dBms of RSSI and above 0dB of SNR, which means the entire building is covered with appropriate LoRa signal levels for the suitable sensor functionality.

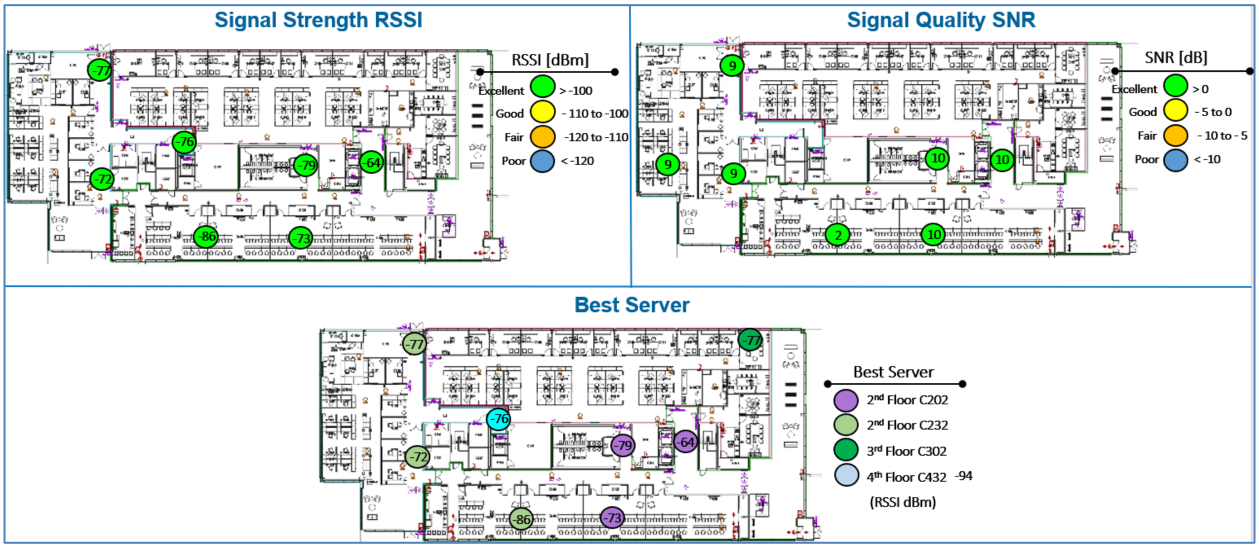


Figure 24 – Location 2 Walk Test Results 1st Floor

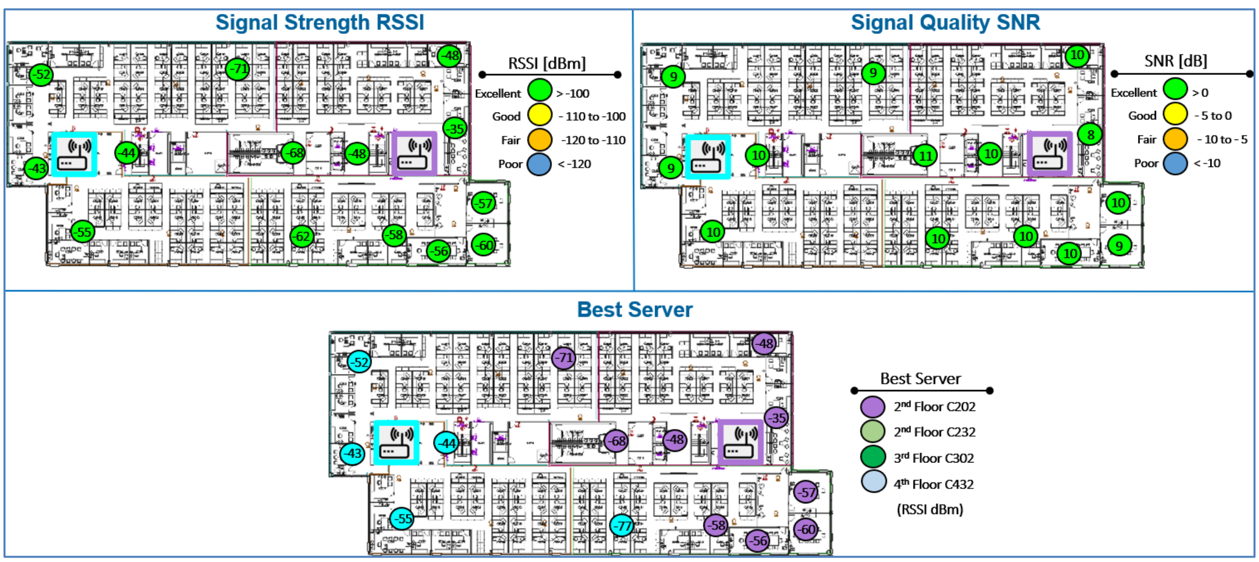


Figure 25 – Location 2 Walk Test Results 2nd Floor

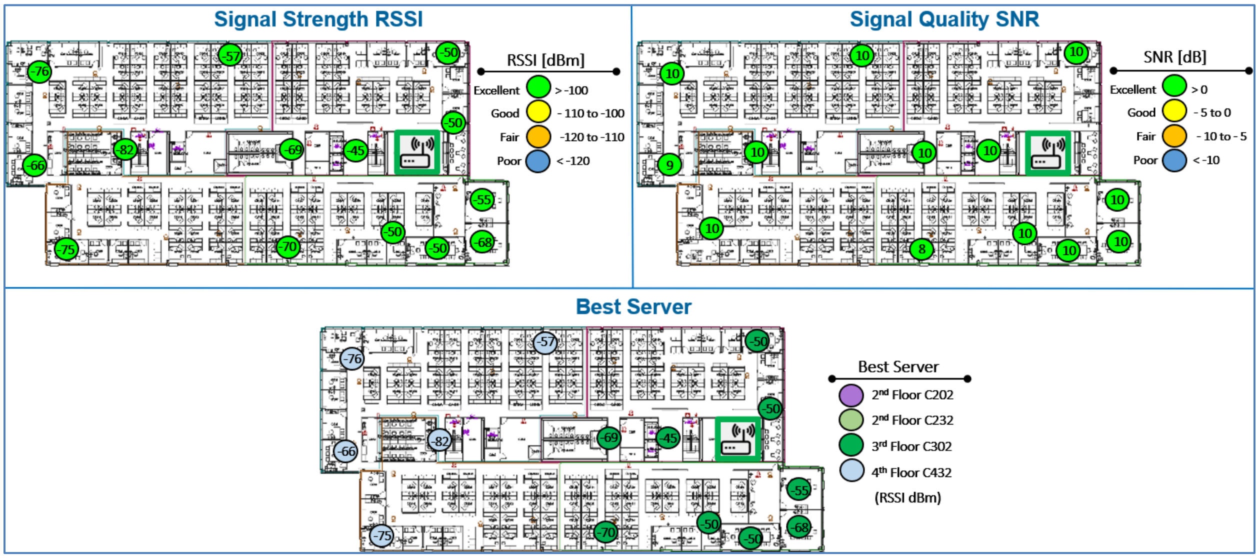


Figure 26 – Location 2 Walk Test Results 3rd Floor

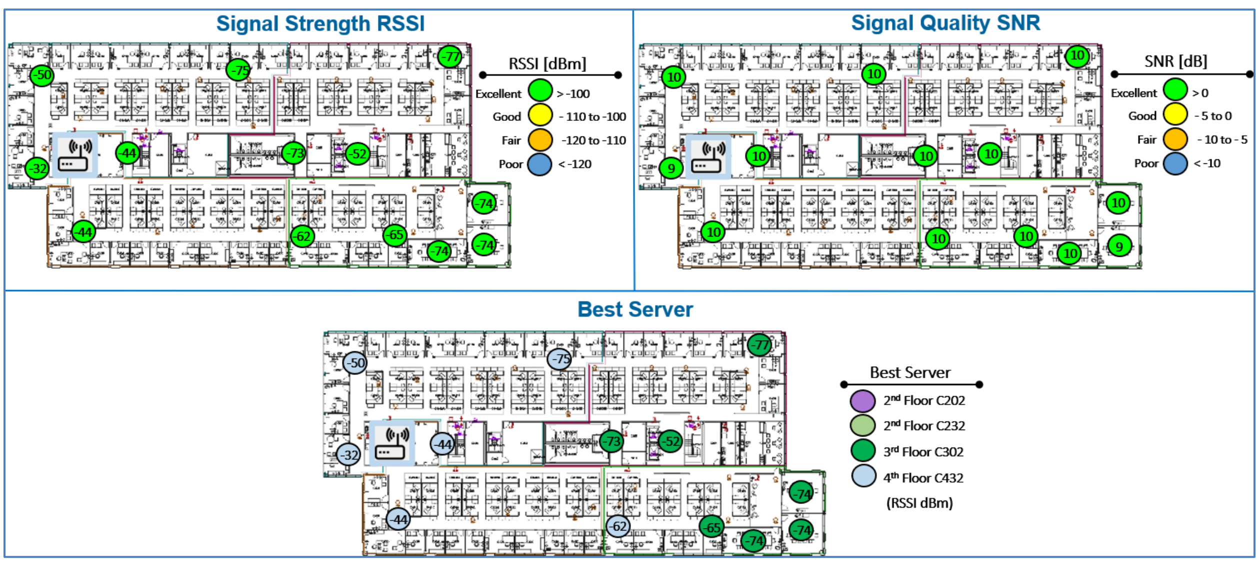
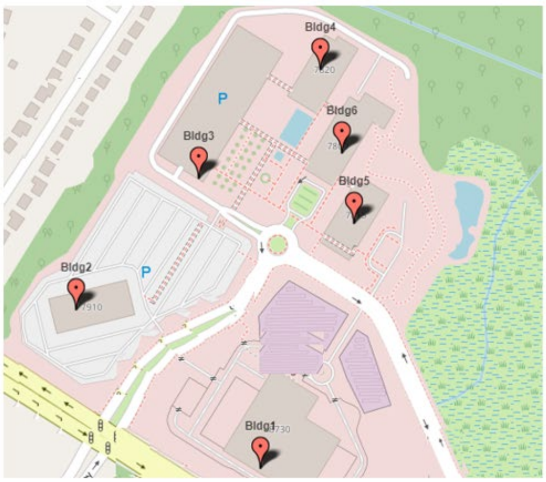


Figure 27 – Location 2 Walk Test Results 4th Floor

4.4. Application Server's Dashboards

The entire campus is exhibited on the main webpage; accordingly, the friendly menu allows a user to dive into specific, building, floor, room, and sensor information (Figure 28). Figure 29 indicates where exactly the sensor is located on the blueprint and allows the user to see real-time and historical data (Figure 30 and Figure 31).



Bldg 5 - Sensors by Room

Entity name ↑	File Room	IDF	Meeting Rooms	Work Stations
Floor - 1	-	1	-	-
Floor - 2	1	1	5	9
Floor - 3	-	1	5	-
Floor - 4	-	1	-	-

Figure 28 – Application Server Main Menu View

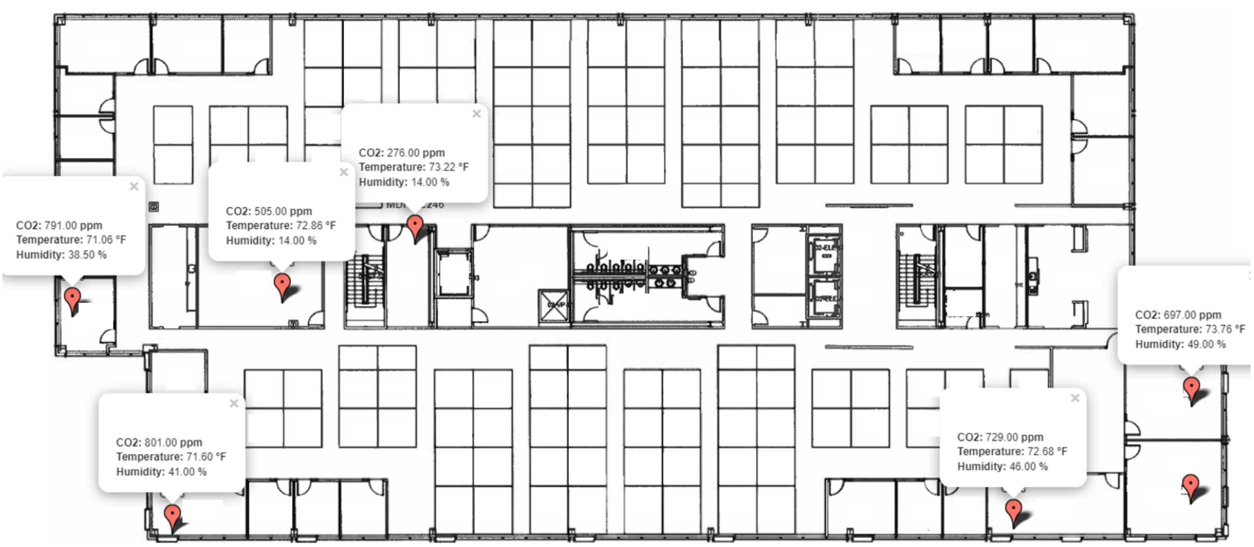


Figure 29 – Application Server Sensors Placement on 2nd Floor

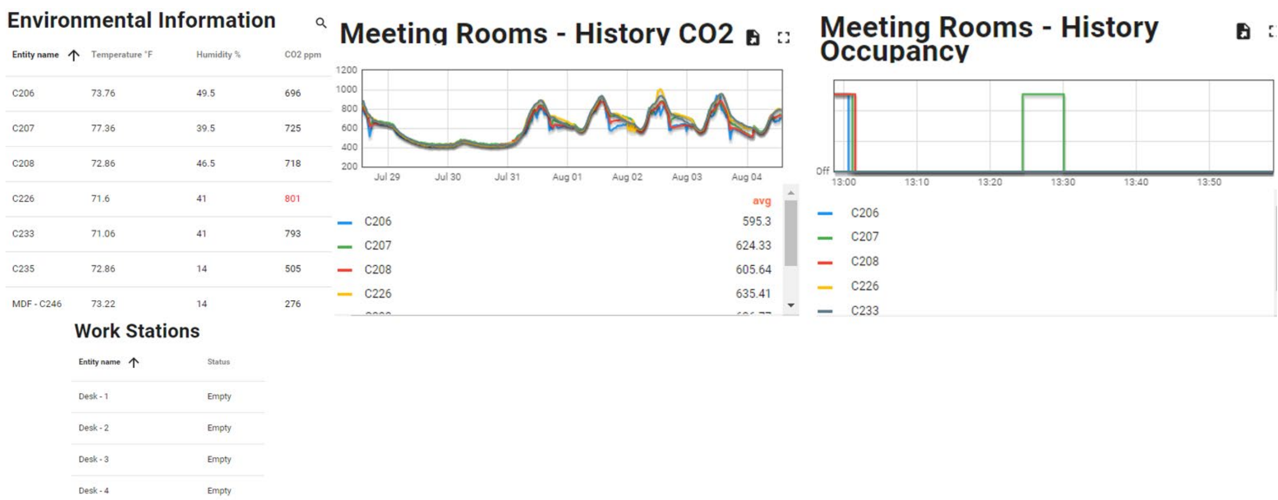


Figure 30 – Application Server All Sensors Data

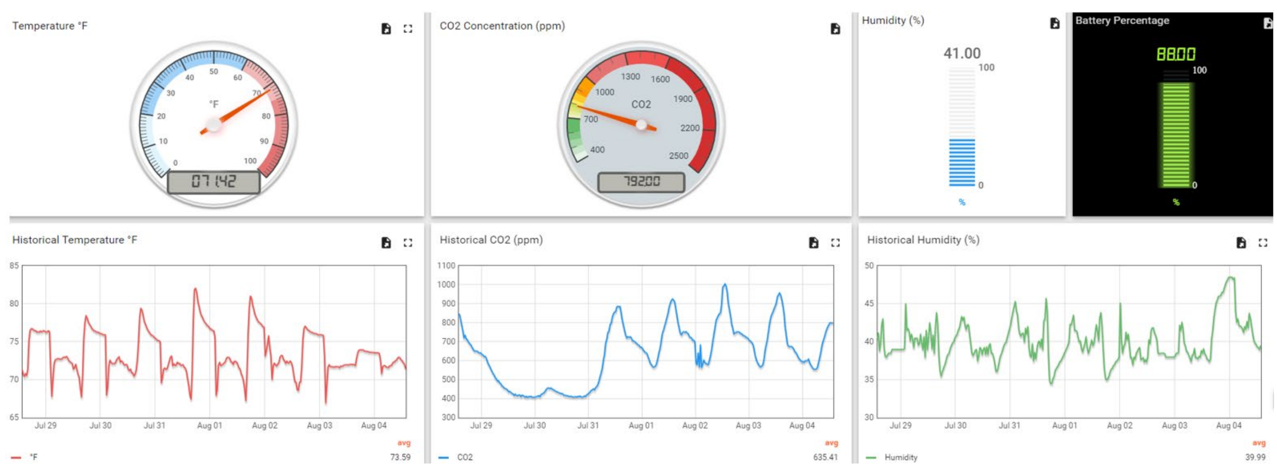


Figure 31 – Application Server Sensors Data Room C226

5. Conclusions and Best Practices

- Using the calibrated propagation model, the measured results show that all the samples are above -100 dBms of RSSI and above 0dB of SNR which means the entire building is covered with appropriate LoRa signal levels for the suitable sensor functionality.

- Based on the results obtained, the planning of the physical gateway placement is significant for developing low-power, long-distance communication via LoRa.

- The gateways are strategically located in order to cover the entire building, and their locations will warrant appropriate signal strength and quality levels. Therefore, one LoRa gateway can cover at least one floor below and one floor above it. Depending on the building size, shape, and design results, it is generally recommended to place gateways on different corners and alternating floors.

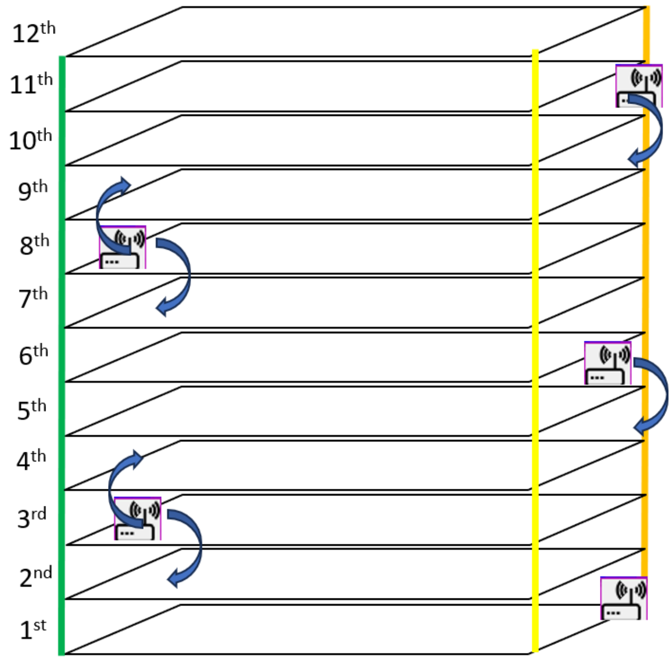


Figure 32 – Gateways Placement Strategy

Action points will be implemented with the goal of enhancing employee comfort, improving operational efficiencies, the efficiency of room occupancy, and reducing operating costs, according to the Table 4 – Action Points.

Table 4 – Action Points

Environmental Variables	Units	Triggers	Actions - Send email notifications +
Temperature	Fahrenheit (F°)	> 80	Turn on the backup AC
		< 62	Turn on the backup Heater
Humidity	Percentage (%)	> 75	Turn on the dehumidifier
		< 25	Turn on the humidifier
CO2	Parts per million (ppm)	> 1000	Turn on the fans and open doors
Remaining battery	Percentage (%)	< 25	Change batteries
Motion	String	Empty	Turn off the lights

Abbreviations

3GPP	3rd Generation Partnership Project
ABP	Activation by Personalization
ADR	Adaptive Data Rate
AES	Advanced Encryption Standard
AppKey	Application Key
AppSKey	Application Session Key
App Server	Application Server
BW	Bandwidth
CR	Coding Rate
CSS	Chirp Spread Spectrum
DDR	Dynamic Data-Rate
DevAddr	Device Address
DevEUI	Device Extended Unique Identifier
DL	Downlink
DLOS	Direct Line of Sight
DNLOS	Direct Non Line of Sight
DR	Data Rate
FCC	Federal Communications Commission
FRT	Fast Ray Tracing
FTD	Field Test Device
GW	Gateway
GPS	Global Positioning System
IoT	Internet of Things
HTTP	Hypertext Transfer Protocol
ISM	Industrial, Scientific, and Medical
JS	Join Server
KHz	Kilohertz
LNS	LoRaWAN Network Server
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
MAC	Medium Access Control
MHz	Megahertz
ms	Milliseconds
NaaS	Network as a Service
NB	Narrow Band
NS	Network Server
NwkSKey	Network Session Key

OTAA	Over the Air Activation
PHY	Physical
RAN	Radio Access Network
Rb	Bit Rate
RF	Radio Frequency
RP	Reflected Path
RSSI	Received Signal Strength Indicator
RX	Receive
SCTE	Society of Cable Telecommunications Engineers
SF	Spreading Factor
SNR	Signal-to-Noise Ratio
ToA	Time-on-Air
TX	Transmit
UL	Uplink
Wi-Fi	Wireless Fidelity

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