Optimized Communication Model for IoT Network Using LoRaWan

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Approval

It is certified that the contents and form of the thesis entitled **"Optimized Communication Model for IoT Networks Using LoRaWan"** submitted by Kamran Yamin have been found satisfactory for the requirement of the degree.

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Dedicated to my exceptional parents: ***Muhammad Yamin & Perveen Akhtar*** *and adored siblings whom tremendous support and cooperation led me to this wonderful accomplishment.*

Certificate of Originality (Turnitin Report)

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I certify that this research work titled "*Optimized communication model for IOT network using LoRaWan"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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List of Abbreviation

RSSI – Received signal stretch indicator
SNR- Signal to noise ratio
SF- Spreading factor
LoRaWan- Long range wide area network
IOT- Internet of Things
Avg- Average

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Abstract

In today's world concept of internet of things is emerging rapidly and high demand of IOT requires a communication standard that can provide lower power consumption, long coverage area and scalability. Some of the communication standards including cellular, wireless sensor or Bluetooth cannot provide these requirements as a package, so to counter these issues LoRaWan is the protocol. Key feature of LoRaWan is that it can provide communication at longer distances with lower power consumption that is ideal in the concept of IOT network. In this study we are going to analyze the performance of LoRaWan in outdoor and indoor scenarios conditions, which will give directions in implementation of network using LoRaWan as a communication standard between the sensor nodes in different scenarios. We will deploy multiple nodes and gateways in different real world created scenarios and test their performance indicators by manipulating spreading factor and distance between end LoRa nodes and gateways. Study was conducted at SEECS building, school of electrical and computer engineering NUST, Pakistan. This study will provide comprehensive picture of desired deployment of the LoRaWan in IOT network to ensure seamless long distances communication. We manipulated the spreading factor from low to high (SF 7 to SF 12) in different outdoor and indoor scenarios to analyze the changes in RSSI, SNR which will ultimately help in the designing of IOT network or wireless sensor network for future. After analyzing the factors optimized placement of infrastructure will be proposed to achieve optimized performance, LoRaWan in internet of things.

Key Words: *LoRaWan, IOT network, Spreading factor, RSSI, SNR, End LoRa node*

Chapter 1: INTRODUCTION

1.1 Description and Motivation

In this era almost everything is getting connected to internet from shoes to refrigerators to televisions to mobile phones to power plants. This interconnection of appliances and devices is called internet of things. Every device in IOT infrastructure is unique and only identified through device's internal system. IOT enables appliances to connect over internet which makes them smart in a sense that these appliances can be operated in a smart way from long distances. IoT works in a way that devices are powered by battery which is off course limited and also the limited bandwidth and range. Number of different technologies are candidates to IoT network which includes Bluetooth, WIFI etc, but the most useful protocol is LoRaWan because of its key features that over sides its competitors. Current in today's business world access to real time data from critical assets of the organization is the key. Organizations that collect real time data from key assets and then act on collected data performs more efficiently and can streamline their services, digital information accelerates so organization cannot ignore it and put it to sidelines. So, way forward is LoRaWan, it provides way to connect your assets and make you able to monitor and unlocking the insights of your business requirements to streamline your performance. LoRaWan is basically a open standard globally to communicate wirelessly that is required in organizations to collect real time information from the objects to tracks objects and assets location and critical data which was never possible before because of high deployment cost and technical issues. Taking benefit from LoRa sensor end nodes, organizations can collect critical information at lower cost to make their process improves and automated, it can make raise to revenues and also creating new opportunities of business. Standard of LoRaWan created by LoRa alliance, a global association that manages and develop LoRaWan. LoRaWan particularly is developed for communication in IOT network to communicate over long distance and transmission of signals through physical barriers than can transmit at lower power consumption, increasing the battery life of end sensor nodes which is scalable and lower deployment cost. Using LoRaWan in IOT infrastructure can enhance the welfare and health of people around the globe, also enhancing the bottom lines of businesses. LoRaWan break the barriers that hinders in communicating wirelessly, it reaches underground tunnels, penetrating concretes and even reaches highest elevation over a long range. It can communicate devices over longer distance even 10 km in line of sight in an open area that too at lowest deployment cost. LoRa is quite robust can make communication possible in hard weathers conditions and congested environments. LoRaWan works on unlicensed frequency bands (i.e. 867 to 869 MHz and 902 to 928 MHz frequency bands). Key features of LoRaWan includes less power consumption, long range communication, scalability and lower cost makes it ideal candidate for IoT network operations as IoT network devices are battery powered which requires protocols that consumes less power over longer distances of communication. LoRaWan infrastructure have sensor nodes, gateways, network server and application server. Sensor nodes are connected to LoRa gateways, sensor nodes collect required information and transmit it to network server through LoRa gateways. LoRa gateway is the device that provides interface a communication between sensor nodes and network server. From network server that information or data is then transmitted to application server for necessary action. This research will provide a complete deployment of LoRa sensor nodes in real time environment which will guide an organization those want to setup LoRaWan in their organizations or anywhere where IoT setup is established to make communication between devices better with lower power consumption over a longer distance.

1.2 Advantages of LoRaWan

- It can make communication possible over a longer distance.
- Consumes less power, uses less energy while communicating devices and objects. Battery can run for good 10 to 15 years which is very critical in IOT concept.
- Sensor nodes can be deployed in difficult terrains.
- Robust to weather conditions.
- LoRaWan is flexible and highly scalable.
- Deployment cost is very less.

- Thousands of nodes can be covered by single gateway which again reduces deployment cost.
- It is secure, encryption is end-to-end using industrial standard Aes-128.
- It provides immunity against signal and multi-path fading at high spreading factor specially.

1.3 LoRaWan Parameters

LoRaWan uses open license free frequency spectrum and it is different in different parts of world, it is not like Wi-Fi and Bluetooth that is harmonized globally such as Wi-Fi makes use of 2.4 and 5 GHz frequency spectrum. You must have to use different frequency bands in different regions which is illustrated in Table 1.1.

Table 1.1. Frequency Range in different regions

Region	Frequency Band
Europe	863-870 MHz
China	779-787 MHz
USA	902-928 Mhz
Australia	915-926MHz

In different regions you have to use different license free frequency and to make it easy LoRa alliance shared document on their platform which gives details of frequency use in different countries which is operated in almost around 150 countries around the globe. LoRa use chirp spread spectrum modulation, which reflects that there is bandwidth in which symbol are modulated and there is center frequency, around that frequency symbols are modulated in a spread waveform which helps in reducing interference. Chirp spread spectrum is also used by whales to communicate to locate their prey over a long distance and that is exactly from where chirp spread spectrum emerge. At modulation side end nodes transmit information in a form of chirps, few up and down chirps and then up chirps with data. At demodulation side, which is obviously receiver end, there is reverse of it which de chirping and then there is spectral analysis to figure out the symbols at transmission side. Another important term is spreading factor which indicates the amount of data bits in a second (data bits/second) that are being modulated in a unit time, which means that if we increase spreading factor communication will be slower, depicts in Fig 1.1 as well.

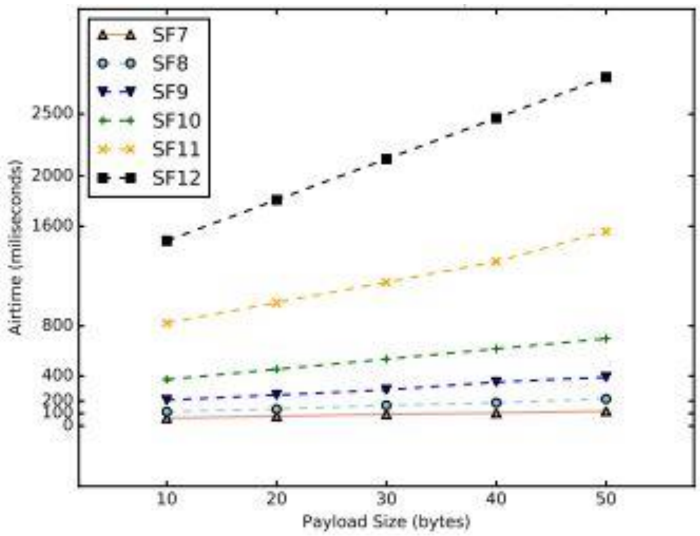


Fig 1.1. Time on air with SF [2]

So longer time on air to transmit consumes more power than less time on air. Using lesser spreading factor will decrease time on air which will then consumes less power to transmit information which is good for battery, it also transmits faster but coverage area which you will get is also limited. Unlike with higher spreading factor with lower spreading factor you cannot transmit over a longer distance, so it is choice and depends on environment and its requirements. If application is time critical and you there is no need to transmit over a long distance, then one can choose lower spreading factor but again it depends on the requirement of application. There is always tradeoff in, there is no single and best spreading factor to choose from. Then there is term duty cycle which is gain different in different region. Duty cycle in LoRaWan means that for how much time your end node can transmit information and for how much time it has to stay silent, data regarding duty cycle is in Table 1.2.

Table 1.2. Duty cycle data

Frequency Plan	**Europe**	**US**	**Asia**
Duty Cycle	0.1-10 %	No limit	No limit

It means in Europe end nodes need to stay silent for maximum of 10 percent of time out of total time nodes are transmitting information. RSSI indicates the strength of signal received, better the value of RSSI better the communication is. Good RSSI values means that devices is listening signal well which indicates better transmission of information. Higher value of SNR means that there is more signal than noise in received signal which is indicator to analyze the quality of received signal.

1.4 Problem Statement

As everything from mobile to televisions to power plants are getting connected to internet, which makes a network called internet of things (IoT). Different protocols are available to make communication between IoT devices. IoT devices are battery powered, so LoRaWan is most ideal protocol to IoT network as it consumes less power and can also operates over a longer distance by using unlicensed frequency bands ranging from 867 to 928 MHz. Existing work is limited to very few scenarios whether it is indoor or outdoor conditions. There is a need of extensive analysis to help future practical deployment of LoRaWan in IOT networks. In this work we did expansion in previous works. We did performance analysis of LoRaWan in IOT network on larger scale. We analyzed SNR and RSSI values by changing spreading factor in number of created scenario in both indoor and outdoor scenario conditions.

1.5 Application

LoRaWan basically took IOT (internet of things) to a whole new level, it can establish communication over a longer distance with less power consumption. LoRaWan is secure provides immunity to attacks, it is highly scalable and cost less in deployment. LoRaWan is being implemented in COVID-19 to track safety concerns and balance health and need of medical professionals. It helps in smart agriculture to monitor the need of pesticides, health of crops. It can be implemented in smart electric and gas metering to track any issues in supply, in most cases meters are installed at congested environments where it is difficult to implement other wired or wireless technologies for tracking, so by implementing end LoRa nodes and gateways supplying companies can easily track any issues and needs to streamline their services in a better way that too by investing less financially. This study will help implementing LoRaWan infrastructure in number of applications as deployers will know beforehand the performance indicators LoRaWan in indoor and outdoor conditions in different scenarios. Organization can improve their revenues by acting on data collected from their assets which ultimately can enhance the bottom lines of businesses. Utility provider can reserve resources using LoRaWan to save cost which benefits them and their customers as well. LoRaWan can make our cities smarter, cleaner and safer, it can improve logistic operation through cities. It can help in agriculture by increasing yield and saving natural resources. Agriculturists can streamline their crops by collecting real time information from the sensor deployed all over their lands that too at lowest deployment costs. LoRaWan can streamline traffic patterns to avoid accidents and mishaps.

1.6 Aims and Objectives

In this study we have aims and objectives to achieve:

- First to study recent development and work in the field of LoRaWan in IOT network.
- To do extensive performance analysis of LoRaWan in IOT networks by deploying LoRa end nodes and gateways in different combinations and scenario conditions.

1.7 Organization of Thesis

This thesis work follows:

Chapter 2 covers the technology and its recent advancements. It includes detailed study of literature and recent work in the field of LoRaWan in IOT network.

Chapter 3 discusses details of LoRaWan, IOT and its applications and key factors.

Chapter 4 presents methodology.

Chapter 5 discusses deployment of methodology and results of experiments.

Chapter 6 includes conclusion based on results of experiments and future work.

Chapter 2: Literature Review

All the relevant concepts is discussed in this chapter. The chapter focusses on the background of important studies (reviewed in this report) that were involved in research. Chronological revision of LoRaWan and other relevant fields are considered to complete this theoretical background. The top-down method has been utilized to explain concepts. This chapter also has some discussion about the related subjects.

2.1 LoRaWan

Wireless LoRaWan is a low power, wide area networking protocol. It connects wirelessly operated things to networks and targets Internet Of Things facets such as mobility, security, bi-directional communication, and localization service.

The architecture used is deployed in the star of stars topology. This essentially means that messages are relayed between central network and end devices. The gateways are connected with standard IP connections and are responsible for conversion of RF to IP Packets and IP to RF packets. The communication utilizes long range characters at the physical layer. All the modes can do bi-direction communication due to allowance of a single-hop link which allows for efficient use of spectrum. Fig 2.1. is representing LoRaWan Architecture.

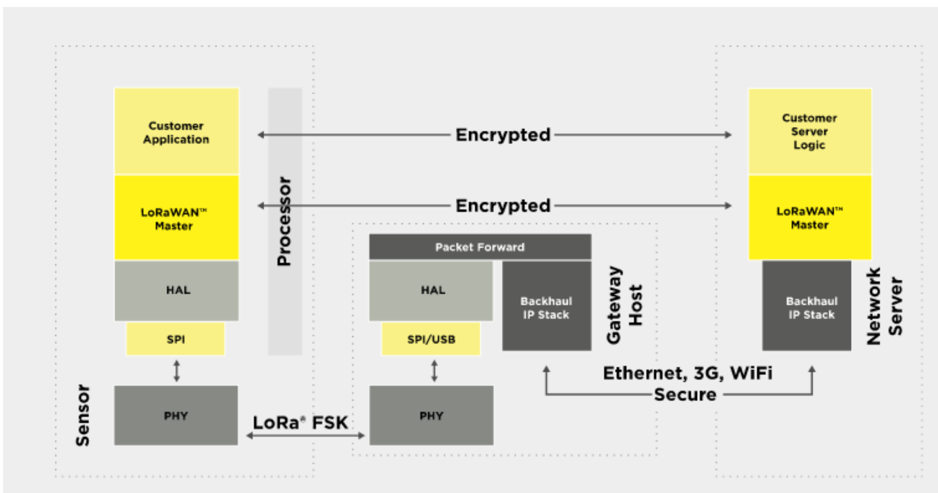


Fig 2.1. LoRaWan Architecture [24]

LoRaWan has three classes: A, B, and C as seen in Fig 2.2. Class A refers to low power and bi-directional devices and is considered a default class that works with all LoRaWan destination devices. For class A, the communication will be generated by the device itself. It will also be completely asynchronous. It gives the opportunity of bi-directional communication as well as network control commands as required. With Class A, uplink transmission is ALOHA type protocol and can be done at any interval.

It allows the end/destination device to enter into low power, sleep state which can be defined by the application. There is no as such prerequisite for wakeups on a recurrent basis. All these factors make class A the low power mode which can do uplink communication as needed. The download link needs to follow an uplink transmission as per the schedule which is dictated by the application of end/destination device. The downlink communication will be buffered until the following uplink event occurs.

Class B essentially involves bidirectional devices and download latency which can be determined. These devices sync with periodic beacons and pink slots at the specified time slots. It allows the network to send download link communication with some additional power conception but at a deterministic latency. Deterministic latency is programmable to 128 secs which suits a variety of different apps. The power consumption is fairly low but still suits different apps that are powdered by battery.

Class C of LoRaWan refers to lowest latency and bi-directional end-devices. Essentially class C reduces the latency. It achieves this by using a half-duplex device open which will be open at all intervals. It allows the server to initiate transmission of download link at any given time as the receiver of end device is open. This translates to no latency. The settlement here is receiver's power drain which makes class C suitable for apps which have access to continuous power. Typically, battery powder devices switch between classes A and C for optimal functioning.

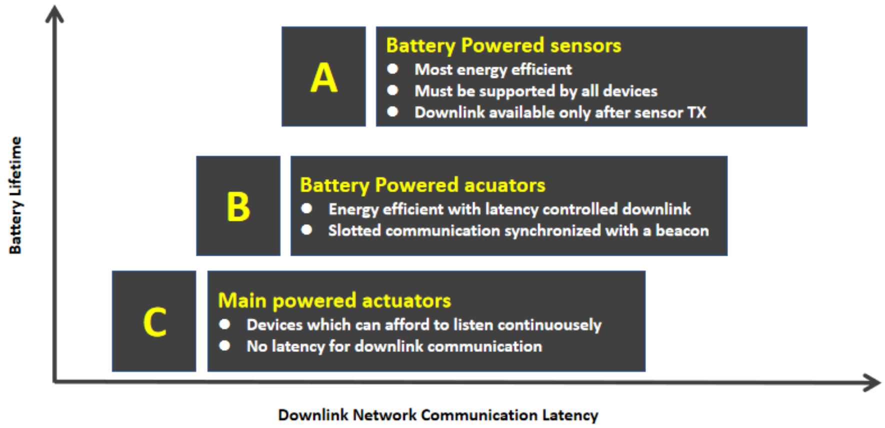


Fig. 2.2 LoRaWan classes [25]

All the communication packets between gateways and end to end devices include a DR setting. The dynamic tradeoff between duration of message and range is possible with the selection of data rate. As the spread spec technology is used, communications that have varying data rates don't engage with one another as well as a set of distant code channels is created which is responsible for increased volume of the gateway. In order to increase the network capacity and life of the battery, LoRaWan server manages Data Rate and Radio Frequency individually for each end-to-end device with ADR scheme. Security is a primary issue of any mass level Internet of Things deployment. LoRaWan specifies 2 layers of cryptographic security; a 128-bit Network Session Key along with a 128-bit Application Session Key. Network session key is given to server and end device. Application server passcode provides authentication as well as integration of packets to the application and network server. Once these two levels are implemented, implementation of shared network becomes secure as the network operator cannot access payload data of users. ABP is used to activate the key during commissioning. The keys can be reconfigured at any point as required.

2.2 LoRa Coverage and Performance in Different Environments

In Countless studies have been published on LoRa by the research community, elaborating on different aspects. Some studies are focused on LoRa coverage [10], [11], [12], [13], [14] while others offer a comparison insight into performance of physical layer between LoRa and other technologies [15], [16]. Certain studies are also done on mitigation of LoRa [17]. When LoRaWan was deployed in suburban areas, the coverage was good. 3 km for Spreading Factor 12, and 2.3 for Spreading Factor 7. In this particular experiment, the area comprised of several low-rise building, and gateway is placed on second floor of chosen building. In [11], authors were able to achieve network coverage for 100 square kilometers with 30 gateways. About fifteen of these gateways were used for cellular network coverage in the same area. The overall density for each gateway came out to be of 7000 inhabitants.

As per another overage study [12], two environments were taken into account: sea and city. For city environment, the packet success rate was 80 percent for less than 5km distance and 60 percent for greater than 5 km but less than 10 km of distance.

For open sea environment, the results differed greatly. The packet success rate was 70 percent at 15km.

In studies [13] and [14], the authors have characterized the performance of LoRaWan in terms of packet loss, signal strength, coverage, delays and power consumption. All the measurements were taken in an indoor environment with the gateway mounted on the same floor. A high percentage of packet loss is monitored, around 40 percent with spreading factor 1 at specific points. For spreading factor other than 12, packet loss was less than 5 percent. 94.7 percent was the slowest delivery ration achieved as per [14].

The lowest DR as per the experimental results was 94.7% at the specified measured point. The reception ratio was good with RSSI greater than -132 dBm. In [1], the authors showed performance and coverage results for indoor deployment of LPWAN. LoRaWan was deployed with one gateway and one server. The entire experiment was setup in an industrial environment which was a warehouse dedicated to flower auction. The communication in the middle of LoRaWan and end devices was blocked by metal trolleys in the site. Based on the results, authors concluded that the entire industrial area could be covered with spreading factor 7 and surface of 34000 m2. The average RSSI values were above -100 dBm and SNR values were generally great than 0 dB. No packet loss was observed apart from the negligible ones.

For outdoor measuring locations, communication with spreading factor of 7 was not possible. However, communication with spreading factor 12 existed with the distant measuring at 400m. The average SNR value were negative and peaked at -16.4 dB.

As far as network scalability was concerned, authors used a simulation model. Every hour, about 75% nodes sent a 20-byte packet. The remaining 25% sent a 20 byte packet every five minutes. The overall packet loss ratio came out to be less than 10% with 6000 nodes served as indicated in Fig 2.3.

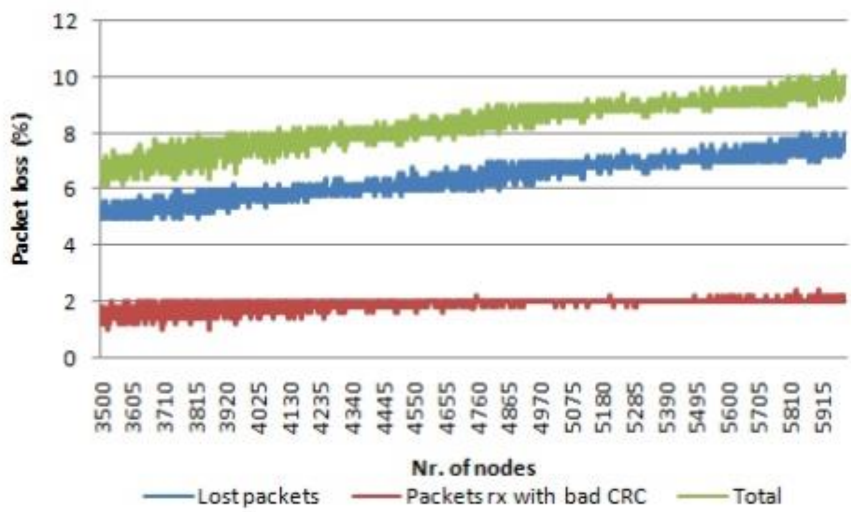


Fig 2.3. Scalability Simulations [1]

2.3 LoRaWan Performance Analysis with Experimental Test Bed

In [2], authors have analyzed the performance of LoRaWan with TestBed environment, taking the following parameters into consideration, packet loss, range, energy consumption, and data range for an indoor use case. The results obtained in this particular paper are obtained from a Testbed environment that comprises of nodes, server, and LoRaWan gateways. They have evaluated the results for future direction.

As per the LoRaWan analysis of Health Care Systems [17], transmission of medical data and hospital environment was taken into consideration. The scenario is carefully analyzed and tested to create a testbed. To do this, authors have used IC880a board which is integrated to Raspberry Pi3.

The gateway supports LoRaWan protocol and operates simultaneously over three different channels. The authors have taken the following scenario into consideration; GW is positioned at the office rooms at roof of the building and tests are conducted over different floors are different locations. The test building had thick walls and glass panels along with mixed material used in certain area which affects the signal propagation of Radiation Factor. The experiments are conducted through four floors of the building with variation in node deployment. The general overview of the floor plan and scenario is shown in Fig 2.4.

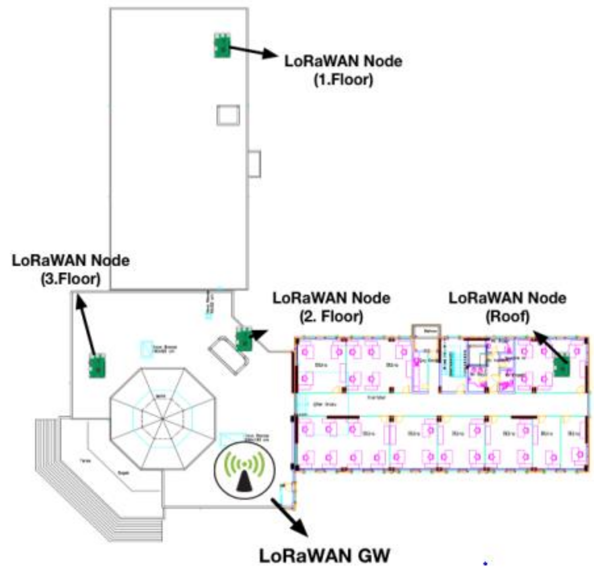


Fig 2.4. Scenario [2]

The authors performed experiments for two different configurations: scenario of packet loss and scenario of frame transmission airtime. The first configuration was planned for all SP and bandwidth of 125 kHz. The experiment was done for ten different times but with the same payload. The data packets were generated and transmitted were between 10 to 50 bytes. The protocol has an overhead of 14 bytes. The total frame size is 24 bytes. The authors performed all the tests using this single channel with 10 ± 1 SNR in noise free environment. The transmission time increased significantly with SF for all payloads. The average results of multiple experiments conducted to support the research show GW node distance impacts the packet delivery as shown in the figure. Moreover, materials used on the floor of the building also affects the propagation of signal. The RSSI and packet loss exhibit a similar pattern which validates protocol communication. The ratio of packet loss is higher for the same building and drops dramatically at floor 2. The sudden drop is attributed to the placement of nodes as it is surrounded by plenty of walls. Essentially, packet loss ratio can be reduced by using multiple gateways at different locations in the building. The gathered results from the study showed that LoRaWan can be utilized in the indoor environment even with a single gateway.

2.4 An Insight Into LoRa RSSI and Packet Loss

Here is brief background of Wireless Sensor Network that was meant for IOT in agriculture in different literature of the recent past.

Mare As indicated in the paper [3], the capability of LoRa radio is indicated by values of RSSI. The authors sent the data to application at different locations using MATLAB. The locations were at different distance from the GW. The spreading factor was constant throughout and was set at 12. The payload of each packet us 19 bytes. The RSSI of the packets received decreases with the increased difference between end device and GW.

The minimum value of RSSI at a 100 m distance. The value of RSSI decreases with the increased distance and obstructions between end device and gateway. The link becomes stable at the distance of 200m. The stable values of SNR and RSSI are attributed to higher value of spreading factor. A higher value of spreading factor allows the packet to be synchronous and adjusted to amplifier’s gain at the gateway. The data packet with a higher spreading factor value is received with specific settings which leads to stable SNR and RSSI values at a distance over 200m. The paper concludes that increased distance will lead to lower SNR and RSSI values.

2.5 LoRaWan Capacity and Uplink Performance

Researchers have studies efficiency of LoRaWan for varying devices [2]. The simulation OF LoRaWan was done by NS3 that is responsible for operation protocols at all levels. LoRaWan is generally found more suitable for devices that require low power which are responsible for generating little traffic. A detailed analysis is done on functional components as well as efficiency in [3]. The results show that a higher SF is responsible for increased range of transmission and is responsible for strengthening the resistance in regard to interference. A lower data rate decreases throughput of every single device and reduces the duty channel scheme as well. It also helps to minimize collision. With the decrease in consumption of energy, the capacity of the channel is also decreased. LoRaWan is highly quick to respond to load of the traffic depending on calculated overall average traffic for every single node.

The ideal nodes number for each cell is based on operation mode of each of the connected devices. The compromise delivery of data, energy and quality presented in [4] discusses a mesh networking system for large area. The authors have deployed 19 LoRa mesh devices over an 800 m × 600 m area. The GW collects the data minute by minute. The results show mesh networking performs better than star topology for same settings.

Another research conducted on capacity as well as scalability of LoRaWan. The upload rate is the parameter of measuring performance. Upload rate is influenced by channel composition, requirements of the application, distance from node, and device distribution. The authors analyzed several scenarios for a single LoRaWan device [6]. The paper primarily focusses on the coverage and capacity of LoRaWan and Sigfox in a large urban region with the help of Telenor Cellular Grid to determine failure uplink to downlink rate. The failure rates can be attributed the loss of penetration and coupling, interference, and time on air.

The paper [7] dives deeper into the uplink performance of LoRaWan uplinks. Researchers used a system to model duty cycle data transmission as well as transmission period. Analytical model is used here to determine the collision along with latency. The discussed research model evaluates the performance of LoRaWan for latency and probability. Paper [4] suggests that LoRaWan offers quality of service in case of indoor applications despite background traffic.

Table 2.1. Literature review - Summary

Title	Objective	Limitation	Year of Publication
LoRa indoor coverage and performance in an industrial environment	Goal was to inquire coverage area in indoor environment. They took use case from flower industry. Deployed end LoRa nodes with trolleys to communicate with server.	RSSI and SNR values received was not good enough. Tested on small scale of scenarios.	2018
Performance analysis of LoRa radio for an indoor IoT applications	Nodes were deployed in indoor environment with single gateway and 3 end LoRa nodes on two different floors.	Tested on very small scale. Only in indoor environment with only one scenario. Used 3 nodes and single gateway only.	2017
Performance Evaluation of LoRa Considering Scenario Conditions	Tested in outdoor environment to find coverage in rural and urban conditions.	Tested in very controlled environment which is practically not feasible.	2018
Performance Analysis of LoRaWan for Indoor Application	They deployed end LoRa nodes in indoor environment on different floors with single gateway.	Very limited scope.	2019

Table 2.1 is summary of research studies we discussed in this section which includes objective of particular research study and limitations in their work.

Chapter 3: Problem Statement and Proposed Model

Problem statement, proposed model and technology used are discussed in detail in this chapter. The chapter starts with problem statement, problems in the current literature, detailed insight into the technology and proposed solution based on the results of the experiment.

3.1 Problem Statement

IoT is getting popular rapidly and within few years billions of devices will be communicating each other. Air conditioners, televisions you name anything in this world will be connected one day with other things through a network. It can help in many practical applications to collect information, like collecting data of humidity in seeds, is there a need of watering and pesticides. Collecting data of electric meters to track any issue to streamline the services beforehand. Tracking car parking, free spaces and pattern of usage of parking area to improve services [3]. So IOT needs a protocol that works over long distance and consumes less energy, cost less and scalable. LoRa is the protocol that works over long distance and consumes less power to transmit and collect information from different sensor nodes deployed. There is extensive need to analyze performance of LoRaWan in different situations which can help in future deployment of LoRaWan infrastructure in such situations. As we studied number of literatures, there is limited study on performance of LoRaWan in both indoor and outdoor conditions so in this research work we tackled this loophole and did performance analysis of LoRaWan in number of scenario conditions in both indoor and out scenario conditions, which will help future deployment of LoRaWan in IOT network.

3.2 Internet of Things

Internet of things, commonly referred to as IoT is essentially a network of devices which are related with one another. The devices can be mechanical machines, digital gadgets, animals, things and even people that have unique identifiers and can transfer data or info over a specified network minus the need or any interaction (human to computer, human to human, computer to human, or computer to computer) [11].

A great example of internet of things is a heart patient with a heart monitoring implant, an automobile with sensors that informs drivers about the tire pressure, or any other object that will/can be given IP address and has the ability to transmit data or information over the network. Lately, many organizations have been using IoT to increase the efficiency, understand customers in a better manner and improved decision making for the business.

3.2.1 How Internet of Things Work?

An eco-system of Internet of Things consists of web enabled devices. These devices are used in embedded systems such as sensors, processors, communication hardware for acquiring, giving out, and acting of the info gathered from the environments. The Internet of Things devices will be in connection to the GW and share data sent which is that analyzed at later stages. These devices also communicate with other devices in the spectrum and share information with one another as needed. Most of the work is done without human interaction. Human interaction is typically required for set up, instructions and during data access. The networking, communication protocols and connectivity is dependent on the deployment of IoT applications [9]. IoT apps also use artificial intelligence and machine learning to make the process of data collection seamless and to inch closer to a dynamic approach. Fig 3.1 is representing the generic architecture of IoT network.

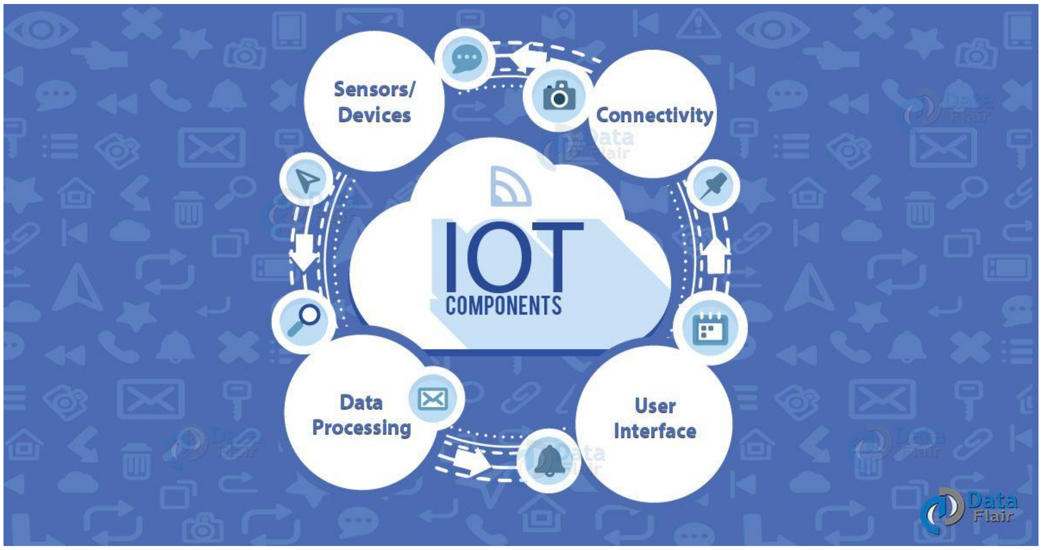


Fig. 3.1 How IOT Works [26]

3.2.2 Importance of IoT

The internet of things helps make lives easier and essentially promotes smart working. Contrary to the popular belief, it gives more control over day to day living. In addition to day to day life improvement, it is essential for businesses to grow. It gives enterprise owners a real time look into hoe the systems work, insights into everything, performance analysis, real time updates on supply chain, operations and more. Essentially, IoT automates the process while minimizing the cost of labor. Improved delivery of services, reduced waste, affordability are only few of the benefits this amazing technology has to offer [3] [6].

Some of the major benefits to organizations include easy monitoring of the business processes, improve customer experience, enhanced productivity of employees, time saving, cost reduction, integration and easy adaptation of business model, better decision making and revenue generation. Internet of Things essentially improves the overall functioning of any industry and results in better business strategies.

Generally, IoT is used in transportation, utility, hospitals and manufacturing industries. Industries like agriculture, automation, infrastructure are also jumping on the bandwagon to optimize the processes.

3.2.3 Pros and Cons of Internet of Things

Major advantages of IoT are easy access of information at anytime and anywhere, enhanced communication in between the devices which are connected, time. money saving with easy data transmission over a connected network, automation of tasks, improved quality of services and minimized need of human intervention [3].

Some of the cons of IoT include: increased connected devices along with increase in the information sharing which possess threat to the security and requires additional security measures. Management of a wide spread network of IoT devices can become a hassle for enterprises. Presence of a small bug can actually corrupt the entire system if proper security measures are not taken. International compatibility of IoT does not exists at the present moment which makes it difficult for devices make by different manufacturers to interact with one another.

3.2.4 IoT Applications

There is a huge number of Internet of Things Applications we can spot in real life. From manufacturing to healthcare to industry, there is no industry that cannot benefit from the miracles of IoT.

The consumer segment has really benefited from the IoT. Smart homes that have smart thermostats, appliances, heating, electronic devices, lighting and more that are easily controlled by mobiles, computers, and remotes are a reality for many. A few years ago, nobody thought this smart homes would become so common. While we are on the subject of smart homes, wearable devices are also on the rise. The sensors and software analyzes the data of users, sends messages and essentially make lives of users easier. Public safety has also improved greatly with IoT devices. For instance, wearable devices can provide instant access to the location in case of an emergency or in life threatening situations.

Healthcare sector has also benefited from the miracles of IoT. Patients' data can be monitored at all times in real time when when the patient is not available in the hospital. Hospitals are also using IoT for management of inventory for medical instruments and pharmacy. Smart building can reduce energy consumption and costs and make the lives of the inhabitants easier. In the fast paced world, humans are always looking to add ease into their day to day living. Internet of Things does this effectively and takes the mundane tasks out of your day, making room for important things.

3.3 LoRaWan

By definition, LoRa is a modulation technology for WLAN and LoRaWan is a protocol that uses LoRa. Both LoRaWan and LoRa belong to non-cellular LPWAN network protocol. They operate with Ingenu, Sigfox and more in an unlicensed spectrum. LoRa is a wireless radio frequency technology which is associated with Semtech and is the driving force of alliance where LoRaWan is developed [1]. LoRa and LoRaWan are regarded as the main LPWA solutions and ecosystems.

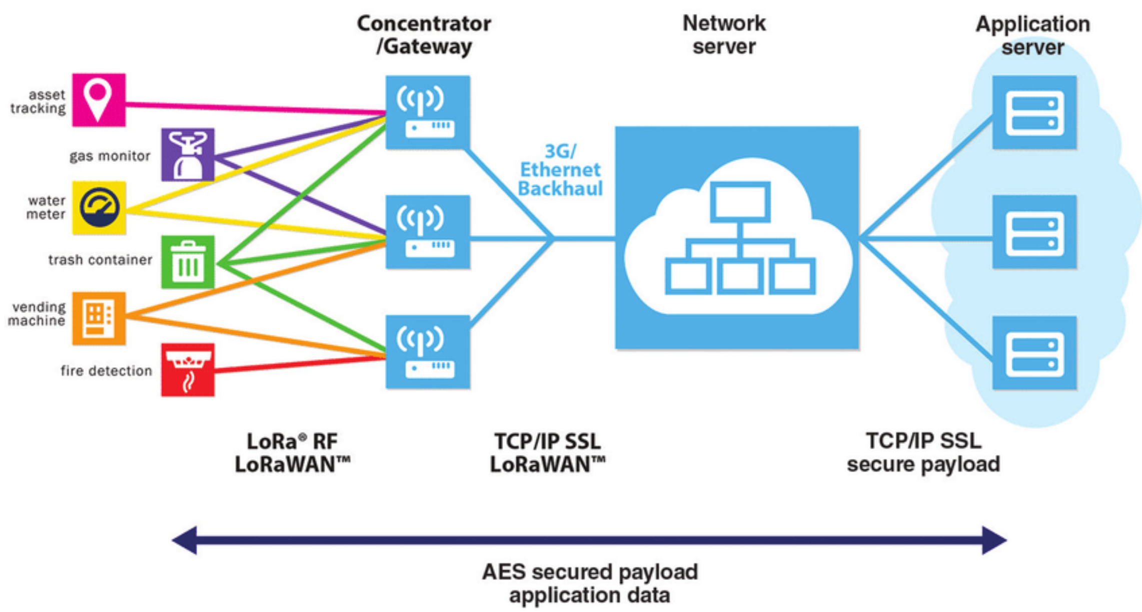


Fig 3.2 LoRaWan

3.3.1 LoRaWan and IoT Connectivity Space

LoRa is currently being used by numerous telecom providers. It is a perfect network to be used for communications between IoT devices, works in perfect harmony with systems used for data gathering where frequent data transmissions occur. LoRa and LoRaWan are ideal for companies who want to step into IoT where larger distanced with the need of low capacity [2]. A great example is smart cities and logistics. For instance, connected cars require more capacity than the oil and gas applications.

Since LoRa is known because of low frequency, it is also low on power. These attributes makes it perfect to be used for devices with smaller batteries. Some other examples where LoRaWan can function optimally is smart car parking, traffic management, smart metering, and waste management as these applications require to control devices from an extended distance. LoRaWan is perfect for apps which need to be operated from an extended distance, need localization, logistic apps, security apps, mining, smart meters and other IoT domains. All in all, it is a great alternative to less ubiquitous solutions for connectivity. There are few uses cases showing in Fig 3.3.

Fig 3.3. LoRaWan Use Cases

3.3.2 When is LoRa a Good Choice?

LoRa is an ideal choice:

- Transport Layer Security - When a system needs a transport layer security at the end nodes. LoRa uses AES CCM by default.
- Wide Availability - When it is available widely for instance, deployment in EU.

- Low Power and Large Range - When applications need to operate on a sweet spot of deployments at a wide range and on low power [4].
- Battery Conservation - When the requirement for low power is important for applications. The data rates can be altered for the conservation of battery.

3.3.3 When is LoRa Not a Good Choice?

LoRa is not a good choice when:

- Uniform Solution – LoRa is designed to operate on different frequencies in different areas. If a uniform global solution is required, LoRa is certainly not the right choice for globally harmonized environments.
- Even Bandwidth – In case the scenario requires even bandwidth (regulations on upstream and downstream of data), LoRa is not to be used.
- Outside EU – If the deployment is done outside EU, LoRaWan is not the most efficient way to work.

3.3.4 Characteristics of LoRaWan

The key benefits and characteristics of LoRaWan will be discussed in this section.

- Long Range – The long extended range characteristic of LoRaWan makes it ideal for communication between long range base stations and sensors. It reduces the number of base stations by 2-3 times when compared to cellular range networks.
- Battery – LoRaWan transmits and receives data on a current lower than 50 mA which reduces the consumption of power dramatically, making the battery life last much longer than conventional networks.
- Bidirectional – LoRaWan offers completely bi directional communication that allows a varying range of use cases that need uplinks and downlinks; smart irrigation, energy optimization, automation in homes, street lighting and more [7].
- Indoor Penetration – Radio Modulation of LoRaWan allows indoor penetration and enables the ability to reach underground nodes of gas and water.
- Open Source – LoRaWan is essentially an open protocol which is managed by LoRa

Alliance. It supervises the development of standard and guarantees the interoperability between different networks.

- Unlicensed Band – The networks of LoRaWan are deployed on ISM bands which are free of cost. It allows any service provide to operate and deploy LoRa networks without needing the acquision for a particular frequency.
- Cost – Using LoRaWan open standard with frequencies that literally don't cost anthing and use of cheap base stations reduces the costs significantly which is a major plus of any industry [8].
- Network Based – Network triangulation is used to locate any of the LoRa devices within the network. It allows new apps for tracking to minimize the cost, and offers improved battery life.

3.3.5 Barriers to Building Private Networks with LoRaWan

While LoRaWan is an ideal fit for many cases, there are certain barriers when it comes to deployment of private networks. Some of the hurdles will be discussed in this section. One aspect which causes interference is existence of multiple gateways. In LoRaWan, all the gateways have the same frequency regardless of who owns them. It allows LoRaWan network to see the traffic. In order to avoid collisions, it is advised to have single network per area.

There is another possibility which is working through LoRa Alliance. With this option, you can set specific channels aside for the operation. The network operators have the option the limit the downlink in the networks from the side of the server to avoid clogging network with low priority end points [9].

Moreover, LoRaWan is asynchronous and does not gives a guarantee of message being received. It is an ALOHA-based protocol. Over 50 percent PER are very common for LoRaWan. It works alright in certain cases such as meter reading apps but is a complete fail for enterprise or industrial networks which require zero packet error rate percentage. This observation shows that LoRaWan is ideal for the uplink networks [10] [13].

Another point to consider is; LoRaWan is essentially a data link layer with a few attributes of Network layer. This layout demands a significant development work. As of late, no vendor is offering and end to end solution dedicated to LoRaWan protocol. Hence, the user needs to work with different vendors to get gateways, server, nodes and essentially the entire ecosystem [12].

There are impediments regarding duty cycle. There are a few impediments intrinsic for 868 MHz bands when it comes to public networks. Specifically in Europe, the fundamental constraint is the 1% duty cycle. It implies on the off chance that you average measurement IoT, the gateway is communicating with the long haul, it can't surpass one percent. Along these lines, the gateway is quite restricted in the amount it can send. In the U.S., FCC guidelines for ISM band do not have such constraint.

A variable MTU payload size is what we have. A large restriction of LoRaWan is that the Maximum Transmission Unit payload size is a variable dependent on the SF of the network relegates to the node. As such—in case you are distant from the GW the no of bytes transmitted is fairly minimal, yet in case you're close the number of bytes are bigger. You basically can't realize that early. Accordingly, the node firmware at the application layer or app must have the option to oblige changes in the payload side. It comes increasingly difficult when developing firmware [14]. A lot corporations tackle the issue by choosing the tiniest accessible MTU at the most elevated SF the network can be allot, that much of the time is exceptionally little, frequently under 12 bytes. So, LoRaWan devices that send bigger measures of information; 300 bytes. It will need to send it in 30 10-byte messages since it might confront a circumstance where they are allocated a smaller MTU [16]. Therefore, those nodes send considerably more than needed because of the perplexing changes in software that will be needed to deal with these altering MTU esteems.

LoRaWan works well assuming you need to expand on carrier-owned and worked public networks. Numerous equipment and network worker suppliers contending in this department, so plenty off decision making to be done [22]. Also, for basic applications, where you have relatively little nodes and needn't bother with a ton of affirmation, LoRaWan works. Be that as it may, if your requirements are more intricate, you will definitely hit genuine road obstructions. Numerous LoRaWan clients haven't encountered those barricades yet basically in light of the fact that their networks are still minuscule [19]. Take a stab at utilizing LoRaWan to work a network with a great many clients, doing various things, and the challenges will unquestionably soar.

Additionally, creating and sending a framework around LoRaWan is an unpredictable cycle [20].

3.3.6 Comparison of LoRaWan with Other Technologies in IOT

Comparison of LoRaWan with other existing technologies in IOT network. Each technology has its own pros and cons. One is suitable for one situation and other is for another situation. Like cellular technology have long range but it is power hungry as well and Wi-Fi have high bandwidth but worse in terms of range and power consumption. LoRa is best when requirement of data rate is not high, and we need long range communication of devices by consuming less power as in many application devices are battery powered so low power consumption is the key for effective communication of devices. For applications that requires high bandwidth and low latency one can deploy other technologies in IOT infrastructure for effective communication. In Table 3.1 you can see comparison of different technologies with LoRaWan, it is evident that LoRaWan have upper hand in terms of range and power consumption collectively.

Table 3.1. Comparison of technologies

	Long Range	**Low Power**	**High bandwidth**
Ethernet	🔴	🔴	🟢
Cellular	🟢	🔴	🟢
Wi-Fi	🔴	🔴	🟢
LoRa	🟢	🟢	🔴
Bluetooth	🔴	🔴	🔴

3.4 Proposed Model

To analyze performance of LoRa in different scenarios in both indoor and outdoor conditions we deployed number of LoRa end nodes in building and as well as in outdoor. For that we selected SEECS (Department of national university of science and technology) buildings for indoor scenarios and university for outdoor scenarios. We deployed nodes with increasing distance according to scenarios designed. We deployed two gateways for both indoor and outdoor conditions. Created local LoRaWan server and application server in Lab. Gateways are basically a medium to connection nodes to LoRa server and application server. As in Fig 3.4, LoRa end nodes broadcast packets that are programmed at lab. Gateways collect these packets and forward it to LoRa server for further processing and transmission. LoRa server send information to application server from where we collected data on which we did analysis of RSSI and SNR values of each transmission against changing spreading factor with increasing distance of nodes between gateways.

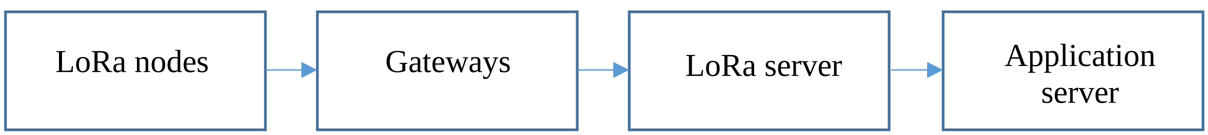


Fig 3.4. Block diagram

3.5 Summary

In this chapter we discussed the problem statement in great detail followed by the solution proposed in the project. The technology used to create the proposed model; IOT and LoRaWan is also elaborated. The chapter features practical use cases of the technologies, limitations, benefits as well as real time applications that can benefit from the technology. The existing work done on LoRaWan is based on very limited scenarios for both indoor and outdoor which is not sufficient. The solution presented analyzes the performance of LoRaWan in IOT for nine different scenarios which presents a more conclusive analysis.

Chapter 4: METHODOLOGY

This chapter discusses methodology of this work. Complete procedure is discussed that how we deployed infrastructure in different defined scenarios and how we collected data and then analyzed collected data. It includes tools, software and hardware used in this research work, their types and purpose of using.

4.1 Brief Description of Experimental Setup

IoT is influencing our day-to-day life from how we behave to how we react. From ACs that now we can control by sitting far away using our mobile phones to cars that helps us to find shortest path towards our destination to smart watches that can track our heart rate, blood pressure and send collected data to servers to protect you from any health issue. IOT is basically a network of devices connected with each other that collect data and share it for further action. IOT is being implement in many different sectors from manufacturing industries to hospitals to agriculture requirements. IOT has a big scope in future as well. LoRaWan is the protocol that fulfill the requirements of IOT which makes it unique as it is consumes less power to transmit, can communicate over long distance, scalable and cost less. LoRaWan is emerging rapidly because of its desired characteristics of communication at the cost of lower power consumption over a longer distance. In this study we did performance analysis of LoRaWan in different scenarios in both indoor and outdoor and outdoor conditions. We deployed end sensor nodes physically, for that we choose NUST university where we tested, collected data and then analyzed RSSI and SNR against increasing spreading factor and distance for each defined scenario. Below is a pictorial representation of the entire methodology.

4.2 Testbed

As discussed, before we did performance analysis of LoRaWan by deploying nodes, gateways, LoRaWan server and application server. We did performance analysis in both indoor and outdoor scenario so for that we needed a testbed on which we can perform our experiments. For that we choose SEECS buildings (school of electrical and computer engineering) department of national university of science and technology for indoor scenarios and its surrounding outside area for outdoor scenarios. SEECS comprises of two buildings, Academic block and administrative block. There is small open area between these two buildings. Academic block has three floors and administrative block has 3 floors. In academic block we have 12 classrooms, lobby area and labs. Administrative block comprises of faculty offices, IT department, data center, administrative offices and labs. In both blocks we have lot of walls, glass doors and wooden doors, few of devices like router, microwave oven that can interfere. Also, there are lot of students in both blocks. We deployed end nodes in these two blocks for indoor testing and open surrounding area for outdoor testing. Outdoor is not that much congested, buildings are there in place, but are at distance from each other.

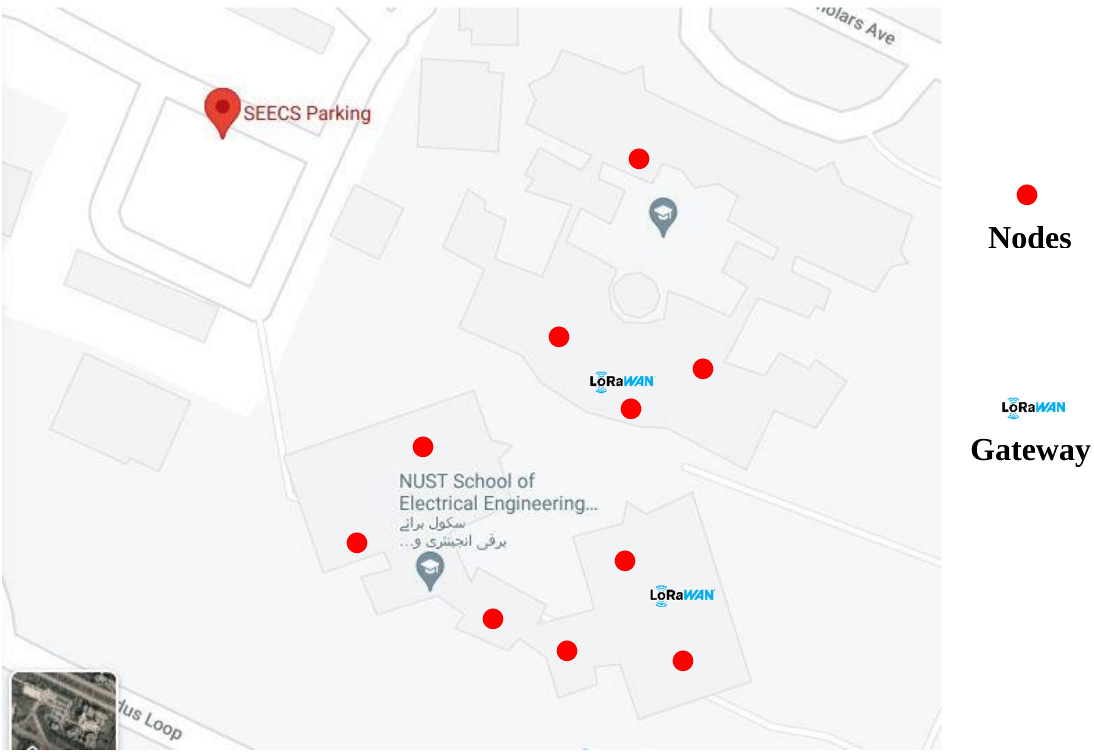


Fig 4.1. End nodes and gateways deployed in test bed

In figure Fig 4.1 we have shown actual map of our test bed where we deployed sensor nodes and gateways to test performance of LoRaWan.

4.3 Tools and Devices

In this research we have used different tools and devices for testing performance of LoRaWan in different scenarios. Each tool and device was crucial in implementing testing. It includes software and hardware. In this section we are going to discuss these devices and software.

4.3.1 End Sensor Nodes

We used 10 end LoRa sensor nodes that are programmed and deployed all over according to planned scenarios. All sensor nodes are programmed and assigned schedules, in which sensor nodes will transmit information with increasing spreading factor in different scenarios. All end nodes are embedded over LoRa server as well. End sensor nodes transmit information to LoRa gateway which act as a medium to communicate end LoRa devices to LoRa server. In Fig 4.2, you can see the actual node while in testing.

Fig 4.2. End node during testing

4.3.2 Gateways

We used two LoRa gateways and embed both on loRa server to act as medium to communicate end devices with LoRa server. Gateways are used interchangeably according to scenarios we created. One gateway was deployed in ground floor of academic block and other was deployed in second floor of administrative block.

Fig 4.3. LoRa Gateway used in testing

4.3.3 Software

We used java to programme end nodes to make end nodes transmit information to LoRa gateways according to schedules we created, gateway further transit it to LoRa server and then to application server to act on collect on collected information. We used chirp stack LoRa to deploy Local server in our lab.

4.4 Deployment

To test performance of LoRaWan in different created scenarios in both indoor and outdoor conditions we used ten end LoRa nodes, two gateways, deployed LoRa server and LoRa application server locally on system in our lab. End nodes are programmed according to schedules we created, where we assigned schedule to transmit information to gateway with increasing spreading factor. These programmed end nodes are then deployed according to scenario we are going to discuss in this section. To deploy LoRa server locally we use chirp stack LoRa server platform and Linux operating system, where we first installed MQTT general Lora gateway and then LoRa database to install LoRa server. In database we created user and password and then install LoRa server and application server. In LoRa server we then embedded end devices and loRa gateways, all this procedure is defined in chirpstack LoRa server manual in detail from start to end on chirpstack.io. [23].

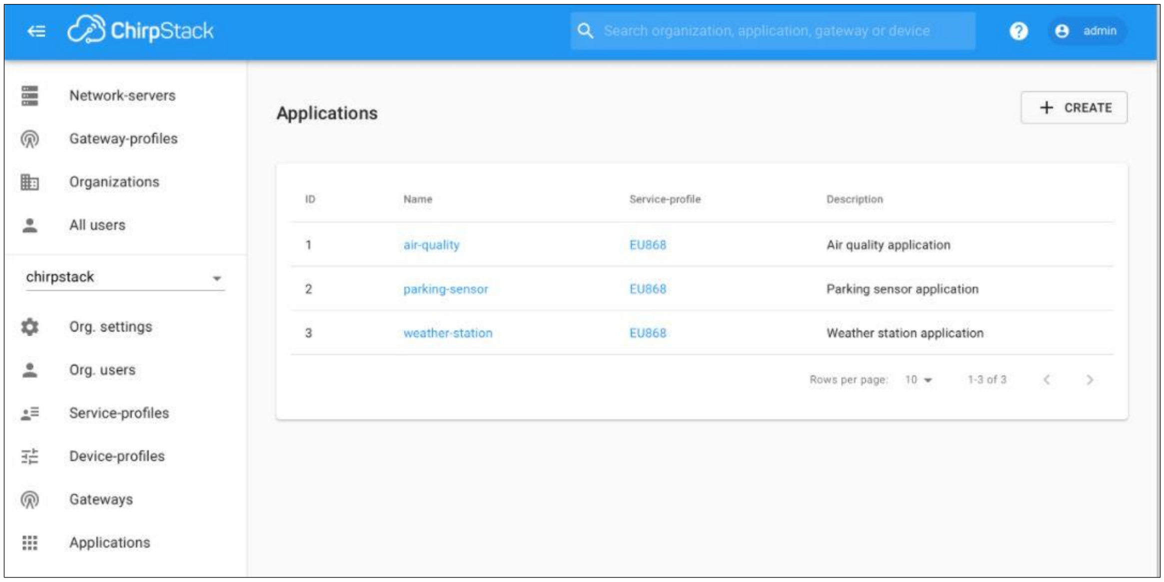


Fig 4.4. Interface of LoRa server

Fig 4.4 is representing the application server based on Chirpstakc.io platform, on this application we can see collected sensory data from end LoRa node in real time.

4.4.1 Flow Chart

Below in Fig 4.5 is the complete flow chart of this research work which we conducted by deploying LoRa end nodes in field. It starts from development of LoRa server over chirpstack.io open-source platform to develop LoRa network server and LoRa application server. Then we deployed nodes and gateways in LoRa server. Programmed LoRa end nodes deployed in different scenarios send sensory data to gateway which then further send it to network server. Network server send data to application server from where we can collect data and analyze it.

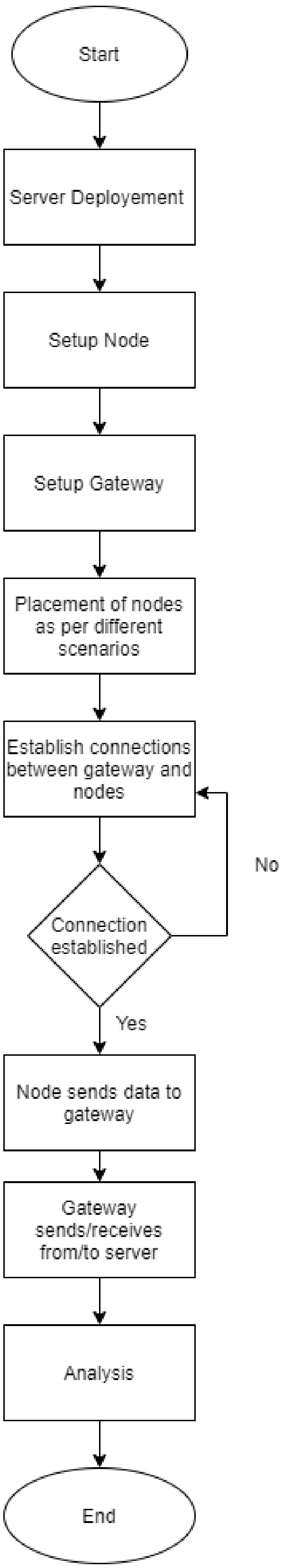


Fig 4.5. Flow Chart

4.4.1 Deployment of Server

As mentioned earlier, Chirp stack server is used for creation of deploying LoRaWAN server and creating a LoRaWAN network. The primary reason why we chose chirp stack is because it offers open-source platform for LoRa network. Provides user friendly interface for management of devices and APIs for integration. Devices includes gateways and LoRa sensors. it also supports multi tenancy and all types of LoRA nodes. The deployment comprises of gateways and sensors as per different scenarios. End nodes will Transmit collected information to the gateway/gateways over LoRa Protocol and gateway will forward the information to the server.

The LoRaWAN Network server is public so anyone with this gateway can forward data packets easily. All the communications happened over MQTT. To store all the data files, PostgreSQL was used. Redis data base was used to store all the non-persistent data; it is also used by both network server and application server. Here are the steps I followed for server deployment:

- After logging in to the machine, I used sudo dash app to update the machine.
- Then I progresses to install MQTT, Redis, PostgreSQL database with the following command: sudo apt install mosquitto mosquitto-clients redis-server redis-tools postgresql
- Next, I set up all the databases for LoRaWAN server to store all the files
- The next step was to create a role and a password for it
- The next step was to set up repository for Chirp Stack
- I then installed the gateway bridge with the apt; udo apt install chirpstack-gateway-bridge
- Enabled the gateway bridge using start and enable commands
- I deployed the Chirpstack network server using the following commands;
    - sudo systemctl start chirpstack-network-server
    - sudo systemctl enable chirpstack-network-server
- After deployment of server, I proceeded to install application server using the following command;
    - sudo apt install chirpstack-application-server

4.4.2 Setting up Gateway

Here are the steps involved in setting up the LoRa gateway:

- I logged in to the router in order to find the IP address of the gateway.
- I types the IP address into the browser in order to open a webpage and entered username

and password.

- In order to update the gateway, I clicked ‘update’ option and used drag and drop to option to update the latest firmware.
- To login into the gateway, I typed ssh followed by gateway address.
- I configured the gateway to Pakistan region and changes the frequency accordingly.
- The next step was to add the path to the configuration files; loRa d and LoRa f.
- Then I configured the uplink and downlink to the UDP port, saved the files and restarted the LoRa forwarder and LoRa d.
- In order to verify what we have just done, I typed tail –f /var/log/lora.log and clicked enter which showed that all the messages were being acknowledged and gateway starts to forward traffic to the server which concludes the configuration of the gateway
- I logged in to the network server and created a gateway profile as well as a service profile.
- Then I clicked create gateway in order to add the gateway and entered the required information such as name, description, gateway ID, network server, service profile, and gateway profile.
- I enabled gateway discovery and added the location and clicked create gateway.
- In a similar fashion, I configured another gateway which was used in some of the scenarios which will be discussed later.

4.4.3 Setting up Node

Here is how I set up the nodes:

- In order to add the node, I created an application profile by adding name and description.
- Next, I created device profiles for each of the nodes.
- I went to the application profile and added the nodes by adding required device profile information and clicked ‘create device’

4.4.4 List of Scenarios

The scenarios on which experiments were performed are listed below. Essentially, LoRa sensor nodes were deployed in different areas of SEECS campus building, both indoor and outdoor. Each of the practical scenarios are explained one by one in detail.

Scenario 1

For scenario 1, LoRa sensor nodes as well as single gateway are placed indoor in the academic block. All the devices were placed on the same floor. The distance between each of the devices was less than 10 meters. Fig 4.6 representing nodes and gateways placement.

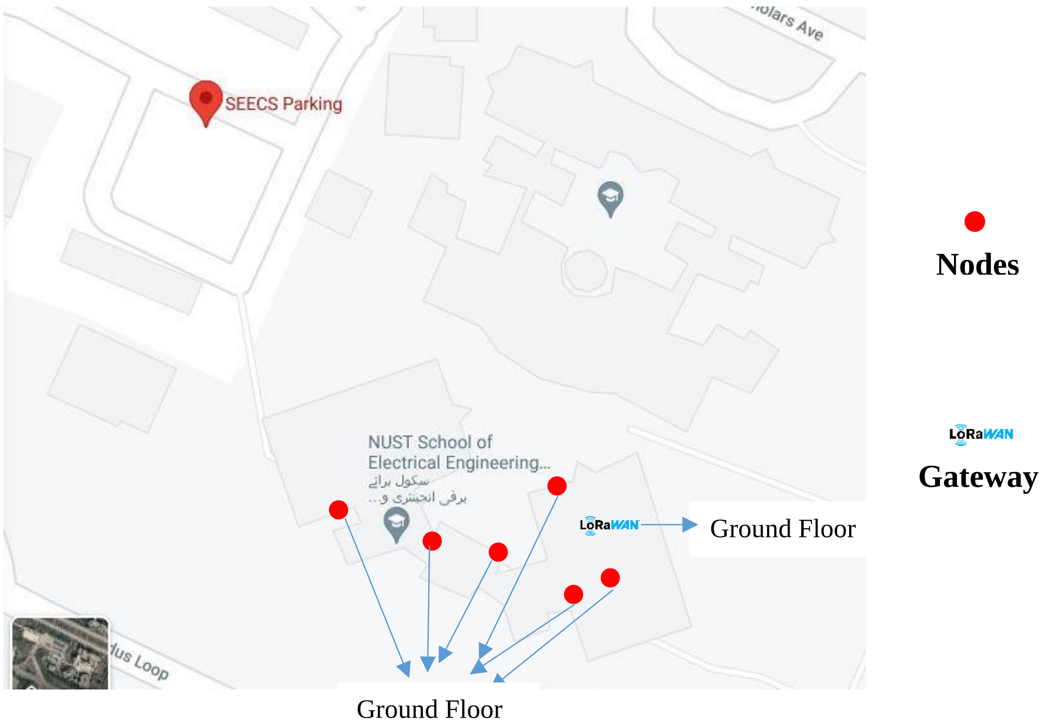


Fig 4.6. Nodes placement (scenario 1)

Scenario 2

For the second scenario, LoRa sensor nodes were placed indoor alongside the single gateway in academic block. All the devices were placed on the same floor and had less than 10-meter distance between them, what differs scenario 2 from scenario 1 is the placement of gateway antennas which were directed towards the nodes in this particular case. Fig 4.7 representing nodes and gateways placement.

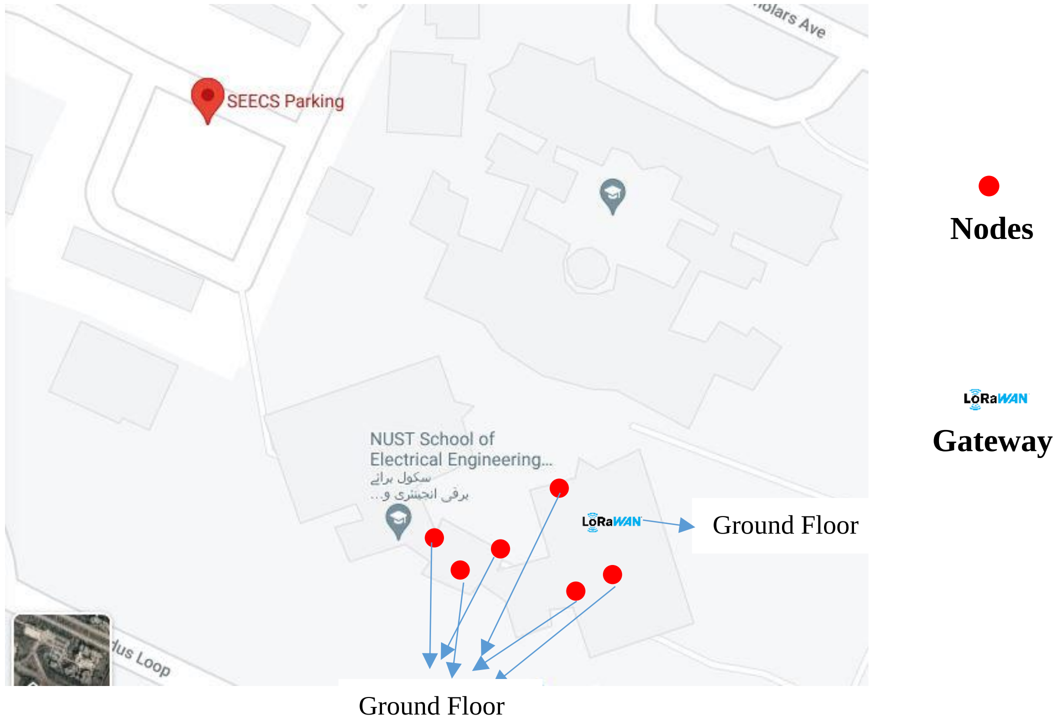


Fig 4.7. Nodes placement (scenario 2)

Scenario 3

For the third scenarios, devices were placed indoors as well gateway for the same block; academic block. Single gateway was used here. We deployed gateway on ground floor and placed nodes on different floors; ground floor and first floor. The distance between the devices was greater than 10 meter but less than 25 meter. Fig 4.8 representing nodes and gateways placement.

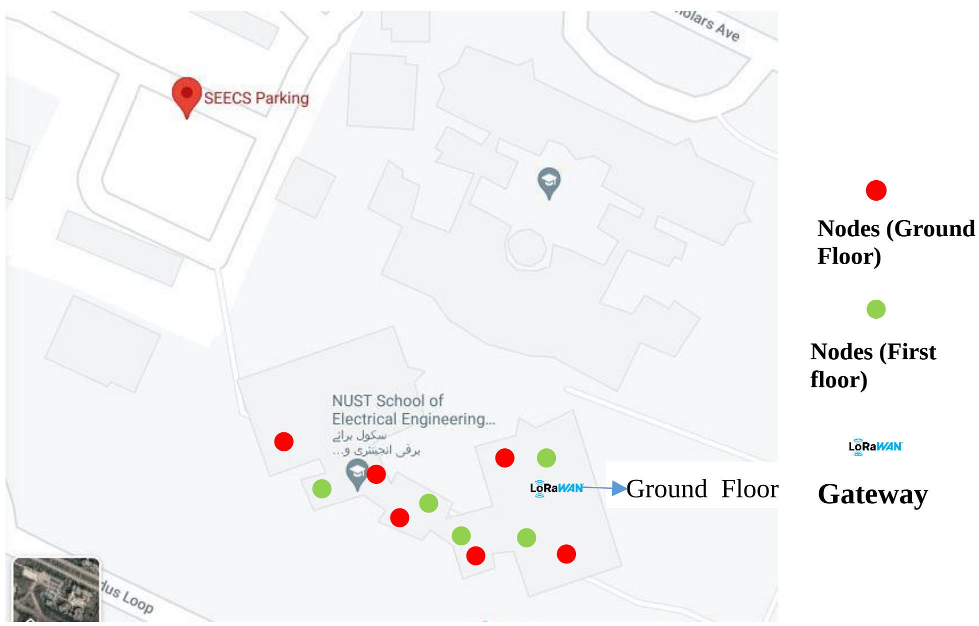


Fig 4.8. Nodes placement (scenario 3)

Scenario 4

For the fourth scenario, the devices were placed indoor in the academic block. The gateway was placed at ground floor with a sensor node. Another node was placed at the first floor. The distance between gateway and nodes was greater than 10 m and less than 25 meter. The antennas of the gateway were pointed in the same direction. Fig 4.9 representing nodes and gateways placement.

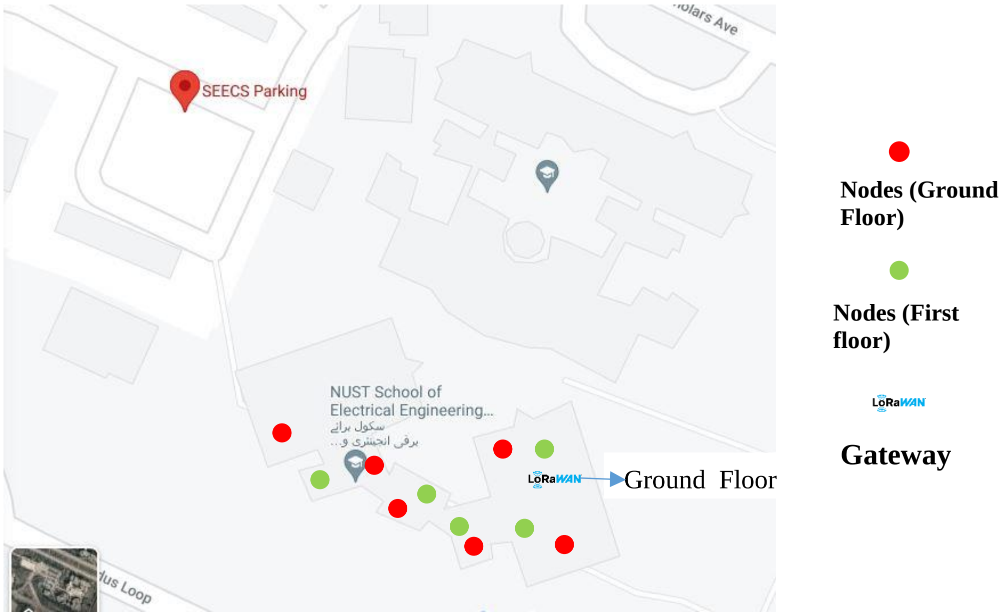


Fig 4.9. Nodes placement (scenario 4)

Scenario 5

For the fifth scenario, experiment was performed indoor. Placed gateway on ground floor. Deployed nodes in the both academic block as well as the adjacent administrative block. There is an open space between the two buildings; administrative and academic. The distance between the devices in this case was greater than 10 meter and less than 200 meters. Fig 4.10 representing nodes and gateways placement in both building of SEECS department.

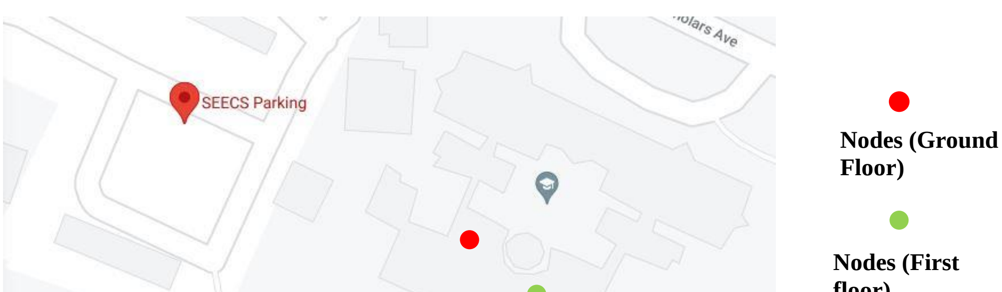


Fig 4.10. Nodes placement (scenario 5)

Scenario 6

The devices are placed indoor for the sixth scenario. A single gateway is used which is deployed in the academic block's ground floor. A few nodes are placed very close to the gateway within the 10 m difference. All other nodes are placed on the edges of the academic block with distance greater than 150 meters. Fig 4.11 representing nodes and gateways placement.

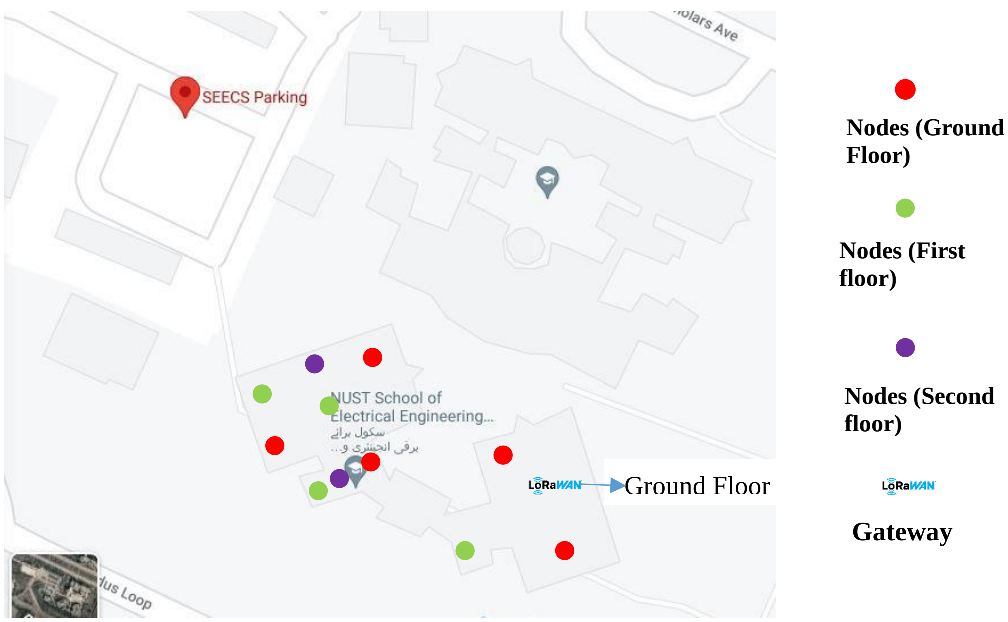


Fig 4.11. Nodes placement (scenario 6)

Scenario 7

The experiment of scenario 7 is also performed indoors. Two gateways are used in this particular experiment. The first gateway is deployed on the ground floor. Second gateway is deployed on the second floor of administrative block. Senor nodes are deployed in both academic block and administrative block. Nodes are placed at far corners of buildings. The distance between devices were greater than 10 meter and less than 50 meters. Fig 4.12 representing nodes and gateways placement.

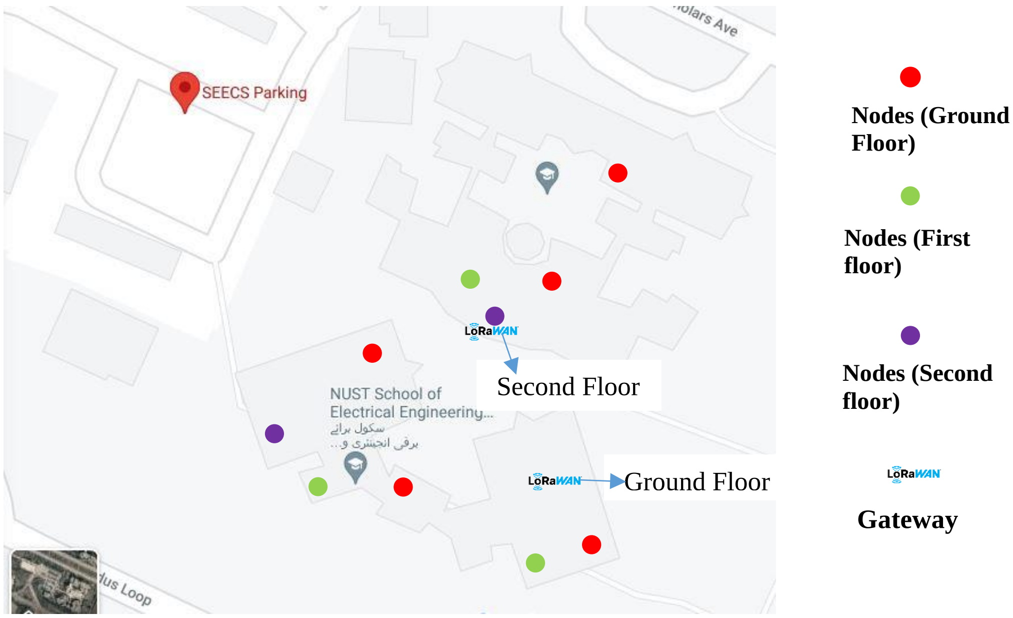


Fig 4.12. Nodes placement (scenario 7)

Scenario 8

The experiments for scenario 8 were performed outdoor. Single gateway is used which is placed in the first floor of academic block close to the edge wall indoors. The nodes are placed outdoor with a distance greater than 10 m and less than 2 km. Fig 4.13 representing nodes and gateways placement.

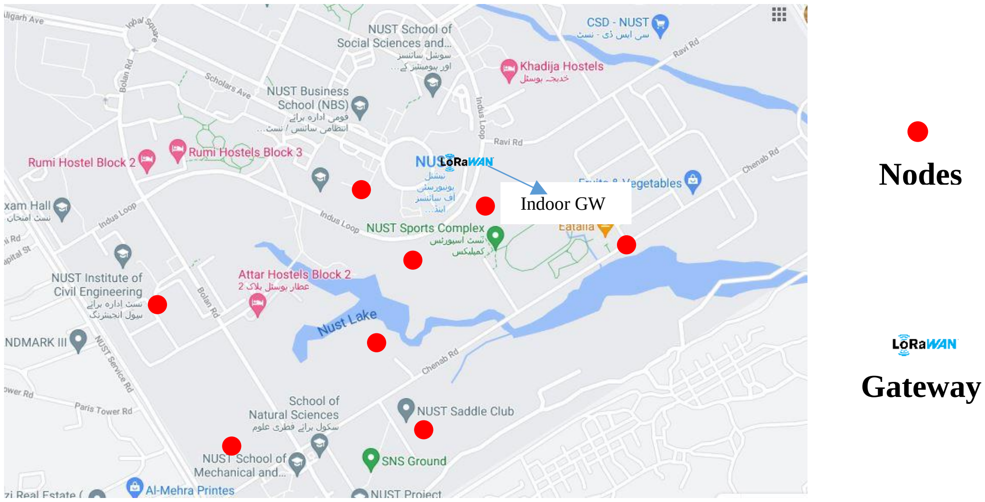


Fig 4.13. Nodes placement (scenario 8)

Scenario 9

For the scenario 9, both the gateway and sensor nodes are placed outdoors. The distance between the devices is greater than 10 m and less than 2 km. Fig 4.14 representing nodes and gateways placement.

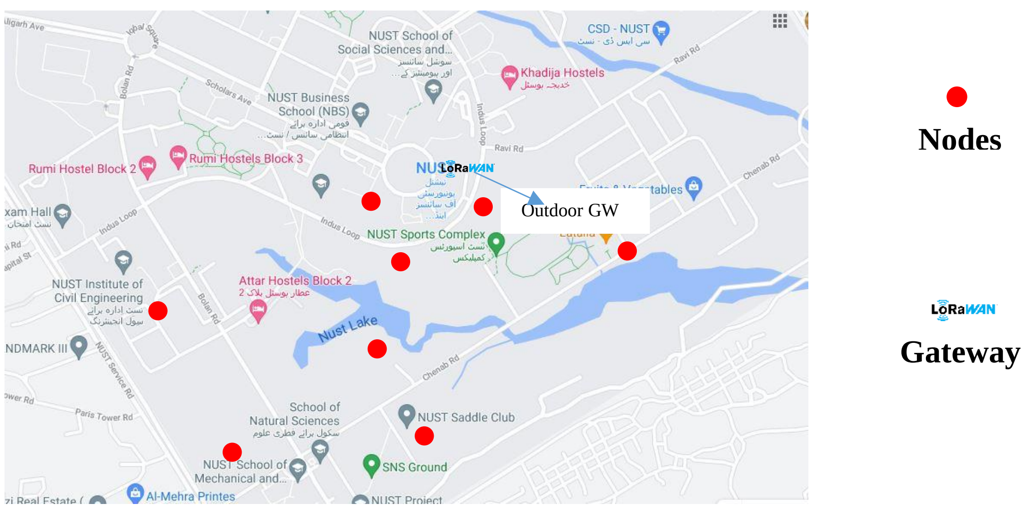


Fig 4.14. Nodes placement (scenario 9)

Tabular Representation:

All the scenarios discussed above are represented in Table 5.1.

Table 5.1. Indoor and outdoor scenarios

Experiment No	Indoor/ Outdoor	Deployment	Distance between Devices
1	Indoor	Single Gateway and Sensor Nodes deployed on the same floor.	Less than 10 m
2	Indoor	Single gateway antennas are directed towards nodes. Devices are placed on the same floor.	Less than 10 m
3	Indoor	Single Gateway and Nodes placed on different floors.	10m < distance > 25m
4	Indoor	Single Gateway Antennas in the same direction and sensor nodes on 2 different floors.	10m < distance > 25m
5	Indoor	Single Gateway and Sensor Nodes in the same and adjacent building	10m < distance > 200m
6	Indoor	One node is placed close to the gateway and other nodes are placed far from the gateway at the corners of the building	10m < distance > 150m
7	Indoor	Two Gateways and nodes far from gateways	10m < distance > 50m
8	Outdoor	Outdoor with the indoor gateway close to the edge wall and outdoor sensor nodes.	10m < distance > 2km
9	Outdoor	Both gateways and sensor nodes are placed outdoors.	10m < distance > 2km

4.5 Data Acquisition

In order to acquire data, I programmed schedules in the deployed nodes to transmit sensory data to gateway. Gateway forwards data to network server. Network server is uploading the data to application server. Through application server, we are monitoring and collecting the data through our system. The transmitted sensory data includes corresponding geo locations, RSSI values, SNR values, profile name and spreading factor. Fig 4.15 is explaining the cycle of data acquisition.

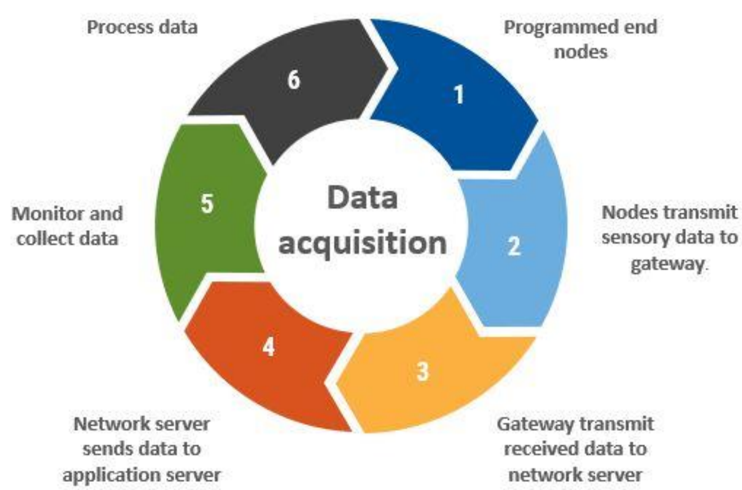


Fig 4.15. Data acquisition cycle

4.6 Data Evaluation

As discussed earlier in previous chapters that end LoRa nodes using different sensors according to application deployed collects information and transmit information to gateway which then reaches to application server from there we can monitor real time information and can collect it. In our case data transmitted from nodes includes RSSI and SNR values against lowest and highest spreading factor. We collected that transmitted data and further gives it graphical representation for better understanding that LoRaWan performed in different created scenario in both indoor and outdoor conditions.

Chapter 5: Results and Analysis

This chapter explains results from experiments we conducted and discusses result on basis of results. The results show a clear comparison between each of the discussed scenarios in the previous chapter. The results came in the form of data sets. These sets were used to create graphs for easy understanding and analysis.

5.1 Parameters

In these experiments, parameters on the basis of which we analyzed the performance of LoRaWan are:

- Received signal strength indicator (RSSI)
- Signal to noise ratio (SNR)
- Spreading factor (SF)

RSSI indicates the strength of received signal which is measured in dBm and usually in negative values.

- RSSI of -40 to -50 dBm is considered excellent
- RSSI of -60 to -70 dBm is considered to be very good
- RSSI of -70 to -80 dBm is good
- RSSI of -80 to –90 dBm is low
- RSSI close to -100 above dBm is very low

SNR indicates the signal against noise, that how much is signal and how attenuation or noise incurred while transmission of signal from one end to another destination end. Value of SNR is always positive, if the value approaches to zero or in negative then it means that signal received have more noise than a signal. We changed spreading factor value and analyzed SNR and RSSI against changing spreading factor. Spreading factor value range is from 7 to 12, spreading factor 7 is lowest and 12 is highest.

Data rate of spreading lowest spreading factor is high, it takes less time to transmit but coverage range is less. For highest spreading factor data rate is less take more time to transmit but coverage area is large.

5.2 Experimental Results

We analysed RSSI and SNR against changing spreading for each scenario.

- Avg RSSI and SNR values of indoor and outdoor experiments.

Table 6.1. Avg RSSI and SNR indoor experiments

Indoor Experiment #	Avg RSSI	Avg SNR
1	-59	10.5
2	-57	10.4
3	-65	10.2
4	-64	10.1
5	-85	5
6	-80	8
7	-62	10.5

Table 6.1 is representing average values of RSSI and SNR that we monitored while testing in different indoor scenarios. In all scenarios from 1 to 7 specified in Table 6.1 we deployed nodes in inside SEECS buildings with different combinations with indoor deployed gateway. We monitored better RSSI and SNR values when nodes were closer to gateway but compromised results when nodes were deployed far from gateway specially in indoor condition, we will discuss for outdoor later. When nodes were placed in adjacent building where gateway was not placed, then we have seen SNR even in negative values and RSSI Crossing -100 dBm but results were stable when we used second gateway. At far corners of building, we even not able to establish connection.

Table 6.2. Avg RSSI and SNR outdoor experiments

Outdoor Experiment #	Avg RSSI	Avg SNR
1	-49	11.5
2	-45	12

Table 6.2 is representing average values of RSSI and SNR in outdoor scenarios. We have implemented in two different scenarios. In one scenario we obviously deployed nodes outdoor, but gateway was in indoor condition and in second scenario both gateway and nodes are deployed outside. There was a different in values when gateway was outside and inside of building. When gateway was outside, we have even seen SNR around 13.5 and 14 decibels.

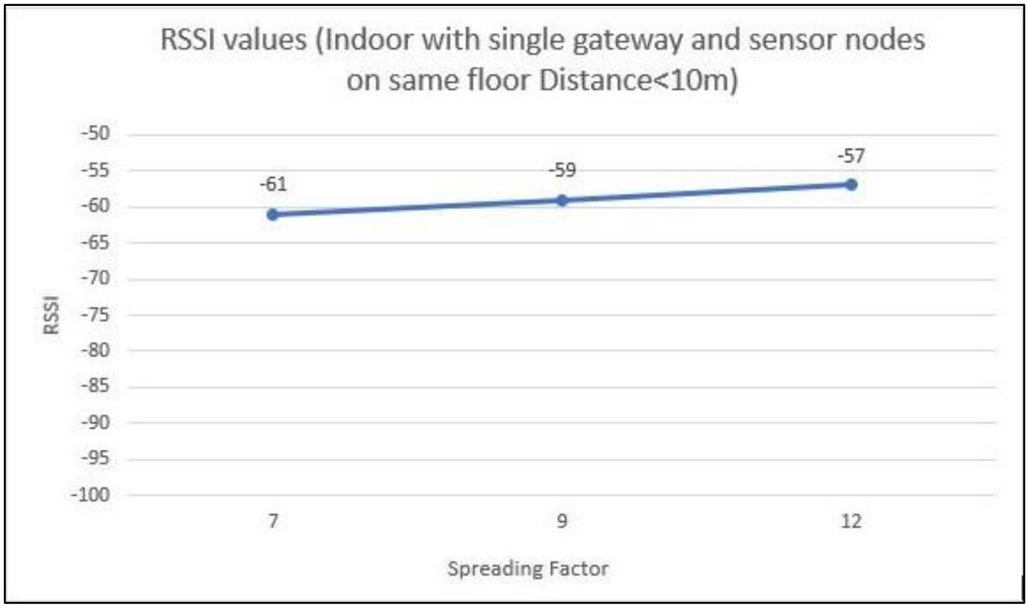
5.2.1 Indoor Results

In indoor experiments nodes are deployed inside the SEECS's buildings and gateways are also placed inside the buildings.

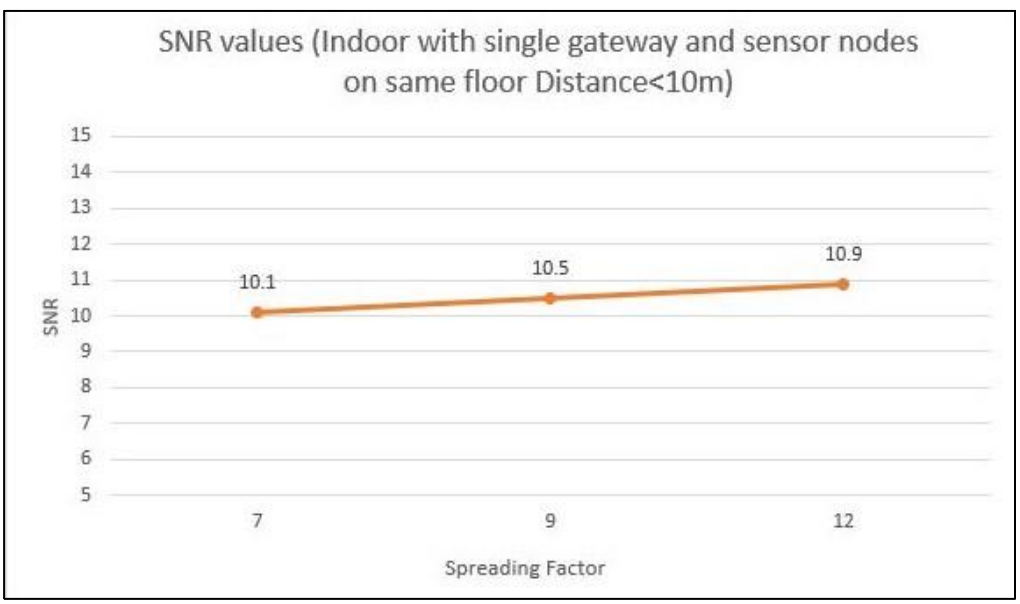
A) Single gateway in ground floor of academic block and sensor nodes on same floor

LoRa sensor nodes as well as single gateway are placed indoor in the academic block. All the devices were placed on the same floor. The distance between each of the devices was less than 10 meters.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Nodes were placed in same floor and same building where we placed gateway. As with increasing spreading factor change in RSSI and SNR values with spreading factor is not significant as nodes are close to gateway.



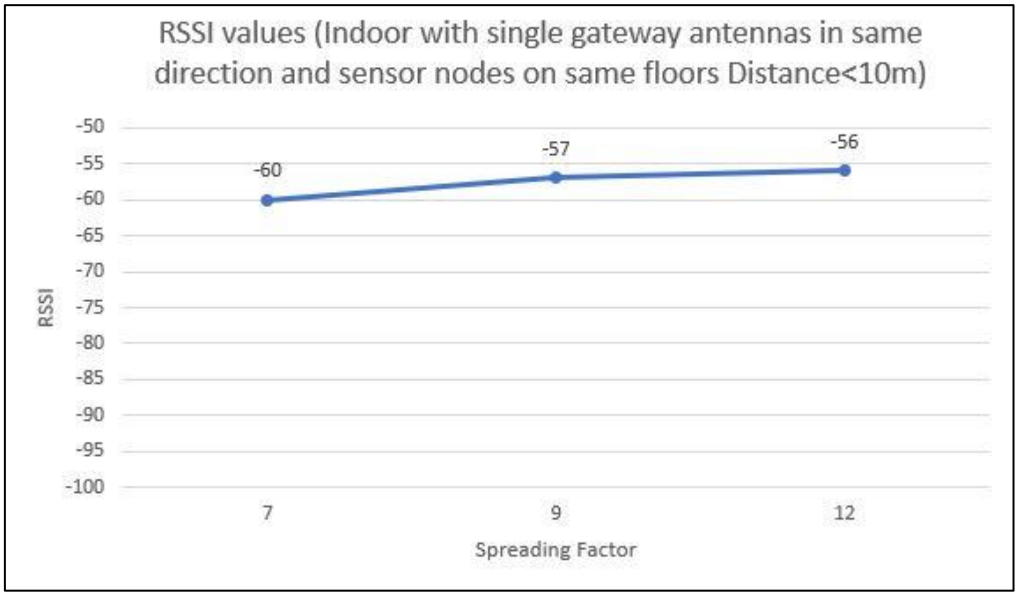
2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Graph is showing SNR value for scenario 1 against lowest and highest spreading factor and again there is not significant change in SNR value as nodes are close to gateway.



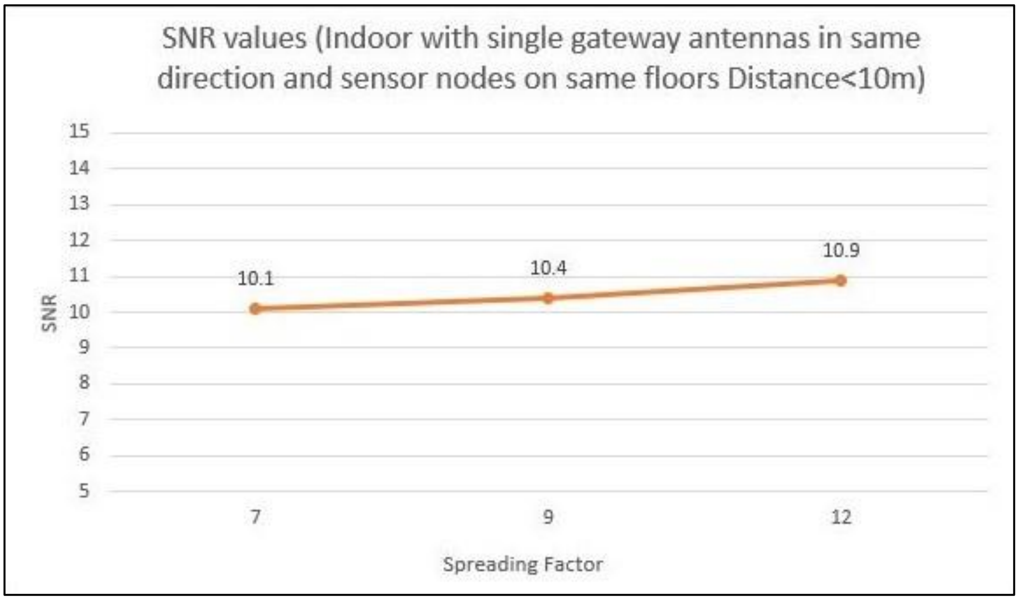
B) Single gateway antennas are directed towards nodes and sensor nodes on same floor

LoRa sensor nodes were placed indoor alongside the single gateway in academic block. All the devices were placed on the same floor and had less than 10 meter distance between them, what differs scenario 2 from scenario 1 is the placement of gateway antennas which were directed towards the nodes in this particular case.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Graph is showing the Avg RSSI value against spreading factor 7, 9 and 12 when nodes were close to gateway and antennas of gateway is directed towards nodes. Values are slightly better comparison to when antennas are not directed but not a major difference.



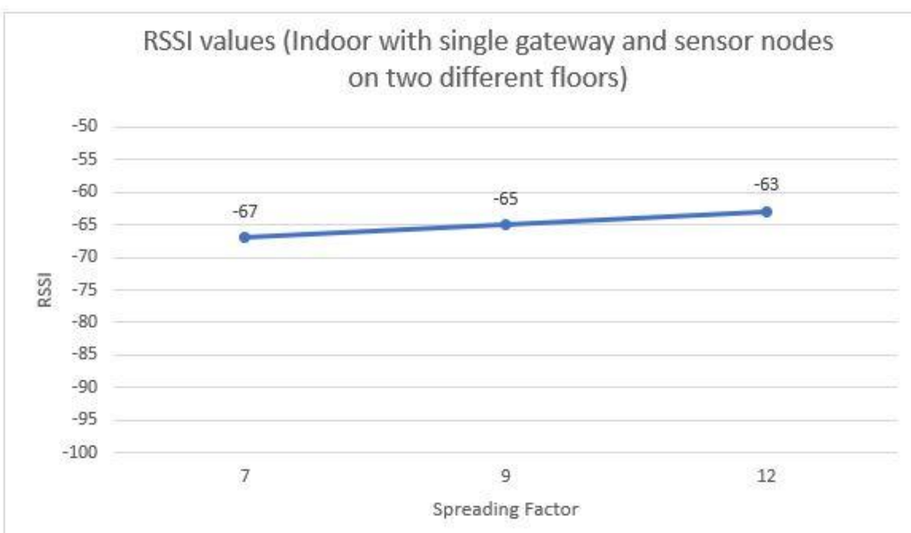
2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Graph is showing the Avg SNR value against spreading factor 7, 9 and 12 when nodes were close to gateway and antennas of gateway is directed towards nodes. Values are slightly better comparison to when antennas are not directed but not a major difference.



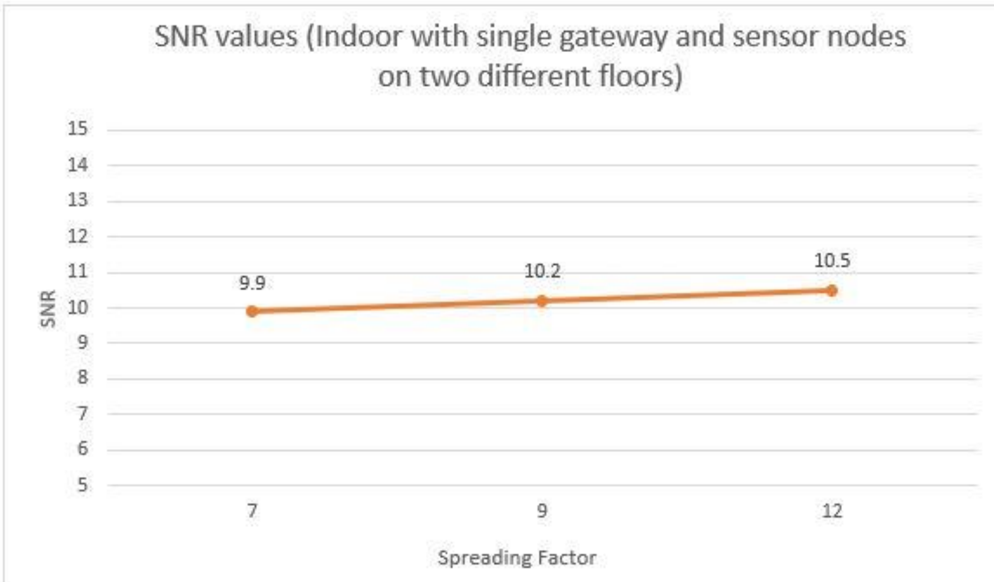
C) Single gateway and sensor nodes on two different floors

Devices were placed indoors as well for the same block; academic block. Single gateway was used here. Gateway was on the ground floor and placed nodes on the different floors; ground floor and first floor. The distance between the devices was greater than 10 meters but less than 25 meters.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Graph is showing avg RSSI value when nodes and gateway are placed in different floor. We have seen slightest worse values comparison to when nodes and gateway was in same floor.



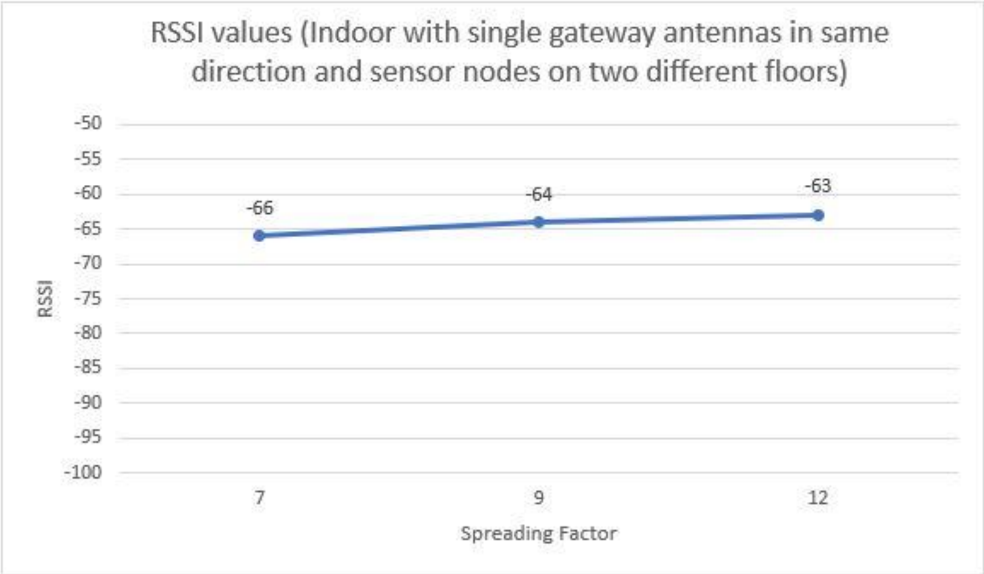
1. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Graph is showing avg SNR value when nodes and gateway are placed in different floor. We have seen slightest worse values comparison to when nodes and gateway was in same floor.



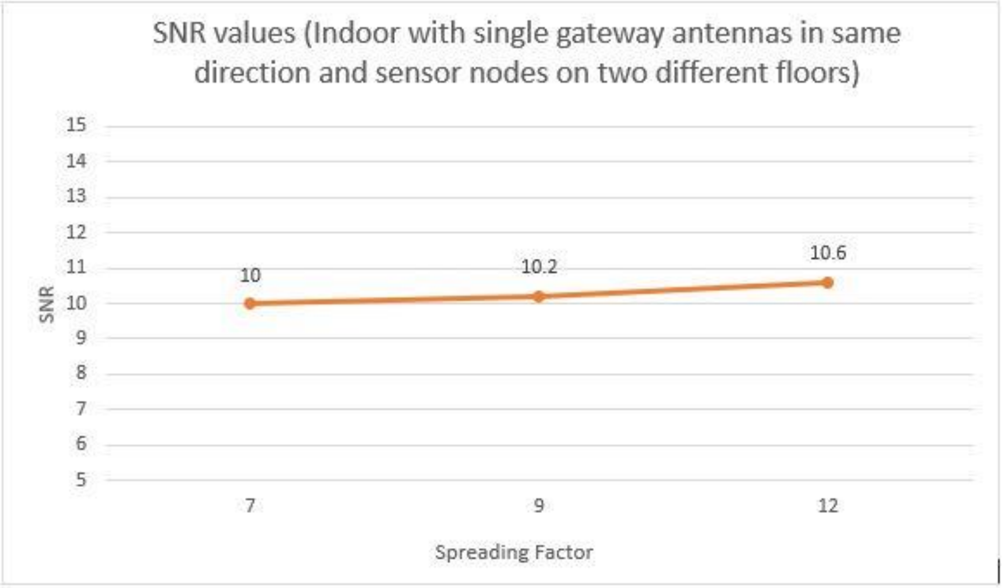
D) Single gateway antennas in same direction and sensor nodes on two different floors

Devices were placed indoor in the academic block. The gateway was placed at ground floor with a sensor node. Another node was placed at the first floor. The distance between gateway and nodes was greater than 10 m and less than 25 meters. The antennas of the gateway were pointed in the same direction.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Slightest difference in RSSI value when we directed gateway antennas towards nodes but different is not noticeable.



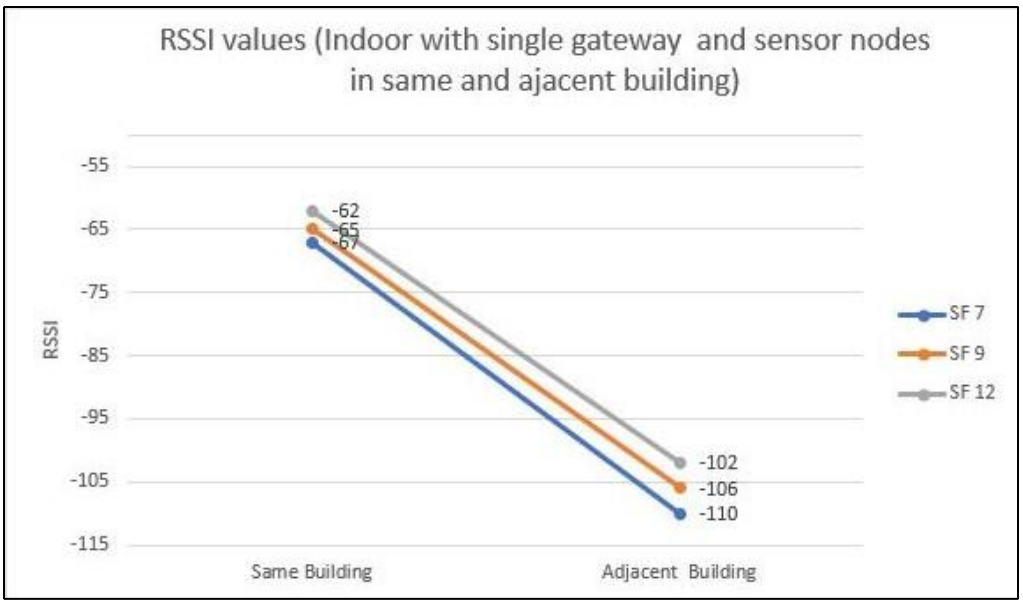
2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Slightest difference in SNR value when we directed gateway antennas towards nodes but different is not noticeable.



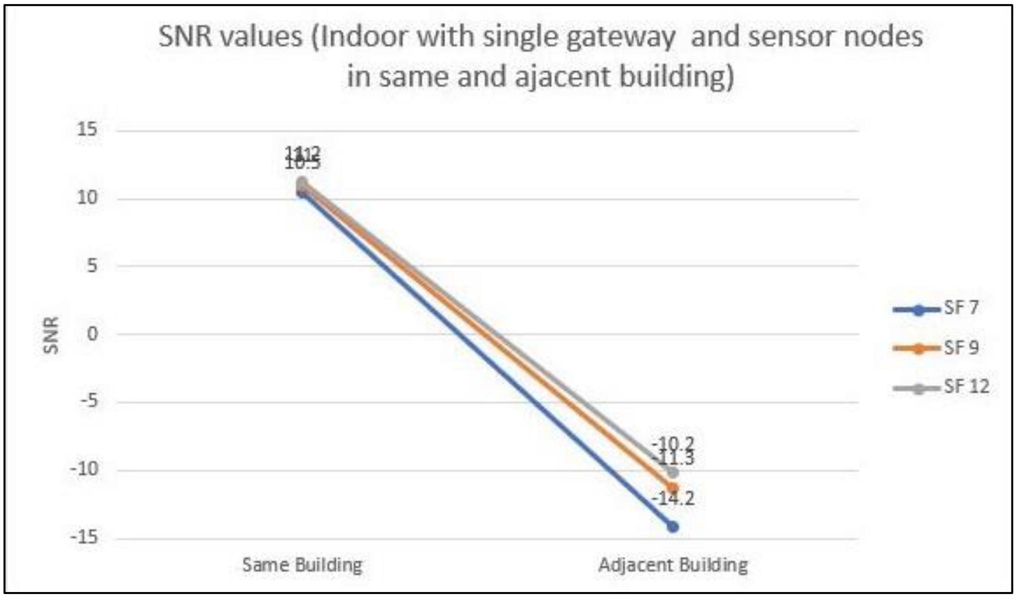
E) Single gateway and sensor nodes in same and adjacent building

The single gateway was placed on the ground floor and deployed nodes in the both academic block as well as the adjacent administrative block. There is an open space between the two buildings; administrative and academic. The distance between the devices in this case was greater than 10 meter and less than 200 meters.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. In this particular scenario we have placed few nodes in same building where gateway was deployed and few nodes in other adjacent building. Graph is showing avg RSSI values in same and adjacent building. We have seen worst results even with high spreading factor for nodes that are deployed in other adjacent building while better results for the nodes in same building at the same time.



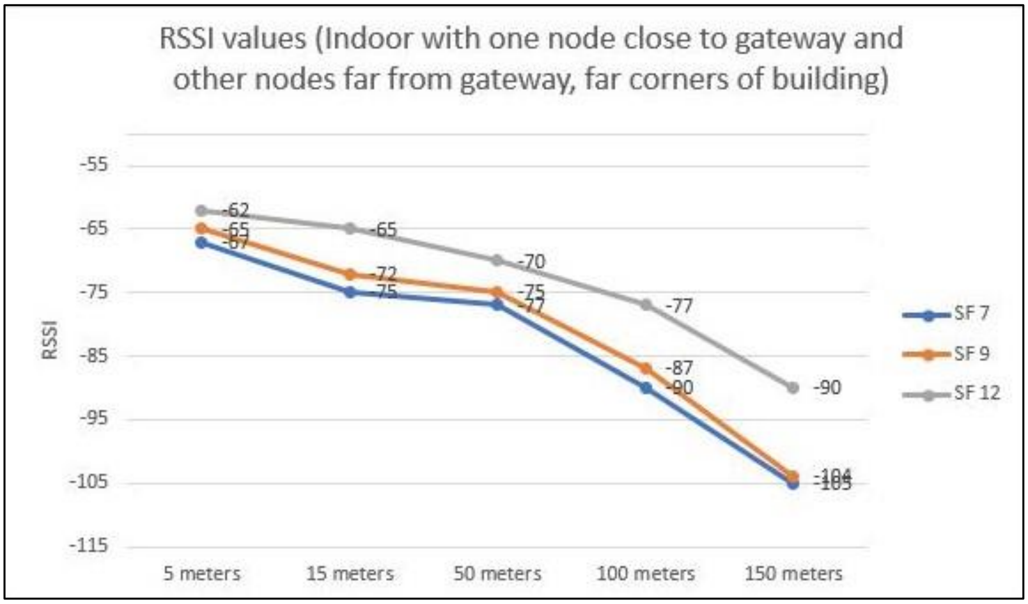
1. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. In this particular scenario we have placed few nodes in same building where gateway was deployed and few nodes in other adjacent building. Graph is showing avg SNR values in same and adjacent building. We have seen worst results even with high spreading factor for nodes that are deployed in other adjacent building while better results for the nodes in same building at the same time. SNR values are in negative values clearly.



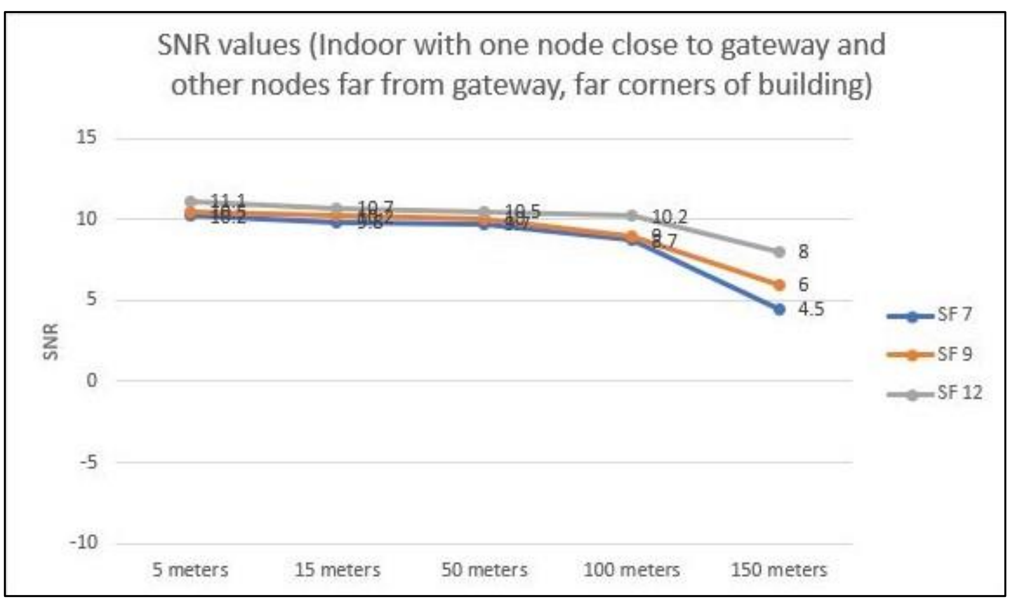
F) One node close to gateway and other nodes far from gateway, far corners of building

A single gateway is used which is deployed in the academic block's ground floor. A few nodes are placed very close to the gateway within the 10 m difference. All other nodes are placed on the edges of the academic block.

1. Graph plotted below is showing average RSSI against increasing distance and SF. This graph is showing avg RSSI values with increasing distance and with changing spreading factor. Nodes are placed at far corners of same building where gateway was deployed. In indoor condition we have seen worst values when nodes are at multiple floors. Value at 5 meters of distance are much better but values for nodes deployed far corners of building are worst. Increasing spreading factor improves values to significant level.



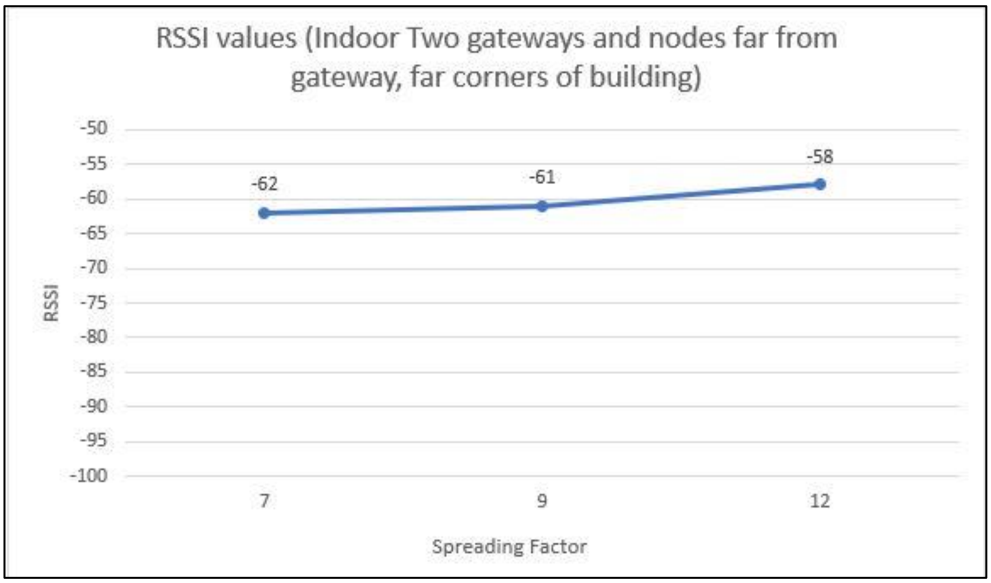
2. Graph plotted below is showing average SNR against increasing distance and SF. This graph is showing avg SNR values with increasing distance and with changing spreading factor. Nodes are placed at far corners of same building where gateway was deployed. In indoor condition we have seen worst values when nodes are at multiple floors. Value at 5 meters of distance are much better but values for nodes deployed far corners of building are worst. Increasing spreading factor improves values to significant level.



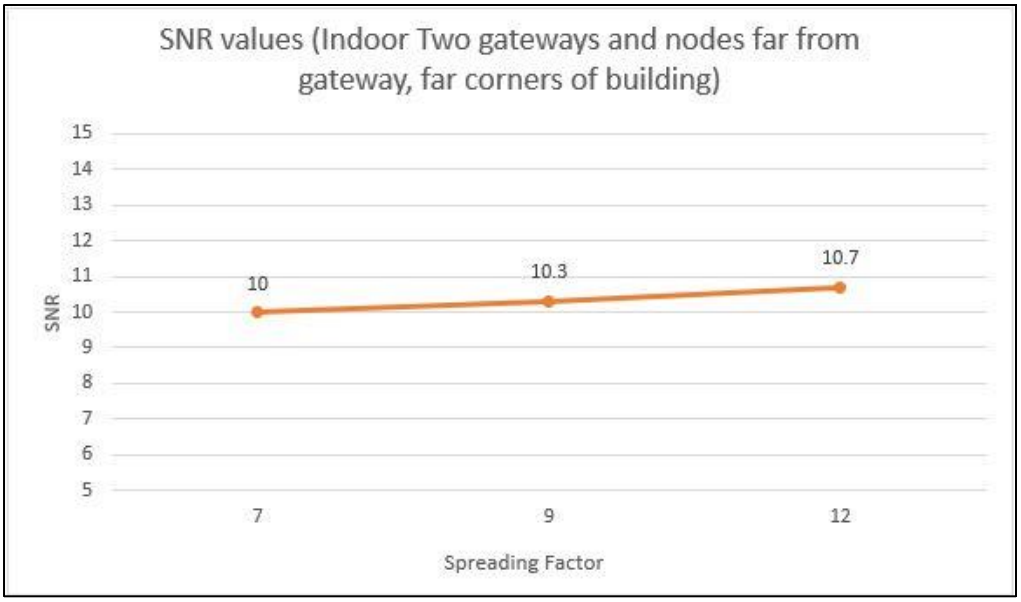
G) Two gateways and nodes far from gateway, far corners of building

Two gateways are used in this particular experiment. The first gateway is deployed on the ground floor of the academic block. The second way is deployed on the second floor of administrative block. Senor nodes are deployed in both academic block and administrative block; one on each floor. The distance between devices were greater than 10 meter and less than 50 meters.

1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Comparison to previous scenario where we used one gateway in this scenario, we used two gateways and values are much improved. Values of RSSI is in -50 and -60 dBm.



2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Comparison to previous scenario where we used one gateway in this scenario, we used two gateways and values are much improved.



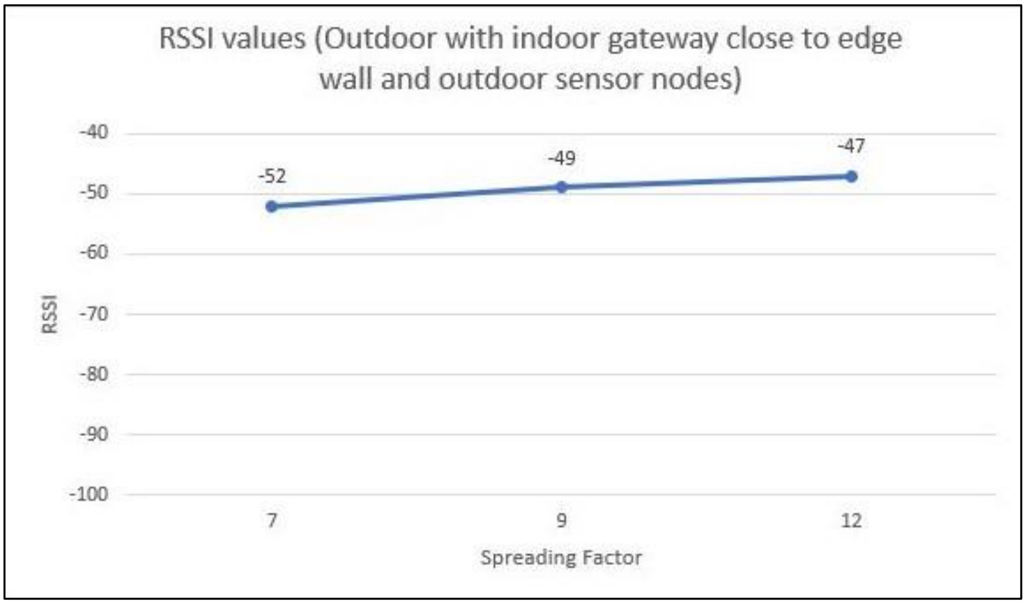
5.2.2 Outdoor Results

In outdoor experiments nodes are deployed inside the SEECS's buildings and gateway is placed inside and outside of the building.

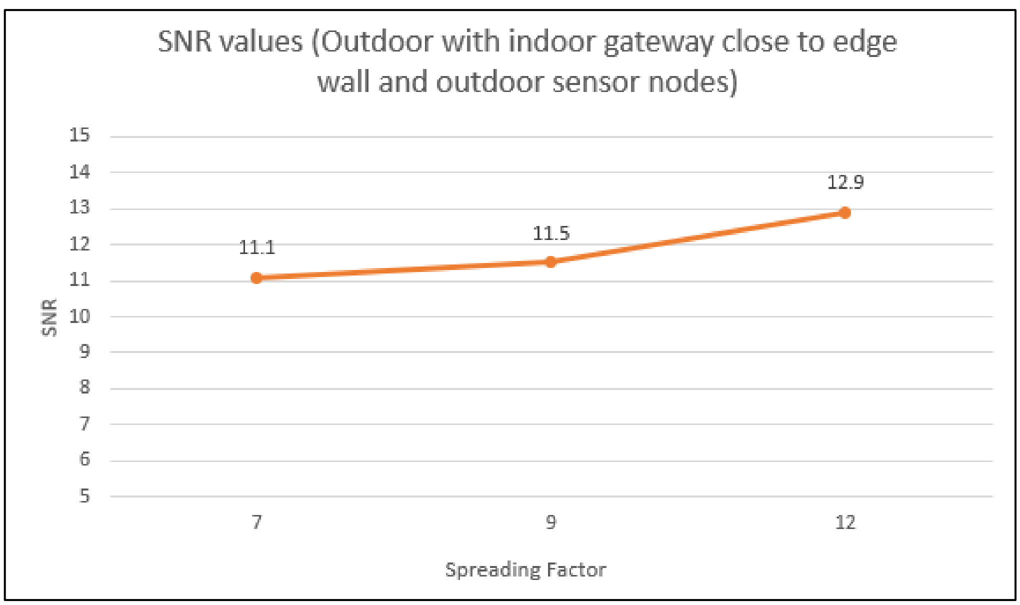
A) Outdoor with indoor gateway close to edge wall and outdoor sensor nodes

Single gateway is used which is placed in the first floor of academic block close to the edge wall indoors. The nodes are placed outdoor with a distance greater than 10 m and less than 2 km.

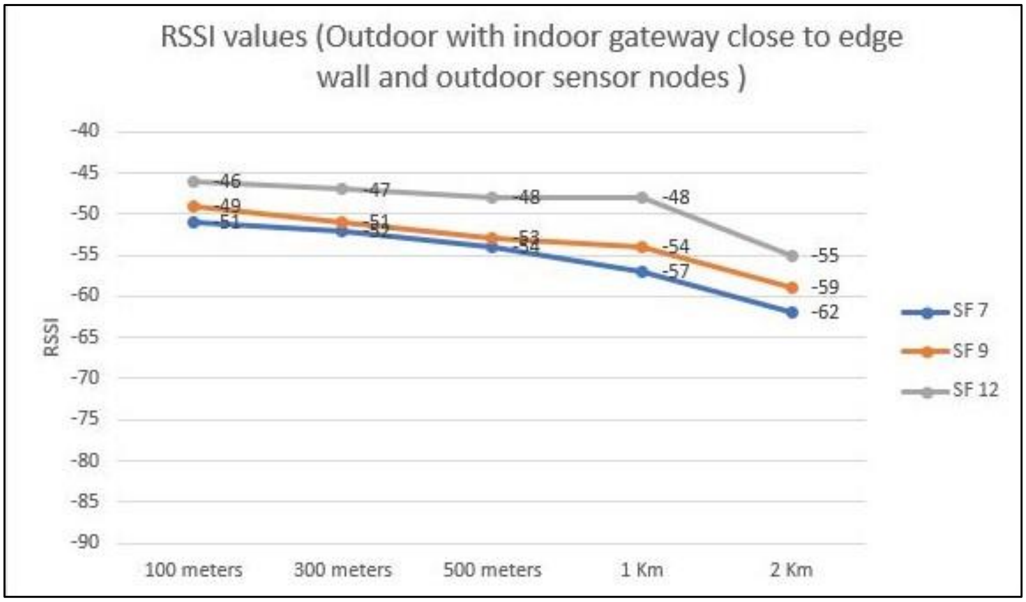
1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. Graph is Showing avg RSSI values when nodes are placed outside of building and there was not obstacle between node and gateway other than that gateway is placed inside of building. We have monitored much better RSSI values in outdoor scenario even seen in -40 dBm ranges.



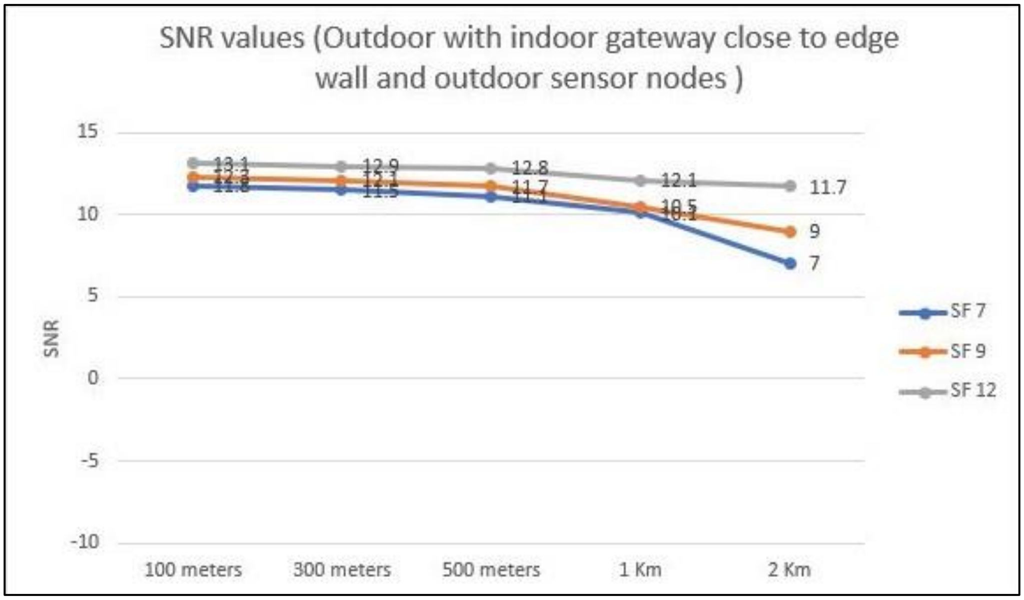
2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. Graph is Showing avg RSSI values when nodes are placed outside of building and there was not obstacle between node and gateway other than that gateway is placed inside of building. We have monitored much better RSSI values in outdoor scenario even seen values of SNR around 13 decibels.



3. Graph plotted below is showing average RSSI against increasing distance and SF. This graph is showing avg RSSI values with increasing distance and with changing spreading factor. We have tested the distance of upto 2 kilometers, even at 2 Km we have monitored better values and with higher spreading factor we have seen better values than lower spreading factor.



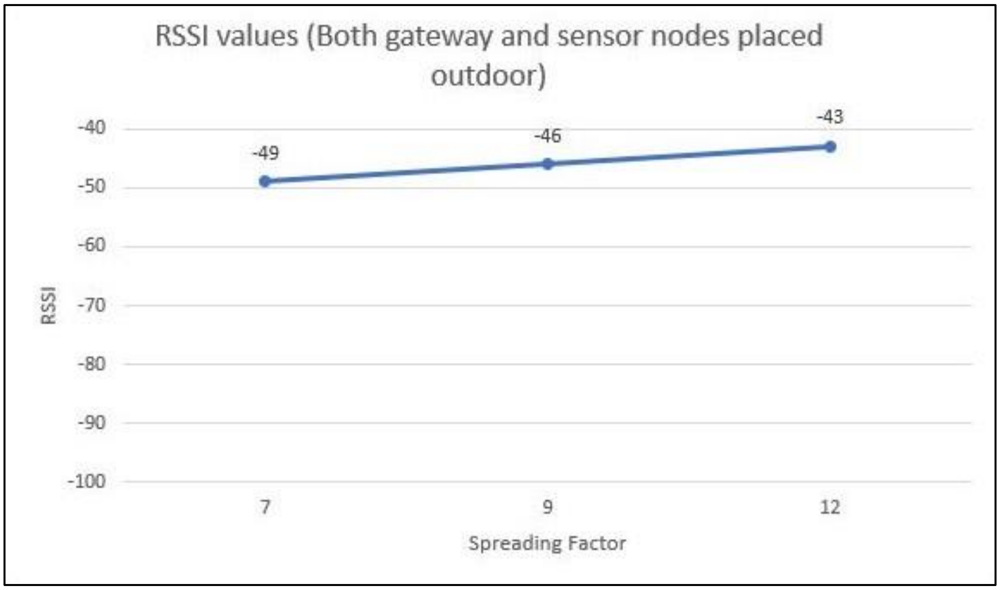
4. Graph plotted below is showing average SNR against increasing distance and SF. This graph is showing avg RSSI values with increasing distance and with changing spreading factor. We have tested the distance of upto 2 kilometers, even at 2 Km we have monitored better values and with higher spreading factor we have seen better values than lower spreading factor.



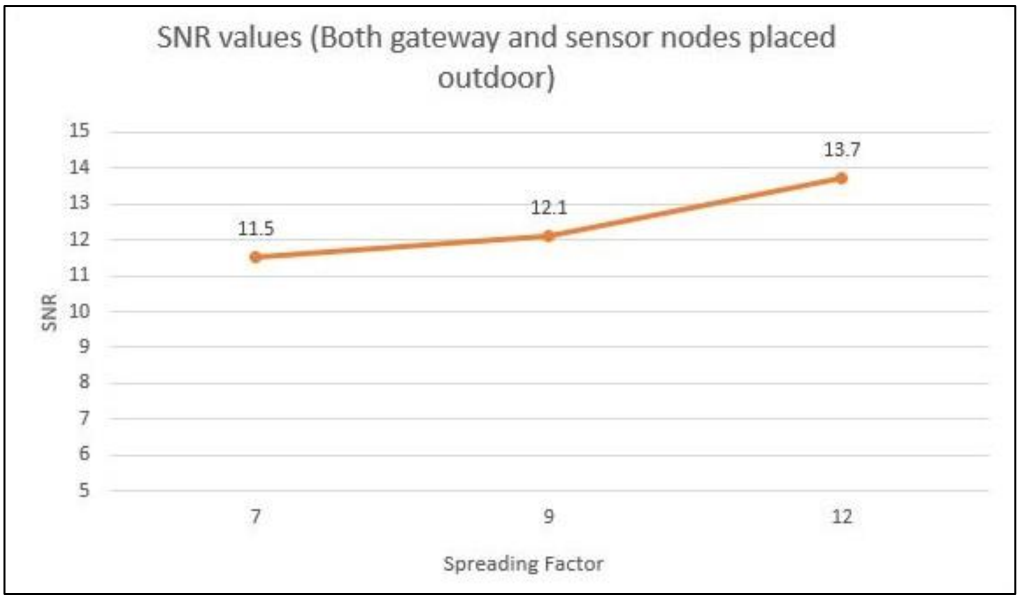
B) Both gateways and sensor nodes are placed outdoors.

Single gateway is used which is placed in the first floor of academic block close to the edge wall indoors. The nodes are placed outdoor with a distance greater than 10 m and less than 2 km.

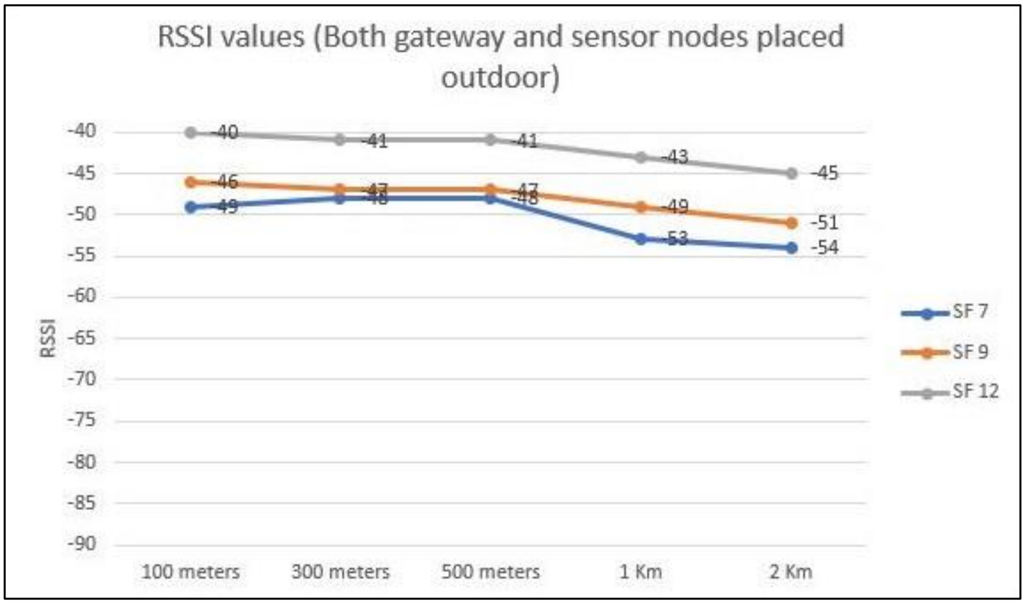
1. Graph plotted below is showing average RSSI against spreading factor 7, 9 and 12. This graph is showing avg RSSI values when both nodes and gateway are placed outside of building and there was no obstacle between nodes and gateway. Results are much improved comparison to previous scenario when gateway was placed inside the building. Even with lowest spreading we have seen better RSSI values.



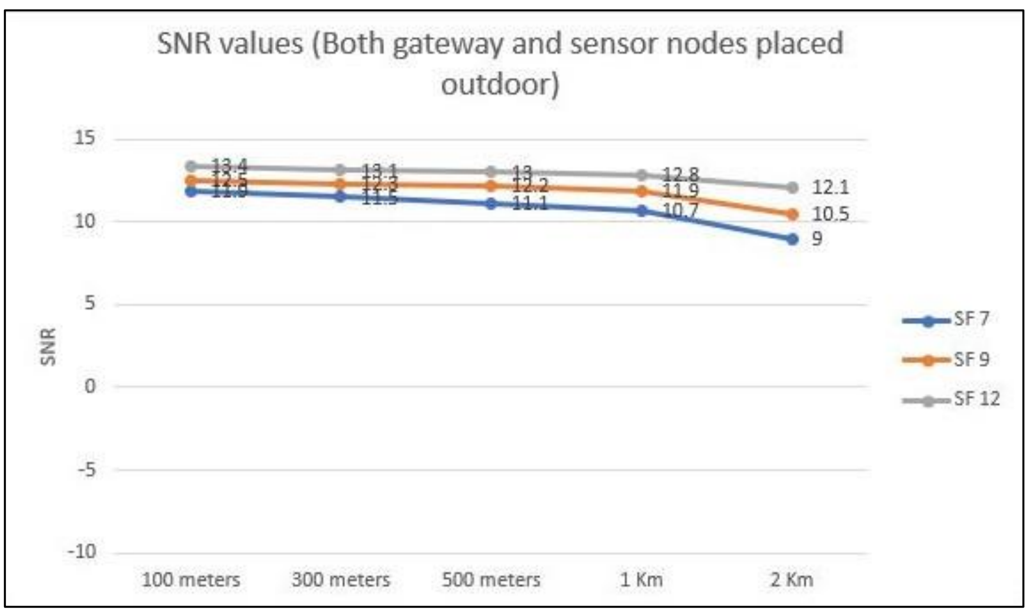
2. Graph plotted below is showing average SNR against spreading factor 7, 9 and 12. This graph is showing avg RSSI values when both nodes and gateway are placed outside of building and there was no obstacle between nodes and gateway. Results are much improved comparison to previous scenario when gateway was placed inside the building. Even with lowest spreading we have seen much better SNR values.



3. Graph plotted below is showing average RSSI against increasing distance and SF. Graph is showing RSSI values with increasing distance and we tested upto 2km. RSSI values are better with spreading factor 12 even at 2km whereas lowest spreading have downward trend.



4. Graph plotted below is showing average SNR against increasing distance and SF. Graph is showing RSSI values with increasing distance and we tested upto 2km. SNR values are better with spreading factor 12 even at 2km whereas lowest spreading have downward trend.



Chapter 6: Conclusion and Future Work

In this chapter conclusion based on experiments conducted to analyze performance of LoRaWan in different created scenario conditions is discussed and also discussed future work related to this research study.

In this work we did expansion in previous works where scope was limited to single scenario whether it is indoor or outdoor conditions. We experimented LoRaWan in number of different scenarios both in indoor and outdoor conditions with different practical combinations. we concluded that in indoor conditions when sensor nodes are close enough to gateway then there is not significant difference in RSSI and SNR values but as soon we started to increase distance, we have seen degradation and when we placed few sensor in adjacent building (there is small open area between two building) then further degradation noticed even it was difficult to establish connection although with higher spreading factor we have seen improved results but when we placed nodes in outdoor scenario then we have seen much better values even better when gateway was also placed outside of building. In outside scenario we have seen more stable connection and better values range even at far distances and changing spreading do effects, with high spreading factor can communicate devices at far distances with better RSSI and SNR. But high SF also increase air on time and energy consumption so we can avoid high SF in critical applications, for critical applications we can go with SF that is somewhat between highest and lowest SF. Our study will help others in deployment of nodes and gateways in optimized way to achieve better communication between nodes, gateway and LoRa server.

6.1 Future Work

This study shows performance of LoRa network in different conditions and in future one can learn from this study that how LoRa network will response in different indoor and outdoor conditions, considering this they can plan their deployment of LoRa end nodes and gateways in both indoor and outdoor conditions. After this study, we are determined to optimize energy consumption even with high spreading factor so, we can do transmission at farthest distances with high spreading factor by consuming less energy because as far now you can communicate over longer distance using high spreading factor, but you have to compromise on extra power consumption. Energy efficient model of LoRa network using high spreading factor can stretch the boundaries of LoRaWan. Few positives of this future will be:

- We can communicate over longer distance with much compromising on power consumption which is the key factor in using LoRaWan.
- Nodes can transmit collected information for years without need to change the battery.
- We can place nodes at difficult locations, such as at coal mine and deep in water without investing more in infrastructure.
- It will reduce the cost of deployment.

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