RaspberryPi-LoRa IoT Connectivity Solution

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Abstract

The report examines the design and implementation of IoT based sensor network using raspberry pi and long-range (LoRa). LoRa is a long-range connectivity spread spectrum modulation technique that performs in sub-GHz unlicensed spectrum and consumes minimal energy. The standard LoRa networks are single-hop and can connect directly to the central gateway. However, this study focuses on, implementing a LoRa multi-hop topology and measure the key parameters i.e. range and energy. The results are then compared to the Bluetooth low energy (BLE) multi-hop topology. For the insight of our study, we used the LoRa Hat module for raspberry pi to set up a LoRa node. A mesh network was created by using five LoRa nodes. Three nodes are configured to function as slaves, one node as a bridge, and one node as a single-channel low-power wide-area network (LoRaWAN) gateway. The gateway is connected to The Things Network (TTN) using python API calls. The Things Network is used to collect, visualize and measure the application data from all sensor nodes. We use various signal propagation tools to model the range of LoRa networks in urban/rural environments. From these experiments, we can conclude that LoRa can achieve a range of 18m vertically in an indoor building and up to 6 km range in densely populated urban environments.

Keywords: Bluetooth, wireless multi-hop networks, wireless sensor networks, LoRa, GPS HAT, Bluetooth Low Energy (BLE), GPS Hardware Attached on Top(HAT)

Contents

List of Acronyms and Abbreviations

3GPP 3rd Generation Partnership Project

BLE Bluetooth Low Energy

BW Bandwidth

CF Carrier Frequency

CR Coding Rate

FEC Forward Error Correction

GPS Global Positioning System

HAT Hardware Attached on Top

IEEE The Institute of Electrical and Electronics Engineers

IoT Internet of things

ITM Irregular Terrain Model

ITU The International Telecommunication Union

LoRa Long Range

LoRaWAN Low Power Wide Area Network

LPWA Low Power Wide Area

LTE-M Long Term Evolution (4G) category M1

MQTT Message Queuing Telemetry Transport

NB-IoT Narrowband Internet of Things

PL Path-Loss

RF Radio Frequency

RSSI Received Signal Strength Indicator

SF Spreading Factor

TTN The Things Network

TX Transmit

1 Introduction

Basically, the Internet of Things (IoT) allows us to connect 'everything' to the Internet and communicate the data information for a specific reason or goal in their state. 'Everything' can include human beings, living objects, physical devices, complete embedded systems, or machines etc., and communicate via the internet, hardware sensors, and embedded software platforms,[1, 2]. The Internet of Things is not a single term, it is a medium that can help to communicate the data information among the connected things. The IoT is believed to be a new revolution in wireless communications technologies. Due to enhancement in wireless technology, the scale of IoT has increased manifolds especially in the areas of consumer marketplace, infrastructure, and Industrial facilities and functionalities etc. [3, 4]. The goal of IoT is to connect and communicate the wireless sensing devices to IoT applications such as measuring the real-time temperature, humidity, air quality monitor, and wireless power transfer. The connectivity solutions characterize based on key parameters such as coverage distance, spectrum, and performance. Short area coverage sensor networks used for indoor IoT[5, 6] solutions support Bluetooth, ANT+, and MiWi. While the outdoor wide-area used the unlicensed LPWA coverage supports SIGIFOX, LoRa/ and licensed NB-IoT, LTE-M etc. for the connectivity solutions. LPWA provides a long-life battery and is specifically used for the sensor and applications that send small packets of data covering the long distance [7, 8]. LoRaWAN is a protocol that was built on top of LoRa physical layer to enable communication between multiple LoRa powered IoT nodes and gateways [7].LoRa is an LPWA wireless physical layer technique whose approximate range is between 2-5 km in urban areas, 5-15 km for rural areas, and more than 15 km for direct line of sight when TX power is set to 20 mW. Whereas, Bluetooth is a short-range wireless communication whose approximate range is 10m with TX power of 2.5 mW.

Description of the problem: The focus of this project is to find the answers to under mentioned questions:

1)Setup the LoRa modules for collecting the temperature measurements.

2)Setup the communication between two LoRa modules.

3)Organize the mesh network using the Raspberry Pi and forward data to the primary node. Present temperature data regularly on display.

4)Publish the data from the mesh network to the web-server.

5)Measure the range of LoRa and compare to models/data and compare the results with BLE project data.

Context of this study :

1): Firstly, designing and implementing a sensor network using simple temperature sensors and Raspberry Pi computers.

2): Secondly, finding the solution relating to the problems

Goal of this study : The study will prove useful for the future IoT researcher to analyze LoRa's mesh network benefits.

Outline: The study is divided into 5 sections, the first section reflects an introduction covering background, description of the problem, context and goal of this study. Section two covers an overview of IoT system architecture and components, section three covers the design and implementation of sensor network. Section four and five provide the test results, summary, and conclusions of the findings.

2 IoT System Architecture and Components

To investigate the working of LoRa mesh network, we use the LoRa/GPS HAT and RaspberryPi to setup the LoRa node and LoRa gateway as shown in figure 1. In the figure, we follow the two realizations. The first realization is related to the LoRa mesh network in which the RaspberryPi node 1 and node 2 will send data via LoRa radio protocol to node 3 which acts as a bridge between LoRa node and LoRa gateway node 5. The second realization describes the temperature measurement from RaspberryPi sensor node 4 and reporting the temperature measurement to LoRa gateway node 5 directly via LoRa radio protocol. The data is collected by the TTN network from the LoRa gateway and it provides visualization of the measured data in the application section.

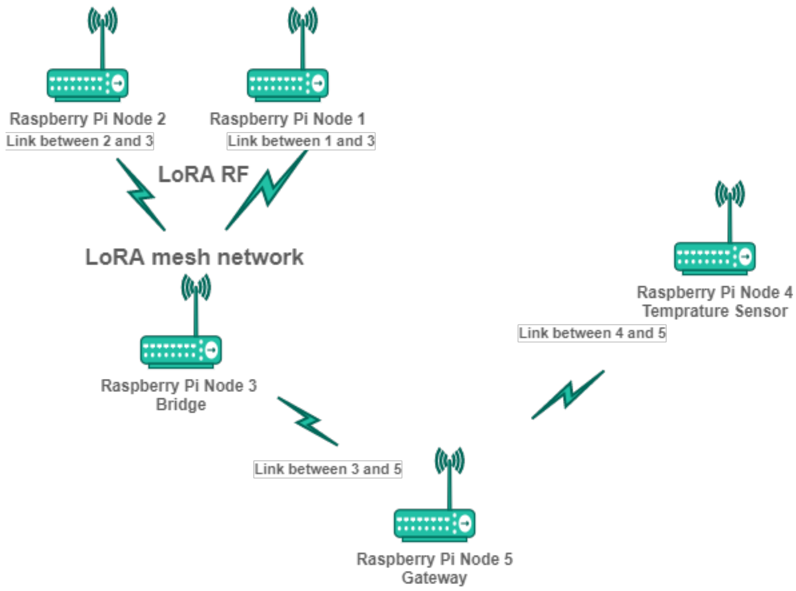


Figure 1: LoRa Mesh Network

The TTN provides an open network and distributed base for the IoT at a minimum cost correlating to higher scope and security [9]. It offers a solution to link several IoT devices, gateways to form LoRaWAN networks.

3 Design and implementation of sensor network

3.1 Temperature capturing

To capture the temperature, we must first enable the one-wire interface the temperature sensor communicates through [10]. This is done in steps. First, you will need to edit the $/boot/config.txt$ file, by inserting $dtoverlay = w1 - gpio$ at the end of the file. After rebooting the Raspberry Pi, you will need to run two commands: $modprobew1 - gpio$ and $modprobew1 - therm$ (do note that all of these commands might require root). Navigate to the $/sys/bus/w1/devices/28 - XXXXXXXXXXXX$ (replace the x:es with whatever your directory says) and then run $catw1_slave$. This will print out two lines of text. Look for a "t" followed by an equal sign and numbers, this will be your temperature in celsius. For example, "t=28625" will mean 28,625 degrees celsius. To make sure we do not have to redo these steps all over again (except for editing the file $/boot/config.txt$) we can create a python script that does this for us [10].

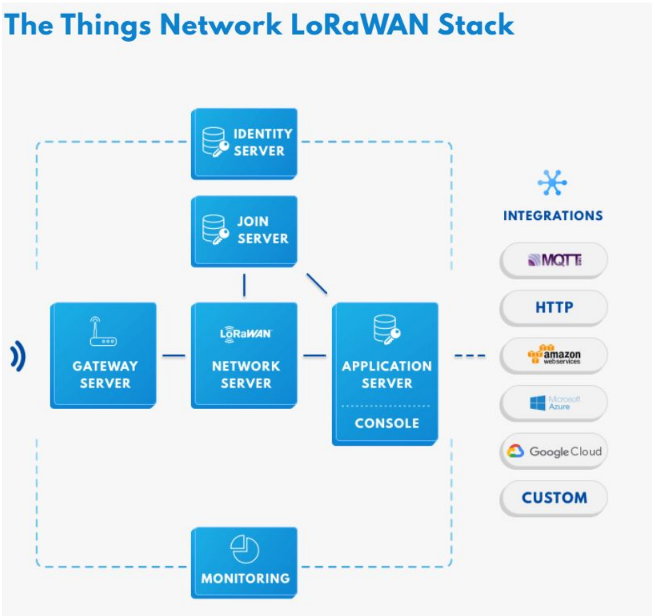


Figure 2: TTN open LoRaWAN network [9]

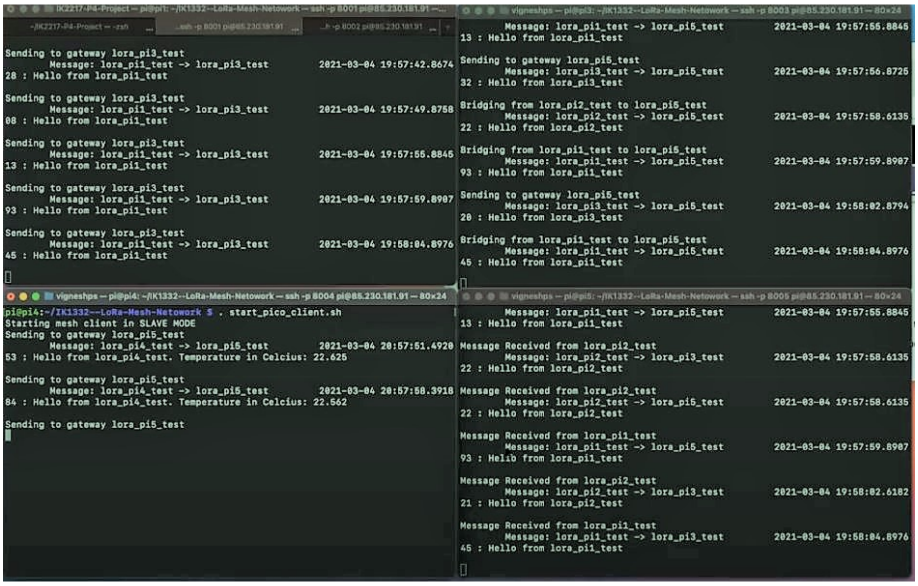
3.2 Data flow with gateway and TTN web-server via MQTT API

To establish the communication between LoRa gateway and TTN [9] web-server we have used the MQTTClient python class constructor. There are four key data members i.e. app id, access key, dev id, and payload are initialized with the correct values as covered in Figure 3.

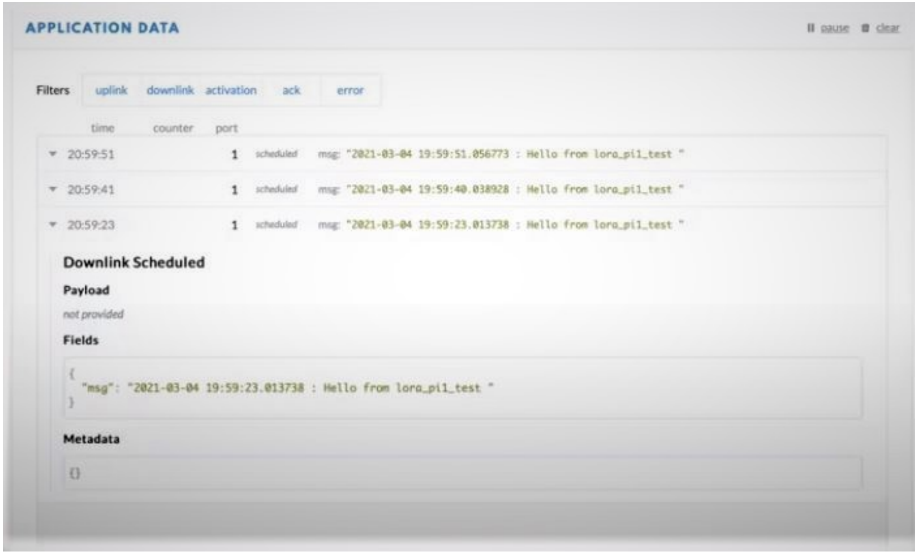
4 LoRa Propagation Model

The primary characteristic requirements for IoT communication are long-range, low data-rate, energy-efficient operation, and the ability to function in lossy environments. LoRa has emerged as a promising technology to enable IoT networks as it adequately satisfies all the above requirements. Studies in real-world settings have shown that LoRa can offer ranges of 8km - 45km based on the various environments (indoor, urban, suburban, rural) and environmental factors such as temperature, vegetation, rain, snow, etc [11]. It has been shown that vegetation and higher temperature significantly reduce communication ranges[11]. In indoor environments, LoRa signals can deteriorate proportionally with the number of walls and floors the signal has to propagate.

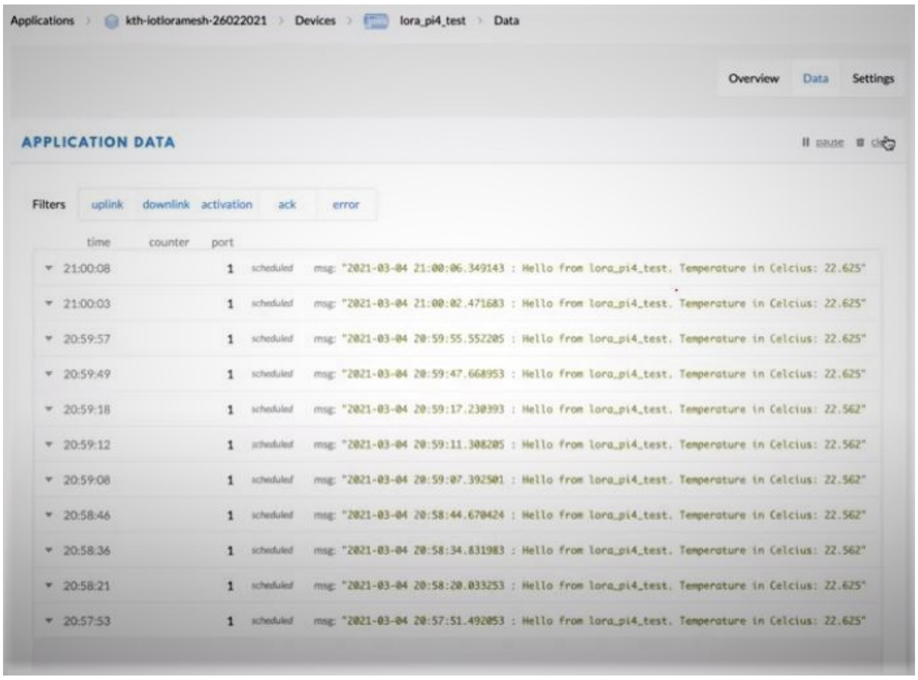
LoRa offers a broad range of flexibility for tuning transmission characteristics by adjusting various physical parameters of the LoRa modem. These parameters include CF, BW, SF, CR, and transmission power (Ptx). Parameters can be configured to achieve a tradeoff between transmission range, data rate, and receiver sensitivity. Carrier frequency is the operating frequencies within which LoRa communication functions. Users can choose from 433, 868, or 915 MHz depending on the region of deployment. In European regions, 868MHz is the most prominent deployment. Along with carrier frequency, the bandwidth can be configured based on the data rate requirements. Higher bandwidths lead to higher data rates but short-range and low sensitivity. The spreading factor is defined as the ratio of the symbol rate to the chip rate. On the sx1276 LoRa modem, the spreading factor can be varied from 7 to 12[12]. SF value of 12 provides a longer range while limiting data rates. Coding rates can be dimensioned based on the required FEC robustness. Coding rate can be set to 4/(CR+4) where CR = $\{1,2,3,4\}$. Higher Coding rates reduce the effective data rates but providers better bit error rate. TX power is the power rating of the transmission antennas. High transmission power allows signals to better propagate obstacles, buildings, walls, floors, etc. However, the permitted TX Power can be dictated by the local wireless regulations. Table **??** shows the sx1276 modem settings to achieve the longest possible range.



(a) Node and gateway terminal output



(b) Web server device1 application data



(c) Web server device4 application data

Figure 3: Demonstration output

Parameter	Value
LoRa Module	Dragino v1.0 LoRa Hat with sx1276
TX Power	14dBm
Frequency	868MHz
Bandwidth	125KHz
Spreading Factor	12
Coding Rate	4/5

Table 1: LoRa modem parameters

Modeling radio propagation is crucial for LoRa network planning and optimization. Modeling allows the network providers to provision the network for the requirement for the deployment. Numerous studies both in indoor and outdoor environments have been carried out owning the popularity of the LoRa networks in recent times. The propagation model/ path-loss (PL) model is impacted by many factors such as distance, frequency band, average antenna heights, geography, and terrain in terms of obstacles, buildings, hills, mountains, people, etc. However, for the indoor environment, additional factors need to be considered such as floor plans, walls, and the type and thickness of building materials.[11]

Many PL models are proposed to model LoRa signal propagation in outdoor environments, e.g. Okumura-Hata, Cost 231-Hata, (ITU) Advanced, WINNER II, WINNER+, and (3GPP) Spatial Channel Model. Similarly, many indoor propagation models can be used to estimate propagation properties, e.g. (ITU)- R P1238, (IEEE) 802.11n, 3GPP, Cost 231 multi-wall, and Motley-Keenan. [11] presents a summary of propagation models. In this report, we fit propagation models for indoor and outdoor scenarios based on the specifications of the sx1276 series of (LoRa) modems.

4.1 Indoor Propagation Model

In this report, we use Motley-Keenan's [13] indoor propagation model to analyze the propagation characteristics of LoRa signals. [14] compares five commonly used indoor propagation models and concluded that Motley-Keenan's model best fits the PL model with the least error and standard deviation.

Free Space propagation loss:

$$L_{dB} = 20Log_{10}\left(\frac{4\pi d f}{c}\right) \tag{1}$$

Motley-Keenan's model is given by:

$$L_{dB} = L_{ref} + 20Log_{10}(d) + n_f a_f + n_w a_w \tag{2}$$

where *Lref* is the loss calculated at the reference distance of 1m using the free space propagation model Equation (1), *d* is the distance between transmitter and receiver, *af* and *aw* are wall attenuation and floor attenuation respectively. *nf* and *nw* are the number of walls and floors respectively.

Figure 4 considers an indoor building constructed with concrete walls of 4 inches and a ceiling with bricks and concrete of 8 inches. The rooms are of a constant dimension of 4m x 4m and are placed adjacent to each other in a square gird. The sx1276 receiver sensitivity is set to -137 dB [12]. The model estimates LoRa signals can penetrate up to 18m vertically (5 floors), and, reach 28 m horizontally (7 rooms) in an indoor environment when the TX power is set to 14 dBm. Attenuation for different materials is used from [15].

4.2 Outdoor Propagation Model

For modeling the range of LoRa transmitters in outdoor environments we use Radio Frequency (RF) planning tool, cloudRF [16] with (ITM) [17]. ITM models and their variations are known to fit the propagation characteristics well for urban/suburban spaces [18].

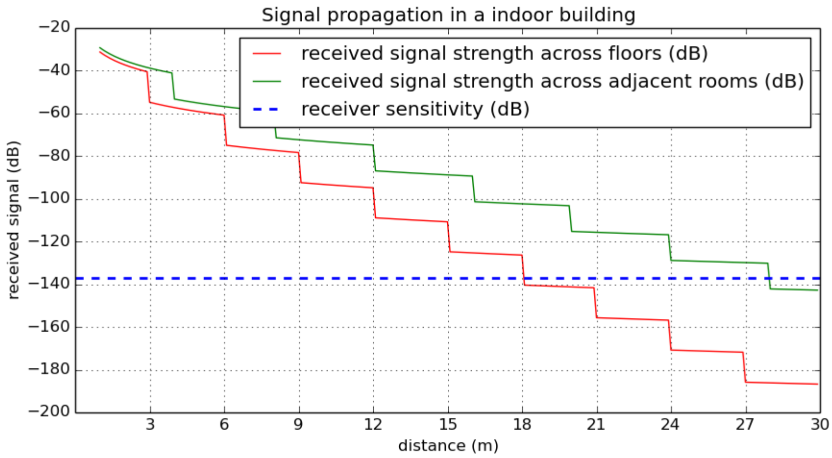


Figure 4: Motley-Keenan's indoor propagation model for LoRa

We use the (RF) planning tool to place a virtual transmitter at the KTH Kista campus (Lat: 59.4044 Long: 17.9490). The transmitter is placed at a height of 10m and a carrier frequency of 500MHz is used. The RF Planning tool uses terrain irregularities to add propagation clutter to the path loss model. Multiple levels of terrain irregularities contexts were applied. (RSSI) values of -94 dBm were observed at 3Km (Figure 5) and -126 dBm was observed at 7.5 Km range (Figure 6). Since the sensitivity of the (LoRa) modems can go up to -137 dBm the real range is higher than the values reported by the RF planning tool.

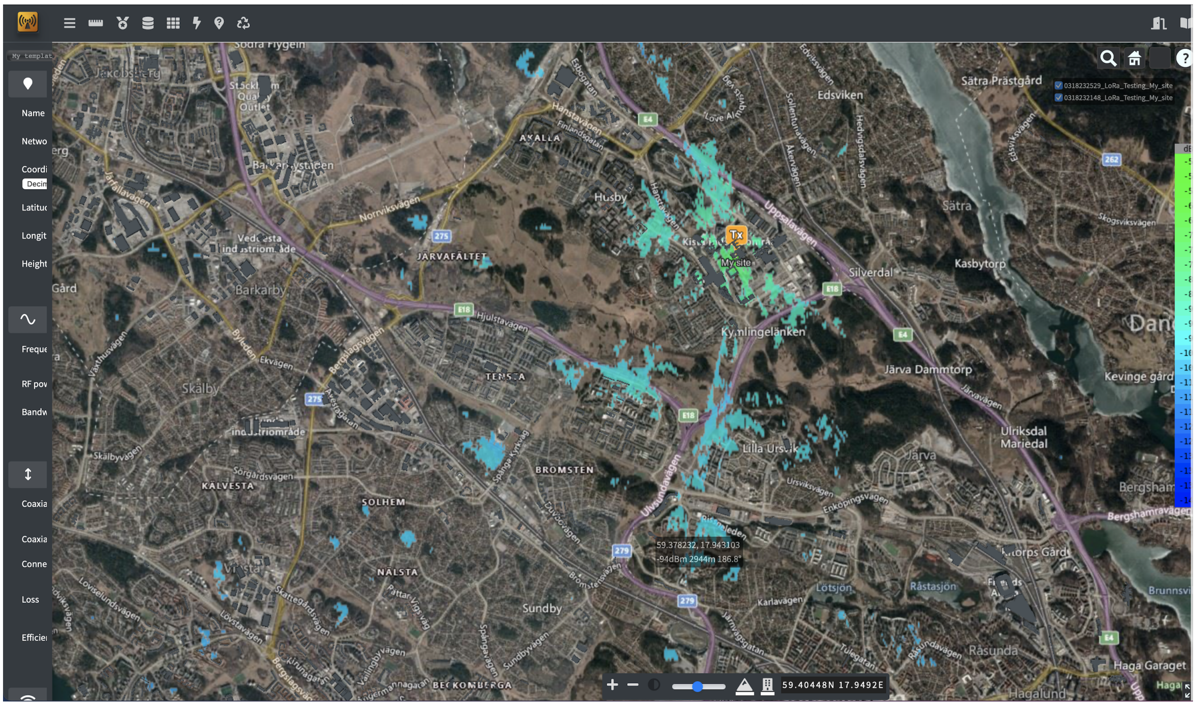


Figure 5: RSSI at 3 Km

4.3 Comparison

When compared to the Bluetooth Mesh network, LoRa can provide higher ranges, mainly owning to the use of chip sequences. Bluetooth networks can provide an outdoor average range of 15m. Such networks are ideal for dense indoor deployments where higher data rates are required, while LoRa networks are ideal for low data rates and outdoor deployments.

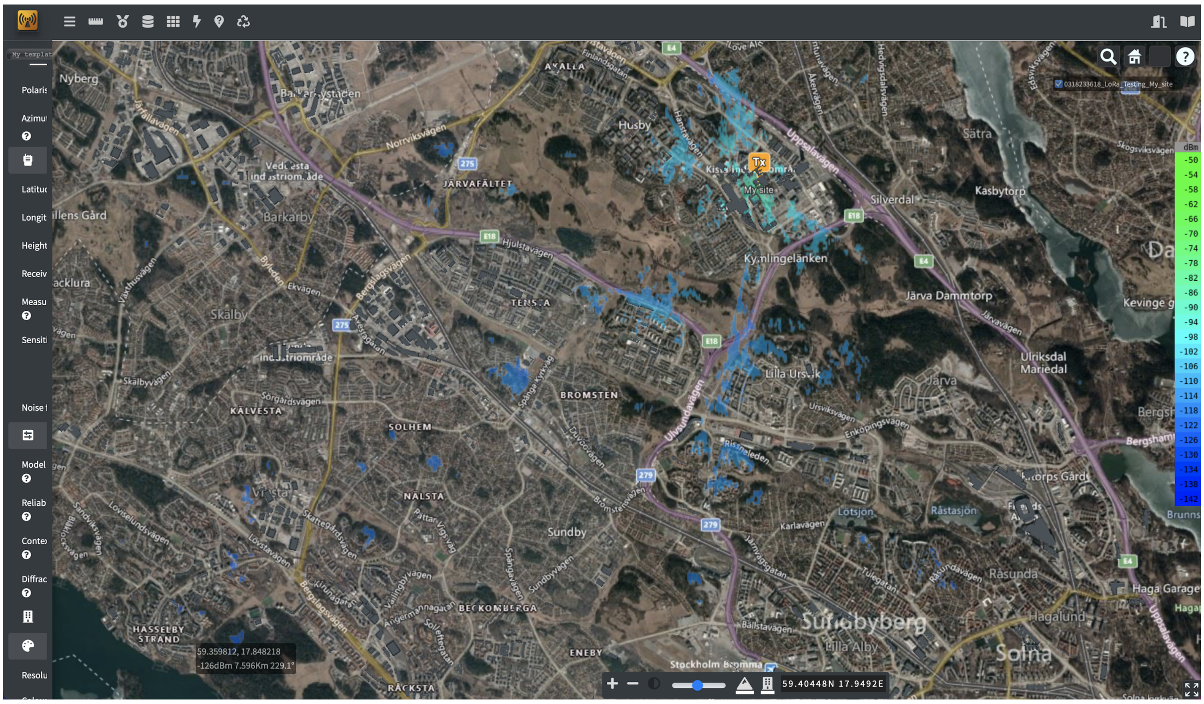


Figure 6: RSSI at 7.5 Km

5 Result

In this section, we summarize the results of the above experiments. In indoor environments, LoRa can achieve a range of 18m vertically across multiple floors, and 28m horizontally across adjacent rooms when modeled with Motley-Keenan's Propagation model. However, in outdoor settings, an optimistic range of 5 km with good signal RSSI can be achieved in sub-urban environments[16]. LoRa suffers a great loss in indoor environments due to attenuation by various materials, and multipath fading. In outdoor environments, the primary factor of signal loss is signal scattering due to obstacles. However, LoRa can achieve higher ranges when the transmitter antennas are placed at higher altitudes. LoRa mesh networks can enable deployments with a coverage area of several tens of kilometers. Such networks scale linearly with the number of bridge networks that are present in the network.

6 Conclusion

In this project, we have designed and implemented a LoRa sensor network using temperature sensors and Raspberry Pis. We have also (theoretically) measured ranges of the LoRa network. We have found that the LoRa network can achieve ranges of 18 meters vertically and 28 meters horizontally indoors, and 5 kilometers outdoors. One of the things that have limited us has been the geographical distance between us. Because of it (and the fact that one of our group members became sick), we have yet to perform the outdoor range tests. This of course also puts a limitation on our test results. Other than that there were some technical challenges to get the ssh service up and running on the pi:s. The work has, in conclusion, been going very well for us. There is nothing we would have done differently. We did miss some meetings, but the work went very well, and the workflow was really smooth. Because of the very low cost to set up the LoRa network (in our case, we used four raspberry pi:s and some add-ons), which is very cheap. Also, it is possible to use only two Pi:s that communicate with each other. There really is no ethical or social aspect of our work. As for the environmental aspect, because the parts in the project are small and lightweight, they do not require much material to make. This is obviously an advantage in the environmental aspect.

7 Appendix

The code can be accessible on our git repo:https://gits-15.sys.kth.se/vips/IK1332-Lora-Mesh-Network and web server link application data can be validated on the mentioned link TTN web-server: https://console.thethingsnetwork.org/.

Team members sprint contributions summary over 4 weeks

Sprint	Activity	Description	Total hours	Results
1	Ramp-up	Go through the reference documents, study up the LoRa and raspberry Pi concepts, setup python work environment, installed all the required API and run test script, prepare sprint plan with team members, and added the tasks in the task planner tool(Asana) for project sprint task progress monitoring	20	Work on the project sprint task planner, started to go through the reference documents.
2	Get components ready such as the LoRa mesh network, temperature sensor, Lora gateway, and web-server	Build/configure gateway and publish the data to a web server. Understand the MQTT API to code for the data send API. Updated the GPIO access library ”wiringpi”, Install and build the legacy single channel LoRaWAN gateway on your Raspberry Pi as per the provided instructions in the TTN. Maintain the sprint planning board and present the progress.	23	Successfully configure the gateway and device run sanity test for single-channel LoRaWAN gateway legacy code on our Raspberry Pi and verify the MQTT quick test based on the publish and subscribe API successfully.
3	Planned to measure the real environment test results for LoRa Mesh and verify the functioning of the Lora mesh network, temperature sensor, Lora gateway, and web server	Worked in the indoor test setup as per the below questions How to use LoRa/GPS HAT to set up a single-channel gateway for the TTN network? How to use LoRa/GPS HAT to set up a LoRa Node? How is the communication between the LoRa?	16	To have an actual demo of our program and how it works.
4	Compare the LoRa test results with BLE results and prepare the project report.	Prepared the project report on overleaf and updated abstract, introduction, and design and implementation of sensor network. Prepare the project presentation, maintain the sprint planning task board, and present the progress.	24	Report prepared

Table 2: Team Member: Amit Choudhary

Sprint	**Activity**	**Description**	**Total hours**	**Results**
1	Ramp-up	Setup google drive, got basic understanding of the project, Study up on the LoRa modules for temperature measure	14	Created a google drive and got a basic understanding of the project, Gain a better understanding for the LoRa modules
2	Get components ready such as the Lora mesh network, temperature sensor, Lora gateway, and web-server	Reading through code/sources online that could be of interest, Present temperature data regularly in the terminal.	14	Gaining knowledge and inspiration
3	Planned to measure the real environment test results for LoRa Mesh and verify the functioning of the LoRa mesh network, temperature sensor, LoRa gateway,and web server	Record demonstration,Read up on how to measure range of LoRa	12	To have an actual demo of our program and how it works. To gain enough knowledge to finish grade A.
4	Compare the LoRa test results with BLE results and prepare the project report.	Updated the sections IoT System Architecture and Components, and Conclusion. Prepare the project presentation	24	Report prepared

Table 3: Team Member: Henrik Cassé

Sprint	Activity	Description	Total hours	Results
1	Setup the hardware	Collect the hardware, setup RaspberryPi for remote access, group discussion, and task split up, check for available API libraries to interface LoRa with RaspberryPi, Run sanity checks to check if all LoRa HATs can be interfaced with RaspberryPi, and run a simple transmit-receive program	20	Hardware collected, setup port forwarding to enable collaborative development, discovered pyLoRa module. Installed the library and dependencies. When through pyLoRa APIs.
2	Get components ready such as the Lora mesh network, temperature sensor, Lora gateway, and web-server	Set up git Repository and update all the RaspberryPi with our codebase, Plan and design a mesh Network, Implement the mesh network, Test the mesh network	20	Completed planned activities
3	Planned to measure the real environment test results for LoRa Mesh and verify the functioning of the LoRa mesh network, temperature sensor, LoRa gateway, and web server	Read on how to model the range of LoRa devices, record demonstration, Theoretically model range of LoRa devices, Carry out the range measurements, Compare the results of BLE and LoRa	19	Successfully modeled the range of LoRa devices and recorded demonstration
4	Compare the LoRa test results with BLE results and prepare the project report.	updated the ”LoRa Propagation Model”, Prepare the project presentation	19	Report prepared

Table 4: Team Member: Vignesh Purushotham Srinivas

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