Feasibility of LoRa for Indoor Localization

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1 Introduction

The concepts of smart cities and smart communities have started to become a reality in this age of the Internet of Things (IoT). In the midst of this IoT revolution, recently, low power wide area networking (LPWAN) technologies[1, 2, 3, 4] have become very popular, as they are an excellent fit to the IoT data traffic that are generated and consumed by many smart cities applications. For instance, if we think of city-scale IoT applications like smart metering, environment monitoring, road traffic monitoring, facility management, smart parking, street lighting, vehicle tracking, waste management, precision agriculture, and home automation, we observe that the basic communication requirements in these applications include a *long radio range* (i.e. several hundred meters of range), *low power* (i.e. an extended battery-life of several months or years), and *low bandwidth* (i.e. a data rate of few kbps). Thus, low power WANs are being considered as the enablers of city-scale IoT.

Among different choices of low power WANs, we study one of the most popular technologies of today, which is called the LoRa WAN [2]. LoRa has so far been mainly adopted by the European countries, although recently, over 100 cities in the USA have begun to deploy city-wide LoRa networks [5]. LoRa has an advertised radio range of up to 9 miles (in line-of-sight), a data rate of up to 50kbps, and a battery life of around 10 years.

Though LoRa is considered for outdoor applications, its properties can also be leveraged for indoor scenarios. As LoRa operates in the sub-GHz band, it obtains more penetration ability making it more resilient to noise and multipath. This property makes LoRa a better choice for indoor localization. Recently for localizing in large facilities (e.g. multistory buildings, large warehouse), multiple access points or beacons need to be installed due to the short range of traditional RF signals e.g. WiFi, Bluetooth Low Energy (BLE). However, due to the long range of LoRa, fewer number of access points or node can perform similar operations.

In this paper, we study the performance and prospect of LoRa in indoor localization. We observed that LoRa is more stable than WiFi and BLE and is more resilient to environment change. We achieved mean error of 1.19m and 1.72m with unprocessed RSSI value in line of sight and non-line of sight respectively.

2 Background

2.1 Overview of LoRaWAN

LoRa [2] stands for *'Long Range'*. It defines the physical layer of an emerging network technology that offers low data rate wireless communication over long distances, while consuming very little power. For example, LoRa radios have a battery lifetime of around 10 years, a communication range of up to 9 miles (line-of-sight), and a data rate of 27kbps–50kbps. Because of these properties, LoRa has gained a lot of attention in the Internet of Things (IoT) applications where battery operated devices require access to the Internet but are physically located miles apart from an Internet gateway.

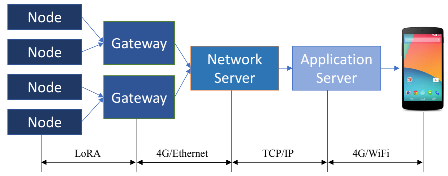


Figure 1: LoRaWAN Network Architecture.

LoRaWAN is a specification for Low Power Wide Area Network (LPWAN) that defines the system architecture and network protocols for LoRa capable devices. LoRaWAN networks are organized as a star of stars topology as shown in Figure 1. Four types of entities are present in a LoRaWAN. The sensor nodes or end nodes send data packets to a LoRa capable gateway. A single LoRa gateway is able to cover an entire city (hundreds of square kilometers). Gateways are connected to a network server over a backhaul network such as 4G or Ethernet. Network servers are connected to an application server via TCP/IP. Users can access the data from application servers on any device with an Internet access such as smartphones or personal computers.

Although LoRaWAN has a long range and a long battery life, the low data rate limits its usage to applications which do not generate large amount of data traffic. IoT applications where LoRa has shown promising results include smart metering, facility management, smart parking, street lighting, vehicle tracking, home automation, waste management, and remote health-care.

2.2 LoRa Physical Layer Properties

LoRa physical layer handles the lower level details of wireless communication. LoRa operates in 433, 868 or 915MHz ISM bands. Key properties of this layer are as follows:

- *Chirp Spread Spectrum (CSS) Modulation:* The LoRa physical layer uses a special type of spread spectrum modulation technique where information bits are encoded as frequency *chirps* (frequency varying sinusoidal pulses) [6]. The use of chirps improves its robustness against interference, Doppler effect, and multipaths [7]. Each symbol is encoded with 2^{SF} chirps, where SF is called the *spreading factor* and takes a value between 7 to 12. There is a trade-off between the spreading factor and the communication range. A higher value of the spreading factor results in a longer time for each symbol transmission and yields a longer communication range. The way chirps are designed for different spreading factors, they are orthogonal to each other at different values of $SF \in [7, 12]$, and thus multiple data packets can be sent in parallel as long as their spreading factors are different.

- *Time-On-Air:* The *Time-on-Air* of a packet, T_a is the duration for transmitting a LoRa packet. It is expressed as a function of the number of symbols per packet n_s, chirp time T_c, and spreading factor SF as follows:

  $$T_a = n_s \times 2^{SF} \times T_c \tag{1}$$

  Since the communication bandwidth and time-resolution are inversely related ($BW \approx 1/T_c$), we can use their relationship to express the above equation as:

  $$T_a = n_s \times \frac{2^{SF}}{BW} \tag{2}$$

- *Duty-Cycle Limit:* The duty-cycle is defined as the fraction of time an end-device keeps the channel occupied for communication. To reduce collisions as well as to increase the fairness of channel use by different transmitters, there is a limit on the maximum duty-cycle for an end-device. For example, European FCC allows a maximum duty-cycle of 1% for EU 868 end-devices [8]. Therefore, if an end-device uses a channel to transmit a frame, the limit on duty-cycle restricts it to transmit on the same channel again until after a period of silence. The device, however, can use other available channels (as long as the duty-cycle limits on those channels are maintained, of course). Formally, given the duty-cycle limit δ, an end-device must not transmit anything on the most recently used channel for a minimum off-period, T_{off}

  $$T_{off} = T_a \times \left(\frac{1}{\delta} - 1\right) \tag{3}$$

  Note that, if there are 8 channels and the duty-cycle is limited to 1%, then the duty-cycle per channel is 1/8%. For example, if an end-device transmits on a channel for 1 second, the channel will be unavailable for it for the next 799 seconds.

2.3 LoRa MAC Layer Properties

LoRa MAC layer determines how multiple end-devices access the wireless media to communicate with the gateways. Key properties of LoRa MAC layer are as follows:

- *Sub-bands and Channels:* LoRa operates on a specific range of frequencies (an ISM band). Each band is divided into multiple sub-bands, and each sub-band is further divided into a number of channels. For example, in the USA, LoRa operates on the 915MHz ISM band that contains the frequencies between 902–928MHz. This band is divided into eight sub-bands, and each sub-band contains 10 channels (eight 125KHz downlink channels, one 500 KHz downlink channel, and one 500KHz uplink channel).

- *Interference:* Each gateway in a LoRa network listens on a particular sub-band. When two end-device communicates with the same gateway, at the same time, at the same channel, and using the same spreading factor, they will cause interference and their packets will collide.

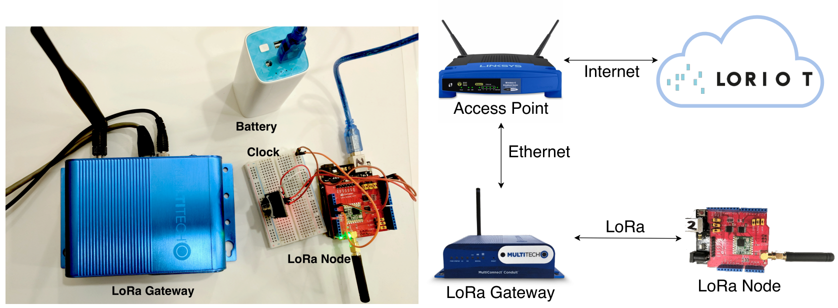
- *Device Classes:* LoRaWAN defines three classes of devices: class A, class B, and class C, in order to meet the demands of different types of applications. Class A devices use ALOHA [9] protocol for an uplink packet transmission, followed by two short downlink receive windows. This class is defined for battery operated devices. It does not require carrier sensing and thus helps keep the energy consumption of an end-device to the minimum. Class B is designed for devices which may require additional downlink communication. Class C devices always listen for ongoing transmissions before transmitting anything. In this paper, we consider only the class A devices which are low power and suitable for IoT applications.

- *Pure and Slotted ALOHA:* ALOHA is a MAC layer protocol that allows a node to send data whenever it is ready. Because there is no coordination among different transmitting nodes, ALOHA yields a high rate of collisions. As the number of devices on the network increases, the number of collisions increases.

  Slotted ALOHA introduces the concept of time-slots and allows a node to send a packet only at the beginning of a time-slot. It eliminates partial collisions (i.e. collisions in the middle of a packet transmission) but the medium access is still not controlled. Collision occurs whenever more than one end device become ready with a packet to transmit. Due to the lack of coordination or a packet transmission schedule, the real-time performance of both pure and slotted ALOHA is extremely poor.

3 System Development

This section provides some highlights from our implementation of the LoRa network that we feel would be helpful to anyone who wants to replicate the complete system. Figure 2(a) shows a photo of the main elements of our LoRa network.



(a) (b)

Figure 2: (a) A LoRa Node is connected with a clock and battery. A Gateway is placed beside the node. (b) A LoRa node communicates with gateway using LoRa protocol. The gateway relays the node's message to access point via Ethernet. The access point connects with server using internet.

3.1 Developing the LoRa Nodes

We develop LoRa nodes in our lab by interfacing a LoRa radio shield [10] with an Arduino Uno [11] that hosts an ATmega328P microcontroller. The radio shield internally uses a transceiver SX1272/73 [12] which is controlled from the Arduino using a modified software library from IBM [13]. Each node is powered by a 10,000mAh USB power bank. The internal 16MHz quartz crystal of Arduino Uno is unreliable for time synchronization as the clock drifts over time. Hence, to time synchronize all the nodes in our network, we interface an external real-time clock [14] with the Arduino board. These real-time clocks are powered by their own battery and their drift over 24 hours after synchronization is too small to be noticeable ($<$ 1ms). Both the modified library and our customized application are written in C. Our source code is open and accessible online from here [15].

3.2 Configuring the Gateway

We use a Multitech Conduit device [16] as the gateway. This is a configurable and scalable Internet gateway for industrial IoT applications where LoRa is used for the local wireless network. The gateway is equipped with an ARM9 processor having a 32-bit ARM and 16 bit thumb instruction set, 16K data cache, 256 MB flash memory and 128$\times$16MB DDR RAM. This runs on an enhanced closed source embedded Linux platform. We use the gateway as a LoRa packet forwarder. The gateway listens to one sub-band at a time, and therefore, a gateway can listen to eight channels simultaneously.

To configuring the Gateway, first we connect it to a computer via the Ethernet port. We set the gateway as a DHCP network via WAN. Finally, we connect it to a WiFi access point via Ethernet. In order to program it, we connect a computer to the same access point and remotely log in to the gateway via secure shell *ssh*. To enable the packet forwarder, we run a script which also logs the packet information on the device. The setup is shown in Figure 2(b).

3.3 Configuring the Server

For the application server, we use a free and open server called the LORIOT [17]. LORIOT is a cloud based LoRaWAN network server. This server platform contains both the network and the application server which are required to setup a LoRaWAN. The platform provides APIs for IoT applications to access the data streams from the end nodes. We use a community network account which has a limit of 1 gateway and 10 nodes. Because of the free community account, we faced some limitations that made the application at the server end unreliable in terms of real-time display of packets, although the gateways were receiving them in real-time. For this reason, we rely upon the packet information logged in the gateway.

4 Experimental Setup

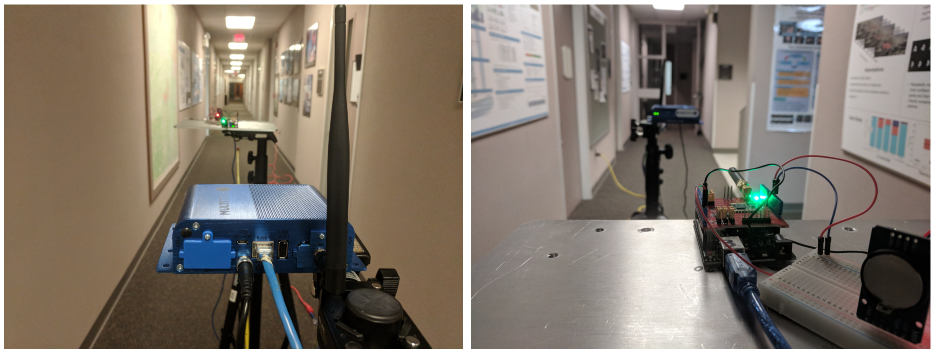
In this section, we describe the environment for our experiment. We consider two scenarios for our analysis. Line of sight (LoS) and non-line of sight.

4.1 Line of Sight

The first scenario is in Line of Sight. In this scenario, we perform the experiment in a long corridor. We set up the transmitter in one end of the corridor and moved the receiver to different distances. Figure 3 shows our experimental setup for line of sight.

4.2 Non-Line of Sight

In this scenario, we placed the transmitter (star in Figure 4) in a room (SN 264) and placed the receiver in the adjacent room (SN 232) as shown in Figure 4. Here, the distance from the transmitter to the common wall was 3.5m. To make the scenario a bit more complex we divided the room with the receiver into two sections using a metal board (orange line in Figure 4). This metal board was situated at 7 meters from the transmitter. Like previous scenario, we kept the transmitter static at a point and moved the receiver around.



(a) (b)

Figure 3: Setup for Line of Sight

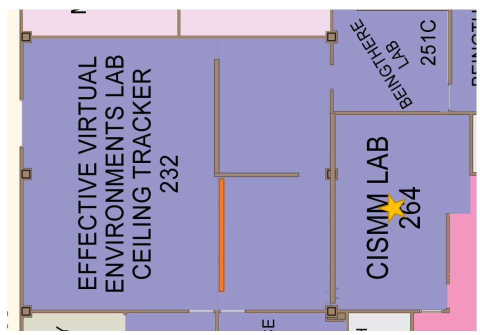


Figure 4: Setup for NLoS.

5 Stability Comparison of LoRa

In this section we compare the stability of the RSSI of LoRa with other RF signal used for indoor localization (e.g. Bluetooth, Bluetooth Low Energy, WiFi). Due to the popularity of WiFi in indoor localization and the low power consumption of Bluetooth Low Energy (BLE), we choose this as our baselines for comparison. In Figure 5, the variance of LoRa is much less than both BLE and WiFi. This stability is the result of the fact that LoRa performs in the sub-gigahertz band. This allows Lora to have higher penetration ability and lower multipath compared to the other two RF signals.

In Figure 6, the mean RSSI, median RSSI and mode RSSI of multiple samples in different distances are present. For mean and median values LoRa and WiFi shows similar behaviours but for mode RSSI WiFi does not show similar behaviour. This means that most of the samples are not valid. Whereas the similar behaviour among mean RSSI, median RSSi and mode RSSI of LoRa proves its consistancy.

We also observed that people walking between the receiver and transmitter

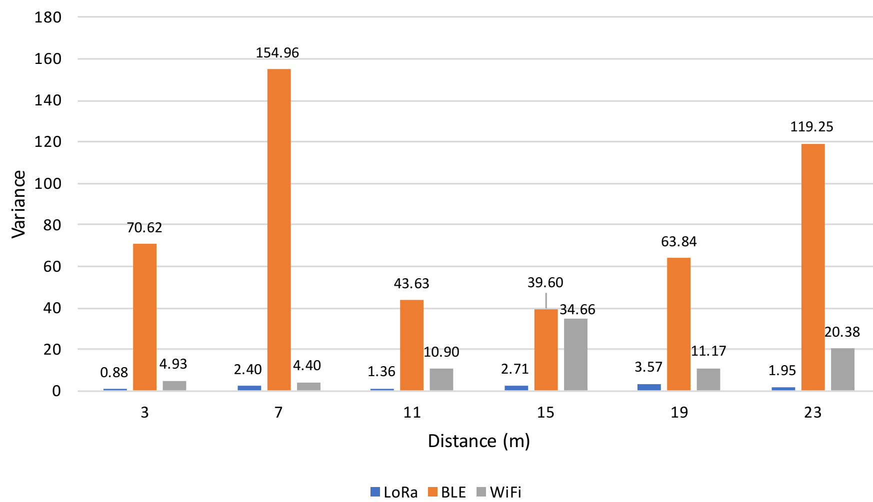


Figure 5: Comparison of variance of RSSI among LoRa, BLE and WiFi

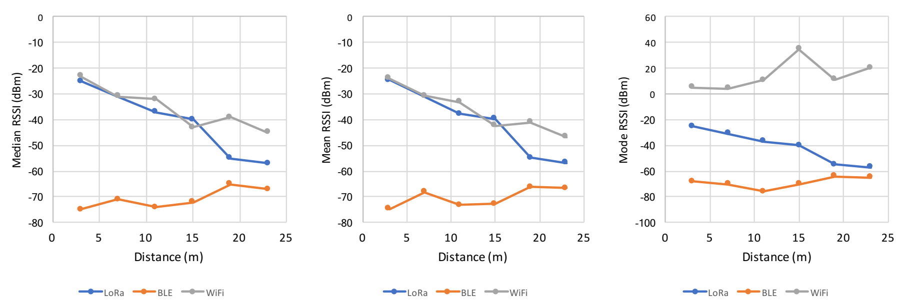


Figure 6: Comparison between mean, mode and median RSSI of multiple samples in different distances.

does not change the RSSI much in LoRa. While measuring data for 7 meters distance, we allowed people to walk between the transmitters and receivers. The BLE RSSI varied most whereas the LoRa RSSI was quite stable.

6 Ranging with LoRa

The most important step of localizing using techniques like trilateration is ranging or finding the distance between the receiver and the transmitter. In this section, we observer the behaviour of LoRa RSSI with distance. We consider two scenarios, line of sight (LoS) and non-line of sight (NLoS) which are described in previous section.

6.1 Line of Sight

In Figure 7, we see the relationship between the RSSI of LoRa and the distance. We show both raw and filtered data. For filtering the data, we use Kalman filter due to its popularity in filtering the noise from RF signals.

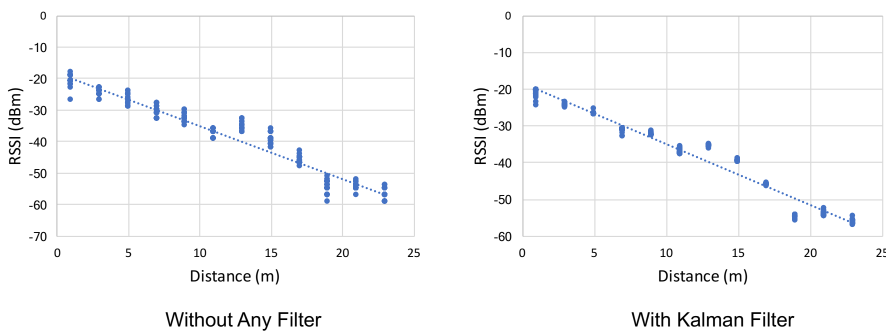


Figure 7: RSSI vs Distance in LoS

We used Least Square Error Linear Regression to calculate the distance from RSSI. We used 50% data to calculate the coefficient values with 95% confidence and 0.94 R-Square value. Then we used this values to calculate the estimated distance for all the collected data including both LoS and NLoS.

In Figure 8, we compare the estimated distance and actual distance for both raw and filtered data. The mean error is 1.19m and 1.09m respectively. It is very prominent that filtering the data does not improve the accuracy much. This happens due to the stability of the LoRa RSSI as mentioned in the earlier section.

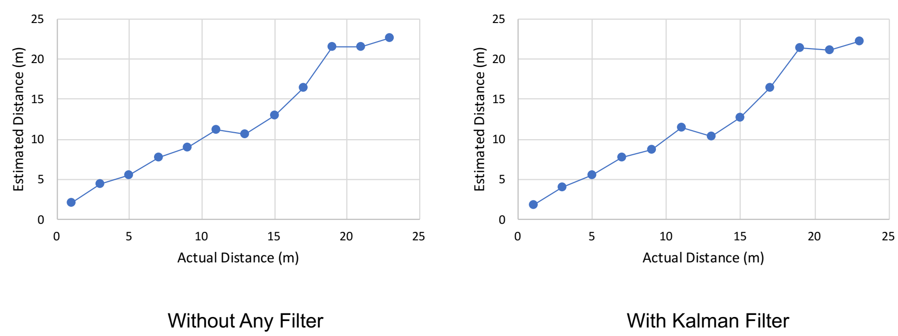


Figure 8: Estimated distance vs actual distance in LoS

6.2 Non-Line of Sight

In Figure 9, the relation between RSSI and distance is shown. It is evident that the variance in NLoS is higher than the one in NLoS. Even though it looks like that applying Kalman filter removes the improves data a lot we can see from Figure 10 that the estimated distances are similar. As mentioned before, we used the coefficients from the LoS linear regression model. Even though the environment has completely changed, we achieved mean error of 1.72m and 1.53m for raw and filtered data respectively. This shows the generality of the model and the independence of LoRa from the environmental changes.

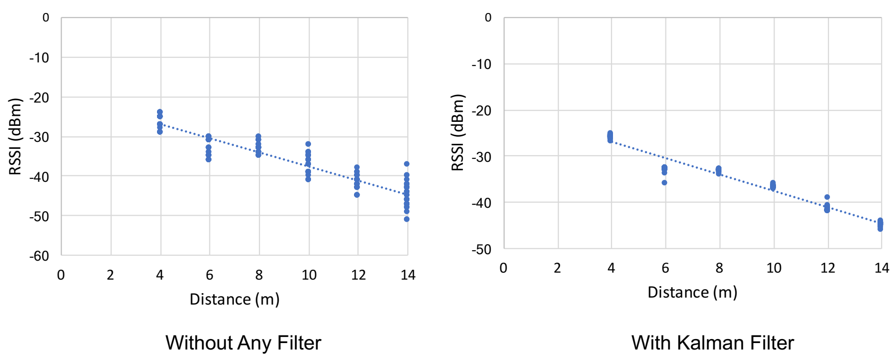


Figure 9: RSSI vs Distance in NLoS

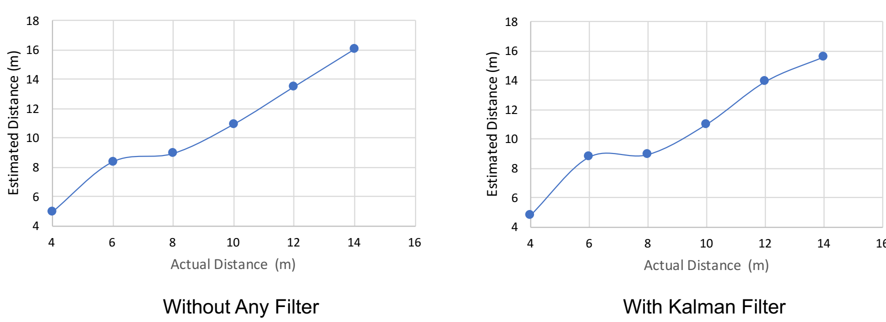


Figure 10: Estimated distance vs actual distance in NLoS

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