LoRaIn: Making a Case for LoRa in Indoor Localization

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***Abstract*—In this paper, we analyze the feasibility of using *LoRa*, an emerging low-power wide-area networking technology, in indoor localization. We define seven criteria upon which a wireless technology's prospect as an indoor localization system depends largely. For comparison, we take two other popular wireless technologies (BLE and WiFi) that have been previously proposed in many modern indoor localization systems. We deploy these three technologies in multiple line-of-sight and non-line-of-sight indoor scenarios including corridors, open spaces, spaces with a varying number of walls, and across floors of multi-storied buildings. Considering the coverage, stability and regularity of signals, accuracy of localization, responsiveness, power, and cost—we conclude that LoRa is a feasible choice for indoor localization solution, especially in wide and tall indoor environments like warehouses and multi-storied buildings.**

I. INTRODUCTION

The recent emergence of a variety of low-bandwidth, low-power, and long-range wireless wide-area networks (LPWANs) such as LoRa, SigFox, and NB-IoT is redefining the IoT revolution. Among these competing technologies, LoRa [2] has been the most popular of all LPWAN protocols that exist today. LoRa is a low-cost sub-GHz radio technology that has a transmission range of up to 9 miles in line-of-sight (around 1.5 miles in non-line-of-sight), lasts up to 10 years on a coin-cell battery, and supports up to 50 Kbps of communication bandwidth. Applications of LoRa include smart metering, environment monitoring, road traffic monitoring, facility management, smart parking, street lighting, vehicle tracking, waste management, and precision agriculture.

Although LoRa is an enormous success in many outdoor applications, its prospect in indoor scenarios remains unexplored. In today's indoor IoT ecosystem, we observe mainly a handful of wireless technologies such as Bluetooth Low Energy (BLE) and WiFi; and occasionally, ANT, Zigbee, and other proprietary communication protocols.

We envision that in future smart buildings, LoRa will be used in conjunction with other existing short-range wireless communication technologies to improve their energy-efficiency. LoRa will help reduce energy waste in sizable buildings in two main ways. First, it will be used as a long-range communication protocol to efficiently control energy-consuming building infrastructure (e.g., elevator, lighting, fire safety), and second, it will be used to localize and track humans and mobile nodes (e.g., service or surveillance robot) to infer the occupancy level and space usage to be able to control HVAC systems. Due to their long-range and penetration capability, these goals can be achieved with fewer transceivers and at a much lower deployment & maintenance cost.

Of particular interest to us in this paper is the ability of a pair of LoRa radios to estimate the range (i.e., the straight-line physical distance) between them. If successful, this becomes significant, especially in indoor scenarios, as LoRa potentially overcomes one of the major issues with existing indoor localization systems – which is the limited coverage of radio transceivers due to the presence of walls, ceilings, and other moving and non-moving obstacles. A single node in a LoRa-based indoor localization system can provide wireless coverage to an eight-story building. It will significantly lower the cost (per unit area) of installation and maintenance of an indoor localization infrastructure.

The problem of indoor localization has been extensively studied for wireless protocols such as BLE [6] and WiFi [8]. However, other than online articles on LoRa's prospect on outdoor geo-location services and a fingerprinting-based outdoor localization approach that uses a different LPWAN protocol [7], there has been no significant effort in considering LoRa as an alternative to BLE or WiFi-based indoor localization systems. According to LinkLabs the low direct path energy due to low power and the multipath correlation resolution due to lower bandwidth makes LoRa unsuitable for localization [1]. However, the penetrability of LoRa through the wall and the presence of multiple penetrable walls in indoor scenarios has not been taken into account. To fill this void, we perform an extensive empirical study to analyze the feasibility of LoRa for indoor localization. Specifically, we study the *ranging* problem, where the goal is to estimate the straight-line distance between a transmitter and a receiver , which is a key step in many localization systems [9], [10].

To establish a framework for our study, we define seven primary criteria that determine the suitability of wireless technology in indoor localization. For comparison, we consider BLE and WiFi that have been previously proposed in many recent [6], [8] indoor localization systems. We conduct thorough experiments in multiple line-of-sight and non-line-of-sight indoor scenarios including corridors, open spaces, spaces with a different number of walls, and across floors of multi-storied buildings. All three technologies (LoRa, BLE, and WiFi) are empirically studied in these environments in light of the performance criteria.

Our experiments reveal that LoRa is more stable than both WiFi and BLE, and it is also more resilient to indoor

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environmental artifacts and randomness such as the presence of walls, ceiling, and moving and non-moving obstacles.LoRa has a lower operating frequency than other protocols (e.g. BLE, WiFi) which increases the penetrability of LoRa through objects. Moreover, LoRa uses Chirp Spread Spectrum (CSS) modulation which has lower multipath effect with less reflection, refraction, and scattering. The higher penetrability and lower multipath effect introduce more stability making LoRa a better choice for indoor localization. Previous work on real-time LoRa [4] ensures the usability of LoRa for localization. Overall, LoRa achieves a mean localization error of 0.76m–1.19m and 0.71m–3.72m in line-of-sight and non-line-of-sight scenarios, respectively, when a simple algorithm is used to map unprocessed RSSI measurements to distances.

II. IMPLEMENTATION

We briefly describe the setups of LoRa, BLE, and WiFi and the environments that we use in our empirical study.

A. System Setup

We develop a LoRa node by interfacing a LoRa radio shield transceiver with an Arduino Uno. We modify an open source software library to develop a program that transmits beacon signals at a predefined interval. We use a Multitech Conduit device as the LoRa gateway which is a configurable and scalable Industrial LoRa gateway. Since Multitech gateway is costly and we need more than one gateways in our experiments, we develop custom LoRa gateways by interfacing a LoRa radio shield with a Raspberry Pi 3 Model B. Unlike the Multitech; these gateways are not capable of simultaneously listening to multiple channels. As BLE transmitters, we use two types of peripheral devices – LightBlue Bean and STM32F4 microcontroller with a nRF52 BLE module. As BLE receivers, we use Ubertooth One and Nexus 5. In WiFi experiments, we use a Linksys WRT310N router and a laptop.

B. Study Environments

We conduct experiments in four indoor scenarios which include both line-of-sight and non-line-of-sight setups. We choose a long corridor (23m) and a large open room (25m×23m) in our campus buildings. We consider both single floor (25.29m with four rooms of different sizes) and multiple floor (four and eight-story buildings) non-line-of-sight scenarios. All experiments are conducted during regular office hours, and we experience heavy traffic. At each position, we record the communication statistics of the transmitter periodically sends a beacon message to the receiver for 2 minutes.

III. RESULTS

In order to analyze LoRa's potential for indoor localization, we evaluate its performance concerning seven metrics mentioned in Table I. Some of these metrics have previously been introduced in [3]. We compare its performance with BLE and WiFi.

A. Wireless Coverage

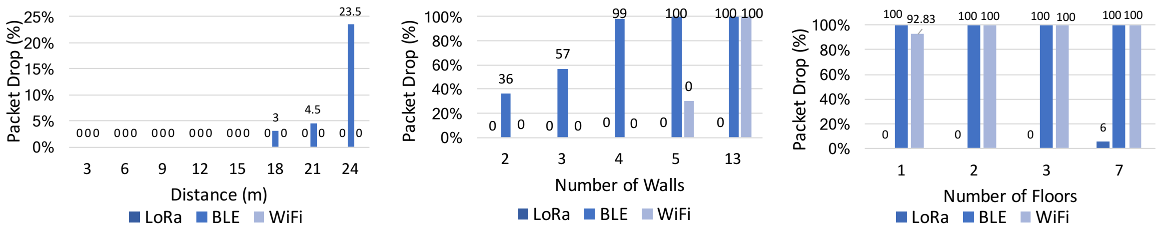
The coverage of wireless technology plays an essential role in reducing the overhead of a localization system. Lower coverage contributes to the burden of setting up additional infrastructure such as a large number of access points. In this experiment, we compare the coverage of LoRa, WiFi and BLE in different scenarios mentioned in Section II. We define the coverage as the area where there is less than 10% packet loss. We choose this as our metric rather than using only signal presence to make sure that there is a reliable communication in the coverage area. Figure 1 shows the packet drop rate for the three wireless technologies in different scenarios.

- Figure 1(a): We measure the packet drop at different distances between the transmitter and the receiver in an open room containing obstacles like furniture and people. When the range is less than 18m, all three protocols manage to send all the packets. However, for longer distance, BLE starts to drop packets due to its lower transmission power than WiFi and a poor penetration capability when compared to LoRa. We also measure the packet drop with the longest indoor distance available to us (75m and non-line-of-sight) and experiences no packet drop for LoRa.
- Figure 1(b): We show the percentage of packets dropped for LoRa, WiFi and BLE for a different number of walls between the transmitter and the receiver. Since LoRa operates in the sub-GHz band (lower frequency than WiFi and BLE), it has more penetration capability. Thus, it shows better performance and incurs no packet loss even when there are thirteen walls between the transmitter and the receiver.
- Figure 1(c): We analyze packet drop in a multi-floor scenario. The combination of lower transmission power and a lower penetration capability makes BLE the worst choice. Although WiFi has a higher transmission power than BLE, it manages to send only 10% packets to the next floor. LoRa, on the other hand, transmits all the packets successfully across three stories. We repeat this experiment in an eight-story building, and LoRa drops only 6% packets on average when there are seven floors between the transmitter and the receiver.

B. Stability of Received Signal

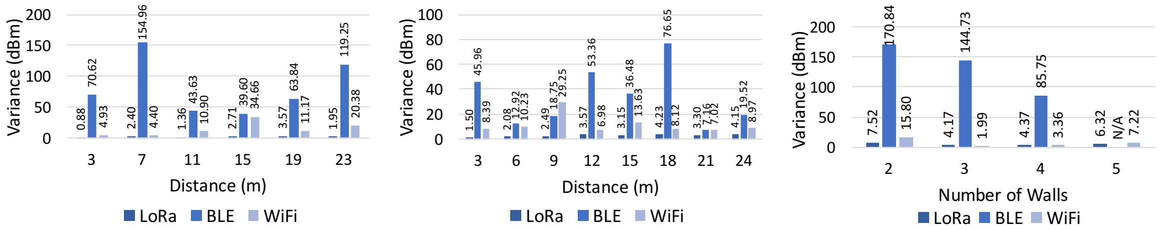
In this section, we analyze the stability of LoRa, BLE and WiFi's received signal strengths. Stability of the received signal indicates higher adaptability to the change of environment and generalized localization model. We use the variance of RSSI at the receiver end as a metric for stability. The lower the variance leads to a stable signal and better localization.

- Figure 2(a): First, we analyze the stability of RSSI in the long corridor scenario. As LoRa operates in the sub-GHz band, it has a higher penetration capability and less multipath effect than BLE and WiFi. LoRa shows the least variance in RSSI (maximum 3.57dBm) compared to BLE (maximum 154.96dBm) and WiFi (maximum 70.62). This is a significant finding as it opens up the possibility of a simple RSSI-based ranging solution for LoRa, which is not practical for BLE and WiFi for their unstable signals at different locations.
- Figure 2(b): Next, we measure the variance of RSSI for the



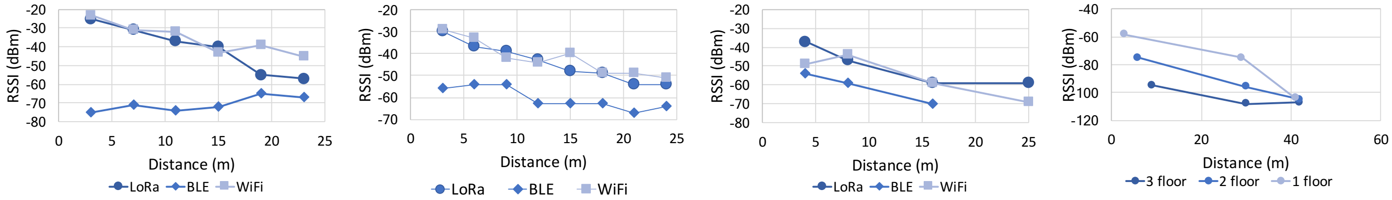
(a) Line-of-sight (Open Room)
(b) Non-line-of-sight (Varying Walls)
(c) Non-line-of-sight (Multiple Floors)

Fig. 1: Packet drop of LoRa, BLE, and WiFi at different distances and scenarios. LoRa outperforms both BLE and WiFi in terms of packet drop in all line-of-sight and non-line-of-sight scenarios.



(a) Line-of-sight (Long Corridor)
(b) Line-of-sight (Open Room)
(c) Non-line-of-sight (Varying Walls)

Fig. 2: Comparison of variance in RSSI measurements at a given position in different test environments. LoRa is more stable than BLE and WiFi in all the scenarios. On the other hand, WiFi exhibits more stability than BLE.



(a) Line-of-sight (Corridor)
(b) Line-of-sight (Open Room)
(c) Non-line-of-sight (Varying Walls)
(d) Non-line-of-sight (Multi-Floor)

Fig. 3: Path loss trend comparison of LoRa, BLE and WiFi in various scenarios. LoRa RSSI shows higher logarithmic relation with distance than both BLE and WiFi. The radio link in (d) is LoRa only.

open room scenario. The variances of both LoRa (4.32 dBm) and WiFi (76.65 dBm) increase, but the increase for LoRa is less than one dBm. This result reconfirms that LoRa has better stability when compared to the other two.

- Figure 2(c): We measure the stability of LoRa, WiFi and BLE in the non-line-of-sight scenario for varying number of walls between the transmitter and the receiver. LoRa has lower variance than BLE and WiFi.
- In the multi-floor building, LoRa shows a maximum variance of 8.55 dBm. We do not report the other two protocols as they are not accessible from different floors.

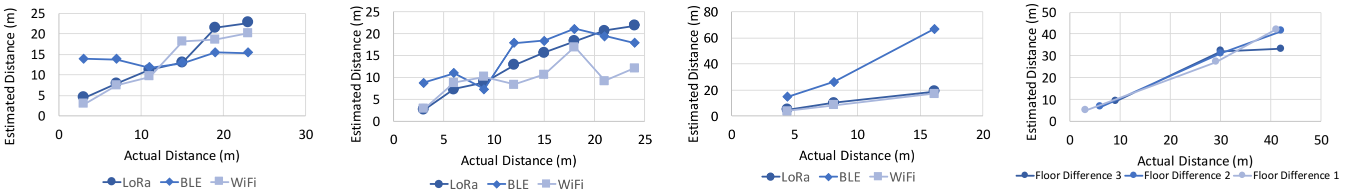
C. Path Loss Trend

We measure the RSSI values at different distances and fit a logarithmic curve (following the log-distance path-loss model) to model the relationship between distance and RSSI. We use the R^2 score as a measure of goodness of fit. A better fit means the technology is more suitable for estimating distances using RSSI-based localization algorithms.

Figure 3(a)–3(d): We plot the trend in RSSI measurements for each of the three technologies for each of the four test scenarios. We make a few interesting observations in these plots. First, LoRa maintains a regular trend in all four cases. Second, BLE is hugely unreliable as its values fluctuate a lot. Note that this experiment is performed in a non-isolated area and human activities were not limited. This caused high fluctuation in BLE RSSI. Third, the regularity in WiFi's trend is somewhere in between BLE and LoRa. Fourth, BLE does not work after 15m. Fifth, both BLE and WiFi do not work across floors. LoRa has the best goodness of fit (85%–96%) in all cases, whereas BLE and WiFi achieve fitness values of 55%–79% and 86%–91%, respectively.

D. Localization Accuracy

We analyze the accuracy of ranging for LoRa, BLE, and WiFi. (Figures 4(a)–4(d)): To obtain the range, we use least



(a) Line-of-sight (Corridor) (b) Line-of-sight (Open Room) (c) Non-line-of-sight (Varying Walls) (d) Non-line-of-sight (Multiple Floors)

Fig. 4: Both LoRa and WiFi perform better in estimating distance than BLE. However, WiFi shows maximum error of 4.06m whereas LoRa has maximum error of 3.72m. The radio link in (d) is LoRa only.

TABLE I: Comparison of LoRa, BLE, and WiFi for Indoor Localization

Performance Metric	LoRa	WiFi	BLE	Performance
Wireless Coverage	$\leq$ 8 Floor & $\geq$75m (NLoS)	<2 Floor & <29m (NLoS)	1 Floor & >10m (NLoS)	LoRa > WiFi > BLE
Stability of Received Signal	0.88-7.52 dBm	1.36-20.38 dBm	18.75-170.84 dBm	LoRa > WiFi > BLE
Path Loss Trend	0.85-0.96	0.79-0.86	0.91-0.55	LoRa > WiFi > BLE
Localization Accuracy	0.76m-3.72m	0.52m-4.06m	1.53m-26.46m	WiFi > LoRa > BLE
Responsiveness & Data Rate	50 kbps	100-250 Mbps	1Mbps	WiFi > BLE > LoRa
Power Consumption	20mA	120mA	24mA	LoRa > BLE > WiFi
Cost	$450	$800	$1040	LoRa > WiFi > BLE

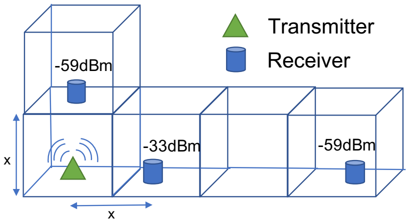


Fig. 5: The effect of denser roof material and omnidirectional antenna on different floors.

square error polynomial regression [5] to map distances to the corresponding RSSI measurements. The estimated distances are then compared against the ground-truth distances to obtain the ranging error.

In the first three test environments, LoRa, BLE, and WiFi show localization errors of 0.76%–1.72%, 4.6%–26.5%, and 0.52%–4.1%, respectively. In the fourth scenario, we show LoRa's ranging performance for different values of floor differences (i.e., the number of floors between the transmitter and the receiver). Even in this extreme case, where BLE and WiFi do not work at all, LoRa's ranging error is within the range of 0.71m–3.72m.

Note that in single floor scenarios, a fixed RSSI value ideally maps to points on a circular perimeter around a transmitter. This model can be extended to a multi-floor case by considering a sphere instead of a circle. However, due to the presence of the ceiling, which is usually made of different and stronger material than the wall, and the omnidirectional antenna (donut shaped radio transmission model) the model becomes a deformed ellipsoid. Whenever the signal penetrates the ceiling, there is a change in the spherical signal propagation model. Figure 5 shows different RSSI for the same distance when the obstacle changes from wall to ceiling. By considering this phenomenon, the path loss model can be improved. This paper, however, does not address this problem and we leave it as future work.

After the ranges are calculated existing localization techniques, e.g. trilateration can be applied. However, in this paper, we focused on the ranging accuracy alone.

IV. CONCLUSION

This paper studies the feasibility of using LoRa for indoor localization. We conduct experiments in multiple line-of-sight and non-line-of-sight scenarios and quantify the performance of LoRa as well as two other popular wireless protocols (BLE and WiFi). We summarize our findings in Table I and conclude that LoRa is the best choice for indoor localization for large spaces and multi-storied buildings.

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