LORA in a Campus: Reliability and Stability Testing

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Abstract: Long Range (LoRa) Technology offers robust wireless solutions for data collection and communication in smart buildings and smart cities by providing superior performance as a solution for the Internet of Things infrastructure. Its four powerful parameters usually govern the communication performance of LoRa; the transmit power, Spreading Factor (SF), Code Rate (CR), and the Bandwidth (BW). This work introduces a comprehensive study of LoRa's behavior and the role of the abovementioned parameters based on experimental validation of the various performance metrics of LoRa. LoRa is tested to evaluate its reliability and stability in reality, where the different environment is adopted in Electrical Engineering Technical College in Baghdad, Iraq. In terms of LoRa reliability, the results show an acceptable Mean Absolute Error (MAE) equals to 11.33dB when comparing reference and experimental LoRa sensitivity for all SF values. Moreover, 18% of packet loss has resulted from a heavy fading environment with minimal power and SF. On the other hand, LoRa sensitivity test shows that the variance calculated for 200 RSS samples in a heavy fading condition equals 29.9064. Both tests quantify the efficiency of LoRa in such a harsh environment and pave the way for future LoRa applications implementation.

1. Introduction

Smart cities have attracted many concerns due to the growing connectivity between sensors and devices and further intelligently processes. Thus smart cities are an interesting subject for researchers, where different conditions parameters and energy consumption are sensed in real-time. The development of (IoT) technology helps smart cities ensure good functionality and smart operation [1]. There has been an overwhelming commitment to design and deploy IoT applications for more than a decade, with economic sectors varying from smart building to intelligent measuring and grid, which have low costs and easily deployed IoT devices [2]. IoT systems are used as an inexpensive way to track projects, such as traffic surveillance, air pollution surveillance, or parking in crowded metropolitan environments. New technology rollout trends may be a mutual access network, where multiple networks may use a similar platform to build new IoT services [2]. The IoT network infrastructure needs to span a large range without depending on inefficient cellular networks. A wide area low-power network (LPWAN) is a suitable solution. LPWAN is a form of a wireless network optimized for long-range, low-bitrate, where end devices may connect with access points over long distances, thus consume less energy [3]. LPWANs are presently being explored to enable low-energy activity in a wide geographic field. Consequently, industry attention is turned to new technology that satisfies such requirements and materialized by Long Range (LoRa).

The key distinction between "Internets” besides "Internet of Things” (IoT) is that "fewer of anything” is accessible in the IoT on an identified device or network device: less bandwidth, low processing energy, and low memory [11]. Either because "things" are powered by batteries that improve lifetime is importance or because their deployment density is supposed to be huge. LPWAN should be the IoT that provides a (very) wide area of radio via base stations and controls transmission rates, duty cycle, and...
transmission energy [11]. LoRa is one such protocol for LPWAN. LoRa proved its powerful performance, especially at activities where there are no resources accessible to end devices (e.g., driven by batteries). The long-range and low-power character of the LoRa module renders it an applicant motivating candidate for intelligent technologies in the civil infrastructure and industrial applications (for example, health surveillance, smart metering, and environmental monitoring.) [4].

It is a genuinely wide amount of LPWAN applications that can benefit from utilizing LoRa technology. For example, smart monitoring applications, civil infrastructure control. Although LPWANs have much in common with conventional wireless sensor networks (WSNs), there are a few vital distinctions in network and end device requirements [5]. The first and most important distinction is that, in contrast to traditional WSNs that typically employ mesh topology, state-of-the-art LPWAN technologies involve gateways to support a finishing unit. The devices communicate directly with one or more gateways [5]. A single gateway's coverage area can differ, depending on the hardware, from hundreds of meters to tens of kilometers, and may involve a huge number of end devices. In recent years, LPWAN developments in the media have gained much interest because of massive private sector investments [12].

1.1. LoRa technology

The conventional telecommunications industry still moves towards IoT assisted by new LPWAN technologies. LoRa is Semtech’s modern development of the spectrum array and is one of LPWAN’s most exciting developments [10]. As mentioned above, LoRa is a wireless modulation used to establish a long-range communication link. Moreover, this technology is designed to be used in long-lived battery-powered applications with extremely significant energy usage. LoRaWAN protocol works in a basic star topology, which is currently the most widely usable topology and customized by Semtech [10].

LoRa is running on the sub-1 GHz spectrum, LoRa frequencies vary according to the area of service, the frequency used in European Union is in the range of 868 MHz, while in Asia is 433 MHz and in Americas is 915 MHz These frequency bands are unlicensed, which makes the LoRa adoption very straightforward for cities or IoT operators [2].

LoRa PHY layer modulation based on Chirp Spread Spectrum (CSS), which is commonly used for radio applications and provides the same FSK connectivity capabilities [6]. CCS is a linear pulse of wide-band frequency, which reduces or rises over time with the encoded data. LoRa PHY layer supports a Forward Error Correction (FEC) code with various code rates. When channel aggregation is used, the payload can change from 2–255 bytes, and the data rate can balance up to 50 Kbps.

LoRa offers a framework for medium access control, allowing several end devices to connect [12]. For example, LoRa gateway like Semtech SX1278 can receive multiple signals with the same carrier frequency as long as those signals are orthogonal (i.e by using different chirp rates settings). Accordingly, LoRa network performance can be increased if bandwidth and propagation variables are used dynamically for communication parameters [12].
1.2. LoRa transmission parameters and LoRa performance

Five main parameters govern LoRa performance for configuration [2].

1- Transmission Power: The Power of the transmitted signal (Ptx) may be configured from 2dBm to 20dBm. The higher Ptx contributes to a stronger received signal strength indicator (RSSI) and a lower Packet Error Rate (PER).

2- Carrier Frequency (CF): In compliance with local frequency requirements, the communication between the end-device system and a gateway is managed across different sub-GHz frequency bands. LoRa operates on sub-1 GHz and can be ranged between 137 MHz and 1020 MHz. In this work, we analyze, in particular, the 433 MHz scientific band activity in Asia (ISM).

3- Bandwidth (BW): the width of LoRa frequencies may vary between 7.8 kHz and 500 kHz. However 500 kHz, 250 kHz, and 125 kHz most common alternatives. Notice that higher BW values permit higher data rates and thus limited airtime. Lower BW values, however, allow for better sensitivity but with a lower rate of data.

4- Coding Rate (CR): To reduce the probability of errors, LoRa PHY provides a cyclic error correction scheme that improves communication at the cost of redundancy. Semtech company provides a code rate set (i.e., 4/5, 4/6, 4/7, and 4/8) [5].

5- Spreading Factor (SF): A LoRa characteristic has specified its chirp rates as Spreading Factors (SF). SF determines the chirping amount per symbol, set from 7 to 12 according to Semtech design. The larger SF, the higher sensitivity of LoRa, enables longer communication and higher airtime for the packet.

BW and SF manifest LoRa PHY properties by defining Time-on-Air of a packet \((T_a)\), is the time required for transmitting a LoRa packet and it is a function of the number of symbols per packet \(n_s\), chirp time \(T_c\), and spreading factor SF as follows in equation (1) [7]:

\[
T_a = n_s \times 2^{sf} \times T_c \quad \text{........................(1)}
\]

Since the communication bandwidth and time-resolution are inversely related, then equation (2) can be expressed as in (2) [4]:

\[
T_a = n_s \times \frac{2^{sf}}{BW} \quad \text{..........................(2)}
\]

It can be noticed that increasing SF by one divides the chirp frequency by two (as \(2^{sf}\) chirps cover the whole bandwidth), and multiply the duration of a symbol by two, also. However, it divides the bit rate by two, as one more bit will be transmitted in each symbol. Moreover, the symbol rate and the bit rate at a...
given spreading factor are proportional to the frequency bandwidth, so a doubling of the bandwidth will effectively double the transmission rate.

In addition to BW and SF, LoRa FEC rate also affects LoRa performance in terms of bit rate. CR is identical to 4/(4+n), and n equals to 1, 2, 3, 4. With this in mind, equation (3) helps to measure the valuable bitrate \( R_b \) since SF bits of information are sent per symbol [4].

\[
R_b = SF \times \frac{BW}{2^{SF}} \times CR \quad \text{………………………….. (3)}
\]

These parameters often impact the sensitivity of the decoder. In general, the improvement of bandwidth decreases receiver's sensitivity, while the rise in the SF improves the sensitivity of the receiving signals. Reducing the rate of coding will help minimize the Packet Error Rate (PER) in small interference i.e. a 4/8 code rate transmission would be more interference reactive than a 4/5 code rate signal [4].

The rest of the paper is organized as follows; Section 2 presents basic knowledge and a summary of similar studies. The introduction of the test platform and environments are given in Section 3. Finally, while the results are shared in Section 4, the evaluation and conclusion are presented in Section 5.

2. Related work

As mentioned above, LoRa is considered one of the promising IoT technologies that provide both long range connectivity and low power consumption. These significant features of LoRa are attracted the researcher’s effort to exploit LoRa in IoT networks and paved the way for establishing smart cities. In this section, some researchers' works on LoRa behavior and LoRa network performance are reviewed and discussed.

In [4], an overview of LoRa and an in-depth study of its functional elements are presented. Field experiments and simulations evaluate the performance of the physical and data link layer. The authors investigated the network's reliability in terms of data rate verse the variation of spreading factors. Based on experiment results and evaluations, it is concluded that SF has a significant impact on network performance. The larger SF, the higher sensitivity of LoRa, enables longer communication and higher airtime for the packet.

In [8], the extensive Narrowband (NB-IoT) and LoRa survey as successful system communication solutions are discussed. Unauthorized LoRa shows the advantage in terms of power and price. LoRa and NB-IoT are analyzed, and their functional gaps are explained in physical characteristics, network architecture, and MAC protocol. From the other side, employing LoRa in IoT applications was investigated in terms of Quality-of-Service (QoS) such as; power consumption & latency, wireless service & range, model implementation, and costs rest of the paper will compare the LoRa and NB-IoT in terms of these factors.
Analysis of the effect of variant LoRa physical layer parameters on tree farm environment was implemented in [3] to evaluate the efficiency of LoRa networks. Some PHY variables, SF and CR, clearly impacted LoRa network efficiency. At varying distances and PHY configurations, real data reliability was inconsistent, unlike the radios stated RSSI accuracy. This study can provide a foundation for deploying LoRa on a tree farm to implement LoRa to agriculture IoT.

LoRa indoor and outdoor efficiency for various conditions were investigated in [9]. The assessment process was based on metrics such as; packet delivery rate (PDR), RSSI, and signal-to- noise ratio (SNR). Different SF and Tx power values were tested and measured separately. The results showed that outdoor locations that didn't have a strong Fresnel Zone require high SF and high Tx power. Indoor experiments were conducted in a five-story department building as well as an underground tunnel. The analyses showed that high SF and transmitting power results in increasing PDR value. Also, tunnel measurements provided some hint that LoRa technology can be used effectively in these harsh conditions. On the other hand, it was found that RSSI and SNR had no distinctive indoor and outdoor findings.

The performance of LoRa is experimentally evaluated in a heavy multipath propagation environment. The researchers adopted two scenarios by setting up the experiment with controlled and variable interference generated using a reverberation chamber and an anechoic chamber. LoRa’s three major configurable parameters: the spreading factor, bandwidth, and code rate, are varied to quantitate LoRa's behavior under these harsh conditions. The results verify that LoRa's behavior against multipath propagation and interference is strictly determined by the three main factors values (SF, BW and CR).

In [6], a test was conducted to determine the best SF used at different distances, using ISM 925 MHz frequency band in Indonesia. Based on the calculation, SF guidelines are SF7 for best channel capacity achievement, SF8 for high throughput and long-range power balance, and SF11 for maximum range and optimum range for LoRa use.

The authors in [1] studied and analyzed LoRa's coverage and transmission efficiency in detail in order to quantify its practical application in smart buildings. The indoor scenario is adopted by deploying three LoRa receiver nodes on the same floor and eight LoRa receiver nodes on different floors in a 16 buildings. Also, the data processing terminal was located in the base of the building. The communication performance of LoRa was evaluated by changing the sending power, communication rate, payload length, and position of the wireless module.

The scalability of the LoRa wide-area network was studied and assessed in [5]. The performance of LoRa was evaluated in terms of packet received versus transmitting power and spreading factors. The findings presented that at the highest spreading factor of 12, 60% of packets are successively received from 30 km on water. On other tests assuming mobile scenarios around 40 km/h, the results showed that LoRa efficiency gets worse due to LoRa-modulated symbol's length, which reaches coherence time. However, communication is supposed to be more efficient when using lower spreading variables.

This work introduces a comprehensive study of LoRa's behavior and the role of the above mentioned parameters based on experimental validation of the various performance metrics of LoRa. LoRa is tested to evaluate its reliability and stability in reality, where the different environment is adopted. In the test applications, RSSI, and packet loss performances were observed for different LoRa parameters (Txp, SF, BW, and CR).
3. Experiments method and results

The new trends all over the world are to employ IoT applications in many governmental businesses to implements smart applications. This required establishing an efficient network infrastructure, which - offers long rang coverage, as well as low power consumption, materialized by new technology (LoRa). The education process as an important governmental sector has also witnessed the revolution of IoT. Accordingly, in this work, a real LoRa network is adopted to evaluate the new technology deployed on campus by analyzing the performance under different scenarios as will be presented.

3.1. Hardware setup

The measurement system consists of LoRa sx1278 with a 5-dBi antenna and Arduino it is an open-source electronic development board, via Arduino in order to be able to control LoRa Model's settings as depicted in figure (1), which transmits and receive the packet and PC as an interface for controlling messages received. The product specifications are illustrated in a table (1).

![Figure 1. Measurement system consists of Arduino and LoRa sx1278 with a 5-dBi antenna](image)

| Product Specifications          | 410-525 MHz     |
|---------------------------------|-----------------|
| Frequency Range                 | IPEX            |
| Antenna                         | 2-20 dBm        |
| Transmit Power                  | 6-12            |
| Spreading Factor (SF)           | 4/5, 4/6, 4/7, and 4/8 |
| Coding Rate (CR)                | 433MHz:         |
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Power (Typical Values)

|                | TX:93mA RX:12.15mA |
|----------------|---------------------|
| TX:           470MHZ: |
| Standby       TX:97mA RX:12.15mA |
|               Standby:1.5mA |
|                |

Bandwidth (BW) vary between 7.8 kHz and 500 kHz

Power Supply 2.5~3.7V Typical 3.3V

Operating Temperature -30 ~ 85 C

3.2. Experiment setup and sites locations

Three different environments are adopted in the collage of Electrical Engineering Technical College in Baghdad, Iraq. In all the three scenarios, the transmitter was fixed on the first floor of the scientific engineering departments building and denoted by (L2X) as in figure (2). The first environment is assumed to be indoor and at the same floor, where two receivers at (L2Da, L2Db) are located at LOS and NLOS with the transmitter. The second indoor environment is adopted to test LoRa’s behavior where the transmitter is located at 2nd floor (L2X), while two receivers are located on the different floors (L1A, L1B) as shown in fig (2). Finally, to introduce a comprehensive overview of LoRa’s behavior all over the campus environment, indoor to outdoor test is suggested. From this perspective, two receivers are located at (G1D, G2D) to conduct the experimental tests. Figure (3), depicts the location of Tx and Rx for the three scenarios.
3.3. Metric

To evaluate LoRa Technology dependence on RSSI and Packet loss in the practical experiment. Received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal.
Packet loss (PL) occurs when one or more data traveling packets across a network fail to reach their destination. Packet loss is caused by errors in data transmission, typically across wireless networks or by network congestion. Packet loss is measured as a percentage of packets lost for packets sent.

4. Experiment results and discussion

4.1. Reliability in terms of RSSI and packet delivery ratio

4.1.1. Comparison between experimental and reference LoRa sensitivity

Figure (4) depicts the comparison results conducted between experimental and reference LoRa sensitivity for BW equals 250 kHz. The minimum RSS measured by Semtech is dependent as reference data, which is compared to the measured minimum RSS at the campus for various SF values in order to validate the adopted model (Sx1278 Ra-02) behavior. An acceptable Mean Absolute Error (MAE) equals 11.33dB is achieved between reference and experimental sensitivity for all SF.

![Figure 4. Comparison between experimental and reference LoRa sensitivity](image)

4.1.2. RSSI measurement vs. Effective parameters (sf, BW, PTx), different scenarios are adopted; indoor (same and different floor), indoor to outdoor, outdoor (fixed CR=5)

In this part of the experiment, 18 cases are adopted from different settings as shown in Table (2).

| Setting | SF | BW(kHz) | CR | Ptx(dBm) |
|---------|----|---------|----|----------|
| S1      | 7  | 125     | 5  | 6        |
| S2      | 9  | 125     | 5  | 6        |
| S3      | 11 | 125     | 5  | 6        |
| S4      | 7  | 125     | 5  | 13       |
| S5      | 9  | 125     | 5  | 13       |
| S6      | 11 | 125     | 5  | 13       |
Generally speaking, like SF and or Tx power are increased, the received signal is also increased. The maximum RSSI measured at all locations is gained with setting 15 (S15), where the power and the spreading factors are maximum. The significant RSSI value is measured at L2Da, which is located in LOS with the transmitter and equals -45 dBm. On the contrary, the minimum RSSI value equals -93 dBm is measured at L2Db as well as G1D. In this work, the effect of BW is also presented and analyzed. Figure (5a, 5b, and 5c) in all scenarios show that the effect of BW is increased; the received signal is increased from 1-2 dBm.
Figure 5a. RSSI measurement vs. Effective parameters in the same floor

![Graph showing RSSI measurement vs. Effective parameters in the same floor.]

Figure 5b. RSSI measurement vs. Effective parameters in the 2nd floor

![Graph showing RSSI measurement vs. Effective parameters in the 2nd floor.]

Figure 5c. RSSI measurement vs. Effective parameters in the indoor to outdoor

![Graph showing RSSI measurement vs. Effective parameters in the indoor to outdoor.]

4.1.3. Packet loss measurement vs. Effective parameters (sf, BW, CR, PTx), different scenarios are adopted; indoor (same and different floor), indoor to outdoor, outdoor (fixed PTx=6dBm).

Packet Loss measurement vs. Effective parameters (sf, BW, CR, PTx). PTx is tuned to be 6dBm during this experiment while varying SF and code rate (CR). The experimental results depicted by the figure (6a, 6b and 6c) verify the reliability of LoRa, where the percentage of packet loss almost equals zero over different campus locations. Even in the worst case, the losses does not exceed 10% as in L1Da. Also, it can be obviously shown, as the code rate decrease, better performance is obtained in terms of losses. For example, in the same floor scenario, S8 has a code rate (4/8) and achieves 3% losses, But at
the same point using code rate (4/5) achieves 0% losses. As SF is increased, the packet losses are decreased. For example, on the 2nd floor, S1 achieves 5% losses, but using S2 setting achieves 3% losses. In all scenarios, BW is not affecting packet losses, as shown in Figure (6a, 6b, and 6c).

![Figure 6a. Packet loss measurement vs. Effective parameters indoor same floor](image1)

![Figure 6b. Packet loss measurement vs. Effective parameters indoor 2nd floor](image2)

![Figure 6c. Packet loss measurement vs. Effective parameters indoor to outdoor](image3)

4.2. Stability test in term of RSSI & pl VS. FADING

4.2.1. Effect of fading on packet loss
This experiment is conducted in an indoor environment, where the receiver is located at the end of a corridor in LOS with transmitter. LoRa stability is tested in terms of packet loss against fading produced by people’s dynamic motion in the corridor. Three fading cases are adopted; heavy fading (when the corridor is densely crowded), moderate fading (less crowded corridor) and low fading (empty corridor and the building structure is assumed to be the only contributor of the multipath) as represented by a figure (7).

![Figure 7. Effect of fading](image)

LoRa parameters are set as; $S_f$ 7, $B_W$ 125 KHz and $T_x$ power 2dBm. LoRa parameters are determined in such a way to test LoRa efficiency with these parameters minimum values. The test results as in figure (8) represent 18% packet loss in the case of heavy fading, while 5.25% and 0% is achieved in the case of moderate and low fading respectively.
4.2.2. Effect of fading on RSSI variation vs. Distance

For the same setting in the previous test, the effect of fading on RSSI variation with distance is conducted for low and heavy fading. Three points are considered to collect data: near field test point, at the middle distance between the transmitter and the receiver. The third point is located at the end of the corridor which is 23m in length. About 200 samples of RSSI is collected at each point and statistically analyzed based on power spectral density function using MatLab software as in figures (9a and 9b). It can recognize that, the effect of distance inversely on the signal strength. Moreover, fading is obvious in distributing the signal resulting in decreasing the meanwhile increasing the variance. In the case of high fading, the variance values are higher than low fading, and also the values of RSSI decrease with distance and load.

**Figure 8.** Effect of dynamic fading on packet loss
5. Conclusion

In the IoT era, the new trends are turned to new technology that satisfies smart application requirements. LoRa, with its powerful specifications, is considered a promising solution. In this work, LoRa in real campus environments is tested to evaluate its performance verse different SF, CR, BW, Tx power values. The evaluation metrics, Packet loss and RSSI were considered to quantify LoRa's reliability and stability. This research shows how PHY factors and distances have affect LoRa's performance in a different manner. SF and CR expectedly affect LoRa performance, but bandwidth does not change performance significantly. When fading cases are adopted (heavy fading, moderate fading and low fading), the results show that LoRa technology may be considered stable, where an acceptable 18% of packet loss results from the worst heavy fading case. Moreover, LoRa reliability is verified by the low value of MAE between experiment and reference test values.
6. References

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