Performance Research of LoRa at High Transmission Rate

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Abstract. In recent years, most of Lora's research in the field of wireless technology has focused on the experimental exploration of its stability and communication range, without much attention to the impact of the actual transmission rate. However, as the length of Lora transmission load increases, the growth rate of low-speed transmission time is faster than that of high-speed transmission time. Therefore, it means that for the transmission of large capacity packets, the lower the transmission rate, the more time it takes; the longer the time, the more power it consumes. In this paper, the SNR, RSSI and packet loss rate of Lora over 3 Kbps in urban area and mountainous area were tested and explored respectively, and the RSSI curve with distance in different environment was obtained. The test results show that the actual communication distance of Lora with high transmission rate of 21875 bps in line of sight environment can reach 3 Km, packet loss rate is less than 1%. In addition, the influence of Lora on communication quality under different occlusion degrees in a certain range was tested. In the range of 500 m to 3 km, when the occlusion ratio was 0-5%, the highest speed reference value was 21875 bps, 5-10% reference value was 6250 bps, and more than 10% reference value was 3125 bps. In this paper, Lora SX1278 transceiver was used, in the same transmission of 100 KB data, the actual transmission rate is further improved by using the maximum duty cycle and improving the request response mechanism. Compared with a Lora system for image transmission, the transmission time is reduced by 81.3% and the transmission speed is increased by 4.3 times, which greatly improves the transmission efficiency of large capacity data such as image.

1. Introduction

The Internet of Things (IOT) has greatly improved our lives and created a world of wisdom for us. Low-Power Wide-Area Network (LPWAN) can meet the needs of a large number of devices connected to IOT, at the same time, it has larger coverage, lower cost and energy consumption [1]. LoRa is an emerging communication technology of LPWAN. It uses chirp spread spectrum (CSS) modulation technology, which is more resistant to interference than Frequency-shift keying (FSK) and is more suitable for long-distance data transmission [2][3]. At present, LoRa technology has been successfully applied in small data services such as meter reading, transmission of temperature information. It uses a LoRa bit rate lower than 1Kbps, and the actual duty cycle which used to send data is less than 1%[4]. The advantage of this method is to make the module sleep as much as possible, thus prolonging standby time and reducing power consumption. However, LoRa offers rates much more than 1 kbps. For example,
Semtech’s LoRa module SX1278 has a maximum encoding bit rate of 300 kbps, an effective bit rate of up to 37.5 kbps, and a sensitivity of -148 dBm [5]. The low-rate (up to 3125 bps) of LoRa at 125 KHz bandwidth is studied for image transmission [6]. However, currently there are few performance tests and studies on LoRa’s higher transmission rate (21875 bps) [7]. This paper studied the performance of LoRa (including packet loss rate, signal to noise ratio, and received signal strength indicator) using high rate for data transmission in different scenes of urban and mountains areas. We propose a novel method to improve the actual maximum transmission rate of LoRa by adopting the minimum transmission period and improving the transceiver mechanism. The test results show that the transmission rate under this method can meet the transmission task (such as image transmission) with more data.

2. Important concepts of LoRa

2.1. LoRa bit rate (BR)
LoRa bit rate is also called data rate (DR). The currently accepted LoRa bit rate calculation formula is as follows,

$$ DR = SF \times \frac{BW}{SF} \times CR $$

where, SF is the spread spectrum factor, which ranges from 6 to 12. BW is the bandwidth in the transmission band, which ranges from 7.8 to 500 KHz. We usually use three values of 125 KHz, 250 KHz and 500 KHz. CR is called coding rate, which is between 4/5 to 4/8. So we can get the range of DR from 0.018 to 37.5 kbps.

The main impact of SF: Along with the increase of SF, the number of chirps required for each LoRa symbol will increase [8]. Therefore, it extends the time that required to send the same length packets, which the time is also called time on air (ToA). The impact of BW: With the increase of BW, the chirp transmission rate will increase, but it will bring more input noises to the receiver, which will reduce the sensitivity [9].

Table 1 shows the configuration scheme for the bit rate used in the measurement.

| DR(bps) | SF | BW(KHz) | CR   |
|---------|----|---------|------|
| 21875   | 7  | 500     | 4/5  |
| 12500   | 8  | 500     | 4/5  |
| 6250    | 8  | 250     | 4/5  |
| 3125    | 8  | 125     | 4/5  |

In the LoRa Semtech SX1278 chip, the maximum available DR is 21875 bps. However, due to the influence of duty cycle, it doesn’t mean that its actual transmission rate is 21875 bps.

2.2. Transmitting Frequency and Output Power
The transmission frequency range of Lora is 137 - 1020 MHz, and there are some differences between different Lora modules. For the Semtech SX1278 transceiver, the corresponding frequency range is 137 - 525 MHz. Generally, we choose 433 MHz as its center frequency (CF) [10].

The output power affects the actual transmission distance of Lora. When BW = 500 KHz, SF = 8, CR = 4/5, the maximum transmission distance that 20 dBm can reach is greater than 17 dBm, which can cover 4 km; therefore, further improving the transmission power will help to expand the coverage of Lora [3]. In this paper, Lora SX1278 transceiver was used, and the maximum transmission power can be set to 20 dBm, which is used in subsequent experiments.

2.3. Air transmission time and Duty Cycle
ToA is the time taken by Lora to send data, its size is related to the data length and bit rate of transmission. It is convenient to get the value of the ToA by LoRa Semtech Calculator Tool. Figure 1 shows the theoretical transmission time at different bit rates and Payload length. The output power is 20 dBm, the preamble length is 8 symbols, the CF is 433 MHz, CR=4/5.
From figure 1 we can see that ToA increases along with the payload length increase, and it varies approximately linearly. The slope of the line with DR of 3125 bps is larger than that of the line with DR of 21875 bps, indicating that the growth rate of the ToA at low speed rate is faster than that at high speed rate, which means that the ToA at low speed rate is longer under the same load length. At the same payload length, the lower the DR is, the longer the ToA gets. For example, when transmitting 255 bytes of data, 12500 bps will cost 176.77 ms, but 3125 bps will cost 707.07 ms. Therefore, large capacity data is more suitable for higher transmission rate.

Duty cycle is the ratio of the ToA and transmission period. The higher duty cycle is, the higher channel utilization is, and the closer the actual transmission rate is to the set DR value. Similarly, a higher duty cycle means that the channel takes longer. The duty cycle defines the interval between two adjacent data transmissions.

3. Measurement process

3.1. Description of steps and key elements
We choosed Semtech SX1278 transceiver and STM32 chip as the transmission module of LoRa, and used FRP antenna (6 dBi gain) as the transmission antenna. The LoRa module is mounted on the ZYNQ motherboard, they were connected by a serial port (UART). The baud rate of the UART was set to 115200 bps. LoRa communicated with ZYNQ through a self-defining UART protocol. Base station and terminal equipment were the same in hardware. They were all composed of LoRa module and ZYNQ motherboard. The data packet received by the base station was saved on the ZYNQ motherboard through the UART. Recording information about each packet including the signal-to-noise ratio (SNR), received signal strength indication (RSSI), ID, and transmission time, etc. Data could be viewed by connecting to the Ethernet port on ZYNQ.

The communication between base station and terminal equipment adopts the improved request response mode: base station continuously receives the response of multiple data packets from terminal equipment after sending a request, so as to reduce the waste of air transmission time caused by multiple requests. Under this mechanism, the base station and the terminal respectively set a timeout. If continuous packet loss occurs during transmission and the packet loss time exceeds the set time, the base station will exit the receiving state until the next request is sent. As long as the terminal receives the request, it starts to continuously send data to the base station. The ToA is 100 ms at a DR of 21875 bps, It is assumed that the minimum transmission period is used, and the time required for the traditional single transmission protocol to complete a data test is 20s, while the improved transmission mechanism in this paper only needs 10s.

When the DR is 21875 bps, the terminal continuously sends the full packet data of 255 bytes. The waveform of the minimum transmission period measured by the oscilloscope is as follows:
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Figure 2. The minimum cycle of LoRa transceiver: DR=21875 bps.

In figure 2, the first occurrence of waveform represents a request command from the base station from left to right, and the second waveform represents the response of the terminal after the request is received.

| DR (bps) | Min Period (ms) | Max Duty Cycle (%) | Max Transmission Rate (bps) |
|----------|-----------------|--------------------|---------------------------|
| 21875    | 130             | 76.92              | 16826.25                  |
| 12500    | 205             | 85.37              | 10671.25                  |
| 6250     | 385             | 92.21              | 5763.13                   |
| 3125     | 735             | 95.92              | 2997.50                   |

In table 2, the maximum duty cycle of 3125 bps is larger than 21875 bps, which is due to the increase of ToA. All the experiments in this paper use the minimum cycle as the transmission period.

In addition, in order to explain the relationship between RSSI and propagation distance, the logarithmic normal model is selected as the RSSI propagation loss model of LoRa,

\[ Rssi = A - 10 \times n \times \log d \]  

Where, A is the RSSI value at 1m from the transmitting point; n is the path loss, in dBm; d is the distance from the transmitting point, in m; Rssi is the RSSI value at d from the transmitting point.

3.2. Description of steps and key elements

3.2.1. Measurement in urban areas

The measurement site was located in the southeast of Beijing University of Technology, and the time was from 7 pm to 12 pm. The devices were powered by 12 V lead-acid battery. The experiment used 430-440MHz omnidirectional FRP antenna with a gain of 6 dBi. OR is the ratio of occlusion length to total path length. The occlusion ratio (OR) is roughly calculated by the Google Maps tool. OR only has practical significance within a certain distance, and the following ORs are all within 500 m to 3 km.

During the whole experiment, the base station is located on the 7th floor (about 25m from the ground), and its southeast view is good; the terminal is always located in the southeast of the base station. The length of each packet is 255 bytes. At 1.3km and 2.7km, the terminal is located on the flyover and the other locations are on the ground. We recorded the timeout, packet loss rate (PLR), SNR and received signal strength indication (RSSI) values of high transmission rate on urban. The measurements results are as follows:
Table 3. Results of LoRa high transmission rate on urban.

| Range (km) | DR (bps) | Timeout (Y/N) | Number of Transmitted Packets | PLR (%) | Average SNR (dBm) | Average RSSI (dBm) |
|-----------|---------|---------------|-------------------------------|---------|-----------------|------------------|
| 0.50      | 21875   | N             | 1000                          | 0.10    | 3.54            | -88.53           |
|           | 12500   | N             | 1000                          | 0       | 5.13            | -87.54           |
|           | 6250    | N             | 1000                          | 0       | 9.39            | -88.31           |
|           | 3125    | N             | 200                           | 0.50    | 10.66           | -88.49           |
| 1.09 (OR:15%) | 21875     | Y         | -                             | -       | -5.14           | -101.78          |
|           | 6250    | Y             | -                             | -       | -4.50           | -104.57          |
| 1.30      | 21875   | N             | 1000                          | 0.70    | 0.75            | -93.68           |
|           | 12500   | N             | 1000                          | 0       | 1.63            | -93.41           |
|           | 6250    | N             | 800                           | 0       | 5.57            | -94.18           |
|           | 3125    | N             | 200                           | 0.50    | 7.93            | -95.06           |
| 1.70 (OR:15%) | 21875     | Y         | -                             | -       | -4.93           | -105.97          |
|           | 12500   | Y             | -                             | -       | -2.58           | -106.20          |
|           | 6250    | Y             | -                             | -       | -2.58           | -106.20          |
|           | 3125    | N             | 400                           | 1.75    | -2.58           | -106.20          |
| 2.40      | 21875   | N             | 1200                          | 1.42    | -2.91           | -98.41           |
|           | 12500   | N             | 1000                          | 0       | -1.88           | -98.12           |
|           | 6250    | N             | 1000                          | 0       | 0.80            | -97.70           |
|           | 3125    | N             | 200                           | 0       | 4.71            | -97.96           |

It can be seen from table 3 that packet loss rates of 3125 bps, 6250 bps, 12500 bps and 21875 bps are very low within 2.4 km in urban environment, indicating that higher transmission rates are available within a certain range in the city.

3.2.2. Measurement in mountains

The test sites include Fragrance Hill, Beijing and Laoshan Mountain, Qingdao. The test uses 430-440MHz omnidirectional FRP antenna with a gain of 6 dBi.

From figure 3 we can see that Base Station 1 and Base Station 2 are base stations. A, B, C, D and E are terminal positions. C is on the top of the mountain, D and E are on the back of the mountain. The experimental device consists of a base station and a terminal, powered by a 12V lead-acid battery. White indicates the base station is located at point Base Station 1, and yellow indicates the base station is located at point Base Station 2. The OR here is mountain shelter.

The measurement selected a series of points according to different distances and different occlusion ratios. Recording the transmission timeout, PLR, SNR and RSSI values of each point. The results are shown in table 4.

![Figure 3. Route map of Fragrance Hill measurement.](image)
Table 4. Results of LoRa high transmission rate in Fragrance Hill.

| Range (km) | DR (bps) | Timeout (Y/N) | Number of Transmitted Packets | PLR (%) | Average SNR (dBm) | Average RSSI (dBm) |
|------------|----------|----------------|-------------------------------|---------|-------------------|-------------------|
| 0.58       | 21875    | N              | 1000                          | 0.10    | 4.92              | -66.87            |
|            | 12500    | N              | 1000                          | 0       | 6.48              | -67.07            |
|            | 6250     | N              | 800                           | 0.13    | 11.10             | -67.79            |
|            | 3125     | N              | 400                           | 0.25    | 11.37             | -68.59            |
| 1.30       | 21875    | N              | 1200                          | 0.33    | 4.61              | -66.93            |
|            | 12500    | N              | 1000                          | 0       | 6.09              | -67.69            |
|            | 6250     | N              | 800                           | 0       | 11.06             | -68.18            |
|            | 3125     | N              | 200                           | 0.50    | 11.19             | -68.39            |
| 1.36 (OR:10%) | 21875  | Y              | -                             | -       | -                 | -                 |
|            | 12500    | Y              | -                             | -       | -                 | -                 |
|            | 6250     | Y              | -                             | -       | -5.56             | -97.81            |
|            | 3125     | Y              | -                             | -       | -0.66             | -94.83            |
| 1.39 (OR:15%) | 3125  | Y              | -                             | -       | -                 | -                 |
| 1.42 (OR:5%) | 21875  | N              | 800                           | 0       | 4.17              | -74.47            |
|            | 12500    | N              | 200                           | 0       | 4.525             | -74.85            |
|            | 6250     | N              | 200                           | 0       | 10.62             | -75.63            |
|            | 3125     | N              | 200                           | 0.50    | 11.20             | -76.85            |
| 2.74       | 21875    | N              | 1000                          | 5.10    | 0.63              | -79.99            |
|            | 12500    | N              | 1200                          | 7.70    | 1.07              | -79.30            |
|            | 6250     | N              | 1200                          | 0.75    | 11.20             | -78.28            |
|            | 3125     | N              | 200                           | 0.50    | 11.36             | -79.53            |

According to table 4, under the same transmission distance, the RSSI value of the above four speeds in Fragrance Hill is higher than that in the city.

The experimental device consists of a base station and a terminal, powered by solar energy. The antenna is 5 m above the ground and the communication equipment is two wireless intercoms. Base stations and terminals are not fixed to test transmission performance in different distances. Base station is located at the foot of the mountain when the range is 1.30 km. The results of the tests are shown in table 5.
Table 5. Results of LoRa high transmission rate in Laoshan Mountain.

| Range (km) | DR (bps) | Timeout (Y/N) | Number of Transmitted Packets | Number of Received Packets | PLR (%) | Average SNR (dBm) | Average RSSI (dBm) |
|------------|----------|---------------|-------------------------------|---------------------------|---------|------------------|-------------------|
| 0.48 (OR:5%) | 21875 N  | 2200          | 2196                          | 0.18                      | 2.36    | -95.94           |
|            | 12500 N  | 800           | 799                           | 0.13                      | 3.95    | -94.19           |
|            | 6250 N   | 600           | 600                           | 0                         | 5.56    | -94.01           |
| 0.58 (OR:3%) | 21875 N  | 1200          | 1196                          | 0.33                      | 5.08    | -77.47           |
|            | 12500 N  | 800           | 796                           | 0.50                      | 6.60    | -77.97           |
|            | 6250 N   | 400           | 398                           | 0.50                      | 11.57   | -79.09           |
| 0.79       | 21875 N  | 1000          | 999                           | 0.10                      | 5.40    | -67.58           |
|            | 12500 N  | 1000          | 1000                          | 0                         | 6.41    | -70.58           |
|            | 6250 N   | 600           | 600                           | 0                         | 12.00   | -69.92           |
|            | 3125 N   | 200           | 200                           | 0                         | 11.56   | -73.25           |
| 1.30 (OR:10%) | 21875 Y  | -             | -                             | 2.79                      | -83.87  |
|            | 12500 Y  | -             | -                             | 1.10                      | -82.94  |
|            | 6250 N   | 400           | 400                           | 0                         | 7.32    | -87.02           |
| 1.42 (OR:5%) | 21875 N  | 1000          | 999                           | 0.10                      | 4.52    | -95.05           |
|            | 6250 N   | 400           | 400                           | 0                         | 7.50    | -95.50           |
| 1.44       | 21875 N  | 1000          | 998                           | 0.20                      | 5.26    | -70.33           |
|            | 12500 N  | 1000          | 1000                          | 0                         | 6.03    | -72.23           |
|            | 6250 N   | 600           | 600                           | 0                         | 9.41    | -70.87           |
|            | 3125 N   | 200           | 200                           | 0                         | 9.91    | -71.11           |
| 2.04       | 21875 N  | 1000          | 1000                          | 0                         | 4.59    | -71.14           |
|            | 12500 N  | 1000          | 1000                          | 0                         | 6.41    | -70.58           |
|            | 6250 N   | 600           | 600                           | 0                         | 12.00   | -69.92           |
|            | 3125 N   | 200           | 200                           | 0                         | 11.56   | -73.25           |
| 2.27 (OR:5%) | 21875 N  | 1800          | 1798                          | 0.11                      | 2.60    | -95.19           |
|            | 12500 N  | 800           | 799                           | 0.13                      | 3.95    | -94.98           |
|            | 6250 N   | 400           | 400                           | 0                         | 5.56    | -94.01           |

It can be seen from table 5 that even the mountainous terrain will have some differences due to the specific environment. The overall RSSI value in Laoshan environment is lower than that in Fragrance Hill environment.

4. Results and Analysis

4.1. Analysis of experimental results

In urban areas, the maximum DR can reach 21875 bps and its transmission range can up to 2.5 km. At the 2.4 km in Table 3, the PLR is only 1.42% when we use 21875 bps to transmit 1200 packets. The lower such as 12500 bps and 6250 bps have 0 PLR when transmitting 1000 packets, which means that the stable range of data transmission can be further extended.
Figure 4. Relationship between SNR and range, relationship between PLR and range (DR=21875 bps, mountains OR<5%).

Figure 5. Relationship between RSSI and range (DR=21875 bps, mountains OR<5%).

In the mountains, the maximum DR can reach 21875 bps and its transmission range can up to 3km. In figure 4 (Solid line indicates SNR, dotted line indicates the PLR), the PLR is 0.11% when we use 21875 bps to transmit 1800 packets at a 2.27 km distance. When we use 21875 bps to transmit 1000 packets at a 2.74 km distance, PLR increase to 5.10%. This is because Base Station 2 is located in the village, but the impact of surrounding buildings is not taken into account. When the OR is 9%, 21875 bps and 12500 bps cause data transmission timeout at a 1.30 km distance. When the OR exceeds 10%, all the four rates in this paper at a 1.36 km distance and 1.39km have a reception timeout, which cannot be used for data transmission normally. In table 4, if the OR is below 5%, data can be stably transmitted by using 21875 bps. if the OR is less than 10%, data can be stably transmitted by using 6250 bps. If the OR is more than 10%, we cannot use the DR above 3125 bps. The effect of OR is shown in table 4.

Table 6. PLR and Maximum DR under different OR.

| Occlusion Ratio (%) | Max DR (bps) | Average Packet Loss Ratio (%) |
|---------------------|-------------|------------------------------|
| 0 - 5               | 21875       | 0.15                         |
| 5 - 10              | 6250        | 0                            |
| > 10                | 3125        | -                            |

It can be seen from table 6 that in the range of 500 m ~ 3 km, the maximum transmission rate corresponding to the occlusion ratio within 5% reaches 21875 bps, while when the occlusion ratio exceeds 10%, the maximum transmission rate drops to 3125 bps. Therefore, in order to use a higher transmission rate, it is necessary to reduce the shielding between the transmission equipment mounting points as much as possible, for instance, choose to increase the antenna mounting height as much as possible.

From figure 5 we can see that RSSI in urban areas is much lower than in mountains. At the same time, OR value has a significant effect on RSSI measurements. Compared to the 2.04km, the 2.27km RSSI reduce to -95.14dBm. This OR includes shelter from mountains, trees, etc.

According to formula (2), the RSSI transmission loss curve in urban and mountainous areas is drawn according to the actual test situation as follows:
It can be seen from figure 6 that the RSSI transmission loss in the city is greater than that in the mountain area. At a distance of 1500 m, the RSSI of the city is -95.56 dBm, while that of Fragrance Hill is -77.97 dBm. At the same time, the RSSI loss curve of Laoshan is lower than that of Fragrance Hill. At a distance of 1500 m, the RSSI of Fragrance Hill is -77.97 dBm, while that of Laoshan is -86.57 dBm, which to some extent reflects the vegetation density in the mountain area influence.

At the same time, combined with the experimental data, it can be found that the RSSI at the point where there is occlusion deviates from the above curve, and the loss of this part of RSSI is the loss of occlusion. For example, in the city where $d = 1100$ m, OR = 15%, RSSI = -93.37 dBm when there is no shelter, but the actual measured RSSI is -101.38 dBm, the loss is about 8 dBm.

4.2. Analysis of transmission performance

In figure 7, In this kind of Lora image transmission system which transmits hexadecimal encrypted data, the maximum transmission of Lora in HITS is 84 bytes at a time. In this paper, the maximum transmission capacity is 255 bytes, and the data capacity is increased by 2.9 times.

Compared with HITS, in figure 7, the maximum DR in this paper is increased by 5.4 times, and the actual transmission rate achieved is increased by 4.3 times[6]. In the same case of 100 KB data transmission, HITS needs 254.02 s, this paper only needs 47.50 s, the transmission time is shortened by 81.3%, and the speed is increased by 4.3 times. In the same transmission time of one minute, the data transmission capacity of this paper can reach 126.20 KB, and the capacity is increased by 4.3 times. In the range of 2.5 km, the packet loss rate in HITS is 0, and the average packet loss rate in this paper is 0.11%.

If the DR is 12500 bps, the actual transmission rate is increased by 2.4 times. In the same case of 100 KB data transmission, the transmission time at 12500 bps is 74.97 s, the transmission time is reduced by 70.5%, and the speed is increased by 2.4 times. In the same transmission time of 1 min, the data transmission capacity can reach 80.03 KB. In the range of 2.5 km, the average packet loss rate of 12500 bps is 0.11%.

5. Conclusion

In this paper, we test and analyze the transmission performance of Lora at higher bit rate, and Lora can transmit data at 21875 bps with a distance of 3 km. In addition, it is found that the occlusion in the real environment will affect the packet loss. To solve this problem, we also test the packet loss rate under 0-5%, 5-10% and more than 10% occlusion ratio in the range of 500 m to 3 km. Among them, 21875 bps
can transmit stably in 5% occlusion ratio. At the same time, this paper explores the RSSI propagation path loss curves under different test environments. The results show that the propagation path loss in urban environment is much greater than that in mountainous environment, and the vegetation density in mountainous environment also affects the RSSI value.

The test data also show that the data throughput of Lora high-speed transmission is larger and the transmission time is shorter. In this paper, the data throughput of 21875 bps can reach 2.10 KB / s. When 21875 bps is used for data transmission, it takes 47.50 s to transmit 100 KB data. Compared with one of Lora's high-speed image transmission system, the transmission time is reduced by 81.3% and the performance is improved by 4.3 times. Therefore, this will greatly improve the capacity of Lora data transmission, which has a profound significance for the application of Lora high-speed rate in image transmission.

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