Experimental Study on Doppler Performance of Satellite Emergency Communicator Based on LoRa System

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Abstract. Aiming at the propagation loss and Doppler frequency shift problems faced by LEO satellite in realizing Internet of Things, the LEO satellite emergency communication machine is tested. The emergency communication machine adopts SX1280 chip as the transceiver unit, analyzes the bit error rate and Doppler frequency shift index of LoRa signal generated by SX1280, and proposes a test scheme combining satellite channel simulator and emergency communication machine. In the range of Doppler frequency shift less than 53 kHz, changing Doppler frequency and its change rate has less than 4 dB effect on signal communication sensitivity. Reducing signal transmission rate and bandwidth can improve communication sensitivity. It proves that LoRa signal generated by SX1280 chip can be effectively used in LEO satellite Internet of Things.

1. Introduction

With the rapid development of the Internet of Things industry, the climax of research and construction of low-orbit satellite Internet of Things has been set off at home and abroad. By moving the base station of the Internet of things to the "sky" and establishing the satellite Internet of things to supplement and extend the ground Internet of things, the relatively small coverage area of the ground Internet of things and the absence of signals in unmanned areas can be effectively overcome [1].

Compared with ground Internet of Things, satellite Internet of Things has larger transmission delay and more obvious Doppler frequency shift. The traditional method of simulating and analyzing communication between satellite and ground mainly adopts field test method, but it is vulnerable to climate conditions, high cost and time-consuming[2]. Considering that LoRa's patent is owned by Semtech, the detailed technical details, including the core modulation technology[3], are not described in the patent document, and it is impossible to generate accurate LoRa transmission signals. Therefore, a channel simulator is needed to simulate the transmission characteristics of real satellite channels. It is necessary to add this channel simulator between LoRa transceivers to simulate the target distance, time delay, Doppler, etc., in order to test the influence of Doppler frequency variation on chip sensitivity.

The LoRa performance test in this paper mainly focuses on BER and RSSI of received data. According to the target requirements of the overall scheme, the bit error rate and anti-Doppler effect of LoRa are analyzed theoretically, and then a LoRa performance test scheme is proposed, which realizes the LoRa test by choosing two test environments: no satellite channel simulator and satellite channel simulator. The adaptability of Semtech's wireless transceiver chip SX1280 in the simulated satellite environment and the influence of Doppler frequency offset on the sensitivity of the chip are verified.

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2. Theoretical analysis

For the application fields of ground LoRa equipment such as agricultural informatization, environmental monitoring, intelligent meter reading, etc., it is seldom necessary to consider the influence of Doppler frequency variation. But for satellites, because of the fast motion speed of satellites and the short time of each passing through the headspace, how to quickly capture signals is particularly important. At the same time, we need to pay special attention to the influence of Doppler changes on LoRa signals. This experiment is based on this. The purpose is to verify the sensitivity and bit error rate of the satellite when the Doppler frequency is constant, that is, when the satellite moves at a constant speed relative to the earth; and the sensitivity and bit error rate when the Doppler frequency changes, that is, when the satellite moves at an accelerated speed relative to the earth.

2.1. BER and SNR

BER (bit error rate) is an index to measure the accuracy of data transmission in a specified time. It is the main judgment basis to measure the reliability of a digital system. The factors affecting the system bit error rate are radio frequency signal-to-noise ratio, demodulation circuit, baseband, A/D, D/A, error correction coding and so on. We mainly consider the influence of signal-to-noise ratio here.

The BER of QPSK with no intersymbol interference in the AWGN channel is used as a reference for BER performance, and its BER formula is:

\[ P_e = Q\left(\frac{2E_b}{N_0}\right) \]  

among them:

\[ Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{z^2}{2}} dz \]  

In equation (1), Eb/N0 represents the density ratio of energy per bit to noise power spectrum [4]. The bit error rate expression for obtaining the LORA signal is as follows:

\[ P_e = Q\left(\frac{2E_b}{N_0}\right) \]  

\[ \frac{E_b}{N_0} = \frac{SNR}{SF \times 2^{SF}} \]  

SF is a spread spectrum factor, representing the number of bits of a symbol. The larger the spread spectrum factor is, the more bits the symbol modulates, the smaller the data rate is. Taking SF as 9, frequency as 2.4 GHz and bandwidth as 1.625 MHz, the BER and SNR are fitted. The relationship is shown in Figure 1.

![Figure 1. The relationship between BER and SNR](image)

As can be seen from Figure 1, the larger the SNR, the smaller the bit error rate.
2.2. Anti-Doppler effect

LoRa signal is based on LFM spread spectrum signal. Because of the linearity of LFM signal, the frequency offset between transceiver and transceiver chips can be easily eliminated in decoder, so the influence of Doppler effect on LoRa signal is very small. According to Semtech's official manual, the frequency offset between transceivers can reach 20% of the bandwidth without affecting the decoding effect [5]. In static test (i.e. without Doppler frequency offset), SF is 9, bandwidth is 1625 kHz, transmission frequency is 2.4 GHz, and reception frequency is 2.4 GHz +400 kHz. Errors begin to appear when the frequency is greater than 400 kHz.

Taking the ground terminal as the reference system, the satellite moves relative to the terminal at a relative speed \( v \), and the Doppler shift is obtained as follows [6]:

\[
\Delta f = \frac{f \times v \cos \theta}{c}
\]

(5)

Where \( f \) is the carrier frequency, \( c = 3 \times 10^8 \text{ m/s} \), \( v \) is the relative motion speed, and \( \theta \) is the direction angle of the relative motion.

For the satellite system, the maximum relative speed of the satellite is 8km/s, and the corresponding maximum Doppler frequency is 64 kHz less than 20% of the bandwidth, so theoretically it will not affect the bit error rate and sensitivity.

3. Program design

3.1. The composition of the emergency communication system

![Emergency communication unit composition and external connection block diagram](image)

It consists of RF processing unit, baseband processing unit (transceiver chip and lower computer unit), clock and power processing unit. According to the overall needs of XX satellite, the receiving and launching of emergency communication machine can work in duplex mode. Power-on defaults to receive open, transmit off working status. The main functions are as follows: 1. telemetry: transmitting downlink spread spectrum telemetry signals to the ground station to guide the ground station to capture satellites; 2. telecontrol: receiving the upstream spread spectrum remote control signals sent by the ground station to complete the de-spreading, demodulation and de-jamming, generating direct command output to the satellite; 3. self-telemetry and command processing.
3.2. SX1280 transceiver chip test board without satellite channel simulator test

The experimental principle block diagram is shown in Figure 3.

![Figure 3. static test connection diagram](image)

SX1280 transceiver chip, radio frequency set at 2.4 GHz, adopts LoRa linear spread spectrum system, bandwidth is 1.625 MHz, information transmission rate is 28.56 kbps, according to chip Lora transmission protocol, 253 bytes of data are transmitted per packet, and 10,000 packets of data for each test during the test. Tests have shown that the product static test communication is normal, no packet loss occurs.

3.3. SX1280 transceiver chip test board joins satellite channel simulator test

The block diagram of the test principle is shown in Figure 4.

![Figure 4. Doppler dynamic test schematic diagram](image)

Since the existing satellite channel simulator frequency is 2 GHz, a mixer is required, and the 2.4 GHz signal transmitted by the SX1280 is down-mixed to the channel simulator, and the signal output from the channel simulator is up-mixed.

Input the target closest distance, the farthest distance, the speed, the acceleration value, the initial distance value and the initial value of the time on the satellite channel simulator to simulate the satellite's distance, velocity, acceleration and signal power attenuation. In the hardware design, considering that the distance between the satellite and the monitoring station is far, the signal transmission delay is likely to cause the receiving end to receive no data or data conflict. The satellite system is about 600km above the ground and the signal transmission delay is at least 4ms. Therefore, ARM uses the SPI DMA method to directly read and write the SX1280, and realizes the transmission and reception of LoRa signals.
4. Test situation

4.1. Test Contents

SX1280 transceiver chip, RF frequency set at 2.4 GHz, uses LoRa linear spread spectrum system, bandwidth 1.625 MHz, information transmission rate 28.56 kbps. Each test counts 10,000 packets of data, 253 bytes per packet. The standard is that the test data does not produce error code.

(1) The simulated satellite fixed orbit height is 600km, and the sensitivity of the SX1280 receiving board is tested;

(2) The initial orbital altitude of the simulated satellite is 600km. The simulated satellite is moving at a uniform speed. The sensitivity of the SX1280 receiving board is tested at 8km/s and 16km/s respectively.

(3) The initial orbital altitude of the simulated satellite is 600km, the simulated satellite accelerates the motion, the initial speed is 0 km/s, the acceleration is 0.02 km/s² and the maximum speed is 8km/s. The sensitivity of the SX1280 receiving board is tested.

(4) The initial orbital altitude of the simulated satellite is 600km, the simulated satellite accelerates motion, the initial speed is 0km/s, the acceleration is 0.2 km/s², and the maximum speed is 8km/s. The sensitivity of the SX1280 receiver board is tested.

4.2. Test results

The test results are shown in Table 1.

Table 1. Adding Channel Simulator Test Results

| status index | Fixed track height | Simulated satellite uniform motion | Simulated accelerated satellite motion (maximum speed to 8km/s) |
|--------------|--------------------|-----------------------------------|-------------------------------------------------------------|
|              |                    | 8 km/s | 16km/s | 0.02 km/s² | 0.2 km/s² |
| Sensitivity  | -96dBm             | -92dBm | -84dBm | -92dBm     | -92dBm    |
| Bit error rate | 0                  | 0       | 0      | 0           | 0          |

From the data in Table 1, the following conclusions can be drawn:

(1) Simulating the uniform motion of the satellite, the communication sensitivity decreases by 4 dB when the velocity is 8 km/s (Doppler frequency offset is about 53 kHz), and 12 dB when the velocity is 16 km/s (Doppler frequency offset is about 106 kHz).

(2) Simulated satellite acceleration motion, the acceleration rate of change has little effect on communication sensitivity when the speed is less than the maximum speed.

4.3. Test after changing the channel bandwidth and transmission rate of the SX1280 transceiver chip

The channel bandwidth of the SX1280 transceiver chip was changed to 0.812 MHz, and the information transmission rate was 14.27 kbps. The test principle block diagram is the same as Figure 4. The test results are shown in Table 2.

Table 2. Test results after changing channel bandwidth of SX1280

| status index | Fixed track height | Simulated satellite uniform motion |
|--------------|--------------------|-----------------------------------|
|              |                    | 8 km/s | 16km/s |
| Sensitivity  | -104 dBm           | -100 dBm | -91 dBm |
| Bit error rate | 0                   | 0       | 0      |
From the data in Table 2, it can be seen that when the bandwidth and transmission rate are reduced to half of the original, the sensitivity increases by 8 dB at fixed orbital altitude (without frequency offset). When the velocity is 8 Km/s (Doppler frequency offset is about 53 kHz), the sensitivity was improved by 8 dB.

When Semtech’s wireless transceiver chip SX1280 communicates, in the range of Doppler frequency shift less than 53 kHz (i.e. maximum operating speed 8 km/s), changing Doppler frequency and its change rate (i.e. changing satellite speed and acceleration) has less influence on signal communication sensitivity than 4 dB. At the same time, reducing the signal transmission rate and bandwidth can improve the communication sensitivity. Each test counts 10,000 packets of data, no packet loss or error occurs. The experimental results show that the SX1280 chip can adapt to the Doppler frequency variation of low-orbit satellites.

5. Conclusion

Using the channel simulator which simulates the transmission characteristics of real satellite channel, the two-way real-time data communication experiment between satellite and ground is completed by the satellite emergency communication machine based on LoRa. By changing the parameters such as Doppler frequency, signal rate and bandwidth, experiments and observations were carried out for three days. The bit error rate and sensitivity of the receiver chip met the overall mission requirements. The satellite emergency communication machine is composed of radio frequency processing unit, baseband processing unit (transceiver chip and lower computer unit), clock and power processing unit. It has the characteristics of miniaturization, low power consumption, long transmission distance, anti-Doppler frequency shift and high reliability. Its core technology can be used as a communication machine for low-orbit satellites, and can provide ranging and positioning services for satellites.

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