LoRa Multi-Channel Access Immunity to Doppler effect in CubeSat Radio Communication †

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Abstract: The currently developed technologies for expanding the Internet of Things are based on satellite constellations in low earth orbit, including CubeSat and nanosatellite constellations. We describe a theoretical investigation of the feasibility of successful communication between a LoRa in a ground station and a LoRa in the satellite, including the Doppler effect that an IoT device may experience. Transmission parameters, including frequency (923-925 MHz), altitude (500-600 km) and angle, were simulated. Laboratory testing measured whether transmission frequencies would affect the transmission quality significantly. The laboratory testing will be used to simulate the frequency shift, This is simulated by changing the intermediate frequency used to transmit data at the transmission station. The optimal parameter values reported here may directly benefit developers of new applications of LoRa and IoTs satellite in their effort to design an effective communication schemes.

Keywords: Doppler effect; LoRa Multi–Channel Gateway; CubeSat Radio Communication; Internet of Things (IoTs).

1. Introduction

LoRa (Long Range) is a proprietary modulation scheme used in infrastructure solutions for the Internet of Things (IoT). The LoRa modulation is based on the chirp spread spectrum (CSS) technique, where the data is encoded by a wideband chirp signal, in which the frequency linearly increases or decreases with time. The CSS modulation technique is preferred for use in IoT wireless networks, due to its relatively low transmission power requirements and inherent robustness against channel degradation mechanisms, for example multipath, fading and Doppler effect. LoRa can improve reception [2], [3].

We studied the communication between a LoRa ground station and a Low Earth Orbit (LEO) IoT satellite, when the Doppler effect interferes, and to demonstrate the possibilities and possible restrictions on the use of LoRa modulation in space applications under very strong Doppler shift conditions. To do this, we tested, in the laboratory, frequency shift of the transmission side device to test data transmission efficiency of the receiving device, when the transmission frequency changed.

The paper is organized as follows. Section 2 explains the LoRa Network, consisting of a LoRa node and gateway and a LoRa network server. Section 3 calculates the center angle of the earth (ϕ) to be used in the Doppler effect calculations. Section 4 describes the laboratory testing. Section 5 concludes.

2. LoRa Network

2.1. LoRa Node and Gateway

LoRa Nodes and Gateways are fundamental components of LoRa networks, since they can interact with the environment as well as forwarding data to a LoRa network server for analysis. LoRa Nodes mainly include sensors, battery, *etc.*, and performs one or more tasks, according to different application requirements. LoRa Gateways forward all uplink radio packets to a LoRa network server after adding metadata, for example, Signal-Noise-Ratios (SNR) and Received Signal-Strength-Indicators (RSSI). Conversely, on the downlink, a LoRa Gateway handles transmission requests coming from a LoRa network server. Typically, it only transmits the received uplink and downlink packets, as a relay, without any payload interpretation [4].

2.2. LoRa Network Server

LoRa network server receives packets forwarded from a LoRa Gateway, and is responsible for packet processing and protocol analysis. Many functions need to be implemented on a LoRa network server [4].

3. Doppler Effect

The Doppler effect is a phenomenon in which an observer receives a frequency from a wave source, different from the original one. When the relative sender and receiver velocities are not zero, it will be noticed that the waves had different frequencies from when they were at rest [1].

3.1. Center Angle of the Earth (ϕ) Calculation

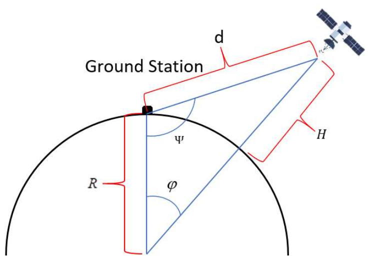


Figure 1. Satellite in a circular orbit with respect to a ground station.

From figure 1, we must find the value of the earth center angle (ϕ), to be used in Doppler Effect calculations, and calculate the center angle from:

$$d^2 = H^2 + R^2 + 2 \cdot H \cdot R \cdot \cos(\varphi) \tag{1}$$

and

$$\frac{\sin(\varphi)}{d} = \frac{\sin(\Psi)}{(H + R)} \tag{2}$$

3.2. Doppler Effect Equation

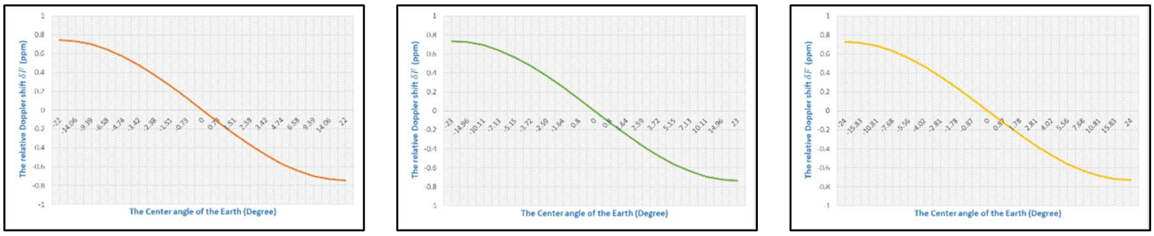
From figure 1, for a satellite moving on a circular orbit at height H and a ground station situated in a plane of the orbit, the relative Doppler shift, δF is defined by [2], [3]:

$$\delta F = \frac{1}{1 + \frac{1}{c} \cdot \sqrt{\frac{g \cdot R}{1 + \frac{H}{R}}} \cdot \frac{\sin(\varphi)}{\sqrt{\left(1 + \frac{H}{R}\right)^2 - 2 \cdot \left(1 + \frac{H}{R}\right) \cdot \cos(\varphi) + 1}}} - 1 \tag{3}$$

where, R is the radius of the Earth, g is the gravitational acceleration on the surface of the Earth.

3.3. Doppler Effect Calculation

From (3), the relative Doppler shift, δF, be calculated and displayed in Figure 2.



(a) Relative Doppler shift δF of the satellite at 500 km over the ground station.

(b) Relative Doppler shift δF of the satellite at 550 km over the ground station.

(c) Relative Doppler shift δF of the satellite at 600 km over the ground station.

Figure 2. Relative Doppler shift δF, (**a**) the relative Doppler shift δF of the satellite at 500 km height over the ground station. ;(**b**) the relative Doppler shift δF of the satellite at 550 km height over the ground station. ;(**c**) the relative Doppler shift δF of the satellite at 600 km height over the ground station.

From figure 2, (a) The highest doppler of a LEO satellite at 500 km is at the Center angle of the Earth (ϕ) = ± 22°, δF = ± 0.744 ppm. (b) The highest doppler of a LEO satellite at 550 km is at the Center angle of the Earth (ϕ) = ± 23°, δF = ± 0.736 ppm. (c) The highest doppler of a LEO satellite at 500 km is at the Center angle of the Earth (ϕ) = ± 24°, δF = ± 0.728 ppm.

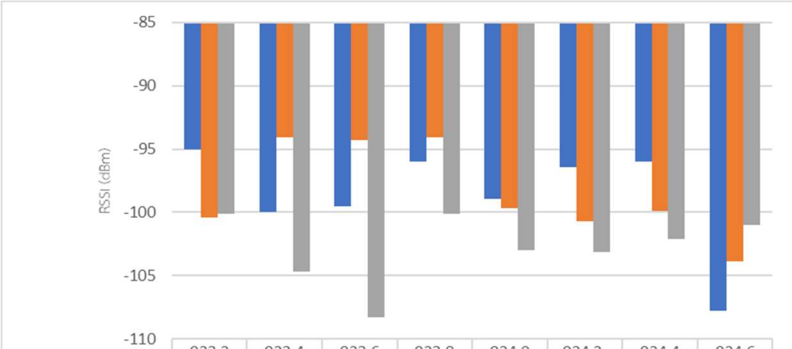
4. Laboratory Testing

From the doppler shift calculation of LEO satellites, we designed a test of the frequency shift of the transmission side device to test the data transmission efficiency of the receiving device when the transmission frequency has changed. This was performed by shifting the frequency away from the center frequency of each channel, then measure the RSSI value from the receiving side device and put it in the form of a graph. The frequency with which data can be received from the LoRa radio transmitter frequency shift test is shown in Table 1.

Table 1. Frequency of data received from the LoRa radio transmitter in the frequency shift test.

Channel (Center Freq.)	Minimum Freq. (MHz)	Maximum Freq. (MHz)
CH1 (923.2 MHz)	923.170	923.227
CH2 (923.4 MHz)	923.370	923.425
CH3 (923.6 MHz)	923.575	923.625
CH4 (923.8 MHz)	923.775	923.823
CH5 (924.0 MHz)	923.975	924.025
CH6 (924.2 MHz)	923.175	924.225
CH7 (924.4 MHz)	923.377	924.425
CH8 (924.6 MHz)	923.575	924.625

From Table 1, the transmitted frequencies obtained from the LoRa radio transmitter frequency shift test, indicate minimum and maximum frequency range in receive-transmit data. Figure 3 shows the relationship between the frequency used to transmission and the RSSI.



	923.2 MHz	923.4 MHz	923.6 MHz	923.8 MHz	924.0 MHz	924.2 MHz	924.4 MHz	924.6 MHz
Minimum Freq.	-95	-100	-99.5	-96	-98.9	-96.4	-96	-107.8
Center Freq.	-100.4	-94.1	-94.3	-94.1	-99.7	-100.7	-99.9	-103.9
Maximum Freq.	-100.1	-104.7	-108.3	-100.1	-103	-103.1	-102.1	-101

Figure 3 Relationship between the transmission frequency and Received Signal Strength Indication (RSSI)

From figure 3, we found that at the highest frequency, that can transmit data, had the lowest signal, measured at the receiver. In the experiment it was found that at the highest frequency It can transmit worse data at both the lowest and center frequencies. The signal level measured from the receiver with the lowest value was -108.3 dBm at maximum frequency of 923.6 MHz and the highest value was -94.1 dBm at center frequency of 923.4 and 923.8 MHz.

5. Conclusion

We analyzed the equations used in the Doppler calculation between LoRa ground station and IoT satellite at LEO and presented the results of laboratory testing. From result of calculation, The highest Doppler effect for a LEO satellite at 500, 550, and 600 km is at the center angle of the Earth, $\phi = \pm 22, \pm 23$, and $\pm 24°$, with the Doppler value of ± 0.744, ± 0.736, and ± 0.728 ppm, respectively. From laboratory testing, it was clear that, at the highest frequency, that can transmit data, had the lowest signal, measured at the receiver. The center frequency tended to be able to receive and transmit data the best, because this was a frequency that meets the standards of the receiver. This experiment showed that LoRa is extremely resistant to frequency shifts. By comparing the experiment with the calculated frequency shift, we found that using LoRa technology in conjunction with LEO satellites is highly promising.

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