# Evaluating Direct Link IoT-LoRa Communication via LEO Nanosatellite: DEWASAT-1

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**Abstract.** The rapid growth of the Internet of Things (IoT) opens the possibility for multiple applications catering to a variety of needs. Combined with Long Range (LoRa) technology, it can provide a global coverage network that connects devices and communicates valuable information. This manuscript evaluates the direct link of IoT-LoRa to the satellite by presenting various ground trials and uplink/downlink tests. The IoT substation communication to the tracked satellites based on predicted passes over the target is tested for coverage and environment losses. Using orbital data analyses and simulation plots, we estimate and validate the Radio Frequency (RF) output data of the received power, signal strength, and Bit Error Rate (BER) of the ground receiver through the telemetry phase. The paper validates the novel concept of using LoRa - Chirp Spread Spectrum (CSS) modulation by varying the spreading factor, elevation, and antenna gain for direct communication from the IoT terminal to Low Earth Orbit (LEO) CubeSat. This is done by excluding the master gateway and establishing a standard for future validations with untried and onboard data by attaining a positive link margin.

**Keywords:** BER · DEWASAT-1 · Direct Communication · IoT · LoRa-CSS · Spreading Factor · Signal to Noise Ratio

## 1 Introduction

The Internet of Things (IoT) is a network connecting several devices as sensors, software, machines – things – to improve real-time decisions and operational awareness. The technology can apply to a small household, a larger industrial workspace, and even a global framework. IoT nodes are connected via the network and process data from the sensors before sending it to the cloud. There has been a growing interest in IoT technology, with forecasts predicting that 75 billion devices will be connected by 2025 [1].

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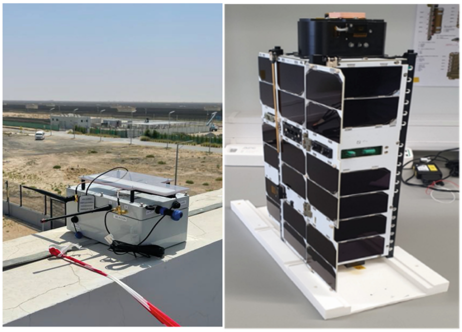
Different protocols have been developed for different use cases. For instance, for devices that have a short communication range and require low power, the IEEE, Bluetooth Low Energy, and ZigBee standards are used as communication protocols [2]. Long Range (LoRa) is based on Chirp Spread Spectrum (CSS) technology and serves as a method of spread spectrum modulation. It is a more resilient modulation scheme and particularly useful when handling IoT technology because its relatively low power consumption can perform long-range communication. LoRa is popular for use cases that involve monitoring large geographical areas with many nodes and less data per node [3].

A common infrastructure setup for an IoT network involves three key components: the IoT devices, a gateway, and the network. The devices perform their respective functions and transfer information to the gateway. The gateway sends data from and to the network, serving as a central node when communicating in a large or rural area. The gateway then sends information back to the devices. Using a gateway reduces the investment required for infrastructure; however, it is not effective in remote areas [4]. According to reference [5], the author recommends a constellation of satellites to solve the remote connectivity problem. This would cover a significantly larger geographical area and opens the possibility of achieving global coverage. This can be done by connecting a series of CubeSats, which have increased in popularity due to recent technological advancements and lower costs associated with the launch [6]. Here a Low Power Wide-Area Network (LPWAN) is used called LoRaWAN to form the connection. Each device can transmit signals directly and independently in this network using bidirectional communication. In 2021, there were about 178 million devices connected to LoRa networks [7].

For optimum transmission of LoRa messages in the network, certain parameters need to be configured. The Spreading Factor (SF) refers to the ratio of chips per symbol and has typical values from 7 to 11 [8]. As SF values get larger, the Signal-to-Noise Ratio (SNR) increases because there are more chips in each transmission. This means longer data packets are required, and the receiver sensitivity is less. The second parameter works to ensure that messages are transmitted without errors. To do this, data packets often have redundant bits added to them. The number of these bits is determined by the Code Rate (CR), which works by collecting and correcting information received [9]. The frequency Bandwidth (BW) used affects the airtime required for a signal to reach the satellite. Since LoRa generally works between 125–500 kHz [10], a bandwidth of 500 kHz would have the lowest airtime but will reduce sensitivity at the receiver. The bandwidth of LoRa modulation defines the maximum shift of central frequency, which is approximately 25% of the BW.

New research recommended using IoT for space-based systems. The suggestion enables a wide communication coverage. Despite the benefits of using a satellite, communicating with devices in space comes with a set of challenges. One of these is the Doppler frequency shift which becomes higher when in space. There are also more channel losses, likely because of atmospheric interference [11]. Some of these effects are combatted using an LPWAN and a constellation of CubeSats, they still need to be accounted for in calculations, simulations, and results. This paper presents the analysis and results done for one of Space-D projects. Space-D is a project initiated by the Dubai Electricity and Water Authority (DEWA) Research and Development (R&D) Center. The project aims to build a constellation of CubeSats equipped with advanced space technology and Commercial off-the-shelf (COTS). DEWASAT-1 is part of this program and was launched on January 13th, 2022. The mission objective is to establish a direct communication link using satellited based IoT communication without utilizing gateways. Figure 1(a) illustrates the IoT terminal used on the ground to communicate with the DEWASAT-1, and the CubeSat structure is presented in Fig. 1(b). The focus of this paper is on DEWASAT-1's primary mission which is the evaluation of the link margin of LoRa CSS communication.

The paper is organized as follows; Sect. 1 includes the literature review LoRa IoT network; Sect. 2 is methodology and simulation, including IoT system architecture, link budget study of DEWASAT-1, and simulations; Sect. 3 presents the results and analysis; and Sect. 4 the conclusions.



(a) (b)

**Fig. 1.** (a) IoT Terminal-left (b) DEWASAT-1 flight model-right

## 2 Methodology and Simulation

### 2.1 IoT-LoRa System

The utilization of a CubeSat constellation as a LoRa gateway enables reasonable coverage for IoT devices in remote areas. DEWASAT-1 is a 3U nanosatellite that is part of the Space-D project and includes the LoRa receiver as a payload. The IoT terminal is developed by the R&D center at DEWA to communicate with the satellite through LoRa CSS modulation. As shown in Fig. 2, the IoT terminal transmits using LoRaWAN Protocol and a CSS modulation. The transmission signal parameters can vary within guidelines set by authorities such as the Telecommunications and Digital Government Regulatory Authority (TDRA) in UAE or limitations created by interference with other transmissions. Figure 2 displays the IoT space architecture where two nanosatellites are used to assess the uplink communication under varying conditions.

During the downlink of telemetry data, the nanosatellite receives housekeeping information and sends it to the ground station via an onboard S-band transceiver. The antenna on the satellite can be a Left-Hand Circular Polarization (LHCP) or a Right-Hand Circular Polarization (RHCP). The downloaded data is received at a specified bit rate through

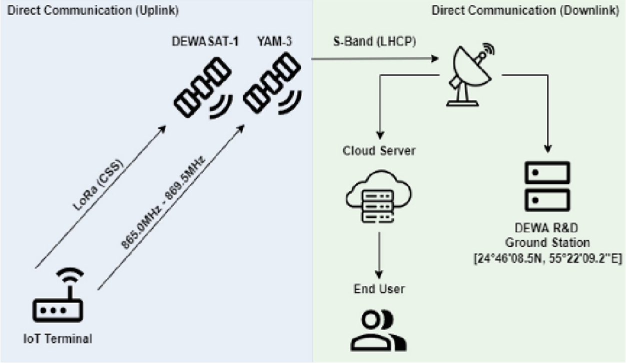


**Fig. 2.** IoT Space architecture

S-X bands at the ground station. Alternatively, the data received by the ground station can be uploaded to the cloud, where it may be used for various IoT Platforms by different end-users.

An IoT Terminal model is designed to meet the requirements and perform the tests defined in the simulations discussed in Sect. 2.2. The IoT Terminal consists of 2 main subsystems, as shown in Fig. 3. The lower part of the system architecture consists of a host processor that controls the main system and scripts. A script is configured with the transmission parameters: frequency, SF, and CR. The upper section comprises the ARM node processor, which hosts the SX1262 based radio for transmission. This radio is capable of transmitting with up to +22 dBm at a low power rating according to the datasheet [12].

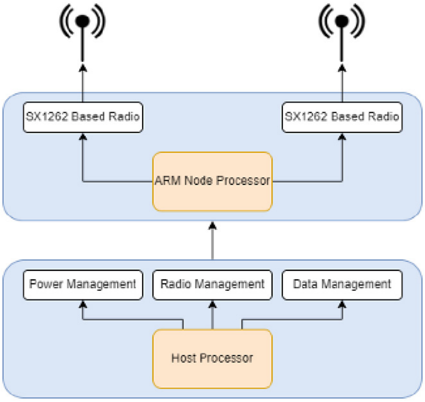


**Fig. 3.** Hardware architecture of the IoT terminal

The transmitted power is configured to 22 dBm at the 865.07 MHz channel. The gain of the antenna can vary based on which antenna is used. In the scope of this paper, two possibilities are evaluated, a 2 dBi and 10 dBi gain antenna with monopole propagation.

Monopole Omnidirectional antenna receives signals equally from all directions whilst directional antenna can detect comparatively weaker signals in a specific direction [13]. Omnidirectional antennas radiate in a flat, 2-Dimensional geometric plane [14]. Hence antenna placement plays an important role in the transmission of the signal. Figure 4 illustrates the typical radiation pattern for a monopole antenna in two dimensions (X and Y) [15]. As illustrated in Fig. 4, the strongest points of radiation occur in the above-ground region of the monopole antenna. LEO Satellites orbit from West to East [16] therefore placing the antenna in the East direction allows for maximum coverage. Lastly, the choice of horizontal versus vertical placement of the antenna is important. Vertical placement of the omnidirectional antenna means the radiation pattern of the antenna is in the north to south pole direction whilst the Horizontal placement gives an east to west radiation.

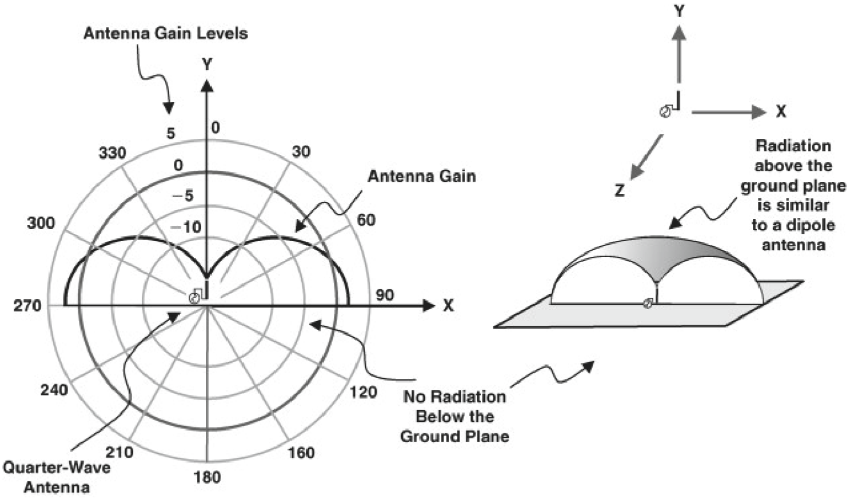


**Fig. 4.** Typical omnidirectional monopole antenna radiation pattern [15]

## 2.2 DEWASAT-1: Link Budget

Space communication is challenging, and a high link margin is difficult to achieve due to channel losses. Thus, it is necessary to study, evaluate and determine the feasibility of using IoT space-based technologies. The assessment of the link budget of DEWASAT-1 is conducted by considering different communication parameters for uplink to validate the communication link between the satellite and IoT terminal. This section focuses on evaluating the essential parameters in LoRa communication, such as BW, SF, and CR.

The study includes the effect of elevation angle on the SNR for different SF. Two studies are conducted, varying the gain value to evaluate and determine the link margin based on these conditions. A positive link margin defines a good communication link where it is calculated based on

$$Link\ Margin = E_s/N_0 - E_s/N_{0,\ required} \tag{1}$$

where $E_s/N_0$ is the signal-to-noise ratio, the estimated value in dB, and $E_s/N_{0,\ required}$ is measured in dB and it is the required value to establish a communication link. The link margin is influenced by serval factors, so different parameters are varied to verify to evaluate its effect on the communication link.

The data rate is an important parameter in terms of data downloading. It is dependent on the factors that impact LoRa communication. In the second simulation, these parameters were varied to observe their impact on the data rate. To consider different scenarios, the study includes considering two bandwidths that are 125 kHz and 250 kHz. The data rate is calculated by

$$Data\ Rate = \left[BW/2^{SF}\right][4/(4 + CR)]SF \tag{2}$$

where the *Data Rate* is in bps, $BW$ is the bandwidth in bps, $SF$ is the spreading factor, $CR$ is the code rate.

Another study involves varying SF to understand its influence on the probability of bit error rate (BER). As the modulation scheme used has a critical effect on the signal BER. Investigating the BER provides sufficient information to evaluate the quality of the communication link. The probability of BER for CSS is calculated using

$$P_e = 0.5\ Q\left(1.28(E_s/N_0)^{0.5} - 1.28\ SF^{0.5} + 0.4\right) \tag{3}$$

Doppler shifts affect the signal, particularly for space communication, as it is dependent on satellite motion. The dynamics associated with the satellite speed influence the Doppler shift. Thus, it is essential to demonstrate that the maximum Doppler shift is within the signal's BW to ensure communication. This value depends on the satellite speed which is 7.6 km/s. Doppler shift is calculated using the equation

$$\Delta f = (\Delta v/c)f_o \tag{4}$$

Where $\Delta f$ is the doppler shift in Hz, $\Delta v$ is the satellite velocity in km/s, $c$ is the speed of light in km/s, and $f_o$ is the central frequency in Hz. The maximum experienced doppler shift is 21.9 kHz, where the central frequency is 865.07 MHz.

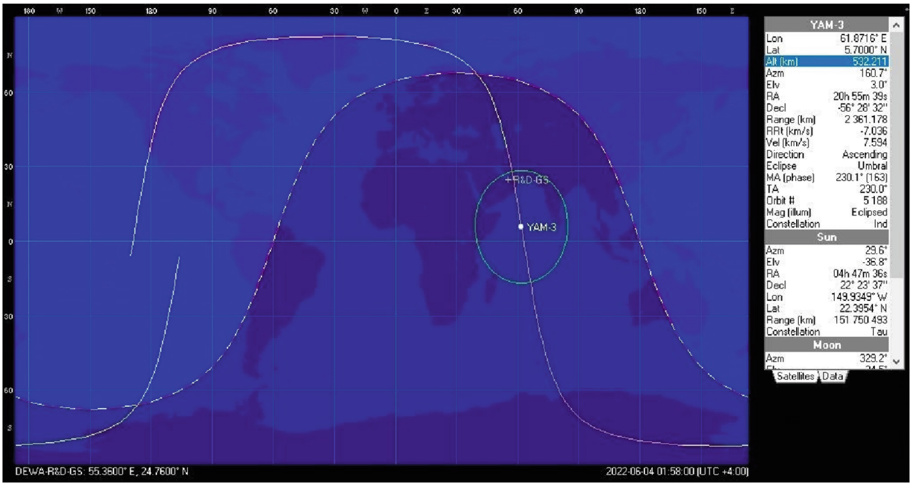
### 2.3 Orbital Simulations

Developing a test with the IoT terminal allows for the evaluation of simulated data against real orbital data. Eutelsat [YAM-3] and DEWASAT-1 were tested to assess the direct uplink test for the LoRaWAN Protocol. The first test setup done was with Eutelsat's 3U CubeSat (YAM-3), where a pass was predicted with the parameters outlined in Table 1. It should be noted that the test is conducted for YAM-3 and DEWASAT-1 for the testing purposes of the IoT terminal, and to ensure a successful LoRa link is established in the two scenarios regardless of the satellite orbit.

**Table 1.** YAM-3 predicted pass time

| Time | Azimuth (°) | Elevation (°) | Range (km) |
|---|---|---|---|
| 04-06-2022 01:58:00 | 160.7 | 3.0 | 2361 |
| 04-06-2022 02:03:11 | 77.8 | 62.9 | 590 |
| 04-06-2022 02:08:22 | 354.1 | 3.1 | 2357 |

As seen in Table 1, the satellite's entry time, known as the Acquisition of Signal (AOS), to the Ground Station's (GS) transmitter is at 01:58:00 local time (UTC + 4:00). The mid-pass is when the satellite is directly above the GS transmitter and offers the best elevation, also known as the Time of Closest Approach (TCS). Finally, Loss of Signal (LOS) is when the satellite is below the ground station's horizon. The higher the elevation, the better the link margin meaning greater success in transmission. Figure 5 shows the satellite's position at the entry pass and the path to be taken. Also, it shows the orbital parameters of the satellite on the right side in real-time such as Coordinates, Altitude, Velocity, and Range (km).



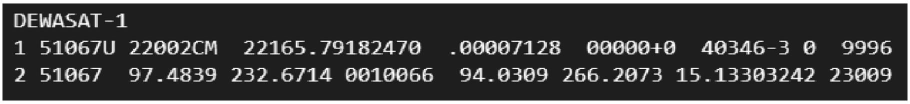
| YAM-3 | |
|---|---|
| Lon | 61.8716° E |
| Lat | 5.7000° N |
| Alt (km) | 532.211 |
| Azm | 160.7° |
| Elv | 3.0° |
| RA | 20h 55m 39s |
| Decl | -56° 28' 32'' |
| Range (km) | 2 361.178 |
| RRt (km/s) | -7.036 |
| Vel (km/s) | 7.594 |
| Direction | Ascending |
| Eclipse | Umbral |
| MA (phase) | 230.1° (163) |
| TA | 230.0° |
| Orbit # | 5 188 |
| Mag (illum) | Eclipsed |
| Constellation | Ind |
| **Sun** | |
| Azm | 29.6° |
| Elv | -36.8° |
| RA | 04h 47m 36s |
| Decl | 22° 23' 37'' |
| Lon | 149.9349° W |
| Lat | 22.3954° N |
| Range (km) | 151 750 493 |
| Constellation | Tau |
| **Moon** | |
| Azm | 329.2° |

DEWA-R&D-GS: 55.3600° E, 24.7600° N

2022-06-04 01:58:00 (UTC +4:00)

**Fig. 5.** YAM-3 Satellite Position and Path

A second test is done on DEWASAT-1 to evaluate and compare the results obtained. In Fig. 7, the path of the DEWASAT-1 satellite is predicted using Orbitron, and the pass details obtained are shown in Table 2. Furthermore, using the Orbitron Software [17], the satellites can be tracked to indicate key orbital parameters of the satellite in real-time such as coordinates, altitude, velocity, and range (km). A Two-Line-Element (TLE) set can be obtained from sites like NORAD [18], which provide the Azimuth and Elevation angle, as well as the Uplink/Downlink frequency used by the satellite. A sample TLE is shown in Fig. 6 for DEWASAT-1, which defines the orbital parameters of the satellite in its orbit.

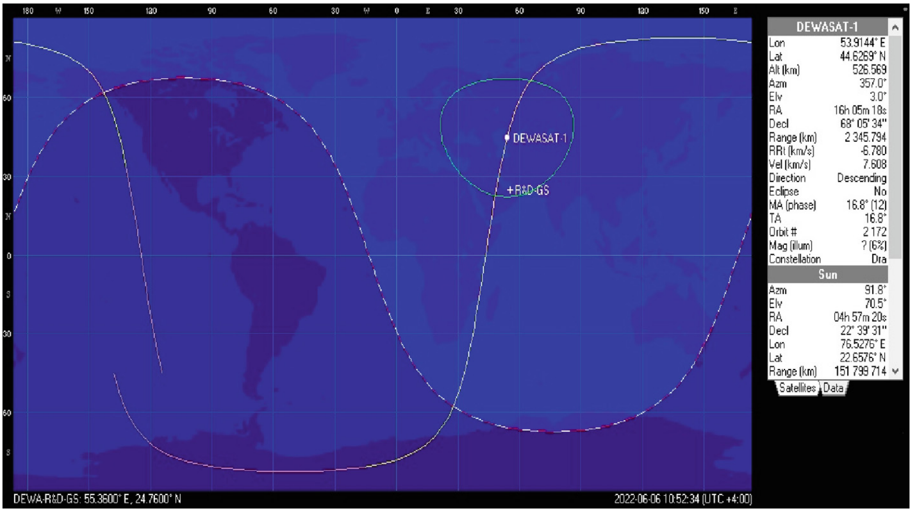


```
DEWASAT-1
1 51067U 22002CM   22165.79182470  .00007128  00000+0  40346-3 0  9996
2 51067  97.4839 232.6714 0010066  94.0309 266.2073 15.13303242 23009
```

**Fig. 6.** TLE for DEWASAT-1

**Table 2.** DEWASAT-1 predicted pass time

| Time | Azimuth (°) | Elevation (°) | Range (km) |
|---|---|---|---|
| 04-06-2022 17:48:20 | 160.8 | 3.0 | 2361 |
| 04-06-2022 17:53:31 | 77.9 | 63.1 | 589 |
| 04-06-2022 17:58:43 | 354.1 | 3.0 | 2364 |
| 06-06-2022 10:52:34 | 357.0 | 3.0 | 2346 |
| 06-06-2022 10:57:30 | 284.6 | 34.2 | 866 |
| 06-06-2022 11:02:26 | 211.7 | 3.1 | 2340 |



| DEWASAT-1 | |
|---|---|
| Lon | 53.9144° E |
| Lat | 44.6269° N |
| Alt (km) | 526.569 |
| Azm | 357.0° |
| Elv | 3.0° |
| RA | 16h 05m 18s |
| Decl | 68° 05' 34" |
| Range (km) | 2 345.794 |
| RRt (km/s) | -6.780 |
| Vel (km/s) | 7.608 |
| Direction | Descending |
| Eclipse | No |
| MA (phase) | 16.8° (12) |
| TA | 16.8° |
| Orbit # | 2 172 |
| Mag (illum) | ? (6%) |
| Constellation | Dra |
| **Sun** | |
| Azm | 91.8° |
| Elv | 70.5° |
| RA | 04h 57m 20s |
| Decl | 22° 39' 31" |
| Lon | 76.5276° E |
| Lat | 22.6576° N |
| Range (km) | 151 799 714 |

DEWA-R&D-GS: 55.3600° E, 24.7600° N

2022-06-06 10:52:34 (UTC +4:00)

**Fig. 7.** DEWASAT-1 satellite path tracking

## 3 Results and Analysis

The assessment and results of the link budget of DEWASAT-1 are represented in this section. Figure 8 demonstrates the effect of elevation angle on the signal-to-noise ratio for different SF values. Several conclusions can be drawn from this plot. First, the figure displays calculations performed at two values of antenna gain, 2 and 10. For each SF and elevation angle value, a higher gain causes a higher $E_s/N_0$. This is because a larger antenna gain provides a higher signal-to-noise ratio, therefore a more reliable communication link. The second result seen in Fig. 8 is that, for any SF or gain value, as the elevation angle increases, the $E_s/N_0$ continues to rise until it reaches 90°, where the best communication link occurs. Third, for every gain and elevation value, increasing SF from 7 to 11 causes $E_s/N_0$ to grow by about 10 dB. Based on these results, the simulation using an antenna gain margin of 2 requires a minimum elevation angle of 20-degrees to establish a communication link. However, using a gain margin of 10 presents positive link margins at lower angles.

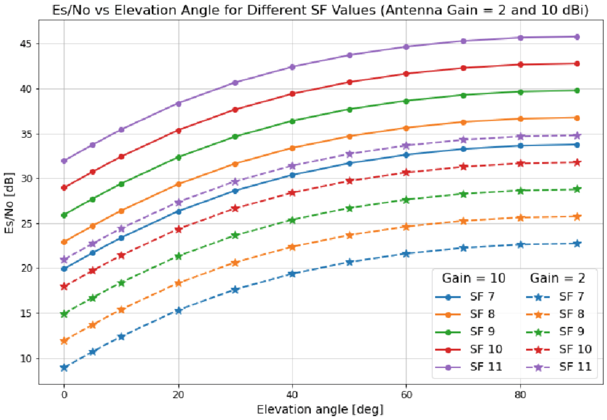


**Fig. 8.** Signal-to-noise ratio for different elevation angle and antenna gain

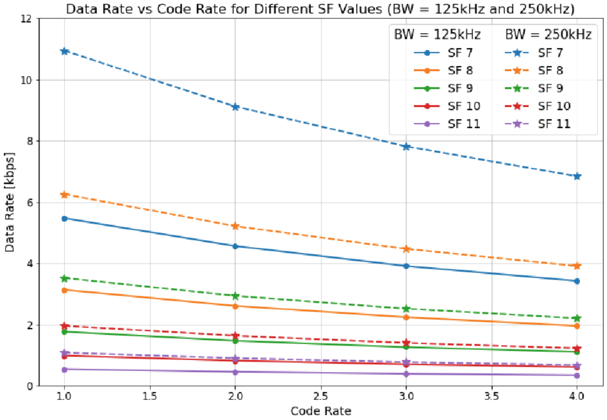


**Fig. 9.** Data rate for different SF and BW

Figure 9 showcases the relationship between data rate and code rate for different values of SF at two possible bandwidths based on LoRa's capabilities. CR shows an almost insignificant effect on the data rate when SF is high. However, smaller values of SF experience a visible reduction in data rate as CR increases. The study performs the calculation at two BW and demonstrates the effect of BW on the data rate and CR. The results show that, at any given code rate and SF, a higher data rate is associated with higher BW.

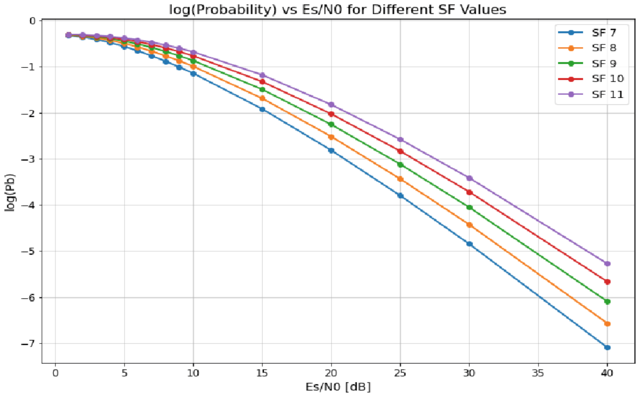


**Fig. 10.** Probability of BER for various SF

Another study done involved varying SF to observe its influence on the probability of BER, as shown in Fig. 10. This investigation is done as lower BER is desirable for the communication. As illustrated from the results, a high signal-to-noise ratio has a lower probability of BER, where the SF of LoRa has a small influence on the $P_b$.

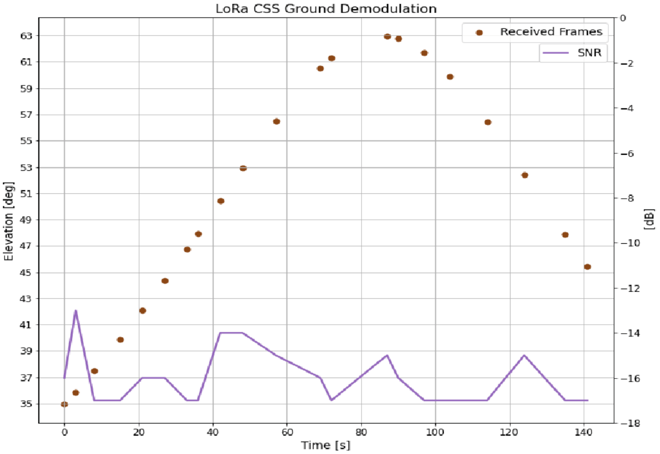


**Fig. 11.** Ground demodulated data received by YAM-3

Using the parameters above, the transmitting IoT Terminal can be set up. The parameters for the above test case: a transmission frequency of 865.070 MHz, a spreading factor of 9, a payload of 15 bytes, and the transmission cycle period was 5 s. In Fig. 11, the demodulated LoRa received frames from the satellite are plotted against the time (X-Axis) and SNR (Y-Axis). The figure shows the corresponding SNR at each LoRa demodulated frame with the respective elevation. As the elevation is higher, the SNR is also high signifying a better-received frame.

A spectrogram is also used, as a method of analyzing the level of intensity (Transmitted Power) on a time-frequency domain. The spectrogram, also known as a Waterfall diagram, allows us to understand and evaluate the power at different frequencies and evaluate the SNR on a visual basis. Often in a waterfall diagram, blue represents low pressure, and red is the highest recorded intensity [19]. The X-axis represents the frequencies, and the Y-axis represents the time spanned. The waterfall spectrum of the received data is shown below in Fig. 12 with the levels legend on the right indicating the low and high-power points in blue and red respectively. The red signal in the figure below is at the center frequency of transmission (865.070 MHz).

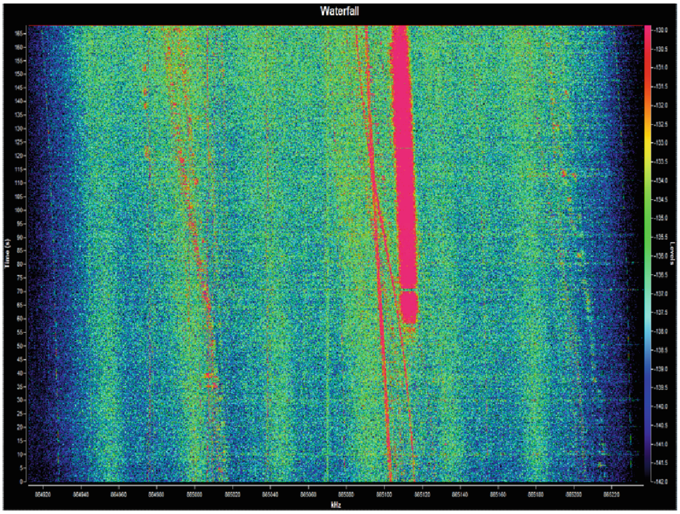


**Fig. 12.** Waterfall Diagram (Color figure online)

Using the same transmission parameters as the first test, similar results are obtained on DEWASAT-1. Figure 13 shows the full spectrum power and the spectrum power at the 125 kHz channel.

Figure 13 outlines 11 different tests done with different parameters. The ones to highlight are the last three tests' names DEWA-LORA-2022-06-04 and below colored (Lime, Aqua, and Blue respectively). The X-axis represents the time, and the Y-axis represents the Power in dbFS (Decibels relative to Full Scale) which is used in digital signals. Focusing on the lower part of the figure, it can be seen that all 3 tests have similar power values, distinctly different from the unsuccessful tests. This means they have a lower dbFS signifying a stronger signal. The lime and aqua signals have a shorter time scale as opposed to the blue signal due to the different pass time of the satellite.

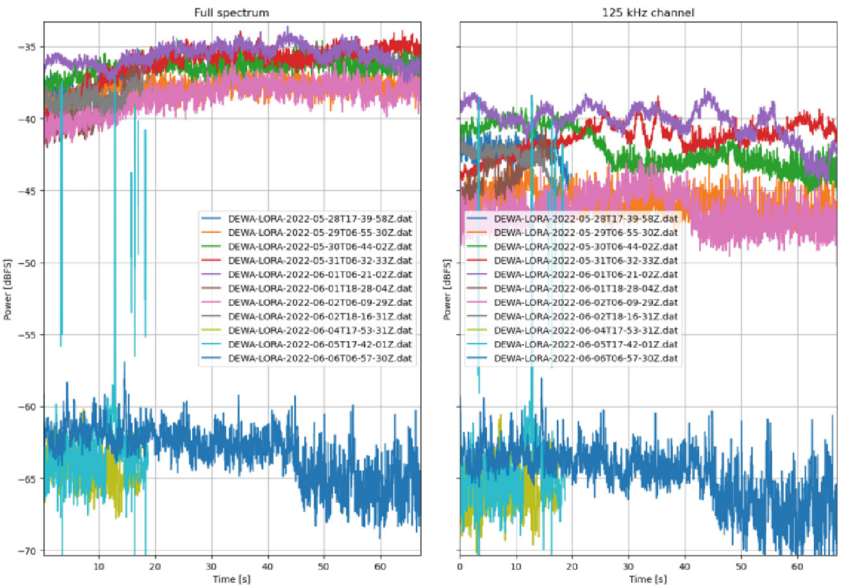


**Fig. 13.** Full and 125kHz spectrum power comparison for DEWASAT-1

## 4 Conclusion

This paper proposes a novel method to evaluate and assess the direct link between IoT-LoRa enabled devices and LEO nanosatellite DEWASAT-1. The results of the direct communication link between the satellite and IoT terminal using LoRa-CSS technology shows a successful link margin establishment signifying positive communication from the IoT terminal to LEO satellite. Despite atmospheric losses and power limitations of the IoT Terminal, a successful uplink was achieved. Orbital data results show a step in the correct direction with multiple LoRa frames demodulated at the ground using CSS.

For future work, the collection of orbital data will continue from DEWASAT-1 and other satellites in the constellation to further analyze the data and enhance the design of the IoT Terminal for improved reliability. Furthermore, the use of multiple IoT Terminals simultaneously will be implemented to evaluate the satellite receiver with multiple joint transmissions.

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