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Mission Concept, Analysis, and In-orbit testing of DEWASAT-1

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Abstract

Satellite-based Internet of Things (IoT) system is rapidly gaining popularity, permitting high connectivity to create an effective and reliable network of smart devices to operate, interact, connect, and share data. DEWASAT-1 is the first utility nanosatellite developed by Dubai Electricity and Water Authority (DEWA). The primary mission of DEWASAT-1 is to provide connectivity using IoT as a primary or backup system for electricity and water network devices and increase the flexibility in monitoring the network. Also, IoT connectivity is expected to enhance operational efficiency and effectiveness. DEWASAT-1 implements a novel method using a direct IoT-LoRa communication system to eliminate the necessity to include LoRa gateways. The satellite receives the LoRa signal through the onboard IoT-LoRa receiver, where the message approaches the nanosatellite directly. The link budget of the S-band transceiver closes at 5 degrees with a data rate of 3 Mbps. The UHF transceiver link budget closes at 0 degrees with a data rate of 2.4 kbps. The data budget illustrates that up to 256 MB of data can be generated and collected per day, where the data downlinked occurs in two passes. The data is then shared with the end-users to be employed for electricity and water utilities.

Keywords: DEWASAT-1, IoT, LoRa, CSS, Link Budget.

Abbreviations

Attitude Determination Control System (ADCS), Bit Error Rate (BER), Binary Phase-Shift Keying (BPSK), Communication System (COM), Chirp Spread Spectrum (CSS), Dubai Electricity and Water Authority (DEWA), Direct Communication To Satellite (DCTS), Electrical Power Subsystem (EPS), Engineering Model (EM), Flight Model (FM), Free Space Path Loss (FSPL), Internet-of-Things (IoT), Low Earth Orbit (LEO), Long Rang (LoRa), On Board Computer (OBC), Quadrature Amplitude Modulation (QAM), Research and Development (R&D), Receiver (RX), Radio Frequency (RF), Spreading Factor (SF), Transmitter (TX), Ultra-High Frequency (UHF), Wide Area Network (WAN).

1. Introduction

Small Satellites have gained popularity over the last few years for their low cost and capability to perform different missions for different payloads [1]. CubeSats are type of nanosatellites that comes in several sizes, which are based on the standard 1-U (Unit) CubeSat. A 1-U CubeSat is a 10 cm cube with a mass of up to 1 kg [2]. Typically, CubeSats consist of the bus and the payload. The bus consists of different subsystems required to operate the spacecraft, such as the COM, EPS, ADCS, and OBC [3]. Furthermore, the payload is determined based on the mission objective. Each mission begins with the mission requirements and identification. By adopting fewer restrictions and incorporating commercial technology, a rapidly expanding nanosatellite sector has made it possible for space missions to become more capable and affordable during the past few decades [4].

Nowadays, utility companies are exploring new energy management technologies that increase their capabilities. Space-D is an initiative of DEWA's R&D center. The project aims to build, design, and implement a series of nanosatellites to form a constellation in LEO. The nanosatellites are equipped with state-of-the-art technologies of remote sensing and communication devices utilized for utilities monitoring. The first nanosatellite, DEWASAT-1, was launched in January 2022, by Falcon-9 SpaceX, while the remaining are under development. DEWASAT-1 is a pilot project to build and implement an IoT-satellite-based network for electricity and water utilities.

IoT devices are growing at a rapid rate. The forecasted growth of IoT looks at having 75 billion devices connected by 2025 [5]. IoT is still the newest trend in the IT industry and is continuing to develop. The IoT is the concept of a worldwide infrastructure of networked physical things that allows for any time, everywhere connection for anything and not just for any one person [6]. IoT and Satellites have made a major leap in enabling DCTS. In fact, DCTS is a method where the Internet of Things device is outfitted with a potent Radio Frequency (RF) transceiver capable of broadcasting the LoRa frames at distances of up to 550 km, which is the altitude at which the

LEO satellites orbit [7]. The LoRa payload provides great impact for data communications between any IoT devices with an RF antenna and LoRa packet configuration and the satellite.

This paper provides a detailed assessment of the mission concept, analysis, and in-orbit validation of DEWASAT-1. The evaluation includes analysis of the link budgets of DEWASAT-1. Also, a detailed description of the payload design and implementation methodology of the mission is included. The orbital data results and successful communication link between the satellite and IoT terminal are presented in the paper.

The rest of the paper is organized as follows: Section 2 presents the related work to DEWASAT-1. Section 3 focuses on the link budget analysis and calculation. Section 4 illustrates and discusses the results. Section 5 concludes the paper.

2. Related Work

2.1 DEWASAT-1 Design and Manufacturing

The Design and development of DEWASAT-1 were done considering the different phases of CubeSat Design stages, including the Mission Concept Review (MCR), Preliminary Design Review (PDR), Critical Design Review (CDR), and Flight Model Readiness Review (FMRR). During the MCR, the mission requirements are identified as well as the system requirements including the payload and subsystem. The PDR and CDR include all the analysis of the design of the subsystem that follows the requirements of the mission where the PDR is the initial design review and then the design is closed in the CDR.

Fig. 1 shows the flight model of DEWASAT-1 which is a 3U CubeSat with a mass of 4.2 Kg and volume structure of 10 cm x 10 cm x 30 cm. It was launched last year in the LEO with an altitude of 550 km, orbiting the Sun Synchronous Orbit (SSO). DEWASAT-1 consists of several subsystems including the mechanical structure, EPS, COM, ADCS and OBC. The EPS has deployable solar panels containing 18 main solar cells and 12 are redundantly distributed through the different surfaces of the CubeSat, increasing the amount of power generation. As a result, the power budget margin exceeds 20% considering the worst-case scenario. Moreover, S-Band and UHF transceivers are used as part of the communication subsystem. The payload of DEWASAT-1 is a software design radio receiver (Satlab Polaris RX) that receives the IoT-LoRa message, stores and then forwards the in-orbit data to the target then to the DEWA user.

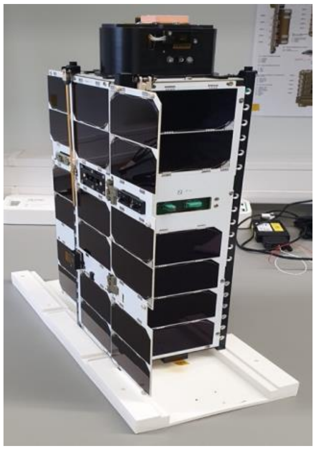

Fig. 1. DEWASAT-1 FM Isometric view

2.2 Mechanical and Thermal simulations for DEWASAT-1

Several tests were conducted after finalizing the design of the mission including mechanical testing and thermal testing to verify that the nanosatellite design can withstand the space environment and survive for the entire mission lifetime. The results of the satellite mechanical analysis that was performed show a satisfactory mechanical design. A random vibration test was conducted for random vibration loads where during the test there was no exceeding factors of safety are detected. Also, the thermal analysis was conducted for DEWASAT-1, and it is simulated considering the worst and nominal cases including both highest and lowest temperatures. Fig. 2 presents the worst case hot and cold temperatures of the satellite. The results indicate that in all cases the temperatures are within the operational and survival limits with a sufficient margin.

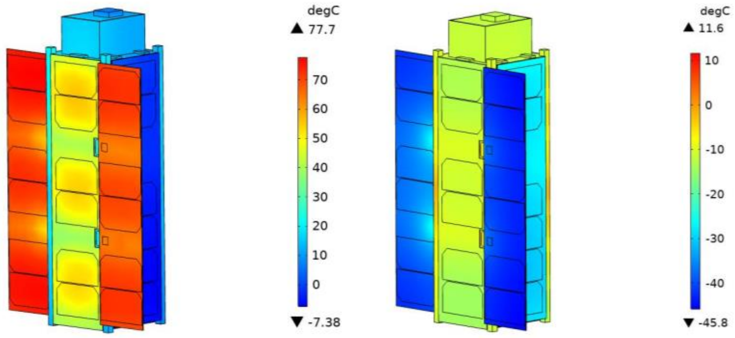

Fig. 2. Worst case satellite temperatures (a) Hot (b) Cold

2.3 DCTS IoT-LoRa System via DEWASAT-1

The inhouse developed IoT terminal utilized LoRaWAN Protocol and CSS modulation to transmit telemetry data to the satellite. Then, the received housekeeping data from the three terminals are transmitted from the satellite to the ground station during the downlink at a specified bit rate using S-band transceiver. Finally, the received data are uploaded into a cloud to be used for various IoT platforms. Fig. 3 demonstrates the process.

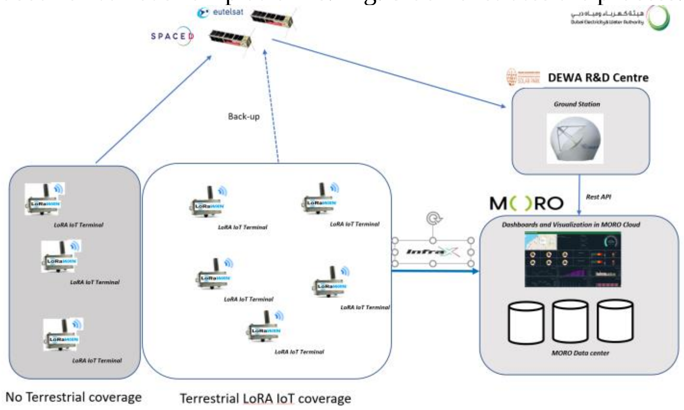

Fig. 3. DEWASAT-1 IoT-LoRa system architecture

2.4 LoRa Payload Test Setup

Several experiments were conducted between ground LoRa terminal (TX) and DEWASAT-1 EM or the FlatSat (LoRa Payload RX). The test included: sending uplink data to the FlatSat, downloading the received data, and sharing the data for decoding. The goal of the test was to measure the received power at LoRa Payload (SatLab Rx) and measure the FSPL of RX, and to compute the BER vs C/N and Link margin prediction for worst case scenario for each tests bench. The figure below shows the test setup for LoRa communication system.

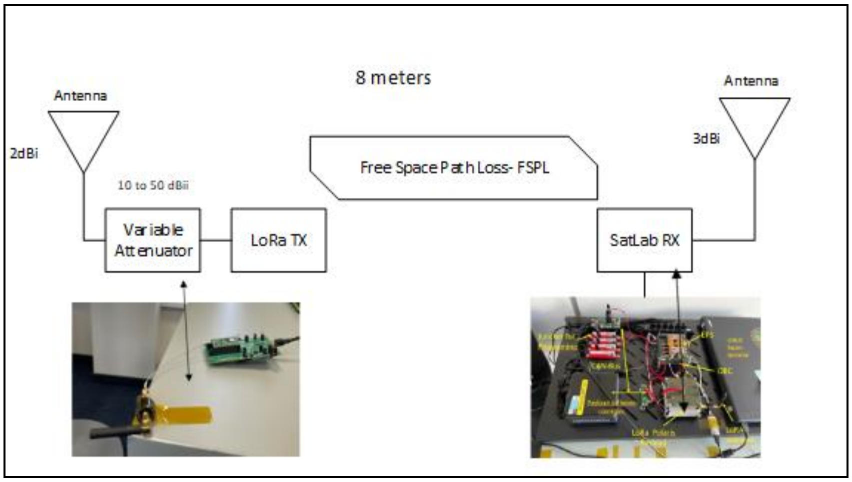

Fig. 4. LoRa test setup

3. Link Budget Analysis and calculation

A full analysis of the link budget for DEWASAT-1 was done considering several factors including the losses that affects the performance of the signal such as antenna pointing loss, rain loss, polarization loss, and implementation loss. The table below displays the input parameters that were used in the calculation.

Table 1. Input data

GND TX power (dBm)	25	Altitude (Km)	500
GND antenna gain (dB)	0	Pointing loss (dB)	0.5
Symbol rate (Symb/sec)	122.07	Polarization loss (dB)	0.5
Frequency (MHz)	865.07	Rain loss (dB)	0.2
Satellite antenna gain (dB)	6.5	Implementation loss	0.5
Receiver noise figure (k)	458	Rate code	0.5
Boltzmann (dBW/Hz/K)	-228.6	Spreading Factor	10
Code rate	4	Bandwidth (KHz)	125
Bit rate (bit/sec)	1.95	Req. Eb/N0	6

The link margin must be positive in the design of the communication system to ensure a reliable and successful communication link between the ground station and the satellite. Link margin in dB is evaluated as [8]:

Link Margin (dB) = $C/N_{0,\ \text{expected}} - C/N_{0,\ \text{Required}}$ (1)

Where the expected and required C/N_0 can be calculated as:

$C/N_{0,\ \text{Required}} = S/N_0 +$ Loss in mod/demod process (2)

$C/N_{0,\ \text{expected}} = \text{EIRP} - L + G_{rx} - 10 \log (BW/3\text{kHz}) -$ Receiver noise power density (3)

Where C/N_0 is the carrier to noise ratio, S/N0 is the signal-to-noise power ratio, loss in mod/demod is the losses accompanied by the modulation and the demodulation of the signal, EIRP is the Effective Isotropic Radiated Power, and Grx is the antenna’s gain in the reception. Table 2 shows the results of the link budget analysis where the last raw in the table is the link margin for different elevation angles. It is clear that the link margin increases upon the increase of the elevation angle.

Table 2. Link margin Analysis

Satellite elevation (deg)	30	40	50	60	70	80	90
Antenna bore angle (deg)	0	0	0	0	0	0	0
Antenna gain towards GND (dB)	0	0	0	0	0	0	0
GND EIRP density (dBW/Hz)	-25.9	-25.9	-25.9	-25.9	-25.9	-25.9	-25.9
Distance (km)	909.4	741.3	636.8	570.5	529.5	507.1	500.0
Free space path loss (dB)	150.4	148.6	147.3	146.3	145.7	145.3	145.2
PFD/4kHz at Satellite	-120.0	-118.3	-116.9	-116.0	-115.3	-115.0	-114.8
Noise temperature (K)	751	751	751	751	751	751	751
Satellite G/T (dB/K)	-22.3	-22.3	-22.3	-22.3	-22.3	-22.3	-22.3
$C/N_{0,\ \text{Required}}$ (dB)	16.0	16.0	16.0	16.0	16.0	16.0	16.0

$C/N_{0,\ expected}$ (dB)	28.4	30.2	31.5	32.5	33.1	33.5	33.6
Link Margin	12.4	14.2	15.5	16.5	17.1	17.5	17.6

4. Results and Discussion

4.1 DEWASAT-1 Lifetime

According to the mission analysis of DEWASAT-1, the design indicates approximately 7 years of the CubeSat lifetime in orbit due to orbital decay depending on launch orbit and operations pointing. Where the simulation results illustrate that the shortest lifetime is 3 years as shown in Fig. 5 assuming launch to 525 km altitude and 4 kg satellite mass. Also, it is noted that all space debris requirements are satisfied for the mission.

Fig. 5. Shortest case satellite orbital lifetime

4.2 Link Budget Simulation

For DEWASAT-1, LoRa CSS modulation is used for uplink while S-band transmitter is used for downlink. Moreover, the UHF transmitter is used as a backup for both the uplink and downlink. Also, since the results from table 2 indicate that downloading data with a low elevation angle is challenging, the study considers an elevation angle of 90 degrees.

4.2.1 Link Margin for Different Frequencies

The link margin for both CSS (uplink) and the S-band (downlink) was calculated using Matlab for different altitudes. From Fig. 6(a), it is obvious that the link margin decreases as the altitude increase. For both the CSS and S-band, the link margin is positive for an altitude less than 700 Km. So, for DEWASAT-1 which has an altitude of 550 Km, the link margin is positive. Also, from the plot, it is noticeable that the S-band has lower link margin than the CSS.

4.2.2 Probability of BER for Different Modulations

The relationship between the probability of the BER and the energy per bit to the noise power density (Eb/N0) (Fig.6 (b)) is used to estimate the quality of the communication link between DEWASAT-1 and the ground station. The analysis considers various modulation techniques such as PSK, QAM, BFSK, and BPSK. The findings demonstrate that the BER varies as the modulation changes, which has an impact on the system's performance. When compared to other modulation systems, DEWASAT-1's modulation scheme has a significantly low BER for small Eb/N0 values.

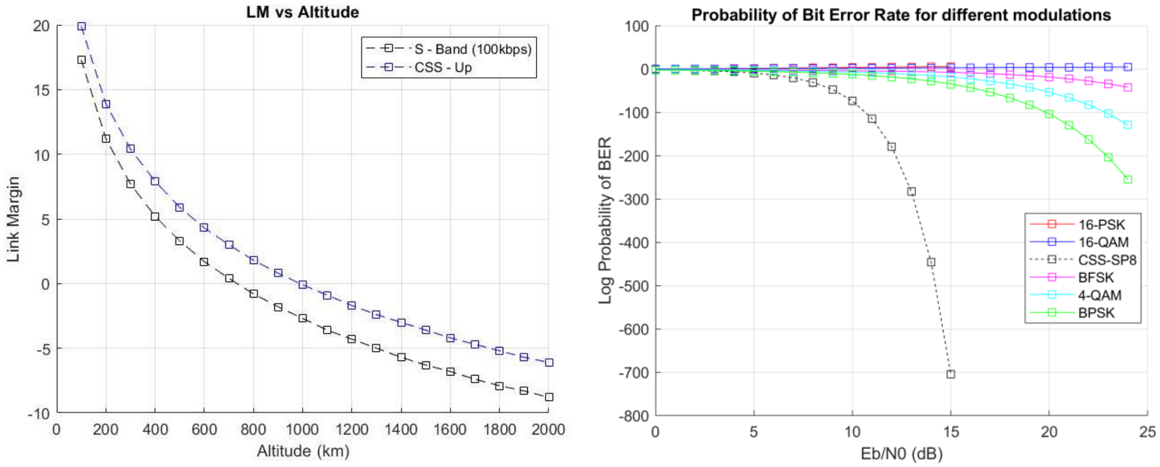

Fig. 6. (a) Link margin for CSS and S-Band (b) BER for different modulations

4.2.2 BER for Different Spreading Factor

The number of chips per LoRa symbol is indicated by the SF [9], which has an impact on the performance of the transmission signal in LoRa communication. While analysing the communication link margin, BER is a crucial factor to consider because, as shown in Fig.7, a greater spreading factor, a lower BER, and thus the number of chips rises.

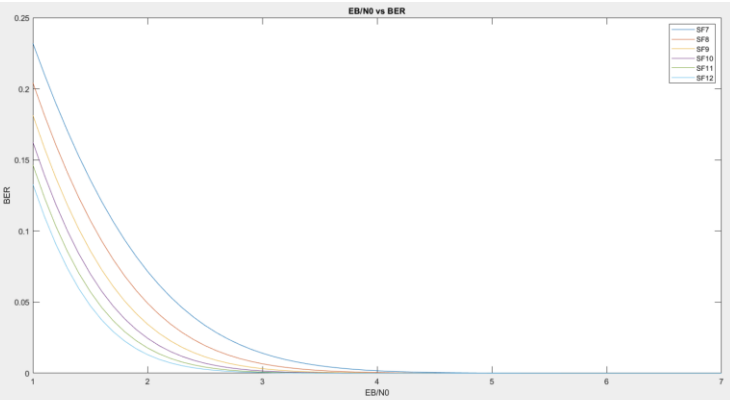

Fig. 7. BER for different SF

4.3 DEWASAT-1 Orbital Data

The housekeeping data in real time that was sent from the terminal and then received by DEWASAT-1 are sorted into a platform for different use-cases developed in R&D. Fig. 8 & Fig. 9 display DEWA’s platform designed for weather data for one month. The weather data include temperature, relative humidity, and air quality index $PM_{2.5}$ and PM_{10}.

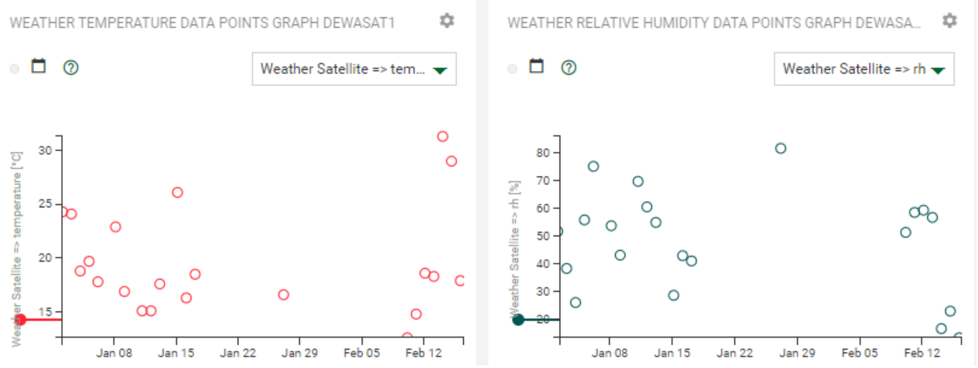

Fig. 8. Weather satellite data (Temperature & Relative humidity)

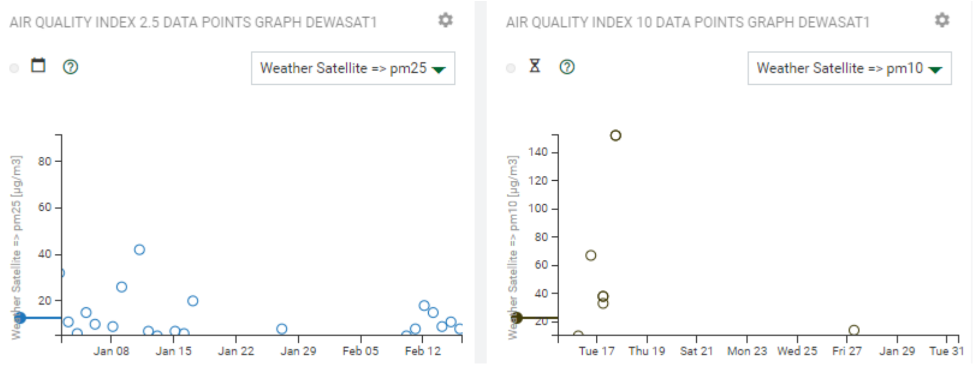

Fig. 9. Weather satellite data (Air quality)

6. Conclusions

In conclusion, DEWASAT-1 was developed by DEWA R&D and launched successfully into its orbit in January 2022. The simulations outcome concluded with a positive link margin for uplink and downlink. Also, accurate simulation was explored for the vital parameters such as carrier to noise, and bit error rate for LoRa modulated signal (CSS), compared with other modulation as BPSK. Currently, the uplink tests from the ground station to DEWASAT-1 were performed positively and still ongoing for tests till his life duty cycle. The satellite orbital data are continuously collected into platforms to further analyse the data to enhance the IoT design. Further investigations on LoRa FHSS needs to be done to validate the performance of data reception compared to LoRa CSS transmission.

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