An Overview of Software-Defined Radio Technology in CubeSat Communications

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Abstract: Small satellites are becoming more popular because they are cost-effective, easy to assemble, and use commercially available parts. However, traditional ground stations that communicate with small satellites require a lot of hardware and are expensive to build. This makes it challenging to get the most out of small satellites' information. Software Defined Radios (SDRs) have been developed to reduce the cost of these ground stations by doing many of the tasks in software. Many universities and organizations are developing SDR ground stations to communicate with satellites in different orbits. Communication with satellites is critical to their development and operation. This paper proposes a ground station that uses SDR technology to communicate with one or more small satellites in Low Earth Orbit (LEO). The station is cost-effective, portable, and easily scaled, allowing it to acquire data from satellites.

Keywords: Small satellites, ground stations, Software Defined Radios (SDRs), software-based operations.

1. INTRODUCTION

In the past, the development and launch of satellites have been prohibitively expensive, which often made it difficult for developers to take risks and introduce new technologies into space. However, the introduction of CubeSats [1], a class of small satellites, has opened up relatively low-cost access to space. CubeSats are typically launched as secondary payloads, which means they share a launch vehicle with another primary payload. To accommodate this, CubeSats must fit within a specific size envelope, usually ranging from 1U to 12U (where 1U is a cube of 10 x 10 x 10 cm) [2]. This size limitation allows for greater flexibility in launching them into space and makes them more cost-effective than larger satellites.

CubeSats have diverse applications in space [3], such as scientific research, commercial services, and educational outreach. They aid Earth observation, atmospheric studies, and in-orbit technology testing. CubeSats offers global internet connectivity, tracks traffic, and commercially provides remote sensing services. They enable students' hands-on learning and space mission participation, revolutionizing space exploration.

Initially, CubeSats were designed with simple payloads and only needed a basic ground/space communications link. However, the latest CubeSat models now carry high-quality remote sensing instruments, such as megapixel cameras, that generate large amounts of data to be downlinked to the ground. As a CubeSat moves over a ground station, the signal-to-noise ratio and other link characteristics may vary, making maintaining a high data throughput rate difficult. Several research papers have suggested using software-defined radio (SDR) technology [3-5] to address this issue to adapt to these changes and ensure reliable high throughput dynamically. By utilizing SDR technology, satellites can quickly and easily adjust their communication protocols, enabling them to maintain optimal performance even as signal conditions change.

Software Defined Radio (SDR) is a versatile technology increasingly applied in CubeSats. SDR allows for the design of adaptive communication systems that adjust to varying link characteristics, allowing for efficient and reliable data transmission. Additionally, SDR provides the capability to perform updates wirelessly and to reuse the same hardware platform for multiple missions with different communication requirements. This technology has become a popular solution for small satellite communication systems. It is expected to continue to play a significant role in developing CubeSat technologies in the future.

This paper presents a comprehensive CubeSat SDR design based on the hardware technology for digital signal processing and the RF subsystem. The design ensures that the CubeSat SDR is adaptable to the dynamic changes in satellite link characteristics, resulting in a higher data throughput rate. Furthermore, the SDR architecture's flexibility allows for future upgrades, keeping the radio design upgradable for many years. The proposed SDR design has several advantages over

traditional radios, including its ability to support multiple waveforms, modulation schemes, and frequency bands. The design also has a low-power consumption profile, which is crucial for CubeSats with limited power budgets. The proposed SDR design will help advance the capabilities of small satellites by providing a high-performance and flexible communication system.

2. SYSTEM OVERVIEW

This section provides an overview of the SDR module and the mission design of the Aalto-1 nanosatellite system [6, 7]. The bus of the Aalto-1 nanosatellite is based on the existing 3U CubeSat designs, measuring 0.34 m x 0.10 m x 0.10 m with a launch mass of around 4 kg and an average power production of 4.8 W. Despite having a design life of two years, the satellite has exceeded its expected lifespan, showcasing the reliability and robustness of the technology used in its development.

Figure 1 provides a visual representation of the CubeSat and its program structure. The model depicted in the figure is a helpful tool for comprehending and analyzing the project's design and objectives.

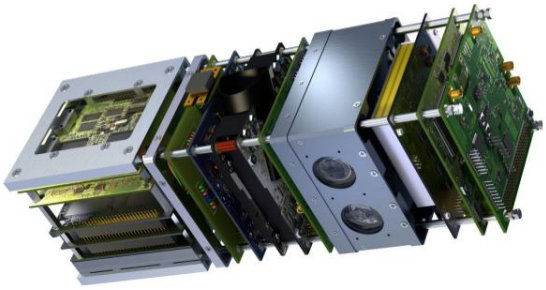


Figure 1. subsystem overview of the CubeSat

The CubeSat subsystems consist of various components such as the Radiation Monitor, the Global Positioning System's (GPS) antenna, the Attitude Determination and Control System (ADCS), the Aalto Spectral Imager, the Electrical Power System (EPS), the On-Board Computer (OBC), the Ultra High Frequency (UHF) radios, the solar panels, and the S-band and UHF antennas. On June 23, 2017, the Aalto-1 nanosatellite was launched as a secondary payload aboard the PSLV-C38 rocket. The orbital parameters are summarized in Table 1.

Table 1. The orbital parameters of the nanosatellite

Type	Orbit LEO
apogee/ perigee	517 km / 497 km
Eccentricity	1.45E-03
Inclination	97 degrees
PERIOD	95 minutes
Rgument of perigee	To be determined
RAAN	To be determined
True anomaly	To be determined

Figures 2 and 3 illustrate the nanosatellite's ground track and three-dimensional orbit, respectively. These visuals provide valuable information on the satellite's coverage area, ground footprint, position, and motion in space. Together, they enhance our understanding of the nanosatellite's orbital characteristics and aid in analyzing its behavior and performance in orbit.

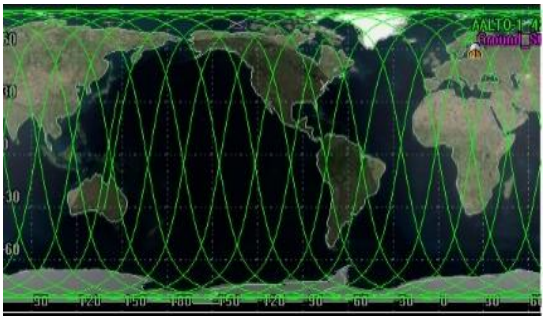


Figure 2. nanosatellite's ground track

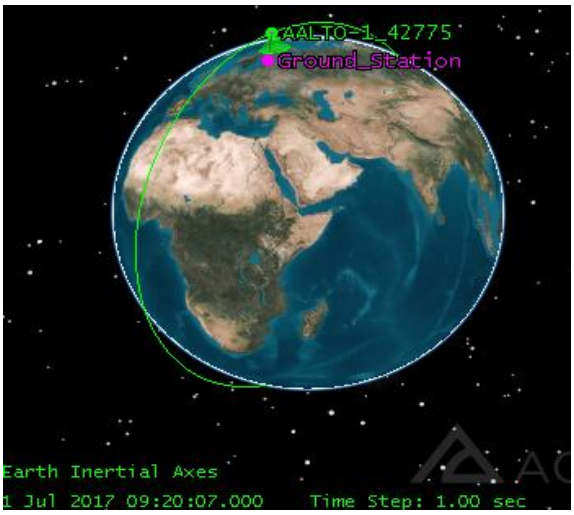


Figure 3. nanosatellite's orbit

The position and velocity of the CubeSat in orbit can be accurately determined using Systems Tool Kit (STK). The figures below

illustrate the precise position and velocity of the nanosatellite, providing valuable visual insights into its orbital dynamics. These figures offer a comprehensive representation of the CubeSat's movement and speed, enabling a thorough analysis of its orbital behavior and trajectory.

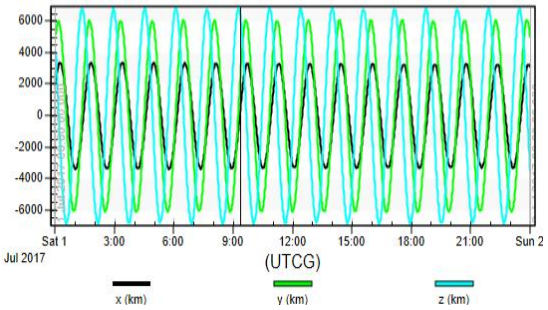


Figure 4. Position of the CubeSat

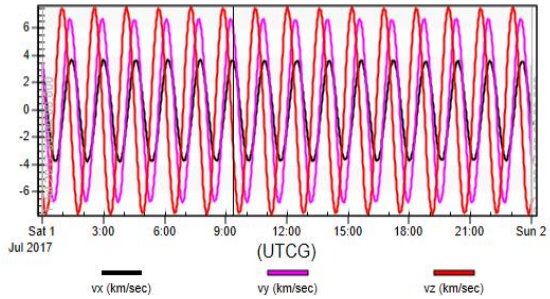


Figure 5. Velocity of the CubeSat

3. SYSTEM OVERVIEW

Software Defined Radio architecture is a wireless communication system design that uses software to process and manipulate radio signals instead of relying on hardware components. It enables flexible, reconfigurable, and programmable radios that adapt to different communication standards and frequencies. SDR architecture improves flexibility, scalability, and upgradability in modern wireless communication systems.

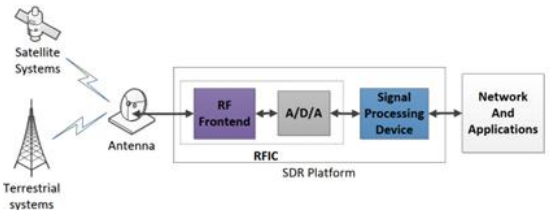


Figure 6. A Radio System Based on Generic SDR Technology

Figure 6 illustrates that the SDR hardware is comprised of a Radio Frequency Front End (RFFE), A/D/A converters, and a signal processing device. It is worth noting that the RFFE and A/D/A are sometimes integrated into a single chip, known as a Radio Frequency Integrated Circuit (RFIC).

SDR platforms currently utilize a range of signal processing devices, including General Purpose Processors (GPP), Field-Programmable Gate Arrays (FPGA), Digital Signal Processors (DSP), Specialized Processing Units (SPU), and Hybrid devices. These five families of signal processing devices have been extensively deployed in SDR platforms, providing a broad range of options for implementing SDR systems.

For example, the Ettus B210 USRP SDR platform, featured in Figure 7, serves as the primary board used in nanosatellite communication and is obtained at an estimated cost of around USD 1000. The board comes equipped with a broad range of features, including RF coverage spanning 70 MHz to 6 GHz, APIs for GNU Radio, C++, and Python, a USB 3.0 SuperSpeed interface, a Standard-B USB 3.0 connector, flexible 12-bit ADC/DAC rates, grounded mounting holes, 2 Transmitters and 2 Receivers operating in either Half or Full Duplex, fully-coherent 2x2 MIMO capability, instantaneous bandwidth up to 56 MHz in 1x1 and 30.72 MHz in 2x2, GPIO capability, and even includes a DC power supply.



Figure 7. Ettus B210 USRP SDR Platform for Nanosatellite Communications [8]

There are many specific software programs used for configuring a software-defined radio, depending on the device you are working with and the functionality you are aiming for. GNU Radio is the most commonly used open-source software, which provides a graphical interface for building and testing SDR applications using blocks, which represent various SDR signal processing chain functions, such as filters, modulators, demodulators, and digital signal processing (DSP). This allows the operator to use these blocks to create a custom signal processing chain tailored to their needs. By connecting the blocks in the desired order, users can

build a ground station receiver to receive and process signals from a nanosatellite.

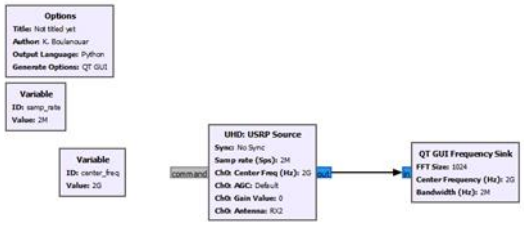


Figure 7. Example of configuration of USRP SDR Using GNU radio

4. CONCLUSION

In conclusion, software-defined radio technology has transformed CubeSat communications by providing a flexible, cost-effective, and adaptable solution for nanosatellite missions. SDR-based radios enable the development of customized applications suitable for the specific needs of a satellite, and their ability to reconfigure and reprogram the hardware via software makes them ideal for CubeSats. As technology evolves and improves, more significant advances and innovations in CubeSat communications can be expected.

References

[1] Twiggs, R.J. A new generation of picosatellite for education and industry low-cost space experimentation. in AIAA/USU Small Satellite Conference Proceedings, 2000. 2000

[2] McKnight, B.R., et al. Design and testing of an additively manufactured advanced hybrid rocket motor propulsion unit for CubeSats (PUC). in 51st AIAA/SAE/ASEE Joint Propulsion Conference. 2015

[3] Selva, D. and D. Krejci, A survey and assessment of the capabilities of Cubesats for Earth observation. Acta Astronautica, 2012. 74: p. 50-68.

[4] Maheshwarappa, M.R., M.D. Bowyer, and C.P. Bridges, Improvements in CPU & FPGA performance for small satellite SDR applications. IEEE Transactions on Aerospace and Electronic Systems, 2017. 53(1): p. 310-322.

[5] SANTOS, W., A Software Defined Radio Approach to Ground Operations of Small Satellites.

[6] Kestilä, A., et al., Aalto-1 nanosatellite–technical description and mission objectives. Geoscientific Instrumentation, Methods and Data Systems, 2013. 2(1): p. 121-130.

[7] Praks, J., et al. Miniature spectral imager in-orbit demonstration results from Aalto-1 nanosatellite mission. in IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium. 2018. IEEE.

[8] Popescu, O., S. Abraham, and S. El-Tawab, A mobile platform using software defined radios for wireless communication systems experimentation. 2017.