SATELLITE TELEMETRY DATA RECEPTION AND PROCESSING VIA SOFTWARE DEFINED RADIO

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1. INTRODUCTION

Satellites have become an indispensable part of today's technology, being used for different purposes, from providing long distance telephone connections, to direct broadcasting of television and radio, and obtaining geological information or other facilities. Satellites also present a particular interest in terms of academic.

A satellite can be logically seen as a set of integrated subsystems. Aimed at monitoring the satellite and its health each subsystem has a set of sensors for measuring the satellite states and conditions. These measurements are transmitted to the ground stations in each satellite pass and are called telemetry data [1].

Telemetry is the highly automated communications process by which measurements are made and other data collected at remote or inaccessible points and transmitted to receiving equipment for monitoring [2].

Satellite telemetry data reception is performed by a radio architecture. Ensuring the functionality of a traditional radio architecture, in a satellite communications is based primarily on hardware, with minimal software configurability.

A traditional radio architecture is shown in Fig. 1.

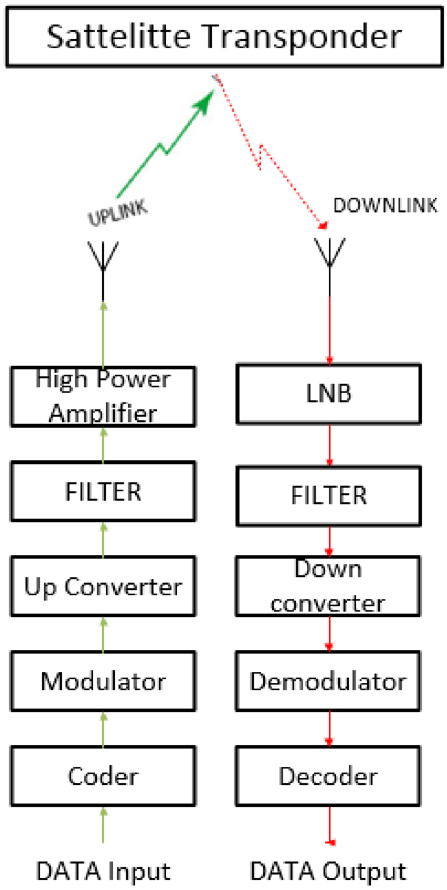

Figure 1. Traditional radio architecture.

The software part is used for network communication interfaces. Considering that in this model prevails hardware components, any system upgrade would mean actually complete system redesign. As a solution for this problem was developed Software Defined Radio (SDR) Software-defined radio is a radio communication system where components that have been typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system [3].

A telemetric station based on SDR, such as Universal Serial Radio Peripheral (USRP) can be programmed to transmit and receive any signal in the corresponding frequency The USRP is usually controlled by GNU Radio software, that present a free software development toolkit that provides signal processing blocks to implement software-defined radios and signal processing systems. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. Within this environment may be created applications using graphical toolkit GNU Radio Companion (GRC).

This toolkit uses a signal processing functional blocks that make up a flow chart. GRC allows the design of a radio system using ”*drag and drop*” interface. After finishing of the design, GRC converts flowchart to a Python file containing the corresponding description of the system. GNU Radio also allows the creation of new functional blocks that would implement new signal processing operations.

2. SDR TELEMTRY STATION

The goal that we set was to design a telemetry station based on SDR and GNU Radio. We used USRP B200 from Ettus Research, which is fully integrated USRP device with continuous RF coverage from 70 MHz –6 GHz with full duplex operational and with up to 56 MHz of real time bandwidth. The proposed architecture for telemetry base station using USRP and GNU Radio is shown in Fig. 2.

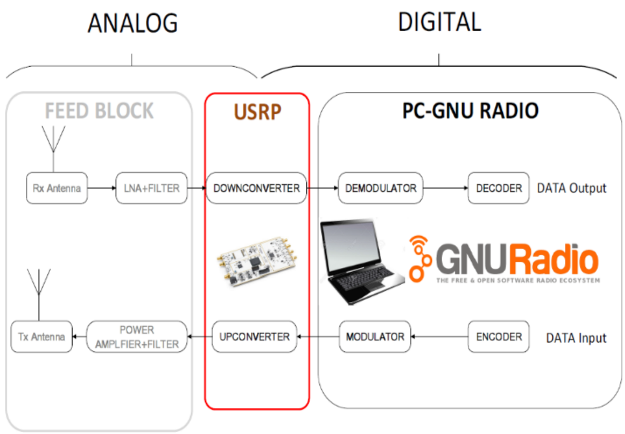

Figure 2. Software Defined Radio Architecture.

In the above architecture is distinguished analog subsystem (feed block) and digital subsystem (GNU Radio, USRP and PC). Analog subsystem acts as an interface for radio frequency environment. USRP, based on the FPGA (Field Programmable Gate Array), in terms of hardware, it has a modular construction, consisting of a base plate (motherboard) to which can be attached daughters boards. USRP is connected to a PC via a Gigabit port or USB. On the PC, GNU Radio operates with further signal processing by digital processing blocks. Conceptually, these blocks performs endless processing of data streams from input ports to output ports.

The basic attributes that characterize a digital processing block are: type of data and number on input/output ports. The GNU Radio package includes about 100 digital signal-processing blocks.

Conventional diagram in the GNU Radio to receive telemetric information is presented in Fig. 3.

USRP block source presents a interactive way to interconnect hardware model. This block also allows interface configuration of SDR's reception, while ensuring configuration of key parameters

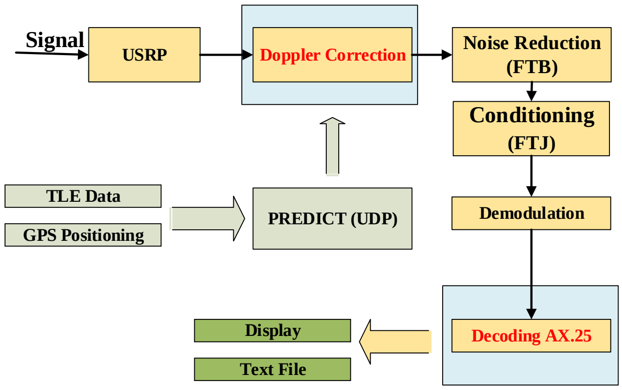

Figure 3. The reception of telemetry information in GNU Radio.

such as reference signal source, the number of acquisition channels, center frequency, sampling rate and others. Doppler correction block is used to adjust the frequency variation on satellite movement, being directly influenced by the satellite orbit data. This correction will be explained in the next section.

3. DOPPLER CORRECTION

The Doppler effect (or Doppler shift) is the change in frequency of a wave (or other periodic event) for an observer moving relative to its source. [4]

This effect appears at achieving communication with a satellite as carrier frequency increases when the source approaches the receiver and decreases when the source moves away from the receiver. Since the frequency deviation is variable it is necessary to make an adjustment for received signal frequency. Frequency adjustment can be achieved so as hardware or through GNU Radio. Hardware method can be excluded because it has a drawback expressed by the additional cost and additional equipment. Using GNU Radio toolkit, Doppler correction may be received with the same precision and speed but with lower budget spending. The software and hardware accuracy correction is the same, but for both methods, time procession is big, because it measures the current frequency then it adjusts the required frequency.

To increase the accuracy of correction we used a method with prediction of the possibility of an error. If we know the current path of the satellite and its coordinates, it is possible to predict the frequency deviation at a certain time.

GNU Radio does not have digital signal processing blocks for satellite coordinates and trajectory, but these data can be received from Predict toolkit via UDP.

Predict is an open-source, multi-user satellite tracking and orbital prediction program written under the Linux operating system. Data such as a spacecraft's sub-satellite point, azimuth and elevation headings, Doppler shift, path loss, slant range, orbital altitude, orbital velocity, footprint diameter, orbital phase (mean anomaly), squint angle, eclipse depth, the time and date of the next AOS (or LOS of the current pass), orbit number, and sunlight and visibility information are provided on a real-time basis.

To receive Doppler correction, has been developed a script, as shown in Fig. 4. The script is used for interconnection between GNU Radio software and Predict toolkit.

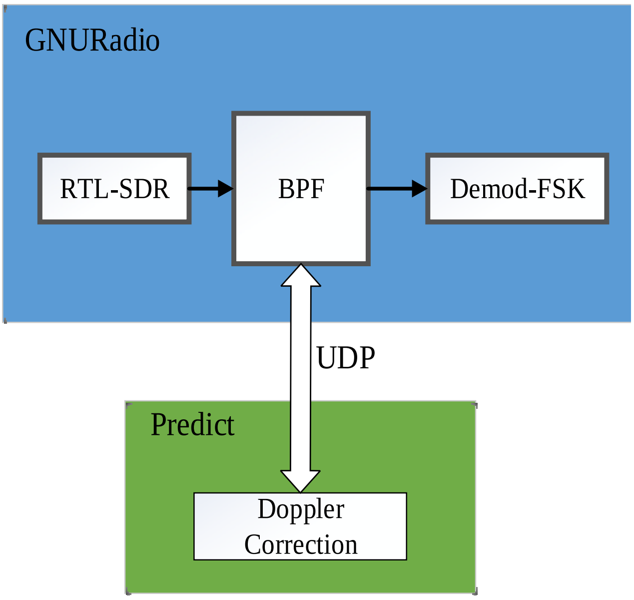

Figure 4. Doppler correction diagram.

The implemented system consists of filtering and demodulation blocks and using Predict it is realized necessary Doppler correction.

The prediction data is calculate based on satellite TLE information. A two-line element (TLE) is a set of two data lines listing orbital elements that describe the state (position and velocity) of an Earth-orbiting object. In the Fig. 5 is represented Predict toolkit that displays the list of satellites and orbital parameters. This list can be modified by the renewal TLE data.

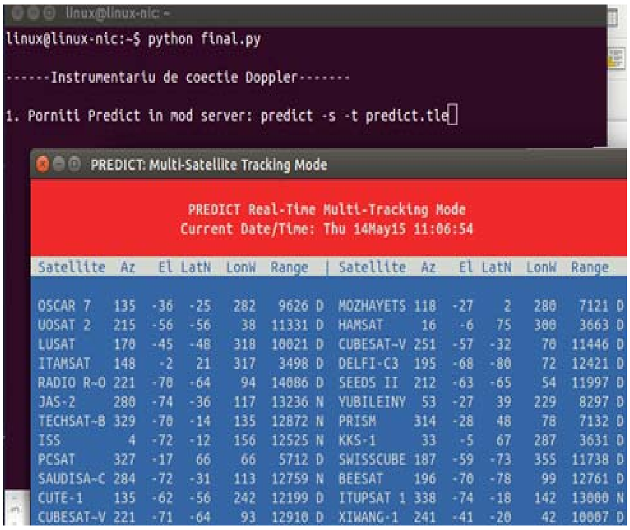

Figure 5. Orbital parameters of satellites.

After software Predict is ran, we start developed script required for sending data about Doppler correction to GNU Radio. It have to be mentioned that Predict was start in server mode. It made possible to Doppler acquisition. The results are shown in the next figure (Fig. 6).

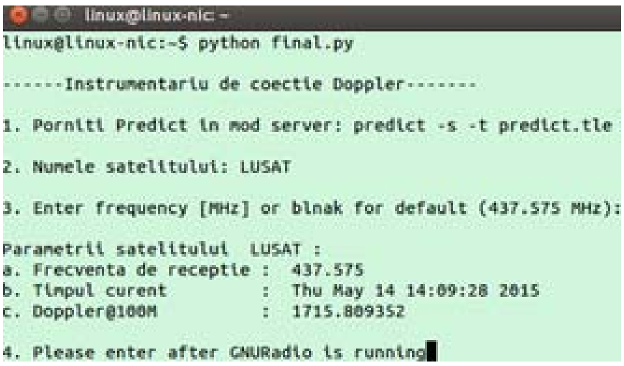

Figure 6. Developed script for Doppler acquisition.

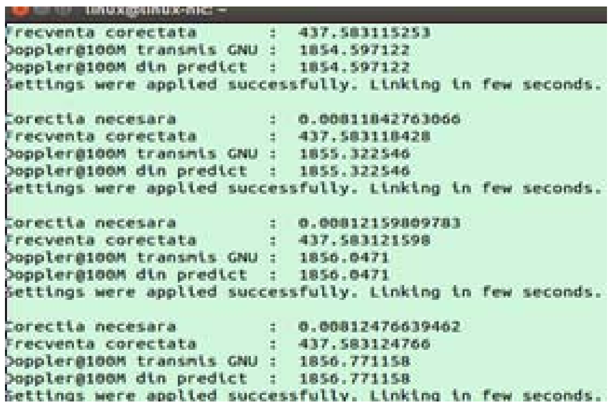

Figure 7. Doppler correction send to GNU Radio.

Data transmission correction is carried out after entering name and frequency of the desired satellite. After entering the data, the script performs a request to Predict. This one transmits correction data to GNU Radio. Also, these data are displayed on the terminal, like is shown in Fig. 7.

The correction data displayed on the terminal may be transmitted to GNU Radio block due to use XMLRPC Server.

Therefore, thanks to prediction data, communication frequency can be adjusted more quickly compared with Doppler correction performed by hardware.

4. IMPLEMENTATION

After writing classes in C++ for digital processing blocks, and using Python language for organizing and interconnecting them were created following digital processing blocks for GNU Radio: AX.25 Decoder, Doppler Correction.

After Doppler correction it will be presented receiving architecture in GNU Radio for telemetry. The first process is general noise levels reduction.

Since the signal normally is not centered at the expected frequency, even Doppler-corrected, a setting must be present that re-centers the frequency and modifies the parameters of all filters to match the new characteristics of the signal.

In the bellow flow graph we have following blocks: Low Pass Filter block that represents a low pass filter for signal adjustment. The next three blocks in the diagram below are used to analyze the signal shape and form logical levels. The block decoding the telemetry gives information created by the protocol AX.25 frame structure described above. Sink File module enables real time data storage on a local storage environment or in a space shared on the network that has access to the workstation. Writing is done in binary format (as standard float 32), and saved data can be processed further either GNU Radio using a block read (File Source) or in other programming environments. The whole diagram is shown in Fig. 9.

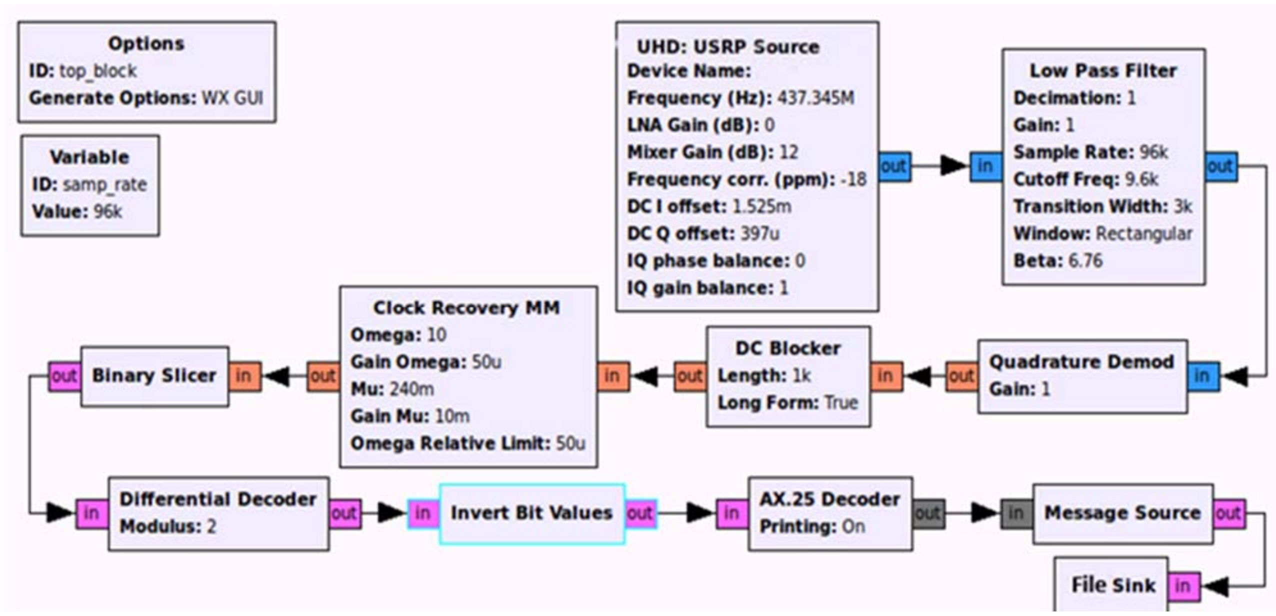

Figure 9. Implementation of created digital signal processing block

5. CONCLUSION

SDR provides a new approach to designing a network of ground stations satellite, an approach that brings primarily significant reduction in design complexity and cost and offers a flexible environment, versatile radio architecture development.

Digital processing modules created (AX.25 decoder) in the development environment GNU Radio, offers a range of possibilities because the encapsulation and decoding blocks based on adaptive communication protocol AX.25 are used by other microsatellites. Also these modules would find implementing in a network of earth stations for more effective communication with microsatellites.

On receipt of telemetry, configuring orbital data of any satellite and taking into account the position of the earth station may be omitted Doppler effect. It applies for any satellite.

Therefore, SDR and especially GNU Radio creates a number of possibilities that go far beyond the limits of traditional radio architecture.

In the designing process we were able to continuously improve the software implementation in stages with subsequent iterative correction of errors that occur during operation.

The results from this work are implemented in TUM Space Technologies Center.

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