ASPECTS OF A LOW-COST GROUND STATION DEVELOPMENT FOR GENSO NETWORK

Vlad DASCAL[1], Paul DOLEA[1], Tudor PALADE[1], Octavian CRISTEA[2],
[1]Technical University of Cluj-Napoca, Faculty of Electronics, Telecommunication and Information Technology, 26-28 Baritiu Street, Tel: +40264 401804, Fax: +40264 591340, Email: dascalvlad@yahoo.com
[2]BITNET CCSS SRL, 56 Vasile Lupu Street, Cluj-Napoca, Tel: +40264441198, Email: octavian.cristea@bitnet.info

Abstract: This paper presents the development and setup of a GENSO ground station at the Technical University of Cluj-Napoca. The ground station will be capable of automatic tracking of selected LEO satellites by using steerable high gain antennas. The ground station will be equipped with a full-duplex VHF/UHF transceiver with SSB, CW and FM modulation capabilities and with a TNC AX.25 protocol compatible, that offers data rates of 9600 bps FSK and 1200 bps AFSK for digital satellite communication. The architecture is based on the design heritage of the ground station built in support of the future Romanian Goliat mission. Tests were completed with good results and demonstrate the technical feasibility of the platform based on link budget calculations. The ground station will represent the Romanian contribution into the worldwide GENSO network and it will also act as a test-bed for the GEOID/HumSAT system.

Keywords: *Nanosatellite, Low Earth Orbit, GENSO network, ground station, Cubesat*

I. INTRODUCTION

Recent efforts to provide low cost access to space for education, science and space-based component testing have led to the development of the nanosatellites [1]. With very few exceptions, ground-space communications are actually made in Amateur Radio bands where the hardware requirements are not as critical as for higher frequencies. A typical student space segment consists of small satellites placed on LEO orbits, often sun-synchronous. These nanosatellites are equipped with low-power transmitters (less than 1W), that operate in Amateur Radio bands (VHF, UHF, L and S) and uses standard communication protocols (such as Packet AX.25).

A typical ground segment is composed of a single low-cost ground station, usually hosted by universities or by ham radio operators. Generally, the ground station is built using commercial off-the-shelf (COST) hardware and software and is capable of communication on one or two of the Amateur Radio frequency bands (VHF/UHF bands) [2]. The ground station is usually equipped with a single azimuth and elevation rotator to track the spacecraft. A single PC is controlling the ground station's hardware and the mission payload data.

There are some typical limitations regarding the ground-space communication. From approximately 15 orbits, there are around 6 passes per day with a time average of 5 minutes each. The LEO nanosatellites are in the communication range less than 3% of the mission time. For the remaining of 97% of the time, the ground stations are idle. Also, typical ground stations are not configured to communicate with other educational spacecraft and the satellites are only configured to communicate with specific ground stations.

To overcome these limitations, a better approach is needed and involves sharing the hardware resources. The potential of near-global coverage for all participating missions, allows for a dramatic increase in mission return and enables access to a large amount of live spacecraft data at very low-cost. Many critical operations would benefit from having uninterrupted coverage for several tens of minutes. The solution for this problem consists in developing of a flexible global Java based software standard which allows existing educational and ham radio ground stations worldwide to be linked together. In this way, the ground stations communicate with each other's satellites and send the mission data (telemetry and experimental data) to the mission control operators via the Internet.

II. THE GENSO PROJECT

GENSO (Global Educational Network for Satellite Operations) [3] is an educational project initiated and coordinated by the ESA's Education Office and endorsed by the International Space Education Board (ISEB), which consists of representatives from education departments of CSA, CNES, ESA, JAXA and NASA. Additional support is provided by radio amateur members of AMSAT-UK [4].

The purpose of GENSO is to develop a worldwide network of university and ham radio ground stations to support the operations of university satellites [5]. This goal is achieved through a distributed open-source software system connected via the Internet, which facilitates the streaming of the mission data from different ground stations to the mission control operators. The Java based software development was carried out by an international team of students and radio amateurs. Currently, the project is in testing phase "GENSO R2 Network" [6] and is expected the release of the software under open-source license.

Access to the GENSO network is possible using one of the two main software applications. The operators of the

Manuscript received October 25 2011; revised November 28, 2011

ground stations use a Ground Station Server (GSS) and mission controllers run a Mission Control Client (MCC) application. The secure access, within GENSO network, is made by the Authentication Server (AUS), which ensures at all times that the entities participating in the network have the permission to do so. The simplest GENSO network is presented in Figure 1.

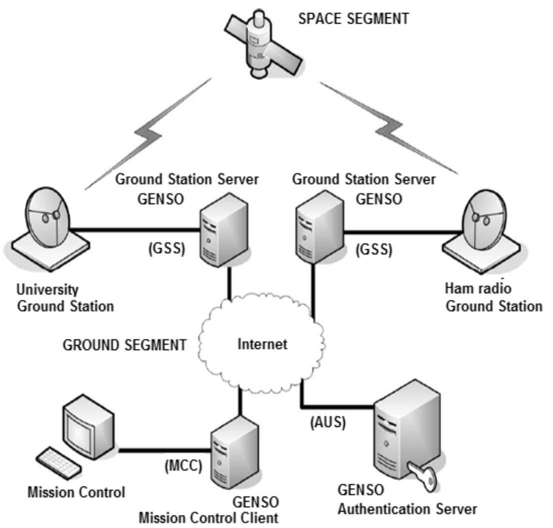

Figure 1. Architecture of GENSO network

The Ground Station Server (GSS) application will be installed on each ground station of the network. After authentication with the Authentication Server (AUS), through the User Interface, the GSS allows participating GENSO ground station operators to automatically track and maintain downlink sessions with all compatible participating spacecraft. Also, the GSS application offers the possibility of uploading telecommands to compatible spacecraft (if allowed by the mission operators). Another feature of the GSS involves optional automated scheduling and establishing dedicated passes for particular missions (through booking negotiations with the MCC).

The Mission Control Client (MCC) application will be installed for each mission control center in the network. After the authentication with the AUS, the mission operators can control its spacecraft using remote stations. Consequently, the MCC application allows participating GENSO spacecraft to be automatically tracked by all compatible ground stations in the network. After the pass, all the retrieved data (telemetry and payload data) will then be sent to MCC regardless of the station location. For dedicated passes, the MCC will negotiate and book capable GENSO ground stations in order to establish uplink sessions with the spacecraft.

The Authentication Server (AUS) acts as a central core of the entire GENSO network and provides control and cohesion for this otherwise distributed system. The University of Vigo in Spain hosts the European Operations Node [7] and coordinates access to the GENSO network through the AUS server. The main purpose of the AUS is to validate the GSS and MSC instances when authentication, to maintain and update the dynamic status of all GENSO ground stations and nanosatellites and to distribute this information to all online nodes (GSS and MSC instances) as requested and necessary.

III. EXPECTED BENEFITS OF THIS PROJECT

The participation into the GENSO educational project resulted from an international university competition at European level, won by the Technical University of Cluj-Napoca. The industrial partner for this educational project is the telecom research company BITNET CCSS from Cluj-Napoca. The development of "One GENSO ground station in Cluj-Napoca" offers important educational benefits, which are presented as follows:

- Represents the Romanian contribution into the worldwide GENSO network and will be the first GENSO sensor available in the Eastern part of Europe.
- The educational value is reflected by gaining experience into LEO satellite communication field (university and OSCAR satellite) and other terrestrial ham radio activities.
- Encourages formation of a coherent space education community within the Technical University of Cluj-Napoca.
- Offers close collaboration with the local and international Amateur Radio community (AMSAT) to support future missions.
- Offers unparalleled near-global access to educational and Amateur Radio satellites in orbit.
- Offers low-cost implementation and fast deployment into GENSO network.
- Ideal for university environment and represents the first step in developing local space infrastructure (ground segment) serving low-budget space missions (tracking, telemetry, experimental data, and even telecommands).

IV. GROUND STATION ARCHITECTURE DESIGN

Figure 2 illustrates a low-cost ground station architecture for university environments, which is specifically built for small satellites in Low Earth Orbit (LEO) such as Cubesats. The technical feasibility of this design is based on the proven setup of the one of the ground stations built for the Goliat satellite mission [8, 9], which has been tested successfully on university and OSCAR/AMSAT satellites.

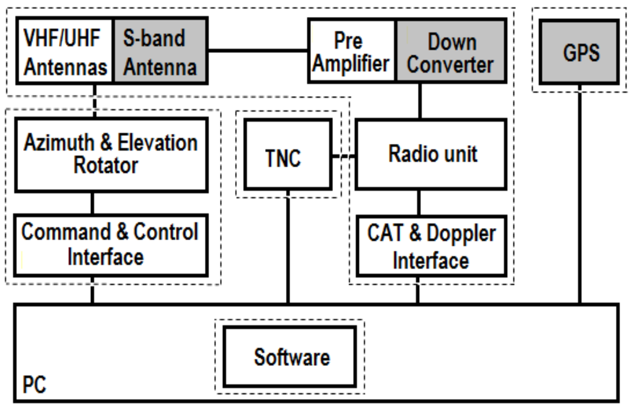

Figure 2. Typical VHF/UHF ground station architecture design

This modular architecture meets different requirements, which are application dependent, and is compatible with the preliminary GENSO hardware performance specifications [10]. The main modules are:

- Rotator block includes the digital interface for automatic command and control of the azimuth-elevation rotator.
- RF block is satellite or application dependent. It consists of the VHF/UHF antennas, dual-band preamplifiers, the transceiver unit and the digital interface for CAT control and Doppler correction. S-Band implementation [11] is achievable with minimum implementation.
- TNC block necessary for different digital satellite communication techniques (Packet AX.25 and APRS).
- GPS block used for time synchronization and accurate geographical coordinates. The GPS module is optional if the ground station is placed in a location with Internet infrastructure.
- PC block contains software applications (open-source or proprietary) used for satellite tracking (TLE updates) and mission data storage.

III. GROUND STATION HARDWARE IMPLEMENTATION

The chosen hardware components are compatible with the GENSO hardware specifications. The geographical coordinates of the ground station are 46º45'N latitude and 23º36'E longitude. For the chosen location, no GPS module is necessary. Primarily, the ground station will operate in the VHF/UHF amateur radio frequency bands. In the near future, it is expected the integration, within the ground station, of an S-band module for increased mission data return. The TUCN ground station will act as a test-bed for the GEOID (GENSO Experimental Orbit Initial Demonstration) [12] and HUMSAT (Humanitarian Satellites) [13] systems. Figure 3 illustrates the desired hardware implementation of the TUCN ground station.

The Yaesu G-5500 [14] azimuth and elevation rotator was chosen for real time tracking and prediction of LEO satellites. The Azimuth rotator features a turning range of 450° (360°+90°), while the Elevation rotator has a rotation range of 180°. The Yaesu G-5500 is remote controlled from the PC unit through the GS-232A [15] digital interface. The GS-232A allows steering the antenna beam towards the satellite, based on the TLE orbital data.

Two high gain VHF/UHF Yagi antennas are used for simultaneous operation in VHF (2m) /UHF (70cm) frequency bands. The X-Quad Yagi [16] antenna is very efficient for LEO satellite communication due to its high performances compared with other stacked array Yagi antenna systems. Linear (H/V) and circular polarization (RHCP/LHCP) switching is achieved through an optional coax relay mounted near the antenna feed points.

The dual-band DBA-270 [17] pre-amplifier improves SNR of the received signal from the satellite in the same bands and allows operating in different AMSAT satellite modes (V/U, U/V, etc.). The UEK-3000 [18] down-converter hardware will convert the 2.4 GHz satellite downlink signal to a VHF/UHF signal (for S-Band implementation).

The Icom IC-910H [19] is an all mode FM/CW/SSB radio transceiver used in VHF/UHF amateur satellite communication. This full-duplex transceiver operates in the frequency range of 144-146 MHz and 430-440 MHz. The IC-910H offers sufficient power for uplink VHF/UHF sessions, eliminating the need of an external high power amplifier. Also, Icom IC-910H is equipped with two data sockets for simultaneous band packet operation at a maximum speed of 9600 bps.

The Doppler Effect [20], [21] is significant in satellite operation especially at high frequencies and must be compensated for. That's why, its essential the integration of a digital control interface for automatic tuning of the uplink and downlink satellite operation frequencies. The Icom IC-910H transceiver is PC software controllable through CT-17 TTL [22] converter hardware (based on MAX232 chip), used especially for automatic CAT control of the rig and for Doppler Effect compensation.

For digital satellite communication capabilities, the ground station will be equipped with Kantronics KPC-9612+ TNC [23] (terminal node controller) hardware, which acts as a radio modem. The KPC-9612+ equipment is an all mode dual port VHF/UHF TNC with AX.25 capabilities and offers full-duplex data rates of 9k6 bps FSK and 1k2 bps AFSK for packet radio satellite operation.

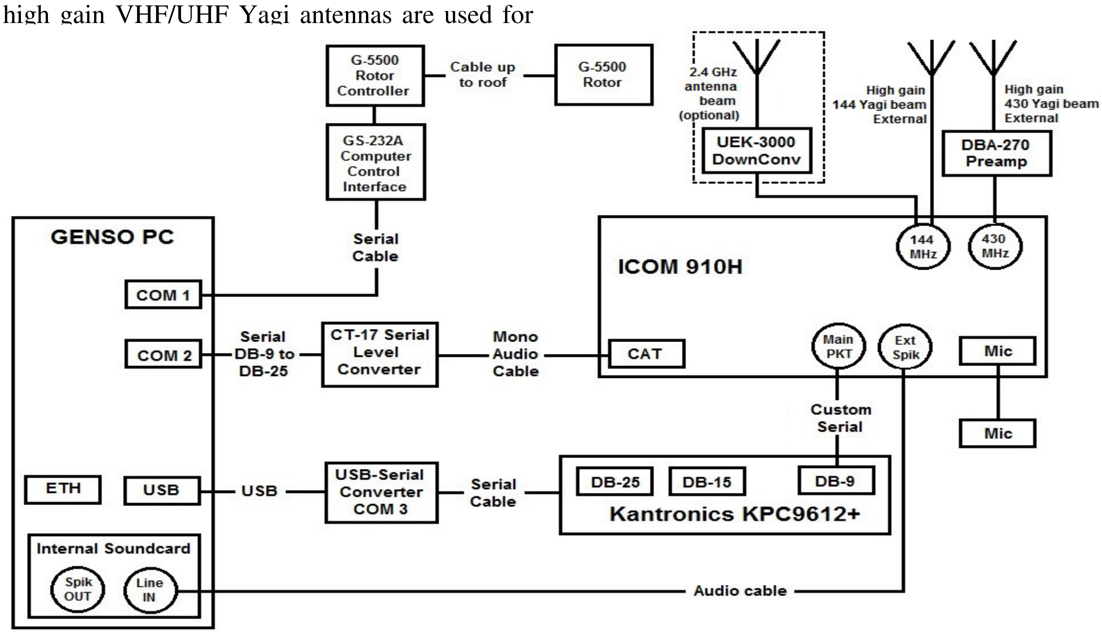

Figure 3. Hardware architecture design for the GENSO ground station

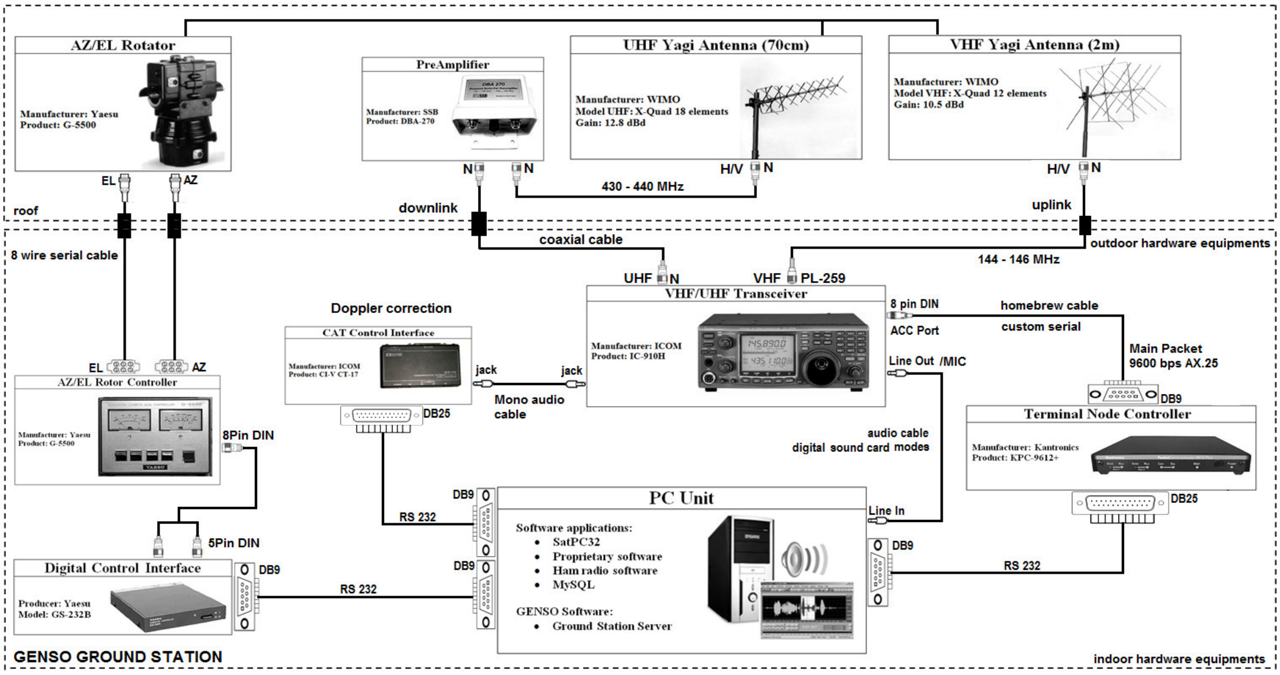

Figure 4. Hardware interconnection for the TUCN GENSO ground station

The current setup of the TUCN ground station is illustrated in Figure 4 and is suitable for AMSAT V/U or U/V satellite mode operations.

IV. GROUND STATION SOFTWARE IMPLEMENTATION

The TUCN ground station will be equipped with ham radio and Java specific GENSO software.

The SatPC32 [24] satellite tracking software was chosen for its popularity and driver support for the chosen COTS hardware. Based on accurate time reference, geographical coordinates and the TLE/AMSAT orbital data, SatPC32 predicts in real time the trajectory of multiple satellites at any given moment. During a pass, SatPC32 automatically steers the Yaesu rotator antenna system towards the LEO satellite, tunes the uplink/downlink frequency of the Icom IC-910H rig and also makes automatic Doppler correction through the CT-17 level converter. For digital satellite communication, simultaneous VHF/UHF packet radio operation is possible using proprietary Kantronics KPC-9612+ TNC software. AGW Packet Engine [25] software is necessary for AX.25 packet radio without the TNC hardware (KISS mode). For the most popular digital soundcard operation modes, the ground station will be equipped with the ham radio WSJT software.

The integration of the TUCN ground station in the GENSO network involves the use of a Ground Station Server (GSS) software application [10]. The functional block diagram for the GSS software application is shown in Figure 5. All the technical details of the hardware components (rotator, transceiver, etc.) are configured manually through the GUI of the GSS application. The Scheduler automatically plans and executes downlink passes for selected GENSO satellites and allows MCCs to make reservations for bidirectional sessions.

The Controller module communicates with the AUS and receives an updated list with GENSO spacecraft details. All the mission data are stored locally in Database and after that, are sent automatically to the mission control operators.

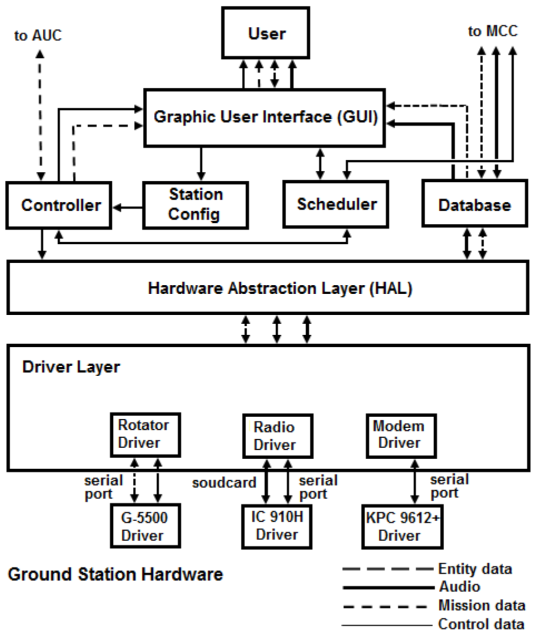

Figure 5. Functional block diagram of GSS application

Hardware Abstraction Layer (HAL) provides the necessary specific drivers for the local hardware in order to ensure the compatibility with the GSS software application.

V. EXPERIMENTAL RESULTS

Preliminary experimental tests were conducted into the VHF/UHF Radio Amateur frequency bands using a ground station that has a similar architecture and performance of a standard GENSO station. The first tests involved tracking and maintaining a LEO satellite communication link during a pass, and have been completed with good results.

The technical feasibility of the platform was demonstrated by receiving CW beacons and telemetry TLM (Mode U) at data rates up to 9600 bps AFSK/FSK from various university and OSCAR satellites (CO-55, CO-57, CO-65, AO-51, etc.). Also, were established contacts with OSCAR microsatellites (VO-52, AO-51) equipped with FM transponders (mode V/U, U/V FM voice repeater) into the VHF/UHF bands, in order to measure the received signal strength.

Link budget simulations have shown that a reliable communication between the TUCN ground station and different LEO nanosatellites is feasible even in worst condition scenario. For now, the TUCN ground station is not online into the GENSO network; as a consequence, no experimental tests were undertaken for this network.

VI. CONCLUSIONS

The GENSO network will represent the global infrastructure in support for future educational nanosatellite space missions. The setup of a TUCN GENSO ground station is ideal for university environments and represents the first step in developing space infrastructure (ground segment) serving low-budget space missions (telecommands, tracking, telemetry and experimental data). For the technical solutions chosen, the experimental VHF/UHF tests undertaken revealed that, during a pass, a steady satellite link between the ground station and LEO satellites is achievable.

ACKNOWLEDGEMENT

The development and setup of the GENSO ground station within the Technical University of Cluj-Napoca is supported by the telecom research company BITNET CCSS from Cluj-Napoca, through the infrastructure, logistical support, and expertise in LEO satellite communication.

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