ARCHITECTURE OF THE GROUND STATIONS - SATELLITES COMMUNICATION NETWORK

[1]Ion Bostan, academician, [2]Ioan-Marius Piso, Dr. eng., [1]Viorel Bostan, prof.Dr.Sc., [2]Alexandru Badea, prof. Dr.eng., [1]Nicolae Secrieru, assoc.prof. Dr., [2]Marius Trusculescu, Dr. eng., [1]Sergiu CANDRAMAN, PhD student, [1]Andrei Margarint, PhD student

[1]Technical University Of Moldova

[2]Romanian Space Agency

1. INTRODUCTION

Space technologies have an important role in the development of different branches of the economy, especially agriculture, geodesy and surveying, ecology and environmental monitoring, prevention and mitigation of floods and other natural disasters etc. In recent years the number of universities that initiate and develop projects in the field of development and launching of pico-nano-microsatellites into space for scientific, socio-economic, commercial purposes etc. is increasing.

Small satellites are built and launched into space with minimal costs, but generally they can ensure an intense exchange of data with ground stations distributed territorially. Ground stations are usually isolated and have limited radio visibility periods between the station and the satellite, including possessing low temporal resolution. A more effective solution would be to create a network of interconnected ground stations that can communicate with remote control. Such networks of ground stations allow monitoring a wide range of satellites, such as educational and commercial satellites for several universities. Development of such networks requires the construction of ground stations located on the territory in a dispersed way with an appropriate antenna system capable of ensuring a good quality and functionality of the communication.

The authors promote the idea of ground stations connection via a computer network in a complex infrastructure, including its connection via the Internet to the Romanian Space Agency (ROSA) and the European Space Agency (ESA), which would help increase usability and efficiency of satellite communications. In this paper we present the concept of development of ground stations network of satellite communication and technical solutions aimed at ensuring reliable "*satellite-ground infrastructure*" communication with remote control and connection to ROSA and ESA.

2. ARCHITECTURE OF THE GROUND STATIONS NETWORK OF SATELLITE COMMUNICATIONS

The project *Connecting the Infrastructure of the National Centre of Space Technologies with the Educational Global Network for Satellite Operations*, conducted during the years 2015-2016, is a continuation of the efforts made for the realization of the State Program "Development of the Moldovan Satellite". The new project's objective is to make the connection of the research centres in Moldova to the pan-European research thematic infrastructure, such as ESFRI (European Scientific Forum for Research Infrastructure) ERICs (European Research Infrastructure Centres), ETPs (European Technology Platforms) etc.[1,2,3].

The idea of connecting ground stations (Figure 1) through a virtual network of computers was developed within the project, which allows considerable extension of the radio visibility period of a satellite and, consequently, increasing the amount of data sent. Another opportunity is the simultaneous reception of data from a satellite via several ground stations, and storing them in the command centre, where the data packages will merge. This system allows improving the quality of "*satellite - ground stations*" communication by reducing the bit error rate (BER). Specialized laboratories (SBNMS, PDI, AEMS, SCT), established within the National Centre of Space Technologies (NSTC), TUM, Chisinau, together with the network of ground stations, form the ground infrastructure of satellite communications with the architecture shown in Figure 1 [1-3]. MS in orbit flight through the actuator drivers of Rotor BIG-RAS/HR model.

An important role in the ground infrastructure is assigned to the ground station with parabolic antenna (Figure 1d) for the reception of images from the MS on the orbit. The parabolic antenna, with a diameter D = 4.3 m, through two separate actuator drivers fitted with drivers, can revolve around two axes in individual regime commanded on the server computer. The kinematic chain of the two actuator drivers is fitted with mechanical torsions to exclude the gear backlash, thus increasing kinematic (angular) accuracy of parabolic antenna orientation towards the MS in orbit flight. MS in orbit flight through the actuator drivers of Rotor BIG-RAS/HR model.

Ground stations endowed with specialized equipment ensure the upward and downward links of the microsatellite (MS) (Figure 1b) in orbit flight with the ground infrastructure (Figure 1c, d). The station is connected to a set of telemetry antennas, and to the parabolic antenna with mixed purpose [1-3], which are able to orient on two axes.

An important role in the ground infrastructure is assigned to the ground station with parabolic antenna (Figure 1d) for the reception of images from the MS on the orbit. The parabolic antenna, with a diameter

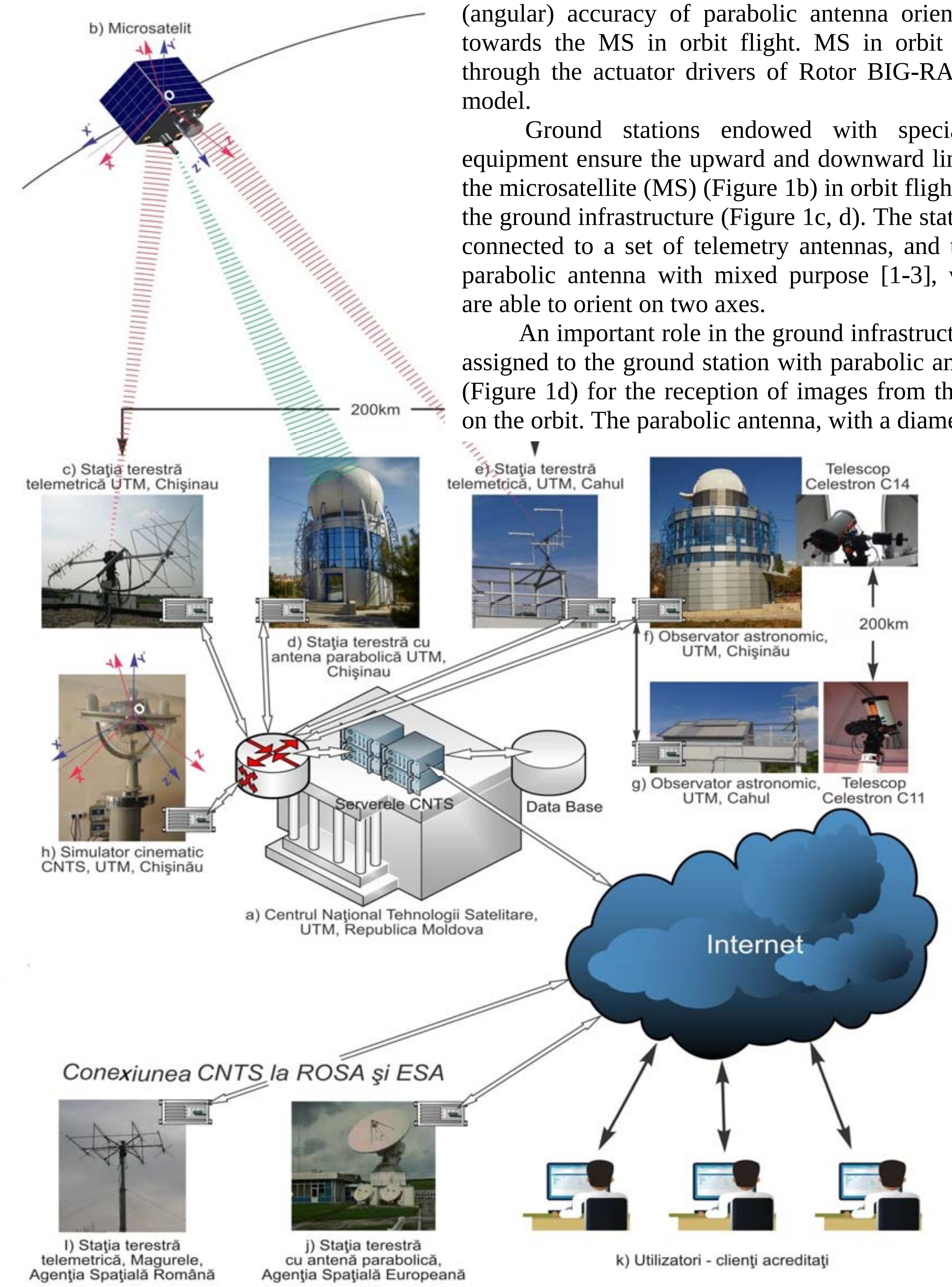


Figure 1. Architecture of ground stations network developed at TUM, Chisinau, with connections to ROSA and ESA.

a) Space Technology Center, NSTC Servers; b) Microsatellite; c) Telemetry ground station of TUM, Chisinau; d) Ground station with parabolic antenna of TUM, Chisinau; e) Telemetry ground station of TUM, Cahul; f) Astronomic observatory with Celestron C14 Telescope, Chisinau; f) Astronomic observatory with Celestron C14 Telescope, Cahul; h) Kinematic simulator of the NSTC, TUM, Chisinau; NSTC connection to ROSA and ESA; i) Telemetry ground station, Magurele, Romanian Space Agency; j) Ground station with parabolic antenna, European Space Agency; k) Users - accredited clients.

Figure 2. Ground station with parabolic antenna, 9 Studentilor str., Chisinau

Figure 3. The parabolic antenna of the ground station, 9 Studentilor str., Chisinau.

D = 4.3 m, through two separate actuator drivers fitted with drivers, can revolve around two axes in individual regime commanded on the server computer. The kinematic chain of the two actuators drivers is fitted with mechanical torsions to exclude the gear backlash, thus increasing kinematic (angular) accuracy of parabolic antenna orientation towards the MS in orbit flight.

For the installation and operation of the ground station with parabolic antenna with mobility on two axes (elevation and azimuth) a building was built in the area adjacent to the location of NSTC (9 Studentilor str., Chisinau) with a foundation of 16

Figure 4. Astronomic observatory of TUM, 9 Studentilor str., Chisinau

Figure 5. Celestron C14 telescope of the Astronomic observatory, UTM, Chisinau.

m. The resistance structure of this ground station was reinforced vertically with two membranes of reinforced concrete to take over reactive torque load generated by dynamic movements of elevation and on the azimuth of the parabolic antenna weighing about 2 t. On the second floor of the building the tracking points of the MS flight is located connected via optical fibre to the support point in Cahul, Branza commune, and to NSTC, Chisinau.

To expand the area of monitoring and altitude control of the MS flight (about 200 km away) a support point equipped with a telemetry antenna was built in the commune of Branza, Cahul (Figure

1e). Ground infrastructure also includes an astronomical observatory located in Chisinau, equipped with a telescope model Celestron C14 and an astronomical observatory located in the support point of commune Branza, Cahul equipped with a telescope model Celestron C14.

Celestron telescopes' both servers are connected to NSTC via optical fibre. Thus, the infrastructure created with two telescopes interconnected and connected to NSTC virtually allows real-time recording of the MS positioning in flight from two land points. All components of the ground infrastructure (Figure 1a, c, d, e, f, g, h) are interconnected by optical fibre, and NSTC has connections with the telemetry ground station in Magurele, Romania, extending to the European Space Agency, based on the implemented project [1-3].

Figure 6. Astronomic observatory, com. Branza, Cahul.

3. REMOTE CONTROL OF SATELLITE OMMUNICATION GROUND STATIONS

The network of ground stations, whose architecture is shown in Figure 1, is designed and constructed so as to ensure the communication among stations regionally / worldwide via the Internet. Ground stations can communicate via client applications with server components based on TCP / IP protocol (Figure 8). The architecture developed (Figure 1) enables centralizing the data received from a satellite by different ground stations in the same database. Client applications can only communicate with the server, Server components having the administrative role. The Server component is the only link of the system which provides access to the database and is able to communicate with all client applications in the system. In order to implement the remote control of ground stations, the "*client-server*" classical architecture was taken as the basis consisting of three parts: a VPN server and a separate network device that interconnects the main server and the clients in a secure manner; the main high-performance server that manages the entire network and provides a web interface for end users; a number of clients PCs worldwide connected to the VPN network. Clients can be of two categories: the first category - only to access the web interface, and the second category - to connect the ground station to the network for its joint use [3-4].

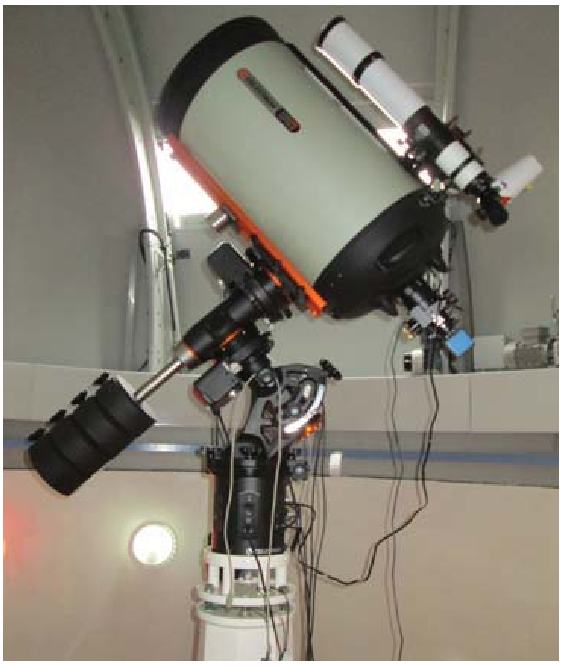


Figure 7. Celestron C14 telescope of the Astronomic observatory, com. Branza, Cahul.

Currently, the VPN server runs on the computer MikroTik Cloud Router with advanced performance - a high level of flexibility and a wide range of possibilities. The main server is running on the "*blade*" type server Sun Microsystems, and Ubuntu Server LTS is used as operating system and provides a range of personalized services developed for the remote control of ground stations. For the purpose of redundancy, a second "*blade*" type server is installed, identical to the main one. The client computer can be any type of PC, from a low-performance SBC to a "*high-end*" desktop computer. The choice depends on the purpose of the end user, which may consist of access to the web interface and / or connection to the ground station.

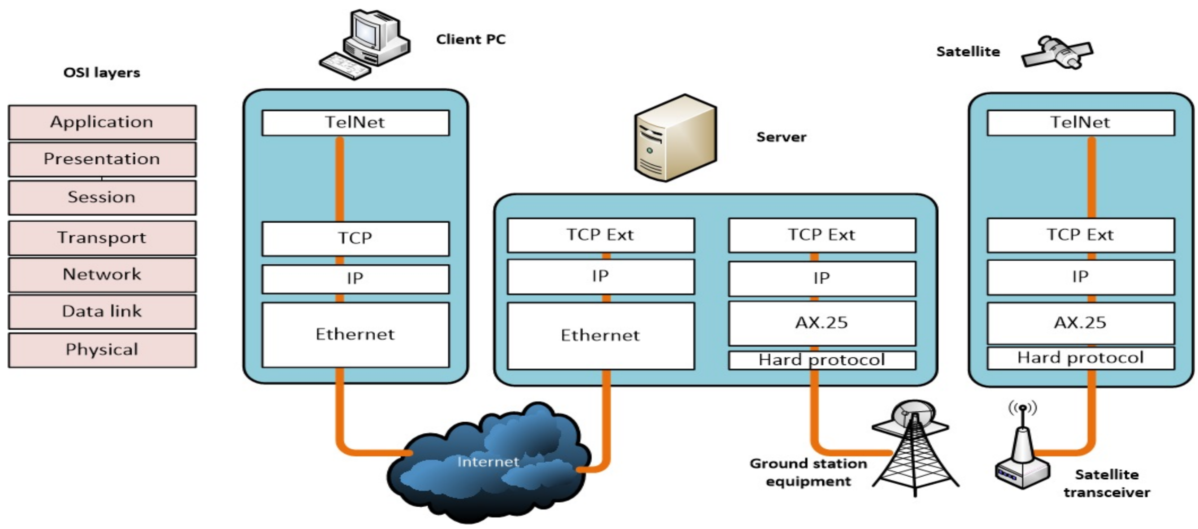


Figure 8. OSI levels for educational missions through small satellites.

At the current stage of implementation, the client software for the connection to the ground station has been tested successfully on a Raspberry PC SBC module and a desktop PC, which is running an Ubuntu distribution, but it can run any other operating system: Microsoft Windows, Mac OS X, GNU / Linux and even on BSD derivatives.

The Software "*server-side*" component was developed at NSTC that provides the following services and/or certain functional destinations [3-4]:

- **Main DB –** the main database for storing data necessary for current operations (data stored for a short period of time);
- **Scheduler** – monitors the main DB for current data, making decisions based on previously acquired data - appealing the **Launcher** or sending data to the **DB archive**; maintaining and updating TLEs and future observations based on updated information;
- **DB archive –** database in which previous data is stored in the long term;
- **Web Client –** GUI component, enables end users to interact with the system in order to schedule new observations or remove old ones, view information about the connected ground stations etc. (only accessed by clients of the VPN network);
- **Web Server –** ensures the functionality of the Web Client component and access to databases;
- **Launcher –** is the service that communicates with clients (those with the ground station connected), sending them commands required to fulfil specific tasks based on some parameters provided by Scheduler;
- **Ground Station –** is the end point of the system that receives and executes the requested commands.

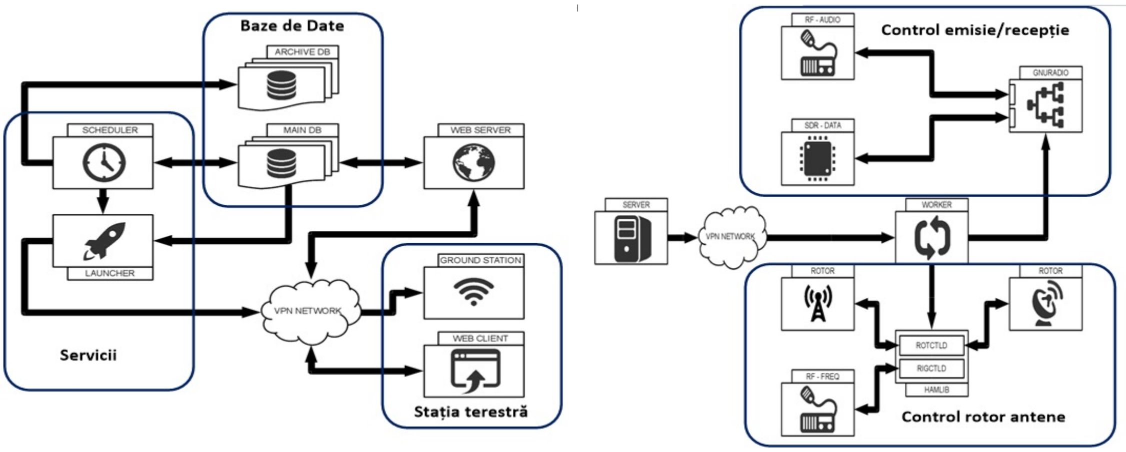
Also, the "*Client-side*" component (Figure 9 (a, b)) was developed within NSTC which is more complex than the "*server-side*" component, including the actual control of the stations (rotor, transceiver) [3 - 4]:

- **Worker –** the main service that controls all the others and sends commands to several executors;
- **Hamlib –**open-source sub-components (rotctld and rigctld);
- **Rotctld –** is responsible for the communication and control of rotors of various types. **Rigctld** can control several types of transmitters-receivers, offering the possibility of change / configuration;
- **Rotor –** is able to control different types of rotors, including those for telemetry antennas with low angular accuracy, and those with large angular accuracy, for parabolic antennas;
- **RF-Freq –** controls / adjusts the operating frequency for different transceivers;
- **GNU Radio –** open-source component with very wide communication possibilities with different types of telecommunications hardware, enabling the reception of signals with advanced post-processing and also sending signals with the desired pre-processing;
- **RF-Audio –** GNU Radio reception and processing via a transceiver audio channel;
- **SDR-Date.** GNU Radio for raw data processing, coming from DST connected devices;
- **VPN network –** client-server communication via secured VPN network tunnel;

Server Link – the client receives all commands from the server-side component.

4. DATA MANAGEMENT FOR INFORMATION RETRIEVAL IN GROUND STATIONS NETWORKS

Monitoring ground stations are not built typically parallel because, on the one hand, the beam of radio waves from the satellite is



a) b)

Figure 9. Server (a) and Client (b) components of remote control of the ground stations.

relatively narrow and, on the other hand, the development of several backup ground stations for a space agency can be very expensive. Networks of educational ground stations can share resources to ensure simultaneously the reception of the data stream from a single satellite. The reception from a "downlinks" satellite offers both opportunities and challenges. The opportunity is to get redundant data from ground stations, and the challenge lies in the need to develop a system that requires the use of appropriate methods of management and data synchronization.

Data management has evolved from the idea of combining multiple data streams from the same satellite, received at a number of geographically distributed ground stations. Theoretically, these data streams received in parallel by ground stations should be identical, but in reality they differ for several reasons (Figure 7):

1. The interaction time of each satellite and ground station differs depending on the route. When two routes overlap, the ground stations being geographically spaced apart, there is a small period of time during which only one of them will be in contact with the satellite. Thus, each station receives different sets of data frames.

2. The received data can be corrupted, resulting in bit errors or even lack of frames / packages caused by atmospheric disturbances, low signal / noise level, technological or constructive inaccuracies of the receiver. These errors can lead to a situation where there are received several data streams in an identical fraction on the overlapping routes of ground stations, when there occures a small part of different information, data being thus corrupted or lost. The idea was to combine in automatic regime data streams, received differently by the network of ground stations and to form a single data stream, ensuring their proper management.

A satellite operator would thus have to monitor only the single data stream consisting of streams information received in the network. Combining multiple data streams from the same satellite, received by geographically distributed ground stations, arise a series of new problems:

- Arranging data frames in the correct order on a single time scale (worldwide). Due to the unsynchronized time from the ground stations and transmission delays in space and on Earth, temporal ordering of the packages can be modified / distorted;
- Identification of similar data packages, if redundant packages have been received from the satellite at the ground network;
- Removing data gaps using redundant information.

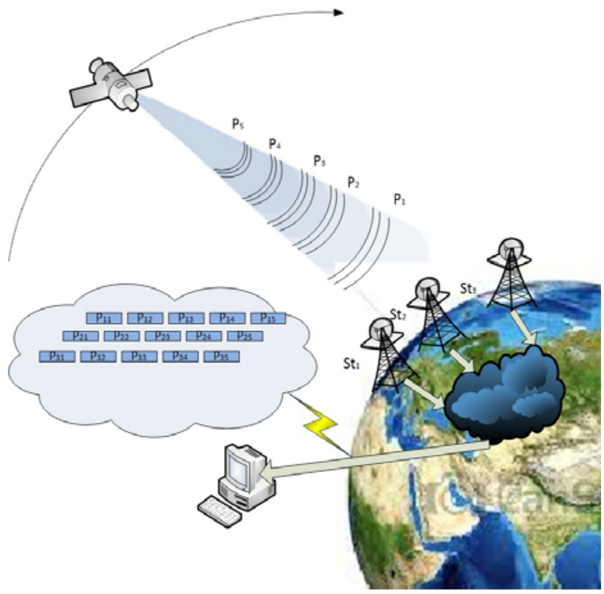


Figure 10. Scheme of data reception in the ground stations network.

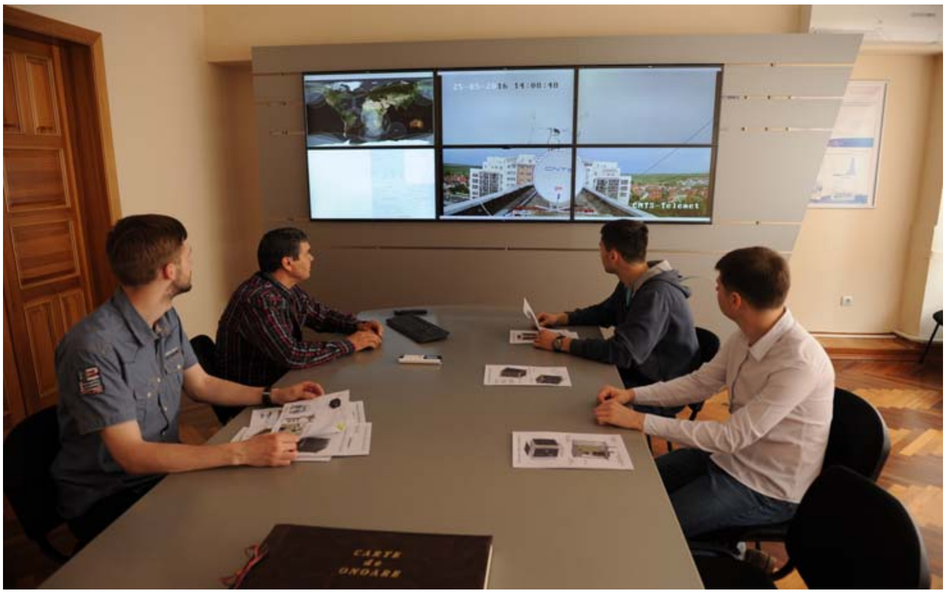


Figure 11. Monitoring the flight of satellites, NSTC, TUM, Chisinau

The complex data management problem was reduced to two separate sub-problems. Firstly, ground stations of the network must be synchronized between them, to command data frames received on a common time scale worldwide. This supposes both synchronizing computer clocks and timing of subsequent data streams. Secondly, the information in the synchronized data streams must be combined to make up for the missing data.

5. TESTING THE REMOTE CONTROL OF THE GROUND STATIONS UNDER REAL CONDITIONS

The project on the creation of the ground infrastructure NSTC with ground stations interconnected and remotely controlled being performed in premiere (within NSTC), needed a series of checks and tests under real conditions of communication with a range of satellites.

Through the competition of researchers from the Institute of Space Sciences, ROSA, Bucharest, there were conducted a series of test procedures in several thematic stages. At the first stage, the equipment was adjusted both to facilitate the remote control of the antennas and of the radio reception / transmission component of telemetry ground stations in Rascani campus of TUM (Figure 1c), the support point in the south in Cahul (Figure 1e), and Magurele of ROSA (Bucharest) (Figure 1l). At the second stage, local control systems and "*Client-side*" software were installed at all ground stations and local control procedures were carried out. At the next stage, the "*server-side*" software component was installed on the NSTC servers and there were performed the "*client-server*" interaction procedures of remote control of ground stations. Subsequently, verification procedures were applied regarding the interaction / connection of the stations with separate and concomitant communication with different educational microsatellites.

All these actions were conducted and coordinated from one centre of monitoring the flight of satellites (Figure 11), which has different ways of control: semi-automatic, automatic with a single station / all stations and automatically planned for a series of satellites. The "*server-side*" software component ensures the merging of multiple data streams from the same satellite received at geographically dispersed ground stations.

An important testing experiment of the "*microsatellite - ground infrastructure*" communication with remote control was conducted at NSTC, TUM. The experiment was performed with an electronic module of microsatellite with functions of image capture and transmission of telemetry data and images launched with a HAB (high altitude balloon) helium balloon in the stratosphere. The flight lasted more than three hours and reached an altitude of 28 667 m. The flight of the electronic module was monitored by the telemetry ground station from the National Centre of Space Technologies, Rascani campus of TUM, with remote access from the control tower of Chisinau International Airport [6-7].

During the experiment of communication with the electronic module installed on HAB, it was also tested the function of the ground station of tracking the balloon using on-board GPS data. In order to ensure the telemetry of the module (internal and environment temperature, module supply voltage and the current consumed etc.), including for receiving and transmitting images, a mobile station was equipped on a car that followed the balloon. The mobile unit, fitted with a 3G modem, was sending data to the server. Ground stations used the appellatives ER1TUM / ER5TUM, officially recognized by the Centre of Radio Frequencies from the Republic of Moldova. Images captured by the module were saved on the SD card and at the same time sent to the ground station.

HAB flight was controlled by the National Centre of Space Technologies, including from the control tower of Chisinau International Airport. Analysing the telemetry data and images transmitted to the ground station a minimum of errors (about 0.3% packet losses) was found which confirms the correctness of technical solutions that laid at the basis of these developments.

CONCLUSIONS

The concept of NSTC infrastructure development with a network of interconnected ground stations promoted within the project *Connecting the infrastructure of the National Centre of Space Technologies to the Educational Global Network for Satellite Operations*, call for competition *Connecting centres of excellence in Moldova to the European research infrastructure* [1] was carried out in full.

Elaborations under the project on connecting NSTC and ground stations in Moldovass in a common network with connection to ROSA and ESA will be available to researchers in international cooperation partnerships in the field of space technologies. The project is part of provisions of the Grant Agreement Nr. 2014 / 346-992 of 24.9.2014 of the European Commission *Financial support for Moldova's participation in the European Union's research and innovation Framework Programme HORIZON 2020*.

Connection of NSTC and of the network of ground stations in Moldova to the Global Network GENSO (Global Educational Network for Satellite Operations) provides premises for expanding international cooperation in the field of satellite technologies, particularly with ROSA, that will stimulate the development of educational projects in the field by involving undergraduate, postgraduate and doctoral students, and young researchers. At the same time, new prospects will open for widening the diapason of interdisciplinary investigations and development of new space products and technologies. This will create a secure foundation for expanding cooperation internationally.

Bibliography

1. *Conectarea Centrelor de Excelență din Moldova la Infrastructura de cercetare a UE. http://www.h2020.md/sites/h2020/fi les/Newsletter-rom-fi n.pdf*

2. Bostan I., Secrieru N., Candraman S., Margarint A., Barbovschi A. *National space technologies center infrastructure connection to global educational network for satellite operation. În: Meridian Ingineresc, nr. 2, 2015, Chișinău.*

3. Bostan I., Secrieru N., Candraman S., Margarint A., Barbovschi A. *Connecting the infrastructure of National Centre of Space Technologies to Global Educational Network for Satellite Operations. In: Proceeding of the 5th International Conference "Telecommunications, Electronics and Informatics", May 20-23, 2015, Chișinău, Vol. 1.*

4. Margarint A., Barbovschi A. *Automation of satellite tracking for worldwide ground stations. In: Proceeding of the 5th Int. Conf. "Telecommunications, Electronics and Informatics", May 20-23, 2015, Chișinău, Vol. 1, p. 421-422.*

5. Levineț N., Ilco V., Secrieru N. *Satellite telemetry data reception an processing via soft ware defined radio. In: Meridian Ingineresc Nr.2, 2015, Chișinău, p. 72-76.*

6. Bostan I., Cantzer V., Secrieru N., Bodean G., Candraman S. *Research, Design and Manufacture of Functional Components of The Microsatellite "Republic of Moldova". - In: 2nd International Communication Colloquium, Aahen, 2014, p. 19-30.*

7. Bostan I., Dulgheru V., Secrieru N., Bostan V., Sochirean A., Candraman S., Gangan S., Margarint A., Grițcov S. *Dispozitive mecatronice, tehnologii industriale și satelitare. În: Academos, nr. 1 (32), 2014, p. 21-25.*

8. Bostan I., Piso I. M., Bostan V., Badea A., Secrieru N., Trusculescu M., Candraman S., Margarint A., Melnic V. *Arhitectura rețelei stațiilor terestre de comunicații cu sateliți. In: Academos, nr. 2 (70), 2016, p. 70-77.*

Recommended for publication: 26.04.2016.