NATIONAL CENTER OF SPACE TECHNOLOGIES INFRASTRUCTURE CONNECTION TO GLOBAL EDUCATIONAL NETWORK FOR SATELLITE OPERATIONS

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1. INTRODUCTION

The primary role of space technology in driving the development of different branches of science and technology is growing, especially for agriculture, geodesy and surveying, ecology and environment monitoring, etc. The idea of sending extremely small satellites into space originated from educational institutions and then adopted in diverse application fields. The paradigm of microsatellites development involved the use of commercial of-the-shelf components, designed for restricted lifetime, but at affordable prices. Recently a lot of universities have nano- and pico- satellite development projects and many of these pico- and nano- satellites were already brought into orbit. Small satellites coupled with ground stations, built with minimal costs, may allow an intense exchange of data. Typically, ground stations are isolated and used occasionally because of a limited period of visibility between the station and a satellite radio. One solution is that such stations to be used to support satellites from other universities, namely the creation of a network of ground stations what would allow remote communication. The development of such a network is not an easy task and requires the construction of ground stations with a proper antenna in order to ensure a good quality connection.

It is suggested the idea of connecting these ground stations via a computer network, which would allow their wider use. Such a mechanism would allow extension of the period of visibility of the satellites, and at the same time, an increase in the amount of received and sent data. To increase the number of stations available, the authors also propose to extend the network of educational ground stations because it has appropriate hardware and Internet access. Another idea is a simultaneous reception of satellite data from several ground stations, and then send them to the control system, which will merge the data packets.

This paper presents the design of a distributed ground station network development and detailed proposal for its practical realization. Clusters formed at Center of Space Technologies TUM with other research centers at the faculties of Radioelectronics and Telecommunications, Computers and Information Technology and Mechanical Engineering aimed at extending directions of activity and research at the intersection of areas such as flight dynamics of spatial objects, orientation and stabilization, design of satellite attitude control systems, capturing images, satellite communications and data transmission to ground stations.

Regarding the connection to a network of ground stations, common infrastructure will provide a new level of operational research and satellite communication for an unlimited number of researchers and PhD students, which will allow a more efficient implementation and promotion of space technologies.

2. STRUCTURE OF SPACE TECHNOLOGY EXCELLENCE CENTRE

The Centre of Excellence for Space Sciences and Technologies, (NCST) has been established by a consortium from Technical University of Moldova, academic institutions and some high-tech SMEs in order to take advantage of the benefits of space technologies and applications in Earth observations, meteorology and astrophysics. The goal of the NCST is to exclude the lack of scientists, engineers and technicians on the area of space research and development by dissemination of experiences in the space domain to contribute building of long-term partnerships between peoples from different European countries to run sustainable outreach activities which can act as a catalyzers, motivating pupils and students at different ages and education levels. The RTD activities of NCST are focused on medium resolution interactive remote sensing and creation of flying missions by involving in these projects most students at different ages and education levels. These goals are supported by the concurrent development of micro- and nano-satellite platforms, an advanced ground control infrastructure and satellite integration facilities, as well as a series of multidisciplinary laboratories for developing and testing of satellite systems and components in simulated space environments. This Centre of Excellence for Space Sciences and Technologies provides students, early career engineers and enthusiasts educational resources in many aspects of space engineering.

Center of Excellence for Spatial Technologies was created to promote laboratories of space technology for students from many specialties from the Technical University of Moldova. Then it was done for other universities, colleges and high schools as a common center with the following structure: Laboratory of satellite components development; Laboratory of simulation and testing of the satellite attitude; Center of Excellence Information Technologies and Communications; Laboratory for processing data and images from satellites; Telemetry ground station; Ground station for receiving satellite images; Astronomical observatory.

The Laboratory of satellite components development was the starting point that was founded to promote the concept of space technologies. Here the idea of creating a nanosatellite designed to stimulate the enthusiasm of young people, to encourage them to get acquainted with the most advanced technologies in electronic communications space. Laboratory are well equipped with computers and equipment for design and development of nano- and micro-satellite components such as electric power systems, on-board computers, data transmission equipment systems, remote sensing (satellite image capture) as well as structural elements of satellites.

Laboratory of data processing and imagery is aimed for familiarizing students and doctoral students with processing methods and application of these results in various fields. Remote sensed images are generally obtained for different purposes. A peculiarity of images obtained from microsatellites is capture during the satellite's movement. This factor causes geometric distortions as well as radiometric ones. The laboratory of satellite data processing deals with the research on methods of pre-processing of distorted images obtained from microsatellites. There were analyzed and processed concrete examples of images for each type of distortion in software environment based on the methods of processing remote sensed images in spatial domain processing as well as in frequency domain processing and compares theirs efficiency. Remote sensing brings together a multitude of tools for better analysis of the scope and scale of different environmental problems that are an important issue of our country. In order to meet the needs, image processing procedures should make it easier than ever to read, explore, prepare, analyze and share information from imagery.

The Excellence Center of Information Technologies and Communications was created as a promising infrastructure for hosting a strong cloud computing computer network, research laboratories, simulation and design of various information systems, communications, including satellite data processing, aerodynamic calculations, etc. Everything in this place is a multi-purpose hall for assuring the various academic meetings, inter-universities and international. This Center will conduct lectures and practical work not only by TUM professors, but will favor those invited to promote the most advanced information and communication technologies. A successful collaboration are workshops conducted by IBM Romania which, under the Academic Initiative IBM, are familiar with the type design technologies, Model Driven Systems Development with IBM Rational Rhapsody, ILOG OPL - Operations Research, mathematical optimization, mathematical programming, Mathematical Programming and Constraint Programming, etc. In future, the researches are expected with the effective participation of students in projects GNSS / LPS based Online Control and Alarm System (GOCA) on base of Mathematical Models and Technical Realization of a Scalable System for Natural and Geotechnical Monitoring Analysis, Numerical modeling in CFD framework with CFD applications in renewable energy conversion systems design, aerodynamics, CFD applications for structure strength, etc.

3. MICROSATELLITE IN EDUCATION AND RESEARCH

The research, design and manufacture of functional components of the microsatellite Republic of Moldova (MS RM) were performed during some projects and funded by the State Program. Following the carried out research, there have been developed and manufactured the basic functional components of MS RM experimental sample shown in Fig 1. After assembling of the functional components inside the case and the PV panels which would provide the conversion of electricity necessary budget, the sizes of MS RM became 285x285x285 (mm) and weight ≤ 9.5 kg. Research on constructive-technological modernization and adjustment of all components of MS RM according to the specification requirements is in continuous development. The changes to be made following the experimental research in laboratory conditions will be taken into account in the manufacture (upgrading) of MS flight sample.

In order to solve efficiently the problem of image capture, compression and coding, this being the most important aspect of the microsatellite mission, there appeared the need for research and development of the module and operation algorithms of the given subsystem. Following the research and analysis carried out, it was proposed a functional structure for the class MS (Fig. 1). The process of image capture is running at the command

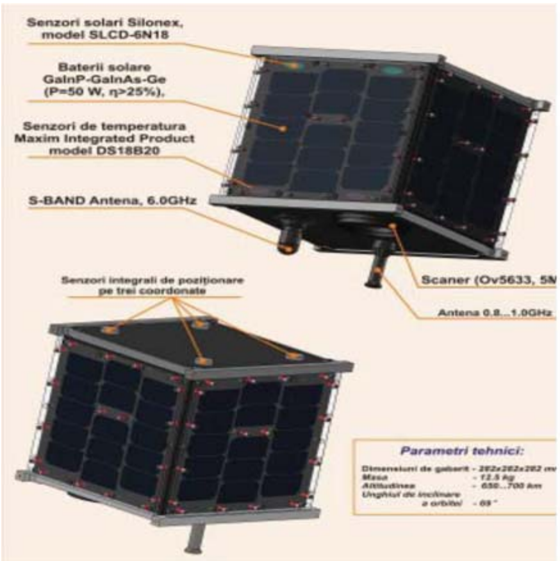

Figure 1. General view of MS *„Republic of Moldova”.*

and under the control of the onboard computer. Was designed the protocol of interactions and the instruction set between the onboard computer and image sensor that are interpreted and executed via the local microcontroller (MCU) with ferroelectric memory (FRAM) MSP430FR57xx of the image sensor, and others - via entities implemented in the programmable circuit PLD MAX II ALTERA. The distinct side of a FRAM-microcontroller consists in radiation tolerance. For communication with the local MCU two RS-232 channels are planned. In the developed sample [7], the integrated circuit OV5633 is used as image sensor. We mention the following features of this sensor: image size 2592 x 1944 pixels (px); frame rate 60 fps@ 752H × 480W; data rate 27 Mpx/s; clock frequency (master clock) 6 ... 27 MHz; size of a pixel 1,75 μm × 1,75 μm and rolling shutter. The image sensor is configurable and this procedure is carried out via the I2C mainline. Setup instructions can be generated by the local MCU and by the onboard computer from the exterior. The instruction to start image capture, *StartImageCapture*, is transmitted from the CBS via the programmable device MAX II ALTERA to the image sensor. When receiving the this instruction, the entity concerned (implemented in PLD) is synchronized in time with the start of a new image capture, which it transmits and records pixel by pixel into the operative memory SRAM. There have been developed the algorithms and the testing software of the image sensor. Captures were carried out in order to certify the quality of the image.

Determination, orientation and stabilization systems of microsatellites attitude are considered among the most important and expensive board components. The correct orientation of microsatellite flying on the orbit defines mostly the opportunity to achieve mission objectives, particularly those relating to capturing the image of the earth's surface. Modern systems of microsatellite orientation are often based on technologies and constructive solutions that generate force couples through the interaction of actuators with the Earth's geomagnetic field. Such systems provide angular positioning with satisfactory precision with small dimensions, limited mass and energy budget.

The architecture of the onboard computing system (OCS) of a satellite is determined by the mission objectives and performances appropriate to technical specifications. In the case of a microsatellite (MS), tasks (OCS) are individualized, including: orientation in space, telemetry and power supply control, communication with ground monitoring stations. Our concept of OCS requires the "specialization" of processors on cosmic mission issues involving the inclusion of a number of processors with diverse architecture, performance and memory capacity. In this case, does not occur the "*migration*" of processors' functions, but their "*stationing",* which would reduce reliability in case of a processor's failure. However, the specialization of processors requires the development of applicative software of modules distributed on specific processors and the development of an operation system of reduced complexity (compared to the simple variant) for the management of onboard computer resource. This concept is less expensive both in terms of hardware, since each processor is optimized for its task and in terms of software, since it requires a smaller volume of complex verification. There is an architectural variant consisting of a local network of microcontrollers with one or two processors of high performance, the others can have performance enough to fulfill the mission requirements. In this case all microcontrollers must be compatible at the soft level. In terms of hard costs, there will be an intermediate cost between the two previous versions (based on the optimal distribution of tasks per processor), and in terms of software - the complexity and the cost will be closer to the first architecture analyzed. Thus, the onboard computer may be optimized based on cost and reliability.

Given the requirements in the specification of MS RM project, there was proposed a structure of the local network of microcontrollers that includes the core microcontroller (MCU) and a set of auxiliary microcontrollers. These MCU perform the following specialized functions: image capture control, regulation and distribution of electricity, telemetry control, thermal regime control, satellite's attitude, orientation and stabilization control. In developing the architecture of the onboard computer with maximum reliability (for a lifetime of 3-5 years) and based on cheap processors without spatial destination, it was decided to choose a family of compatible microcontrollers. Another aspect of the development of the onboard computer system lies in the need to process multiple concurrent data streams and real-time control of applications, which can create conflicts, which in turn may cause the collapse of the entire system.

The communication subsystem includes an innovative radio solutions for nano- and micro satellites which were investigated and verified within the context of the L-COM for the telemetry data changing at frequencies 145/435 MHz and leading edge C-COM, which use corresponding C-band frequencies much more effectively than schemes known so far, therefore allowing effective, cost-efficient and broadband radio communication with such satellites in future.

4. CONCEPTION OF THE NATIONAL CENTRE OF SPACE TECHNOLOGIES GROUND STATION INFRASTRUCTURE

Ground stations for transmitting and receiving of telemetry data and satellite images represents the terrestrial infrastructure of microsatellite project. This infrastructure is located in the park - Museum of Technics, which enables all TUM's specialties students to familiarize with these problems. It has developed two distinct nodes: the telemetry communication located in NCST with antennas on the roof of the building, and the second node is receiving station for digital images located in a building with a special architecture (fig. 2). This infrastructure is widely used for promoting space technologies. Primarily to development and their design involved a large number of students for undergraduate thesis, master, including PhD students. Secondly, it is used to perform practical work and laboratory for smart grid related disciplines, radio and satellite communications. Were developed software for parabolic and telemetry antennas control, and a graphical user interface (GUI) for satellite position monitoring.

Figure 2. CNTS ground station.

In order to extend the promoting possibilities of space technologies, an Astronomical Observatory was decided to build as the ground infrastructure component of the Space Technologies Center of Excellence. With the financial support of the Ministry of Education, there was purchased astronomical equipment with remote computer control, based on the telescope Celestron C14 Edge

HD model with CGE-PRO mount, which was mounted in a specially constructed building located in the previously mentioned park and connected to the Space Technology Centre, which enables to track the moon, the sun, all the planets, objects in low Earth orbit, such as the International Space Station orbit, aircrafts and others. The telescope and its infrastructure will be used for educational purposes for the study of planets, sun, moon and other objects, including astral phenomena and Earth bodies (satellites). Recently, there has been performed some work on the connection of the Astronomic Observatory and Ground Station with the Space Technology Center, a complex that will facilitate more efficient observation and identification of the astral phenomena and Earth space bodies (satellites). Presently practiced solutions most often make use of a single ground station. If such a solution is used for communicating with the satellites located at the Low Earth Orbit (LEO), the station has a poor visibility of a satellite, which results in the station being operated merely 10-20% during the day. Since many institutions (e.g. universities) send small satellites and build their own ground stations, the potential of the available mechanisms remains unfulfilled.

At the current stage space technologies has advanced extremely high in many areas, including satellite communications, which can be viewed from several points of view. One of them is creating global networks of communication, both in space segment and the terrestrial. These networks are usually specialized for special transmissions, navigation, etc. Many of the satellites, belonging to different countries and universities, are monitored in most cases from the area of corresponding state or institution. Not every country can afford to build ground stations in various places of the world. This refers in particular to educational satellites, those budget allocations are minimum. There are two ground stations built up at the Center of Space Technologies from Moldova, which are able to communicate with satellites in a limited area. Currently it is possible to put a basis to achieve a goal as this one: creating a global network for monitoring a wide variety of satellites, including educational. Although at the conceptual level there are different possible solutions, it is necessary to describe and solve a number of issues, including organizational, technical (hard and soft), standards and protocols of communication. The main problem consists in diversity of architectures and configurations of ground stations. It is necessary to find such solutions that will allow this diversity to be connected into one global network. For the future missions, new technologies to meet the

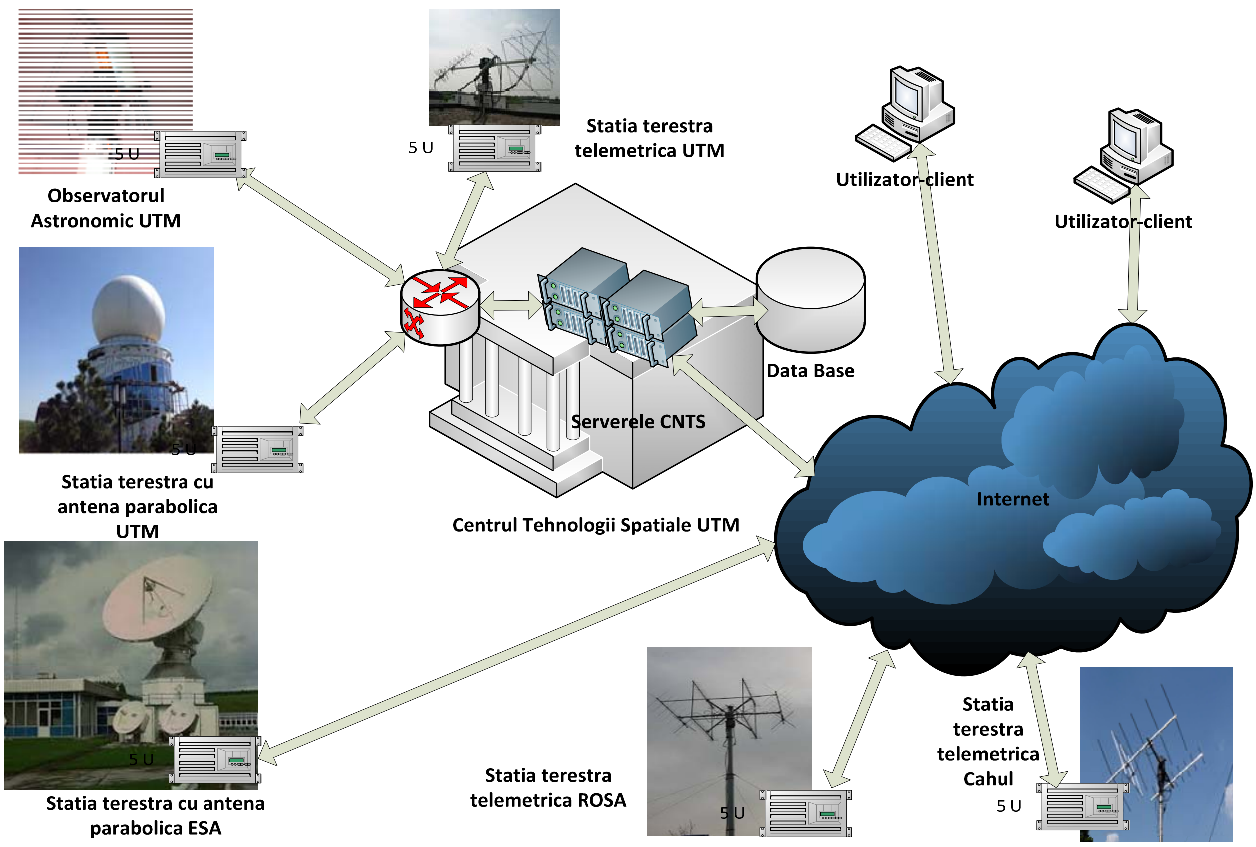

Figure. 3. Ground stations network conception.

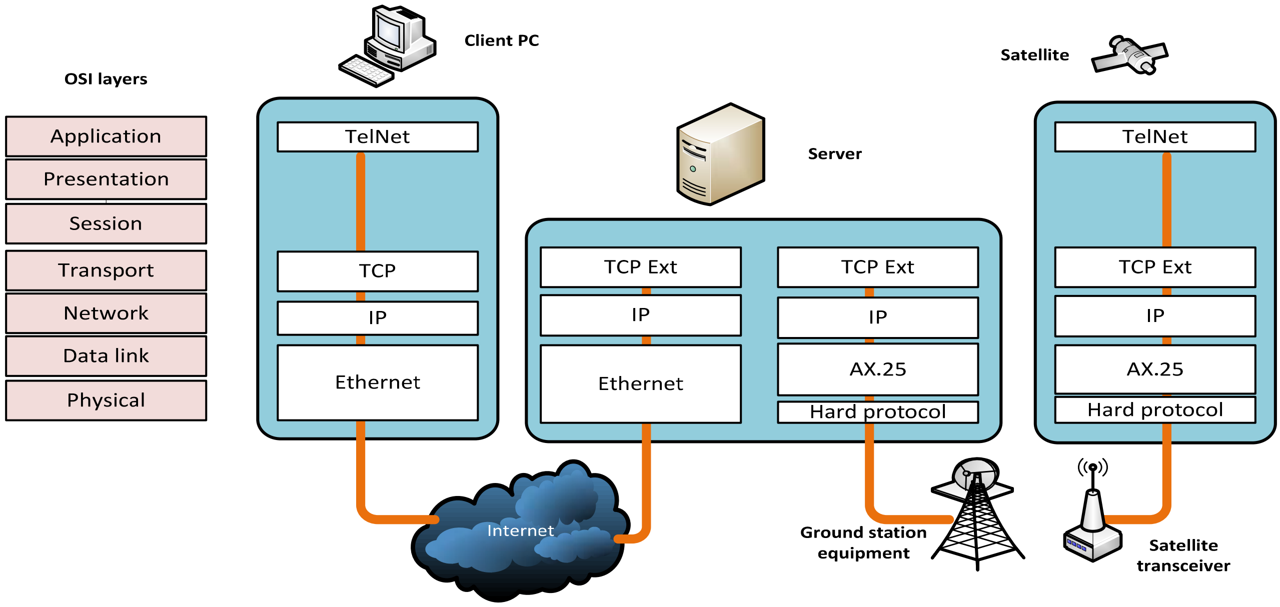

Figure 4. OSI layer references for educational small satellite missions.

challenges of higher performance, reduced costs and new concepts such as autonomous space are required. It is proposed the concept of a ground station network (fig. 3), with applying advanced technologies to improve the design and performance of our ground systems, just like with satellites. Having the experience in the engineering of complex hardware and software systems and with the support of the European Space Agency will be developed the ground segment that will serve as a gateway to access, control and exploit these new space systems and provide services and return on investment for students, scientists, industry engineering.

5. GROUND STATION REMOTE-CONTROL PROGRAM

The ground station network is designed to communicate between ground stations located all around the world via the Internet. Ground stations by means of client applications communicate with Server components through the protocol layer based on TCP (fig. 4). This architecture allows the centralization of the data received from a satellite by various ground stations in the Data Base. The Client applications are able to communicate with the server only. Thus, the Server components plays the administrative role. This is the only part of the system that has access to Data Base and is able to communicate with all the client applications in the system.

Ground station consists of RF side and tracking side. On tracking side we have a rotor that can move on 2 axes, and a custom developed driver for rotor motors with IMU module on rotor. The inertial measurement unit is used for calibrating the position of antenna hooked on rotor. The antennas need to be pointed to north and parallel with horizon. The calibration is performed before every satellite pass. The RF side consists of a stack of two by two cross-polarized Yagi antennas on 2 m and 70 cm, each connected to a LNA. The receiver is a SDR front-end device called USRP B200 connected to a PC via USB (fig. 5).

Server side is based on Ubuntu Server 14.04. All data about satellites, radio frequencies on satellites transponders, modulation types is staked in a Sqlite type database. All scripting and executing is done by python and bash scripts. The web interface, from which we can access all the schedules, received RF data, decoded data and which allow to add an

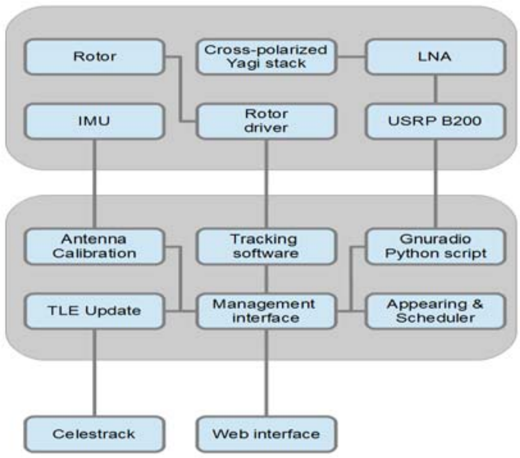

Figure 5. Overall architecture of the ground station system.

observation of a satellite is based on Django framework. For decoding data from weather satellites such as NOAA, it is used a console version of ”*Wxtoimg”* decoding software, that provides more than 15 images processed from the received RF data.

6. DATA MANAGEMENT FOR INFORMATION RECOVERY IN GROUND NETWORKS

Typically ground station parallel tracking is not performed because the satellite beam is relatively narrow and reserving several ground stations from a space agency can be very expensive. Educational ground station networks can share their resources without commercial interest and promote the parallel reception of a data stream from a single satellite. Receiving downlinks from a satellite in parallel contains opportunities as well as challenges: The opportunity is to take advantage of redundant ground station links. The challenge is the realization of such a system, using proper data management and synchronization methods. The data management evolved from the idea to combine several data streams from the same satellite, received at geographically distributed ground stations. Theoretically, these data streams received in parallel on terrestrial stations should be identical, but in reality received data differs mainly due following factors: 1. The interaction time between the satellite and each ground stations differs for traces overlaid. When two traces overlaid, but geographically distant ground stations are taken into account, there is still a small period of time where only one of these will be in contact with the satellite. This result in different sets of data frames received at the individual stations. 2. The received data can be corrupted, resulting in bit errors or even missing packets. They are caused by atmospheric disturbances, low signal to noise ratio or inaccuracies at the receiver side. This leads to the situation that the received data streams are in a large fraction identical for traces overlaid ground stations, only a small portion differs in corrupted or lost information.

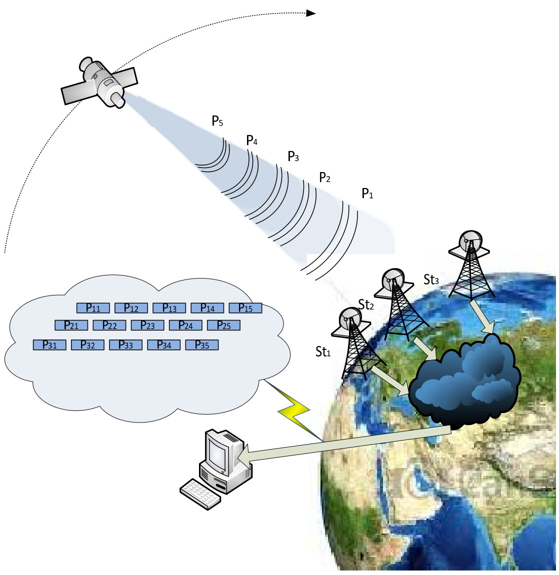

Figure 6. Data management in ground station network.

The idea was to develop a system which can automatically combine different data streams received in a ground station network to one single data stream using proper data management. A satellite operator would then monitor only a single data stream, composed from the information of the streams received in the network. Combining several data streams from the same satellite received at geographically distributed, overlapping ground stations opposes the following challenges:

- Bringing data frames in the correct order on a global timescale. Due to unsynchronized clocks on the ground stations and transmission delays in space and on Earth, the temporal ordering of the packets can be altered;
- Identifying identical data packets, if redundant packets were received from the ground network;
- Reconstruct data gaps with redundant information.

The problem of data management can be divided in two separated sub-problems, which are handled separately:

First, participating ground stations of the network have to be synchronized with each other. Synchronicity between participating ground stations is required to order the received data frames on a global timescale. Synchronization is here related to synchronizing computer clocks, as well as synchronizing data streams.

Second, the information from the synchronized data streams has to be combined to reconstruct data gaps.

7. INTERNATIONAL COOPERATION AND FUTURE PROJECTS

The concept of ground station network was promoted as project ”*Connecting the infrastructure of National Centre of Space Technologies to Global Educational Network for Satellite Operations*” for competition call ”*Connecting of Excellence Centers in R. Moldova to the European Research*

Infrastructure in accordance with the EC" Grant Contract Nr.2014/346-992: "*Financial support to the participation of the Republic of Moldova in the EU program Horizon 2020*". This project aims to connect ground stations that are part of the Center of Spatial Technologies infrastructure in a common network together with the partners from ESA and ROSA, to control systems for Earth areas capturing and transmission of the obtained data to the destination ground system, to control data exchange to minimize geometric/radiometric distortion of the satellite images, as well as increasing research level at such level that it will meet the rigors of competition and collaboration with leading research institutions from Europe. The project aims the procurement, development, synthesis, adjustment and implementation based on the equipment, together with partners from ESA and ROSA, of the systems of control of connection of the ground stations of microsatellites in a common network, which will allow remote reception, analysis, research, application of data downloaded from microsatellite and their testing in the network. Purchased equipment will be available for collective use by other universities originating not only from Moldova, but also from Europe and worldwide, connected to common network, for research and educational purposes. Realizing this project through connection with GENSO can solve successfully these problems for Centre of Space Technologies, as well for rest of centers connected to ESA's GENSO:

- The ground stations will be able to monitor a range of satellites, not just its own, which in turn will increase the level of their yield;
- It will be possible to monitor each satellite one by one from various ground stations, thus accumulating data over a larger segment of the orbit.

The project will expand the research infrastructure in space technologies at all participating centers, creating conditions for much higher level of practical applications. At the same time it will open new perspectives for broadening the diapason of the interdisciplinary research works and development of technologies and products, new missions will be realized with educational satellites. It will deepen interaction between specialists from different fields and from different research institutions and industries. Will be synthesized control systems for parabolic/telemetry antennas and receive channels in various frequency bands VHF, research of the microsatellite's attitude influence on images taken by it, for the purpose of testing of the systems for the microsatellites developed at UTM and ground stations.

Connection of the ground stations into one network, common infrastructure will provide a new level of research and communication with operational satellites for an unlimited number of researchers, PhD, students and enable more efficient implementation, promotion of space technologies, streamline the exchange of experience and access to medium to high-scale infrastructure in order to stimulate long-term development of scientific collaboration and research in Centre of Space Technologies from R. of Moldova and Centers of Excellence from Europe, will give the opportunity to participate and organize international scientific events during the project.

Connecting the Centre of Space Technologies to the European research infrastructure within European Space Agency (ESA) will create a foundation for continuing cooperation with other European research centers after finalizing the project. Realization of the project will expand tremendously the research infrastructure in the field of spatial technologies at all of these centers, will create conditions for realizing tasks at a much higher theoretical and applied level, will open perspectives for considerable broadening of diapason of researches with interdisciplinary character and development of technologies and products, will be implemented new missions for educational satellites.

8. CONCLUSIONS

The field of small satellite formations and constellations attracted growing attention, based on recent advances in small satellite engineering. The utilization of distributed space systems allows the realization of innovative applications and will enable improved temporal and spatial resolution in observation scenarios. On the other side, this new paradigm imposes a variety of research challenges. This contribution proposes new networking concepts for space missions, using networks of ground stations. The developed approaches combine ground station resources in a coordinated way to achieve more robust and efficient communication links.

The implementation of this ground station concept will expand the research infrastructure in space technologies at all participating centers, creating conditions for much higher level of practical applications. At the same time it will open new perspectives for broadening the diapason of the interdisciplinary research works and development of technologies and products, new missions will be realized with educational satellites. It will deepen interaction between specialists from different fields and from different research institutions and industries. Connecting the Centre of Space Technologies to the European research infrastructure within European Space Agency (ESA) will create a foundation for continuing cooperation with other European research centers after finalizing the project. Realization of the project will expand tremendously the research infrastructure in the field of spatial technologies at all of these centers, will create conditions for realizing tasks at a much higher theoretical and applied level, will open perspectives for considerable broadening of diapason of researches with interdisciplinary character and development of technologies and products, will be implemented new missions for educational satellites.

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