Sofia University "St. Kliment Ohridski", Bulgaria

Title: Small Satellite Mission in Support of the Science Expeditions' Activities of in the Antarctic

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Need

The region of the Antarctic continent poses many challenges for the international expeditions aimed at its study and exploration for scientific purposes. On one hand, there are an extremely harsh environment and weather conditions through all the year: low temperatures, snow, ice, cold water, strong winds, difficult terrain, etc., which all make the human life and activities very difficult. On the other hand, there exists a special statute of the ice continent, making it the biggest nature protected area on the Earth. The strong restrictions on the human industrial and business activities applied to Antarctic cause additional difficulties to build the commonly used elsewhere ground infrastructure needed to support the full-scale human life. The design and use of small satellites to provide a support for the various human activities on the ice continent can provide a lot of benefits to the international science community. At present, there are virtually no satellite missions dedicated especially to the needs of the Antarctic expeditions mostly because of the lack of a single big customer and business niche justifying the cost for development, deployment and operation of a large "classical" satellite system [1, 2]. With the recent advances of the small satellite technologies and the related sub-systems, it becomes possible (according to our preliminary investigations) to develop low cost, high performance satellite mission, fulfilling the above mentioned communication service gaps. This is namely the objective of our mission proposal "*SofiaUniversitySat*".

Mission Objectives

Small satellites (stand-alone or in a constellation) can provide critically important services and data for the Antarctic human activities in areas such as high-speed two-way data-transfer (e.g. between the various ground sensor networks needed for scientific, safety and other applications, and the rest of the world), two-way communication services (e.g. file transfer, e-mail and other) for professional, personal or rescue needs; permanent (full year) Antarctic surface monitoring to study biological and natural phenomena on the continent; weather monitoring and forecast, and other. The following mission objectives are identified: 1) *The primary objective* of our mission is to provide possibility for a stable, relative fast and cheap satellite data-transfer communication (up&down links) between the Antarctic bases of the different nations and the rest of the world for the purpose of the various ground science projects (e. g. from ground sensor networks), to help the Antarctic bases logistics and security needs and also for the personal needs of the bases team members (personal e-mail and multi-media communication in off-line mode, etc.). In particular, as a test Antarctic base application case, to prove the concept, our project aims at providing such services to the Bulgarian Antarctic base [3] located on the Livingston Island (*Fig. 1*), part of the South Shetland Islands with location 62°38'29"S/60°21'53"W. We aim at providing capabilities for transfer of ~500 MB data per day between the Antarctic base and the satellite control station in Sofia (or other suitable). Similar service could be provided to other Antarctic bases as well. 2) *The second mission objective* is to provide data for meteorological purposes and Antarctic weather forecasts in the required details on a daily basis. Such a goal would be implemented through satellite based atmospheric sensors and also through ground meteorological sensors networks. The latter would be sending their data for processing to a weather forecast data processing center (e. g. in Bulgaria) using the satellite communication service outlined in #1 above. For the satellite based atmospheric data collection, our primary goal is to implement an optical sensor for monitoring the various cloud systems. Such a sensor would allow collecting imaging data in the VIS and NIR spectrum (0.4-1.1 μm), in the LWIR (10-12 μm), as well as in the low atmospheric transmittance window (6-7 μm). 3) *Our third mission objective* is to provide permanent (12-month) remote sensing data from the Antarctic surface for the purpose of ground science projects and 4) *fourth mission objective* is to provide data for ground level observation of natural and biological objects on the ice continent surface. We target to achieve image resolution of 15 m in the LWIR range. In fact, the Antarctic science missions collect a lot of data (meteorological, biological, physical, geological, medical, etc.), which usually have to be additionally processed *after* the expedition end. The proposed possibility for online data transfer and data treatments in the big university centers *before* the expedition end will considerable improve the effectiveness of the more or less expensive Antarctic science missions. Finally, 5) *Our fifth mission objective* is to accumulate permanent data and provide information about the location and trajectory of the ships traveling in the Antarctic region for the purpose of Antarctic expeditions logistics and stuff security.

Fig. 1. a) Antarctic map and the Livingston island position; b) The Bulgarian base; c) Typical meteorological station

Concept of Operations

Communication link budget and performances:

In the full text of our presentation we have done a detailed analysis of the characteristics of the communication process in dependence of the used frequency bands, antennas (see *Fig. 2*), transmitters, receivers of the both Earth and satellite stations, modulations, coding, access, energy consumption, etc. Here, for an illustration, we present the results from a simple link budget [1, 2] in two cases: 1) using stearable narrow-beam dish antenna and 2) using immovable wide-beam 4-patch microstrip linear array antenna for the Earth station. Data is given in *Table 1*. The important parameter is the achievable bit rate of the data transfer versus the distance between the satellite and the Earth station. *Fig. 3* presents schematically the bit-rate values during the LoS (Line-of-Sight) period (i.e. from the "satellite rise" to the "satellite set"). One can see, that the uplink data speed is ~11.2 Mb/s, while the downlink data speed is ~37 Mb/s, when the satellite is in a zenith position over the given Earth station. These parameters are obtained for a pair of simple Tx/Rx microstrip path antennas, placed on the restricted satellite front-end aperture. When we use 2-path or 4-path antenna arrays, which is geometrically realizable (see *Fig. 4*), the achievable data-transfer speed could considerably increase, but stearable, switchable or reconfigurable satellite antenna have to be used in this case (like these shown in *Fig.2*).

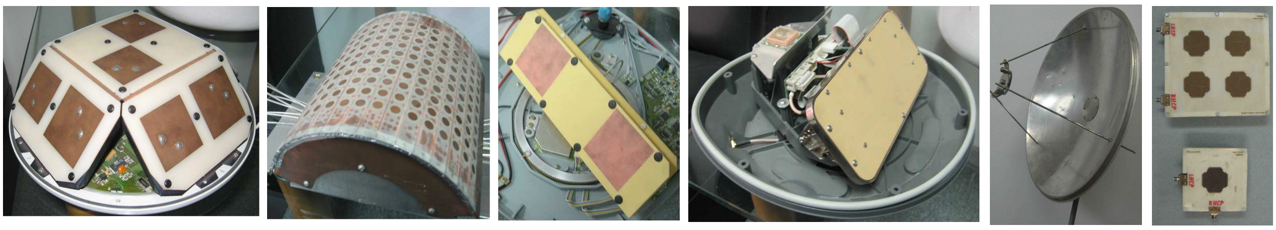
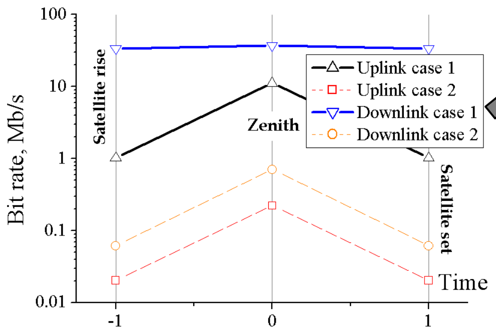


Fig. 2. Variants of steerable, switchable or fixed antennas for the Earth station and for the satellite station

Table. 1. Parameters of the communication process for narrow-beam (steerable) and wide beam Earth antennas

Channel	f, GHz	Case description	Losses, dB	Carrier/noise C/N_0	Bit rate r_b
Uplink (case 1; narrow-beam Earth antenna 1.2 m; steerable)	2.4	EIRP (Earth antenna) 26.5 dBW (50 % efficiency; standard power 1 W); Satellite antenna $G/T = -16$ dBK; $E_b/N_0 = 9.5$ dB; margin 3.5 dB	–155.6 dB (600 km) –160 dB (2000 km)	83.5 dBHz (600 km) 73.1 dBHz (2000 km)	11.2 Mb/s (600 km) 1.023 Mb/s (2000 km)
Uplink (case 2; wide-beam Earth antenna)	2.4	EIRP (Earth antenna) 9.5 dBW Satellite antenna $G/T = -16$ dBK	- " -	66.5 dBHz (600 km) 56.1 dBHz (2000 km)	223.8 kb/s (600 km) 20.4 kb/s (2000 km)
Downlink (case 1; narrow-beam Earth antenna 1.2 m; steerable)	8.2	Gain (satellite antenna) 7.5 dB; power 4 W; Earth antenna $G/T =$ 14.2 dBK; $E_b/N_0 = 9.5$ dB; margin 3.5 dB	–155.6 dB (600 km) –160 dB (2000 km)	98.7 dBHz (600 km) 88.3 dBHz (2000 km)	37.15 Mb/s (600 km) 33.8 Mb/s (2000 km)
Downlink (case 2; wide-beam Earth antenna)	8.2	Gain (satellite antenna) 7.5 dB; power 4 W; Earth antenna $G/T = -$ 13.5 dBK	- " -	71.5 dBHz (600 km) 60.9 dBHz (2000 km)	708 kb/s (600 km) 61.6 kb/s (2000 km)



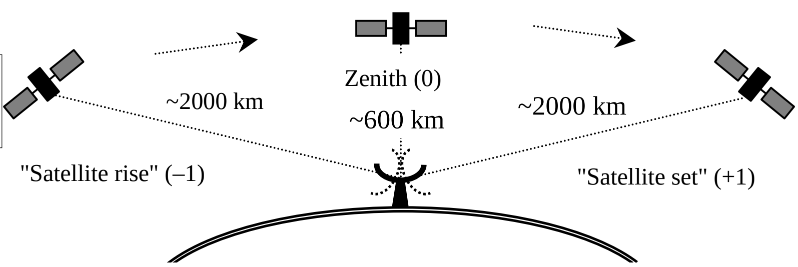


Fig. 3. Bit rate values during the satellite movement over the Earth station for three specific positions

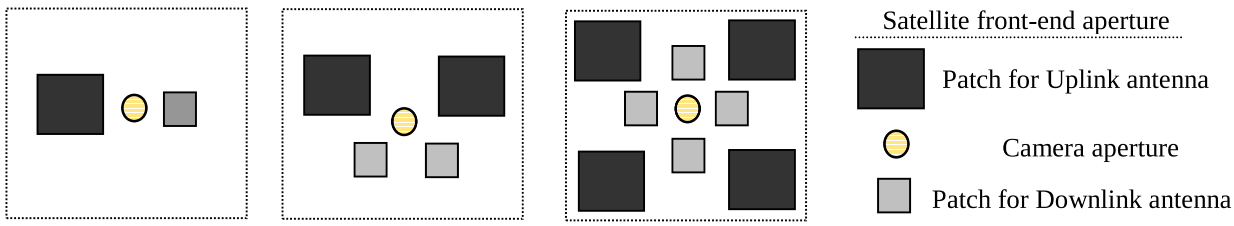


Fig. 4. Schematic front-end aperture of the microsatellite with different disposition of the antenna patches and arrays

<u>Meteorological and other data collection and possible transfer</u>:

The <u>typical meteorological station</u> (*Fig. 1c*) consists of following devices/sensors: thermometer (with Pt lamella with linear temperature dependence of its conductivity), barometer, anemometer with a wind vane (for determination of the wind speed and direction; both placed at a 10-m height mast), hygrometer (for the air humidity); rain gauge (in the Antarctic it should be supplied with heater to work with snow), etc. All of these measurements devices/sensors work automatically and the collected data can be coded by different ways. Using SYNOP code, a single measurement with all of these sensors “produce” data, which can be saved in 13 5-digit groups. If the data is collected every 10 minutes, the total 24-hour information volume will be not more than 18-24 kB. By similar way we can evaluate the data volume in MB collecting from the <u>other scientific missions</u> (geological, biological and other, including high-resolution pictures – our mission objectives 3, 4 and 5). We evaluated that the total volume of these data could not exceed a reasonable limit of ~500 MB per day. Moreover, possibilities exist for extra applications. For example, we additionally consider the practical realization of very interesting research, connected with the so-called GNSS Radio Occultation. The analysis of greenhouse gases, especially water vapor is essential for the modern climate research. The Global Navigational Satellite Systems (GNSS) radio occultation make possible the simultaneous and continuous measurement of both temperature and water vapor in different altitudes and different locations on the Earth. When the GNSS signals, sent from 20000 km pass through the atmosphere of the Earth, they get bent and delayed (*Fig. 5*). The changes in the refraction angle can be used to calculate the distribution of temperature and water vapor in the atmosphere along a profile from the ground (0 km) up to 100 km. These results are comparable with other measurements, approved by the World Meteorology Organization. Results from such sensors are assimilated by the European Center for Medium-Range Weather Forecast (ECMWF). The sensor, which is used by ESA, is called GRAS (GNSS Receiver for Atmospheric Sounding). It consists of three antenna-receivers. The weight of the whole instrument with the attendant electronics is about 30 kg. As far as we are speaking about a microsatellite, the number of the antennas can be reduced to one, which will not considerably decrease the accuracy of the system. Thus, the weight of the system can be reduced by probably 50 % or more. Yunck [3] form Jet Propulsion Laboratory, suggests that such systems can be compressed into satellites as heavy as 3 kg.

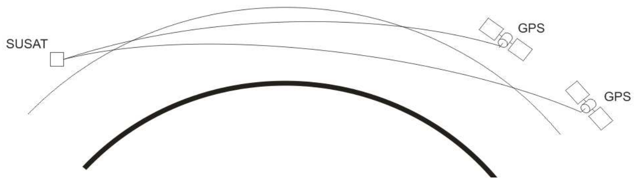


Fig. 5. Curved signal paths from the GPS satellites

Key Performance Parameters

We will evaluate here the main key performance parameter, connected with the primary objective of our mission – the total information volume in MB, which can be transmitted through the up/ downlink channels during a single communication session. The simplified orbit analysis shows that our satellite will pass over the Bulgarian base on Livingston Island ~2 times/daily, while over Bulgaria – ~1 time/daily (see *Fig. 6*; orbit inclination 84 deg). If the 3-dB beamwidth of the satellite antenna diagram is ~30 deg (or ~200 km "tape" over the Earth surface), the satellite will be "visible" for high-speed data transfer over a given Earth position for ~3 min. This is a small LoS period, but if we use switchable or stearable antennas for both, Earth and satellite stations, this period could increase up to 9-10 min. For two-way communication connections, when bi-directional data-transfer protocols are applied, the effective data-transfer speed is evaluated at ~10-% level from the calculated in *Table 1* due to variety of reasons. Therefore, the total data volume for a single communication session is evaluated at ~100 MB for the uplink channel and ~300 MB for the downlink channel. In general, this is enough for online transfer of the meteorological data and the daily satellite images, but there exist reserves, if more than 1-2 communication sessions per day can be realized, using more than 2 Earth stations. In the case of needs to upload more data trough the downlink channel (for example, high-resolution images), a data-transfer speed of ~50 % from the given speed in *Table 1* can be reach, if simple uni-directional data-transfer protocols are applied.

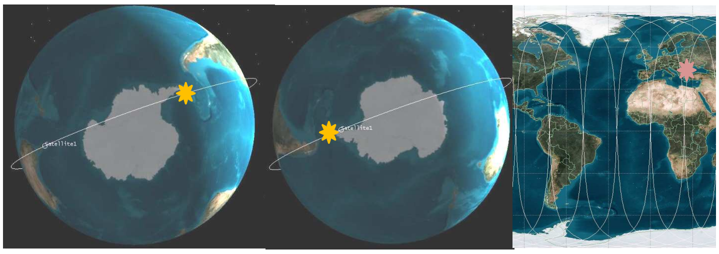


Fig.6 Simple orbit investigation (Sofia and Livingston Island are marked)

Space Segment Description

Due to the fact, that our primary mission objective is connected mainly with the communication process, the other space segment parameters are simple listed here as: mass ~38 kg (including antennas Tx/Rx, GNSS/GPS & UHF/VHF telemetry, without the payload module), volume ~80 liters (350x350 mm is the front-end aperture), average power ~50 W, voltage 33.5 V, battery with min. 3500 mAh, 2-liters tank for Ar gas. More concrete data are given in the full text.

Orbit/Constellation Description

Since the realization of a high-speed data transfer depends on the concrete disposition and the distance between the satellite and the Earth stations (and their antennas), in the full text of our presentation a detailed description of the optimized microsatellite trajectory has been done, especially over the Antarctic continent (see for example *Fig. 6*). We consider also possibilities to increase the number of communication sessions per one day using two options: 1) Micro/ Nano Satellite constellation and 2) Random distribution of a network of more Earth communication stations applying inter-university agreements. Finally, we discuss an important according to us problem – is it possible to get a future synchronization of the efforts in the area of communications by the small satellites and standardization of the used frequency bands, modulations, access methods, data-transfer protocols, etc.? The aim of these efforts will be the realization of a standardized high-speed data transfer for support of the Antarctic scientific expeditions by small satellite constellation in the communication area only. In this connection we consider also a specific, but powerful option – to use a set of very light plasma thrusters for realization of small, but well-defined corrections of the satellite trajectory. An electrothermal thruster with efficient microwave discharge (η ~ 0.9) is developed in Faculty of Physics, Sofia University [5]. This coaxial plasma source works at pressure close to atmospheric (in Ar gas) at low level of microwave power $P \leq 10$ W both in continuous and pulse regimes and it produces dense plasma with high gas temperature T_g ~ 1500-3000 K. The Laval type nozzle (*Fig. 7*) has a diameter of the throat 0.2 mm and the maximum velocity v ~ 1000-2000 m/s. The calculated maximum thrust at gas flow rate 150 sccm is in the range 4.5-9 mN and the specific impulse is in the range 105-210 s. This parameter shows that our electrothermal thruster is suitable for realization an orbital maneuver of a microsatellite (~30 kg) with delta-V Δv ~ 13-26 m/s for 24-hour period**.**

Fig. 7 Ar-plasma jet in atmospheric pressure, experimentally observed in Faculty of Physics

Implementation Plan

The future implementation of the proposed mission is supported by several organizations in Bulgaria: Sofia University as a host of the unique Bulgarian Antarctic base on the Livingston Island [3]; CASTRA – Cluster for AeroSpace Technology, Research and Applications http://castra.org/, which has a plan to implement a project with the first Bulgarian small satellite in the next 3 years and the Bulgarian Antarctic Institute (BAI) http://www.bai-bg.net/, member of several Antarctic organizations (COMNAP, SCALOP, EPB and SCAR), which support for realization of the proposed project is crucial. For the practical assembly of the Bulgarian small satellite itself we already are collaborating with a few European universities, but the realization of the issues in the area of communications will be based on our own efforts in Bulgaria. We have an analysis for the most important known risks (satellite body assembly, launch, initial satellite orientation, telemetry, etc.), but the most important problem for our project is the permission for utilization of the selected frequency bands for up/downlink connections (out of the standard amateur UHF/VHF bands).

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