Enhancing space data exploitation through DTN-based data transmission protocols

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Abstract—**Data distribution and access are major issues in space sciences as they influence the degree of data exploitation. The European FP7-Space project "Space-Data Routers" (SDR) has the aim of allowing space agencies, academic institutes and research centres to share space data generated by single or multiple missions, in an efficient, secure and automated manner. The project includes the definition of limitations imposed by typical space mission scenarios in which the National Observatory of Athens (NOA) has been involved, including space exploration, planetary exploration and Earth observation missions. In this paper, we present the mission scenarios and the associated major SDR expected impact from the proposed space-data router enhancements.**

Keywords: space science, space data dissemination, deep space missions, cross missions, multiple missions, earth observation, space weather

I. INTRODUCTION

Vast quantities of space data have to be transferred from space to the operation centres and, beyond, to the research institutions in order to be analyzed and exploited. The basic aim of Space Data Routers project is to allow space agencies, universities and research centres to share space data generated by a single or multiple missions, in a more flexible, secure and automated manner [1].

Currently, efficient space-data exploitation faces two major obstacles. Firstly, research institutions have limited access to scientific data since their limited connectivity time to satellites directly confines their scientific capacity. Secondly, space-data collection centres, such as ESOC, lack sufficient mechanisms for efficient communication with interested end-users, let alone the lack of mechanisms for efficient data dissemination. The result is frequently quite disappointing: space data remain stored and unexploited, until they become obsolete or useless and consequently are being removed. In the context of space-data exploitation, the situation is expected to aggravate in the near future: space data volume will increase (consider the upcoming Sentinel missions, for example), but the mechanisms for disseminating and exploiting data are not yet in place. Therefore, the efficient exploitation and dissemination of space data should not be considered as a peripheral issue, but rather as an important missing mechanism from the European Infrastructure.

The Space-Data Router implements a dual role: It increases communication flexibility in Space and forms a mission-/application-oriented communication overlay for data dissemination, on Earth. To achieve these goals the adopted methodology has evolved along the following four stages:

- Selection of various space mission scenarios with diverse requirements and limitations
- Design and implementation of a space-data router based on the delay-tolerant networking (DTN) technology
- Integration testing and evaluation of the SDR within a core existing testbed
- Development of a pilot application to integrate thematically various practical special mission scenarios

The scope of this paper is to present a number of space mission scenarios in which NOA has been actively involved during the previous years. The scenarios have been properly selected so as to address effectively the objectives of the project. In addition, along with the scenarios' description, the technical and scientific impact of using the new DTN architecture in each case is also briefly presented.

II. SPACE MISSION SCENARIOS

As mentioned previously, the application scenarios presented in this paper, have been properly selected to match with the scientific objectives of the project. The four major scientific objectives of the project are summarized below:

- To boost dissemination capability for space data *on Earth*
- To allow for exploiting and disseminating data from *deep space* missions
- To deliver efficiently to end users *vast volumes* of data
- To allow for *cross- and multi-mission* scientific applications

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In the following sections an overview of four scientific scenarios is presented, with each one corresponding to one of the previously mentioned objectives.

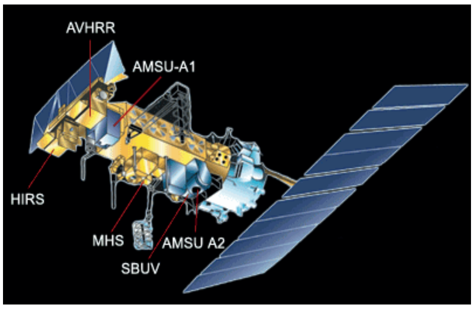

Fig. 1. A NOAA satellite and its instruments with AVHRR among them

A. *Space-data on Earth scenario – NOAA/AVHRR*

The Advanced Very High Resolution Radiometer (AVHRR), aboard the NOAA meteorological satellites (Fig. 1.), is a cross-track scanning system with five spectral bands having a ground resolution of 1.1 km and a frequency of earth scans twice per day. Each pass of the satellite provides a 2399 km wide swath. AVHRR data are used for retrieving various geophysical parameters such as sea surface temperatures, energy budget, and vegetation content. Through the High Rate Picture Transmission (HRPT) service (1700MHz, at a transmission rate of 665,400 bps) installed on the NOAA satellites, user stations throughout the world can acquire data from three or more consecutive overpasses.

In the specific scenario, as a demonstration, AVHRR data will be gathered from various ground stations and disseminated as a composite dataset in real-time via network nodes, which will incorporate the concepts and protocols of Delay Tolerant Networking. This scheme is similar to the one described in the currently running WMO's (World Meteorological Organization) RARS project which is focused on delivering NOAA ATOVS data (AVHRR and ATOVS sensors are both mounted aboard NOAA polar satellites) within no more than 30 minutes from acquisition [2].

Impact using SDR. DTN-based SDR will increase data availability and delivery throughput for real-time access to satellite data. Moreover, the deployment of the DTN nodes is expected to contribute to an effective utilization of the ground communication infrastructures, enhancing thus the data sharing mechanisms, circumventing the downlink constraints. At the same time, the scalability potential of the SDR concept will be assessed. Applicability of the approach to other types of direct readout broadcasting systems (e.g. MODIS) will be further examined.

B. *Deep space scenario – Mars Express*

The scenario involves data transmission acquired by the OMEGA sensor on-board ESA's Mars Express satellite, shown in Fig. 2 [e.g., 3]. The European Space Operations Control Centre (ESOC) in Darmstadt communicates with Mars Express via the ESA's New Norcia ground station in Perth (Australia) with a secondary ESA station at Cebreros (Spain). The New Norcia ground station, DSA1 (Deep Space Antenna 1), is one of the nodes of ESA's tracking station network (ESTRACK). ESTRACK is a worldwide network of ground stations providing links between satellites in orbit and the Operations Control Centre at ESOC. The core ESTRACK network comprises eleven terminals located at ten stations in seven countries. Two of them (New Norcia and Cebreros) form the European Deep Space Network.

Fig. 2. ESA's Mars Express satellite

During each orbit around the planet Mars, Mars Express spends some time turned towards the planet for instrument observations and some time turned towards Earth for communication with DSA1. The communication with DSA1 lasts 8 hours on a daily basis. The scientific data are stored onboard Mars Express using a 12 Gbit solid state mass memory prior to the downlink to Earth. Transmission and reception of data are done in both S-band (carrier frequencies for the uplink 2.1GHz and the downlink 2.3GHz) and X-band (carrier frequencies for the uplink 7.1GHz and the downlink 8.4GHz). The data collected by the scientific instruments are transmitted to DSA1 at a rate of up to 230 Kbps. On a daily basis, between 0.5 and 5 Gbits of scientific data are down linked from Mars Express to DSA1 [4].

Once downloaded from space to the ground station, the Mars Express / OMEGA data are transferred to ESOC in Darmstadt, Germany, where spacecraft attitude and orbital information are added, and then data are retransmitted to the instrument's principal investigator's (PI) science team for scientific processing and analysis. After a period of approximately six months, processed data are sent to ESA's European Space Astronomy Centre (ESAC) in Spain for storage into the publicly available Planetary Science Archive (PSA).

Impact using SDR. The Deep Space communication scenario includes alternative space routes using relays that support the DTN stack and communicate directly with the DTN nodes of the ground segments. Using SDR, various ground stations form an internetwork that allows for communication with Deep Space using alternative routes among the two ends. As a result, deep-space antennas, interconnected with DTN, will allow for a continuous data downlink from Mars Express. In addition, user's access time to scientific data will be increased and reliability and quality of communication will be improved.

C. *Vast data volume scenario - UHI*

Land surface temperature (LST) is a multi mission, single parameter case study, requiring the transfer, dissemination and exploitation of large volumes of data. Knowledge of surface temperature and its temporal and spatial variations within a city environment is of prime importance to the study of urban climate and human–environment interactions [5, 6]. For the purposes of the SDR project, the satellites that carry thermal infrared sensors useful for the study of LST distribution are considered. Overall, three different spatial resolutions of 3km, 1km and 100 m, respectively, provide a different perspective to the study and characterization of the Urban Heat Island (UHI) phenomenon, schematically described in Fig. 3. In particular, 1km spatial and few images per day temporal resolution (e.g. MODIS, AVHRR and (A)ATSR) is an adequate compromise which gives the general picture of the hot spots and relevant patterns at a regional scale. If one wishes to investigate the phenomena in a finer scale, then one should use the high-resolution images (90/120m, e.g. Landsat TM and ASTER) for local/municipality level studies for long-term planning. However, the diurnal variation of the phenomenon is only possible with geostationary satellites (MSG-SEVIRI). Currently, one of the main problems

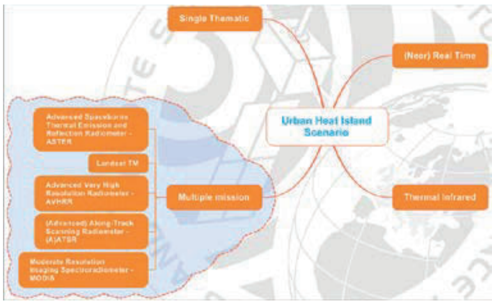

Fig. 3. Schematic representation of the UHI principle

Impact using SDR. In this scenario, the employment of DTN-based SDR will allow for the efficient gathering of large volumes of data from different missions. The proposed network architecture will enable the storage of all data at the same location, thus facilitating their processing and exploitation. In addition, the adoption of DTN will benefit the integration of real-time, near real-time or on-demand data sets in the UHI scenario. Finally, it will allow for flexibility and scalability, which is of prime importance as, in the near future, the number of relevant sensors and satellite platforms that will serve LST monitoring, is expected to increase.

D. *Cross-mission space data scenario – Space weather*

The term “space weather” refers to conditions on the Sun and in the solar wind, Earth's magnetosphere, ionosphere, and thermosphere that can influence the performance, efficiency, and reliability of space- and ground-based infrastructure and can endanger unprotected humans in space conditions or above the Earth's poles [7, 8]. Nowadays, information from a single spacecraft vantage point can be replaced by multi-spacecraft distributed observatory methods and adaptive mission architectures that require computationally intensive analysis methods [9]. Future explorers far from Earth will be in need of real-time data assimilation technologies to predict space weather at different solar system locations.

The objective of this scenario is to now-cast and, ultimately, forecast the influence of solar disturbances (which propagate through interplanetary space and impinge on the terrestrial magnetosphere) on the development of electromagnetic waves in the magnetosphere and the wave effect on radiation belt variability.

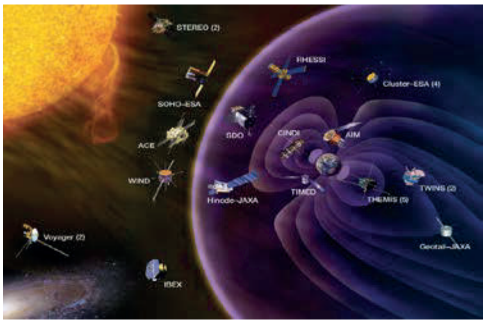

Fig. 4. Study of space weather using multiple and cross- missions

Impact using SDR. The main requirement for this application scenario is the real-time availability of electric field, magnetic field and charged particle data as recorded by multiple missions in geospace and in the solar wind. The use of a DTN-based network architecture is expected to offer a) real-time data acquisition from multiple missions for monitoring ULF/VLF wave occurrence and its effects on radiation belt dynamics and b) low bit error rate data transmission even under harsh/challenged communication conditions.

III. CONCLUSIONS

The topic of this paper has been the enhancement of space data dissemination and exploitation using novel DTN-based space data routers network architectures. Four scientific application scenarios have been presented, which address various issues, ranging from terrestrial space data distribution to deep space data transmission and from large data volume management to cross mission data handling and dissemination. In all four scenarios the positive impact of adopting the proposed architecture has been highlighted.

ACKNOWLEDGMENT

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