Space data routers: Space networking for enhancing data exploitation for space weather applications

I.A. Daglis[1,2], A. Anastasiadis[1], G. Balasis[1], D. Paronis[1], and S. Diamantopoulos[3]

[1]Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
[2]Department of Physics, University of Athens, Greece
[3]Department of Electrical and Computer Engineering, Democritus University of Thrace, Greece

Abstract:
The comprehensive characterization of magnetospheric processes has received a boost through the transition from single spacecraft to multi-spacecraft observations. This evolution has set the foundations for the deeper understanding and eventual forecasting of magnetospheric processes and the Sun-Earth connection and space weather in general. However, multi-spacecraft distributed observation methods and adaptive mission architectures require computationally intensive analysis methods. Moreover, accurate space weather forecasting and future space exploration far from Earth will be in need of real-time data assimilation technologies. The most important capability requirements in this effort are:

• Simultaneous sampling of space plasmas from multiple points with cost-effective means and measuring of phenomena with higher resolution and better coverage to address outstanding science questions;
• Achieving unique vantage points such as upstream at L1, solar polar orbit, or, desirably, beyond the edge of the heliosphere;
• Enabling the prompt, light-speed return of vast new data sets from anywhere in the solar system;
• Synthesizing to enrich our understanding by means of system-wide measurements exploiting new data analysis and visualization techniques.

From the above, it is evident that data sharing and data access are major issues in space sciences, as they influence the degree of data exploitation. The collaborative research project “Space-Data Routers”, has the aim of allowing space agencies, academic institutes and research centers to share space-data generated by single or multiple missions, in an efficient, secure and automated manner. The approach of “Space-Data Routers” relies on space internetworking – and in particular on Delay-Tolerant Networking (DTN), which marks the new era in space communications, unifies space and earth communication infrastructures and delivers a set of tools and protocols for space-data exploitation. The project has defined limitations currently imposed by typical space mission scenarios and aims at surpassing them. In the case of the Sun-Earth connection scenario, we plan to test and validate the capabilities of Space-Data Routers in providing: a) Simultaneous real- time sampling of space plasmas from multiple points with cost-effective means and measuring of phenomena with higher resolution and better coverage to address outstanding science questions and b) Successful data transmission even in hostile communication conditions.

The basic aim of “Space Data Routers” project (SDR) is to allow Space Agencies, Academic Institutes and Research Centres to share space-data generated by a single or multiple missions, in a natural, flexible, secure and automated manner. In particular, SDR will:

- boost the dissemination capability for Space Data on Earth by extending end user access to space data through communicating Ground Stations and Space Research Centers,
- allow for exploiting Data from Deep Space and disseminating it naturally through unified communication channels,
- exploit European Scientific Capacity as well as ESA’s existing infrastructure, resources, protocols policies and assets,
- allow for cross-mission scientific applications, by demonstrating the capability of the DTN space-data overlays to administer thematic cross-mission space-data.

The proposed approach relies on space internetworking – and in particular in Delay-Tolerant Networking (DTN), which marks the new era in space communications, unifies space and earth communication infrastructures and delivers a set of tools and protocols for space-data exploitation within a single device. 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.

One of the scenarios considered within the SDR project relates to Sun-Earth connection and space weather application and aims to demonstrate the potential of exploiting data from relevant space missions and disseminate it naturally through unified communication channels

Sun-Earth connection

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. Nowadays, information from a single spacecraft vantage point is being replaced by multi-spacecraft distributed observatory methods and adaptive mission architectures, which require computationally intensive analysis methods. Future explorers far from Earth will be in need of real-time data assimilation technologies to predict space weather at different solar system locations.

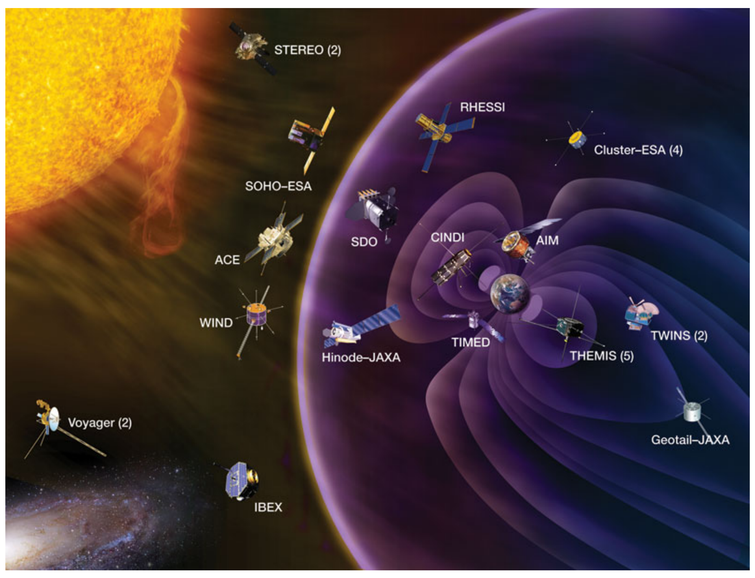

Figure 1. Schematic representation of all currently operating Heliophysics missions (credit: NASA)

The science core of this scenario is now-casting and, ultimately, forecasting 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 effects on radiation belt variability. We plan to test the capability of Space-Data Routers to efficiently distribute to registered end-users the relevant data streams from the two current NASA missions (ACE and THEMIS), an ESA mission (Cluster) and an upcoming NASA mission (Radiation Belt Storm Probes).

Expected impact using SDR:
The main requirements for this application scenario are 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 the DTN architecture could provide/improve:

- Real-time data acquisition from multiple missions for monitoring ULF/VLF wave occurrence and its effects on radiation belt dynamics.
- Successful data transmission even in harsh/challenged communication conditions.

Design and deployment of a pilot application for retrieval & dissemination of magnetospheric data

Overall Objective

Demonstrate the potential of the proposed architecture to carry through data queries and transfers of large data volumes via multiple ground terminal nodes (as well as space nodes in the future) and multiple transmission paths.

Current phase

- A DTN network of several nodes, located in different sites have been set up constituting the data dissemination overlay on top of the Internet. DTN architecture and the accompanying Bundle protocol (RFC 5050), in conjunction with space transport, space link layer protocols and the corresponding convergence layers, are in deployment phase. In addition, **new routing and transport features have been integrated into the DTN architecture** along with the resource sharing and data dissemination policy, in order to complement the necessary functionality of DTN nodes. Regarding the underlying network, namely the Internet, due to a novel naming scheme that has been developed, automatic mapping between DTN identifiers and underlying network addresses is possible.
- **A high-level pilot application interface** has been designed in order to comply with the various data structures and hierarchies encountered both in planetary and earth-observation data. For the testing and demonstration phase a rather generic data structure has been adopted for the application's back-end as shown in Fig. 2. In parallel, a user-friendly GUI for querying the database and submitting the relevant tasks has been implemented.

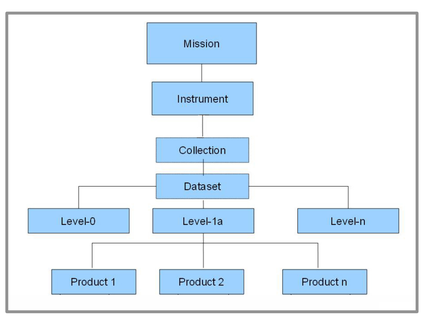

Figure 2: Generic data structure adopted for the design of the application's back-end

Subsequent phase- Testing of the prototypes

In the immediate subsequent phase of the project, the router integration and the application implementation will involve the testing of the aforementioned prototypes under real-case scenarios among which is the case of magnetospheric data.

Since space nodes are not available, the testing of the developed prototypes will be based on the assessment of the potential deployability of the application for content dissemination and retrieval in an 'internet-like' but delay wise communication environment . Some of the criteria that will be used are:

- The efficiency to deliver (speed vs data volume, errors) large volumes of data over terrestrial internetworks
-The level of compliance with the users’ preferences (user’s think times, patience before response is received, typing and web-surfing habits) .

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