Data transmission, handling and dissemination issues of EUCLID Data

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NETworking technologies for efficient SPACE data dissemination and exploitation

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18-19 February 2014

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SPACE-DATA ROUTERS
SEVENTH FRAMEWORK PROGRAMME
SPACE-DATA ROUTERS project has received research funding from the Seventh Framework Programme of the European Union (Grant Agreement No 263330, FP7-SPACE-2010-1)

IAASARS

The NETSPACE Workshop was organized by the Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing

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Table of Contents

Preface

The NETSPACE Workshop was organized by the National Observatory of Athens in the framework of the "Space-Data Routers for Exploiting Space Data" project. The "Space-Data Routers" project received research funding from the Seventh Framework Programme of the European Union, through Grant Agreement No 263330. The project was implemented by a consortium with the following participants: University of Thrace (Coordinator), National Observatory of Athens, University of Plymouth, Telespazio VEGA Deutschland GmbH and Space Internetworks Ltd.

The basic aim of the project was to allow space agencies, academic institutes and research centers to share space-data generated by a single or multiple missions, in a flexible, secure and automated manner. Currently, space-data exploitation faces two major obstacles: Firstly, scientific centers have limited access to space data since their connectivity time via satellites limits their scientific capacity. Secondly, space-data collection centers lack efficient mechanisms for communicating with interested end users. The result is frequently quite disappointing: space data remain stored and unexploited, until they become obsolete or useless and consequently being removed. In the context of space-data exploitation, the situation is expected to worsen. Space data volume will increase, but the mechanisms for disseminating and exploiting data are not yet in place. Along these lines, the ultimate goal of the project was to boost collaboration of the European Space Agency, European Space Industry and European Academic Institutions towards an efficient architecture for exploiting space data. The proposed approach relied 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.

The NETSPACE Workshop aimed in disseminating the results of the "Space-Data Routers" project and in promoting exchange of experience in the following technology areas:

- Space applications with increased data dissemination requirements
- Multi-mission space applications
- Current approaches and policies in space data dissemination and exploitation
- Delay/disruption-tolerant networks (DTNs)
- Architecture, design, implementation, and evaluation of communication systems for space
- Security/privacy concerns and solutions in space communications
- Novel space mission objectives based on new networking technologies

The Workshop was well attended and the participants, representing the Greek and international scientific and industrial community in the space sector, had very constructive interactions on the topics of the meeting. The present volume contains a number of selected papers presented at the Workshop, which were reviewed by the Scientific Committee.
I would like to thank everybody for their contribution to this effort.

Professor Ioannis A. Daglis
University of Athens / National Observatory of Athens
Athens, April 2014

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.

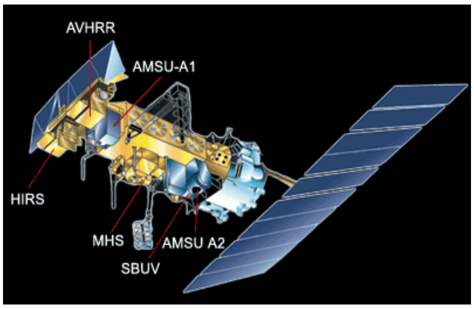

Fig. 1. A NOAA satellite and its instruments with AVHRR among them

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

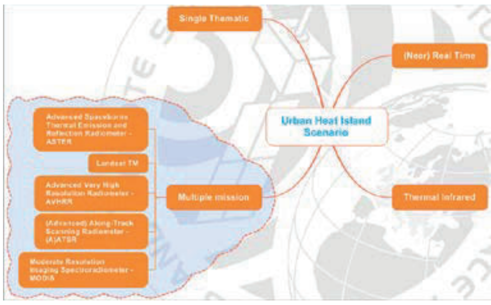

Fig. 3. Schematic representation of the UHI principle

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 r egional 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

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

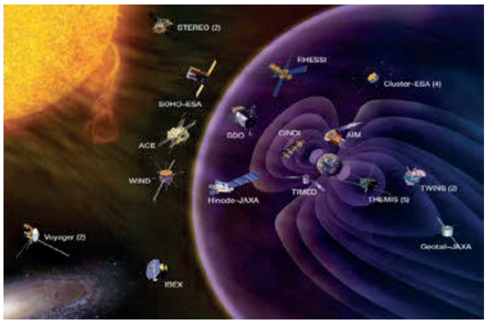

Fig. 4. Study of space weather using multiple and cross- missions

terrestrial magnetosphere) on the development of electromagnetic waves in the magnetosphere and the wave effect on radiation belt variability.

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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An Application for the Discovery and Dissemination of Cross-Mission Space Data

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Abstract- Discovering and accessing cross-mission Space Data is currently a laborious and error-prone task, with each mission having its own proprietary data portal that offers an unfamiliar non-consistent user interface, and which requires separate authentication credentials from any other portal. The result is often inefficient data gathering and missed opportunities from Scientists unaware that a dataset from a mission even exists. We aim to solve this problem through the Space Data Routers Dataset Management Application – a Web-based aggregator of dataset meta-data designed specifically to improve the discovery and dissemination of cross-mission Space Data.

Keywords: space data, cross-mission, data discovery, Web application

I. INTRODUCTION

One of the biggest issues with current Space-Data Collection Centers, such as ESOC, is the inability to search for datasets that cut across missions. There are many scenarios where this ability is vital, but without a centralized repository that aggregates datasets from across missions and Data Providers, the user must laboriously locate the required datasets from a variety of disparate repositories, each with its own distinct user interface and authentication mechanism.

To solve this issue, we have developed a cross mission dataset management application as part of the EU funded Space Data Routers project, the goal of which is to boost collaboration and competitiveness of European Space Agency, European Space Industry and European Academic Institutions towards an efficient architecture for exploiting space data.

The approach of the Space Data Routers project is two-fold: space internetworking via Delay-Tolerant Networking (DTN), and a Web-based application for the aggregation and dissemination of space data. This paper presents this application.

The SDR Dataset Management Application (SDR-DMA) has been designed from the outset to provide a single interface to a wide range of datasets from across different missions, enabling the user to search for the datasets they need from a common interface that permits sophisticated filtering and sorting of datasets according to their needs. Once the datasets have been selected, they can then be downloaded via a single button, regardless of the location of the servers that the datasets happen to be stored on.

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This paper discusses the issues and challenges involved in implementing such an application. The paper is organized as follows. Section 2 describes existing solutions to dataset retrieval. Section 3 discusses the issues involved with aggregating cross-mission datasets. Finally, section 4 presents our solution to these issues in the form of the SDR-DMA.

II. EXISTING METHODS OF ACCESSING SPACE DATA

Currently, individual missions store their datasets on servers dedicated to each mission. If a user wishes to aggregate cross-mission data, they not only need to access it from across these different servers, they must also search for it using a variety of different search interfaces – that's if they even know it exists in the first place.

For example:

- PROBA gathers images of the Earth and other data, and sends it directly to a server located at Redu station, from where users may download it once authorized.
- On PROBA 1, CHRIS data can be downloaded via FTP (at *https://oa-es.eo.esa.int/ra/index.php*), but only after emails have first been exchanged between the user and the Data Provider.
- For OMEGA data on the Mars Express mission, the data are stored on a dedicated server at the IAS (Institut d'Astrophysique Spatiale). Users may download this data after six months, but only through the ESA Planetary Science Archive.
- Finally, NASA's WIND project data must be accessed via the *Wind* project Web page (*http://wind.nasa.gov*), which can be used to identify the entry point for each instrument data environment and to provide some degree of common documentation.

This is just a small sample of the different missions and the datasets that exist. For each mission there is a very different interface requiring different navigation techniques and usually different authentication credentials, making cross-mission searching of datasets extremely time consuming.

III. ISSUES ENABLING CROSS-MISSION DATASET RETRIEVAL

Cross-mission dataset retrieval is not unique to Space Data, and is a common problem in any field where multiple data providers provide access to thematically similar data independently of one another. The end result is always one of incompatible data formats, disparate servers with no central directory, and different user interfaces offering differing levels of usability, each of which the user must learn to navigate if they are to retrieve successfully the datasets that are important to them.

In many ways, this issue is similar to that of aggregating data from across different Web sites, where data is kept in disparate server, presented in different user interfaces, and all requiring separate authentication credentials. This is a common problem on the Web, however, and can be solved in two different ways:

1. Provide tools to find new servers, crawl data and infer the data's structure.
2. Provide a more formal solution involving a central database of aggregated meta-data.

A. *Scraping servers and inferring the structure of data*

This is the most common approach on the Web, where the sheer number of data providers in any one field precludes a more structured approach. Examples include travel sites, where information such as hotel reviews, prices and room availability, air fares, car hire, travel insurance and destination reviews are scattered far and wide across the Web, making efficient cross-destination searching an exercise in utter futility.

Other examples include price comparison sites, job sites and even dating sites, which regularly "scrape" one another's data to populate their databases quickly.

This process of *Web scraping* uses software that reads an HTML Document and attempts to extract data (perhaps presented in an HTML table element) from its surrounding HTML layout and presentation markup [1].

As well as developing bespoke HTML scrapers, there are general solutions that aim to enable the user to extract structured data from Web pages with ease. Solutions such as Dapper [2], Import.io [3], Yahoo! Pipes [4], Helium [5] and even Google Spreadsheets [6] achieve this to a better or worse degree, but all involve manual user input to train the tool to recognize the data from the surrounding HTML.

The advantages of this approach are that the independent data providers do not need to be consulted before-hand and so are free to continue formatting their data in whichever format they wish. This flexibility also enables the data formats to change over time, and so is not only backwards compatible with legacy datasets (or Web pages in this case), it's also future-proofed as long as the Web page's structure (i.e. the Document Object Model) remains unchanged.

Given that most Space Data missions provide access to their datasets via some form of proprietary Web-based portal, this is potentially an attractive solution, as it enables the SDR-DMA's database to be populated automatically with virtually zero involvement from the Data Providers.

The disadvantage, however, is not only the level of manual input that must be made for each data source in order to train the Web scraper, but also that there is no guarantee that the data retrieved is formatted correctly. The scraper will simply try to extract what it thinks is data based on pattern recognition using regex patterns and XSLT [7]. Furthermore, the Web scraper must be retrained whenever a Data Provider's dataset portal changes, making this approach far from scalable or maintainable..

Despite the advantages of this flexible approach, for Space Data, the data itself must remain accurate, and so a more formal solution is preferred.

B. *A central database of aggregated meta-data*

The second approach is to build a dedicated database of aggregated meta-data that describes the datasets that are provided by the different data providers, and publishing a well-specified standard for that meta-data that is rigorously adhered to. This ensures data consistency and integrity, as the Data Providers themselves publish the datasets' meta-data to a centralized database in well-defined format.

This approach is used in many professional fields where information must be transferred across providers and consumers, without compromising data integrity. Examples include bank statement data, insurance data or other financial data (e.g. the *Financial products Markup Language*), with each field defining its own agreed-upon set of meta-data that is rigorously adhered to across the sites using it.

Although ensuring data integrity, this approach requires the data providers to provide the meta-data for each dataset they wish to publish, a task that can be arduous for providers with significant amounts of datasets. Equally challenging is defining the set of meta-data in such a way that it reliably captures all of the different types of datasets that exist across the different data providers. A final disadvantage is the limited flexibility of this approach. If new meta-data is required, the whole system must be refactored to include it.

Despite this inflexibility, this second approach is preferred as it retains the integrity of the meta-data of the datasets being searched for, and this more than anything else is the top priority within the field of Space Data, as it limits the possibility of errant data being used and skewing experimental results.

The following section presents the SDR-DMA that we have developed to manage datasets, and shows how we have used this second approach to provide a consistent uniform interface to dataset meta-data from across missions in a way that maintains data integrity.

IV. THE SDR DATASETMANAGEMENT APPLICATION

A. *Overview*

The SDR-DMA enables a user to search through, retrieve, and access a large set of datasets provided by many different Data Providers from across different missions. These datasets can be searched across, sorted, filtered and downloaded via a rich Web-based Graphical User Interface provided by the Web app.

In addition, the Web App also provides a comprehensive set of features for data providers to manage their datasets (including adding, editing and deleting them), and also an administrative interface that enables administrators to register new data providers with the Web App, and to alter users' roles.

These roles ensure users can only access the features and data that their role allows them to. For example, only administrators can assign a user the role of data provider, while only data providers can upload, edit and delete their datasets.

B. *Supported meta-data*

A set of descriptive meta-data has been defined that encompasses enough of the meta-data used by different missions to enable cross-mission searching. This meta-data is presented in full in Appendix 1.

This set of meta-data provides an adequate compromise to permit cross-mission searching with sufficient detail required by the user's search, while also being generic enough to encompass the majority of missions and their meta-data.

C. *Search interface and data filters*

In order to enable the user to search through datasets using this meta-data, a search interface has been developed that presents a set of filters, enabling the user to drill down through the meta-data to extract exactly the set of datasets specific to their needs. A screenshot of this interface is shown in figure 1.

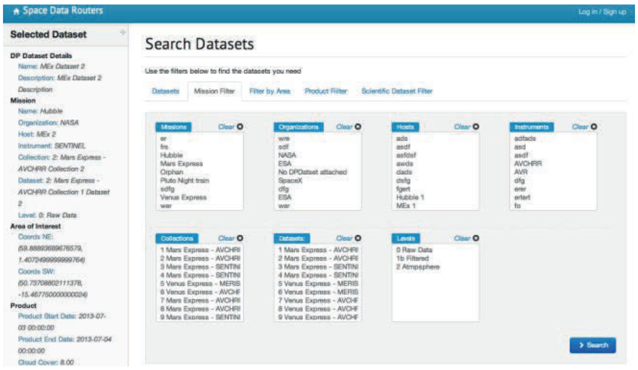

Figure 1. Screenshot of search interface

In addition to the Mission filters shown in figure 1, the search interface will also permit the user to filter data according to geographical area, date of acquisition, target, instrument, host, and many other parameters (see Appendix 1 for full list of meta-data that can be used to filter a query).

The benefit of this approach is that this meta-data comes from datasets generated by different missions. As such, the user need only use this single search interface to perform their cross-mission search, and then download their data from across different Data Providers, again with a single click of a Download button (see section D).

D. *Authentication and Downloading*

In order to download a dataset, a user must first be registered with the SDR-DMA. Upon registering, a secure connection is established between the SDR-DMA's server and the SDR Control Server, which acts as a mediator between the SDR-DMA and the Data Providers (as well as other functions specific to data transfer across the set of Data Providers).

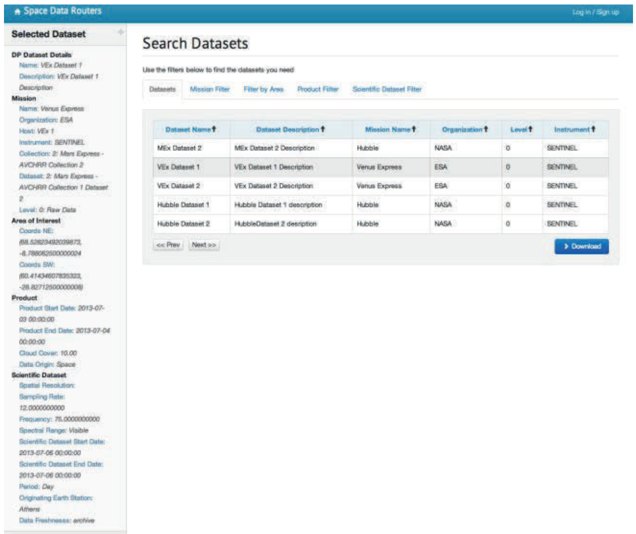

Figure 2. Downloading selected datasets

The user's details are sent to the Control Server, which registers the user's IP address and email address, and generates an endpoint passphrase for the user to use.

If the Control Server successfully registers the user's details, then the full details of the user (except the passphrase) are stored in the SDR-DMA's Users Database.

When the user clicks the download button to download a dataset, the browser sends the user's IP address and the user's passphrase to the SDR-DMA over SSL, which then passes these details onto the Control Server. If the Control Server responds with a message indicating success, the SDR-DMA returns the successful response back to the client and informs them the appropriate Data Providers will initiate download.

If, however, the Control Server refuses the request, it will send its refusal back to the SDR-DMA, which again must return the response to the user. In this way, the SDR-DMA acts as a proxy between the client and the Control Server.

E. *Authentication and User Management*

Some users can be granted an Administrator role within the SDR-DMA, which enables them to perform user management tasks, such as editing user details, approving or denying new registrations and deleting users.

Administrators have total control over users, but they have no control over Data Providers' datasets. Only the Data Providers themselves can edit or delete datasets, and even though, only the datasets belonging to them – a Data Provider cannot interfere with another Data Provider's datasets.

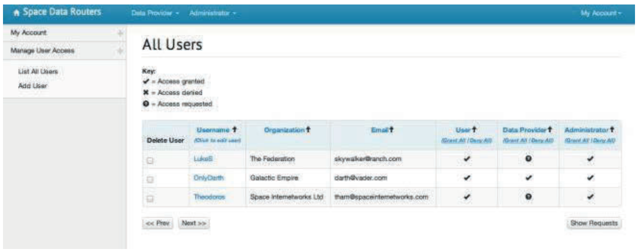

Figure 3. User Management

F. The Data Provider's Interface

Data Providers can register their datasets with the Web App through the Data Provider's main page. Users registered as data providers will see a Data Provider menu option in the header, which will give them the options of viewing their currently registered datasets, or of adding new ones.

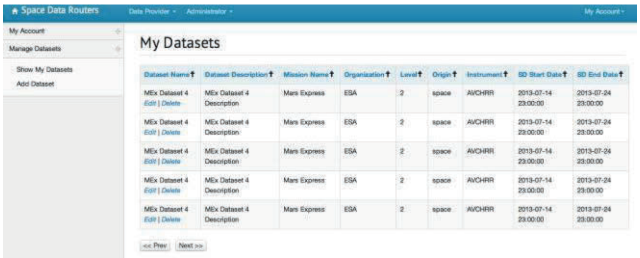

Figure 4. Show Datasets

Each data provider can only see and manage the datasets that they have registered – they have no access to other data providers' datasets.

The Web App does not store the datasets themselves; rather, it stores meta-data that describes the datasets and a URL that is used to locate the dataset on the data provider's server.

G. The SDR-DMA Architecture

The SDR DMA has been developed as a Single Page Web App [8] comprising a rich client rendered in a Web browser, and a thin server application, which exposes a ReSTful interface [9] to the client, and which has also been developed specifically for the SDR DMA. An architectural overview of the Web App is provided in figure 5.

The client contains all of the code necessary to present an attractive and intuitive user interface to the user, to validate a user's queries, to authenticate them, and to enable Data Providers and Administrators to manage datasets and users respectively.

The server largely contains code to authenticate users and their requests, and database management code to provide data management operations on a MySQL database. The ReST API specifies a set of HTTP commands and syntax that can be used by the client to send instructions to the server, and by the server to send appropriate responses back to the client.

This architecture ensures the client and server are loosely coupled such that any type of client (e.g. a mobile app developed for iOS or Android) can interface with the server without needing the server to be refactored; equally, a new server can be developed using a different server platform and database without the need for the client to change.

It also enables Data Providers to register new datasets with the Web App automatically via the same ReSTful API used by the client, ensuring the Web App is always up to date.

The ReSTful API can be seen as the glue of the whole system, and is the crucial component necessary to ensure continued Data Provider support for the SDR-DMA, as it can be used to automate the provision of dataset meta-data.

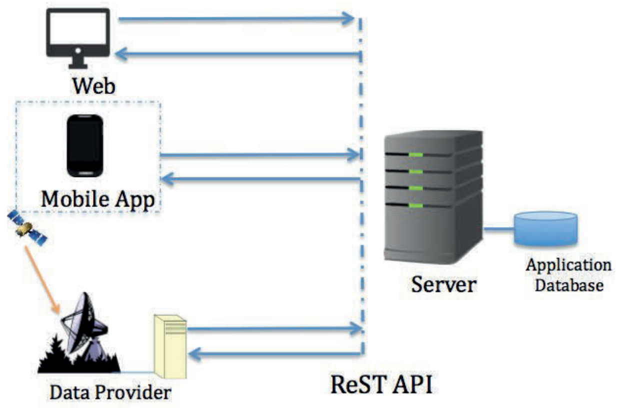

Figure 5. Architectural view of the SDR-DMA

Upon receiving a dataset from a satellite (or other host), the Data Provider can use a converter to read the dataset's meta-data (as encoded by the instrument that generated it) and convert it to the format required by the SDA-DMA (see Appendix 1).

Once converted, it can be sent to the SDA-DMA using a single HTTP request over SSL with the dataset's meta-data encoded in the body of the request using JSON format [10].

Once the converter in place, any new data that arrives at the Data Provider can automatically be sent to the SDR-DMA, ensuring its database remains constantly up to date, and enabling the wider dissemination of Space Data across the Scientific Community.

V. CONCLUSION

This paper has presented the SDR-DMA, our approach to improving the discovery and dissemination of Space Data, particularly in relation to Cross Mission data. The subset of meta-data we have identified for cross-mission searching and the use of the ReST API to automate meta-data publication are both novel within the realms of Space Data Collection Centers, and should be of great benefit to the Space Data community.

The work presented here is still in prototype form, but works within the datasets we have used as part of the Space Data Routers project. Our next goal is to test the prototype with a wider range of datasets from different Data Providers, to ensure the SDR-DMA can encompass as many different missions as possible.

ACKNOWLEDGMENT

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VII. APPENDIX 1 – META-DATA FOR QUERYING DATASETS

SDR-DMA users can query the database using the following list of meta-data to discover and retrieve cross-mission datasets.

- *satellite name*
- *origin*
- *acquisition date start*
- *orbit*
- *originating station name*
- *instrument name*
- *data freshness*
- *acquisition date end*
- *target*
- *measured parameter name*
- *processing level*
- *coords ne*
- *acquisition time start*
- *period*
- *spectral range name*
- *mission name*
- *coords sw*
- *acquisition date end*
- *measured parameter*
- *feature type*
- *organization*
- *cloud cover*
- *sampling rate*
- *spatial resolution*
- *feature name*

Data transmission, handling and dissemination issues of EUCLID

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***Abstract* The key features of the Euclid Science Ground Segment (SGS) are the amount of data that the mission will generate, the heavy processing load that is needed to go from the raw data to the science products, the number of parties involved in the data processing, and the accuracy and quality control level that are required at every step of the processing. This enforces a data-centric approach, in the sense that all the operations of the SGS will revolve around a Euclid Archive System (EAS) that will play a central role in the storage of data products and their metadata.**

Since we will need large, reliable computing resources, the backbone of the ground segment is formed by a series of Science Data Centres (SDC), one in each participating countries of the Euclid Consortium. The EAS consists of a single centralised metadata repository which contains and indexes all metadata (and corresponding data locations). In contrast the data files are stored on storage distributed across the SDCs, with each product stored in at least two locations. The distribution algorithm should favour those SDCs where the data is most likely to be used, this minimizing the movement of huge amounts of data between the SGS components.

Since Euclid will not be launched until 2020, we do not intend to limit ourselves to a particular technology for data transmission at this stage. However, a number of options are being considered and are described in this paper. The key point in any solution we will choose should be flexibility to changes in the configuration of the SGS, alterations in Euclid survey planning, or internal changes in the SDCs.

It is obvious that a good knowledge of the available bandwidth between the Euclid SDCs is a key input for planning the data processing flow of the Euclid mission. Although the bandwidth is expected to grow significantly until the launch of the satellite, we have already started testing the bandwidth in order to identify possible bottlenecks and to monitor the bandwidth increase over time.

Keywords: Euclid, Data transfer, Data storage, Information systems

I. THE EUCLID MISSION

Euclid is an ESA medium class astronomy and astrophysics space mission, planned for launch in 2020 [1]. The Euclid mission aims at understanding why the expansion of the Universe is accelerating and what is the nature of the source responsible for this acceleration which physicists refer to as dark energy [2]. Dark energy represents around 75% of the energy content of the Universe today, and together with dark matter it dominates the Universes' matter-energy content.

Euclid will explore how the Universe evolved over the past 10 billion years: to address questions related to fundamental physics and cosmology on the nature and properties of dark energy, dark matter and gravity, as well as on the physics of the early universe and the initial conditions which seed the formation of cosmic structure.

The imprints of dark energy and gravity will be tracked by using two complementary cosmological probes to capture signatures of the expansion rate of the Universe and the growth of cosmic structures: Weak Gravitational Lensing [3] and Galaxy Clustering (Baryonic Acoustic Oscillations [4]).

Euclid will be equipped with a 1.2 m diameter Silicon Carbide (SiC) mirror telescope made by Airbus Defense and Space feeding 2 instruments, VIS and NISP, built by the Euclid Consortium : a high quality panoramic visible imager (VIS), a near infrared 3-filter (Y, J and H) photometer (NISP-P) and a slitless spectrograph (NISP-S) [1]. With these instruments physicists will probe the expansion history of the Universe and the evolution of cosmic structures by measuring the modification of shapes of galaxies induced by gravitational lensing effects of dark matter and the 3-dimension distribution of structures from spectroscopic red•shifts of galaxies and clusters of galaxies

II. THE EUCLID SCIENCE GROUND SEGMENT

The Science Ground Segment (SGS) is responsible for data processing and archiving. The SGS includes

- The Science Operations Centre (SOC), managed by ESA. The SOC performs the Level 1 data processing (from raw to edited telemetry) the results of which are ingested into the Euclid Archive System (EAS).
- The National Science Data Centres (SDCs), provided by the Euclid Consortium (EC). The SDCs are responsible for science processing and the creation of science-ready data products (Level 3), as well as the crucial corresponding quality controls (QC3). The SDCs also provide simulated

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data or reprocessed external data from ground based observatories.

- The Organisation Units (OUs), are teams of EC scientists which develop the algorithms developed by the SDCs. Although an important part of the SGS their role is largely ignored in this paper.

The key features of Euclid are the amount of data that the mission will generate and the precision required in the data processing. The requirement to have the quality control on each step of the processing and the number of parties involved in the data processing demands the traceability of each data product from the science-ready data down to the raw data. This implies knowledge of intensive data lineage for each item created during processing.

The above requirements enforces a data-centric approach: all SGS operations revolve around the Euclid Archive System (EAS) a central storage and inventory of the data products and their metadata including quality control. The EAS serves as the only interface between the SOC and SDCs. The EAS further supports *orchestration* and *monitoring & control* functions during data processing. The SOC and the EC have the joint responsibility of guaranteeing homogeneity in data access, and of providing integrity, security and the appropriate level of quality control.

III. The EAS Architecture

The data products in Euclid SGS consist of the data files and the metadata description of the data files (which includes extensive links to parent data products, processing parameters, and quality estimation). The EAS concept is based upon a logical architecture of distributed data product storage with a single globally accessible metadata repository which inventories and indexes all metadata and corresponding data locations. Fig. 1 shows the central role of the EAS in the SGS logical architecture. The EAS will support the administration of continuously changing and improving algorithms and calibration procedures and will serve the EC as a whole to monitor and trace the actual state of art of processing and its

Fig. 1. SGS logical architecture [1]

quality control, including the undoubtedly countless re-processing by the numerous pipelines. The system should avoid the unnecessary movement of huge amounts of data between the SDCs whilst maintaining a coherent view of the data reduction status through the metadata. It should be noted that this definition of an "archive" is very different from that of traditional "static archives", and is instead a key part of a complete integrated information and processing system.

The EAS provides the common backbone to the EC for the full administration of the calibration and the derivation of the final data products in a distributed fashion by at least eight SDCs spread over Europe (SDC-CH, SDC-DE, SDC-ES, SDC-FI, SDC-FR, SDC-IT, SDC-NL, SDC-UK) and a single SDC in the USA (SDC-US). This involves a large number of (calibration) scientists and operators.

There is a requirement for a publically accessible archive of the final data products, in order for the science community at large to be able to take advantage of the results of the Euclid mission. This requirement will be satisfied by a interface to public data within the EAS. Such archives have been implemented for all other ESA missions and have normally been "static archives" containing stable data products and metadata.

The EAS will be jointly developed by ESA and the EC. ESA take the lead for the EAS core system (which consists of the metadata storage system and the public interface) while the EC is responsible for the distributed data storage, data transfer and interfaces to the pipeline processing and SGS subsystems including *orchestration* and *monitoring & control* components

IV. The EAS Distributed Data System

In contrast to the Euclid metadata, which is stored centrally, the Euclid data is stored on storage nodes distributed across the SDCs. For safety, all products will stored in at least two geographically remote locations, with some probably being present in every SDC. The distribution algorithm should preferentially transfer data to those SDCs where the data is most likely to be used, this minimizing the movement of huge amounts of data between the SGS components. It should be possible to reconfigure the system in the case of changes in the survey planning or SGS composition (i.e. number and location of SDCs).

Since Euclid will not be launched until 2020, we do not intend to limit ourselves to a particular technology for data transmission at this stage. However, a number of options are being considered and at least one of these will be included in the ESA prototype which is currently being used to support Euclid SGS development. The system we create should be highly flexible and able to integrate any storage solution which an individual SDC chooses to adopt in 5-6 years time.

A. SDC Data Transfer Clients

The first option being considered is an extension of the approach used by the Astro-WISE [5]. The original data storage grid of Astro-WISE is based on the combination of full mesh topology with 6 independent storage nodes (Groningen, Leiden, Nijmegen, Bonn, Munich and Napoli). This approach

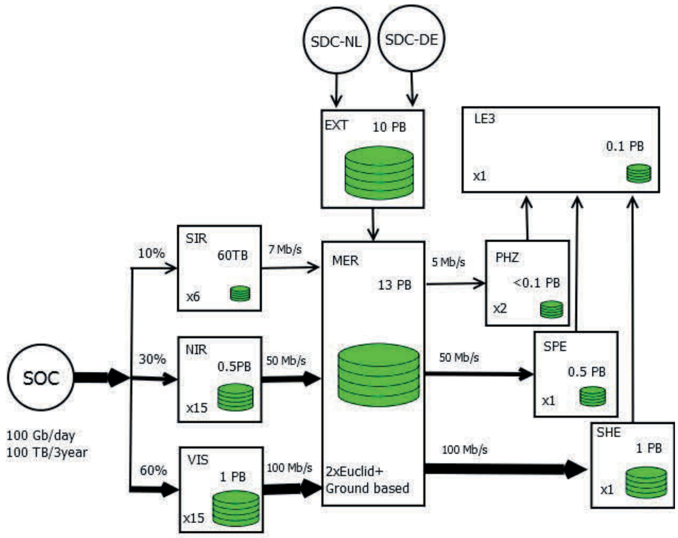

Fig. 2. Preliminary estimate of Euclid data volumes during operations [1]

is used to manage data storage from OmegaCAM and VISTA instruments and was extended for Lofar Long-Term Archive to include Grid storage [6].

In this approach a light-weight client at each SDC provides data access and transfer service using a number of different protocols (e.g. sftp, http, gridftp). The file location is stored in the EAS metadata, to mimic the behavior of a global "file-system".

This system has the advantage of being applicable to new storage solutions that may be introduced in the future and allows each SDC to implement its own storage solutions. This is important: the infrastructure in the SDCs is heterogeneous, since many of them are based on large existing facilities which support a range of projects.

The client will have a common section of Python code with modules to support local SDC data transfer protocols. It will provide basic file transfer functions, namely: store, retrieve, copy, delete, check.

This simple approach should be flexible enough to be supported over a long time period (at least 15 years) and be adaptable to support new storage solutions at the SDCs. In developing the client we do not expect to need to develop a system from scratch, but aim to make use of existing solutions (e.g. Gaia has a file transfer system which is based on Aspera).

File transfer would be triggered in a number of different scenarios:

- When a file is ingested into the EAS, a copy in a second SDC should be immediately be made
- Prior to a pipeline being run, the Euclid Interface Abstraction Layer (IAL) will check that all necessary files are present at the SDC. If not then the missing files will be requested via the data transfer system.
- When data is set to be "public" in the EAS a copy should be immediately transferred to the SOC data storage node.
- To support other functions it should be possible to request, copy or delete data files according to the results of flexible queries on the metadata or when required by the orchestration system.

B. Using an Existing Distributed File System

The Euclid System Team is also investigating the possibility of using an existing distributed file system (DFS), of which there are a large number competing examples [7]. Amongst these iRODS is widely used for astronomical data systems.

A preliminary analysis shows that there is no existing DFS or data grid which will, on its own, satisfy the EAS data storage and transfer requirements. Two examples of such requirements are the cut-out service (which should be able to return to the user image cut-outs for a number of objects distributed across the sky) and the ability to replicate files according to queries based on EAS metadata. The crucial issue which must be addressed is the necessity to ensure the consistency between the metadata in centralised storage and the data files stored on distributed storage nodes.

V. Data Volumes

Fig. 2 shows a preliminary estimation of the data volumes during the mission operations created by the various pipelines which make up the full processing for a single processing run. However, we emphasise that we expect to reprocess the data on numerous occasions. Such reprocessing will sometimes involve a simple pipeline and sometimes all the pipelines. Similarly some reprocessing will involve only a section of the Euclid survey data, while others will involve all of it. This makes it difficult to assess the actual data volumes passed through the system.

Estimating the volumes passed from SDC to SDC is even harder. Currently it is expected that each SDC will process the data from an allocated section of the sky, as opposed to the alternative scenario when each SDC is responsible for a given pipeline. However, some pipelines, most notably those for the complementary ground-based data required to process Euclid data (shown as EXT in Fig.2) will run only at dedicated SDC in the Netherlands and Germany.

VI. Transfer Performance

Our concept is to rely on existing connections between the various SDCs and between the SDCs and the SOC. From the point of view of networking technology we do not intend to be innovative unless needed. Although the bandwidth is expected to grow significantly until the launch of the satellite, we have already started testing the bandwidth in order to identify possible bottlenecks and to monitor the bandwidth increase over time.

In January 2014 we measured the bandwidth between all SDCs using the iperf program [8]. At each SDC an iperf server was running. Using a crontab we asynchronously launched connections between pairs of SDCs with a single client and 5 parallel clients. Each connection was tested 8 times per day for 5s. The average bandwidth we achieved was 206 Mb/s for single client and 324 Mb/s for 5 client connections. None of the connections exceeded 1Gb/s. Using the traceroute program [9] we analyzed the path the data takes. We found that all connections make use of the local national research networks which themselves are interconnected by the GÉANT network [10]. Interestingly almost all connections are routed through the UK. Connections to the SDC-US (located in Pasadena) are typically 3-4 times slower than connections within Europe. Fig. 3 shows examples of the data transfer rates obtained between SDC-NL, SDC-CH and SDC-UK.

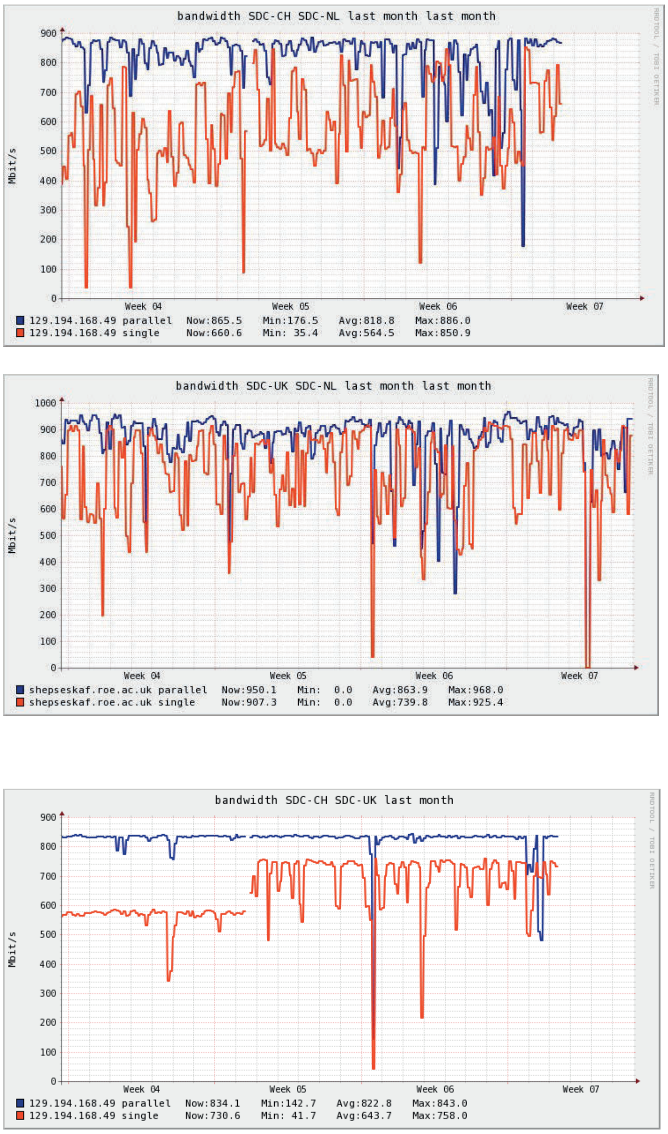

Fig.3. Examples of data transfer rates obtained in January 2014 between SDC-NL and SDC-CH (top),) SDC-NL and SDC-UK (middle), SDC-CH and SDC-UK (bottom).

VII. CONCLUSIONS

The requirement for a highly distributed SGS for Euclid is well established, as are the requirements for an EAS with a centralised metadata repository and data storage nodes distributed across the SDCs. Data storage and transfer systems are currently under study using the EAS prototype. It is important that the selected system guarantees the consistency between the metadata in centralised storage and the data files stored on distributed storage nodes.

The data transfer rates we currently see in our monitoring program are already sufficient to support the proposed SGS architecture, especially if the SDC runs all the pipelines required to process a given region of the the sky (external data excepted). An alternative scheme, whereby each SDC runs only the pipelines they develop would be more problematic.

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WMO Space Programme data access challenges

Update on the RARS initiative

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***Abstract*—The paper highlights current challenges of ensuring timely access worldwide to environmental satellite data and products for WMO programmes in meteorology, climate, related applications and space weather. New initiatives are required to meet evolving needs. An update is provided on the Regional ATOVS Retransmission Service (RARS) as an example of cost-efficient trade-off between timeliness and completeness to acquire data from Low-Erath Orbit satellites.**

Keywords: data accessibility, timeliness, RARS

I. INTRODUCTION

The World Meteorological Organization Space Programme aims to expand the space-based observing system for weather, climate and related environmental issues, and to facilitate the access to, and use of satellite data and products worldwide. This activity is now expanding to space weather.

User surveys are regularly pointing to data access as a major limiting factor to the optimal use of satellite data and products. This issue is addressed at different levels: (i) organizing the user community to express precise requirements and engage in a dialogue with data providers; (ii) setting up portals to facilitate the discovery of available data and products and inform on data access mechanisms; (iii) supporting standardization of data and metadata formats and transmission protocols for data exchange; (iv) encouraging data retransmission satellites via Digital Video Broadcast (DVB) systems; and more generally (iv) reviewing the overall data dissemination concept in order to adapt to various and evolving user needs and technical capabilities.

II. DATA ACCESS CHALLENGES

A. Data explosion

The evolution of Earth observation satellite capabilities over the current decades results in an exponential increase of satellite raw data rates and of the amount of data the users have the potential to exploit. A parallel evolution of information and telecommunication technology offers ever improving solutions to acquire, manage, distribute and store these data. Although it is always a challenge to reach out to users in developing countries, data dissemination is greatly facilitated by cost-efficient means such as re-broadcast by telecommunication satellites in DVB-S/S2 standard, or ftp access to data or products from data centres. However, the new paradigm of Earth Observation satellite data access reveals new challenges.

B. Sustainable data management

First of all, data and metadata standardization has become a prerequisite, e.g. in the WMO Information System (WIS), in order to ensure efficient data discovery and interoperability. Furthermore, there is an increasing perception that it would not be a sustainable goal for all potential users to systematically acquire and process all the raw data; instead, a widely accessible set of raw data should be supplemented by high level products generated by specialized centres and made available to the community, hence the importance of rigorously documenting these products and demonstrating their quality. Finally, the increasing societal demand for climate monitoring and climate services reinforces the importance of following best practices for data stewardship and long-term data preservation.

C. Direct Broadcast

An essential feature of meteorological satellites since the 1960's is their Direct Broadcast capability by which observation data acquired by the spacecraft are continuously transmitted in a publicly accessible data stream, thus allowing a user with a direct readout station to receive these data in real time when the satellite is in his area of visibility, which often is the primary area of interest. As data rates have evolved from a few kb/s to almost 100 Mb/s, larger bandwidths and higher frequency bands are required, moving from the old VHF to L-Band and X-Band. While the use of X-Band is necessary to accommodate high data rates, the L-Band allocated to meteorological satellite services remains highly needed because it is less affected by rain than X-Band, which is of primary importance for meteorological systems.

III. AN EXAMPLE: RARS

A. Access to Low-Earth Orbit satellite data

The near-real time access to data from non-geostationary satellites, such as the constellation of sun-synchronous polar-orbiting meteorological satellites, poses a particular technical challenge because of the necessary trade-off between coverage and timeliness. On one hand, acquiring data by a direct readout stations enables real-time access but its coverage is limited to data in the acquisition area of the station, typically two of four times a day during 10-15 minutes. On the other hand, acquiring full-orbit data recorded aboard the satellite enables access to the whole global data set, but with the drawback of data storage until it can be dumped to a ground station, which increases data latency by up to 100 minutes.

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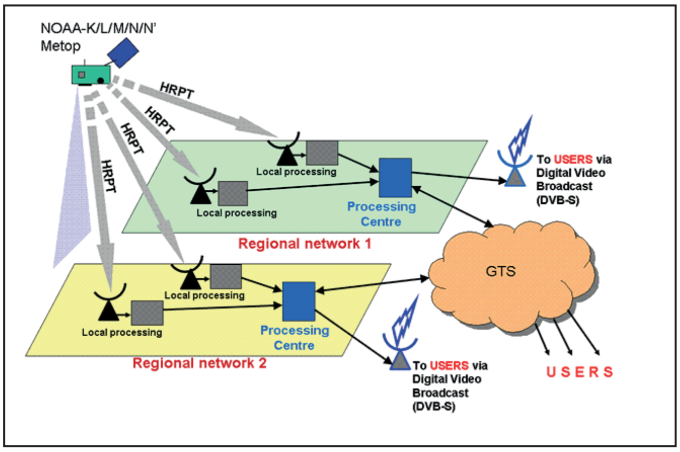

Fig. 1. Schematic diagram of the RARS network

B. *RARS concept*

Several approaches have been developed to find the best trade-off between these two options, either through adding additional ground stations to reduce on-board data latency, or through sharing data from a network of direct readout stations operating in a coordinated manner and redistributing the data through different means. The latter is the option taken in the so-called Regional ATOVS Retransmission Service (RARS) concept illustrated in Fig.1, whose initial objective is to deliver satellite atmospheric sounding data from at least 90% of the globe, within 30 minutes from acquisition for ingesting into for Numerical Weather Prediction models.

C. *RARS status*

The global RARS network is comprised of three components:

- The EUMETSAT Advanced Retransmission System (EARS) managed by EUMETSAT covers mainly the European, central Asian and Atlantic areas and involves 18 stations from Canada, Denmark, France, Greece, Norway, Oman, Russian Federation, Spain and the USA;

- The Asia-Pacific RARS coordinated by the Bureau of Meteorology, Australia, with one telecommunications node in Melbourne and another in Tokyo, involves 16 stations from Australia, China, Japan, Republic of Korea, New Zealand and Singapore;

- The South America RARS with one coordination node in Argentina and another in Brazil, involves 6 stations from Argentina, Brazil, and Chile.

Interoperability of the data sets from these different stations is ensured through the adoption of standard practices regarding data formats, coding, and pre-processing software. A global monitoring is performed to check the timeliness, integrity and consistency of the datasets. Different means are available to make RARS data globally available, either using rebroadcast by telecommunication satellite beams, or point-to-point telecommunication within the WMO Information System, and/or FTP transfer from regional nodes to major user centres.

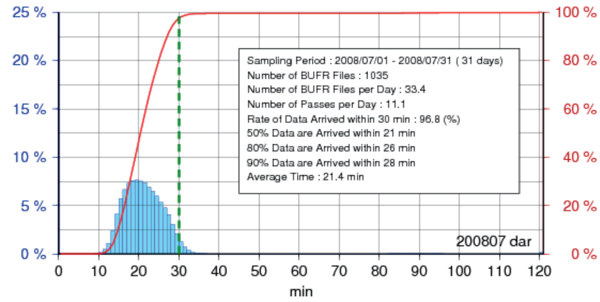

Fig. 2. Time period between observation and receipt of each data set

Currently, the RARS system involves more than 40 direct readout stations which altogether enable the acquisition of satellite sounding data from around 80 % of the globe with a target of maximum 30-minute data latency. Additional stations are being considered in order to fill residual gaps in the South Pacific and South Atlantic areas. The RARS initiative has nearly completed its first objective, in terms of both timeliness (Fig.2) and quasi-global coverage (Table 1).

TABLE I. CURRENT AND PLANNED NETWORK STATUS

Regional component	**Number of stations current (planned)**	**Fraction of global coverage**
Europe/Atlantic	18 (19)	40% (41%)
Asia-Pacific	16 (19)	30% (36%)
South America	8 (9)	14% (17%)
Overall network	**42 (47)**	**77% (84%)**

D. *Perspectives*

The main ongoing development is to extend the RARS initiative to the collection and retransmission of additional sensor data, in particular advanced hyperspectral infrared sounders. Since data volumes are orders of magnitude higher than for traditional sounders the network operation must be optimized by selecting stations with minimum overlap with each other, and by sampling the data through channel selection, data reduction and compression.

ACKNOWLEDGMENT

I thank all the organizations sharing data from their direct receiving stations through the RARS network. Particular thanks are due to the European Organization for Exploitation of Meteorological Satellites (EUMETSAT) for its leading role in this initiative and to the United Kingdom MetOffice for operational support and monitoring.

A DTN-ready application for the real-time dissemination of Earth Observation data received by Direct Readout stations

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Abstract— **The effective dissemination of satellite data in real-time or near-real-time is a crucial parameter for disaster monitoring in particular. To date data exchange between Direct Receiving stations has not been fully exploited for real-time data dissemination. Stations around the world store data locally, which are then disseminated on-demand via Internet gateways based on the standard TCP-IP protocols. On the other hand, Delay Tolerant Networks (DTNs), which deliver data by enabling store-and-forward transmission in order to cope with link failures, service disruptions and network congestion, could prove as an alternative and complementary transmission mechanism. In this paper, a scheme for the effective dissemination of Earth Observation data received by DR stations is proposed based on transmission capabilities provided by DTNs.**

Keywords: Delay Tolerant Networks, Space Data Routers, Direct Broadcast, Direct Readout Stations

I. INTRODUCTION

The majority of the Earth observation satellites operates in low Earth sun-synchronous orbit and transmits data captured by a variety of sensors. Generally, a spacecraft collects data and then stores it on-board until it passes over dedicated ground stations to transmit the data. Additionally, some satellites (e.g. Terra, Aqua, Suomi-NPP, NOAA series satellites) have the so-called Direct Broadcast (DB) capability, which is based on a real-time data transmission sub-system. Compatible Direct Readout (DR) stations on the ground in direct line-of-sight are able to receive these transmissions.

A. NOAA AVHRR and High Rate Picture Transmission

The Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA series meteorological satellites (or POES satellites) 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 (at 02:30 and 14:30 local solar time). Each pass of the satellite provides a 2399 km wide swath. The satellite orbits the Earth 14 times each day from 833 km above its surface. The High Rate Picture Transmission (HRPT) service installed on NOAA satellites has for some two decades been the main source of high quality data from polar orbiting meteorological satellites at major user stations throughout the world [1]. The data stream not only contains full resolution images in digital format but also the atmospheric information from the suite of sounding instruments. Through HRPT reception the user site can acquire data from three or more consecutive overpasses twice each day from each satellite, giving high resolution data coverage of a region extending to about 1500 km radius from the user station.

The NOAA HRPT system provides data from all spacecraft instruments (AVHRR/3, HIRS/3, AMSU-A and -B, SEM-2, DCS/2, SARSAT and sometimes SBUV/2, ARGOS data Collection System) at a transmission rate of 665,400 bps. Over 200 HRPT ground stations operate worldwide. Most of these stations collect imagery primarily for meteorological forecasting. Most stations do not archive data; others save a few selected scenes based on institutional interests. However, as interest in regional and global environmental studies increase, efforts are being made to develop internationally cooperative ventures to save data from several HRPT stations to obtain periodic regional (e.g. pan-European) or global full resolution data.

A new version of HRPT (AHRPT) was implemented on the European Metop satellites operated by EUMETSAT [2]. While Metop HRPT follows the same general concept of transmitting in real-time, due to evolving technology and new data transmission standards, the newer system is not compatible with the NOAA HRPT system. AHRPT data is disseminated in L-Band, with a data rate of 3.5 Mbps. Local data coverage is of a radius of up to 1500 km.

To date, data exchange between local stations world-wide is limited. EUMETSAT has established the EUMETSAT Advanced Retransmission Service (EARS) [3] which provides polar satellite data from the EUMETSAT Metop and NOAA satellites with timeliness suited to the needs of European operational short range regional numerical weather prediction models. The target timeliness for delivery of data is in the range 30 to 45 minutes from instrument sensing. The geographical coverage of EARS is primarily over data-sparse sea areas around Europe. The NOAA HRPT transmissions are received by a network of dedicated HRPT stations operated by partner organizations in the EARS project as depicted in Fig. 1. These stations provide the raw data to a EUMETSAT Product

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Processing Node (PPN) located at the partner organizations site. The PPN handles and processes the data as necessary for the particular EARS service. The resulting products are sent from the PPN to EUMETSAT where these are then forwarded to users via the EUMETCast-EUMETSAT's Broadcast System or Regional Meteorological Data Communication Network (RMDCN)/Global Telecommunications System (GTS) for Environmental Data. EUMETCAST is a multi-service dissemination system based on standard Digital Video Broadcast (DVB) technology. It uses commercial telecommunication geostationary satellites to multicast files (data and products) to a wide user community.

The World Meteorological Organization (WMO) has established the Regional ATOVS Retransmission Services (RARS) as an effort to expand EARS to Northern and Southern Hemisphere regions [4]. The top level objective of the RARS project is to deliver data from the Advanced TIROS Operational Vertical Sounder (ATOVS) from at least 90% of the globe within no more than 30 minutes from acquisition via an inter-regional exchange mechanism among various local stations. The ATOVS aboard NOAA satellites consists of the Advanced Microwave Sounding Units -A and -B (AMSU-A, -B), the Advanced Microwave Sounding Unit-B (AMSU-B) and the High Resolution Infrared Radiation Sounder Version 3 (HIRS/3).

B. *MODIS Instrument*

MODIS (Moderate Resolution Imaging Spectroradiometer) aboard the Terra and Aqua satellites which were put into polar sun-synchronous orbits in 1999 and 2002 respectively. MODIS has a viewing swath width of 2,330 km and views the entire surface of the Earth every one to two days [5] [6]. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm, and it acquires data at three spatial resolutions - 250m, 500m, and 1,000m. The two satellites have the built-in capability to transmit their data to ground stations via their Direct Broadcast Service to the user community; this applies to real-time MODIS data from the Terra spacecraft, as well as to the entire real-time data stream of the Aqua satellite. These data may be received by anyone with the appropriate receiving station, without charge. The broadcast data are transmitted in X-band.

C. *SUOMI-NPP*

In January 2012, NASA has renamed its newest Earth-observing satellite, namely NPP (National Polar-orbiting Partnership) launched on October 28, 2011, to Suomi-NPP in honor of the meteorologist Verner E. Suomi who is recognized widely as 'the father of satellite meteorology'. NPP is a joint NASA/IPO (Integrated Program Office)/NOAA LEO weather satellite mission initiated in 1998 [7]. The primary mission objectives are: 1) to demonstrate the performance

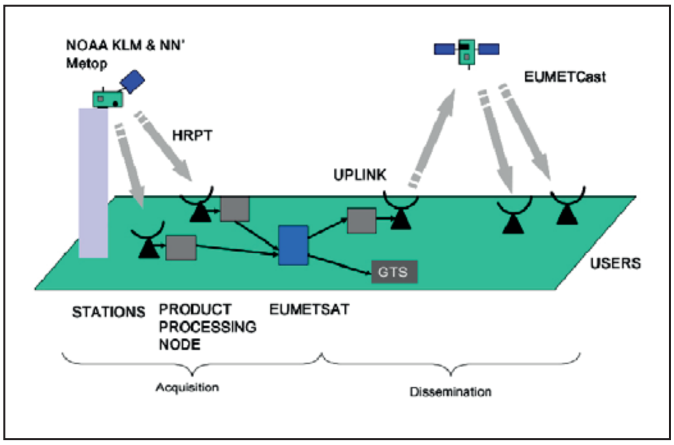

Fig. 1. EUMETSAT Advanced Retransmission Service (adopted from [3])

of four advanced sensors and their associated Environmental Data Records (EDR), such as sea surface temperature retrieval and 2) To provide data continuity for key data series observations initiated by NASA's series missions (e.g. Terra and Aqua). The mission instruments on NPP are VIIRS (Visible/Infrared Imager and Radiometer Suite), CrIS (Cross-Track Infrared Sounder), OMPS (Ozone Mapping and Profiler Suite), and ATMS (Advanced Technology Microwave Sounder). This suite of sensors is able to provide cloud, land and ocean imagery, covering the spectral range from the visible to the thermal infrared, as well as temperature and humidity profiles of the atmosphere, including ozone distributions.

Since February 2012, the Spacecraft uses an Earth-coverage pattern antenna to provide downlink for Direct Broadcast Users. It provides real-time mission data (which includes instrument science data, instrument engineering data, and instrument telemetry data), and real-time Spacecraft housekeeping data via its High-Rate Data (HRD) system [8]. The data rate is 15Mbps at a nominal downlink frequency of 7812 MHz. In normal operations broadcast data operate continuously providing real-time data to the Direct Broadcast Users. Currently, the VIIRS, CrIS and ATMS instruments broadcast the HRD they collect immediately, on the chance that local users on the ground below are listening.

II. The Proposed DTN Architecture and the Data Dissemination Scheme

DTN architecture allows for efficient utilization of the network, using in-network storage and taking advantage of the network availability among the interconnected nodes. Although DTNs were originally developed for high-propagation delay and for challenged connectivity environments such as deep space, the broader research community has investigated possible architectural enhancements for various emerging applications (e.g., terrestrial infrastructure, ground-to-air communications, content retrieval and dissemination) [9]. Identifying the potential deployability of Internet applications to DTN environments is an open issue. DTN inherently addresses a number of issues that arise in such a networking scenario, while it is general enough to allow for appropriate

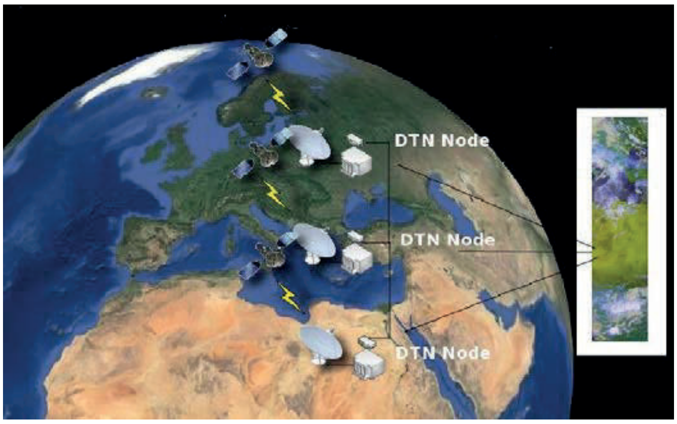

Fig. 2. The proposed dissemination scheme for DR stations.

extensions. In this context, deploying the proposed application for real-time dissemination of satellite data among interconnected DR stations is challenging.

In the framework of "Space-Data Routers for Exploiting Space Data" project (FP7-SPACE-2010-1) [10], DTN architecture was designed and constructed for the effective dissemination of data among DR stations. The specific DTN architecture consists of eight nodes (running on Linux/Ubuntu OS) which are placed in five different facilities and are connected via the Internet. DTN nodes were constructed based on Interplanetary Overlay Network (ION) of Jet Propulsion Laboratory of NASA [11]. DTN functionality is based on the Bundle Protocol which has been implemented according to its specification in RFC 5050. Upon the completion of installation of the DTN nodes, the overall overlay network was tested. Two different test cases used in order to test the core functionality and measure some essential metrics, such as the Round-Trip Time (RTT) of small-sized bundle transfer and the duration of transfer of bigger fixed-sized bundles.

The communication scheme proposed in this work is based on pre-scheduled contacts of the involved nodes. More precisely, satellite data streams generated by the various instruments on-board a specific spacecraft are continuously broadcasted. As soon as the satellite scans a certain portion of the earth and after this image is received by a local station, a contact is established with a DTN node and data transmission is initiated. These DR stations form a DTN overlay. Most importantly data received by a certain station are automatically forwarded to the next available participating station belonging to the same "interest" group through a flexible routing solution. Thus, a composite image of an extended area (or potentially an image of the entire globe, depending on the "interest" groups formed) is constructed in each node in an imperceptible way. The routing mechanism developed provides a dynamic framework that allows for the update of the network contact plan and the remote management of nodes by an administrative node. Upon processing of the received data streams, stations are able to further disseminate new products to other interested third party entities exploiting the DTN overlay and the filtering capabilities provided by a web-based tool. This scheme is described in Fig. 2.

As regards, routing complexity, the line-of-sight times and connectivity is known well in advance since reception start and end-times are known in advance for each station. The adopted routing mechanism developed in the SDR project comprised three main components which can accommodate the data dissemination scheme presented in this work: a) the Multi-Objective Contact Graph Routing (MOCGR), b) the management and contact plan update mechanism (MCPUM), and c) The storage availability notification mechanism (SANM)

MOCGR is a sophisticated algorithm used to provide available routes towards the destination, exploiting contact information available to all nodes participating on the overlay. This information is then coupled with a number of routing criteria embedded on the bundle protocol header at the node that initiates data transmission, allowing the algorithm to calculate the best available route depending on the sender requirements. The MOCGR mechanism is an extension of the Contact Graph Routing (CGR) algorithm [12].

CGR is a dynamic routing system that computes routes through a time-varying topology of scheduled communication contacts in a DTN network. It is designed to support operations in a space network based on DTN, but it could also be used in terrestrial applications where operation according to a predefined schedule is preferable to opportunistic communication, as in a low-power sensor network. The basic strategy of CGR is to take advantage of the fact that, since communication operations are planned beforehand in detail, the communication routes between any pair of "bundle agents" in a population of nodes that have all been informed of one another's plans can be inferred from those plans rather than discovered via dialogue (which is impractical over long one-way-light-time space links). MOCGR relies on accurate contact plan information provided in the form of contact plan messages.

Contact plan messages are of two types: contact messages and range messages. In order for the MOCGR to provide valid routes towards the receiving station, the routing parameters that are included in the contact plan should be modified every time a network node changes its status. The local node or an administrative node should update the network contact plan information accordingly and transmit update messages to all network nodes. To provide our routing scheme with such functionality, a Manage and Contact Plan Update Mechanism (M-CPUM), has been developed which renders the system flexible and adaptive to any status changes. This mechanism includes contact plan update messages along with management commands that are also vital for network status modifications. Finally, the Storage Availability Notification Mechanism (SANM) is an application that enables a DTN node to inform other nodes about its storage availability. SANM exploits M-CPUM in order to notify all the nodes of the network when an important change at the node storage resources has been discovered. Nodes that are continuously receiving huge space-data traffic loads should inform the entire network that they are not able to handle more load, as soon as they notice that their storage capacities are being exhausted.

III. DISCUSSION

The effective dissemination of DB satellite data is a crucial parameter for disaster monitoring in particular. Currently, ad-hoc networks are established on local or regional scales which are either administered by agencies such as EUMETSAT or by research institutions. In the latter case, data exchange is performed on demand via standard internet protocols. DTN protocols and the relevant networking infrastructure which allows for efficient utilization of the network, using in-network storage and taking advantage of the network availability among the interconnected nodes can be built on top of the existing infrastructure homogenizing thus the underlying dissemination mechanisms. With the advent of new sensors and system such as the Sentinels, data volume and consequently network congestion are expected to be high. Thus alternative and advanced routing mechanisms must be sought to cover future needs and requirements. Towards this direction, DTNs may offer an effective infrastructure and new reliable mechanisms.

ACKNOWLEDGMENT

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Enhancing deep space communications for scientific data transmission and exploitation

Case study: OMEGA/Mars Express

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Abstract— **Communication and dissemination and exploitation of data from Deep Space missions face two major impediments: limited access capabilities due to narrow connectivity window via satellites (thus, confined scientific capacity) and lack of sufficient communication and dissemination mechanisms. The Space-Data Routers (SDR) project aims into boosting collaboration and competitiveness between the European Space Agency, the European Space Industry and the European Academic Institutions towards meeting these new challenges through Space Internetworking. Among the main scientific objectives of the project is, through the examination of a specific scenario, the enhanced transmission and dissemination of Deep Space data, through unified communication channels. For this purpose, we test alternative scenarios for augmenting the data volume received from OMEGA/Mars Express, through the enhancement of Deep Space connectivity with ground receiving. First results have shown the potential of SDR in efficiently meeting the new enhanced challenges in Deep Space data transmission and handling.**

Keywords: Space Data Routers, Space Internetworking, Delay Tolerant Networking, DTN, OMEGA, Mars Express, data transmission, Deep Space Communications

I. INTRODUCTION

Nowadays, dissemination and exploitation of data from Deep Space (DS) missions face two major impediments: limited access capabilities due to narrow connectivity window via satellites (thus, confined scientific capacity) and lack of sufficient communication and dissemination mechanisms between Space-Data Collection Centers and the end-user community. Although large quantities of space data have to be transferred from space to the operation centers and then to the academic foundations and research centers, due to the aforementioned impediments more and more stored space data volumes remain unexploited, until they become obsolete or useless and are consequently removed. In the near future, these constraints on space and ground segment resources will rapidly increase due to the launch of new missions.

Furthermore, current technical schemes for DS communications are insufficient, since they involve paths that are manually selected, require constant human intervention, and prohibit automation and sharing of space network resources. Moreover, the current implemented transfer, dissemination and exploitation mechanisms are far from being adequate to meet these new increased requirements. Specific challenges are:

- Large transmission delays (RTT between Earth and Mars between 7min and 46min)
- Big Earth-Mars distance: 55.7 to 401.3million km
- Limited bandwidth available
- Disrupted links (orbital visibility)
- Error rates
- Limited bandwidth available
- Noisy communication links
- Limited time frame
- Power available on mission
- Buffer capacity

Current and future Mars and DS missions, in general, call for increased storage and communication resources, enhanced connectivity and multi-path options for reliable data transfers. Future science data requirements dictate high communication rates. In particular, the new missions added to the current operating ones (i.e. Mars Science Laboratory, ExoMars, and Mars Sample Return mission etc.) render DS transmissions to Earth even more challenging. Characteristic examples are the ExoMars and Mars Sample Return missions. Each of those two missions will deploy an orbiter, a l ander and a rover. The descent module of Mars Sample Return will also encompass an ascent vehicle that will collect martian soil and, for the first time, will return it back to Earth for detailed analysis [1]. The orbiters will also be able to operate as data relay satellites and might serve other missions as well. ExoMars' scientific data will be transmitted back to Earth via Mars orbiter relay satellites.

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Here below, we examine the specific case of current operations of the Mars Express satellite, the technical constraints in data transmission, the proposed scenario for alternative communication and data transmission using Space Internetworking and in particular Delay Tolerant Networking (DTN).

II. MARS EXPRESS OPERATIONS AND CONSTRAINTS

Mars Express (MEx) is ESA's orbiter to Mars. The orbiter successfully entered Martian orbit on 25 December 2003 and finally moved into its operational near polar orbit later in January 2004.

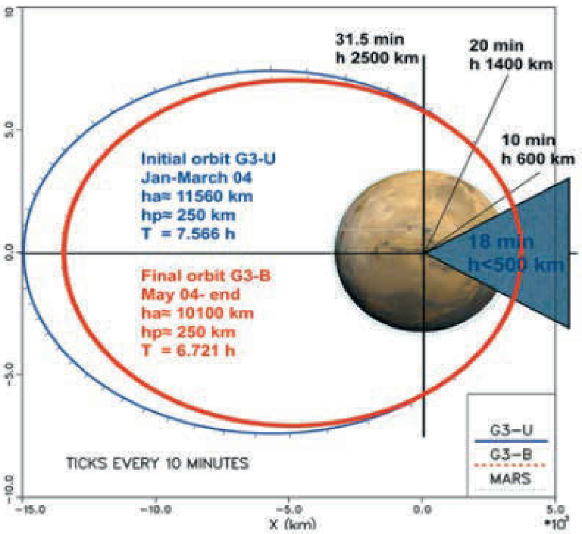

Fig. 1. Orbit characteristics for the nominal and the first extended mission. The initial orbit (blue) was changed to the final (red) in April 2004 [2].

MEx's onboard scientific payload comprises seven scientific instruments [2]. One of them is OMEGA, a spectro-imaging instrument that observes almost the totality of the martian surface from a polar orbit. It provides spectra of the surface and the atmosphere between 0,35 µm and 5,2 µm with a ground resolution varying from 350 m to 10 km. Such observations allow mapping the main minerals and thus exploring the details of the martian geology and the processes that modified the surface.

The orbital period of MEx is 6,645 hours. There is a 'pericentre window' of approximately 20 min with the best observation conditions in less than 500 km orbit altitude for the surface and subsurface instruments (HRSC, OMEGA and MARSIS) (Fig. 1). Within this window, the actual observation time is further narrowed by the amount of data that can be downloaded. A significant segment of each orbit is used to turn the fixed-mounted spacecraft antenna to Earth for data downlink and command uplink. During the 'downlink windows', the antenna cannot be used for specific pointed science observations. The location and duration of these downlink windows depend on the availability of ground stations and can be selected by the scientists, within certain constraints. The average daily downlink duration is between 8 to 10 hours, spread over several sessions of about 3 hours each. Typically, one out of four pericentre windows is blocked for Earth communications (Fig. 2).

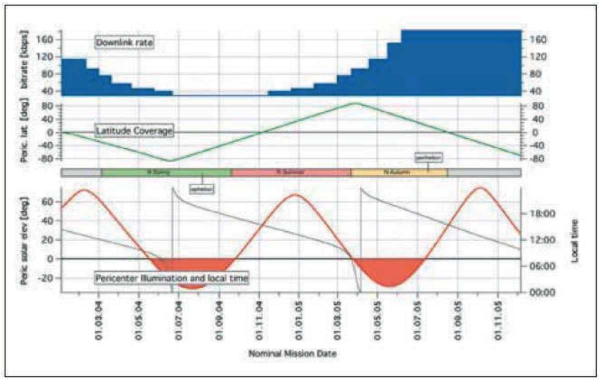

Fig. 2. Evolution of Mars Express downlink rate, pericenter latitude, illumination conditions and local time since the nominal mission [2].

Furthermore, the maximum duration of inertial pointing window in one orbit is 90 minutes. For nadir and nadir-like observations, the max duration is 68 minutes per orbit. No more than two science pointings per orbit are allowed. However, operational constraints are induced by eclipse, occultation and availability in downlink volumes. From the 687 days of one Martian, the period around day 230 is not available due to solar conjunction and the period around day 660 is not available due to solar opposition. Concerning the availability in downlink volumes, as the Earth-Mars distance increases data rates (and the resulting science data volume) decrease and as more ground stations are available the total downlink science data volume is increased. The maximum data rate allocated to the payload is in the range of 80 to 100 kbps, which has to be shared by all instruments, except HRSC, OMEGA and MELACOM which have been allocated high-speed (IEEE) links (between 0.1 and 25 Mbits/s).

III. THE SDR PROJECT

The Space-Data Routers (SDR) project aims into boosting collaboration and competitiveness between the European Space Agency, the European Space Industry and the European Academic Institutions towards meeting these new challenges through Space Internetworking. Among the main scientific objectives of the project is, through the examination of a specific scenario, the enhanced transmission and dissemination of Deep Space (DS) data, through unified communication channels.

A. DTN overview

Desired properties for DS communications include, but are not limited to, the following: (i) automatic store-and-forward data forwarding; (ii) operation through multiple network hops; (iii) transfers that can span multiple ground stations on Earth; (iv) autonomous networking potentially supported by dynamic routing procedures; (v) high data rate transfers that effectively utilize contact opportunities and minimize data delivery time; (vi) secure transmissions; and (vii) multiple quality of service levels [11]. Future science data requirements dictate high communication rates, as shown in Fig. 3.

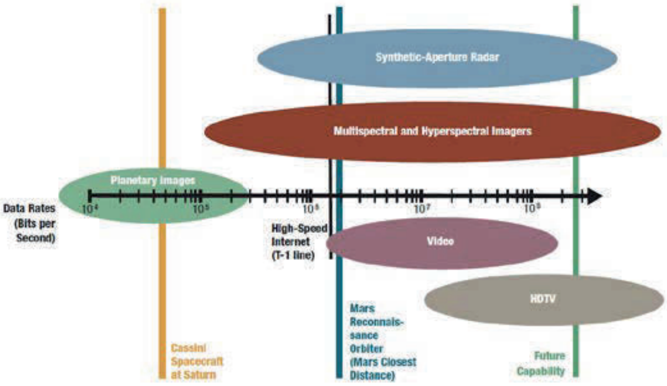

Fig. 3. High bandwidth communications for future space missions [1].

Space internetworking gradually replaces or assists traditional telecommunication protocols. Future space operations are scheduled to be more dynamic and flexible; many of the procedures, which are now human-operated, will become automated, interoperable and collaborative.

In this framework, the Delay Tolerant Networking (DTN) is an emerging key technology for future missions in DS. Industrial activities worldwide tend to shift towards internetworking devices and protocols. DTN has the potential to reduce space mission costs and increase scientific return through the flexibility of reaching DS and disseminating data on Earth. Key research achievements in the area of space and networking are the design, implementation and evaluation of new transport protocols for DS communications, such as the Deep-Space Transport Protocol (DS-TP), extensive analysis of the applicability of IP and DTN in space environments, space communication Testbed design and implementation and novel mechanisms for service differentiation.

The first demonstration of DTN applicability over DS networks was recently made by NASA JPL using the NASA Space Communications Testbed (SCT) [3][4] and the Deep Impact/EPOXI space mission. The first test of the deep space communication network (Interplanetary Internet-InterPlaNet), known as "Deep Impact Networking (DINET) experiment", was successfully tested from mid-October to mid-November 2008 [5]. The Deep Impact/EPOXI spacecraft was used as a DTN router for image bundles flowing from one machine to another over interplanetary links. The spacecraft was in communication, using DTN, with nine ground stations at JPL, designed to simulate a M ars relay network with orbiters, landers, and earthbound nodes. The Interplanetary Overlay Network (ION) DTN implementation [6] was used with retransmission LTP over CCSDS CFDP. NASA's demonstration of the successful transmission of relay data through the orbiting Mars Odyssey, Mars Global Surveyor, and MEx by the Mars Exploration Rovers has shown not only the benefit of using a relay satellite for multiple landed assets in a d eep space environment but also the benefit of international standards for such architecture capable of mitigating current availability limitations with respect to volume, timeliness, and continuity, achieving thus:

- Increased connectivity time in space
- Extended exploitation of science data
- Enhanced reliability of space communications
- Capabilities for sophisticated and thematic dissemination of space data
- Interoperability and data administration efficiency.

B. *Current Deep Space Communication scheme*

The communication type used between Mars and Earth is a "long haul" characterized by (a) higher levels of users, (b) more stringent performance requirements (such as higher quality circuits), (c) longer distance capabilities, (d) higher traffic volumes and densities, (e) larger switches and trunk cross sections, and (f) fixed and recoverable assets. On the other hand, landers and orbiters communicate with "short haul" communications characterized by efficiently handling traffic over distances less than 20 km. The Proximity-1 Space Link Protocol (UHF1) is the standard protocol used for the relay communications by all missions to Mars and is designed to ensure error-free delivery of data.

For data transmission and reception to Earth, there are two ground stations networks: the ESA tracking network station (ESTRACK) and NASA/JPL Deep Space Network (DSN).

The European Space Operations Control Centre (ESOC) in Darmstadt communicates with MEx via 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). The core ESTRACK network comprises eleven terminals located at ten stations in seven countries [7]. DSN Goldstone, Madrid, Canberra stations with 34 and 70m antennas provide additional support. Madrid station provides 4 - 6 hours extra downlink time per day.

During each orbit around the planet, MEx is turned towards Earth for communication with DSA1 for 8 hours on a daily basis. The scientific data are stored onboard MEx 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 [8].

Once downloaded from space to the ground station, the OMEGA/MEx 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) 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 and dissemination in the publicly available Planetary Science Archive (PSA) [9].

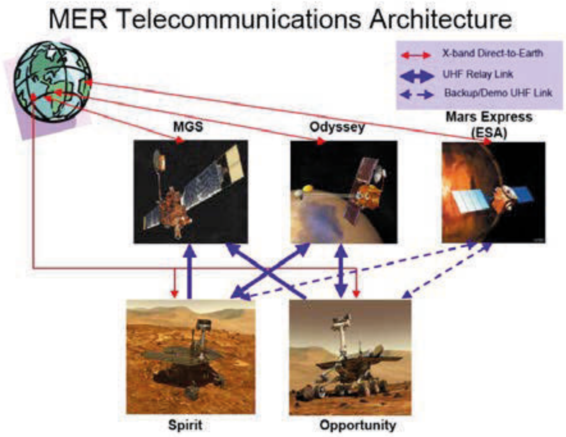

Fig. 4. Current pattern for data transmissions between Earth-Mars and rovers-orbiters [10].

IV. DEEP SPACE COMMUNICATIONS SCENARIO

The current communication pattern on Mars is that MEx serves as data relay for rovers on the martial surface (Fig. 3) providing cross support with Mars Science Laboratory rover "Curiosity" and as a backup data relay to "Phoenix" Mars Lander [10].

The Deep Space scenario aims at the:

- Elimination of data loss
- Increase of received data volume (extremely important for OMEGA)
- Increase of access speed to DS data

In particular, the DTN protocol is tested in terms of:

- Reduction of time latency between Earth and MEx
- Improvement of reliability and reduction errors code transmission
- Improvement of data bandwidth suitable for the upcoming new needs

C. Scenario description

In the framework of the SDR project, we consider a scenario that involves OMEGA data transmission. We consider two separate issues considering the capabilities of SDR in terms of augmenting the data volume received from MEx, through the increase of spacecraft's connectivity with Earth ground receiving stations

The scenario uses the current general pattern on DS communications with the participation of the international Testbed and the addition of supplementary to currently implemented DTN nodes in conjunction with realistic link simulation for DS communications. For this purpose, the test network that has been established for validation of the Space Data Routers includes nodes of the network overlay located at the premises of each partner of the SDR project. Communication is over the general Internet, which provides a realistic environment for the terrestrial communication. Increased connectivity aspects are considered through deployment in the DTN Testbed.

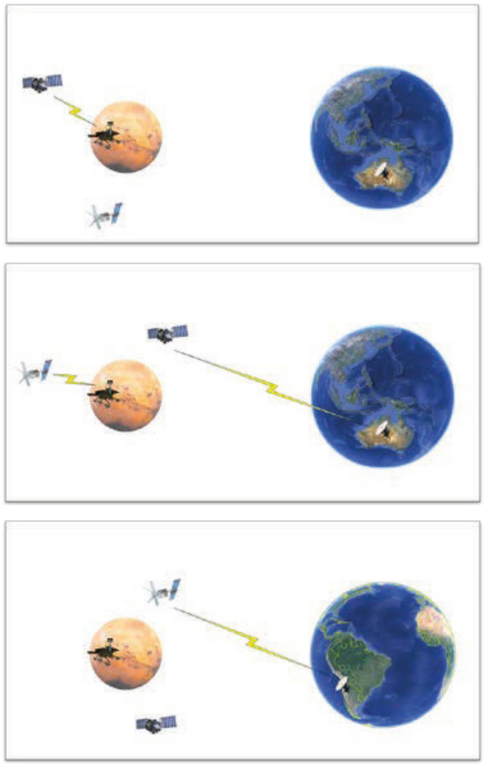

Fig. 5. Consequtive sequence of data transmission in the scenario.

Details on the implementation of the scenario are provided in [11][12]. DS communication includes alternative space routes using relays that support the DTN stack (Fig. 6) and communicate directly with the DTN nodes of the ground segments. Using SDR, various ground stations form an internetwork that allows for communication with DS using alternative routes among the two ends. DS Antennas, interconnected with DTN, would allow for a continuous data downlink from Mars Express. However, since the Space-end does not support a DTN node, a space link is simulated as described in [11]. Further details on the implementation of the scenario are described in [12][13].

Connectivity time, reliability of the DTN and the efficiency of the approach are evaluated, similarly to the internet architecture.

- increase connectivity time in space,
- achieve storage instead of temporary buffering,
- acquire routing possibilities relying mainly on predetermined manual procedures,
- follow an hourglass shape of the protocol stack, with DTN in the middle, possibly replacing IP in space and collaborating with IP on Earth.

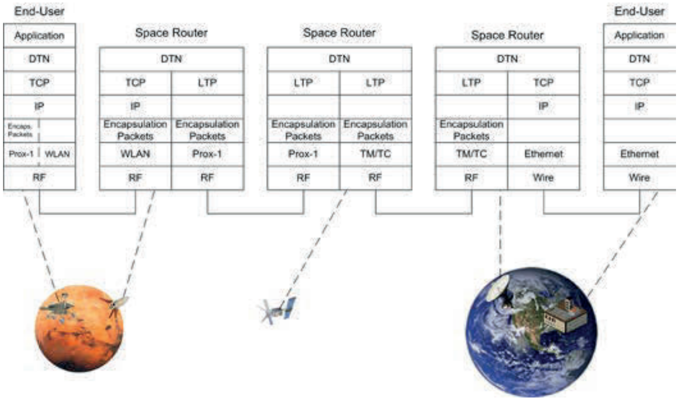

Fig. 6. Communication scenario – protocol stack [13].

V. CONCLUSION

Based on simulation results, it is proved that: (i) Delay-Tolerant Networking enhances communication speed; (ii) efficiently supports reliable data transfers in challenged networks; and proves that (iii) dynamic routing is feasible in Space. Technical performance on simulation scenarios is described by [11]. In terms of scientific return, enhancements in transmission speed and realibility have induced:

- Improved exploitation of massive data volumes (increasing the return of all scientific missions)
- Reduction of communication costs
- Elimination of scientific loss
- More allocated time for downlink scientific data
- Increased volume of downlinked scientific data as well as greater flexibility for scientists in planning science pointings and downlinks.

Furthermore, the Madrid NASA's DSN station is essentially used as second ground station for MEx, already offering 4 to 6 hours extra downlink time / day. The use of an additional ground station, provides possibilities for additional downlink time and therfore fulfill the initial scientific objectives of the MEx mission. Finally, Space Internetworking not only can bridge the communication gap between DS and internetworking protocols but also fill the gap of agency interoperability (thus operational flexibility, capability and access to additional resources) and cross support as well.

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7-SPACE-2010-1, SP1 Cooperation, Collaborative project) under grant agreement n° 263330 (project title: Space-Data Routers for Exploiting Space Data). This presentation reflects only the authors' views and the Union is not liable for any use that may be made of the information contained therein.

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Cluster Science Archive: the ESA long term archive of the Cluster mission

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Abstract— **The science data archive of the Cluster mission is a major contribution of the European Space Agency (ESA) to the International Living With a Star program (ILWS). Known as the Cluster Active Archive (CAA), its availability since 2006 has resulted in a significant increase of the scientific return of this on-going mission. The Cluster science archive (CSA) has been recently developed in parallel to CAA at the European Space Astronomy Center of ESA in Madrid, Spain. It is the long-term science archive of the Cluster mission developed and managed along with all the other ESA science missions' data archives. CSA design and data services are based on the CAA interface and its user-friendly services. Publicly opened in November 2013, CSA is available in parallel to CAA during a transition period until CAA public access closing, foreseen in Spring 2014. It is the purpose of this paper to present the available data services of CSA, the ones being developed and possible future services.**

Keywords: Cluster mission, space plasma physics, data archive

I. INTRODUCTION

Solar-terrestrial physics, magnetospheric dynamics and space weather combined is a major field of research. It is supported by a significant number of space missions financed by all space agencies worldwide and coordinated by the International Living with a Star (ILWS) program.

II. THE CLUSTER MISSION

The SOHO and Cluster space missions together represents a major contribution of the European Space Agency (ESA) to the ILWS. They form the first cornerstone mission of the ESA Horizon 2000 science program. SOHO is a solar observatory located at the Lagrangian point L1, launched in 1995 and still successfully operated. Cluster is the first constellation of four spacecraft flying in formation around Earth, enabling the first *in-situ* 3D mapping of the terrestrial space environment under two very different solar cycles.

Since their launch in 2000, the Cluster spacecraft relay the most detailed information about how the solar wind affects our planet magnetic environment. The solar wind (the perpetual stream of subatomic particles expelled by the Sun) can damage communications satellites and power stations on Earth. Science output from Cluster is a leap forward in our knowledge of space plasma physics, i.e. the science behind space weather and the Sun-Earth connection. It has been key in improving the modelling of the magnetosphere and understanding its various physical processes. Cluster data have enabled the publication of more than 2300 publications, including more than 1900 refereed papers and counting.

III. THE CLUSTER ACTIVE ARCHIVE

This substantial scientific return is often attributed to the online availability of the Cluster data archive, originally called the Cluster Active Archive (CAA). CAA is a unique online archiving effort which contains the entire set of Cluster high-resolution data and other related products in a standard format and with a complete set of metadata [1]. The total amount of data in compressed format now exceeds 50 TB. The data archive is publicly accessible and suitable for science use and publication by the worldwide scientific community. The CAA aims to provide user-friendly services for searching, accessing and visualising these data and ancillary products (e.g. position of the spacecraft). Accessing CAA requires to be (freely) registered and CAA currently accounts more than 1,500 users. CAA users download on average 1 TB of data every month.

The coverage and range of products are being continually improved with more than 200 datasets available from each spacecraft, including high-resolution magnetic and electric DC fields and wave spectra; full three-dimensional electron and ion distribution functions from a few eV to hundreds of keV; and various ancillary and browse products to help with spacecraft location and event identification.

IV. THE CLUSTER SCIENCE ARCHIVE

Opened in November 2013, the Cluster Science Archive (CSA) now supersedes the Cluster Active Archive as the public interface to the Cluster mission archive. CSA is the long-term archive of ESA's Cluster mission. It is provided and maintained alongside ESA's other solar system science archives at ESAC, located near Madrid, Spain. The archive provides online access to high-quality, validated, high time resolution data from the Cluster instruments together with auxiliary and support data products (e.g. orbit information). In addition, the CSA provides value-added capabilities such as data visualization services and VO support. The design is based on the CAA interface so the look, feel and capabilities will be familiar to the users of its predecessor. The CSA services can be accessed either via its Graphical User Interface, or via command line including data streaming. Data can be quickly browsed thanks to the availability of pre-

NETSPACE- NETworking technologies for efficient SPACE data dissemination and exploitation
edited by O. Sykioti and I.A. Daglis

generated plots. On-demand plotting enables to generate graphics of publishable quality. User guides and calibration reports have been produced by all instruments teams to help scientists in their data interpretation, while softwares developed by the community are made available to speed up their data analysis.

Both CSA and CAA archives will remain publicly available for a few months before the closing of the CAA public access (foreseen in Spring 2014). Until one year post-operations, the CAA will continue to validate and ingest data while interacting with the instrument teams, including cross-calibration activities. The CAA will also retain responsibility for the development of value added products, maintaining the Cluster data & metadata standards and provision of some mission operations services such as the instrument team access to the raw data.

A. Graphical User Interface: basic features

The access point to the Cluster Science Archive is the following: http://www.rssd.esa.int/csa. Users need to be registered to the CSA to download data. Registration enables to track the archive usage, store user profiles, and warn users if a major problem is found on a particular dataset over a certain time period (e.g. calibration issue). The CSA graphical user interface (GUI) is not a website like CAA but a Java Desktop Application that can be started from the CSA website.

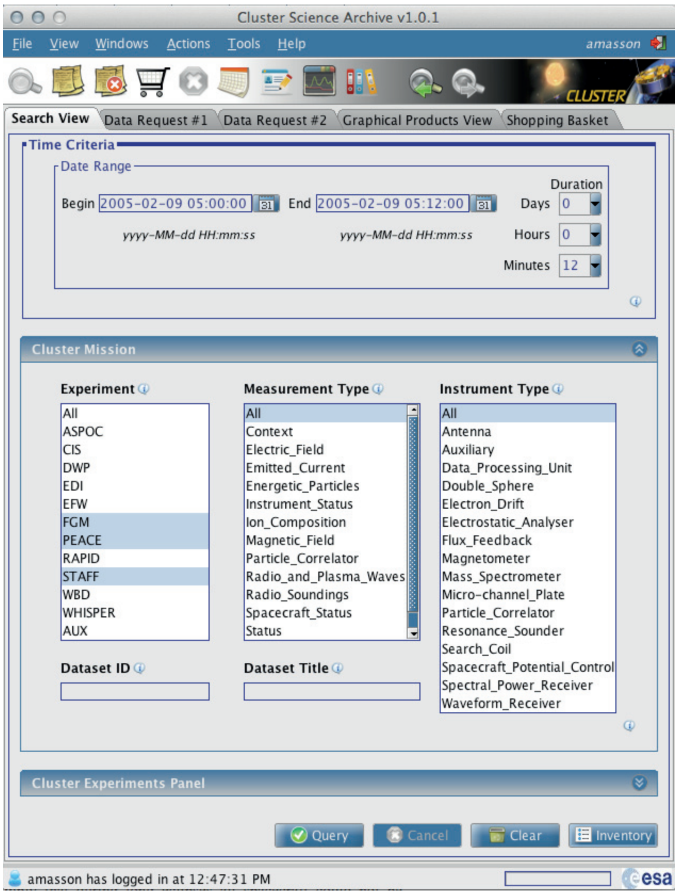

Fig. 1. Search view of the Cluster Science Archive GUI.

1) Data selection

This GUI enables to select multiple datasets for a specific time period. This selection is performed in two steps. First, the "Search view" where the user selects a time period and the different Cluster experiments of interest. A snapshot of the search view is presented in Fig. 1. A time period has been set to 2005-02-09 05:00-05:12 UT (top part) and three experiments have been selected: FGM, PEACE and STAFF (see Table 1 for the definition of all Cluster experiments acronyms and the main physical quantities they measure). Once the "Query" button is pressed, the GUI interrogates the database and dynamically displays the datasets containing data in a new tab, entitled Data Request #XX. If a dataset contains no data on any of the satellite, it is not visible. If it is only available on some of the spacecraft, this dataset can only be selectable for those satellites. For instance, for the time period selected, PEACE data are only available for the Cluster 4 satellite (Fig. 2). Please note also the short list tick box located above the experiment panel on the right side. This allows selecting only the most scientifically used datasets of each experiment. Several data requests can be executed in parallel, which is a new feature.

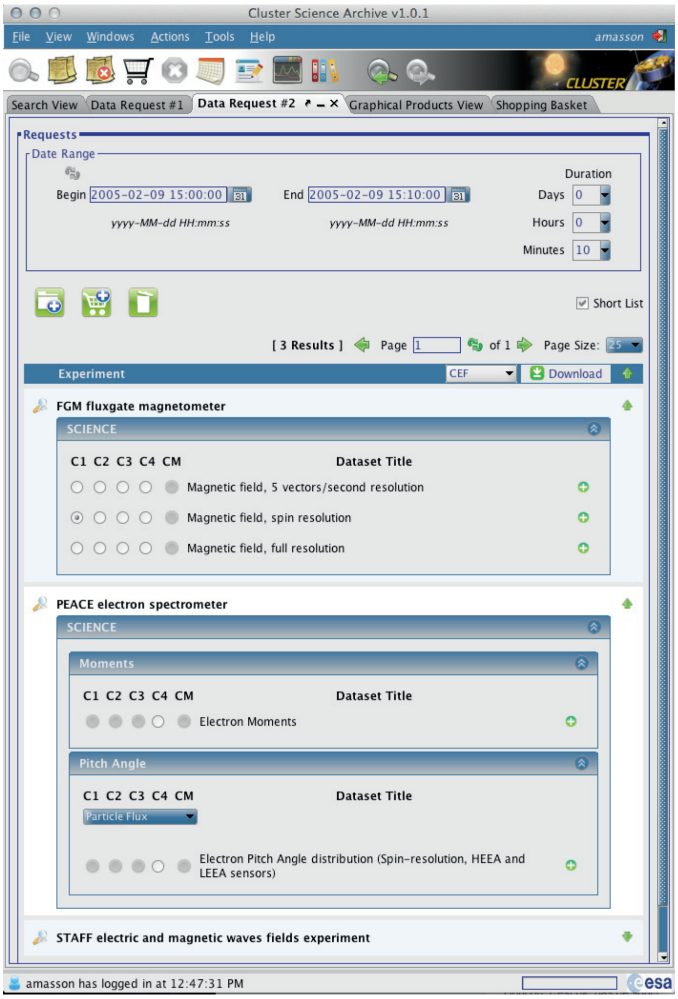

Fig. 2. Data Request view on the Cluster Science Archive GUI.

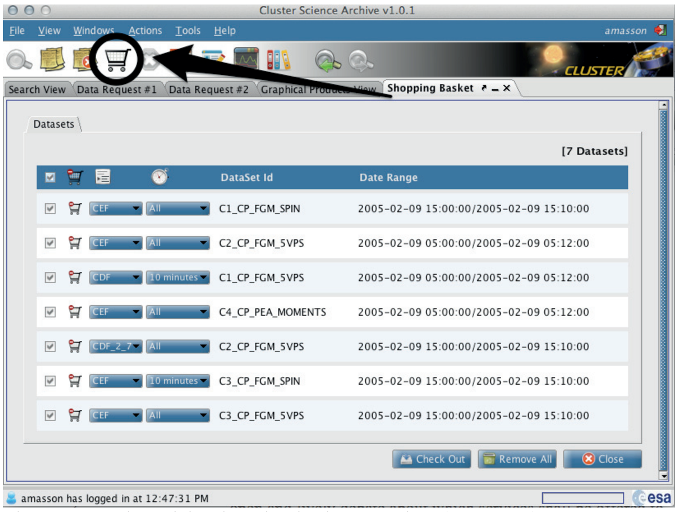

Fig. 3. Snapshot of the shopping basket overview (CSA GUI).

2) Direct download

Once the datasets are selected, they can be immediately downloaded by simply clicking on Download (see Fig.2 on the top right of the experiment panel). By default the data are delivered in CEF format, which is an ASCII format. Alternatively, CDF v2.7 or v3.3 formats can be selected from the drop down on the left side of the download button. Then, the CSA server estimates the size of the data requested. If the size is less than 100 MB, the data are downloaded directly with all datasets compressed in one gzip file. Otherwise, an email is sent to the user as soon as the datasets are ready to be downloaded.

3) Shopping basket download

Three icons are located above the experiment panel in Fig. 2 on the left side. The middle icon displays a shopping basket with a "+" sign. By clicking on this icon, the datasets are pushed to the shopping basket. The first time this icon is clicked, a shopping basket overview is displayed where all datasets selected are visible. This operation can be done from any data request tab created. Once all datasets are selected and pushed to the shopping basket, the user is invited to click on the shopping basket icon on top of the CSA window (see Fig. 3). The user can then download all the datasets selected in one go by clicking on *Check Out*, with the option to choose between one of the three formats proposed and any delivery time interval for every dataset (instead of 1 file per dataset per time period, multiple files can be delivered in slices of 10 minutes, 1, 3, 6, 12 hours, or daily. An email is then sent to the user as soon as the datasets are ready to be downloaded.

B. Graphical User Interface: value added services

1) Metadata display

The header of each CSA dataset is composed of metadata, which describes the data content of the dataset. This metadata information can be visualised by simply clicking on any dataset. In Fig.4, an example is given where a click on the power spectral density dataset of STAFF has triggered a side window where key metadata information is displayed.

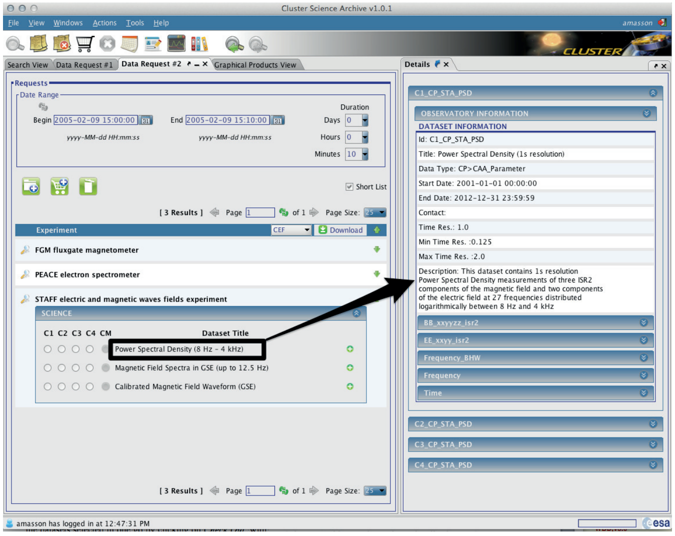

Fig. 4. Metadata information of a STAFF dataset displayed on a side of a data request window.

2) User profiles

The Cluster Science Archive is populated with hundreds of datasets while a scientist may often download or visualizes more or less the same type of datasets. Profiles are made for that. Every user has the opportunity to store this type of information in three kinds of profiles

- *General* profile: to store a list of datasets
- *Graphical profile*: to store a list of graphical products
- *Time* profile: to store a list of preferred events

A profile can be created or datasets can be added to an existing profile using the left icon of the three icons located above the experiment panel in any data request view (see Fig. 2). A similar icon is available in the graphical Products view (see Fig. 5). Existing profiles can be managed by clicking on the top icon displaying red, blue and yellow folders.

3) Data Visualisation

Key scientific datasets for each Cluster experiment can be visualized on the CSA. This data service has two main purposes.

The first one is to quickly browse through the data. Thus, plots of around 400 datasets (i.e. 100 per satellite) have been pre-generated for the entire length of the Cluster mission for any user to quickly browse through its favorite datasets. The pregenerated plots are either daily or 6 hours long plots. Once generated, the arrows located on the right of the *Plot Panel(s)* button, below the date range setup, allows to visualize the previous or the next daily or 6 hours long pre-generated plot (see Fig. 5).

The second type of plot is simply related to the on-demand plotting capability. It concerns a slightly higher number of datasets. The display of any combination of these datasets is possible and can also be saved as a graphical profile. A limit of 54 hours long has been imposed. Once the on-demand plot

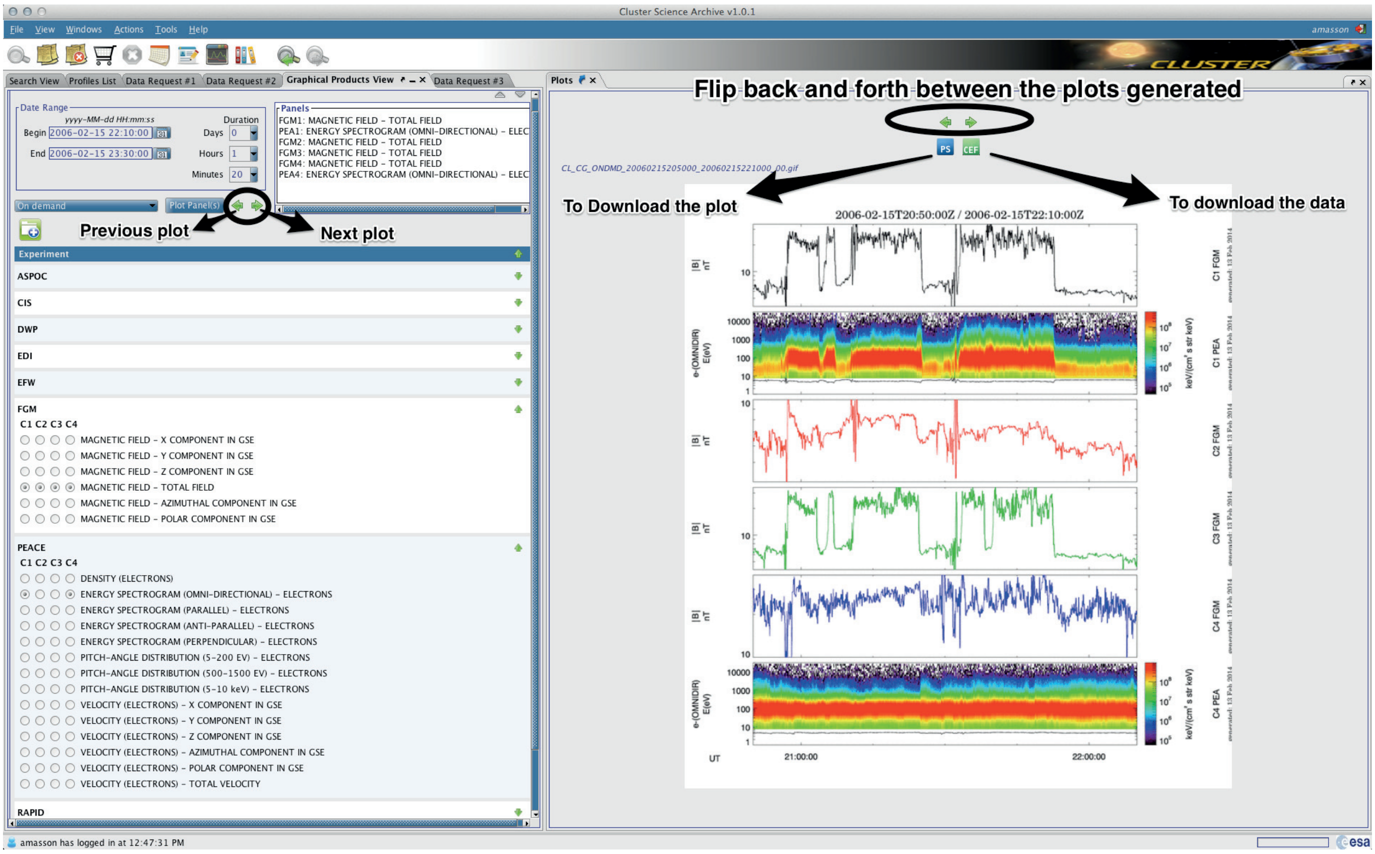

Fig. 5. Graphical display of the magnetic field amplitude measured by FGM on all 4 Cluster satellites together with the display of the omni-directional electrons spectrograms measured by PEACE

is generated, two icons appear on top of this plot: PS and CEF (see Fig. 5). Clicking on PS will download the plot displayed in PS format, of quality suitable for publication. Clicking on CEF will download the data displayed in CEF format. Above these two icons, two arrows allow to go back and forth through the plots that have been generated, which is also a new feature.

There is delay of around 1 year between the measurements in space and the availability of the pre-generated plots. However, a much fewer subset of these plots (with predefined lists of datasets) is available online usually a few hours after data acquisition at the Cluster Science Data System web QuickLook plots: http://www.cluster.rl.ac.uk/csdsweb-cgi/csdsweb_pick.
These plots are preliminary since they are based on rough calibrations. These plots are being reprocessed based on the latest version of the data and will be soon available on the CSA.

C. *Accessing CSA via Matlab and IDL*

The Cluster archive inter-operability subsystem (CAIO) allows Cluster scientists to have direct access to the Cluster Science Archive, i.e. without using the CSA java based graphical user interface. It supersedes the so-called command line of the CAA. A dedicated website explaining how to use the CAIO with many practical examples is available at: http://csa.esac.esa.int/csa/aio/

The CAIO allows to download any Cluster dataset via Matlab, IDL, a batch script (via wget) or by using a java client programme, downloadable from the CAIO website. The CAIO website also provides a complete user manual, and detailed examples on how to call it from Matlab, IDL and wget.

D. *Data Streaming*

This feature allows a faster delivery of the data. It indeed enables immediate streaming of one dataset to the users machine (instead of a zip file being created on the CSA server and then sent). This feature is limited to one dataset per request, of Cluster Exchange Format type.

Dataset can be downloaded in uncompressed format (default) or in gzip format. There is no error logging. This implies in particular that if the connection is broken for any reason, the dataset has to be requested again. For more details, please check the CAIO website.

E. *Future developements*

Obvious developments include the availability in the short-term future of the Double Star data. Double Star is the first sino-european collaborative space mission composed of two satellites whose data are highly complementary scientifically to the Cluster measurements.

The CSA will also soon welcome the data products produced by two FP7 EU funding projects named ECLAT and MAARBLE. ECLAT, the European Cluster Assimilation

Technology, has enabled the design and the generation of ground-based contextual observations for the Cluster mission, including

- IMAGE FUV products with Cluster magnetic footprints,
- SuperDARN ionospheric convection measurements MIRACLE measurements of ionospheric currents in the Scandinavian sector,
- Detailed magnetic field modeling and Cluster footprint tracing,
- Detailed Cluster boundary-crossings information,
- State-of-the-art physics-based modeling of the magnetosphere using the GUMICS code.

The MAARBLE (Monitoring, Analyzing and Assessing Radiation Belt Loss and Energization) FP7 project has two focused and synergistic aims: to advance scientific research on radiation belt dynamics; and to enhance data exploitation of European space missions through combined use of European and US spacecraft measurements and ground-based observations. MAARBLE employs multi-spacecraft monitoring of the geospace environment, complemented by ground-based monitoring, in order to analyze and assess the physical mechanisms leading to radiation belt particle energization and loss. Particular attention is paid to the role of ULF/VLF waves where Cluster plays a key role. Related datasets, highly complementary to the Cluster data, will be soon ingested in the CSA.

A data mining tool has been developed as part of the CAA but was never made public. This data mining tool enables for instance to generate VO tables of all data collected in burst mode in a specific region of space. It is the intention of ESA to make a simplified version of this tool publicly available as part of the CSA in the mid-term future. This implementation will be done in close collaboration with other data mining tools such as AMDA not to duplicate efforts but being complementary. Connections with other archives and data services will of course be part of the future developments of CSA.

V. CONCLUSION

The Cluster Science Archive is the long term ESA archive of the Cluster mission. Its design is based on the CAA. It now offers nearly all the data services provided by CAA to the scientific community. This proceeding was meant to provide a quick overview of the various services offered by the CSA to the scientific community such as data visualisation or command line capabilities (which enables data access via Matlab or IDL softwares). Upcoming services are being implemented (e.g. distribution plot visualisation). Possible new services such as data mining are considered.

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TABLE I. CLUSTER EXPERIMENTS

Acronym (Principal Investigator)	Instrument	Measurement
ASPOC (K. Torkar, IWF, Austria)	Active Spacecraft Potential Control experiment	Spacecraft potential control by means of the emission of Indium ions beam (operations until June 2008)
CIS (I. Dandouras, IRAP/CNRS, France)	Cluster Ion Spectroscopy experiment	Ion composition (Hydrogen, Oxygen and Helium) and 3D ion distribution functions for energies between 0 and 40 keV
DWP (M. Balikhin, Sheffield Univ., UK)	Digital Wave Processing instrument	Coordinates the operations of the EFW, STAFF, WBD and WHISPER instruments; particle/wave correlator
EDI (R. Torbert, UNH, USA)	Electron Drift Instrument	Three components of the electric field **E** (at best 1s time resolution) and the electron drift velocity (at best ~ 4s spin time resolution)
EFW (M. André, IRF, Uppsala, Sweden)	Electric Field and Wave experiment	DC electric field **E** waveforms (two components in the spin plane) up to 10 Hz in normal mode, 180 Hz in burst mode (few hours per orbit) and up to 36,000 samples per second during short internal burst mode - few tens of seconds - twice per orbit
FGM (C. Carr, Imperial College, UK)	Fluxgate Magnetometer	DC Magnetic field **B** magnitude and direction (waveforms, 3 components up to 10 Hz, better sensitivity than STAFF below 0.5 Hz)
PEACE (A. Fazakerley, MSSL/UCL, UK)	Plasma Electron and Current Experiment	3D distribution functions of electrons with energies between 0.7 eV and 30 keV enabling the characterization of the local plasma: electron density, bulk flow and temperature together with electron pitch angle data.
RAPID (P. Daly, Max Planck, Germany)	Research with Adaptive Particle Imaging Detectors	3D distribution of energetic ions and electrons flux for up to eight energy channels (energy range: ~30 keV to 400 keV)
STAFF (P. Canu, LPP/CNRS, France)	Spatio-Temporal Analysis of Field Fluctuation experiment	Search coil magnetometer measuring the 3 components of the magnetic field fluctuations (waveforms) up to either 10 Hz or 180 Hz (burst mode); better sensitivity than FGM above 0.5 Hz. Spectrum analyzer using the two electric field components and the 3 magnetic field components to compute in real time the 5x5 cross-spectral matrix at 27 frequencies distributed logarithmically in the frequency range 8 Hz to 4 kHz. Spectrum analyzer data enable to derive propagation and polarization parameters of waves in this frequency range.
WBD (J.Pickett, Univ. Iowa, USA)	Wide Band Data receiver	Electric field waveform (in the range of 100 Hz to 577 kHz and magnetic field waveform in the range 70 Hz up to 4 kHz
WHISPER (J. -L. Rauch, LPC2E/CNRS, France)	Waves of High Frequency and Sounder for Probing of Density by Relaxation	Electric field **E** spectrograms of natural waves in the 2 kHz – 80 kHz range; triggering of plasma resonances by an active sounder enabling the measure of the electron density in the range 0.2-80 cm^{-3}

On the role of advanced data routing protocols in enhancing the characterization and understanding of magnetospheric processes

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Abstract— **Magnetospheric processes play an important role in the Sun-Earth connection and space weather in general. The availability of multi-spacecraft observations can lead to the comprehensive characterization of magnetospheric processes and set the foundations for a deeper understanding and eventual forecasting of them. 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. Here we present the architecture and basic functionality of a Delay Tolerant Networking (DTN)-based application specifically designed in the framework of the "Space-Data Routers" (SDR) project, for data query, retrieval and administration that will enable the addressing of outstanding science questions related to space weather, by providing simultaneous real-time sampling of space plasmas from multiple points with cost-effective means and measuring of phenomena with higher resolution and better coverage.**

Keywords: space science, space data dissemination, cross missions, multiple missions, space weather

I. Introduction

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 [1, 2]. Nowadays, information is no longer gathered merely from a single spacecraft vantage point but also by multispacecraft distributed observatory methods and adaptive mission architectures that 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.

The most important capability requirements in enabling space weather prediction 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.

A number of NASA and ESA space missions delivering data of significance to space weather are currently in operation. Among them, missions targeting the Sun, such as the long-standing Solar and Heliospheric Observatory (SOHO), but also Hinode and the Solar Dynamics Observatory (SDO). Pending advances in basic research, these missions can provide valuable clues towards an understanding of the onset and dynamical evolution of solar eruptive phenomena such as solar flares, coronal mass ejections and solar energetic particle events. In the near future, ESA's Solar Orbiter (SolO) and NASA's Solar Probe Plus (SPP) missions promise to advance our understanding substantially, by providing vantage points near the Sun (SolO) or, in-situ, at the regime of the genesis of the supersonic, super-Alfvenic solar wind (SPP). Solar wind variations are currently monitored by WIND and the Advanced Composition Explorer (ACE) at L1, while the response of the terrestrial magnetosphere is being recorded by the Cluster and THEMIS missions. The currently operating heliophysical space missions are schematically illustrated in Figure 1.

Our goal was to test the capability of Space-Data Routers to efficiently distribute to registered end-users these and future voluminous data from missions observing from different heliospheric locations.

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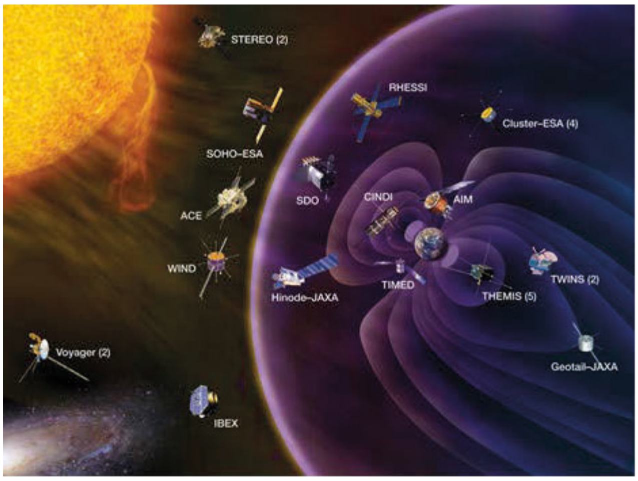

Fig.1 Illustration of the Heliophysics missions

II. SPACE WEATHER SCENARIO

The objective of this scenario was 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. This scenario serves the purpose of a cross-mission single thematic space data scenario. In the following we are presenting the missions and the relative data that we used for the space weather scenario in the framework of the SDR project.

A. The Cluster and THEMIS missions

We outline here the Cluster and THEMIS missions that we used, in order to monitor the electromagnetic wave activity in geospace for the purposes of the SDR project.

The Cluster mission is a collection of four spacecraft flying in formation around Earth, relaying the most detailed ever information about how the solar wind affects our planet in three dimensions [3]. The solar wind (the perpetual stream of subatomic particles given out by the Sun) can damage communications satellites and power stations on Earth. The operation lifetime of the Cluster mission ran from February 2001 to December 2009. In October 2009, the mission was extended until the end of 2012.

The launch of Cluster was performed in 16 July and in 9 August 2000 (two launches of two Cluster satellites each, using two Russian Soyuz rockets from Baikonur, Kazakhstan). At each launch, two Cluster satellites were placed in elliptical orbits with an altitude varying from 200 to 18 000 kilometres above Earth. The two satellites of each launch were then released one after the other and used their own onboard propulsion systems to reach the planned operational orbit (between 19 000 and 119 000 kilometres from the planet).


Fig.2 Illustration of the Cluster mission

Having four identical spacecraft, Cluster was the first space project ever having to establish a production line for four spacecraft. Using identical instruments simultaneously, three-dimensional and time-varying phenomena can be studied.

The THEMIS (Time History of Events and Macroscale Interactions during Substorms) mission answers long-standing fundamental questions concerning the nature of the substorm instabilities that abruptly and explosively release solar wind energy stored within the Earth's magnetotail [4]. The primary objectives of the mission are to

1. Establish when and where substorms begin;
2. Determine how the individual components of the substorm interact;
3. Determine how substorms power the aurora, and
4. Identify how local current-disruption mechanisms couple to the more global substorm phenomena


Fig.3 Illustration of the THEMIS mission

THEMIS accomplishes these tasks by employing 5 identically-instrumented spacecraft in carefully chosen orbits whose apogees line up once every 4 days over a dedicated array of ground observatories located in Canada and the northern United States. Three inner probes ~10 Earth radii (RE) from Earth monitor the current disruption onset, while two outer probes at 20 and 30 RE remotely monitor plasma acceleration due to lobe flux dissipation. THEMIS was launched on 17 February 2007.

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

Our overall objective was to 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.

In order to accomplish our objective, we have ingested in the SDR data base, the magnetic field data form the Cluster (four satellites in CDF format) and the THEMIS (five satellites in ASCII format) missions. This selection served as an evaluation test for the sufficiency of DTN Space-data overlays to administer thematic cross-mission space data.

A DTN network of several nodes, located in different sites has 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. A user-friendly GUI for querying the database and submitting the relevant tasks has been implemented (see Figure 4).

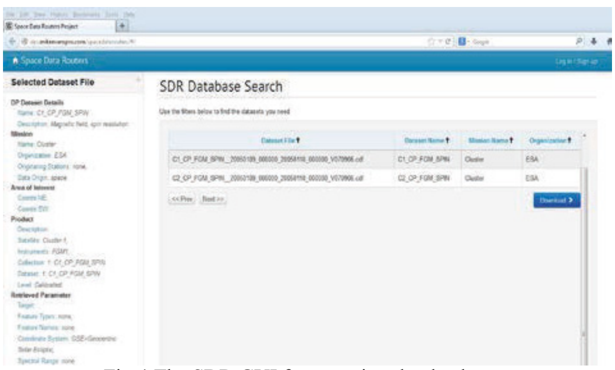

Fig.4 The SDR GUI for querying the database

C. 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 availability of 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 collaborative research project “Space-Data Routers” (SDR), 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 main goal is to allow space agencies, academic institutes and research centers to share space-data generated by single or multiple missions, in an efficient, secure and automated manner. Here, we present the architecture and basic functionality of a DTN-based application specifically designed in the framework of the SDR project for data query, retrieval, and administration that will enable the addressing of outstanding science questions related to space weather, by providing simultaneous real- time sampling of space plasmas from multiple points with cost-effective means and measuring of phenomena with higher resolution and better coverage.

ACKNOWLEDGMENT

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The new dimension of the Copernicus Data Network

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***Abstract*— The Copernicus program, previously known as Global Monitoring for Environment and Security (GMES), will provide accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change, and ensure civil security.**

The GMES Space Component (GSC) comprises five new satellites known as Sentinels that are developed by ESA specifically to meet the needs of the Copernicus Programme.

The Sentinel system includes the Sentinel Satellites, Sentinel flight operation systems and the Sentinel payload data system. The first three Sentinels are currently under industrial development, with Sentinel-1 planned to launch in March 2014. All the dedicated Sentinels, Contributing Missions and Ground Segment infrastructure will be part of the overall Copernicus/GMES Space Component architecture.

The article addresses a new concept of the Network and Security resources for the Payload Data Ground Segment (PDGS) designed to handle large amount of data, support near-real time applications and provide high performance with a strong level of Security. The Copernicus Data Network is based on a twin centralized infrastructure with an high speed Internet access and the utilization of commercial Dense Wavelength Division Multiplexing (DWDM) technology; the utilization of the state-of-art LAN technology at the different facilities and a gradual virtualization of the dissemination services complements the Copernicus Network and Security elements.

I. INTRODUCTION

The ESA Earth Observation (EO) Networks have been historically designed and implemented to support the Payload Data Ground Segment (PDGS) of a specific Mission (e.g. specific Network for Envisat or ERS).

Over the years, the EO systems have evolved towards a Multimission and a services oriented infrastructure; it was clearly visible a constant increase of the Network resources utilization together with the strategic importance of the Network into the overall PDGS infrastructure; such considerations marked the direction toward a new dimension of the EO Networks that cover the actual and upcoming users/missions needs.

The rationale behind the new EO Networks architecture is presented along with a host of new features taking into consideration the following drivers:

- Increase the system availability up to a minimum of 99.5%;
- Ensure and guarantee an end-to-end level of service;
- Introduce new cost-effective and state-of-art systems and services;
- Increase the quality and stability level;
- Increase the performance and the handled volume of data;
- Support stringent time response requirements (e.g. dissemination/distribution after 3 hours of sensing or Emergency Services for crises management);
- Network simplification (design and operations);
- Allow remote operations and management;
- Introduce virtualization of different elements (e.g. virtual archive);
- Allow full access to the ESA EO data to the science community;
- Increase of Security.

This paper describes the centralized Copernicus Network and Security architecture with two scalable 10 Gigabit Internet access as global data dissemination points.

II. THE COPERNICUS DATA NETWORK

A. The Copernicus Wide Area Network (WAN)

The Copernicus WAN interconnects the facilities depicted in Figure 1 with different data speeds (1 or 10 Gbps/s) in a IP MPLS (IPv6 ready) full meshed Network. The WAN interconnects the following facilities:

- AVS-GEO. Farnborough (UK) hosting Sentinel-1 Processing and Archiving Center (PAC) and Sentinel-2 PAC;
- DLR, Oberpfaffenhofen (DE) hosting Sentinel-1 PAC and Sentinel-3 PAC;
- ACRI, Sophia Antipolis (FR) hosting Sentinel-3 PAC and Sentinel-2 Mission Performance Center (MPC);
- CLS, Toulouse (FR) hosting the Sentinel-3 PAC;
- INDRA, Madrid (ES) hosting the Sentinel-2 PAC;
- EUMETSAT, Darmstadt (DE) hosting the Sentinel-3 marine Center;

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- KSAT, Svalbard (NO) hosting the Core Ground Stations (CGS) for all the three Sentinels;
- E-GEOS, Matera (IT) hosting Sentinel-1 and Sentinel-2 CGS;
- INTA, Maspalomas (ES) hosting Sentinel-1 and Sentinel-2 CGS;
- CLS, Brest (FR) hosting the Sentinel-1 MPC;
- ESA-ESRIN, Frascati (IT) hosting the Payload Data Monitoring and Control centers (PDMC);
- T-Systems central service area in Frankfurt hosting the common network services and dissemination services;
- EDRS receiving stations (planned 2014).

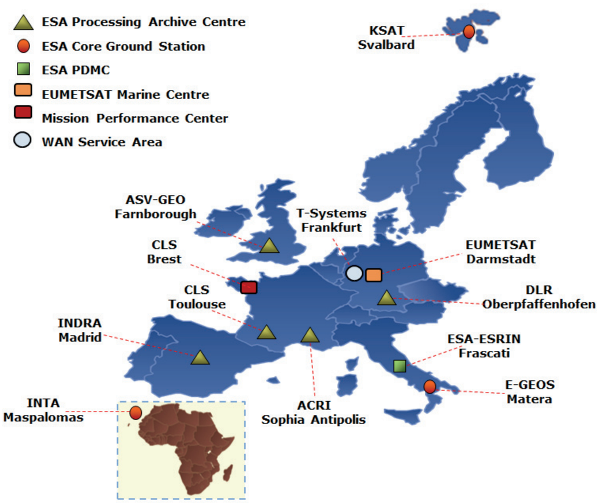

Fig. 1. The Geografic distribution of the Copernicus Data Network

The backbone is based on Dense Wavelength Division Multiplexing (DWDM) technology implemented by T-Systems on the Telekom Global Network (TGN) DWDM platform.

The DWDM platform offers a transparent optical wavelength connection between two locations at a dedicated bandwidth of 1 Gbps, 2.5 Gbps or 10 Gbps. By using the DWDM platform the facilities are connected via two physically diverse paths to the Twin-Core Data Centres in Frankfurt. This leads to a very scalable and robust service platform with the central service areas as the hub site.

Due to their remote location, the lines to Svalbard and Maspalomas are not end-to-end DWDM in the initial phase; the Svalbard access network is actually composed by two network segments: one from Svalbard to Oslo provided by KSAT via Broadnet (initially 1 Gbps and later 2.5 Gbps), plus the DWDM segment under T-Systems responsibility from Frankfurt to Oslo (2x 10 Gbps). The two networks are interconnected in a PoP located in Oslo. Maspalomas access network is totally managed by T-Systems and is based on an IP backbone. The capacity in the first phase is 1 Gbps with a planned upgraded to 2.5 Gbps driven by the satellite schedule.

The IP/MPLS network is implemented via redundant Cisco ASR 100x routers at each ESA facility and two Cisco ASR 9010 routers at the central service area in Frankfurt; the IP/MPLS backbone span over the DWDM infrastructure (IPoDWDM) which allows high performance, quality-of-service and scalability with full-mesh any to any IP connectivity. OSPF (RFC2328) and BGP/MPLS IP Virtual Private Networks (RFC4364) implement the MPLS VPNs.

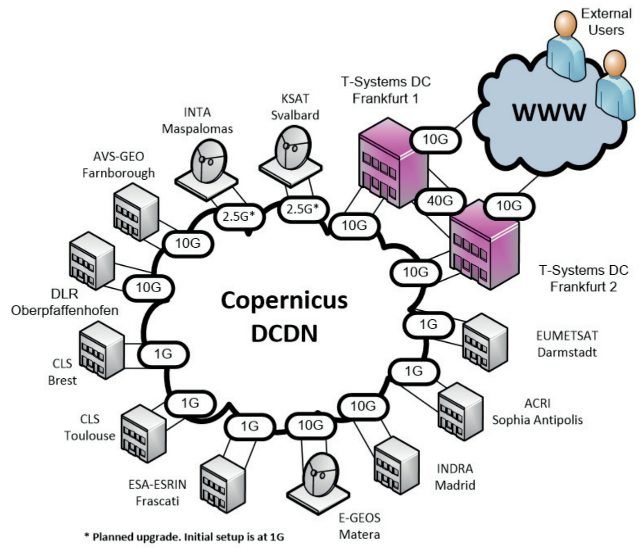

Fig. 2. Logical view of the Copernicus Data Network

The Copernicus Network is connected to the existing ESA Earth Observation networks via and Network to Network Interface (NNI) implemented in ESRIN, Frascati. This connection, based on a back-to-back redundant 1Gbps links, allows the data exchange between the two networks. It has been used in deployment phase, implements some minor data flows and is available for any future need.

The target availability of the geographic links is equal to 99.95%. The two lines are configured in active-active mode, which means that in a given time both links are used to carry the Sentinel traffic.

Under nominal conditions, the primary link is used to transport the circulation data while the second link is used for the dissemination and PDGS administration traffic; during contingency (i.e. one line fault) traffic shaping is activated inside the available line. The bandwidth shaping parameters will be monitored and fine-tuned according to the actual traffic needs.

III. THE NETWORK SERVICES

The Copernicus Network has been designed with different on-board services that are below listed and shortly described.

The **Internet Access** is provided via a redundant 10 Gbps access based on Deutsche Telekom's IP-Transit Service (AS3320) which provides full Internet connectivity based on comprehensive peering agreements on a global scale. Additional bandwidth to the Internet can be provided by adding further IP Transit access points at the central service area in Frankfurt. The interconnection with GEANT is implemented via Level-3, however, it is under evaluation the direct interconnection between the Copernicus Network and GEANT via DFN.

The **auxiliary services** consist of the Domain Name Service (DNS), Network Time Protocol (NTP) and Mail Relay

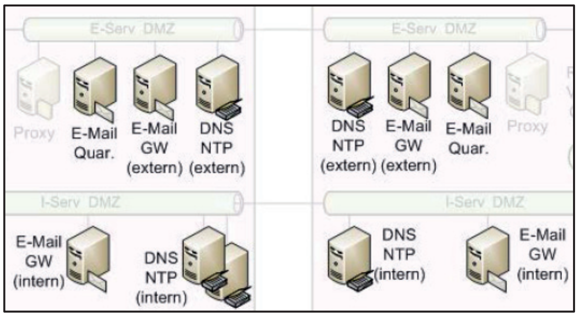

Fig. 3. Copernicus Data Network Auxiliary Services

The Copernicus external DNS service manages all the public domains used by the PDGSs and associated with sentinel public IP addresses (i.e.: sentinels.eo.esa.int, sentinel1.eo.esa.int, sentinel2.eo.esa.int, sentinel3.eo.esa.int). The external DNS are logically interconnected with the ESA corporate DNS which are the owner of all esa.int domains; DNS zones Master/Slave mechanism has been implemented between the two DNS systems. The internal DNS service is available for all the internal and management DMZs of the PDGS, and manages the name resolution for the internal PDGS systems.

The centralized NTP service is provided by the same DNS appliance and it is composed by two pairs of servers, two for the internal and two for the external NTP service. The NTP source is distributed by three stratum-1 servers (connected to the GPS antenna) deployed within the T-Systems backbone and used to synchronize the whole infrastructure. The ESA dedicated NTP servers act as stratum-2 servers which ensure the required precision and minimum time offset.

The Mail Relay Service enables the PDGS systems to exchange SMTP messages with the external world. Both inbound and outbound directions are supported by the service and the setup is customized according to the specific needs of the Sentinel PDGS. As per the other services the SMTP gateway is split in internal and external servers dedicated respectively to the Internal LANs and public DMZs of the PDGS. Following the security policy, only well-defined and authorized hosts can reach the Mail Relay and the access is granted on an IP based authentication mechanism. Security is enforced by the Anti-Spam and Anti-Virus features which scan and analyze all the SMTP traffic. A quarantine area is also implemented to temporarily store mails and content considered to be malicious or spam.

The Copernicus resources can be securely accessed via Internet by using the **Remote Access Services** (only remote administration and maintenance purposes); two different solutions are available and are implemented based on the connectivity requirements: the PC to LAN and the LAN to LAN.

The PC to LAN service allows secure connection from the personal computer of the remote user to one security zone of the PDGS. It is based on a dedicated Cisco VPN gateway (VPN termination), and on the T-Systems infrastructure (TelesSec) for the user authentication based on One Time Password (OTP) token. Each RAS user is authenticated and authorized to access only the requested resources.

The LAN to LAN RAS service is intended to interconnect a remote site with different work positions to the PDGS resources. The service is composed by the central provider's Intraselect VPN service and a dedicated VPN gateway installed at the remote premises. The remote gateway, using the Internet access of the facility, creates an encrypted VPN tunnel with central gateway; after an initial data flow screening, the traffic is routed up to the destination.

IV. The Security Elements

The Network is equipped with a sophisticated and redundant "Security Defense Perimeter" which contains the following elements:

- Central analysis system (''Early Warning System");
- Redundant DDoS self-learning detection and mitigation;
- Peripheral firewalls with local IPS/IDS;
- Redundant central firewalls to enforce the EU/ESA security policies;
- IDS/IPS traffic screening at each facility and in the central infrastructure;
- Redundant HTTP/FTP Proxies.

All the security elements generate a large amount of information which is constantly analyzed by the security engineers of the Security Operation Center of T-Systems located in Stuttgart, Germany. Cyber-attacks identified by the SOC will be addressed in coordination with the ESA EO security team and according to the agreed Security Operational Procedures (SecOps).

V. Testing, Validation and Performance

Particular attention has been given to the test and validation of the different Network and Security elements, including the performance measurement under nominal, contingency and system stress conditions.

An extensive test campaign has been performed to verify the redundancy and failover behavior of the system. The different test cases have addressed and simulated most of the possible faults of the lines, firewalls, routers, links, auxiliary services and security elements; as final test, a complete switchover of the prime data center in Frankfurt has been performed to simulate unavailability of one data center.

The performance tests show that the WAN lines are stable, error free and able to carry the full capacity. Room for improvement has been identified for the round trip delay between the interconnected facilities.

The certification of the Security Defense perimeter has been performed in order to validate the initial setup of the security services and to identify all the necessary actions to improve and fine tune the configuration of each security device (i.e.: DDoS and IDPS). The test has been performed by an independent company specialized in security and vulnerability assessment which manages a network of 'legal' botnet distributed across the world. The simulation of a real attack was aimed at violating the network and creating service disruption via denial of service attacks. The results provided directions to further enforce the security of the Copernicus network.

TCP Throughputs	min/max*
1 Gbps WAN Links	824/987 Mbps
10 Gbps WAN Links	9.2/9.97 Gbps
FTP - Single TCP Session (<100MB File Size)**	20/100 Mbps
FTP - Single TCP Session (3GB File Size)**	230/480 Mbps
Network Latency – one way delay	**min/max**
Between Mainland Europe	9/42 ms
Europe to non Mainland facilities	33/58 ms
Packet Loss & Jitter* **	
Packet loss ratio	0%
Packet Jitter	0.001 ms
Redundancy	**min/max**
Routing Convergence TIme	3/5 sec
Network Services failover time	0 to few ms

* Depending on the actual round trip delay
** Default end systems TCP parameters (no tuning)
*** 6 hours test, no link congestion

Fig. 4. Test Results Highlights

VI. Services Operations

The operations of the Copernicus WAN and security services are part of the overall Agency framework for the operations of the Sentinel's ground segment.

The performance of the service operations is regulated via a Service Level Agreement which is composed by several service level targets. Such SLA covers all the areas starting from the actual services availability and performance up to reaction and implementation time of the provider.

The Network and Security operations are managed by T-Systems via the International Service Desk that can be accessed 24/7/365 by using a web-portal, mail or telephone. The primary objective of the Service Desk (SD) is to resolve incidents and minimize the impact on Copernicus PDGS. All the incidents are registered, classified and a ticket is assigned to the relevant units (e.g. specialists, service partners) for resolution.

Second level network support is provided by Network Operations Centre (NOC) and Security Operations Center (SOC). The NOC Team has an extensive knowledge of network operations and it is capable to access the various online tools and techniques. The NOC is responsible for the smooth and stable operation of the network and provides the operational services for the solution (e.g. Change and Release Management). The SOC staff is specialized on security operations and is responsible for the management of the Copernicus security services (e.g.: DDoS, IDPS) in order to identify and react against security attack and coordinate the mitigation actions with the Agency relevant interfaces.

A Copernicus PDGS/CDS Central Helpdesk will process and filter the different anomalies received from the different GS elements, and will engage the anomaly review board when needed.

Conclusions

The Copernicus Data Network is "ready to use" for the Sentinel 1 commissioning phase, and will be completed in 2014 for the remaining facility of Sentinel1, Sentinel 2 and Sentinel 3. The selected model allows complexity reduction and simplification of the operational model, improvement of Security by centralization of policy enforcement, and utilization of efficient and cost-effective technology for multi-protocol and near real time services.

The Copernicus network and security services are based on commercial off-the-shelf products and technologies which ensure a cost-effective and state-of-the-art solution. Most of the facilities are using 10 Gbps lines since the initial setup following a cost-benefit analysis and the need to avoid critical changes during the Sentinel 1 operations phase.

The initial dissemination capability over Internet of 10 Gbps can be increased up to 40 Gbps with the existing infrastructure, and use complementary dissemination solution or additional infrastructure upgrade to increase the dissemination capability.

Centralization and virtualization of the dissemination facility services is on-going in order to facilitate and improve the user data access. Internet peering optimization is under analysis, including the interconnection with academic and research networks (i.e. NREN).

The cleanness of the lines allows the systems to use high TCP Windows size to improve the TCP throughput. The FTP tests shows the throughput performance increasing with the size of the files; this is due to the fact that with larger files the TCP Window size is gradually increased reducing the effect of the WAN latency on the TCP acknowledge mechanism.

The test results analysis shows the importance of the end-system fine-tuning (application and Operating System), in particular in order to fill the available line capacity, the following elements have to be optimized and verified by the different PDGS elements:

- Use of big TCP Windows size. The scaling factor allow in theory to have very big Windows Size (1 GByte), but memory and buffer on the systems limit the maximum usable Windows size and than the maximum performance achievable with a single TCP session;
- Use of applications designed to work with multiple TCP session (i.e.: multi thread FTP or multiple data transfer sessions);

Configure the MTU at 9K byte on all the interfaces and devices of the PDGS, including the embedded switches of the ESX servers. This allows a performance improvement for the 10G connections.

Using Space-Data-Routers for the timely and targeted downloading of Land Surface Temperature data to local users

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Abstract— **Land Surface Temperature (LST) imagery is necessary for the assessment of the urban thermal environment, an issue of increasing scientific interest due to climate change and urbanization. The problem of the exploitation of the large satellite-derived LST archive is of spatio-temporal nature. The LST input datasets are acquired from various sensors with Thermal Infrared (TIR) bands onboard geostationary (e.g. Meteosat Second Generation MSG viewing Europe and Africa) and near polar orbit (e.g. Terra and Aqua) satellites. The problem of directing and downloading the vast volumes of quarterly-hour datasets to the local users timely and accurately is not solved yet. In particular the geostationary dataset is large. The daily European LST dataset (96 images) volume is 624MB/day, that is 222.4 GB/yr. In total the decadal archive to be searched will be of the order of TerraByte. We investigate the possibility to deploy Space-Data Routers to deliver this task. This is of primary importance for the future development of a global urban observatory with hundreds of users.**

Keywords: Land Surface Temperature; Urban Heat Island; thematic quiries; big data; Space Data Routers

I. INTRODUCTION

Land surface temperature (LST) is a key parameter in the land-surface processes on all scales, combining the results of surface-atmosphere interactions and energy fluxes between the atmosphere and the ground. Urbanization introduces new surface materials (such as concrete, asphalt, tiles), and when coupled with the emission of heat, moisture and pollutants initiates one of the most dramatic human-induced change on the Earth's surface. Therefore, knowledge of LST and its temporal and spatial variations within a city environment is of prime importance to the study of urban climate and human–environment interactions and has been extensively monitored by satellite sensors (Weng, 2009; Stathopoulou and Cartalis, 2009; Hung et al., 2006; Keramitsoglou et al., 2012).

Several satellite missions have onboard spatial resolution TIR sensors and have by now acquired a considerable global archive of LST images over the last 40 years. Nevertheless, depending on the temporal and spatial requirements of a study, one has to select from broadly three categories of LST sensors. This is shown in Table 1. These missions have been providing continuous monitoring of LST distribution at the spatial resolution ranging from 3-5km for geostationary platforms to 100m from low earth orbiters. In most cases, service providers (e.g. NASA, ESA, EUMETSAT) distribute LST images as standard data products.

Multi-mission is required as complimentarity of different spatial and temporal resolutions serve the better characterization of thermal patterns. Overall, the three different spatial resolutions of 3-5km, 1km and 100 m, provide a different perspective to the study and characterization of the Urban Heat Island (UHI) phenomenon. Category B with 1km spatial and few images per day temporal resolution is an adequate compromise which gives the general picture of the hot spots and relevant patterns at a regional scale. Category C, the high spatial resolution images (~100 m), should be used for local/municipality level studies for long-term planning. Although rich in spatial detail, both Categories B and C fail to depict the diurnal variation of the phenomenon. At this point it is important to appraise the contribution of Category A (MSG-SEVIRI), which can provide an important signal for the study of the diurnal variability.

As LST is a highly dynamic parameter, research institutions who are interested in monitoring LST require access to vast quantities of space data so that they analyze and exploit them. 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. The main advantage of the Space-Data Router is that it operates on top of existing network protocols and technologies, creating a DTN overlay that interconnects networks with very diverse characteristics, such as space and terrestrial. Therefore DTN provides the basic functionality for efficient space-to-earth data dissemination. In addition the router is developed on top of real space protocols allowing for the direct interoperation with current space infrastructure. Furthermore, a sophisticated application will also be

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implemented in order to support, highlight and assess system's capabilities.

Category	Thermal Sensors	Satellites	Spatial Resolution	Temporal Resolution
A	MSG-Seviri	MSG	~3-5 km	Every 15 min
B	AVHRR AATSR MODIS	NOAA-n ENVISAT Terra/Aqua	~1 km	Synergistically, a few images per day
C	ASTER TM, ETM+	Terra Landsat	~100 m	Synergistically, 1 image per week

Table 1. Different categories of thermal infrared sensors that are used in the LST scenario of SDR project

In the present note, we evaluate the possibility to use SDR to fulfill the requirements of timely and reliable LST data collection (single theme) from multiple satellite missions. For this purpose we have designed and implemented a dedicated scenario.

II. Area of Study and Data

A. *Area of Study, Athens (Greece)*

On the southeastern edge of the Greek mainland lies the city of Athens. Athens is the capital and largest city of Greece. The urban area is confined by high mountains interrupted by small openings, whilst it is open to the sea from the south (Saronikos Gulf). The city of Athens is characterized by a strong urban heat island effect, mainly caused by the accelerated industrialization and urbanization during recent years.

B. *Data*

- MSG-Seviri: The MSG LST product is computed within the area covered by the MSG disk, over 4 specific geographical regions (Europe, N. Africa, S. Africa, and S. America), every 15 minutes. For each time-slot and geographical region (Europe in the case presented here), the LST field and respective quality control data are disseminated through the Land Surface Analysis Satellite Applications Facility (LSA SAF; https://landsaf.meteo.pt/). For the present scenario the quarter-hour LST product from May 1st to September 30th 2009 were used. The daily European LST dataset (96 images) volume is 624MB/day, which is 222.4 GB/yr. In total the decadal archive to be searched will be of the order of TerraByte.
- MODIS: 50 MODIS images are used for the scenario acquired by MODIS Terra and Aqua in July 2009.
- Landsat TM: This dataset alone does not constitute a big dataset, however it is included in the scenario for two reasons: i) for completeness and to enhance the multi-mission concept and ii) to evaluate the scheduling improvements for automatic downloading.

III. Scenario: Land Surface Temperature/ Single thematic, Multi-mission

The implementation requires the development of a geo-database and its population with European LST maps acquired every 15 min from MSG geostationary satellite. The challenge is to demonstrate innovative sustainable space data exploitation methodologies for the fast assessment of the thermal environment of cities for future standard data production. It is important that the user will be able to exploit the large database fast with intelligent thematic automations, such as:

- A scheduler with a calendar interface that would enable the user to request that a specific dataset would be downloaded on specific dates in the future. For example:

"Every Monday at 08:00 UTC, starting from 1 June 2013 ending 31 June 2013, download all products:

PRODUCT=LST

Bounding Box Coordinates = ...

COLLECTION = EUROPE

Acq. Time start=17:00 UTC (and later until...) Acq Time end=04:00 UTC (the next day)"

- Data-matching features that allow the user to select a specific arrangement of filters and have data sent to them directly whenever new data is added that matches the filter. For example:

"Send an email alert when the first Landsat image over Athens is available".

In this case the user might turn on and turn off the alert.

IV. Expected impact using SDR and thoughts for the future

By the LST single thematic, multi mission scenario we wish to demonstrate that SDR allows for data gathering from multiple missions for one scientific objective. In addition, same storage location for all data is of importance in that concept. This is also of interest when real time and on demand datasets are integrated in the scenario. Furthermore, as in the near future a number of relevant sensors and satellite platforms that will serve LST monitoring are in development this concept can be enhanced. In particular, the European Space Agency (ESA) Sentinel-3 satellites are planned for launch from 2013, offering a Sea and Land Surface Temperature Radiometer (SLSTR) with a 1 km resolution in the thermal channels and a daily revisit time. The geostationary GOES-R satellite is due in 2015, with a 2 km resolution in the thermal channels from a new Advanced Baseline Imager (ABI). The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is due to launch in 2016, designed to replace NASA's Aqua, Terra and Aura satellites and offering the Visible and Infrared Imagery Radiometer Suite (VIIRS) sensor for LST. Coupled with these large 'traditional' missions, in the future there is likely to be an increase in 'small satellites' (Sandau et al., 2010) that enable relatively quick and inexpensive missions, which could for example help to observe dynamic surface temperature patterns.

ACRONYMS

- **AATSR** Advanced Along Track Scanning Radiometer
- **AVHRR** Advanced Very High Resolution Radiometer
- **ESA** European Space Agency
- **EUMETSAT** European Meteorological Satellite Organisation
- **MODIS** Moderate resolution Imaging Spectroradiometer
- **MSG** Meteosat Second Generation
- **NASA** National Aeronautics and Space Administration
- **NOAA** National Oceanic and Atmospheric Administration
- **SEVIRI** Spinning Enhanced Visible and Infrared Imager
- **SLSTR** Sea and Land Surface Temperature Radiometer
- **TM** Thematic Mapper
- **ETM+** Enhanced Thematic Mapper

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A DTN-based architecture for the dissemination of high volumes of space-data

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***Abstract*—As space missions such as the Sentinels and Euclid are scheduled to launch in the near future, robust networking mechanisms will need to be in place in order to transfer huge volumes of space data produced on board to interested parties in a timely and efficient fashion. In this position paper we study the applicability of DTN as a supportive mechanism for the dissemination of space data from storage locations to end-users. Furthermore, we propose a DTN-based communication model to support low-earth orbit earth observation missions.**

Keywords: Space communications, DTN, space data

I. INTRODUCTION

Until recently, raw scientific data produced in space were transmitted to Earth over a limited number of contacts with ground stations. These data were, then, relayed to one or more research institutes, where they would be processed and stored for further exploitation by other interested parties.

With the deployment of more sophisticated scientific instruments and sensors onboard satellites and spacecraft, though, the development of more advanced communication payloads has been deemed necessary to support the increase in the amount of space data produced.

Furthermore, since a single communication window per orbit may not be enough to support the transmission of data onboard a Low Earth Orbit (LEO) satellite to Earth, mission designers are investigating architectures that exploit multiple ground stations receiving data produced by a single mission. This, in turn, calls for more sophisticated networking protocols, able to cope with the characteristics of such a communication model.

The ground segment is also expected to be affected by the increase in the amount of space data, since petabytes of data will need to be stored and disseminated to research institutes. Reliance on common Internet technologies to share all these data will certainly overload the networking facilities of space agencies. To this end, novel dissemination architectures are investigated to provide near real-time access to data, mitigating, at the same time, the exhaustion of network resources.

Delay-Tolerant networking (DTN) [1] has been proposed as a candidate technology to support future space communications. Designed to operate in networking environments where connectivity is challenged, it can be deployed in LEO space missions, allowing satellites to communicate with multiple ground terminals as they orbit around the Earth.

The terrestrial deployment of DTN can also benefit the dissemination of space data once they are on the ground. Indeed, with its store-and-forward functionality, it can facilitate the transfer of huge volumes of data between storage locations, taking advantage of the off-peak periods of the network.

In this paper we propose a DTN-based network architecture to support the dissemination of Earth Observation space data to multiple end-users. We particularly focus on LEO missions generating and transmitting huge volumes of data to multiple ground stations.

The rest of this paper is organized as follows. Section 2 briefly describes the background and surveys the related work, while Section 3 presents the introduced mechanisms. Finally, we conclude in Section 4.

II. RELATED WORK AND MOTIVATION

Bundle Protocol [2], the core component of DTN, is designed to support a set of services crucial for space communications, such as the store-and-forward functionality and custody transfer. A number of experiments have showcased the ability of DTN to transfer space data from either deep space or LEO missions. Indeed, in [3], 300 images were transmitted from the JPL nodes to the Deep Impact spacecraft. In [4], images from a LEO Earth Observation satellite were transmitted to three ground terminals on Earth, demonstrating, among others, the capability of DTN to pre-fragment large files before transmission. That said, there exist space missions employing dissemination models that are not inherently supported by the DTN platform. The two satellites composing the MODIS mission, for example, continuously broadcast data to ground terminals on Earth. This model, namely Direct Broadcast, facilitates data dissemination providing a decentralized approach, allowing any end-user operating a ground terminal to receive, process and disseminate space data and their products.

Apart from its applicability in space data dissemination models, DTN has been used to transfer data between storage centers in [5]. Such an approach has not been investigated, though, in the context of space data dissemination.

III. DTN BROADCASTING

Although DTN multicasting has been discussed almost since the very beginning of DTN, the same does not apply for its broadcasting capabilities. In this paper we focus on missions that broadcast data to multiple ground terminals for further processing.

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As ground terminals receive data, they forward them to centralized storage facilities. This functionality can be accomplished by including a list of optional receivers on the header of each bundle. Nodes noted as optional receivers are able to store locally data they receive although they may not be the original destination end-point for them. Combining this functionality with the notion of late binding, supported by DTN, data can both multicasted and broadcasted at the same time, depending on the configuration, as depicted in Fig. 1.

A broadcast group ID can alternatively be employed to support Direct Broadcasting. End-users subscribed to a specific broadcast ID store data noted with the same ID before forwarding them to their destination.

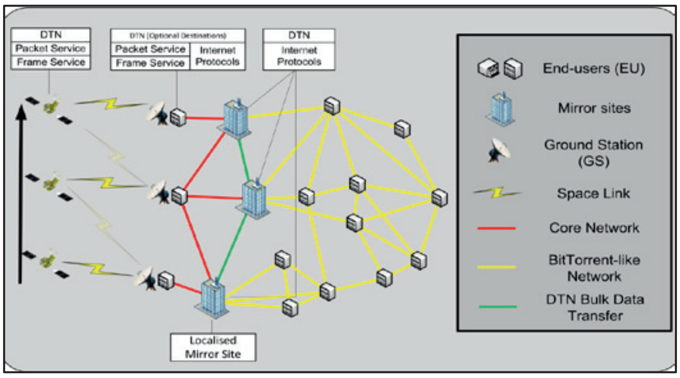

Fig. 1. Proposed dissemination architecture based on DTN

IV. Distributed DTN-Enabled Storage Facilities

Large storage facilities are employed to support the dissemination of huge volumes of space data to interested end-users. The deployment of local mirror sites has been proposed as a m eans to increase efficiency and performance. Transporting, though, so many data over the Internet takes its toll in terms of increased link congestion and delays.

To mitigate this issue, the DTN architecture can be leveraged to enable the automated transfer of files only during specific periods of time during the day. Such periods can be, for example, periods during which network resources are under-utilized. The time difference between regions can further facilitate the efficient transfer of data, since the off-peak periods of network activity depend on the time.

By keeping more than one copies of a dataset on the network, a distributed dissemination model can be employed to deliver space data to end-users. In particular, the deployment of the BitTorrent architecture can improve resource management inside the network, increasing efficiency. Since the performance of the BitTorrent protocol depends mainly on the number of users that are able to share their data, multiple copies of the same file will greatly facilitate the dissemination of data.

V. Conclusions

Although DTN has been proposed to support a plethora of space missions, ranging from Interplanetary to LEO ones, there are still dissemination models that it cannot support. In this work we propose a DTN-based architecture to support space missions that employ the Direct Broadcast dissemination model. In particular, we propose the development of DTN broadcasting, as a means to support this kind of missions. Furthermore, we leverage DTN to increase efficiency in the terrestrial network, deploying it in storage locations to facilitate the transfer of files to mirror sites. In this way, resource management and performance are enhanced, facilitating space data dissemination.

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