Space Data Routers for the Exploitation of Space Data

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The goal of the "Space-Data Routers" (SDR) project is to explore concepts for an enhanced architecture for the exploitation of space data capable of mitigating current availability limitations with respect to volume, timeliness, and continuity. The objective is to establish a mission / application-oriented communication overlay for data dissemination on Earth and to include into this overlay space born sources and network nodes. Technically, that is achieved by deploying the Delay Tolerant Networking (DTN) stack and integrating the interfaces of various Space and Internet communication and networking protocols, including TM/TC, Space Packets, and AOS along with Ethernet, TCP/IP and UDP. In addition, the overlay supports and enforces policies for resource and data sharing as well as for data dissemination. These concepts will be implemented through the development of the Space-Data Router, a DTN-enabled device that will interconnect space data providers, ground stations, research centers, and academic institutions in a much more efficient and decentralized manner than today.

I. Overview

Space data exploitation by research centers and academic institutes today is constrained by limitation in the access to scientific data with respect to volume, timeliness, and continuity. Typically data are collected and pre-processed by space data collection centers and are then distributed from there according to the orders placed by the user community. In many cases order management and dissemination of data still requires human interaction and this implies considerable bureaucratic overhead. Direct access to real-time data downlinked from Earth Observation (EO) spacecraft is sometimes available but is then typically limited to the pass over the ground station used and of

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course requires all processing to be done by the user. These characteristics of the current situation are illustrated on the left hand side of Figure 2.

Major efforts are being undertaken especially by new EO missions to reduce the time between measurements and the availability of related products and to automate order management and product dissemination. However the essentially centralized approach and the limited cooperation between programmes constrain the positive effects for the user community.

The novel approach pursued by the Space Data Routers Project is to develop a *mission and application oriented overlay network for space data dissemination*. We expect that such an overlay will allow space agencies, academic institutes and research centers to share space data generated by a single or multiple missions, in a natural, flexible, secure and automated manner.

An overlay network is a virtual network of nodes and logical links that is built on top of an existing network with the purpose to implement a network service that is not available in the existing network. The concept is inspired by the Peer to Peer (P2P) overlay networks[1] that have been created on the Internet and are still evolving. Specialized overlay networks provide a large variety of services, including content sharing and distribution, efficient downloading of large files, computational resource sharing, group communication, multi-casting, flexible routing, and telephony. More commonly known examples of such networks include Napster, Gnutella, KaZaA, BitTorrent, Seti@home, and Skype.

SPACE-DATA ROUTERS

http://www.spacedatarouters.eu/

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The Team

Organization	Special Expertise
Democritus University of Thrace, Greece (DUTH)	Networking technologies, DTN Project Coordinator
National Observatory of Athens, Greece (NOA)	Research Institute – a typical SDR end user
VEGA Space GmbH, Germany	Space ground segments, space link protocols
Space Internetworks Ltd, Greece	Networking technologies, DTN
University of Plymouth, UK	Communications security

Figure 1. The Space Data Routers Project

The space data dissemination network overlay will be implemented by the *Space Data Router*, conceived as a device to which the participants of the network interface and that implements data communications using existing communication services such as the Internet. As has become very evident in the fate of the Napster[‡‡] network, application specific network overlays need to consider economic and security aspects in addition to their technical

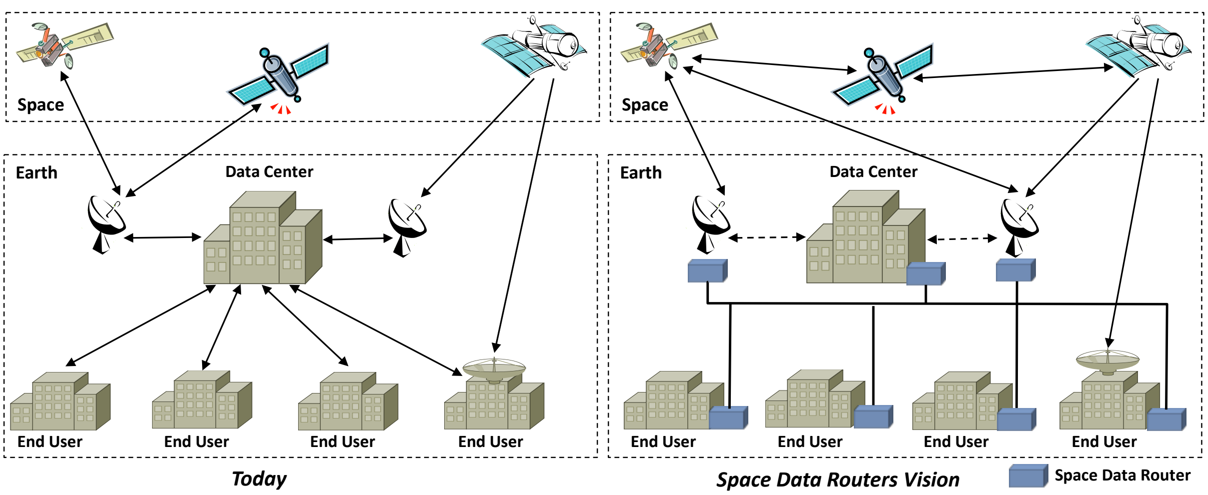

Figure 2. Space Data Dissemination Today and as Envisaged by the Space Data Routers Project

[‡‡] We refer to the original Napster founded in 1998 as a pioneering peer-to-peer file sharing Internet service that emphasized sharing audio files, typically music. This operation ran into legal difficulties over copyright infringement and finally ceased operations.

goals. In the area of space data dissemination this implies that Space Data Routers will also have to provide features that enforce agency or mission policies and ensure that application restrictions and requirements are met.

We anticipate that Space Data Routers will initially be implemented directly on top of existing communications infrastructure and will create an overlay network comprising academic institutions, research centers and ground operation centers. The advantages expected in this phase are mainly in the automation of dissemination management and file delivery and distributed storage of space data. To really boost space data dissemination it will however be necessary to expand the overlay network into space, allowing for communication between space assets and direct access to the science data of space equipment based on the operator's policies. This second stage is illustrated on the right hand side of Figure 2. The main advantages of the second stage, apart from those of the first stage, are increased connectivity with space assets through multiple ground centers or gateways, interagency communication, efficient resource allocation and further alleviation of congestion and storage requirements of the ground centers.

Extension into space implies that the protocols used within the overlay must be able to cope with communications conditions in Space in particular with long delays (in case of deep space missions) and frequent disruption of connectivity. The technology developed for such conditions is the Disruption / Delay tolerant Network[2] (DTN). As shown in Figure 3 the Bundle Protocol[3] (BP) of DTN is located above the transport layer and can be operated across several regional networks with different, potentially incompatible characteristics. It uses store and forward message switching for the transmission of data between nodes storing data to bridge periods in which connectivity is not available. The BP can be run over TCP, the transport protocol of the Internet, but that protocol is not capable of dealing with high latency. For connections with very long delays the Licklider Transmission Protocol[4] (LTP) has been developed. DTN is increasingly recognized as emerging technology for space communications, especially for communications in deep space. Having already been tested in a number of stressed terrestrial environments, as well as in space conditions, DTN is being adopted as a standard architecture in both CCSDS and IETF standardization.

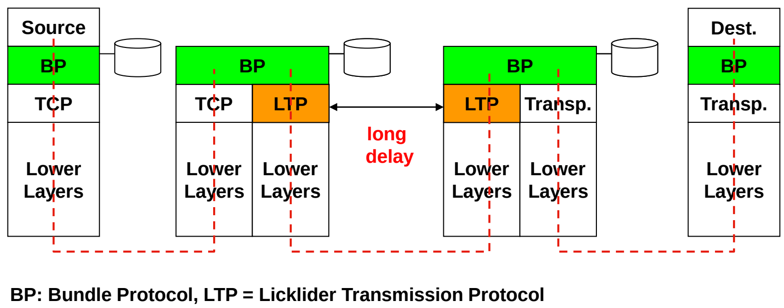

Figure 3. Store and Forward Message Switching by the Disruption / Delay Tolerant Network (DTN)

Technically the BP presents a network overlay capable of bridging networks of different characteristics in Space and on Earth, and therefore appears to be the ideal choice for a dissemination network including ground based and space born nodes and providing support for EO, scientific, and deep space missions. Beside that DTN features such as support of scheduled contacts can probably be exploited to support optimization of transfer and access policies. We therefore plan using DTN as the basis for the Space Data Router and augmenting it with the features required for effective space data dissemination. As part of this work we will study deployment on DTN over various communication layers including the Internet but also the current space link protocols such as CCSDS Packet Telemetry[7] and Telecommand[8] and AOS[9] data link protocols.

In summary, the work plan of the project includes the following tasks

1) Analysis of scientific requirements and derivation of technical requirements on the Space Data Router device and the protocols to be used for dissemination of space data; this step has been completed.
2) Implementation of the DTN overlay including additional features needed to address agency policies regarding the dissemination of the data, the use of resources and priorities, as well security mechanisms.
3) Implementation, evaluation and optimization of link-layer protocols for space communications, namely the TM/TC and AOS protocols.
4) Integration of all components of the router into a functioning device and establishment of a test network including nodes at all partners for validation purposes.
5) Design and implementation of a demonstrator application that will support scientists and researchers in requesting and obtaining space data in a decentralized and automated manner and thereby increasing both the volume and timeliness of the data.
6) Evaluation of the overall system efficiency including the Space-Data Router and the demonstrator application.

In the remaining part of this paper we will outline scientific objectives and associated use cases, describe the requirements derived for the protocols and the demonstrator application, detail the plans for utilization of DTN and summarize work performed for the integration of space link protocols and the establishment of the test network for evaluation.

II. Scientific Objectives and Scenarios

A. Overview

We have identified four scientific objectives against which Space Data Routers will be validated. For this purpose, we have selected seven use cases / scenarios from work currently performed or planned at the Institute for Space Applications and Remote Sensing (ISARS) of the National Observatory of Athens (NOA). A summary of the objectives and the associated scenarios is provided in Table 1; a detailed description of the scenarios can be found in ref. 13. As an example, we describe scenario 7 to more detail.

Table 1. Scientific Objectives and Use Cases

Objective	Use Case / Scenario
O1 – Space-Data Routers will boost the dissemination capability for Space Data on Earth. *Demonstrate the capability of the Space-Data Routers to extend end-user access to space data through communicating ground stations and space research centers.*	S1 – Hyperspectral images captured by CHRIS on-board ESA's PROBA-1 satellite are received and processed for research purposes by NOA/ISARS.
	S2 – Images captured by the AVHRR (Advanced Very High Resolution Radiometer) on-board POES satellites of NOAA are used on a regular basis, both for research and for services provided by NOA/ISARS. However, due to downlink constraints, NOA/ISARS is able to acquire high-resolution images only when satellites pass over Greece. The possibility of continuous access to POES data would permit NOA/ISARS to acquire images of other parts of the Mediterranean in near-real time as well.
O2 – Space-Data Routers will allow for exploiting Data from Deep Space *Demonstrate the potential of exploiting data from deep space and disseminate it naturally through unified communication channels.*	S3 – Hyperspectral images are captured by OMEGA on-board ESA's Mars Express satellite. Data are processed for research purposes by NOA/ISARS. They are available online through ESA' Planetary Science Archive.
	S4 – The Rosetta mission has multiple spacecraft (the orbiter and the lander), multiple funding agencies (ESA and NASA), investigators and instrument providers from many countries, and is a deep-space mission. NOA/ISARS has the responsibility of the SREM (Standard Radiation Environment Monitor) unit on-board Rosetta and will collaborate with other instrument groups to define this scenario in detail.
O3 – Space-Data Routers will exploit European scientific capacity as well as ESA's existing infrastructure, resources, protocols policies and assets. *Demonstrate the capability of Space-Data Routers to deliver efficiently to end-users vast volumes of data over terrestrial internetworks*	S5 – New deployments in Space, such as SENTINEL for example, is expected to increase data return by an order of magnitude. Practically, this increase will create a bottleneck at the Ground Segments that retrieve and facilitate the dissemination of data. Therefore, an efficient data distribution scheme is required urgently.
O4 – Space-Data Routers will allow for cross-mission scientific applications. *Demonstrate the sufficiency of DTN space-data overlays to administer thematic cross-mission space data.*	S6 – A number of NASA and ESA space missions delivering data of space weather significance are currently operating. The main requirements for this application scenario are the real-time availability of electric field, magnetic field and charged particle data as recorded by multiple missions in geo-space and in the solar wind. We plan to test the capability of Space-Data Routers to efficiently distribute to registered end-users the relevant data streams from the two current NASA missions (ACE and THEMIS), an ESA mission (Cluster), and an upcoming NASA mission (Radiation Belt Storm Probes).
	S7 – Land Surface Temperature, multi-mission, single thematic study (see the more detailed description in this paper.)

B. Land Surface Temperature (LST), Multi-Mission, Single Thematic Study

The case study will address the Urban Heat Island (UHI) phenomenon of Athens, Greece, where the city center temperatures are often several degrees higher than the surrounding rural areas. In order to satisfy the scientific monitoring requirements of the diurnal cycle of this dynamic phenomenon, several thermal infrared satellite images have to be used. Synergistic use of sensors with similar characteristics but on-board different satellites is necessary so that data scarcity due to the temporal resolution of the satellite sensors is reduced. In addition, the users' need for near-real time monitoring poses a further requirement for timely delivery of the raw satellite images to the service provider for further processing before the added-value product is delivered to the users.

1. *Data Collection*

Currently, for monitoring the UHI phenomenon at regional scale a number of sensors exist with thermal infrared bands exhibiting varying spatial resolutions. These are ERS-2 ATSR, ENVISAT AATSR, NOAA AVHRR, Terra and Aqua MODIS, Landsat-TM, and Terra ASTER. For the purpose of the UHI study the satellite sensors that carry provide data useful for the determination of LST distribution are grouped into three categories, based on their spatial resolution as shown in Table 2. As an Example, sample LST maps generated from the group A sensor data is shown in Figure 4. The following needs to be considered:

Table 2. Groups of Thermal Infrared Sensors

ID	Sensors	Spatial	Temporal
A	AVHRR, AATSR, MODIS	~ 1 km	A few images per day
B	ASTER, Landsat	~ 100 m	1 image every week
C	MSG-Seviri	~ 3 km	Every 15min

- Multi-mission data are required as complementarity of different spatial and temporal resolutions help improving characterization of thermal patterns.
- Overall, the three different spatial resolutions of 3km, 1km and 100 m provide a different perspective to the study and characterization of the UHI phenomenon.
- Group A with 1 km 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.
- Group B, the high resolution images (90/120m), should be used for local/municipality level studies.
- Although rich in spatial detail, both Groups A and B fail to depict the diurnal variation of the phenomenon. At this point it is important to appraise the contribution of Group C (MSG-SEVIRI), which can provide an important signal for the study of the diurnal variability.

2. *Current Problems*

One of the problems in acquiring these data sets is that they are all at different locations. Even for the same sensor/mission the location may be different for real time and on-demand data. Furthermore, real time is only ensured when the receiving station in within ISARS. Any other route means near real time (even hours of delay) which means that any future service based on this data cannot be provided in real time. Beyond the challenges posed by distributed data acquisition, aggregation of geographically remote data sources towards single interfaces in a timely fashion, given security access concerns, has also been an ongoing issue with regards to dissemination.

3. *Expected Impact of Space Data Routers*

Long term improvements expected from data acquisition via a Space Data Router based network overall include:

- The application allows for data gathering from multiple missions for one scientific objective;
- Advanced protocols allow for successful data transmission even in harsh/challenged communication conditions;
- Depending on the mission, better interconnection between Space and ground assets;

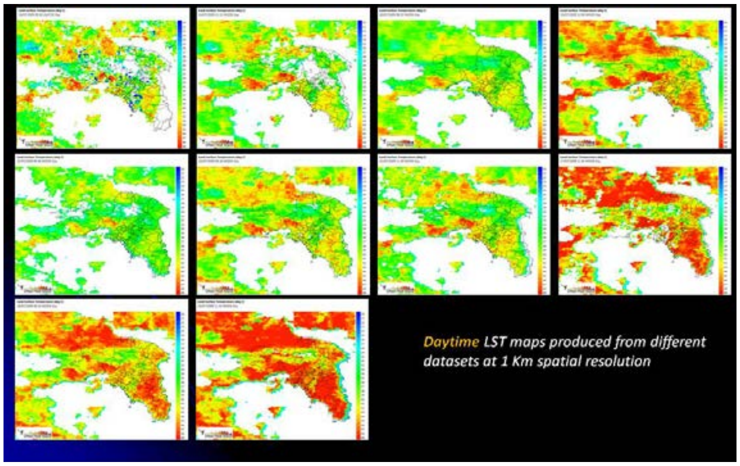

Figure 4. Examples of 1 km Daytime LST Maps of Athens *(Source: Thermopolis 2009 campaign, ESA)*

- Data can be transferred to other DTN nodes in Space before being dumped in Earth when direct delivery is not possible;
- Same access method will be available for all data independent of their actual location;
- Real time data acquisition will be improved.

III. Application Requirements

Within the project we plan to develop a demonstrator application for the acquisition of space data by research organizations. As a first step, requirements on the application have been derived from an analysis of the use cases described earlier[14].

The primary aim of the Space Data Routers application will be to serve users with data objects, retrieved from the (distributed) storage locations. The infrastructure will be designed so it may interface with a wide variety of space data providers, as long as the content of the data they store can be formalized as either an object or a data stream.

The application will be implemented as a web front-end coupled with a database. The front-end will include filtering functionality so that a user can locate and select the required data. The application will interact with four types of entities: data providers, user institutions, infrastructure providers, and administrators. The data providers category will include the owners of space data collection instruments and will interface with the application through the objects or data streams they collect; it is likely that the objects or streams will have a single Earth location at one moment in time, but that location may change over time, depending on the characteristics of acquisition. Access to the collected objects or streams may be either restricted, requiring authentication, or public. The user institutions will be the beneficiaries of the collected data. The infrastructure providers will be the entities managing the collection of networks and links that connect providers and users; the configuration of the infrastructure may change to improve access speed to data, based on the potential traffic to be created between the participating endpoints. The administrators will be entities in charge of running the application; depending on the level of separation required, administrators may have no direct access to data, but only facilitate communication between endpoints.

The database will include metadata information, such as data collection instrument characteristics, users/institutions and associated credentials, as well as storage locations and capabilities. It is envisaged that, for simplicity and process distribution reasons, the application will be separated from storage and will only point to storage locations rather than directly include a data storage component.

With regards to the user institutions, the implementation will use the current examples to aggregate data sources/objects and present them to the user as a design and functionality baseline. In order to gain access to any stored information, users must be authenticated to the application and their access to various objects will be logged and available for inspection by the data provider organizations. The data, depending on whether it is on-demand or real-time, will be either downloaded as a file or as a stream. In the case that the data is streamed in real-time, the application may launch a client application to interface with the incoming data stream. The data providers will also require access authorization/monitoring functionality, in order to control and review how users access their data. As a primary function, data providers will be able to enable/disable access to data for a given user organization that requests it. While its details are yet to be defined, the application is likely to interact with the network, as it will inform the infrastructure of the location of the users who are granted access to each specific type of data or/and download that specific type of data on a regular basis. Finally, the administrators would be able to oversee and monitor (to a certain degree) the access and permissions to the application by both data providers and data users. Access, and the ability to authorize access, will remain with the data owner only, in order to maintain security.

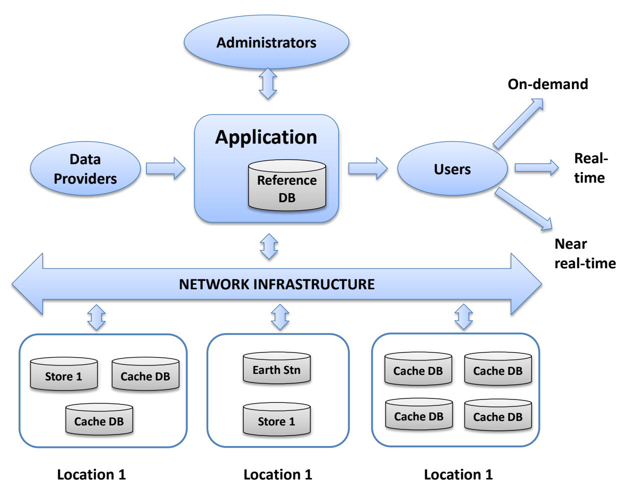

Figure 5. Proposed Architecture for the SDR Application

The application will facilitate three forms of data access: *on-demand, real-time*, and *near real-time*. From an interaction perspective, the on-demand alternative is built around the traditional request-response model, where data-objects that are previously collected and stored are specifically requested by users. When the user requests the object, the application will query the database to locate it and then it will return it to the user. Depending on the frequency of requests and location of the users, the application will include functionality either to migrate the requested (type of) data in order to move it closer to the most frequent users or to inform the network to duplicate this data closer to the users in the case of more widespread demand. The second alternative, real-time access, requires the data to be sent as an automatic upload to the registered users as it arrives from the instruments and is recorded in the database. The application, in collaboration with the underlying transport and routing infrastructure, may decide either to mirror or buffer the data or to combine a multicast and unicast approach. Finally, in the near-real-time scenario, users would request/receive a data object as soon as it is available, using a notification scheme or a push transfer.

In order to provide the required functionality, the application will include several types of processes: registration of new users/organizations, registration/upload of new data, user download of data objects, and cross-layer interaction with the network infrastructure. These processes, together with the associated entities involved in the process, have been the basis for a proposed architecture, presented in Figure 5.

IV. Protocol Requirements

Requirements on the protocol have been derived from an analysis of the use cases and the concepts developed for the SDR application described earlier[15]. The following key requirements have been extracted:

A. Robustness / Reliability (Noisy Channels)

Space communication channels exhibit relatively high error rates, when compared to error levels present on terrestrial Internet links. In addition, long delays and frequent network partitions in space require that sending nodes (e.g. satellites, landers, etc.) buffer space data for long periods of time, especially when data gets received at the destination with errors and needs to be retransmitted. Primary protocol functionality for space data transfers is the provision of reliable data services: the largest portion of space data should be delivered in its entirety and without errors. The acknowledgement mechanisms to be deployed must take into account the respective long propagation delays of space links.

B. Store and Forward

Space links are characterized by intermittent connectivity. Usually, a simultaneous end-to-end connection between a spacecraft and the respective destination node on Earth may either never exist or just temporarily take place, depending on the network scenario. Space networks should support store-and-forward functions to overcome network disruptions. In contrast to the terrestrial Internet routers that store packets at temporary memory for negligible amount of time, space nodes often need to store messages for long time-scales that can reach minutes, hours, or even days in some space missions.

Terrestrial networks will also need to support an appropriate store-and-forward mechanism. Indeed, vast volumes of data will be transferred between nodes belonging to the Space-Data overlay. We can efficiently exploit network resources by transmitting non-real-time data when network traffic is low, for example during the night hours.

C. Asymmetric Channels (Uplink / Downlink)

Forward traffic, i.e. data flowing from Space to Earth over space links, can typically be transmitted at much higher speeds than reverse traffic (i.e., from antennas on Earth to spacecraft). The downlink rate to uplink rate ratio may take a value of 1000:1 or even greater. Management of traffic in space networks should take into consideration data rate asymmetry. Network protocol stacks in space environments require mechanisms that minimize or control acknowledgement traffic, i.e. uplink traffic that acknowledges successful receipt of space data, in order to accommodate highly asymmetric links.

D. Hop-by-Hop Reliability

Recent practices of transmitting space data towards Earth via intermediate relay satellites have shown clear advantages: increase in space data throughput, better energy resources exploitation for power-limited spacecraft, improvement of space mission efficiency, and reduction in mission costs. Growing needs for space networking shape new paradigms for space data transfers: static and direct-to-Earth links are expected to be gradually replaced by multi-path connections, and alternative routing paths become available to many spacecraft.

E. Resource Sharing

One of the major weaknesses of the existing Space-Earth communication infrastructure is the lack of available resources; in general, each space asset and the corresponding communication channel are available for use only by the owning space agency. Therefore, if during a time interval a space observation device is not producing any data, downlink to Earth could be underused or even idle. Space Data Routers protocols should aim at unifying all available communication channels in a shared global system, in order to achieve better utilization of the network infrastructure.

F. Exploitation of Alternate Routes

In future space communications the necessity to expand routing and to overcome the current use of pre-determined routes is vital. A space data router therefore should dynamically configure the route of any packet towards its destination, based on network information that is available at the moment. It will also have the option to override any preconfigured route. This may be imposed by a change of network topology, due to a space node failure, to unpredicted space weather conditions, or to a modification of network contact plan for any other reason. Alternate routing is not available in current Space-to-Earth communications and its use in Space-Data Routers will develop a dynamically adjustable system and will eventually result in an overall network state improvement.

G. Policies

With the use of Space-Data Routers, information will be disseminated using shared resources and by exploiting nodes owned by different agencies. Some of the distributed data may also be confidential and must be protected. New policies will be defined and rules will be established that may apply for both inter-agency and intra-agency communications. Thus, the designed protocols will provide an option for data availability policy and space-data routers will include an automated administrative mechanism to make network resources available for requesting nodes.

H. Load Balancing (Traffic)

One of the main purposes of the project is to adjust routing processes in order to deal with very large amounts of data. The protocol mechanisms will provide a new routing functionality that will base routing decisions on traffic flows and will ensure that congestion in terms of bandwidth and channel occupancy is avoided.

I. Load Balancing (Storage Capacity)

Limited storage capability of nodes distributing space data, along with the huge quantity of space data that are produced from space observations and propagated to base stations on Earth, impose the design and implementation of a routing mechanism that will be able to balance storage load on the system.

J. Security

The potentially sensitive nature of space-data mandates the use of high-standard security mechanisms covering *authentication, integrity* and *confidentiality.* In modern IP networks there are many tools to ensure secure communication through the internet. IP Security (IPSec), SSL and TLS protocol are widely used methods that provide privacy, integrity, and authenticity to data transferred across IP networks. However, the introduction of Space Data Routers along with the additional DTN layer in the protocol stack impose fundamental changes the the security of space-data transfer through the Internet. The following issues need to be considered.

1. Routing

The nature of space-data itself is a major setback for their transfer through the Internet. Such data could possibly include sensitive information of national interest. That means that an entity located in a country, which requests data from a data center, may not want these data to pass through an SDR located in a hostile or simply untrusted area during their flow, even if these data were encrypted.

The lack of a fixed, pre-determined route for delivery of space data, along with the diversity of agency policies, data security requirements and confidentiality agreements lead to the conclusion that space-data routing is highly associated with the notion of trust. Thus, routing protocols should also include the “trust” factor, in order to achieve confidentiality at a first level.

2. DTN Layer

Another major issue is that by introducing the DTN layer to the protocol stack, IPsec and other security mechanisms can no longer function properly. For example, IPsec wouldn’t be able to cope with IP packets that included a DTN header just because it does not recognize what a DTN header is. Thus, modifications need to be done or even new mechanisms need to be introduced, similar to those used in current IP networks. These new (or modified) mechanisms must take into account the DTN layer. In addition, they must be able to cope with data fragmentation.

3. End-to-End or Hop-by-Hop

With the usage of SDRs the number of places where security can be applied has raised. The new model gives the opportunity to check data integrity and authentication and introduce confidentiality via encryption at end-to-end or/and hop-by-hop level between SDRs. However, adding many security layers can have a negative impact on the network's performance as security implies additional overhead. Encrypting data in an end-to-end approach means that data are kept under encryption during their way to the destination avoiding the need for additional encryption between the two SDRs.

Finally, the security mechanisms that are going to be used, need to take into account the fact that an SDR can store data for a much longer period than a normal router. Thus, significantly strong encryption algorithms along with a large key have to be used. Again this increased level of security comes with a cost in particular with respect to performance.

V. Initial Router Architecture and Test Network

A. Overview

The initial router architecture[16, 17] utilizes the protocol stack shown in Figure 6 including standard protocols and primarily existing components; it will be enhanced step by step to support the specific requirements discussed earlier. For terrestrial communication the Bundle Protocol directly interfaces to TCP/IP. For Space to ground communication, we use the Licklider Transmission Protocol[4] (LTP) above the Packet Telemetry[7] and Telecommand[8] or the AOS[9] data link protocols and the Space Packet Protocol[11]. The Encapsulation Service[12] is used to package Bundles for transfer across the space link.

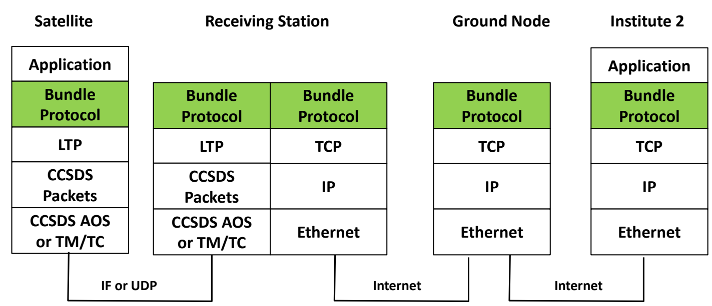

Figure 6. Protocol Stack Supporting Space and Terrestrial Communication. *For space communication, UDP is used in pure simulation and IF interfaces are used with special hardware in the loop.*

The space link will be simulated with and without special hardware in the loop as detailed later in this paper. In case of pure simulation, TM and TC frames are transmitted via the Internet using UDP and letting LTP handle data loss and re-sequencing. When special hardware is in the loop then data are modulated and transmitted via a 70 MHz IF link.

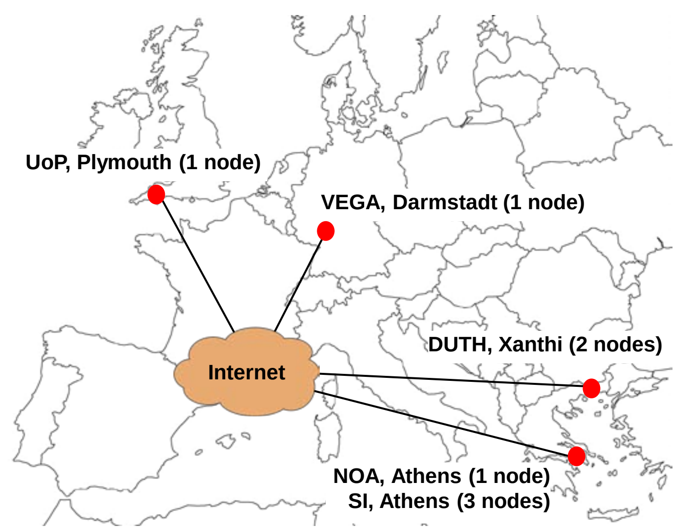

Figure 7. Test Network for Space Data Router Evaluation

The SDR nodes run on standard PC hardware and the Linux operating system. For DTN we use the NASA Interplanetary Overlay Network (ION)[§§]. The integration of space link protocols is based on ESOC infrastructure software components and on commercially available standard TM/TC processing equipment as detailed in the next section.

[§§] See http://code.nasa.gov/project/interplanetary-overlay-network-ion-software-distribution-dtn/

Figure 7 shows the test network that has been established validation of the Space Data Routers. Nodes of the network overlay are located at the premises of each partner and communication will be over the general Internet, which provides a realistic environment for the terrestrial communication.

B. Simulation of the Space Link

One important objective of the project is evaluating the performance of DTN over space link protocols currently in operational use. We are using the CCSDS Space Packet protocol[11] and the Encapsulation Service to wrap up bundles for the transfer via the space link. On the data link layer we use either the CCSDS Packet Telemetry[7] and Telecommand[8] protocols or the CCSDS AOS[9] protocol. The interface between LTP and the space link protocols is implemented by a very thin convergence layer being defined within the project.

DTN over space link protocols will be evaluated in three different configurations. In the first configuration shown in Figure 8 we use standard equipment used in ground stations of many space agencies.

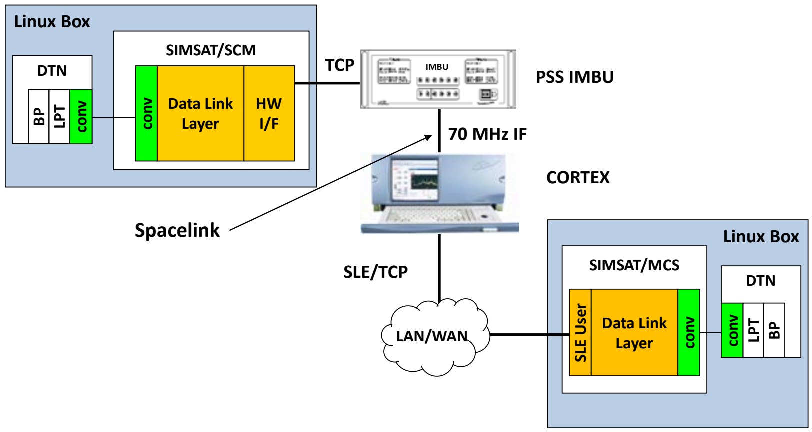

Figure 8. Space Link Simulation with Hardware in the Loop

The Integrated Modem and Baseband Unit (IMBU)*** which is used within the ESA Portable Satellite Simulator (PSS) receives fully formatted and multiplexed telemetry frames from the software simulator and performs Reed Solomon encoding and modulation on IF level. On the uplink the IMBU receives an IF signal, demodulates it, and decodes the Command Link Transmission Units (CLTU), which it forwards to the software simulator that handles the TC protocol.

The ground part of the TM and TC protocol is performed by the commercial Command, Ranging, and Telemetry processor, CORTEX†††, which interfaces to the IMBU at 70 MHz IF. It transmits telemetry frames to and receives CLTUs from a Mission Control Center via standard Space Link Extension (SLE) services[18] over a TCP/IP connection.

In our test set-up the MCS is replaced a basic MCS simulation model that handles the SLE interfaces and the higher layers of the TM/TC protocol and interfaces to a DTN node via the convergence layer. Likewise the space born part of the "space link bridge" is implemented by a basic Spacecraft Model (SCM) which interfaces to a DTN node as well. The simulation of the end-points also includes simulation of transmission delays and link disruption due to visibility constraints. The software used in the test bed reuses components of the ESOC Ground Systems Test and Validation infrastructure (GSTVi), which in turn runs within the simulation infrastructure SIMSAT.‡‡‡

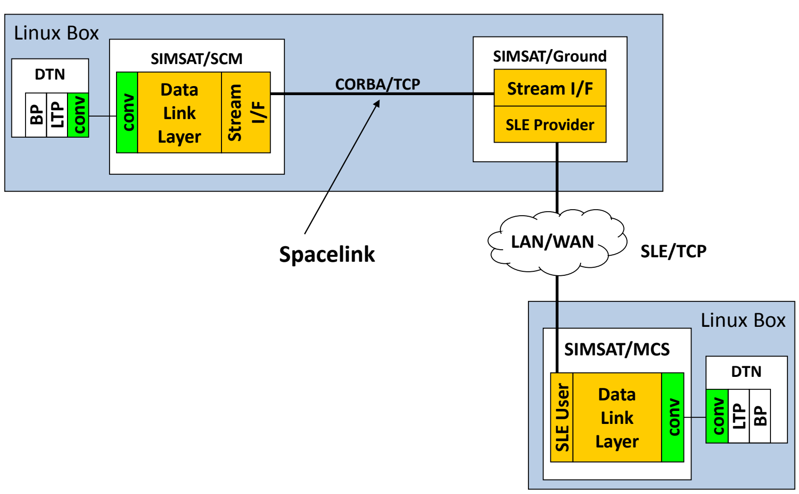

Figure 9. Simulated Space Link and Ground Station

*** See http://www.spacelinkngt.com/PSSIMBU.html
††† See http://www.zds-fr.com/upload/docs/030004-ftp62-ed7-crt.pdf
‡‡‡ See http://www.egos.esa.int/portal/egos-web

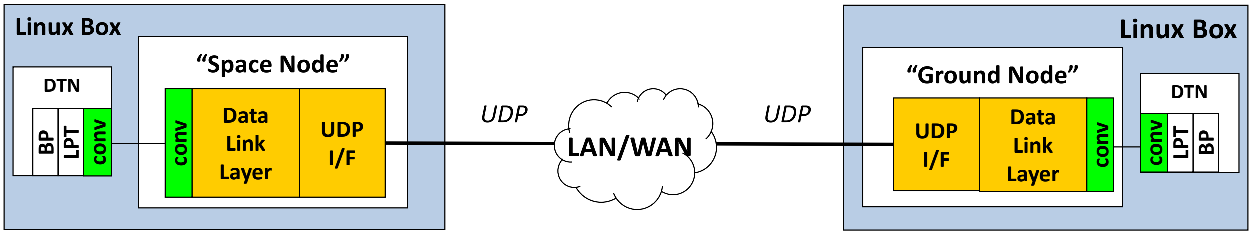

Figure 10. Simulation of the Space Link Across the Internet

Due to the implied cost, the hardware based test bed exists only once. To allow use of multiple space links, we develop a fully simulated version of the same configuration where the combination of IMBU and CORTEX is replaced by a Ground Station simulation model available from GSTVi. This configuration is depicted in Figure 9.

Finally we develop a configuration in which the telemetry and telecommand frames are exchanged between a "space node" and a "ground node" using UDP as shown in Figure 10. With this configuration it will be possible to use space link protocols also between nodes at different geographical locations. Whereas the former two configurations are limited to use of the CCSDS Packet Telemetry and Telecommand protocols this configuration also supports use of the AOS protocol on the forward (ground to space) and the return (space to ground) link.

Figure 11. Test Bed Hardware at VEGA

VI. Project Status and Plans

The project has completed the first phase in which we have analyzed a number of real world scenarios and elaborated requirements on the protocols, the infrastructure, and the demonstrator application. An initial architecture for the DTN Overlay and Space Data Router device has been established and an initial version of the test network has been deployed.

Implementation of the DTN Overlay and of the Link Layer is well progressed and we expect to complete the integration of the components this year. Similarly, the required policies of the architecture are currently being designed, linking the established requirements and network infrastructure with the application implementation, which is due to start in summer 2012. It is envisaged that the full prototype architecture will be finalized and undergoing benchmarking tests in 2013 and early 2014.

Appendix A
Acronym List

AOS	Advanced Orbiting Systems
CLTU	Command Link Transmission Unit
DTN	Disruption / Delay Tolerant Network
EO	Earth Observation
GS	Ground Segment
GSTVi	Ground Segment Test and Validation infrastructure
IF	Intermediate Frequency
IMBU	Integrated Modem and Baseband Unit
ION	Interplanetary Overlay Network
IP	Internet Protocol
LST	Land Surface Temperature
LTP	Licklider Transmission Protocol
MCS	Mission Control System
MCS	Mission Control System
P2P	Peer to Peer
PSS	Portable Satellite Simulator
SCM	Spacecraft Model
SCM	Spacecraft (simulation) Model
SDR	Space Data Router
SGM	SLE Ground Model
SIMSAT	Simulation Infrastructure for the Modeling of Satellites
SLE	Space Link Extension
TC	Telecommand
TCP	Transmission Control Protocol
TM	Telemetry
UHI	Urban Heat Island

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