SPACE-DATA ROUTERS

PROJECT FINAL REPORT

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4.1 Final publishable summary report

4.1.1 Executive Summary

Currently, Space-Data exploitation faces two major obstacles: Firstly, Space Centers and Academic Institutions have limited access to scientific data since their limited connectivity time via satellites directly confines their scientific capacity. Secondly, Space-Data Collection Centers lack sufficient mechanisms for communicating with interested end-users let alone the lack of mechanisms for data dissemination. The result is frequently quite disappointing: Space data remains stored and unexploited, until it becomes obsolete or useless and consequently is being removed.

Along these lines, the ultimate goal of “Space-Data Routers” was 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 proposed approach relies on space internetworking – and in particular in Delay-Tolerant Networking (DTN), which marks the new era in space communications, unifies space and earth communication infrastructures and delivers a set of tools and protocols for space-data exploitation within a single device:

The Space-Data Router.

Space-Data Routers implement a dual role: They increase communication flexibility in Space and form a mission-/application-oriented communication overlay for data dissemination, on Earth. Technically, they achieves that by deploying the Delay Tolerant Networking stack and by 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 parallel, they employ the agencies’ policies for resource and data sharing as well as for data exploitation. This goal was realized in three stages:

- At the first stage emphasis was given on the design and implementation of a Space-Data Router; a crucial component for space internetworking. Space-Data Router incorporates the concepts and protocols of Delay Tolerant Networking along with the resource sharing and data dissemination policies of various Space Agencies.

- At the second stage, the Space-Data Router was integrated within a core existing Testbed, tested and evaluated in terms of application requirements, overlay architectural design, compatibility with ESA equipment, protocols and policies, scalability in communicating with deep space components, and interoperability with NASA’s equipment. Application scenarios were carefully selected to demonstrate with clarity the impact of our proposed approach on data exploitation and data dissemination.
- At the third stage, a pilot application was developed to integrate thematically various missions. A cross-mission approach benefits scientific centers worldwide and also allow for more accurate and timely data analysis. The application allows for investigating in depth the potential of creating thematically-oriented space-data overlays in the future. In particular, our goal at the third stage was to
    - Demonstrate the sufficiency of DTN Space-data overlays to administer thematic cross-mission space data.

4.1.2 Project context and objectives

As the number of space elements increases, space communications enter a new era, where 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. As a consequence, space internetworking will bring a revolution in space communication since:

- the volume of data delivered will explode communication cost will be reduced
- interoperability will be possible
- resource sharing will be feasible, allowing joint missions as well.

That said, space communications may evolve similarly to the Internet architecture in three major aspects:

1. the store and forward architecture, which now emphasizes on storage instead of temporary buffering

2. the routing possibility, which now relies mainly on predetermined manual procedures.

3. the hourglass shape of the protocol stack, with DTN in the middle, possibly replacing IP in space and collaborating with IP on earth.

That said, the typical methodology for exploiting and disseminating space data has to be reconsidered. In particular, the centralized model of data dissemination through costly and bureaucratic operations constitutes a serious bottleneck for data exploitation. By and large, the new DTN-enabled architecture calls for a new dissemination model as well.

Why DTN-enabled Space-Data Routers?

Delay Tolerant Networking (DTN) is the emerging technology to support the new era in Space communications, especially for communications in Deep Space and for interconnecting Space Agency assets on Earth. Having already been tested in a number of stressed terrestrial environments, as well as in Space conditions, DTN becomes a standard architecture included in both CCSDS (Consultative Committee for Space Data Systems, [CCSDS]) and IETF standardization procedures.

By and large, the need for deployment of some form of Delay/Disruption-Tolerant Networking has been recognized by the Internet Architecture Board and also from Interagency Operations Advisory Group (IOAG) - Space Internetworking Strategy Group (SISG) [SISG Report] and CCSDS Management Council (CMC), which directed CCSDS to design the new standards. The project coordinator represents ESA in the corresponding CCSDS committee.

ESA's strategic goal to conform to the new architecture relies on four major arguments:

2. DTN has already reached a level of maturity as a technology on the ground, standardized by the Internet Engineering Task Force [Bundle Protocol, DTN Architecture].

3. DTN appears as a key technology for future missions in deep space; consequently, industrial activities worldwide will be shifted towards internetworking devices and protocols.

4. DTN could be designed in a manner that exploits ESA's existing infrastructure in Space and on Earth, without requiring a new investment strategy from scratch.

5. DTN has the potential to reduce space mission costs and increase scientific return through the flexibility of reaching Deep Space and disseminating data on Earth.

As a deliverable, Space-Data Router constitutes a pioneering technological target for Europe, for two major reasons: (i) it allows for exploiting massive data, increasing the return of all scientific missions and (ii) it bridges the communication gap between Deep Space and internetworking protocols but also the gap of agency interoperability. In essence, Space-Data Routers satisfy both technological and scientific objectives of European missions towards exploiting and disseminating space data.

There also exists a socio-political dimension in "Space-Data Routers" project that should not be underestimated. It is quite safe to say that currently space community is fragmented. This fragmentation is present not only between space agencies but also amongst participants of the same space agency. Legacy equipment developed in a mission-by-mission basis hinders the deployment of unified efforts towards space exploration. Within "Space-Data Routers" we not only favor unification in a technical level, but also go beyond that, allowing agencies to use their own policies regarding resource-sharing and to take advantage of pre-existing equipment.

Scientific objectives

We define four major scientific objectives:

1. "Space-Data Routers" will boost the dissemination capability for Space Data on Earth.
   We demonstrate the capability of the Space-Data Routers to extend end-user access to space data through communicating Ground Stations and Space Research Centers. See Scenario 1 and Scenario 2

2. "Space-Data Routers" will allow for exploiting Data from Deep Space.
   We demonstrate the potential of exploiting data from Deep Space and disseminate it naturally through unified communication channels. This will be evaluated using the missions Rosetta and Mars Express along with the existing Ground Station infrastructure. See Scenario 3 and Scenario 4
3. "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 using a projection of generated data from ENVISAT, SENTINEL, etc. as case studies. See Scenario 5.

4. "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. We describe the application framework along with the thematic cross-mission space data collection for measuring urban heat island phenomenon of Athens. See Scenario 6 and Scenario 7.

In general, "Space-Data Routers" boost the scientific capacity of ESA and Europe in Space Sciences and the new space communication era. Practically, "Space-Data Routers" will allow ESA to build its own internetworking strategy, on its own infrastructure, and also determine its resource sharing policies and guarantee space security aspects, independently. In turn, Space-Data Routers will allow ESA and Europe to deploy its own Space-Data Dissemination policy, immediately.

Technical objectives

The main advantage of 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 will be developed on top of real space protocols allowing for the direct interoperation with current space infrastructure. Furthermore, a sophisticated application will also be implemented in order to support, highlight and assess system's capabilities.

Currently, Ground Centers constitute the gateway to communicate with space assets. Therefore, all space data are transferred directly to the Ground Centers and stored there, temporarily. Each research center or academic institution that is interested in acquiring these space data is frequently required to negotiate with the Ground Center prior to proceeding with the actual transfer of data. This approach appears to be rather time consuming and causes storage exhaustion and congestion in the case of several recipients. The only advantage, but also the bottleneck, is the centralized control of the ground centers regarding data dissemination.

Space-Data Routers main goal is to increase the efficiency in space data transfers, by increasing automation and resource exploitation while decreasing the overall transfer time and provide security and centralized control. The first stage of improvement is based on the direct application of Space-Data Routers on top of the existing infrastructure. The routers will create an overlay network between academic institutions, research centers and Ground Centers. First stage's advantages are mainly the automation in file delivery, the distributed storage of space data, and Ground Center management of dissemination.

The DTN architecture is a prominent candidate for space internetworking. Therefore it is widely accepted that in the near future that Space missions will adopt the DTN protocols as a common architecture for space communications. The deployment of DTN in space, will allow for communication between space assets and direct access to the science data of space equipment based on Agencies' policies. House-keeping data and control commands will be routed through a dedicated route from the Ground Centers to space assets. The main advantages of the second stage improvement, apart from those of the first stage, are increased connectivity with space assets through multiple Ground Centers – gateways, interagency communication, efficient resource allocation and further alleviation of congestion and storage requirements of the ground centers.

4.1.3 Main S&T results/foregrounds

In this section the main scientific and technical results per Work Package are presented.

Work package number	WP2	Type of activity	RTD
Work package title	System Requirements		
Start month	1		
End month	5		
Lead beneficiary number	1		

The objective of WP2 was to align evaluation scenarios with application and protocol requirements, emphasizing on data dissemination and exploitation. Application requirements were adjusted to the dual nature of the underlying network, terrestrial and space, focusing on current and future space mission needs. Scenarios were designed in a manner that exploits the topological and communication characteristics that may impact on application services.

T2.1: In this deliverable an extended description of seven space mission scientific scenarios is presented in which the National Observatory of Athens is currently involved. For each scenario operational and application details are described and the current limitations and restrictions with respect to data acquisition and dissemination are presented. Additionally, emphasis was given to the definition of the scenarios' requirements, as well as to the expected impact on each scenario by using the new architecture. The seven scientific scenarios contained in D2.1 are briefly described below.

- The first scenario is related to the study of ecosystem dynamics, using CHRIS onboard PROBA-1 hyperspectral data. The purpose of this scenario is the use of hyperspectral images from CHRIS sensor onboard PROBA-1 satellite for monitoring vegetation status in space and time.
- The second scenario is concerned with the effective combination of real-time and archived AVHRR HRPT data from local HRPT receiving stations worldwide. 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 be very beneficial, since it would permit NOA/ISARS to acquire images of other parts of the Mediterranean in near-real time as well.
- Scenario 3 deals with a deep space mission and more specifically with the efficient acquisition and dissemination of hyperspectral images captured by OMEGA on-board ESA's Mars Express (MEx) satellite.
- Scenario 4 is concerned with the efficient acquisition and dissemination of image data captured by OSIRIS instrument on-board ROSETTA deep-space mission. ROSETTA is an interplanetary spacecraft whose main objective is to rendezvous with Comet 67P/Churyumov-Gerasimenko.

- The fifth scenario is related with new deployments in space and in particular with the case of ESA's Sentinels satellites. The ESA Sentinels constitute the first series of operational satellites for Global Monitoring for Environment and Security (GMES).
- Scenario 6 deals with a cross mission application that combines data from multiple satellite instruments with the aim of studying 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. 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. Future explorers far from Earth will be in need of real-time data assimilation technologies to predict space weather at different solar system locations.
- A multiple-mission application is the subject of scenario 7. The aim of this application is the study of the time and space variations of land surface temperature (LST) in a city environment using image data from multiple different mission instruments. 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.

T2.2: In this task we focused on the requirements and characteristics of the application to provide the required functionality to all the stakeholders. The application will be implemented as a web front-end coupled with a database and will interact with four types of entities: data providers, user institutions, infrastructure providers, and administrators. The database will include various metadata information, such as data collection instrument characteristics, users/institutions and associated credentials, and storage locations and capabilities. It is envisaged that, for simplicity and process distribution reasons, the application will be separate from the storage and, therefore, 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 organisations. 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 authorisation/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 organisation that requests it.

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, previously collected and stored, are specifically requested by the 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.

In order to provide the required functionality, the application will include several types of process: registration of new users/organisations, registration/upload of new data, user downloads 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. As part of the normal functionality, information contained by the reference database will be queried and used by the network infrastructure to optimise the data paths. In order to support this functionality, a number of combinations of dedicated storage locations, earth stations, and cache storage, geographically distributed, will contain the data objects and stream to be retrieved. The data exchange will include several types of exchanges: signaling/AAA/control, data objects / streams download, data objects / streams replication between SDR and provider database, and data replication within SDR.

T2.3: In this task, we focused on the special characteristics of space-data transmission and the limitations they impose on protocols design. Scenario and application requirements have been studied in order to extract these limitations and focus on their demands. Specifically, several key requirements that we extracted and have to be given credit are the following:

1. **Robustness/reliability**, especially for noisy channels, where sending nodes (e.g. satellites, landers, etc.) buffer space data for long periods of time, especially when data arrives at destination with errors and needs to be retransmitted. As a result, network congestion in space entities often takes the form of storage congestion. Therefore, we will apply functionality into protocols that provides reliable data services with error-free space-data delivery.

2. **Store-and-Forward mechanism** that will use some form of permanent memory, provide a level of reliability to data delivery in order to overcome network disruptions.

3. **Asymmetric channels** should be taken into consideration, since downlink rate to uplink rate ratio may take a value of 1000:1 or even greater values. Hence, network protocol stacks in space environments require mechanisms that minimize or control acknowledgement traffic.

4. **Hop-by-hop reliability** should be also attended, since space networks reliability is better supported when the end-to-end path is divided into a series of links, in which data transmission is ensured.

5. **Resource sharing**, a feature that will help overcome one of the major weaknesses of the existing Space-Earth communication infrastructure, the lack of available resources. The vital need to fully exploit rare and valuable space resources will be handled by Space Data Routers protocols. In particular, the project will aim at unifying all available communication channels in a shared global system, in order to achieve better utilization of the network infrastructure.

6. **Exploitation of alternate routes** will be a feature of the designed routing mechanisms. A space data router will dynamically configure the route of any packet towards its destination, based on

network information that is available at the moment.

7. **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.

8. **Load Balancing (in terms of traffic).** One of the main purposes of the project is to adjust routing processes in order to deal with the vast amounts of data that are being transmitted towards Earth base stations and that have increased from Kilobytes or Megabytes to even Terabytes during the recent years.

9. **Load Balancing (in terms of storage capacity).** We are planning to design and implement routing mechanisms that take into consideration the limited storage resources and attempt to balance storage load on the overall system.

10. **Security**, a network element that comprises three vital characteristics, authentication, integrity and confidentiality, will have to be given special credit. The sensitive nature of space-data transferred (presumably images of a country where military bases might be shown) makes the usage of a high-standards security mechanism vital. Several additional security setbacks and requirements are mentioned below:

11. **Routing** protocols and mechanisms should cope with the space-data nature, which could possibly include sensitive information of national interest. 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 security in the level of trust. Thus, routing protocols should also include the "trust" factor, in order to achieve confidentiality at a first level.

12. **End-to-End or Hop-by-Hop** based security are two alternatives that may be used. The new model gives the opportunity to check data integrity and authentication and introduce confidentiality via encryption, in end-to-end or/and hop-by-hop level, between SDRs. However, adding so many security layers can have a negative impact on the network's performance as security leads in additional overheads. Encrypting data in an end-to-end approach means that data are kept under encryption during their way to the destination. Thus, it is not necessary to add more encryption in the part of the network between two SDRs.

Work package number	WP3	Type of activity	RTD
Work package title	Implementation of DTN overlay		
Start month	5		
End month	20		
Lead beneficiary number	1		

T3.1: In the framework of Task 3.1 a DTN overlay was constructed over a number of nodes distributed across the facilities of the partners. The implemented DTN architecture includes eight nodes whose distribution across partners is depicted in figure 1. The interconnection of DTN nodes has been done through the Internet, ensuring continuous and reliable communication among them.

The functionality and the performance of the DTN overlay were tested upon the completion of its installation and configuration. Two different sets of experiments were performed in order to ensure that the Bundle Protocol functionality is provided and an initial assessment of its performance was made. In the first set of experiments, small-sized bundles were exchanged between all nodes in the DTN overlay and the Round-Trip Time (RTT) was measured for each pair of nodes. In the second set of experiments, fixed-size files were transferred from each node to every other node in the DTN network and the duration of transfer was measured. Thus, we confirmed the successful exchange of bundles among all the nodes in the DTN overlay and we recorded the performance test results.

T3.2: Main objective of this task was to investigate the mechanisms based on which, space agencies and prime investigators will share their resources in the future. A number of roles and network elements, as well as the relationship between them, are presented, followed by the requirements that should be met in order for this complex communication model to be acceptable by all participating members. In particular, within the «Space-Data Routers» project, we envisage a powerful mission communication model, depicted in Fig. 1, that is expected to emerge over the next few decades. According to this model, missions may be jointly operated by multiple space agencies, with different elements of mission functionality managed by different MOCs, space communications services may be provided by multiple space agencies, and data may be routinely relayed among spacecraft—even among spacecraft deployed for different missions, by different space agencies—on their paths to and from the MOCs. That is, not all data received by a spacecraft will necessarily be "uplink" and not all data transmitted by a spacecraft will necessarily be "downlink". Furthermore, the data exchanged among spacecraft, MOCs, and investigators may be significantly more complex. For example, streaming video may be produced by crewed spacecraft. Files may be transferred, using the CCSDS File Delivery Protocol. Standard Mission Operations Services messages may be published to multiple subscribers, in space and/or on Earth, using the CCSDS Asynchronous Message Service.

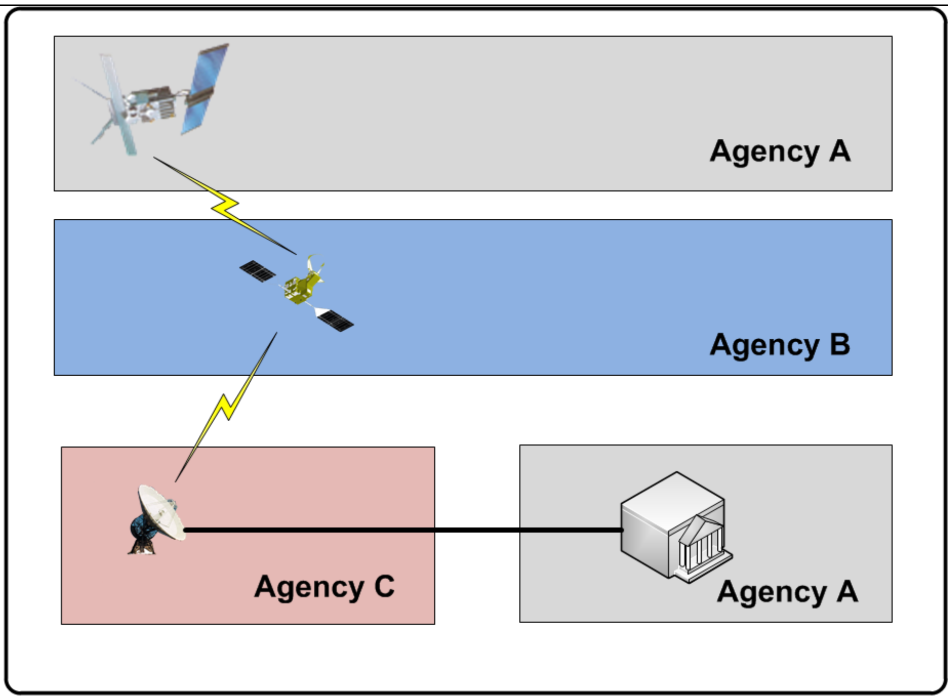

Figure 1. New communications model envisaged by Space-Data Routers

The aforementioned complex communication model should be able to meet the following requirements:

- **Interoperability**

Ground and space assets of all participating organizations should function as potential elements of mission cross support, increasing total mission data return while reducing the risk of critical data loss.

- **Local Control**

All organizations should retain complete control of their flight and ground communication resources. Only those resources that have been explicitly offered as cross-support elements are made available to other organizations, and only to the degree explicitly authorized by the organizations that offer them.

- **Resource protection**

Rate control and congestion forecasting mechanisms built into the Space-Data overlay should protect flight and ground assets from utilization beyond authorized levels. Mission data confidentiality, authentication, and integrity verification are also major requirements.

T3.3: The primary aim of the space routers DTN 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 security mechanisms to support the data retrieval have been designed in conjunction with the application requirements, detailed in deliverable *D2.2 Applications Requirements Report.*

The security requirements have been developed based upon:

- A stakeholder questionnaire that seeks to understand the end-user requirements for security and availability within a Space Data DTN.
- Expert analysis of the Space Data DTN architecture and application of information security design principles.

It became evident from the stakeholder questionnaire that although many of the usage scenarios made use of public data and therefore security was not a key priority (at least compared to availability) at least one scenario did. It was therefore imperative to ensure the architecture design incorporated sufficient security controls to enable the successful transmission of data.

In order to assist in understanding, these requirements have been presented under each of the standard security services: confidentiality, integrity, availability, authentication, authorisation and accountability. Within each service, specific requirements are defined for each aspect of the Space Data DTN.

From an architectural perspective, the security includes four entities: management application, data originator, end users, and trusted DTN nodes. The management application oversees all types of interaction/operation, from user authentication to data retrieval. To begin with, the exchange of information between users and the application will be subject to AAA mechanisms. The management application utilizes a reliable internet connection to communication to data originators, end users and trusted DTN nodes, to communicate meta-data and service requests.

The data itself is secured utilising a key distribution consisting of two key phases. The first phase involves computationally and communications intensive establishment of the long term key infrastructure. This can involve PKI components such as digital certificates. In addition, due to the limitations many devices may have in space (including power), low energy and memory consumption algorithms need to be considered, such as elliptic curve based PKIs.

The second phase refers to the secure session establishment. In this context, the term *session* depends on the security assertions and underlying scenario and is used to describe the situation where a node needs to create a confidential channel to some destination (not necessarily the final destination of the data, as end to end security cannot always be guaranteed or offered). Preference is given to one-pass security protocols.

In order to provide actual data encryption in Space-Data overlay we have developed our own implementation of one ciphersuite used by Payload Confidentiality Block (PCB). More specifically, we have implemented the arc4 cryptographic algorithm.

The security policy database on the local node is configured and managed in the ionsecadmin. Every security-aware node can have access to long-term keys and the security policy through the ionsecadmin.

T3.4: In the framework of Task 3.4 and in order to enable the efficient space-data transfer and dissemination among the earth ground stations, we have created a complete routing solution that incorporates a number of different criteria in its routing selection algorithm. Our routing solution provides a dynamic framework that allows for the dynamic update of the network contact plan and the remote management of nodes by an administrative node. Finally, we have also implemented a mechanism that utilizes this dynamic protocol and allows a node to inform the entire network about any possible updates in its storage availability.

The proposed routing mechanism comprises three main components:

- the multi-objective contact graph routing mechanism
- the management and contact plan update mechanism (M-CPUM)
- the storage availability notification mechanism (SAN-M)

Multi-Objective Contact Graph Routing Mechanism

A basic part of the Space-Data overlay implemented for the Space-Data Routers project is the Multi-objective Contact Graph Routing (MOCGR) mechanism. As the name suggests, a sophisticated algorithm is 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 by the transmitting node allowing the algorithm to calculate the best available route depending on the sender requirements.

The Multi-Objective Contact Graph Routing mechanism is an extension of the Contact Graph Routing (CGR) algorithm. 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 also could 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 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. The route calculation algorithm is described below:

Starting from the transmitting node, Dijkstra’s algorithm is exploited to calculate available paths towards the receiving node. At this stage, some contacts may be eliminated depending on the Bundle Header information. More specifically, a contact cannot be used if it involves a node with low storage capacity and the Storage Requirement bit, embedded on the Bundle Header, is set to on. The same applies for the Trustability requirement. A contact that is not trusted by the sending node is eliminated from the route calculation process. After this step, the selection of the best route is based on whether the sending node wants to minimize the financial cost or the delivery latency. A bit embedded on the Bundle Header provides that information to each node that receives a bundle, so that it can route it according to this requirement.

Critical bundles are sent on all available paths, regardless of the financial cost and delivery latency, though untrusted and low-storage nodes are still avoided.

Manage and Contact Plan Update Mechanism

In order for the MOCGR to provide valid routes towards the receiving station, the aforementioned routing parameters 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 and transmit update messages to all network nodes. Therefore, we created a Manage and Contact Plan Update Mechanism (M-CPUM), which renders the system flexible and adaptable to any status changes. This mechanism includes contact plan update messages along with management commands that are also vital for the network status modifications. M-CPUM comprises two applications that take place on sender and destination node, namely *cpumSend* and *cpumReceive* respectively.

The design of a M-CPU message, and its format that allows for the efficient integration of different update commands within a bundle payload, are thoroughly described in [D3.3]

Storage Availability Notification Mechanism

One of the main objectives of this project is to effectively distribute the traffic load to the DTN nodes of the network. The increased amount of data that is transmitted towards Earth base stations requires the design of new mechanisms that will be able to balance this load among the available storage resources and consequently maximize the overall network performance by avoiding overloading specific nodes.

Storage Availability Notification Mechanism (SAN-M) is an application that enables a DTN node to inform other nodes about its storage availability. SAN-M exploits M-CPUM in order to notify all the nodes of the network when an important change to the node storage resources has been discovered. Nodes that are continuously receiving vast space-data amounts 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. This information will then be utilized by the network nodes, which will adjust their routing decisions. SAN-M therefore ensures that *custody denial* signals, data drop due to storage congestion are avoided. A notification using SAN-M will be also transmitted when storage is free again and the node is able to handle traffic load.

SAN-M application can be executed by the node's administrator when either the node's storage availability is lower than a minimum threshold, or when a previously congested node is again able to accept network load. Depending on the node characteristics and requirements, automatic execution of the application is also feasible, using a daemon that continuously checks storage availability in comparison to a minimum threshold on the accepted ratio of storage occupancy.

SAN-M creates an M-CPUM update message in order to update the contact plan of all network nodes. This message includes two commands for each contact of the contact plan that has as destination node the node that executes the SAN-M application. The first one is a *delete contact* command and the second one is an *add contact* command, in which the *storage availability* flag has been modified properly. Nodes that receive the M-CPUM message will alter their contact plan respectively and will utilize this information in order to adjust their routing decisions accordingly. The SAN-M application uses a predefined service number in the destination endpoint identifier. In our configuration we use *x.1*, in which *x* denotes the node number and *1* the service number.

Detailed application configuration and usage for *cpumSend*, *cpumReceive* and SAN-M can be found in [D3.3].

T3.5: In the context of T3.5, a transport protocol has been designed and implemented, in order to provide the available functionality for space-data dissemination via the Space-Data Routers. Delay Tolerant Payload Conditioning (DTPC) protocol is an end-to-end transport protocol that is designed to be used on top of the Delay-Tolerant Networking (DTN) architecture. DTPC protocol complements the DTN services offered by the Bundle Protocol (BP) [RFC 5050] and operates only at the endpoints of the communication system enabling the following end-to-end services:

- Application data unit aggregation
- Retransmission-based reliability
- In-order delivery of application data units
- Duplicate suppression

Offered Services

a) **Aggregation**
BP introduces significant overhead when used to transfer application data units whose size is comparable to BP's header size (i.e. the size of the primary block plus the size of the payload block plus the size of each extension block that may be in use). In order to decrease this overhead, DTPC protocol offers an aggregation service that can be used to aggregate multiple application data units from different applications located in the same node, which are destined to a common bundle node and characterized by a common transmission profile. Whenever an aggregation process is completed, DTPC passes the aggregated data unit to BP for transmission.

b) **End-to-End reliability**
BP's hop-by-hop reliability cannot always guarantee application reliability. For example, in case of an intermediate custody node failure or erroneous route calculations, BP may fail to deliver application data to the destination node. In such cases, retransmission mechanisms should be incorporated into the applications themselves. DTPC protocol takes away this requirement and handles end-to-end retransmissions on behalf of the applications. Whenever a DTPC item, the unit of DTPC protocol's data transmission activity, is handed down to BP for transmission, the BP "acknowledgment by application" request is included in the transmission request parameters and an

acknowledgment reception timer is set. Upon the expiration of this timer prior to the reception of an acknowledgment for this item, the item is retransmitted.

c) **In-order delivery and duplicate suppression**
In DTN-based networks, each bundle is uniquely identified by a creation timestamp and a sequence count. BP, however, does not incorporate any mechanism that enables in-order delivery of bundles, neither any mechanism for suppressing duplicate bundle delivery. DTN applications require such services, as well. DTPC protocol offers these services based on its own sequencing mechanism. In DTPC, each item is uniquely identified by a sequence number and is delivered to an application as long as all previous data units have been successfully delivered or expired. Additionally, DTPC protocol blocks the delivery of application data units that have already been delivered.

A detailed presentation of the DTPC protocol, including protocol terms and definitions, DTPC item format, configuration, usage, and testing applications is described and available in [D3.4]).

T3.6: In the framework of Task 3.6 we have tested and evaluated the protocols and mechanisms that constitute the DTN Overlay. These separate mechanisms, namely the Security, Routing and Transport Mechanisms were designed and implemented during the tasks T3.3, T3.4, and T3.5 respectively. During this task (T3.6) we expanded the DTN testbed that was designed during the T3.1 (DTN Architecture Report), we incorporated the three aforementioned mechanisms into Interplanetary Overlay Network (ION), an open-source DTN network platform, and we installed the complete system in each one of the testbed nodes. After setting up the DTN Overlay in our infrastructure, we proceeded with a testing and validation procedure. During this procedure we eliminated all conflicts that emerged from the integration of the distinct parts into the overall program. In addition, we verified that each mechanism maintains its functionality and finally that the DTN Overlay layer works as expected: data is successfully transmitted from source to destination, in a way that it is transparent to the application, by a) encrypting the confidential data, b) routing the data bundles based on the desired functions (e.g., minimum cost, load balancing, minimum delivery latency), and c) applying reliability on the end-to-end data delivery. First we demonstrated that each component of the DTN overlay is functional, by presenting some of the experiments that validate the distinct functionalities of each mechanism separately; next we illustrated three indicative complex scenarios where the DTN Overlay is examined as a complete framework and the developed mechanisms combine their functionalities to provide a robust network overlay. Finally we described the testbed expansion and the installation of the additional nodes.

Work package number	WP4	Type of activity	RTD
Work package title	Link-layer Implementation		
Start month	5		
End month	20		
Lead beneficiary number	2		

T4.1: The hardware used for the Hardware Link Layer Implementation have been ordered to the suppliers, received at VEGA premises, and installed in the VEGA test bed environment.
Two hardware units are used for the project:

- The ESA Portable Satellite Simulator (PSS) is used in ground stations as a telemetry generator and telecommand sink. It includes a standard PC running the SIMSAT based simulation software and the Integrated Modem and Baseband Unit (IMBU), a special hardware unit that implements the TM and TC channel coding layer as well as a space link modem.
- A suitable telemetry and telecommand processing system as used in satellite ground stations (a candidate is the CORTEX system from Zodiac but final selection will be made during the project)

These 2 systems have been interfaced at IF, modulated subcarrier, or baseband level to simulate the space link. The hardware units are used in the configuration shown in Figure 2.

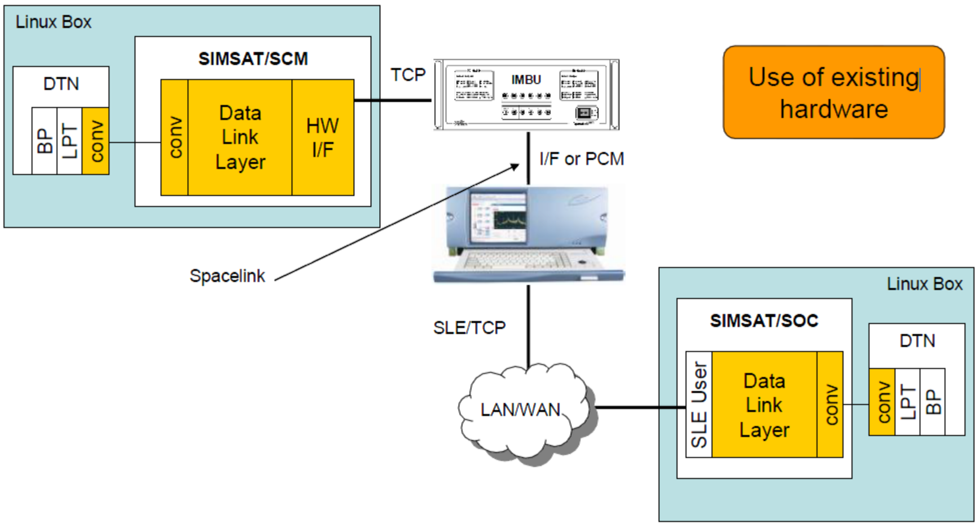

Figure 2. Use of existing hardware

Specific software have been developed to implement those elements of the data link layer that are not provided by the hardware units and for the implementation of the convergence layer. The configuration supports the Packet TM protocol on the downlink and the Packet TM protocol on the uplink.

The LTP packets are encapsulated in CCSDS packets as defined by the Space Packet Protocol specification. The software runs within the SIMSAT runtime environment.

T4.2: Using the outputs of the T4.1, a second configuration has been prepared and implemented. This configuration is equivalent to the previous one with simulation models replacing the hardware units. This configuration allows for deployment of DTN nodes without the need for special hardware in order to implement scenarios with multiple links at multiple locations within the budget constraints of the project. The configuration is shown in Figure 3.

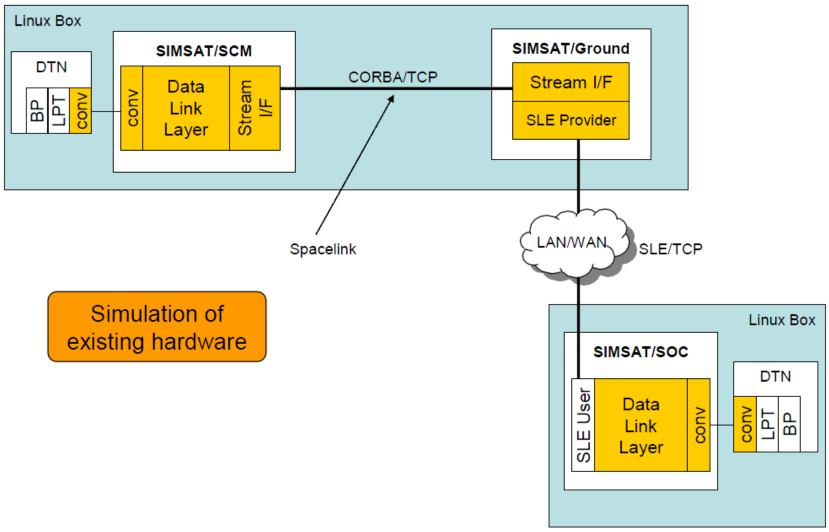

Figure 3. Simulation of existing hardware

The following components compose the system:

- SIMSAT: the simulation runtime infrastructure.
- MMI plug-ins: the MMI components allowing monitoring and controlling the models and the simulation.
- DTN Node: the implementation of the DTN stack allowing to interface the components with other DTN nodes.
- Runtime Configuration Manager (RTCM): runtime manager responsible to start the simulation models, control their processing, and check their status.
- Configuration manager (with Database): web-based application allowing to configure the system.
- CORTEX: telemetry and telecommand processing system able to exchange data at IF level. The CORTEX is a representative legacy system typically used in Ground Stations.
- IMBU: telemetry and telecommand processing system able to exchange data at IF level. The IMBU implements the same hardware interface as one typically implemented in a spacecraft.
- IMBU I/F: interface model allowing to interface the IMBU with the rest of the simulation.
- S/C Model: model of a spacecraft, implementing the standard CCSDS protocols.
- TTC Stream: implementation of a simulated spacelink on top of CORBA/TCP.
- SLE Ground Model: simulation model implementing the provider side of a SLE interface.
- NIS Model: simulation model implementing the user side of a SLE interface.
- MCS Model: simulation model implementing a spacecraft monitoring and control system.

Each of the models running in the simulation can be monitored and controlled via the standard SIMSAT MMI and via specific MMI plug-in components developed for the system.

T4.3: In addition to hardware link layer implementation (D4.1) and the simulation of hardware using SIMSAT models (D4.2), a third configuration is provided where the space data link protocol stack is fully integrated within the DTN architecture.

The space link simulation is based on UDP allowing it to take advantage of the DTN functions related to insertion of a propagation delay and to simulate the effects of noise. The LTP segments will be encapsulated using the encapsulation service defined in CCSDS 133.1- B-1 and transmitted via the space link as encapsulation packets. This configuration supports the following 3 combinations of data link protocols:

- Downlink Packet TM – Uplink Packet TC
- Downlink: AOS– Uplink AOS
- Downlink: AOS– Uplink Packet TC

The data link layer integrated within the DTN architecture is shown in Figure 4.

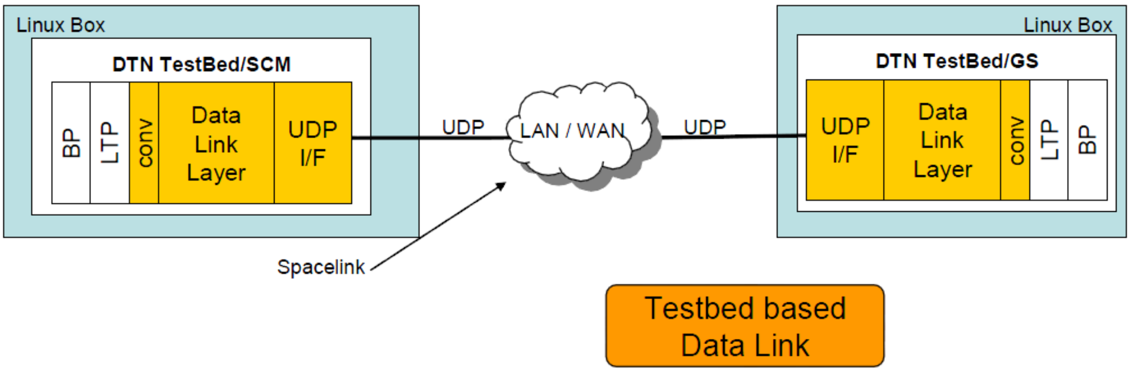

Figure 4. Testbed based Data Link

T4.4: Several tests were conducted to validate the implementation of the link layer. In particular, the following Test Cases will be considered within the testing activity:

- Spacecraft to Ground

The test case Spacecraft to Ground tests the capability to send files from space to ground.

- Ground to Spacecraft

The test case Ground to Spacecraft tests the capability to send files from ground to space.

- Bi-directional

The test case Bi-directional tests the capability to send files from space to ground and from ground to space at the same time.

T4.5: The DTNDLL test bed was further developed to the integration of the space link protocol Proximity-1 (CCSDS 211) in order to allow a “ground station, orbiter and rover” scenario.

Proximity-1 protocol was developed as part of the Space-Data overlay. A number of tests were devised for the validation of the protocol.

T4.6: The following scenario was devised to test the functionality of the Proximity-1.

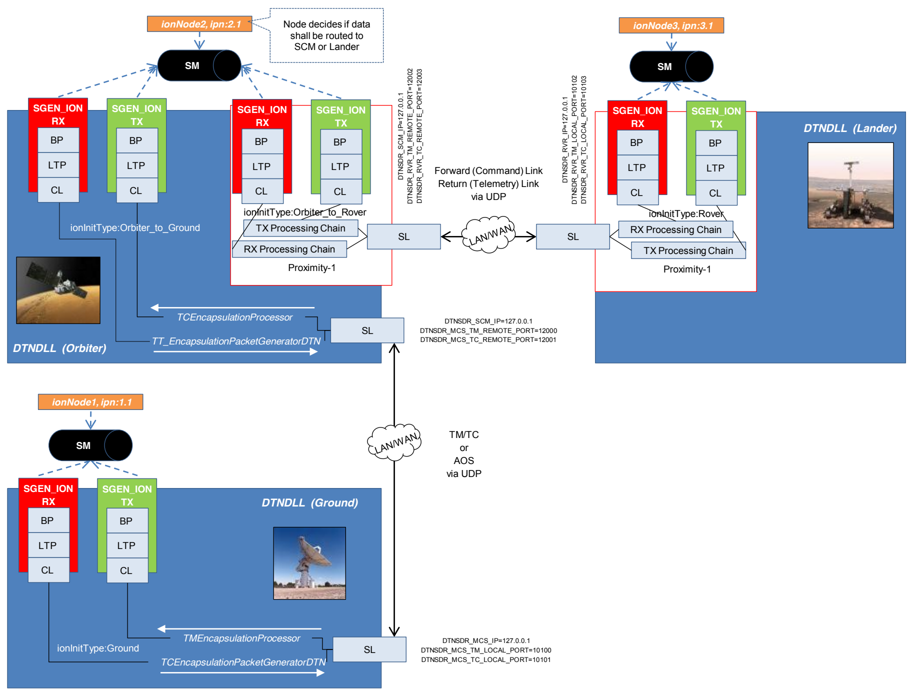

Figure 5. Proximity-1 validation scenario

Work package number	WP5	Type of activity	RTD
Work package title	Router component integration and validation and integration into Testbed		
Start month	5		
End month	34		
Lead beneficiary number	3		

T5.1: In the framework of this task, we detailed the Space-Data Router technical characteristics and highlighted the concepts that need to be evaluated for their functionality, efficiency, compatibility with ESA infrastructure, and deployability in future ESA missions. More specifically, we described the protocol stack configurations that are needed to support both terrestrial and space communications. In terrestrial links, the protocol stack that is going to be used is depicted in Figure 6, while the protocol stack suitable for space communications is depicted in Figure 7.

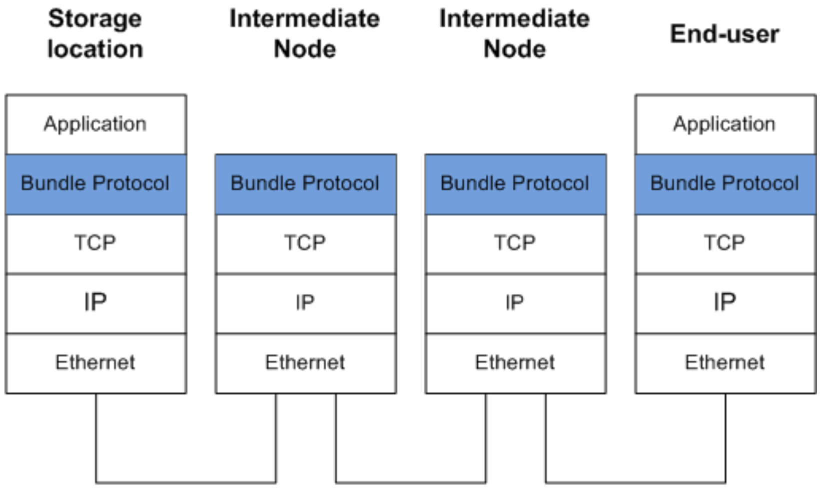

Figure 6. Protocol Stack Configuration for terrestrial communications

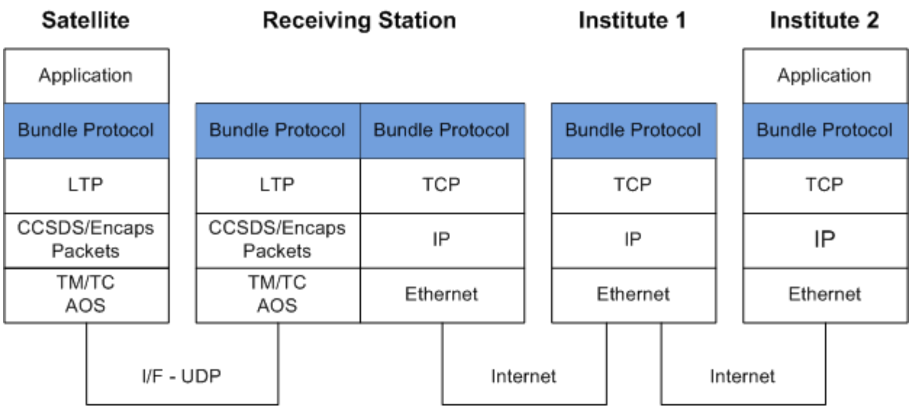

Figure 7. Protocol Stack Configuration for space-to-Earth communications

T5.2: In order to interconnect the Bundle Protocol (BP) and the associated Licklider Transmission Protocol (LTP) with the lower network layers, a convergence layer has been implemented. This layer is used as an adapter between the LTP and the data link layer implementing the packet TM/TC and AOS protocols.

The convergence layer uses the shared memory of the ION stack to exchange data with the LTP. Together with the ION DTN stack are provided network layers allowing exchanging data over TCP/IP or UDP. In this case, the following protocols are used: BP/LTP/TCP or BP/LTP/UDP. The implemented convergence layer, together with the data link layer allows using the following protocols: BP/LTP/ConvLayer/PacketTCTM or BP/LTP/ConvLayer/AOS.

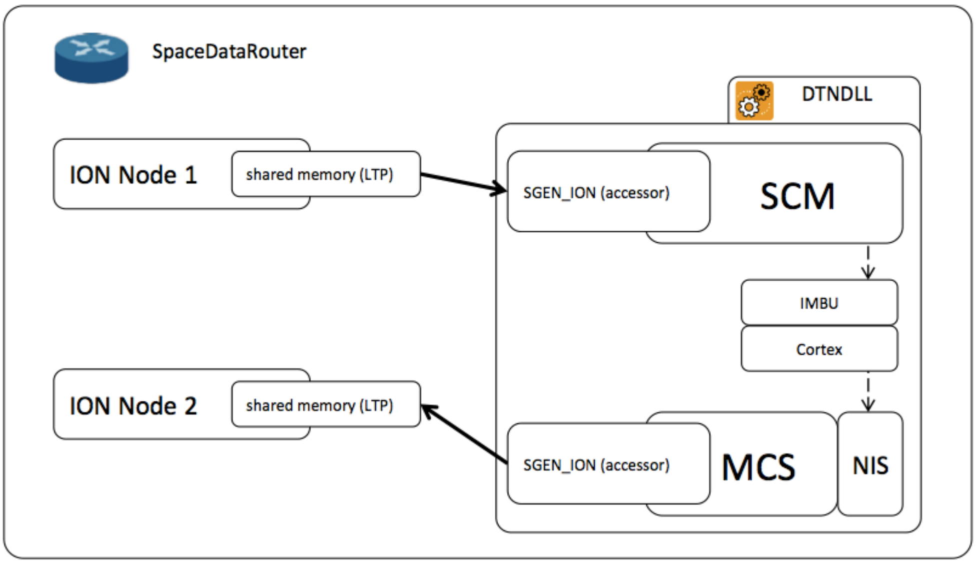

Figure 8. Convergence layer architecture

Internally, the ION stack uses a shared memory to pass data between the LTP and the lower network layers. This mechanism is kept as is, and the DTN ION stack is not modified there. A "ION accessor" component has been developed allowing to exchange data with the shared memory used by the ION LTP. The "ION accessor" read/write data to the shared memory to communicate with the LTP, and provide/read data from a space packet in order to communicate with the data link layer (packet TM/TC and AOS). For encapsulation of the LTP data into a space packet, an encapsulation packet is used.

T5.3: Since all convergence layers were developed in the previous tasks, in this task the necessary validation tests were performed in order to guarantee the correct interaction between the DTN overlay and the link layer protocols.

T5.4: In the framework of Task 5.4 of Work Package 5, router administration tools were designed and implemented. The primary aim of the tools is to allow an end-user to interconnect to the DTN overlay [D3.1] of the Space-Data Routers project. Thus, the end- user's workstation (PC, laptop) becomes a DTN node, being able to exchange space data with the rest of the nodes in the DTN overlay.

Major requirement for the administration tools was to keep the user intervention to a minimum and follow an automatic configuration approach as much as possible. The target group of end-users mainly includes space scientists and astrophysicists, and our target is to reduce their involvement in the network configuration and allow them to focus on the space data and knowledge dissemination.

The configuration of an end-user node relies on the three distinct components of the Space-Data Routers architecture: the administrative server, the web application server and the end-user application.

T5.5: In the framework of Task 5.5 of Work Package 5, a set of experiments has been conducted based on realistic scenarios. The purpose of the experiments is the validation of the functionality of the Space-Data Router.

More precisely, the functionality of the three main components of the Space-Data Routers architecture (administrative server, web application server, end-user application) was broken into sub-tasks and each of them was validated.

T5.6: In the framework of Task 5.6 of Work Package 5, the individual components of the Space-Data Routers architecture were integrated in order to ensure the proper functionality for the dissemination of the space-data among data providers and end-users, as well as any necessary configuration procedure.

The overall architecture consists of the administrative server, the web application server, the end-user application and the data provider server.

During this task, the data provider server was developed, which will run in each DNT node that will operate as a data provider. It will receive requests from the web application server for a dataset download, and trigger the final communication between the DTN nodes which will exchange the dataset over the DTN overlay.

Work package number	WP6	Type of activity	RTD
Work package title	Application implementation		
Start month	20		
End month	29		
Lead beneficiary number	6		

T6.1: The main focus of the work has been on the Space Routers Application. The main purpose of the Web App is to enable the easy search through, retrieval of, and access to, a large set of datasets that will be provided by many different Data Providers. 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.

The Application itself is now being designed using an MVC (Model View Controller) pattern to maintain user state, and Twitter's Bootstrap UI framework is being used to expedite user interface development.

T6.2: Security mechanisms for user authorisation were integrated to the core application. These mechanisms 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.

T6.3: A complete operational HTML mockup of the application has been created, together with a document that explains its proposed operation, states any assumptions that have been made (and asks for clarification), and which describes scenarios for the end-user to run through to ensure that the functionality of the mockup is what the end user is both expecting, and is comfortable using.

T6.4: Since a Space-Data overlay is employed to support communications between participating nodes (either in Space or on Earth), a naming system should be devised to facilitate the configuration of each node. In this context, a Domain Name System, running on an administrative node, was developed to provide unique naming to each user/node having access to the Space-Data network and application.

The DNS Database containing information pertaining to the participating nodes is the main element of the DNS System. This database is stored on the administrative system and is exploited by the SDR administrative tools to create a configuration script for each participant accessing the Space-Data overlay. The contact name, IP address, Endpoint ID are the three important fields that allow for the unique naming of the nodes.

The following procedure is employed to populate the database: When an end-user or data provider node is requiring access for the first time to the space-data application, its IP address and its contact name, provided during the sign- up procedure, are transmitted via a web-service to the administrative node database. At the same time, an Endpoint-ID (EID) and passphrase are generated and transmitted to the database. Since the EID field is set as the database key, each node is uniquely characterised by it.

After the entry is inserted in the DNS database, the SDR administrative system, developed in WP5, authenticates the end-user credentials (EID and passphrase) and subsequently transmits the correct configuration files that sets up the protocol stacks, local storage locations, naming and routing.

Work package number	WP7	Type of activity	RTD
Work package title	Evaluation		
Start month	34		
End month	41		
Lead beneficiary number	5		

T7.1: The purpose of task T7.1 was to validate the capability of the Space-data routers to extend end user access to space data through communicating Ground Stations and Space Research Centers, increasing the connectivity with space assets will allow for faster and timely transfers. The NOAA AVHRR/MODIS scenario was selected as a reference scenario for this task.

A topology of 5 nodes, depicted in Figure 9, was employed for the needs of this scenario.

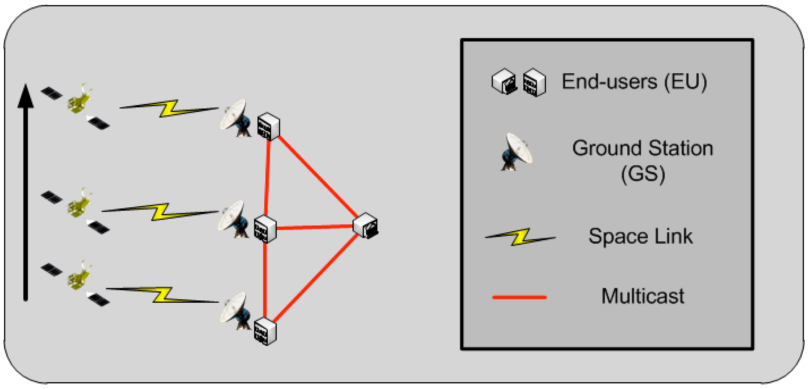

Figure 9. Topology used in task T7.1

Functionalities such as multicasting were evaluated in this scenario. This scenario showcased the network efficiency, resiliency in errors and data completeness offered by the Space-Data overlay.

T7.2: In this task, we evaluated the potential of exploiting data from deep space and disseminate it naturally through unified communication channels. Mars Express was used a basis for the scenario simulation of this task. Mars Express (MEx) is the European Space Agency's first spacecraft built to explore another planet.

The baseline scenario involved the transfer of space data from Mars Express to Earth, whereas an extended scenario with data generated by a Rover on the surface of mars was used to evaluate the Proximity-1 protocol, as well as the advanced routing mechanisms developed in the framework of the Space-Data Routers project.

These scenarios showcased the robustness and interoperability provided by the Space-Data overlay. In terms of scientific impact, the Space-Data overlay can provide increase scientific data volumes, reliability, elimination of scientific data loss and improved exploitation of large scientific data volumes.

T7.3: Task T7.3 evaluated the capability of Space-Data Routers to deliver efficiently to end users vast volumes of data over terrestrial internetworks. A scenario involving Cluster and Themis missions was employed in this case. 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. 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.

For the needs of this scenario, two different topologies were employed. More specifically, as simple topology involving spacecraft directly communicating with ground terminals saw used as a base scenario. A relay satellite was employed in the extended to scenario.

The SDR platform was able to overcome several episodes of complete loss of signal, with lost data being retransmitted until 100% of the dataset was successfully received in the ground. Furthermore, data were seamlessly relayed from Cluster to another satellite, with the latter having the responsibility to transfer data to Earth.

Resilience and routing flexibility were showcased through this scenario. Furthermore, the Space-Data overlay averaged a very high data transfer rate, taking into account the heavy networking load inflicted by the delivery of large volumes of data.

T7.4: During task 7.4, we evaluated the sufficiency of DTN Space-data overlays to administer thematic cross-mission space data. The Urban Heat Island scenario was used as a reference scenario for this objective. More specifically, this scenario involves the delivery of data of the same type generated by different missions. In particular, data from MSG-Seviri, MODIS and Landsat TM were used.

The web-application was used to filter the scientific data based on their metadata and deliver it to the end-user over the Space-Data overlay.

Work package number	WP8	Type of activity	OTHER
Work package title	Dissemination, Standardization and Exploitation Plans		
Start month	1		
End month	42		
Lead beneficiary number	4		

T8.1: The project website was made available to the public, in the address http://www.spacedatarouters.eu . The website was conceived to be simple and easy to browse. Information regarding the project, such as its objectives and technical descriptions is provided. Furthermore, the consortium working on the project and the main team from its partner are presented. Finally, the documents pertaining to the project are hosted and are easily accessible.

A major objective of this task was the Impact Creation Plan Report. In this deliverable a brief description of the project's partners was presented with emphasis on their individual dissemination plans as well as on their planned actions for exploitation.

The project progress was presented in the following events:

- Space Data Routers for Exploiting Space Data, ESAW 2011, Darmstadt, 10-11 May 2011, VEGA (M. Goetzelmann, Telespazio VEGA).
- Space Data Routers, Let's Embrace Space, Budapest, 12-13 May 2011, DUTH (V. Tsaoussidis, DUTH).
- Enhancing space data exploitation through advanced data routing protocols, The 10th Hellenic Astronomical Conference, 5-8 September 2011, Ioannina, NOA (A. Anastasiadis. NOA).
- Authenticated Key Exchange (AKE) in Delay Tolerant Networks‖ 27th IFIP International Information Security and Privacy Conference, Springer IFIP AICT, June 4, 2012, Heraklion, Greece (S. A. Menesidou, V. Katos, DUTH).
- Space Data Routers for the Exploitation of Space Data‖, 12th International Conference on Space Operations, June 12, 2012 Stockholm, Sweden (M. Götzelmann, V. Tsaoussidis, S. Diamantopoulos, I. A. Daglis, T. Amanatidis , B. Ghita, Telespazio VEGA, DUTH, NOA, SI, UOP).
- Space mission characteristics and requirements to be addressed by space-data router enhancement of space-data exploitation‖, 10th international conference on Wired/Wireless Internet Communication, June 06, 2012, Santorini, Greece (I. A. Daglis, O. Sykioti, A. Anastasiadis, G. Balasis, I. Keramitsoglou, D. Paronis, A. Rontogiannis, and S. Diamantopoulos, NOA, DUTH).
- DTN-tg A DTN Traffic Generator, 10th international conference on Wired/Wireless Internet Communication, June 06, 2012, Santorini, Greece (T. Amanatidis, A. Malkotsis. SI).
- Semi Markov Modeling for User Mobility in Urban Areas‖ 2nd Stochastic Modeling Techniques and Data Analysis International Conference (SMTDA 2012), June 8, 2012, Chania, Greece (A. Papadopoulou, L. Mamatas, and V. Tsaoussidis, DUTH).
- Participation of the SPACE EU Conference, and presentation of the project progress, February 28-29, 2012, Brussels, Belgium (S. Diamantopoulos, N. Bezirgiannidis, A. Malkotsis, DUTH, SI).
- A Novel Security Architecture for a Space-Data DTN, 10th international conference on Wired/Wireless Internet Communication, June 06, 2012, Santorini, Greece (B. Ghita, UOP).
- SPACE-DATA ROUTERS – Exploiting Space data for enhanced sharing of data from space missions , 2nd FP7 Space Conference, November 15, 2012, Larnaca, Cyprus (Nikolaos

Bezirgiannidis, DUTH)

- Presentation of the project in the Department of Electronic and Electrical Engineering, University College London, February 19 2013, London, UK (Anastasios Malkotsis, SI)
- Enhancing the characterization, understanding and forecasting of magnetospheric processes through advanced data routing protocols, IAGA General Assembly, Merida Yucatan Mexico, August 30 2013, (I.A. Daglis, NOA)
- Usage of DTN Space-Data overlays to administer Thematic Cross-mission space data, ESA living planet symposium 2013, Edinburg, September 9-13 2013 (D. Paronis, NOA)
- Towards Flexibility and Accuracy in Space DTN Communications, CHANTS 2013, September 30 2013, Miami, USA (Nikolaos Bezirgiannidis; Fani Tsapeli; Sotiris Diamantopoulos; Vassilis Tsaoussidis, DUTH)
- A DTN-based architecture for the dissemination of high volumes of space-data, NETSPACE Workshop, February 19 2014, Athens, Greece (Sotiris Diamantopoulos, DUTH)
- Presentation of technical work on the Space-Data Routers, NETSPACE Workshop, February 19 2014, Athens, Greece (Anastasios Malkotsis, SI)
- An application for the Discovery and Dissemination of Cross-Mission Space Data, NETSPACE Workshop, February 18 2014, Athens Greece (B. Ghita, M. Evans, UoP)
- Project presentation in the Department of Physics of Aristotle University of Thessaloniki, April 2 2014, Thessaloniki, Greece (Anastasios Malkotsis, SI)
- Presentation of project in Politechnica University of Bucharest, 10/4 – 15/4/2014, Bucharest, Romania (B. Ghita, UoP)
- Organization of splinter session titled “Space Data Routers: enhancing space-data exploitation” in the EGU assembly, Presentation of Project work, Vienna, Austria, April 30 2013 (SI)
- Presentation of Project work, EGU assembly, Vienna, Austria, April 30 2013 (Sotiris Diamantopoulos, DUTH)

T8.2: DUTH participated in standardization boards and bodies such as CCSDS. One example of such a board is the committee responsible for the Solar System Internetwork Architecture. Protocols and mechanisms developed in the framework of the Space-Data routers project have been proposed as standards in the IRTF and IETF.

T8.3: The exploitation plans were provided in deliverable D8.4.

T8.4: A summer seminar was hosted in DUTH in months May, June and September 2013. The seminar was attended by a large audience. Apart from an introduction in Space communications and space-data dissemination, hands-on experience with the software and hardware used in the framework of Space-Data Routers was provided. Assignments, dissertations and Master Theses related to the Space-Data Routers project were given throughout the project duration.

T8.5: Cooperation with CCSDS, ESA and NASA was seeked thoughout the project. Furthermore, frequent contact with other projects was established, as a means to exchange views and collaborate on providing the best available tools for the dissemination of space data.

4.1.4 Potential impact, main dissemination activities and exploitation of results

4.1.4.1 Potential impact

Strategic impact

Space Internetworking has the potential to boost space communication in a similar manner that Internet dominated communications on Earth. Furthermore, Space Internetworking has the potential to interoperate with the Internet and utilize the existing infrastructure for disseminating and exploiting space data that remains unexploited in Ground Segments for years. Space Research Centers and Academic Institutions are quite often unaware of existing data therefore lacking a significant advantage in producing scientific knowledge.

Scientific knowledge is the primary objective of all missions – therefore, the importance of disseminating and exploiting space data is self-justified.

Space Internetworking has gained significant momentum during the last couple of years: NASA, ESA and JAXA committed resources to CCSDS in order to standardize protocols and services; DTN was decided by CCSDS Management Council (CMCM) and Internet Architectural Board (IAB) to become the IP for space; Time magazine has listed DTN as one of the top ten future technologies; NASA has tested DTN in Spacecraft; ESA has funded the largest software project to create a DTN evaluation Testbed. The latter is undertaken by the group of the project coordinator, at DUTH. Note that Greece recognized the strategic importance of DTN for Greek Space Industries and has invested significant budget to design DTN protocols for space; and also schedules to commit more resources in the near future, in collaboration with ESA.

Simply-stated, our project will boost both mission scientific return as well as space internetworking capabilities for European Space Research Centers, Academic organisations and industries. That said, impact can be analyzed based on three different directions:

(i) Impact of Space-data dissemination and exploitation on mission scientific return

(ii) Impact of Space Internetworking on European Society, including research institutions, business entities, space organisations, European security and space exploration capacity, European scientists and citizens.

(iii) Impact of "Space-Data Routers" on Space Internetworking technology itself.

We analyze the three categories in detail below.

<u>Impact of Space-data dissemination and exploitation on mission scientific return</u>

Based on selected scenarios we show that our proposal will:

- extend end user access to space data through communicating Ground Stations and Space Research Centers.
- deliver efficiently to end users vast volumes of data over terrestrial internetworks.
- boost the potential of exploiting data from deep space and disseminate it naturally through unified communication channels.

- enhance the collaboration of Space Centers and Academic Institutions and allow them to administer thematically cross-mission space data

That said, science will benefit from exploiting existing space data, which in turn will increase reliability of scientific analyses as well as scientific capacity. Beyond that, science will benefit further in the future by exploiting and disseminating better data from deep space.

Impact of Space Internetworking on European Society

All major Space agencies are readying themselves for a significant transition to a new communication era, where virtual channels, reservation of communication slots and static management will be replaced with dynamic routing, flexibility of communication paths, and capacity for dynamic operations. What appears as a single change (i.e., traditional standards to IP-based communications) will have a domino effect on most communication and management activities for operations in Space. For example, Space communication time may reach a 24 x 7 objective; science data volume will increase, and end-user delivery architectures or processing capacity may become a real bottleneck.

- Impact on ESA leadership objective

Future Space missions may be collaborative large missions to exploit deep space, or missions and constellations to observe climatic changes, weather changes, fire alarms or assist other social but also defense objectives – for the benefit of European citizens. Space resources have also been proven one of the best financial investments worldwide, something which is reflected by the aggressive policies of several countries such as China and India to explore space. However, space resources are useful only if they are capable to pass information reliably on earth; and occasionally if they are capable of passing urgently and securely information on earth. Space internetworking services exactly that goal of reliability, security and connectivity. In this context, agencies with internetworking capabilities will be able to collaborate, share resources for mutual benefits, or even rent equipment to improve their financial capacity. In conclusion, ESA will gain a significant advantage, along with NASA, in the new era of Space exploration.

- Impact on Science and Research

The existing centralized architecture, the predetermined communication schedules and the limited capacity for data distribution worldwide, limits also the capacity of data processing. Indeed, a twofold problem has emerged:

6. (i) Space data may be lost or delayed: communication protocols currently use pre-scheduled virtual channels, and in several occasions, data requires retransmission. Consequently, data on the other end requires extensive storage with increased risk to overflow when schedules are violated due to extraordinary and unpredicted events. Furthermore, data transmission over single paths and for predetermined duration increases serial retransmission efforts, which impacts the total delay of delivery.

7. (ii) Volumes of Space data, especially science data, may remain unprocessed. The requirement for specific service protocols, along with the inflexible tunneling schemes to reach end users confines the possibility of flexible data processing by experts, educational institutes or organizations. Instead, it has led to a situation where also the end users are determined a priori

and, in the same context, dedicated to perform specific tasks. Several experts have limited or no access to important data.

- Impact on European Business

A new communication model that unifies space and earth communications triggers a number of changes and signals a new competition era for space industries. That is, new products will emerge for communicating, processing large volumes of data, observing space. Missions may become more ambitious and therefore this will be reflected on industrial products as well.

The new standards will allow for new business to emerge, similar to Space Internetworks, a partner in our consortium. Also, traditional networking industries may be involved in space communication protocols as well and exploit the already significant amount of space resources. By and large, the impact of space internetworking will be also significant on the amount of resources that each agency has in space; the more the resources the better the results. This will certainly boost the Space communication industrial sector significantly.

Impact of "Space-Data Routers" on Space Internetworking technology

"Space Routers" will have a dual impact on Space Internetworking technology. The proposed space router will demonstrate an architectural approach, which may be used as a reference to allow for more sophisticated future designs, contribution to standards, independent policies and security guarantees. The enhancement of the existing testbed will allow for creating a core but scalable dissemination infrastructure but also will allow for reliable evaluation and testing of new services and protocols, prior to adopting them for space operations; this will boost ESA capacity to invent new protocols and exploit new ideas.

- Architectural Impact

We expect a significant benefit for ESA. ESA has recently invested several hundreds of millions on new equipment for its communication infrastructure. Therefore, the transition to space-internetworked communication requires careful planning. ESA's architecture is centralized for a reason: the mission control centre in Darmstadt is the major gateway for most Space data. As such, it processes enormous amounts of data, forwards data to authorized entities, monitors operational status of tens of missions, commands devices in Space. In addition, the management schedule of operations is predetermined and strictly followed, reserving communication channels and resources long before the actual communication. The expected change will require a significant effort also for adapting their management strategies; not only their protocols. "Space-Data Routers" will invest on ESA's existing protocols such as TM/TC but also include policies to exploit appropriate management scenarios as well.

Besides the target benefit for accessing and delivering Space data to a wide range of authorized entities, "Space-Data Routers" will have a great impact on Earth communications as well. On board routing allows for flexible routing among Space devices and ground stations, which, in turn, allows for 24 x 7 communications with every location on Earth. That is, monitoring, controlling and information exchange becomes more reliable, flexible and cheaper; a development that has great consequences in emergency situations, rescue operations, disaster operations, but also in most scientific domains as well.

The convergence layers scheduled for this project will be used as a reference for further enhancements, providing potentially particular services and functions to connected layers; and the proposed architecture will allow for further optimization of protocol stacks, in connection with specific applications, space operations and space conditions and technological constraints. For example, the transport layer's functionality and architectural design depends on specific scenarios; whether or when an end-to-end service on top of the bundle layer is useful or not is currently in dispute. ESA will be able to optimize its own architecture considering factors such as the number of committed resources that could act as internetworking nodes, the cost and gains of resource sharing, the efficiency of internetworking in space etc. In conclusion, the architectural reference point that we propose here may also act as a tool for ESA to build their own policies and strategy.

Testbed Impact

Space missions are not the appropriate test-bed for new experiments. Instead, every single component in a mission requires extensive testing, prior to deployment.

That said, the lack of a reliable test-bed becomes a significant disadvantage. Hypothetical benefits and risks cannot really be verified or quantified. Our Testbed intends to bridge this gap, between expected and not-yet-predicted impact. It is not impossible, what appears as the most promising transition, to result in a failure not only to satisfy all the objectives but also basic requirements. No other similar dedicated and specialized test-bed exists in Europe, and efforts in the USA, China, India and Japan are still in the incubator; although the US has a clear-cut advantage.

The enhancement of the existing DTN/IP test-bed can promote future Internetworking protocols for Space and accelerate the transition to DTN or even IP, occasionally, allowing for:

spacecraft to act as "Internetworking nodes" seamless interoperability between Space and ground-base systems continuous connectivity

Despite its tremendous potential, the delivery of internetworking services poses considerable challenges and risks. Continuous connectivity allows the delivery of huge volumes of data, enforcing unparalleled buffering and processing requirements. Consider a Space entity that acquires and directly sends scientific data that should be delivered 100% reliably. Buffering all unacknowledged data (in order to provide reliability) calls for excessive memory requirements, as well as efficient buffering management techniques. The details of associated parameters cannot just be studied in theory.

Furthermore, various security mechanisms and services will be required to provide protection for data traversing Space devices that act as routing devices for several agencies. In contrast to current Space infrastructure, many nodes can be sponsored and controlled by multiple organizations (such as the Internet). We classify two aspects to security for Space networks: protection of the network infrastructure and protection of the data traversing the network. The protection of the infrastructure will be similar to the protection required for the Earth-based Internet infrastructure. There will be a need to exchange routing information securely among the nodes as well as to securely manage them. For the internetworking infrastructure to protect itself, all nodes can authenticate themselves to each other to ensure that they are not being spoofed by an untrustworthy entity. Security mechanisms are therefore required for both the Space infrastructure and the data flowing through it. We intend to exploit the capabilities to address all these limiting factors and investigate potential solutions that will facilitate the convergence of space and internet protocols.

4.1.4.2 Dissemination activities and exploitation results

The main dissemination activities carried out throughout the Space-Data Routers projects were the following:

- Setting up a project website with information on the project's consortium, scope, objectives, milestones and activities, and with easy access to public results.
- Developing and distribution of promotional material such as posters that were presented to space related conferences and workshops.
- Presentation of scientific and technical results at conferences and congresses. All partners promoted the results of the project participating in keynotes and panel discussions.
- Establishing relationships with research institutions working on related topics, and organizing joint events to achieve a mutual understanding of the solutions being developed and to explore possibilities for coordinated development efforts.
- Establishing contact with potential users of the knowledge and solutions developed by the project, and organizing events with these users to explore possibilities of knowledge transfer and valorization of solutions.
- Organising the NETSPACE workshop, to showcase the impact of Space-Data Routers
- Organising a splinter session in the EGU General Assembly
- Organising a Special Issue in Space Communications
- Hosting a summer school in DUTH, attracting the interest of a large audience

4.1.5 Project public website and relevant contact details

The project public website can be found in the address:
www.spacedatarouters.eu

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