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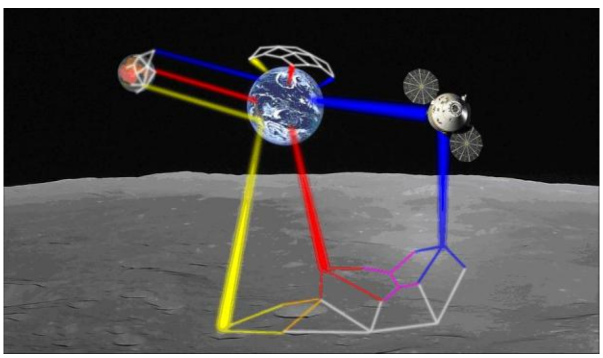
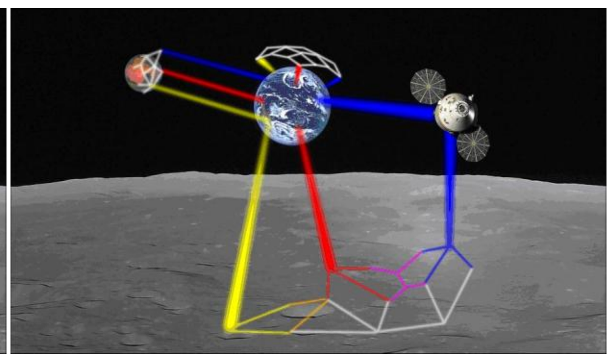
Interagency Operations Advisory Group
Space Internetworking Strategy Group

Solar System Internetwork (SSI) Issue Investigation and Resolution

01 August 2010





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1 Introduction

In the process of generating the Operations Concept for the Solar System Internetwork (SSI), the Space Internetworking Strategy Group (SISG) identified ten issues that required in-depth expert analysis. Work was allocated across eight SISG Issue Teams:

- **Issue 1 Team:** Define a complete set of Interagency Operations Advisory Group (IOAG) services, including SSI-recognized services.
- **Issues 2 and 3 Team:** Define the top level requirements for Service Management and Network Management.
- **Issue 4 Team:** Define the “last hop” delivery options.
- **Issue 5 Team:** Define the process for planning and disseminating contact plans and related coordination methodology.
- **Issues 6 and 8 Team:** Define the relationship between delay/disruption-aware (Delay/Disruption Tolerant Network [DTN]) and delay/disruption-unaware (Internet Protocol [IP]) operations and use the results to establish a set of operational requirements for the Consultative Committee for Space Data Systems (CCSDS) DTN Working Group.
- **Issue 7 Team:** Address on-demand communications services
- **Issue 9 Team:** Identify Figures of Merit (FOM) and analyze various space segment scenario alternatives to determine the best SSI evolutionary path.
- **Issue 10 Team:** Identify FOM and analyze potential ground support configurations to determine the best SSI evolutionary path.

The Issue 1 Team focused on the two Service Catalogs that describe the cross-support services that will be offered by the ground tracking assets operated by the IOAG member agencies. While IOAG Service Catalog #1 addresses current mission scenarios where access is provided to a single space/ground data link, IOAG Service Catalog #2 addresses in-space relay and network internetworking, i.e., DTN and/or IP technologies and other new upper layer services.

The Issue 2/3 Team examined the need for Network Management information exchange across agency boundaries in order to configure the SSI, as well as the Service Management interfaces by which users can express their communications requirements to the SSI providers. The team identified Network Management and Service Management requirements that can be provided to the CCSDS.

The Issue 4 Team studied how the SSI will handle services for spacecraft that need specialized link layer services, or that do not or cannot implement SSI user node functions. Typically these services include Link layer or Physical layer mechanisms at the edge of the SSI to support “last hop” communications with spacecraft in emergency or other unusual situations (such as Entry, Descent and Landing [EDL]), or with legacy spacecraft that do not have a Network layer capability.

The Issue 5 Team considered the mechanisms for planning and disseminating contact information; however, the team soon decided that this subject would be better addressed in Section 4.2 of the SSI Operations Concept document and consequently the team suspended the separate analysis.

The Issue 6/8 Team addressed concerns about operational requirements, with a particular focus on translating a set of European Space Agency (ESA)-generated requirements for file-based operations into an input to the Space Internetworking Systems Delay Tolerant Networking (SIS-DTN) working group within CCSDS (the group responsible for determining how essential operational issues will be handled in a DTN-based architecture). The SIS-DTN working group then incorporated many of these requirements into the CCSDS Green Book, which also defines how DTN and IP routing may be collaboratively used within the SSI.

The Issue 7 Team responded to a concern that on-demand communication services (i.e., scenarios in which a user node would autonomously make on-demand requests for network access) had not been adequately addressed. The overall finding is that such services can in fact be readily accommodated by the proposed SSI architecture and operations concept.

The Issue 9 Team primarily focused on the space mission options for alternative paths by which the IOAG agencies can evolve in the 2015-2020 time frame towards the envisioned, post-2020, fully internetworked end state. Using the 2016 and 2018 Mars missions as a case study, the team identified five options for consideration. A collection of stakeholders assessed these options using a set of agreed FOM. Two options emerged as the most highly ranked, with nearly identical scores. The first of these options represents the currently understood mission baseline, which scored well primarily due to cost and risk considerations. The other favored option is to augment the Electra relay payload with its own internal storage and a DTN protocol stack, while deploying a DTN network layer at the ground tracking station; this option scored well based on improved Quantity, Quality, Continuity, and Latency (QQCL) metrics, as well as the programmatic value of moving farthest towards the desired SSI end state.

The Issue 10 Team, again using the Mars 2016/18 missions as a reference, focused on determining the best ground support configuration to facilitate evolution towards the SSI in the case where missions may have a mix of legacy and DTN data streams that need to be multiplexed onto shared channels. The team examined six options: two NASA and ESA legacy configurations (Configurations 1 and 2); two configurations that adopt modified versions of Space Link Extension (SLE) forward and return packet services (Configurations 3 and 4); and two that adopt the new SLE/Cross Support Transfer Service (CSTS) forward frame service(s) that handle Advanced Orbital Systems (AOS) and Telecommand (TC) frame and frame multiplexing (Configurations 5 and 6). The study included development of two sets of FOM—one for technical issues and one for cost and risk. The team consensus was to select Configuration 5, which, while it increases Ground Station and provider costs, provides the most generality and extensibility and also has the least cost and complexity for both the Orbiter and the users.

All of these analyses are documented in the remainder of this report. The main sections of the document contain summary conclusions from each team, and the appendices contain detailed presentation materials that were used in the process of reaching team consensus. These Issue Team studies supported the development of the SSI Operations Concept, which is fully consistent with the results described in this document.

2 Issue 1: Define a Complete Set of IOAG Services, Including SSI-recognized Services

2.1 Overview

This IOAG Service Catalog #1 and Service Catalog #2 documents describe the cross-support services that will be provided by the ground tracking assets operated by the IOAG member agencies. Catalog #1 addresses current “near term” mission scenarios and Catalog #2 addresses the true SSI environment.

The two catalogs respond to the Interoperability Plenary (IOP)-2 recommendation seeking to “establish a common basis across the Agencies for the consolidation of ground-based cross support by 2011. Agencies should agree to implement IOAG recommendations for missions which may benefit from cross support and/or international cooperation. It is an IOAG goal to have a plurality of the participating Agencies capable of providing ground-based cross support of an agreed common IOAG Service catalog by the end of calendar year 2015.”

While IOAG Service Catalog #1 addresses the support of current mission scenarios, including the ground-based cross-support services currently available or envisaged in the short term, IOAG Service Catalog #2 addresses space communication services for in-space relay and network cross-support scenarios that would enable future Solar System Internetworking; i.e., Catalog #2 comprises typically DTN and/or IP technologies.

The IOAG approved Service Catalog #1 at the beginning of 2010 and expects to finalize IOAG Service Catalog #2 by the end of the same year.

2.2 Technical Discussion: Service Catalog #1

Catalog #1 includes the ground-based cross-support services currently available or envisaged in the short term for supporting the (simple) scenario described in Figure 2-1. Such a scenario is sometimes referred to as an ABA scenario to show that an Agency B is providing services to an Agency A Control Center for accessing an Agency A spacecraft.

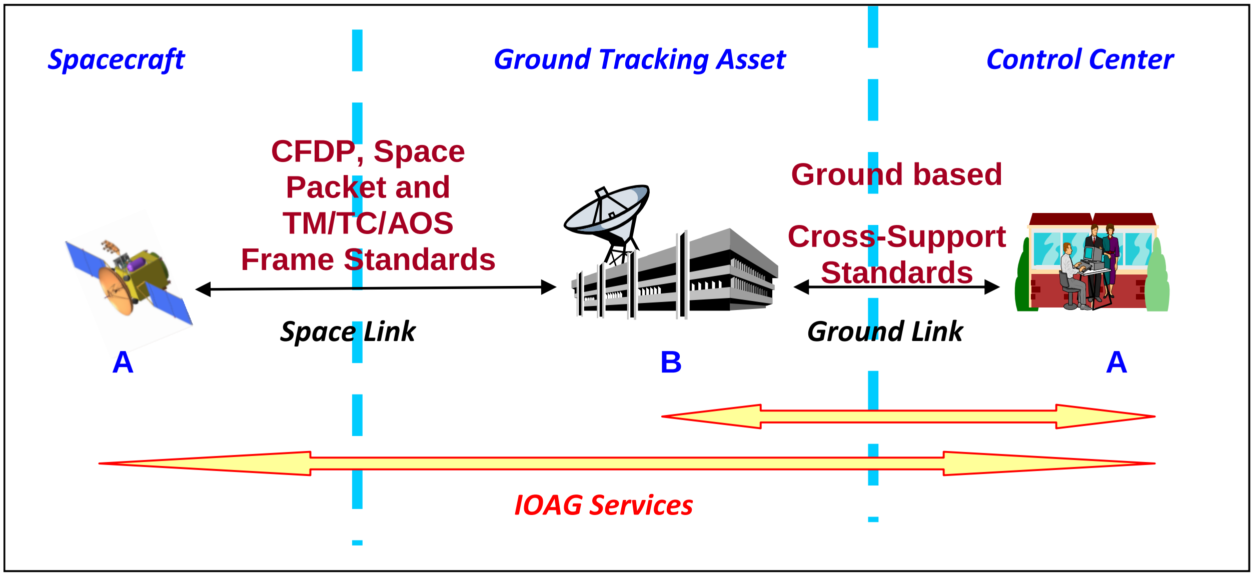

Figure 2-1: ABA Scenario for Service Catalog #1

IOAG Service Catalog #1 is structured into "core" and "extended" services, with the understanding that "core" services will be implemented by all IOAG Agencies, while "extended" services will be considered for bilateral cross supports.

Given that an IOAG Service can be built on top of a number of combinations of Space Link Interface standards and Ground Link Interface standards, the issue team identified groups of IOAG services within Catalog #1. Each group includes several service types for which the applicable standards have also been identified. Some of those standards are "to be written" and the IOAG will provide input/requests to the CCSDS as needed.

The Service Groups included in Catalog #1 are:

- Forward Data Delivery Services Group: these services allow transfer of data from a control center to a spacecraft
- Return Data Delivery Services Group: these services allow transfer of data from a spacecraft to a control center.
- Radio Metric Services Group: these services allow the results of radio metric measurements to be provided to a control center

IOAG Service Catalog #1 has identified the following IOAG "core" services (the relevant implied core Ground Link Interface standards appear in parentheses):

- Forward Communications Link Transmission Unit (CLTU) Service (SLE Forward CLTU)
- Return All Frames Service (SLE Return All Frames)
- Return Channel Frames Service (SLE Return Channel Frames)
- Validated Data Radio Metric Service (CSTS Offline Radio Metric, over CSTS Transfer File)

IOAG Service Catalog #1 has identified also the following IOAG "extended" services (implied standards appear in parentheses):

- Forward Space Packet Service (SLE Forward Space Packet)
- Forward Synchronous Encoded Frame Service (SLE Forward Synchronous Encoded Frame)
- Forward File Service (CSTS Forward File Service, over CSTS Transfer File)
- Return Operational Control Field (OCF) Service (SLE Return OCF)
- Return Unframed Telemetry Service (CSTS Return Unframed Telemetry)
- Return File Service (CSTS Return File, over CSTS Transfer File)
- Raw Data Radio Metric Service (CSTS Real Time Radio Metric)
- Delta DOR (Differential One-Way Ranging) Service (CSTS D-DOR pre-correlation Data, over CSTS Transfer File)

In addition, Service Catalog #1 defines Service Management functions, which allow for interaction between the space agencies to coordinate the provision of the above space communications and radio metric services. Moreover, these functions allow the results of radio link status to be provided to a control center.

Services provided by an IOAG member agency are requested and controlled via standard service management functions. Service management by itself is not a service. It is a function performed cooperatively by both the tracking network (on the service provider's side) and the mission operations center (on the service user's side).

IOAG Service Catalog #1 also describes one Link Monitoring function—Engineering Monitoring Data Delivery (CSTS Engineering Data Monitoring). This function will allow a Control Center to receive data regarding the status of the space link between a Ground Tracking Asset and a remote spacecraft. Such monitoring data are not limited to the status of the space link; they may also include information about the status and/or processing of the equipment at the Ground Tracking Asset.

2.3 Technical Discussion: Service Catalog #2

The IOAG Catalog #2 identifies the cross-support service types to be provided by the ground tracking assets operated by the IOAG member agencies in the SSI scenarios comprising typically DTN and/or IP technologies. A typical scenario for Catalog #2 considers services provided to the Agency A Control Center for accessing an Agency A Spacecraft (Lander or Orbiter) through a Ground Tracking Asset and a set of Spacecraft (Orbiters and/or Landers) possibly belonging to various agencies.

IOAG Service Catalog #2 complements IOAG Service Catalog #1 in the sense that Services defined in Catalog #1 can be regarded as a subset of Catalog #2, with the understanding that the applicability of IOAG Catalog #1 Services is limited to the ABA scenario described in Figure 2-1. I.e., in ABA scenarios Agencies can use all IOAG Services defined in Catalog #1, in addition to all the services defined in Catalog #2.

A typical scenario for Catalog #2 is shown in Figure 2-2, where a Lander belonging to Agency A is accessed by its Lander Control Center through an Agency B Orbiter Control Center using an Agency C Ground Tracking Asset communicating with the Orbiter belonging to Agency B. Catalog #2 also considers that in the future, more complex communications topologies are expected to evolve, encompassing more intermediate nodes, thus offering alternate communication paths.

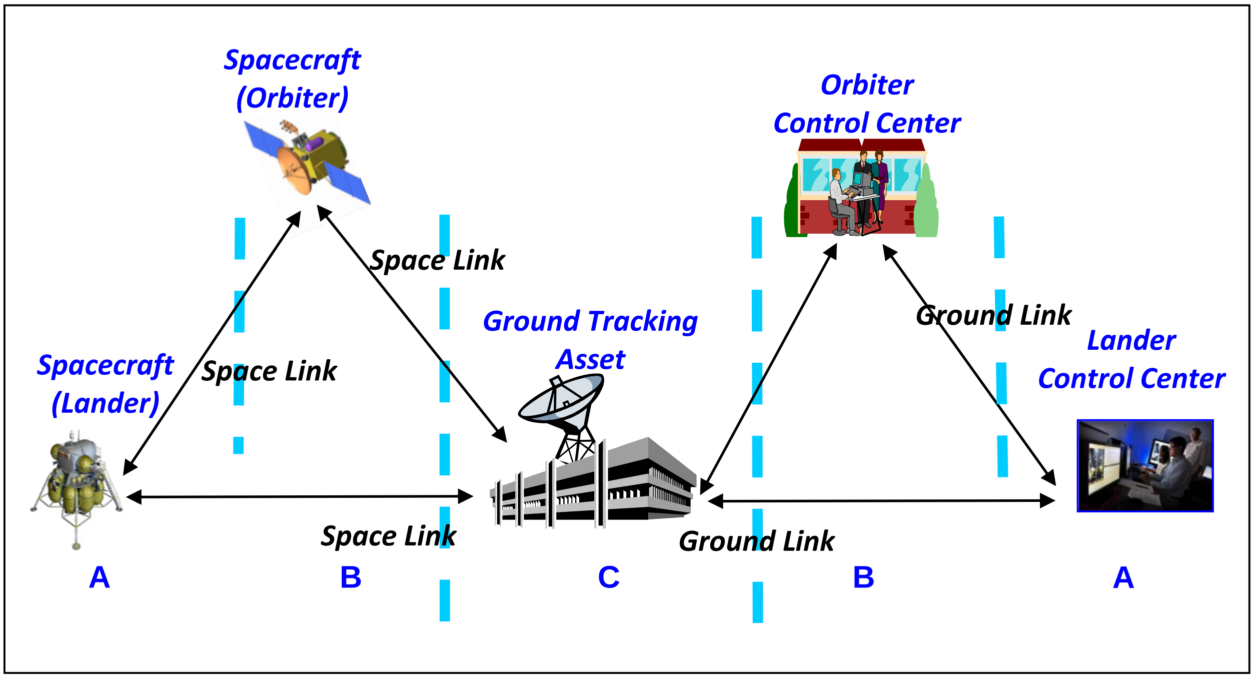

Figure 2-2: Example ABCBA Scenario for Service Catalog #2

In addition to the Service Groups defined in Catalog #1 (i.e., Forward Data Delivery Services Group, Return Data Delivery Services Group, and Radio Metric Services Group) IOAG Catalog #2 also includes:

- Time Services Group: these services allow the calculation of time correlation elements and synchronization by means of time distribution

IOAG Service Catalog #2 has identified the following IOAG services with their relevant implied Ground Link Interface standards.

- Forward Internetworking for DTN
- Forward Internetworking for IP
- Forward Last Hop Delivery
- Return Internetworking for DTN
- Return Internetworking for IP
- Return First Hop Delivery
- Time Synchronization Service

The issue team's analysis showed that, in general, only DTN and IP communication capabilities would be sufficient to support the above IOAG Services in an "ideal SSI" environment. However, for cases of mixed topology (e.g., non-DTN-enabled nodes present together with DTN-enabled nodes), a CCSDS Delivery Agent for First/Last Hop applications and a limited set of Ground Link Interface standards are still needed, in addition to the DTN and/or IP protocol suites. The Ground Link Interface standards required by Catalog #2 are:

- CSTS Forward Frame Service
- SLE Return Channel Frames
- CSTS Forward File Service
- CSTS Return File Service

The above mentioned file services take care of file transfer between a ground tracking asset and a CCSDS last/first hop Delivery Agent. Once the SSI is established, additional forward and return applications, such as CCSDS File Delivery Protocol (CFDP) and Asynchronous Message Service (AMS), can run on top of the Forward/Return Internetworking Services for either DTN or IP in a way that is actually invisible to intermediate SSI nodes.

Although Catalog #2 does not add any new IOAG radio metric services, the Last/First Hop Delivery Service in Catalog #2 can provide radio metric services that were not possible in Catalog #1 (i.e., Open Loop Recording, and Proximity-1 radio metric data [Doppler and range]).

Proximity-1 Timing Services may also be provided via First/Last Hop Delivery Services.

Conversely, the IOAG Time Synchronization Service will allow aligning clocks to a common timescale, thanks to clock correlation and time transfer activities.

The introduction in Catalog #2 of space communication services for in-space relay and networked cross-support scenarios creates a number of new requirements on the CCSDS Cross Support Service Management Specification that have been identified for eventual standardization by CCSDS. There are also new requirements for mechanisms to be used to convey SSI network management information to the objects in space that need to be managed. Moreover, DTN networks will consist of a combination of "connected systems with wide-bandwidth, low-delay links" and "disconnected systems with low-bandwidth, noisy, and perhaps long-delay links," thus DTN network management will be more complex than managing a connected system.

The SISG decided that, in the networked environment covered by Service Catalog #2, the term Service Management and its scope are (conventionally) limited to the management of the service provisioning and to providing the control needed to ensure that the relevant SSI nodes interact as needed to enable the service provisioning. Conversely, the aspects related to the management of the SSI Network (i.e., those related to the [DTN-S] protocol suite and those related to network schedule information) are controlled by SSI Network Management functions responsible for the management of the SSI Network layer entities.

Service Catalog #2 identifies two main classes, and therefore two functions, related to the management of the SSI Network:

1. the configuration of DTN parameters that are properly a part of the DTN protocol suite, and
2. the configuration of parameters concerning planning and opportunities for carrying out the DTN communications.

These two functions are addressed by Bundle Protocol (BP) Network Management and SSI Contact Planning.

In addition, the SSI network also includes IP nodes, which will need to be configured and properly managed too. However, it is assumed that the management of the IP nodes will be carried out by standard means not relevant for cross support, and therefore management of IP nodes is not explicitly addressed in Catalog #2.

2.4 Team Membership

Team Lead: Gian Paolo Calzolari (ESA/ESOC)

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3 Issues 2 and 3: Define Top Level Requirements for Service Management and Network Management

3.1 Overview

The service provided by the SSI to users is delivery of application data units according to their requested qualities of service, using the protocol mechanisms that are part of the SSI. To that end, the SSI will include a network layer communications infrastructure consisting of nodes that execute store-and-forward routing and the links that connect them. The SSI will use link-layer connectivity service, and the knowledge of that connectivity as a function of time will be used to configure time-aware forwarding, such as Contact Graph Routing. Within the SSI an individual data transfer on a given link will be accomplished by local decisions and automatic actions taken on the SSI nodes, rather than by means of 'manual' configuration commanded remotely. The nodes will act in accordance with policies and rules agreed for mission operations. In other words, network management will provide direction, rather than manage each and every individual data transfer. There will be times when particular links are underutilized and times when they are oversubscribed.

Although the nodes forming the SSI will, in general, be provided by different agencies, no requirement for one agency to be able to use network management to command another agency's assets has been identified. Therefore, source and destination of management interactions will be within one agency, but the flow of such management requests may well be through spacecraft or other types of SSI nodes of other agencies. Nonetheless, there will be a need for network management information exchange across agency boundaries; i.e., interoperable network management achieved by means of common network management/reporting protocols.

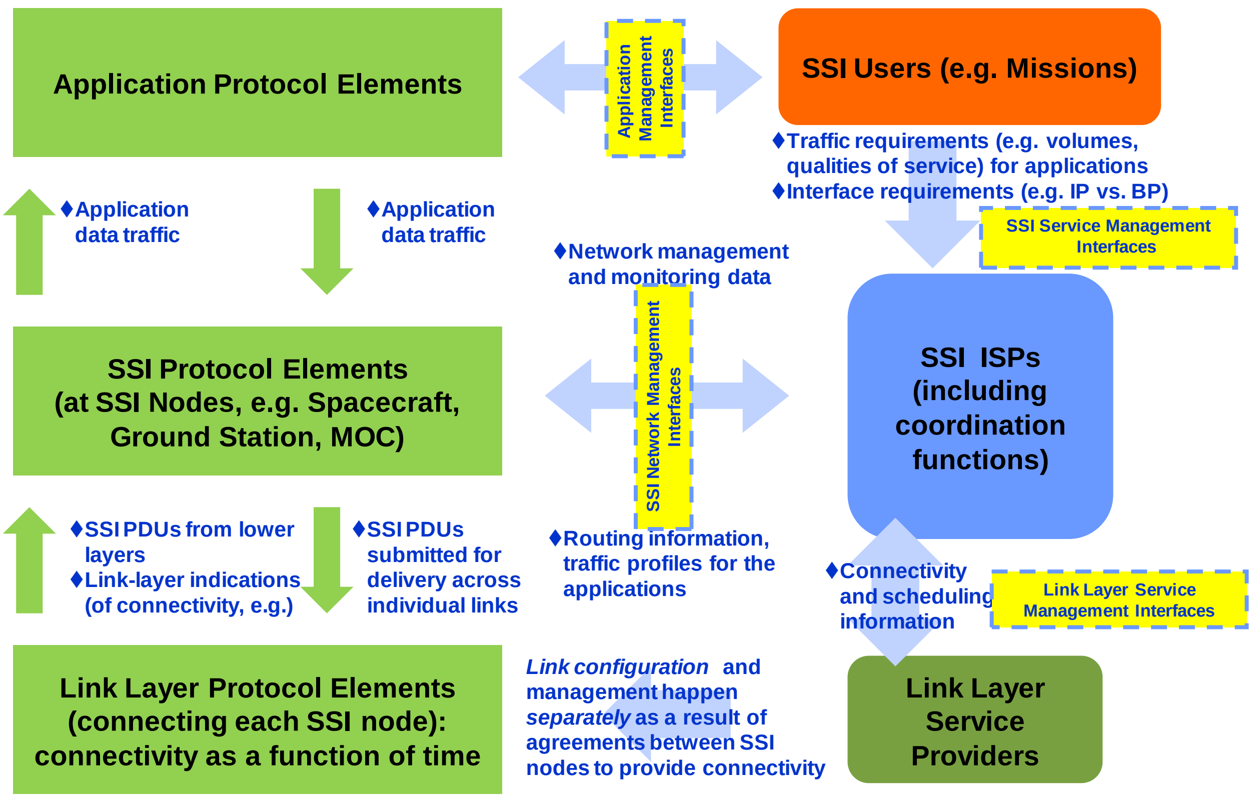

Figure 3-1: SSI Service Interfaces

The left side of Figure 3-1 illustrates the SSI communications protocol stack proper and the flow of Protocol Data Units (PDUs), while the right side depicts the entities involved in configuring and monitoring the SSI. Missions (i.e., SSI Users) have requirements for communications in terms of type of data (commanding, telemetry), frequency of contact, total bandwidth, etc. The User Mission Operation Centers (MOCs) not only control the spacecraft, but also communicate via the SSI Service Management interface communications requirements on behalf of their missions to their agencies' SSI Internet Service Providers (SSI-ISPs[1]), a process that resembles today's user loading profile assessment performed jointly by ground station providers and their client missions. The SSI-ISPs are administrative entities, typically one per agency, that serve as the management interfaces between missions and the SSI. They interact with other SSI-ISPs to negotiate the communication (link) schedules that provide the 'raw material' that the SSI builds on to provide a communications infrastructure.

SSI Providers will coordinate with their agencies' SSI-ISPs to provide communications services to missions (e.g., Tracking, Telemetry, and Command (TT&C) networks, relay spacecraft). A given

[1] The role of the SSI-ISP as an administrative and managing entity is similar to that of an Internet Service Provider (ISP) in the terrestrial Internet. The SSI-ISP is NOT a cross-support transfer service provider within the SSI, but administers the SSI nodes that in turn provide such services.

element, such as a spacecraft with data relaying capability, may act both as SSI User and SSI Provider elements, the latter depending on particular resources like position, mission phase, power, storage capacity, etc.

3.2 Technical Discussion: Service Management

Service Management in the SSI refers to the 'configuration' aspect of the underlying services (connectivity) used to construct the SSI. Missions and SSI-ISPs will work together using the SSI Service Management Interface to establish the underlying connectivity and nominal routing plan. The network layer protocol to be used (i.e., the mode of operation that will apply) will be primarily determined according to the round-trip delay and persistency of the connectivity between the end nodes, the percentage of data loss the higher layer protocols and/or applications can tolerate, the directionality needed (e.g., conversational vs. asynchronous), and the required Quality of Service (QoS) (e.g., in terms of jitter, latency, throughput, or goodput). Different applications (voice, video, data) will, in general, have different requirements for each of the boundary conditions. The key role of Service Management will be to capture the application requirements and to inject them into the SSI planning process.

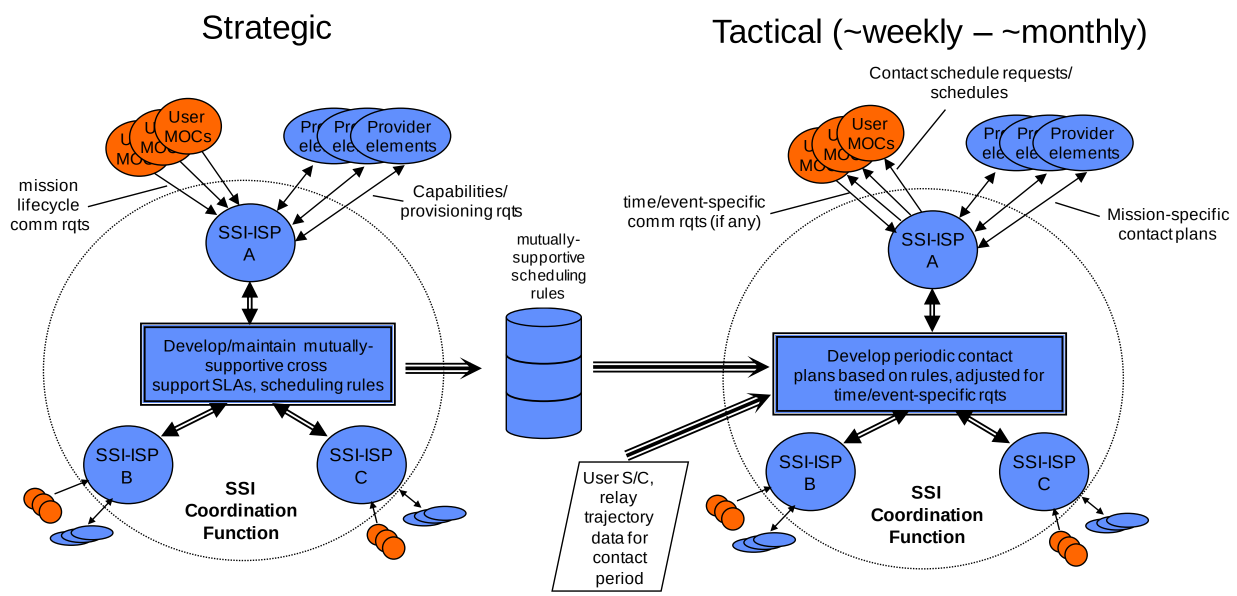

Figure 3-2: SSI Configuration Process

Figure 3-2 illustrates the SSI planning cycle. The Agency A SSI-ISP will collect the long-term (strategic) communications requirements of the Agency A missions and will have knowledge of the Agency A assets' provisioning capabilities. If the mission requirements cannot be satisfied using the Agency A resources, the SSI-ISP will enter into negotiation with other agencies' SSI-ISPs to develop a set of mutually supportive peering Service Level Agreements (SLAs) and a set of mutually supportive scheduling rules that will satisfy the SLAs. Different fields of exploration entail different mission families that will be looked after by different groups, which may be dealt with more easily by one SSI-ISP per mission family. There are shared resources that must be factored into the planning process, however, and this coordination function is assumed to be performed at the agency level.

Months or weeks ahead of the actual service provisioning (when, for example, the geometrical and operational constraints regarding the feasibility of the various links are known sufficiently well) the tactical planning will be performed on the basis of the scheduling rules, refined contact requirements, and refined asset availability information. From this process the contact plan will be derived where it is assumed that the input data are globally available, but each SSI-ISP will manage the resources for which it is responsible. Some constraints may require SSI-ISPs to enter into negotiations with other SSI-ISPs as to resolve resource conflicts.

For more details on the SSI service management definition, refer to the slides in Appendix B.

3.3 Technical Discussion: Network Management

3.3.1 Capability/Authority and Needs of SSI Providers

Providers of SSI services (e.g., ground stations and relay spacecraft) will interact with their agencies' SSI-ISPs to maintain a notion of what connectivity is possible, both with other missions in the same agency and with missions from other agencies. SSI providers will be able to enter into agreements with their agencies' SSI-ISPs to provision link-layer connectivity with other SSI nodes. The provisioning of connectivity with nodes of another agency will imply an inter-SSI-ISP agreement. Providers will not be 'controlled by' the SSI, except via whatever interactions between the mission and the SSI are mandated by the mission's agency within the scope of the agreed cross-support service provisioning.

SSI-ISPs (as to enable the provision of SSI services) will be able to enter into agreements with missions in their agencies and with other SSI-ISPs primarily according to the coarse-grained configuration of the SSI as a whole, as SSI routing will have to be set up to meet the communication needs of the missions. SSI-ISPs will form a federated community of interest with no central management or ownership. SSI-ISPs will work with their missions to effect the agreed-to configuration.

Providers of SSI services will need to know the agreed-to SSI configuration (connectivity, routing, etc.) to manage physical connectivity according to the configuration. SSI-ISPs (as the administrators of the SSI service providers) will need to know the agreed-to SSI configuration (connectivity, routing, etc.), the application communication requirements, and the possible connectivity among SSI nodes (to explore new possible configurations).

3.3.2 Capabilities and Needs of SSI Users

Users of SSI services (e.g., rovers, spacecraft, rover MOCs) will interact with their agencies' SSI-ISPs to communicate their communication requirements, and will be able to transmit and receive data according to the negotiated traffic profile (i.e., constraints on data rates and qualities of service as a function of time). Over-profile data traffic may be reprioritized (shaped) by the SSI.

3.3.3 SSI Network Management Functions and Capabilities

Network Management functions that will also be applicable in the SSI context are often summarized as Fault, Configuration, Accounting, Performance, and Security (FCAPS):

- Fault detection and reporting
- Configuration, such as router ID, convergence layer adapter parameters, routing protocols and parameters (including static routes as a special case), etc.
- Accounting, e.g., numbers of bundles sent and received; forwarded, possibly per (source, destination); number and nature of security faults. In cases where a given link is exclusively reserved for use by a given mission (e.g., last hop to a landed asset), accounting may be based on time rather than data volume
- Performance, such as monitoring of the number of times transmissions were interrupted, throughput/goodput of links, etc.
- Security with the associated parameter settings

As part of its capabilities, SSI Network Management will:

- Collect relevant management information based on schedule, on exception (alarm) or response to a query
- Modify particular management information items
- List, suspend, resume, reprioritize, terminate Bundles at a given node
- Modify Convergence Layer Adapter (CLA) parameters as appropriate
- Modify routing/forwarding protocol parameters as appropriate, e.g., insert static routes or modify Contact Graph Routing information

The SSI needs to offer users the means to accommodate and recover from certain unplanned events, such as a spacecraft safe mode. In many cases, the inherent flexibility offered by SSI dynamic routing capability in combination with appropriate priority/QoS assigned to different concurrent data flows may respond well and rapidly enough. The richer the available connectivity is, the less such events will require preparation of special recovery configurations in advance. However, as long as data relaying is provided by secondary payloads of planetary orbiters, missions may require a backup communications scenario that is preplanned and can be invoked on short notice if the need arises (as was done for instance for Mars Express [MEX] in support of Phoenix). The preparation of such a backup scenario can be part of the SLAs negotiated between SSI-ISPs. The SLAs should also document how and by whom the backup communications scenario can be invoked.

In case of temporary outage of certain resources (e.g., relay spacecraft temporarily in safe mode) the inherent flexibility of the SSI in combination with priority of traffic is expected to accommodate the invocation of such a backup scenario without requiring a regeneration of the SSI contact plan. A more disastrous failure, like extended outage or even permanent loss of certain resources, will require extensive re-planning. Even in such cases, however, the SSI will behave more gracefully than the topologies in use today, as nodes in the neighborhood of the lost asset can make local decisions on how to best forward the 'stranded' data even before a new contact plan is in place.

Whenever it is possible to generate and distribute a revised contact plan in response to outages, it will be advantageous to do so. It should be noted that it will be sufficient to re-plan around the outage, but not end-to-end. However, even in scenarios where such re-planning is not feasible, the SSI will provide a gracefully degraded service due to its capability to better use alternative assets, as all assets are interconnected by interoperable, standardized network protocols. Resources will, of course, be finite, and therefore in such cases low priority bundles may get discarded.

For more details on the SSI network management definition, refer to the slides in Appendix B.

3.4 Team Membership

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4 Issue 4: Define Last Hop Delivery Options

4.1 Overview

The SISG charted the Issue 4 team to determine how the SSI will handle services for spacecraft that do not or cannot implement SSI user node functions. Although the SSI provides network layer services, it must be capable of enabling such link layer (or even physical layer) services for spacecraft in emergency situations or legacy spacecraft. Ultimately, the study team determined that the SSI will deliver the necessary data to a "Delivery Agent" application on the penultimate node, and that application will perform the necessary link or physical layer operations to deliver the commands to the target spacecraft.

To enable this service, the MOC of the target mission must embed the required link layer data structures (packets or frames) into a file, along with the necessary link configuration and delivery information. The SSI will transport this data as usual, until they are delivered to the specialized application running on the Relay Spacecraft. The Delivery Agent application will accept the data to be delivered and the associated instructions, and perform the necessary link configuration and data delivery services at the requested time.

The Proximity-1 protocol will be typically used between the Relay Spacecraft and the end user spacecraft. Proximity-1 will support the direct transmission of space packets between the Relay Spacecraft and the target spacecraft, but frames or other data structures (e.g., Bose-Chaudhuri-Hocquenghem [BCH] encoded TC frames) may also be transferred over reliable bitstream (User Defined Data [UDD]). The delivery instructions will state how the link is to be configured, how the data are to be extracted and sent (packets, frames), when the data are to be sent, how often, and under what conditions this transmission is to be terminated.

A similar return service will also be implemented by a Delivery Agent application on the Relay Spacecraft. As with the forward service, this application will accept a service request instructing it how to configure the proximity link radio, what data to capture, and when to record the data. The application will place the resulting data set in a file, along with a report of what was done and its success or failure, and then send it, using SSI services, back to the user. These return services may deliver essential telemetry, open loop sampled data from the radio frequency (RF) link itself, and timing or radiometric data from Proximity-1.

4.2 Technical Discussion

The SISG study team's intent was not to fully specify all of the technical elements of the architecture, rather, it was to define the abstract concepts, architecture, and assumptions completely enough to enable the CCSDS to develop the necessary technical architecture and standards. In the abstract, the "last-hop" service would be configured as shown in Figure 4-1.

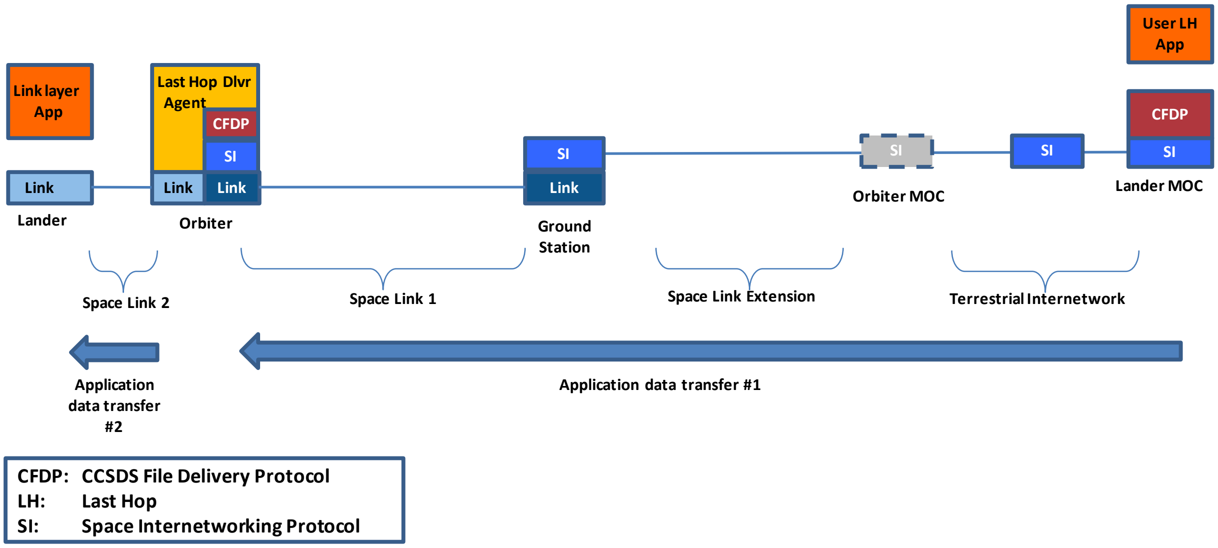

Figure 4-1: Nominal End-to-End "Last Hop" Configuration

The user (Lander MOC) will develop the Forward Delivery Package that contains the required commands for the Lander Spacecraft using the User Last Hop (LH) Application. The implementation of this application will not be standardized, but the format and structure of the Forward Delivery Package that it must construct will be. The file will then be shipped, using standard CCSDS File Delivery Protocol (CFDP) running over Space Internetworking protocols (IP or DTN) to the Orbiter. On the Orbiter another standardized application called the Last Hop Delivery Agent will accept this file and perform the necessary link layer delivery operations.

Figure 4-2 provides an abstract view of the contents of the Forward Delivery Package, which has three major elements:

1. Instructions on when to provide the service (if required), how to extract data (description of the data structures), how to deliver the data (once, continuously, etc.), and when to terminate (number of retries, time out, signal, etc.)
2. The Proximity link service management parameters describing how to configure the "last-hop" link (UDD or packet service access point [SAP]), data rate, channel
3. The data to be delivered (TC frames, BCH code blocks, space packets, AOS frames or other well defined link artifacts)

Figure 4-2 shows these data elements in one master file; however, the CCSDS will determine whether to use single or multiple files. The study team also assumed that the proximity link service management should utilize the concepts and terminology in the existing standard link layer Service Management specifications to the greatest extent possible.

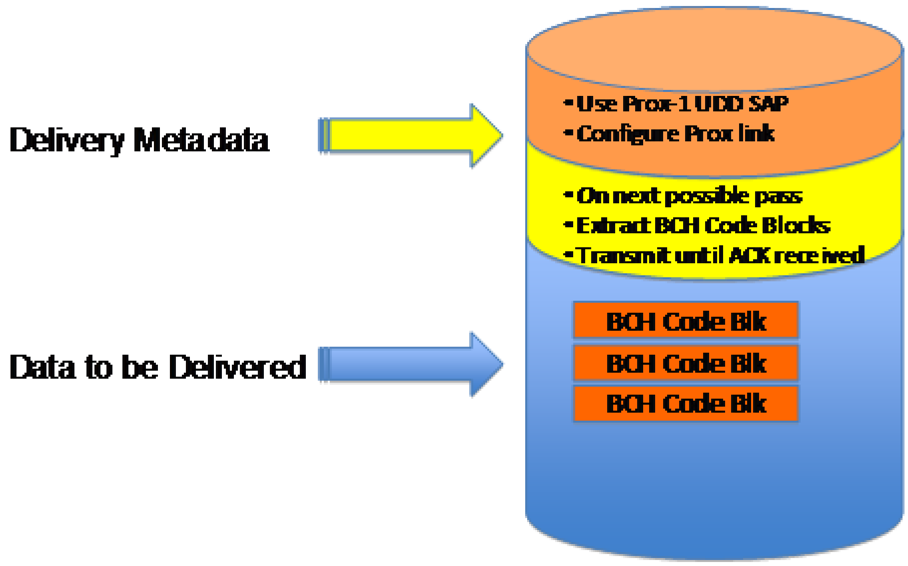

Figure 4-2: Nominal Structure of the Forward Delivery Package

For the corresponding Return Delivery Package, only the service request elements are sent to the Orbiter, and the return file includes the captured data and descriptive information relating to the delivered service.

This last-hop concept is specifically defined to operate in the SSI context, but it also may be applied where the SSI has not yet been deployed. The service, itself, is only bound directly at two points: the Delivery Package syntax and semantics, and the functionality delivered across the last-hop proximity link. Figure 4-3 shows a configuration that utilizes a legacy Orbiter to deliver the service. In this deployment the Last Hop Delivery Agent might be implemented entirely on the Orbiter, if it is possible to upload this new functionality. More typically, for legacy Orbiters, the interpretation of the Delivery Package will be done within the Orbiter MOC, and then discrete commands for the spacecraft and the radio will be sent from the Orbiter MOC to the Orbiter to properly configure the radio and perform the service.

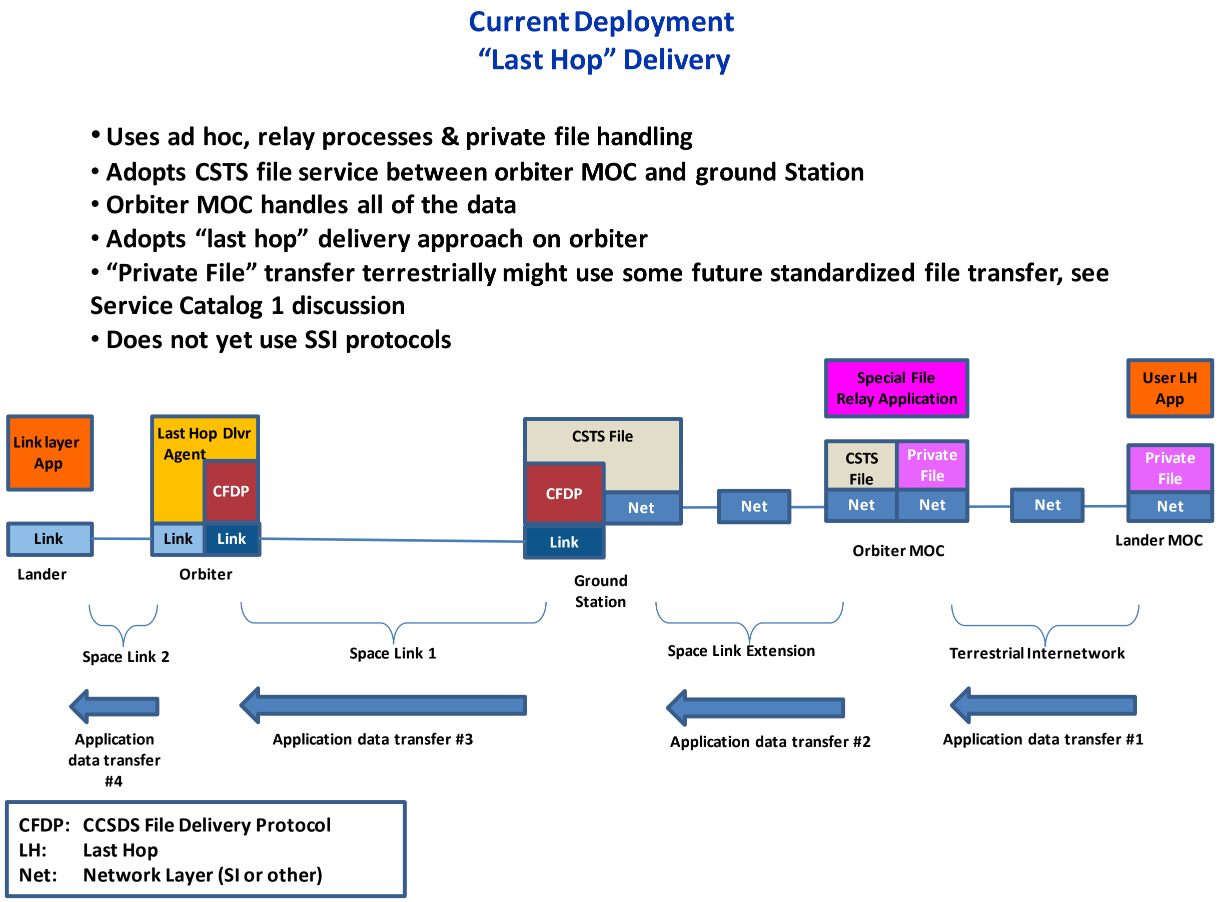

Figure 4-3: Legacy Orbiter Delivering Last Hop Service

For more details on the intended design of the service, the return services, and the underlying assumptions, please refer to the slides in Appendix C.

4.3 Team Membership

Team lead: Peter Shames (NASA/JPL)

Team members: Gian Paolo Calzolari (ESA/ESOC), Wolfgang Hell (ESA/ESOC), Chris Taylor (ESA/ESTEC)

5 Issue 5: Define Process for Planning and Disseminating Contact Plan and Related Coordination Methodology

5.1 Overview

At the September 2009 SISG meeting, the following issue was identified for study: Define process for planning and disseminating contact plan and related coordination methodology.

The assignees for this study (M. Denis and C. Edwards) determined that this issue was central to the overall SSI concept of operations and, as such, was already being addressed in detail within the *Operations Concept for a Solar System Internetwork* document, which was in preparation at that time under the auspices of the SISG. A detailed discussion of the SSI contact planning process can be found in Section 4.2 of that document. Accordingly, at its November 2009 meeting, the SISG determined this issue to be closed.

6 Issue 6: Integrate Delay/disruption-aware (DTN) and Delay/disruption-unaware (IP) Applications and Issue 8: Define Operational Requirements for CCSDS DTN Working Group

6.1 Overview

The SISG created Issue 8 (Define operational requirements for CCSDS DTN working group) to ensure that the CCSDS SIS-DTN working group would adequately address SISG concerns about operational requirements. ESA put considerable work into generating a set of requirements for file-based operations and wanted to ensure that the essential operational issues involved would also be addressed by the Delay/Disruption Tolerant Networking protocol suite being developed by the DTN working group. The issue was slightly complicated by the fact that the CCSDS DTN working group was already underway in anticipation of the IOAG/SISG needs and in advance of the final operational concepts and architecture being provided to CCSDS from the SISG.

To address Issue 8, the SISG provided a list of ESA-developed requirements for file-based operations (FBO) to the SIS-DTN working group for incorporation into the working group's rationale document (Green Book) Rationale, Scenarios, and Requirements for DTN in Space. The working group considered and dispositioned these requirements, incorporating many of them into the Green Book.

While incorporating the SISG's FBO requirements into the Green Book, the CCSDS SIS-DTN working group simultaneously addressed SISG Issue 6 (Integrate delay/disruption-aware [DTN] and delay/disruption-unaware [IP] applications).

6.2 Technical Discussion

6.2.1 Issue 8: Define Operational Requirements for CCSDS DTN Working Group

The ESA FBO requirements provided by the SISG to the SIS-DTN working group represented the beginnings of work on an architecture for multi-hop space communications using file transfer (possibly as provided by the CCSDS File Delivery Protocol, CFDP and including the CFDP 'multi-hop' extensions) as the basic network operation. The requirements represented a holistic or unified approach to space mission operation, including application-layer (in particular, file transfer), transport-layer, and network-layer functionalities.

Before forwarding the FBO requirements to the CCSDS group, the SISG issue team reviewed them and identified those requirements that are applicable in an internetworking context. For example, many of the FBO requirements dealing specifically with file manipulations, while reasonable requirements for mission operations, are application-layer requirements and are consequently beyond the scope of the SIS-DTN group.

The SIS-DTN's dispositions of the FBO requirements fell into the following categories:

- Incorporation of the requirement into the SIS-DTN Green Book, with the caveat that many of the requirements applied to a full architecture/protocol suite and not necessarily to the space internetworking layer (i.e., that the scope of the requirements was broader than just the internetworking layer)
- Assertion that the requirement was redundant with other FBO requirements or was a 'negative requirement' (e.g., there is no requirement for autonomous route discovery)
- Assertion that the requirement, while applicable to spacecraft operations, was not a valid requirement on the space internetworking layer

The SIS-DTN working group discussed these dispositions with the SISG via email and by virtue of SISG member presence at the Spring CCSDS Meetings in Noordwijk, Netherlands. Table 6-1 summarizes the dispositions:

18 General Requirements	12 adopted; 2 asserted redundant; 1 unverifiable; 1 negative requirement; 2 out of scope for the SIS-DTN WG
14 Data Transport Requirements	9 adopted; 4 redundant; 1 out of scope;
27 Data Transfer Requirements	26 adopted; 1 redundant
12 Data Management Requirements	10 adopted; 1 redundant; 1 statement of rationale
3 Data Utilization Requirements	3 adopted

Table 6-1: Summary of SIS-DTN Working Group Dispositions of SISG FBO Requirements

The full set of FBO requirements provided and their dispositions by the SIS-DTN working group are included in an Appendix D.

6.2.2 Issue 6: Integrate Delay/Disruption-aware (DTN) and Delay/Disruption-unaware (IP) Applications

During the process of defining operational requirements, the SIS-DTN working group also clarified the expected interactions between IP and DTN in the 'in-situ local networking' scenario (shown in Figure 6-1). Essentially, confusion had arisen surrounding the concept of 'islands of IP bridged by DTN', which could be misinterpreted as using DTN to support end-to-end IP communications across delayed/disconnected realms. The issue was further clouded by the (possible) overlay nature of the Bundle Protocol (the prime candidate for a DTN layer protocol), which can be run over IP (such as in the terrestrial Internet).

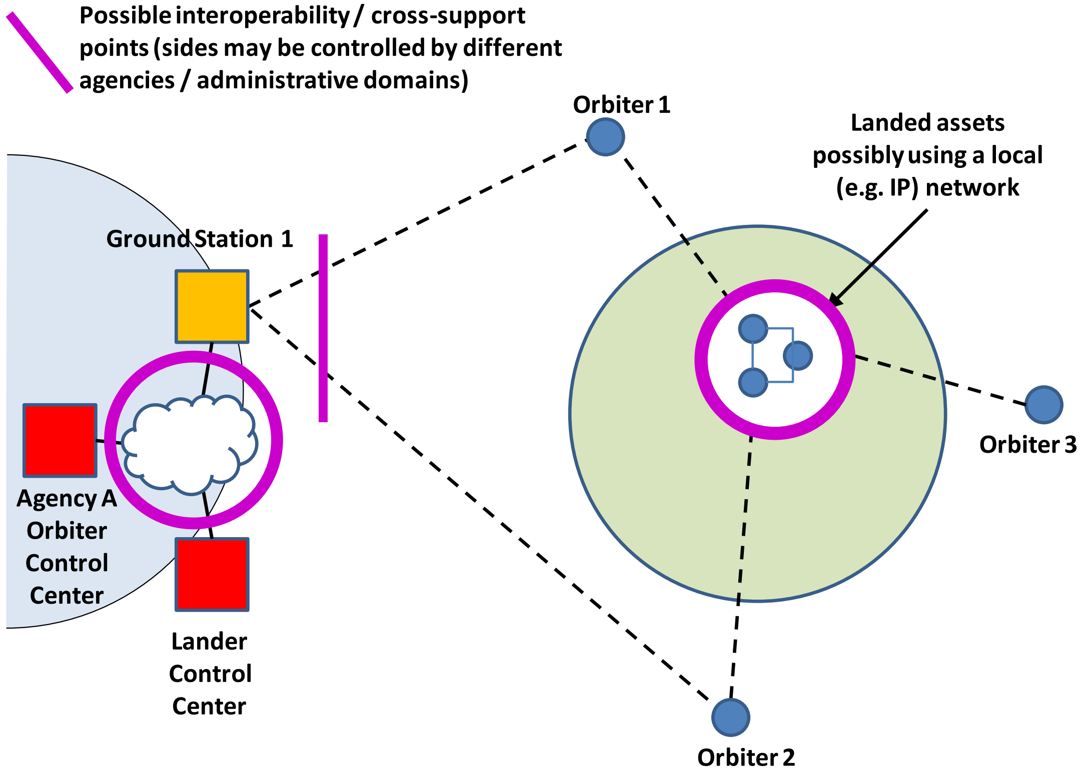

Figure 6-1: In-Situ Local Networking Scenario from the SIS-DTN Green Book

The alternatives for end-to-end communication are shown in Figure 6-2. If the end-to-end network path is relatively well connected with low delay, then use of native IP protocols is possible. If the end-to-end path may be disrupted, then applications should use the DTN suite natively for communications (item 2 in Figure 6-2). For simplicity, however, an in-situ local network might choose to use DTN as the basis for its local internetworking (even if the local environment could support IP) to facilitate communications with remote elements such as mission operations centers. Using this approach, the applications would see DTN as the internetworking protocol and know nothing of IP. The DTN layer could then use any underlying protocol(s) to provide the DTN service, such as 802.11, BlueTooth, etc. If the local network supported it, the DTN layer might choose to use IP as a 'link-layer' service underneath DTN, but the IP-based service would be invisible to the applications.

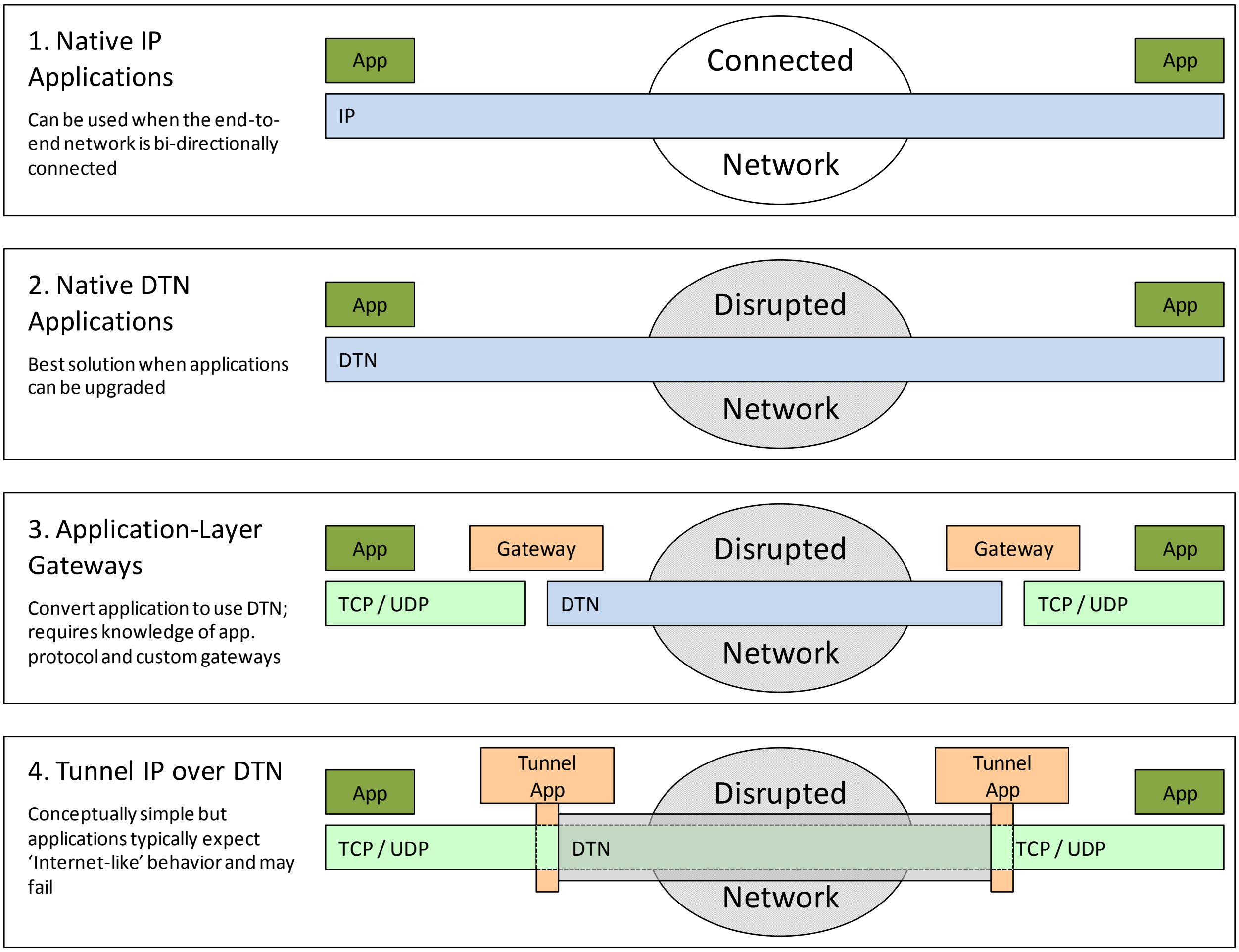

Figure 6-2: End-to-End Communication Alternatives

Alternative (3) of Figure 6-2 shows application-layer gateways translating between IP and DTN. This approach is preferred for situations where IP-based applications must be used at the end systems. Alternative (4) corresponds to the 'islands of IP' concept discussed above. While technically possible, alternative 4 is a brittle and problematic solution, since the end systems will likely inherit the implicit assumptions made by IP that do not necessarily hold over the disrupted network. Such applications could fail or behave in unpredictable ways if they are confronted with large delays and significant misordering that could result from transport over the disrupted network. This alternative is not recommended and, if implemented, extensive testing of the applications is encouraged.

6.3 Team Membership

Team lead: Keith Scott (NASA/JPL)

Team members: Chris Taylor (ESA/ESTEC), Scott Burleigh (NASA/JPL), Michael Schmidt (ESA)

7 Issue 7: On-Demand Communication Services in the Context of the SSI

7.1 Overview

At its September 2009 meeting at the European Space Operations Centre (ESOC), the SISG raised an issue concerning the fact that on-demand communication services had not been addressed in the SSI discussions to date. M. Schmidt (ESA/ESOC) and C. Edwards (NASA/JPL) were assigned the action to consider the needs and requirements for on-demand services in the context of the future SSI end state. After an initial presentation on the topic, D. Israel (NASA/GSFC) and J. Schier (NASA/HQ) provided additional inputs regarding the already existing Demand Access Service (DAS) provided by the NASA Space Network (SN); those additional inputs are also included here.

The overall finding of the issue team is that on-demand telecommunication services can be readily accommodated into the proposed SSI architecture and operations concept.

7.2 Technical Discussion

Current deep space communication services are typically fully scheduled activities, involving advanced planning to determine the specific time windows during which links will be established and the specific link configuration (data rates, coding, modulation, duplex mode, etc.) that will be used.

In the future, we envision scenarios in which a user node would make on-demand requests for links autonomously. For instance, rather than pre-scheduling a proximity link session between a Mars lander and a Mars relay orbiter via ground planning, an application on the lander could autonomously request such a link from the relay orbiter only when the link is needed to support a desired network service.

Such an on-demand paradigm is not currently used for today's Mars relay scenarios due to the very short geometric contacts and the need for the orbiter to integrate science activities with relay service provision. On-demand services, however, would fit well within possible future SSI scenarios. As an example, consider a Mars outpost with multiple robotic users on the Martian surface, within the footprint of a dedicated Mars Relay Satellite providing extended (but perhaps not continuous) geometric visibility. On-demand link establishment would enable more flexible, dynamic, and autonomous surface user operations, implementing links to the relay orbiter only when network services are needed by the surface users. Such a strategy could reduce operations costs by eliminating much of the manual planning activity currently required to schedule individual links, and would minimize user energy costs by establishing links only when actually needed.

On-demand services could fit into the SSI operations concept in a straightforward manner. A key SSI concept is the notion of a contact plan describing the temporal connectivity of the network, i.e., the time windows during which various nodes are connected by links and the capabilities of those links. In a scheduled service paradigm, all those links are scheduled in advance and integrated into the contact plan. In an on-demand paradigm, those pre-scheduled windows are simply replaced by the windows during which a link could potentially be supported in response to an on-demand service request. There may still be temporal considerations—e.g., times when a given link is not possible due to geometry or known a priori engineering constraints—that would need to be reflected in the contact plan.

End-to-end services may involve a combination of on-demand and scheduled links. On-demand approaches are most applicable to links over short distances, where the process for requesting and establishing a link can be carried out quickly. Long light time links (for instance, between an Earth station and a planetary relay orbiter) are likely to continue to be manually scheduled. Thus, a user on the surface of Mars could make an on-demand request for a link to a Mars relay orbiter, which would then forward the data to Earth during a scheduled link session.

One potentially complicating issue arises in the context of an oversubscribed on-demand service provider. In this case there enters a stochastic aspect to the response time within which a requested on-demand link request can be satisfied. (Of course, there are already stochastic elements of latency even in the scheduled SSI paradigm, based on finite bandwidth of individual links and uncertainties in overall network traffic.)

Support for on-demand users will require standardized mechanisms for link requests and link establishment for all applicable links. (It is worth noting that the Proximity-1 Space Link Protocol already provides such capabilities; we could, in principle, make on-demand service requests today from the Mars rovers, Spirit and Opportunity.)

NASA's SN, comprised of the Tracking and Data Relay Satellites (TDRS) and associated ground stations, currently provides DAS, which allows users unscheduled return link service via the Multiple Access (MA) system. This return service is accomplished by providing a full-period receive system for each DAS user via ground-based beamforming of the TDRS MA phased array signals and multiple strings of receiver equipment. No on-demand service request is necessary. A user simply begins transmitting when service is desired.

This already-existing service fits well into the SSI operations concept as previously described. The SSI contact plan would include all windows during which a link could be supported in response to on-demand service requests, while also accounting for periods of link unavailability due to geometry or engineering constraints.

In summary, on-demand telecommunication services can be readily accommodated into the proposed SSI architecture and operations concept.

7.3 Team Membership

Team leads: Chad Edwards (NASA/JPL) and Michael Schmidt (ESA/ESOC)

Team members: David Israel (NASA/GSFC) and Jim Schier (NASA/HQ)

8 Issue 9: Identify Figures of Merit (FOM) and Analyze Various Mission Scenario Alternatives to Determine the Best SSI Evolutionary Path

8.1 Overview

The SISG chartered the Issue 9 team to examine options for alternative paths by which the SSI can evolve in the 2015-2020 time frame towards the envisioned, post-2020, fully internetworked end state. In particular, the 2016 ExoMars/Trace Gas Orbiter (ExoMars/TGO) and the 2018 Mars Astrobiology Explorer-Cacher (MAX-C) and ExoMars Rover—elements of the recently announced ESA/NASA Mars Exploration Joint Initiative (MEJI)—will involve multi-hop relay scenarios, providing an excellent opportunity for evolution towards the SSI end state.

The team identified five options for consideration, derived from specific implementation strategies for these 2016 and 2018 Mars missions. A collection of stakeholders quantitatively assessed these options, based on a set of defined FOM. Two options emerged as the most highly ranked, with nearly identical scores. The first of these options represents the current baseline, with use of ESA's Packet Utilization Standard (PUS) Service 13 for reliable data transfers; this option scored well primarily due to cost and risk considerations. The other favored option augments the Electra relay payload on the 2016 ExoMars/TGO spacecraft with its own internal storage and a functional DTN protocol stack, and also deploys a DTN network layer at the ground tracking station; this option scored well based on improved QQCL metrics, as well as the programmatic value of moving farthest towards the desired SSI end-state.

8.2 Technical Discussion

Given the charter to examine options for SSI evolution in the 2015-2020 time frame, the team quickly focused on the ESA/NASA MEJI. Specific elements of MEJI in this time frame include

- 2016 ESA/NASA ExoMars/TGO: This mission will consist of an ESA-provided orbiter bus carrying a suite of NASA- and ESA-provided science instruments focused on the study of trace gases in the Martian atmosphere. NASA will supply a launch vehicle and will also supply a UHF relay payload based on the Electra software-defined radio, providing relay services to missions launched in 2018 and beyond. The mission will also deploy an ESA-provided EDL Demonstrator, released on approach to Mars, to demonstrate ESA EDL technologies.
- 2018 NASA/ESA MAX-C/ExoMars Joint Rover Mission: This mission will deploy a pair of rovers within a single Mars Science Laboratory (MSL)-heritage EDL system. The NASA MAX-C rover and ESA ExoMars rover will be mid-sized rovers, larger than the Mars Exploration Rovers but smaller than MSL; MAX-C is designed for a one Earth year nominal surface mission, while ExoMars is designed for 180 sols.

This mission set offers several interesting characteristics for the purposes of the requested study. It involves a number of store-and-forward relay operations scenarios; involves a pair of collocated surface assets in the 2018 opportunity; has the potential for more complex network topologies than prior Mars missions; falls in the desired 2015-2020 time frame; is just entering formulation phase, so the design is not yet frozen (although plans for the 2016 mission are moving forward rapidly); and entails de facto multi-agency cross-support and interoperability considerations.

The team identified a number of FOMs to be applied in the evaluation of considered options

- QQCL Performance: measures of the quantity, quality, continuity, and latency of end-to-end data delivery
- Cost: sum of flight and ground implementation costs to achieve the selected option, along with impact on mission operations costs
- Risk: technical risk associated with implementing the selected option, as well as the extent to which the selected option increases or decreases mission risk during flight operations
- Programmatics: extent to which the selected option moves towards the desired SSI final state, characterized by a functional BP/IP network layer, as well as the ability of the selected option to accommodate existing missions.

The team established five options for consideration, as outlined in Table 8-1.

Option #	Description
Option 1:	**Current Baseline**: This option represents the current baseline for the 2016 and 2018 missions. The 2016 orbiter utilizes the ESA PUS Service 13 to provide reliable data transfer over the deep space uplink and downlink. Reliable proximity links, using the CCSDS Proximity-1 link protocol, complete the reliable end-to-end link. Relay and user MOCs employ a File Transfer Protocol (FTP)-based interface.
Option 2a:	**CFDP Between Relay MOC and S/C**: This option uses acknowledged CFDP for reliable data transfers over the deep space link.
Option 2b:	**CFDP Store-and-Forward Overlay**: This option utilizes CFDP-based file transfers at all interfaces, including between MOCs, with forwarding automated with the use of CFDP store and forward overlay.
Option 3a:	**DTN Option A (DTN operating at ESOC)**: In this option, the Electra relay payload on the 2016 ExoMars/TGO spacecraft is augmented to implement a DTN network layer. ESA's operations remain unchanged, using PUS Service 13 for nominal communications with the orbiter and for relay services to an ESA landed asset. However, relay services to a NASA landed asset utilize Class-1 CFDP over DTN. Electra includes internal storage and a DTN bundle agent for reliable store-and-forward capability. A DTN node is added at the Orbiter MOC.
Option 3b:	**DTN Option B (DTN operating at ground tracking stations)**: This option is similar to Option 4, with an augmented Electra payload providing DTN functionality. However, this option removes the DTN node from the orbiter MOC and instead deploys a DTN node at the ground tracking station, allowing a NASA user mission (e.g., MAX-C) to flow data directly to the ground station, bypassing the Orbiter MOC.

Table 8-1: List of Evolutionary Options Considered in the Issue 9 Study

The Issue 9 team, along with additional participants from ESA and NASA, including representatives from the 2016 and 2018 missions, rated the various options based on the FOMs described above. The group also assigned weighting factors to the various FOMs, allowing the calculation of an aggregate score for each option. Figure 8-1 illustrates the results of the FOM analysis, with the contributions from each of the four FOM areas indicated.

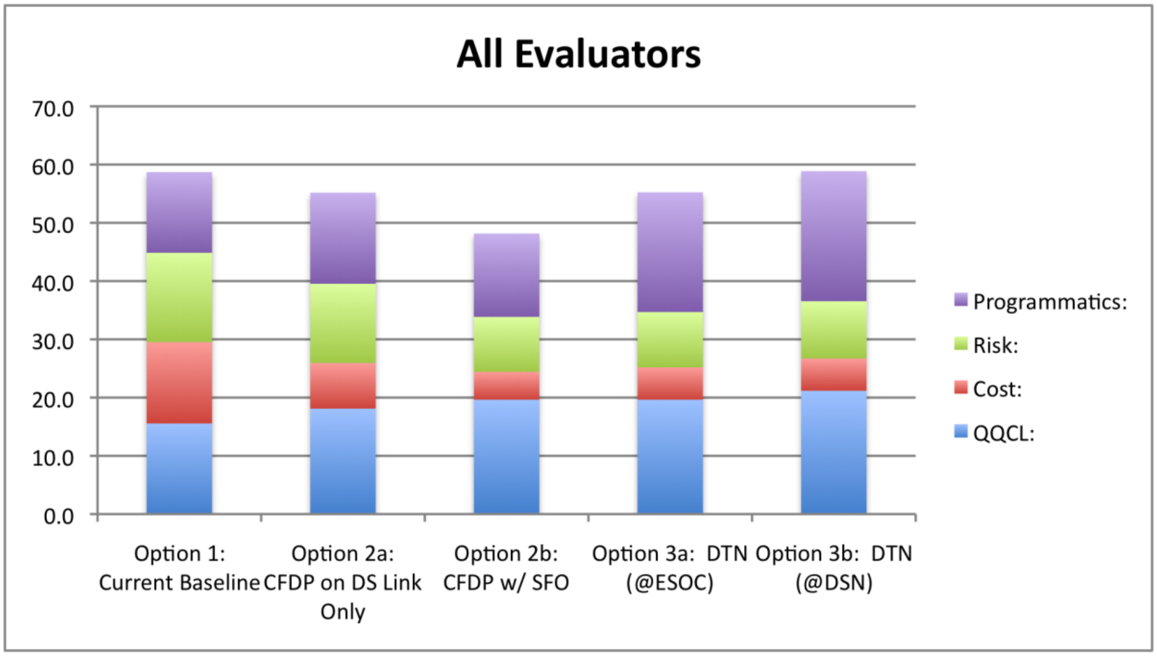

Figure 8-1: Figure of Merit Analysis Results

The favored options were Option 1 (the current baseline) and Option 3b (the DTN option with the ground station configured as a DTN node). While their total scores were nearly identical, the contributions from the different figures of merit were quite different. Option 1 scored highest in areas of cost and risk, reflecting the high heritage of the baseline flight and ground software systems. On the other hand, Option 3b scored highest in the areas of QQCL performance parameters and overall programmatics, as it represents the largest step towards the desired SSI end state.

Option 2b, which would deploy CFDP with a store-and-forward overlay, had the lowest score. The team found that the significant software development required for this option was not productively directed towards the desired network-enabled SSI end state, and hence was not cost effective; much of this CFDP Store and Forward Overlay (SFO) development would subsequently be scrapped to be replaced by a true DTN network layer.

The team cautions that this FOM analysis should not be considered as the ultimate answer, but rather as a useful exercise to explore various aspects of the option trade space. It was also an effective way to engage the 2016 and 2018 Mars mission project personnel, exposing them to the potential benefits of the different options, and allowing the SISG team to hear concerns from a project perspective. The analysis clearly shows the dynamic tension between reuse of heritage solutions (with advantages of low cost and risk) vs. moving aggressively towards the desired DTN-enabled end-state (with programmatic and QQCL advantages). Ultimately, the decision on the path forward will be critically dependent on the relative importance of these two factors.

See Appendix E for details on the Issue 9 analysis.

8.3 Team Membership

Team leads: Chad Edwards (NASA/JPL) and Wolfgang Hell (ESA/ESOC)

Team members: S. Burleigh (NASA/JPL), G. P. Calzolari (ESA/ESOC)

Additional stakeholders who participated in the FOM analysis: P. Schmitz (ESA/ESOC; 2016/2018 ExoMars Project), Chris Taylor (ESA/ESTEC), T. Komarek (NASA/JPL; 2016 ExoMars/TGO Project), Chris Salvo (NASA/JPL; 2018 MAX-C Pre-project)

9 Issue 10: Ground Support Considerations

9.1 Overview

While Issue 9 primarily examines options for SSI evolution for the space segment, Issue 10 is specifically concerned with determining the best ground support configuration to support the SSI. The default assumption in the Issue 9 study is that the ground-based interfaces between the Lander MOC, the Orbiter MOC, and the Ground Station will be Space Internetworking (SI) interfaces (IP or DTN) supported by SLE from the Orbiter MOC to the Ground Station, and running over TC and TM space communication protocols. The Issue 9 study does not discuss forward and return synchronous AOS on the space link, support of SSI compliant missions and traditional TT&C missions, or the specific SLE options and ground support configurations needed to support these capabilities. Issue 10 addresses these issues in detail and identifies an optimal configuration using an Analysis of Alternatives (AoA) approach.

9.2 Technical Discussion

The scope of the Issue 10 Ground Support Study is shown in Figure 9-1, which represents the best space segment option selected by the Issue 9 study. This scenario supports a traditional TT&C Orbiter and also provides an SSI relay/router function via a modified Electra radio on the Orbiter to provide DTN services. The ground configuration shown is one of the possible configurations that could be adopted. The Issue 10 study identified six possible configurations for these ground assets (see Table 9-1): two NASA and ESA legacy configurations (Configurations 1 and 2), two configurations that adopt modified versions of SLE forward and return packet services (Configurations 3 and 4), and two that adopt new SLE/CSTS forward frame service(s) that handle AOS and TC frame and frame multiplexing (Configurations 5 and 6).

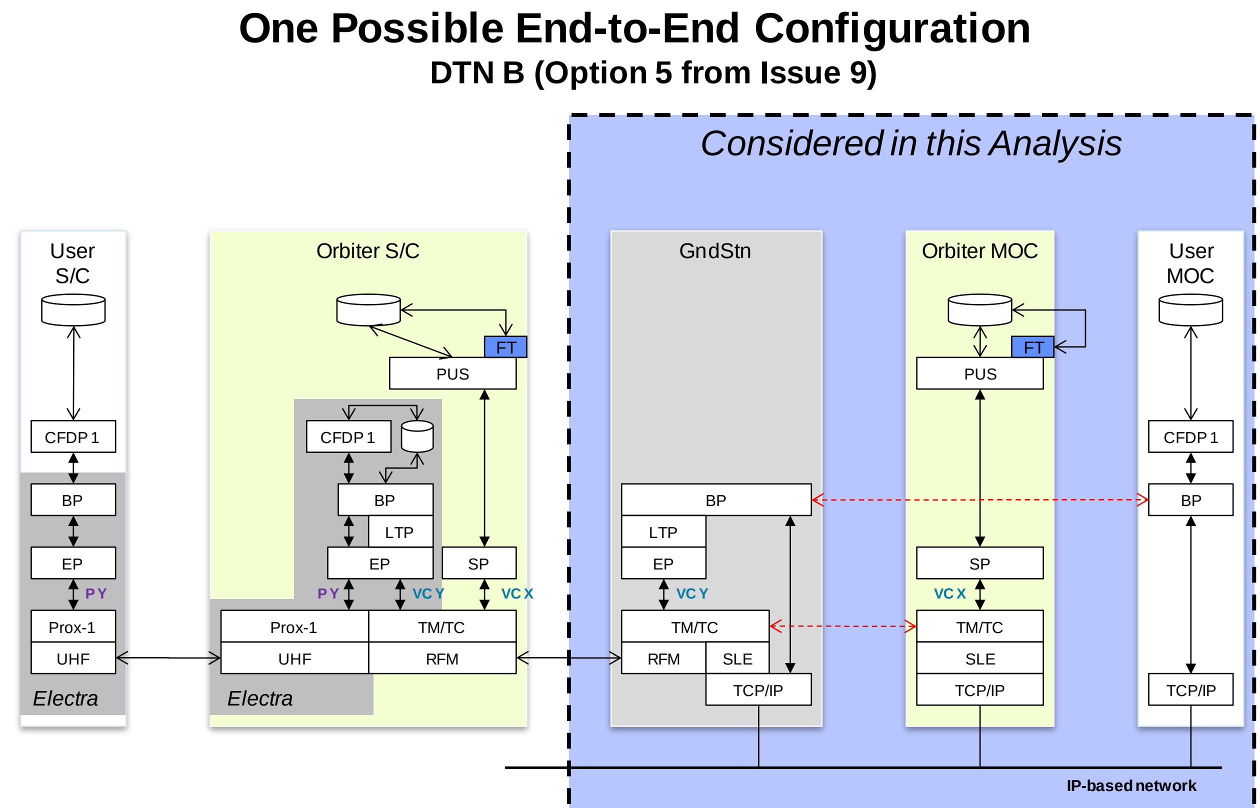

Figure 9-1: Ground Support Study Focus

In the NASA and ESA legacy configurations, the Orbiter MOC handles all of the data, and the primary variants concern where DTN is implemented and how the Orbiter MOC is implemented. The primary variant in the other configurations is where the implementation of the full SSI stack is done, either in the Ground Station or in the User MOC. Table 9-1 summarizes these options, and shows the initial analytical results.

Comparison Table for Initial Analysis

#	Gnd Stn	Orb. MOC	User MOC	Notes
1	FCLTU+RCF old, FSEF new	FSEF new, DTN + LTP, Full CCSDS stack, Mux manager, frame generation	Basic DTN, No SLE/ CSTS	FCLTU weak for AOS, Least-1 extensible
2	FCLTU+RCF old, FSEF new	FSEF new, NO DTN stack, Full CCSDS stack, Mux manager, File xfer for EP, frame generation	File xfer for EP, DTN +LTP	FCLTU weak for AOS, Least extensible
3	FSP2+RSP2 new, Full CCSDS stack, Mux manager	FSP2+RSP2 new, NO DTN stack, packet generation	FSP2+RSP2 new, DTN +LTP	FSP2 good for AOS (TBC), More extensible than 1 & 2: more cost for GS + User MOC
4	FSP2+RSP2 new, DTN +LTP, Full CCSDS stack, Mux manager	FSP2+RSP2 new, NO DTN stack, packet generation	Basic DTN, No SLE/ CSTS	FSP2 good for AOS (TBC), More extensible than 1 & 2 & 3: more cost for GS
5	RCF old, F-Frame new, DTN+LTP , Mux manager	RCF old, F-Frame new, frame generation	Basic DTN, No SLE/ CSTS	F-Frame excellent for AOS (TBC), Most extensible: costs moderate for users, more for GS
6	RCF old, F-Frame new, Mux manager	RCF old, F-Frame new, frame generation	RCF old, F-Frame new, DTN+LTP	F-Frame excellent for AOS (TBC), Very extensible, wrt #5 simpler GS but more complex User MOC

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Table 9-1: Issue 10 Study Options

Table 9-1 shows where identical (or nearly identical) configurations are allocated for each of the key elements, along with the team's initial notes. Red text highlights where the DTN functionality is allocated in each configuration.

One of the key assumptions in this study was that the Orbiter MOC will require complete access to standard TT&C services to operate the Orbiter spacecraft. The team did not want to preclude use of SSI protocols for this function, but wanted to ensure that this basic capability was in place. The study included a full AoA, including development of two sets of FOM—one for technical issues and one for cost and risk. The team used weights to assign relative values to the different FOMs, and employed a consensus approach to develop the FOMs, weights, and scoring.

This analysis is largely qualitative, although the team applied relative quantitative estimates to reflect and normalize the quality, complexity, and cost of the different configurations for each FOM. Accurate cost estimates for the service users and service providers should ultimately be used to provide solid validation of the study's outcome, but the team has enough experience with these systems to be confident that the relative evaluations will not change substantially.

The costing assumptions included adoption of common standards and assume each agency is implementing a single user and service provider that will be reused.

The favored configuration (Configuration 5) is shown in Figure 9-2 (forward path) and Figure 9-3 (return path). The forward/return terminology, while somewhat archaic from the point of view of internetworking, is appropriate in the context of ground support, which must handle traditional as well as SSI services.

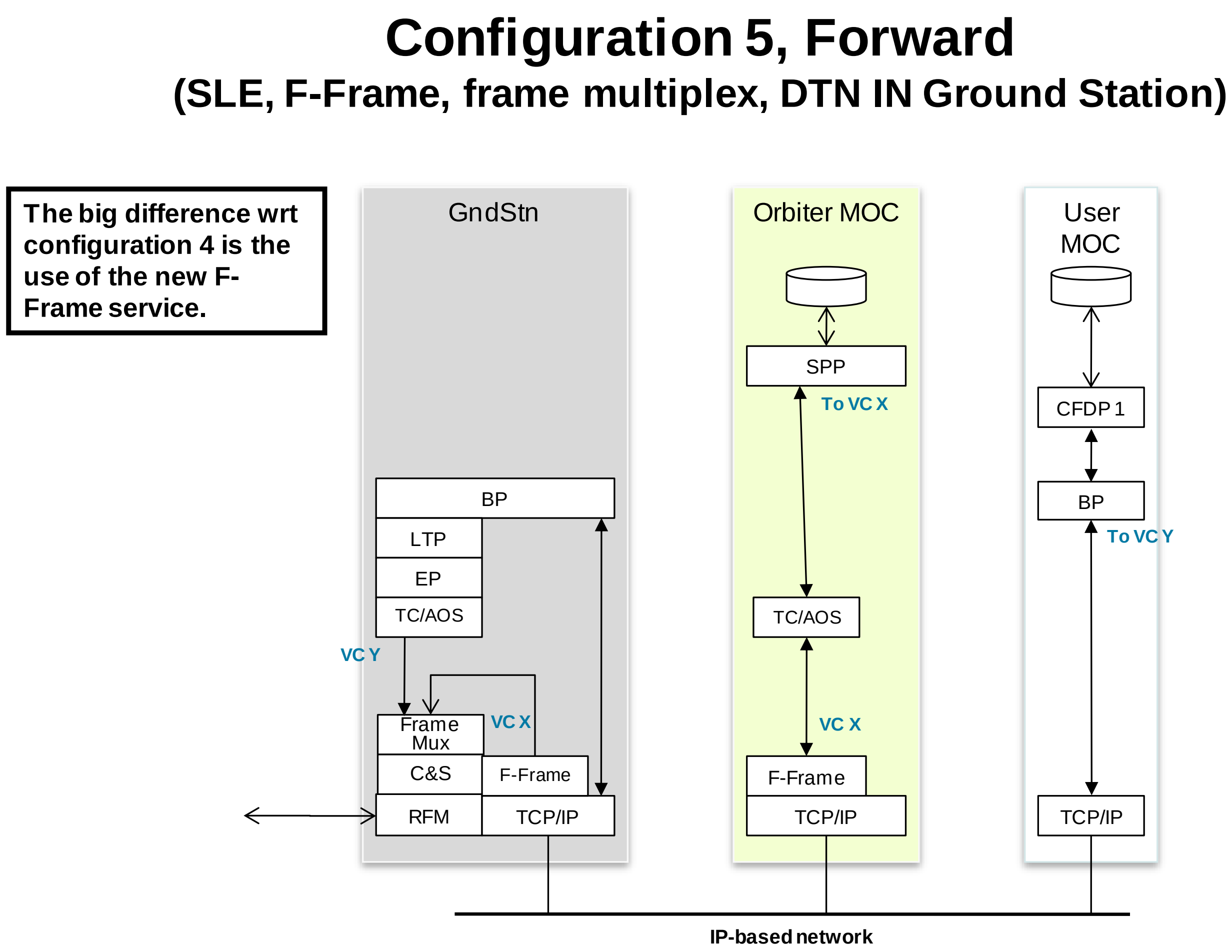


Figure 9-2: Selected Forward Configuration

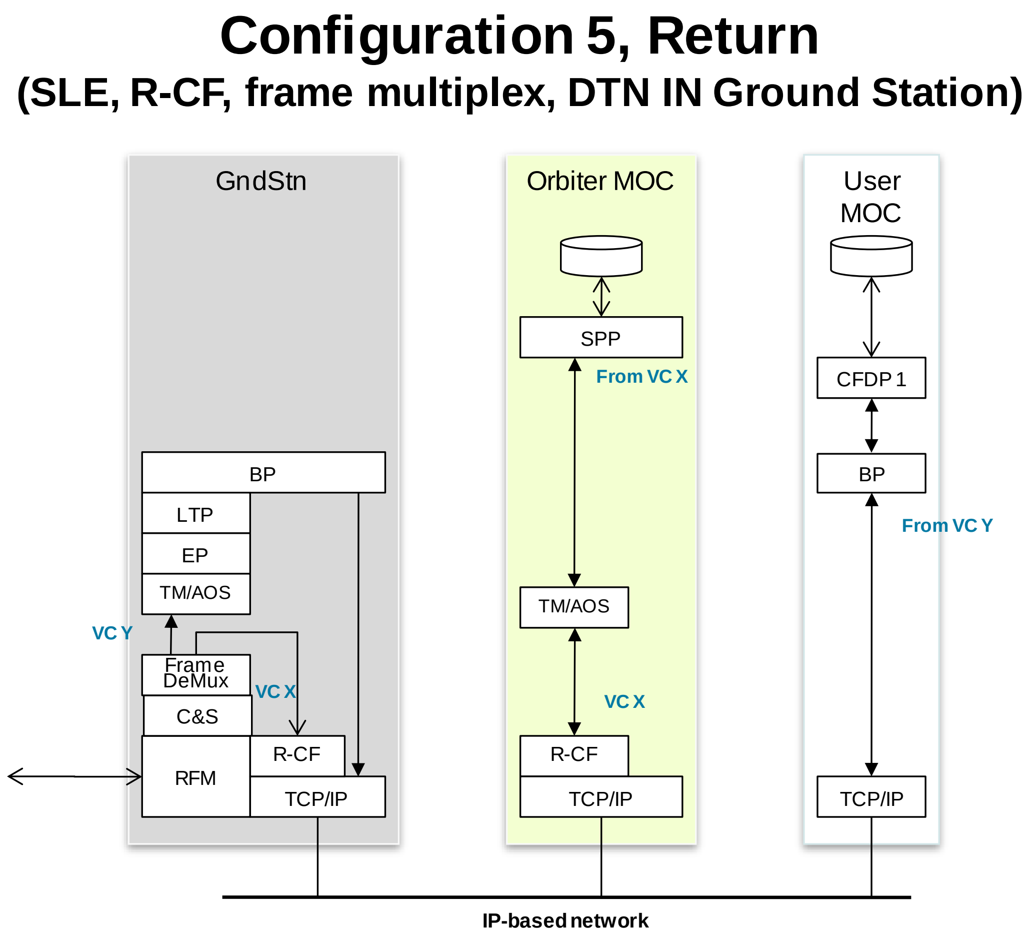


Figure 9-3: Selected Return Configuration

NOTE: Figures 9-2 and 9-3 are symmetric, and show the very simple Orbiter MOC and User MOC configurations and the allocation of all of the lower level DTN and link layer processing to the Ground Station. Also note that the Orbiter MOC can become a full SSI node with the addition of the CFDP and BP protocols, as shown in the User MOC.

The technical FOM analysis heavily favored Configurations 5 and 6, largely because they provide the greatest flexibility and interoperability.

- The team selected Configuration 5 because it has the higher scores, provides the greatest flexibility, and subsumes the all of the features of Configuration 6, where users can still provide their own local implementations running over a frame service
- A sensitivity analysis, which altered the weights to favor user complexity over simpler ground stations, did not change the relative rankings

The Cost/Risk FOM analysis favored Configuration 1, largely because it requires no implementation or changes, and thus incurs the lowest cost. However, Configurations 5 and 6 were moderately strongly favored over the other configurations when the team considered the remaining cost/risk FOMs.

- The team selected Configuration 5 because it has an almost identical score to 6, provides the greatest flexibility, and subsumes all the features of Configuration 6. (Higher capability for roughly the same cost is to be preferred.)
- A sensitivity analysis, which altered the weights to favor user complexity in exchange for simpler ground stations, ranked Configuration 5 the highest of all, followed by Configurations 1 and 6

In all cases where movement toward an SSI final state was a strong consideration, Configurations 5 and 6 were favored or strongly favored. The team consensus was to select Configuration 5, which, while it increases Ground Station and provider costs, provides the most generality and extensibility and also has the least cost and complexity for both the Orbiter and the users. Both Configurations 5 and 6 support all of the possible configurations analyzed in the Issue 9 study and also readily support full adoption of the SSI suite in the Orbiter MOC.

For more details on the study, including the underlying assumptions, the alternative configurations, and a full discussion of the AoA, please refer to the slides in Appendix F.

9.3 Team Membership

Team lead: Peter Shames (NASA/JPL)

Team members: Gian Paolo Calzolari (ESA/ESOC), Wolfgang Hell (ESA/ESOC), Wallace Tai (NASA/JPL)

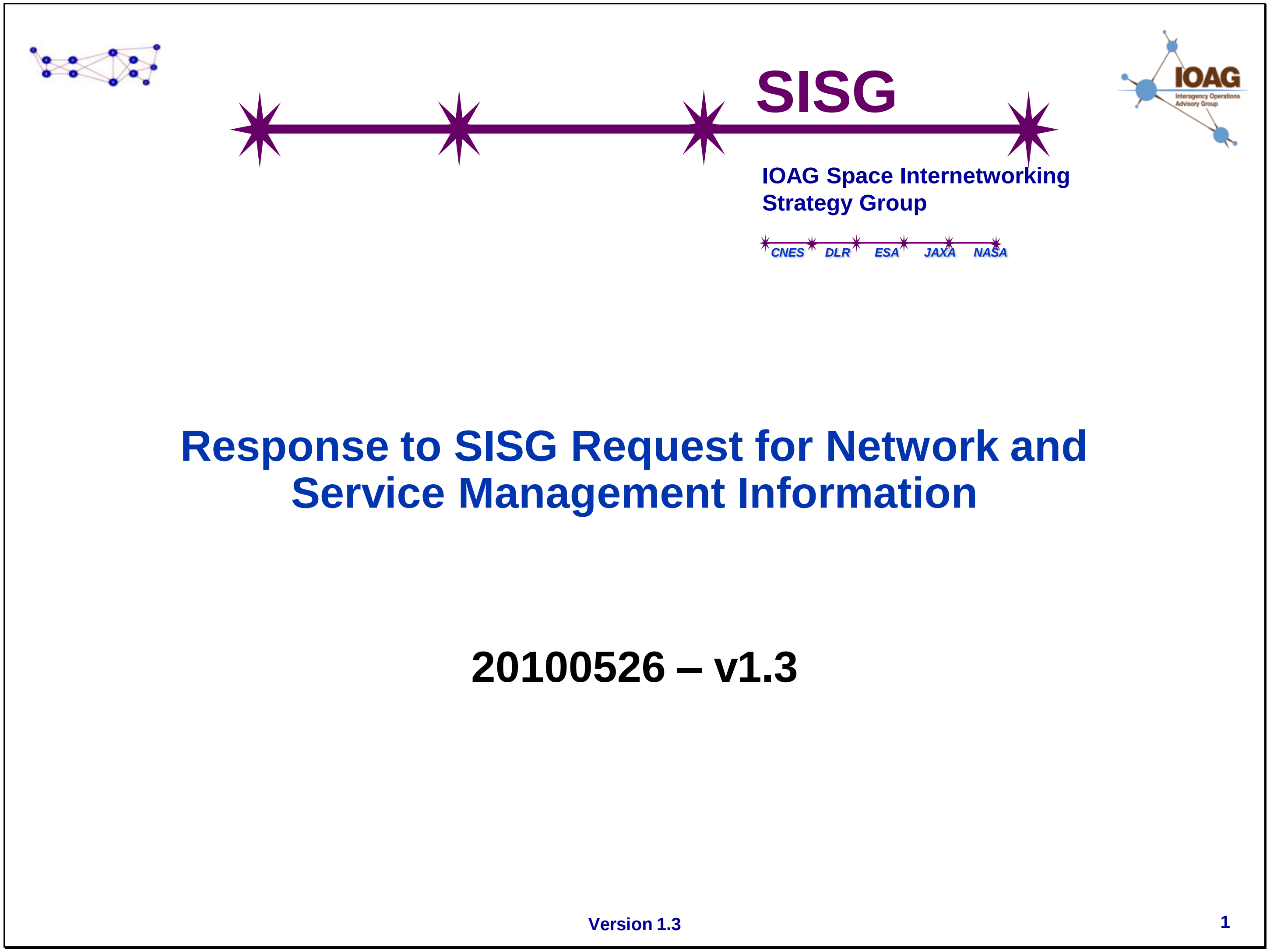
Appendix A. Acronyms

AMS	Asynchronous Message Services
AOA	Analysis of Alternatives
AOS	Advanced Orbital Systems
BCH	Bose-Chaudhuri-Hocquenghem
BP	Bundle Protocol
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CLA	Convergence Layer Adapter
CLTU	Communications Link Transmission Unit
CNES	Centre National d'Etudes Spatiales (French space agency)
CSTS	Cross Support Transfer Services
DAS	Demand Access Service
DLR	German Space Agency
DOR	Differential One-Way Ranging
DTN	Disruption Tolerant Network or Delay Tolerant Network
EDL	Entry, Descent and Landing
ESA	European Space Agency
ESOC	European Space Operations Center
FBO	File Based Operations
FCAPS	Fault, Configuration, Accounting, Performance, Security
FOM	Figures of Merit
FTP	File Transfer Protocol
IOAG	Interagency Operations Advisory Group
IOP	Interoperability Plenary
IP	Internet Protocol
ISP	Internet Service Provider
JAXA	Japan Aerospace Exploration Agency
LH	Last Hop
MA	Multiple Access
MAX-C	Mars Astrobiology Explorer-Cacher
MEJI	Mars Exploration Joint Initiative
MEX	Mars Express
MOC	Mission Operations Center
MSL	Mars Science Laboratory
OCF	Operational Control Field
OSI	Open Systems Interconnection
PDU	Protocol Data Unit
PUS	Packet Utilization Standard
QoS	Quality of Service
QQCL	Quantity, Quality, Continuity, and Latency
RF	Radio Frequency
SAP	service access point
SFO	Store and Forward Overlay
SI	Space Internetworking

SC	Spacecraft
SIS-DTN	Space Internetworking Systems Delay Tolerant Networking
SISG	Space Internetworking Strategy Group
SLA	Service Level Agreement
SLE	Space Link Extension
SN	Space Network
SSI	Solar System Internetwork
SSI-ISP	Solar System Internetwork-Internet Service Provider
TC	Telecommand
TDRS	Tracking and Data Relay Satellite
TT&C	Tracking, Telemetry, and Command
UDD	User Defined Data

Appendix B. Issue 2 and 3 Supplementary Material

Slide 1



Slide 2

SISG

Issue Resolution Plan (From ESOC Meeting)

IOAG Interagency Operations Advisory Group

ISSUE	RESOLUTION PROCESS	RESP. PARTIES
2. Service Management not sufficiently defined	1. Assign to SISG Ops Concept Working Group 2. Define top level requirements for Service Management (interaction between service provider and user) a. Identify boundary conditions in terms of delay and disruption where different modes of operations can be deployed. b. Define interfaces between users (control center/spacecraft) and providers c. Identify management needs for services DUE DATE: 15 Mar 2010	Ops Concept –WG
3. Network Management not sufficiently defined	1. Assign to SISG Architecture Working Group 2. Define requirements for Network Management (monitor and control of comm. nodes, e.g., capability to update routing tables) a. Capability of provider (authority of provider) b. Capability of user c. Needs of provider d. Monitoring, control, and reporting options DUE DATE: 15 Mar 2010	Architecture -WG

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Slide 3

SISG

Context for Network and Service Management in the SSI

IOAG

- The principal concept of the SSI is to build a network layer *communications infrastructure* that meets the requirements from all missions and then to use that infrastructure to support end-to-end communication among users
  - The infrastructure consists of nodes that do store-and-forward routing and the links that connect them
  - Not trying to manage each individual transfer; rather the nodes take local decisions in accordance with policies and rules set for mission operations; there will be times when particular links are under-utilized, and times when they are over-subscribed
- The service provided *by the SSI to users* is “delivery of application data units according to their requested qualities of service”, using the protocol mechanisms that are part of the SSI
- The service *used by the SSI* is the link-layer connectivity and the knowledge of that connectivity as a function of time (in order to configure time-aware forwarding such as Contact Graph Routing, e.g.)

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The main philosophical difference between the SSI and the way things are done now is that in the SSI, we envision providing a communications infrastructure that is separate from individual data transmissions. The routing/forwarding fabric of the SSI will be responsible for managing transmission of user data across the (given) infrastructure. There is a feedback loop allowing missions and the SSI to request that additional connectivity be provided (later slides)

The fundamental service provided by the SSI is delivery of application data units to their (addressed) destinations, regardless of where those destinations are in the network and according to the QoS requests of the applications.

If we envisioned running routing protocols that 'discovered' the current and/or future connectivity (maybe via some interface to query a node as to its upcoming schedule) then we could get by with just the physical connectivity without separate knowledge of future scheduled. It's a useless distinction, however, since the nodes themselves will have to know their own upcoming schedules in order to operate.

With regard to the services used by the SSI, "link-layer connectivity" includes all underlying connectivity such as the Internet protocols when SSI nodes are connected by IP networks.

Slide 4

SISG

Interoperability and Network Management

- We do not currently see a requirement for one agency to be able to use network management to command another agency's assets
- We think there is a need for agreement on the network management *information* and a way to exchange that information across agency boundaries
  - For reporting and accountability
- Ideally, for some types of information that agencies are willing to share freely (e.g. accounting?), common network management / reporting protocols would be developed

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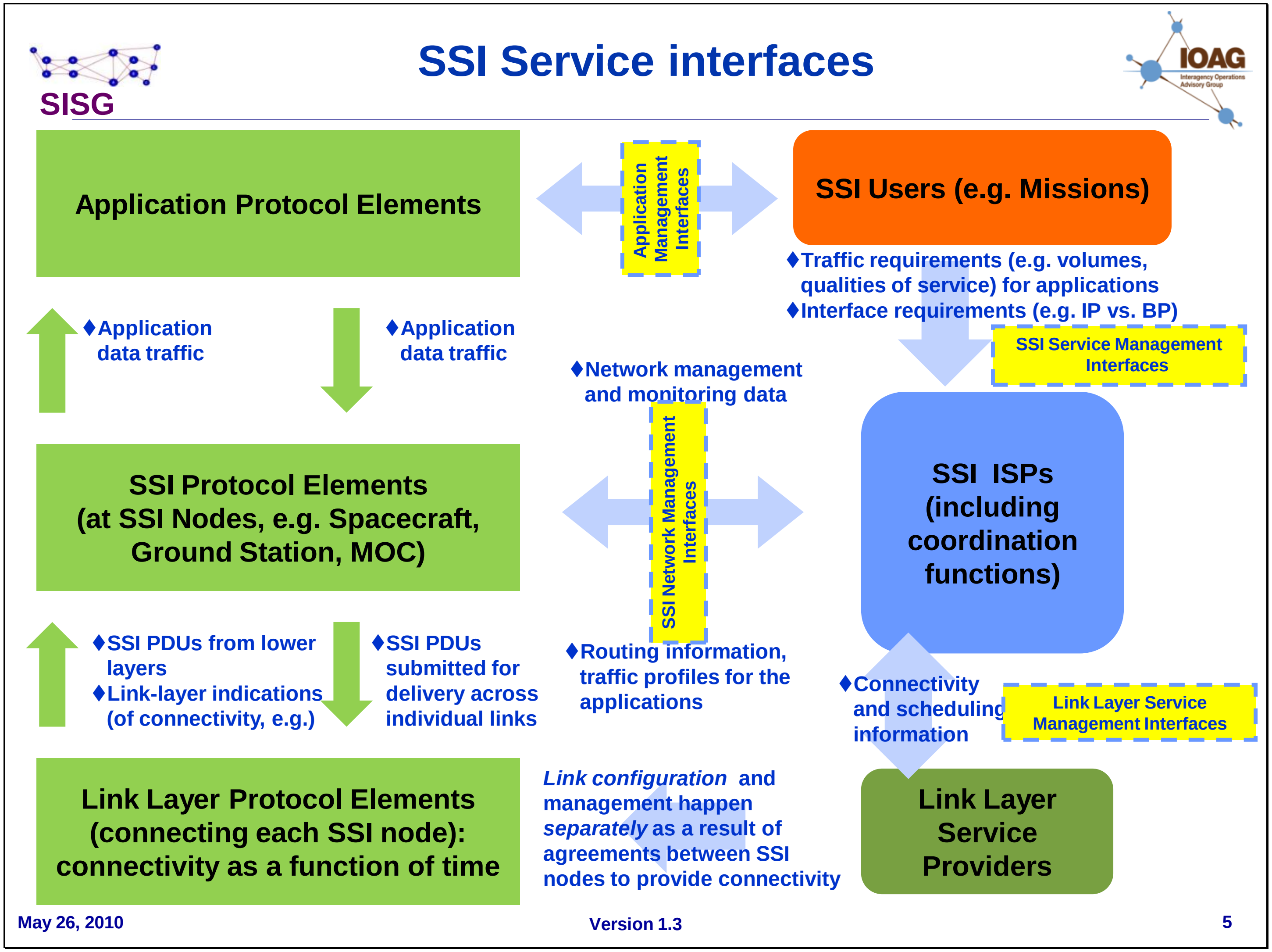
Slide 5


SISG
SSI Service interfaces
IOAG
Application Protocol Elements
Application Management Interfaces
SSI Users (e.g. Missions)
♦Traffic requirements (e.g. volumes, qualities of service) for applications
♦Interface requirements (e.g. IP vs. BP)
SSI Service Management Interfaces
♦Application data traffic
♦Application data traffic
♦Network management and monitoring data
SSI Protocol Elements (at SSI Nodes, e.g. Spacecraft, Ground Station, MOC)
SSI Network Management Interfaces
SSI ISPs (including coordination functions)
♦SSI PDUs from lower layers
♦Link-layer indications (of connectivity, e.g.)
♦SSI PDUs submitted for delivery across individual links
♦Routing information, traffic profiles for the applications
♦Connectivity and scheduling information
Link Layer Service Management Interfaces
Link Layer Protocol Elements (connecting each SSI node): connectivity as a function of time
Link configuration and management happen separately as a result of agreements between SSI nodes to provide connectivity
Link Layer Service Providers
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Traffic profile: amount of 'allowable' traffic by QoS class. The SSI node may interact with the application to ensure that the application's traffic meets its profile. For example, if a particular application is allowed to send 100kBytes/day of priority-16 traffic, but instead sends 500kBytes/day, the SSI Node needs to interact with the SSI Coordination function and the application to resolve it.

Slide 6

SISG

Definitions: Entities

- Missions (Users)
  - Have *requirements* for communications
    - Commanding, Telemetry
    - Frequency of contact, total bandwidth, …
  - May be able to *provide communications services* to the SSI
    - Depending on their particular resources like position, mission phase, power, storage, …
- User MOCs: control spacecraft and interface between missions and their agencies' SSI ISPs, possibly via mission family / exploration field specific representatives
- Provider Elements: coordinate with their agencies' SSI ISPs to provide communications services to missions (e.g. TT&C networks, relay spacecraft)
- SSI Internetworking Service Providers (SSI ISPs):
  - Are administrative entities, nominally one per agency, that are the management interfaces between missions and the SSI
  - Communicate with missions in their agency and with other SSI ISPs to ***negotiate*** the communication (link) schedules that provide the 'raw material' that the SSI builds on to provide a communications infrastructure

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Slide 7

SISG

Service Management and Network Management in the SSI

IOAG

- **Service Management in the SSI** refers to the 'configuration' aspect of the underlying services (connectivity) used to construct the SSI
  - Missions and SSI ISPs working together to establish the underlying connectivity and nominal routing plan

- **Network management in the SSI** refers to the activities, methods, procedures, and tools that pertain to the operation, administration, maintenance, and provisioning of SSI resources
  - Operation deals with keeping the network (and the services that the network provides) up and running smoothly. It includes monitoring the network to spot problems as soon as possible, ideally before users are affected.
  - Administration deals with keeping track of resources in the network and how they are assigned. It includes all the "housekeeping" that is necessary to keep the network under control.
  - Maintenance is concerned with performing repairs and upgrades. Maintenance also involves corrective and preventive measures to make the managed network run "better", such as adjusting device configuration parameters.
  - Provisioning is concerned with configuring resources in the network to support a given service.

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A common way of characterizing network management functions is FCAPS—Fault, Configuration, Accounting, Performance and Security.

Functions that are performed as part of network management accordingly include controlling, planning, allocating, deploying, coordinating, and monitoring the resources of a network, network planning, frequency allocation, predetermined traffic routing to support load balancing, cryptographic key distribution authorization, configuration management, fault management, security management, performance management, bandwidth management, route analytics and accounting management.

Data for network management is collected through several mechanisms, including agents installed on infrastructure, synthetic monitoring that simulates transactions, logs of activity, sniffers and real user monitoring.

Slide 8

SISG

Issue 2

IOAG
Interagency Operations Advisory Group

ISSUE	RESOLUTION PROCESS	RESP. PARTIES
2. Service Management not sufficiently defined	1. Assign to SISG Ops Concept Working Group 2. Define top level requirements for Service Management (interaction between service provider and user) a. Identify boundary conditions in terms of delay and disruption where different modes of operations can be deployed. b. Define interfaces between users (control center/spacecraft) and providers c. Identify management needs for services DUE DATE: 15 Mar 2010	Ops Concept - WG

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Slide 9

SISG

Issue 2a: Boundary in Terms of Delay and Disruption Where Different Modes of Operation Can Be Employed

IOAG

- "Mode of operation" here is interpreted as 'what network layer protocol could be used'?
- From 'suspended' CCSDS Cislunar Space Internetworking working group:
  - In terms of **delay**, the Internet Protocol suite can function to about 10s RTT
  - In terms of **loss**, it's really up to the applications
    - TCP traffic will suffer greatly if the packet loss rate is > ~2%, but nobody's planning on using TCP
  - In terms of link **directionality** (i.e. simplex vs. duplex links) both IP and BP can handle simplex links; IP is limited to protocols that do not require bi-directionality (e.g. UDP) and special routing considerations apply
  - In terms of **disconnection / partitioning**, IP will only deliver packets when end-to-end connectivity is available.

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People seem fascinated by these types of things, but as there's no real clear-cut answer. I've seen even TCP systems that run reasonably well over 20-30s round-trip times. This works because there are only a handful of nodes and some optimizations to reduce round trips (like not running ARP between the nodes), but still using regular Internet routing protocols (OSPF).

Slide 10

SISG

Issue 2a: Boundary in Terms of Delay and Disruption Where Different Modes of Operation Can Be Employed

IOAG

- "Mode of operation" here is interpreted as 'what are the application-layer paradigms that are supportable (e.g. conversational, asynchronous, …)'?
- We have different applications that have different QoS requirements for (e.g.) delay / latency / …
- Different applications (e.g. voice, video, data) have different requirements for each of the boundary categories (e.g. delay, loss rate, …)
- Service management has to be able to capture the application requirements and inject them into the SSI planning cycle

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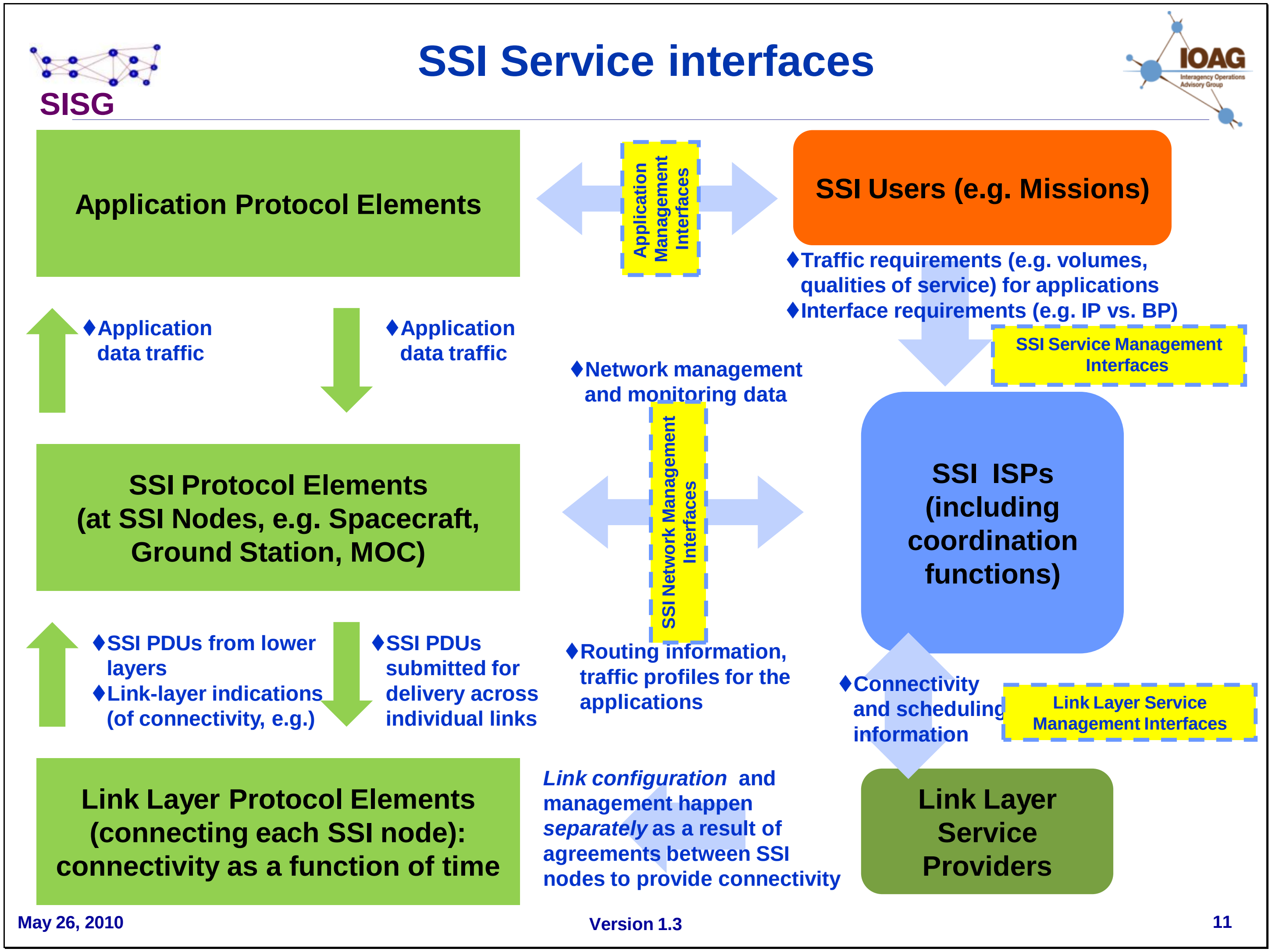
Slide 11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Link Layer Service Providers
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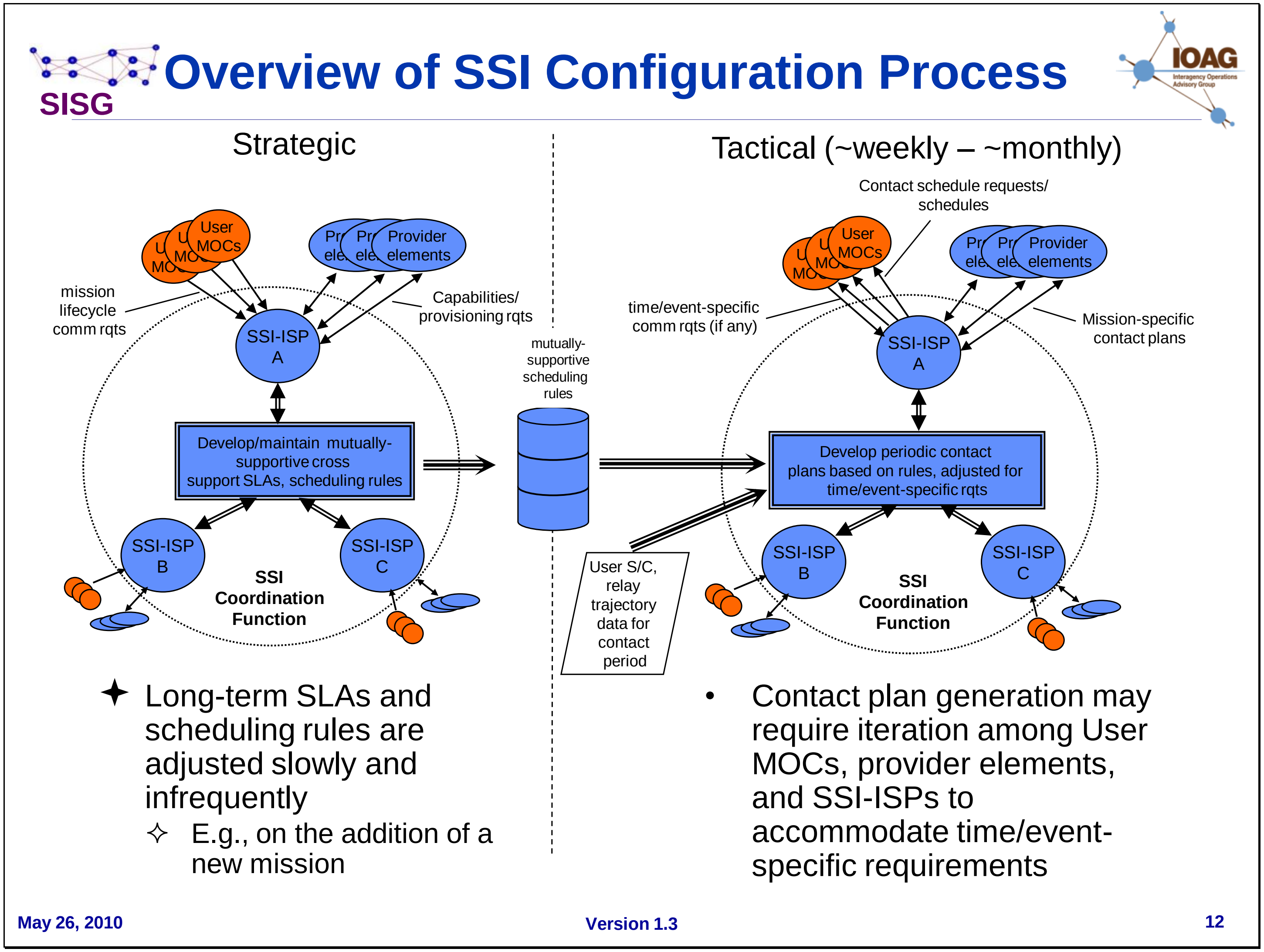
Traffic profile: amount of 'allowable' traffic by QoS class. The SSI node may interact with the application to ensure that the application's traffic meets its profile. For example, if a particular application is allowed to send 100kBytes/day of priority-16 traffic, but instead sends 500kBytes/day, the SSI Node needs to interact with the SSI Coordination function and the application to resolve it.

Slide 12


SISG
Overview of SSI Configuration Process
IOAG
Strategic
Tactical (~weekly – ~monthly)
User MOCs
Provider elements
mission lifecycle comm rqts
Capabilities/ provisioning rqts
SSI-ISP A
Develop/maintain mutually-supportive cross support SLAs, scheduling rules
SSI-ISP B
SSI-ISP C
SSI Coordination Function
mutually-supportive scheduling rules
User S/C, relay trajectory data for contact period
Contact schedule requests/ schedules
time/event-specific comm rqts (if any)
Mission-specific contact plans
Develop periodic contact plans based on rules, adjusted for time/event-specific rqts
Long-term SLAs and scheduling rules are adjusted slowly and infrequently
E.g., on the addition of a new mission
Contact plan generation may require iteration among User MOCs, provider elements, and SSI-ISPs to accommodate time/event-specific requirements
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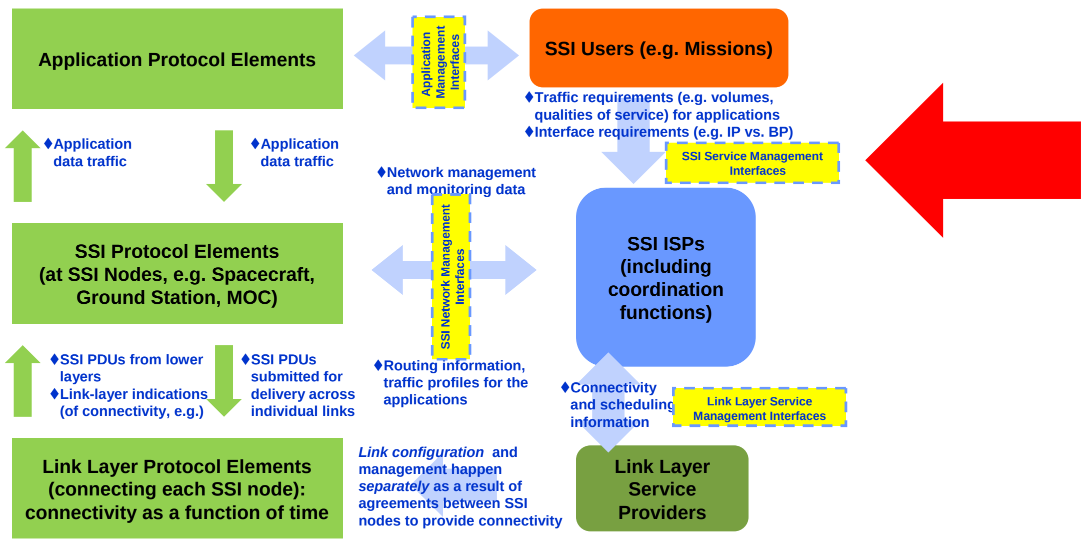
SISG

Issue 2c: Identify Management Needs for Services

- This is the service interface between Users and the SSI Coordination Function
  - QoS: Jitter, latency, throughput
  - Interfaces: [IP, BP] connectivity, legacy support



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SISG

Issue 3

IOAG

ISSUE	RESOLUTION PROCESS	RESP. PARTIES
3. Network Management not sufficiently defined	1. Assign to SISG Architecture Working Group 2. Define requirements for Network Management (monitor and control of comm. nodes, e.g., capability to update routing tables) a. Capability of provider (authority of provider) b. Capability of user c. Needs of provider d. Monitoring, control, and reporting options DUE DATE: 15 Mar 2010	Architecture - WG

- **This really covers two areas:**
  - “Traditional” network management
    - Configurable parameters
    - Ability to update routing tables, list currently held bundles, return accounting information, …
  - Capabilities / interfaces between users and providers and among providers

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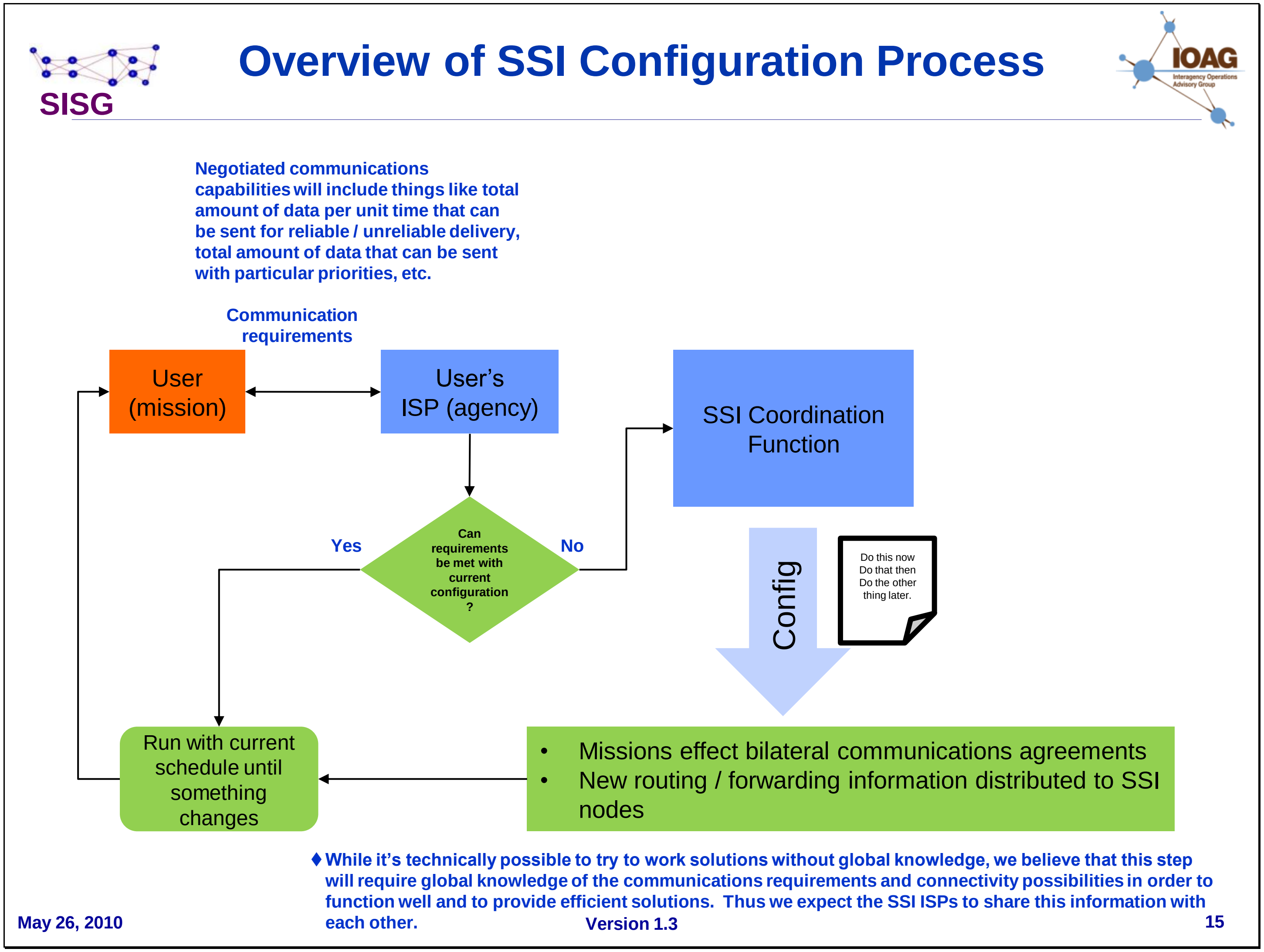
SISG
Overview of SSI Configuration Process
IOAG
Negotiated communications capabilities will include things like total amount of data per unit time that can be sent for reliable / unreliable delivery, total amount of data that can be sent with particular priorities, etc.
Communication requirements
User (mission)
User's ISP (agency)
SSI Coordination Function
Can requirements be met with current configuration ?
Yes
No
Config
Do this now Do that then Do the other thing later.
Run with current schedule until something changes
• Missions effect bilateral communications agreements
• New routing / forwarding information distributed to SSI nodes
♦ While it's technically possible to try to work solutions without global knowledge, we believe that this step will require global knowledge of the communications requirements and connectivity possibilities in order to function well and to provide efficient solutions. Thus we expect the SSI ISPs to share this information with each other.
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SISG

Issue 3: Capability of Provider (Authority of Provider)

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Interagency Operations Advisory Group

- Providers of SSI services, e.g. ground stations, relay spacecraft
  - Interact with their agencies' SSI ISPs to maintain a notion of what connectivity is *possible*, both with other missions in the same agency and with missions from other agencies
  - Can enter into agreements with their agencies' SSI ISPs
    - To provision link-layer connectivity with other SSI nodes (provisioning connectivity with nodes in another agency implies inter-ISP agreement)
  - Are NOT 'controlled by' the SSI, except via whatever interactions between the mission and its SSI are mandated by the mission's agency
- SSI ISPs (as providers of SSI services)
  - Can enter into agreements with missions in their agencies and with other SSI ISPs, e.g.:
    - Provision of link-layer connectivity between nodes
    - Agreements on the coarse-grained configuration of the SSI as a whole (e.g. SSI routing will be set up to meet the communication needs of the missions)
  - Form a federated community of interest
    - There is no 'head' SSI ISP
    - In theory, participation is driven by members getting more out of the network by banding together than any single member could get out of using only their own assets
  - Work with their missions to effect the agreed-to configuration

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In the SSI model, missions are still autonomous (or perhaps ‘missions are still only responsible to their parent agencies’).

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SISG

Issue 3: Needs of Providers

IOAG

- Providers of SSI services
  - Need to know the agreed-to SSI configuration (connectivity, routing, …)
    - In order to manage physical connectivity according to the configuration
- SSI ISPs (as providers of SSI services)
  - Need to know the agreed-to SSI configuration (connectivity, routing, …)
  - Need to know application communication requirements
  - Need to know the *possible* connectivity among SSI nodes (to explore new possible configurations)

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SISG

Issue 3: Capabilities of Users

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- Users of SSI services (e.g. rovers, spacecraft, rover MOCs)
  - Interact with their agencies' SSI ISPs to communicate their communication requirements
  - Can transmit and receive data according to the negotiated traffic profile (constraints on data rates and qualities of service as a function of time)
    - Over-profile data traffic may be re-prioritized (shaped)
- SSI ISPs (as consumers of SSI services)
  - N/A

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SISG

Overview of FCAPS Network Management Functions

IOAG

- Fault Detection and Reporting
- Configuration
  - E.g. router ID, convergence layers and parameters, routing protocols and parameters (including static routes as a special case), etc.)
- Accounting
  - Numbers of bundles sent and received, forwarded, …, possibly per (source, destination), number and nature of security faults
  - In cases where a given link is exclusively reserved for use by a given mission (e.g. last hop to a landed asset), charging may be based on time rather than data volume
- Performance
  - Monitoring of the number of times transmissions were interrupted, throughput / goodput of links
- Security
  - Configuring security parameters

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Slide 20

SISG

SSI Network Management Capabilities

IOAG

- Telemeter relevant management information
  - Based on schedule
  - Based on exception (alarm)
  - In response to query
- Modify particular management information items
- List, Suspend, Resume, Re-prioritize, Terminate Bundles at a given node
- Modify CLA parameters as appropriate
- Modify Routing / Forwarding protocol parameters as appropriate
  - E.g. insert static routes, modify Contact Graph Routing information

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SISG

SSI Network Management Capabilities

IOAG

- The inherent flexibility offered by SSI dynamic routing capability in combination with appropriate priority / QoS assigned to different concurrent data flows in many cases may respond well and rapidly enough to 'unplanned' events. The richer the available connectivity is, the less such events will require the in advance preparation of special recovery configurations.
- However, in particular as long as data relaying is provided by secondary payloads of planetary orbiters, missions may require a backup comm. scenario that is preplanned and can be invoked on short notice if the need arises (as was done for MEX in support of Phoenix).
- The preparation of such backup scenario can be part of the SLA negotiated between the SSI ISPs. The SLA should also document how and by whom the backup comm. scenario can be invoked.
- In case of temporary outage of certain resources (e.g. relay spacecraft temporarily in safe mode), the inherent flexibility of the SSI in combination with priority of traffic should accommodate the invocation of such backup scenario without absolutely requiring the regeneration of the SSI contact plan.
- A more disastrous failure like extended outage or even permanent loss of certain resources will require a re-planning, although even in such case the SSI will behave more gracefully than the topologies we use today and even in such case the re-planning only needs to be done around the outage, not end-to-end.

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SISG

SSI Network Management Capabilities

- Assuming Contact Graph Routing (CGR), depending on the exact circumstances, contact anomalies will be handled in the following ways:
  - A link failure known about ahead of time, e.g. by inference from a spacecraft failure, such that contact plan revisions can be distributed to the participating SSI nodes before routing decisions are made will simply result in different routing decisions. No problem will arise provided that alternate contact capacity, i.e. future planned contact intervals, is available. If the available alternate capacity is insufficient for transmission of all affected bundles, low-priority bundles will be discarded.
  - If the link failure is known ahead of time, but the contact plan revisions reach the SSI nodes before the start of the contact but only after routing decisions have been made, then bundles will automatically be re-forwarded at the end of the originally planned contact interval because the CLA did not de-queue them for transmission at the times predicted by CGR. The re-forwarding procedure will result in revised routing decisions for the affected bundles to the extent that alternate contact capacity is available.
  - If the link failure is completely unanticipated, then the CLA will de-queue bundles for transmission as planned and attempt to transmit them, but nothing will happen. In this event, convergence layer (e.g., LTP) ARQ procedures will detect convergence layer protocol failure and thereupon cause the bundles to be re-forwarded immediately.

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SISG

SSI Network Management Capabilities

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- Conclusion:
  - The notion is that if a link that is in the contact plan unexpectedly becomes unavailable, then, if this information can be propagated to other SSI nodes, bundles that would have been routed over the now failed link can take other paths. Those other paths would use (link-level) connectivity and bandwidth that was already provisioned (the idea being to build the link connectivity plan as 'infrastructure' that has some extra capacity in it over and above the absolute minimum needed to support the a priori requirements). Thus no change in the link configurations would be needed.
  - Timely distribution of contact plan revisions is always helpful but would never be a prerequisite to autonomous recovery from an SSI resource outage.
  - Local, autonomous anomaly resolution is a fundamental principle of delay-tolerant networking, since one can never rely on getting timely assistance from other entities in the network.

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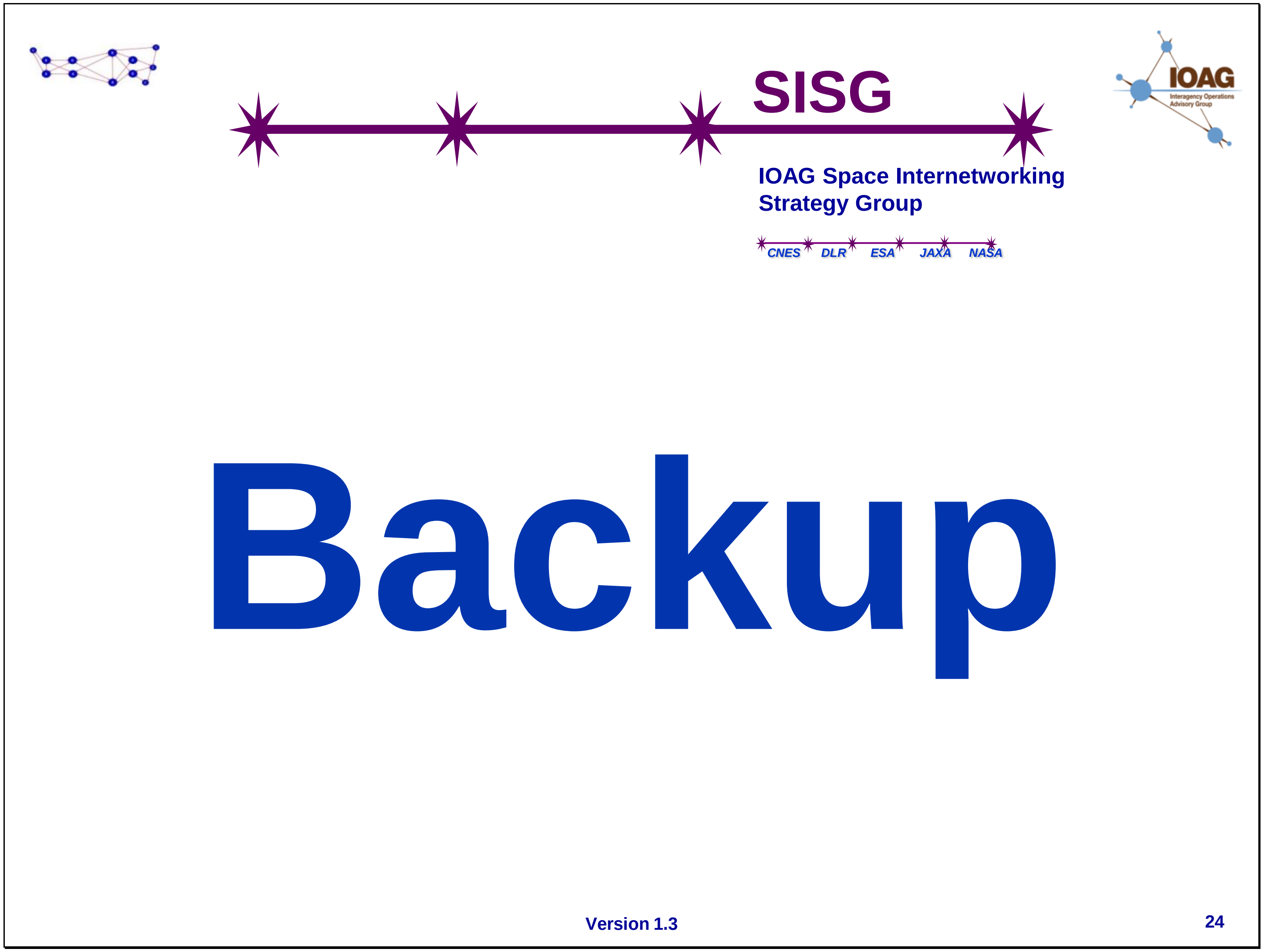
Slide 24


SISG
IOAG
IOAG Space Internetworking Strategy Group
CNES DLR ESA JAXA NASA
Backup
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Slide 25

SISG

Management Information for SSI Nodes: Standard Information for Bundle Protocol

IOAG Interagency Operations Advisory Group

Category	Item	RFC5050 Section
Endpoints	Singleton endpoint that the bundle node is required to be a member of	3.1
Registrations	What endpoints is this node a member of? For each registration: active or passive? For each registration: delivery failure action (defer, abandon, other)	3.1
Convergence Layers	For each CL: convergence layer identifier For each CL: convergence layer configuration parameters *(reference to another set of management data that includes things like per-link info (speed, peer(s), schedule, …) for the set of links that the CL is managing)*	3.1
General Accounting	Number of bundles originated for transmission Number of bundles received from convergence layers (possibly the numbers received BY convergence layer) Number of bundles delivered to applications Number of bundles taken custody of Number of custodial bundles received but NOT taken custody of Number of bundles transmitted (possibly by CL) Number of bundles abandoned Number of bundles deleted	3.1
Custody	Conditions under which a Bundle Node may take custody of bundles Rules for setting custody retransmission timers? Where (e.g. memory vs. disk) and how much storage is available to hold custodially-held bundles.	5.1
Administrative Records	Bundle agent generates bundle reception status reports Bundle agent generates custody acceptance status reports Bundle agent generates bundle forwarding status reports Bundle agent generates bundle delivery status reports	5.1
Fragmentation	Bundle agent implements fragmentation	5.8
Static Routing	List of static routes (mapping between destination EID and/or destination CL address)	
Dynamic Routing Protocols	Routing protocol identifier *Routing protocol configuration parameters (reference to another set of management data)*	
PendingBundles	List of the bundles this node is currently trying to forward (bundles this node has received, needs to forward, but hasn't yet; metadata for each bundle including an indication of whether or not this node has taken custody of the bundle, retention constraints on the bundle, etc.)	

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Slide 26

SISG

Management Information for SSI Nodes: Licklider Transmission Protocol (LTP)

IOAG

Category	Item	RFC5326 Section
General Configuration	LTP Engine ID	2
	One-way light time to remote LTP engine (per remote LTP engine)	6.5
	DTN EID-to-LTP Engine-ID Mapping Table	2
	Default LTP segment size (per destination LTP Engine ID?)	4.1
Timers	Checkpoint Timer Value	6.2
	RS Timer Value	6.3
	Timer Suspend State	6.5
	Default 'additional latency' value	6.5
	'Cancel Timer' Value	6.15
Checkpoints	Checkpoint retransmission limit (per active session)	6.7
	Default value of the checkpoint retransmission limit	
	Default discretionary checkpoint frequency (bytes/time?)	2
General Accounting	Number of red segments transmitted (global and per active session)	
	Number of red segments received (global and per active session)	
	Number of green segments transmitted (global and per active session)	
	Number of green segments received (global and per active session)	
	Number of red segments retransmitted (global and per active session)	
	Number of system error conditions encountered	6.22
	Number of transmission sessions started	
	Number of transmission sessions completed	7.4
	Number of transmission sessions cancelled	7.5
	Number of reception sessions started	
	Number of reception sessions completed	
	Number of reception sessions cancelled	7.6
	Number of reception problems encountered (global and per active session)	6.11
	Number of reception problems acceptable before canceling the session (per active session)	6.11
	Default number of reception problems acceptable before canceling reception	
	Number of transmission problems encountered (global and per active session)	6.13
	Number of transmission problems acceptable before canceling the transmission (per active session)	6.13
	(per active session) RS retransmission limit	8.2
	(per active session) CR segment retransmission limit	8.2
	Number of concurrent ongoing sessions	
Security	Number of replay segments detected	9.2

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Slide 27

Management Information for SSI Nodes: Contact Graph Routing

Category	Item	CGR.doc section
Graph Information	Set of contact intervals For each contact interval, a capacity (product of transmission rate and duration; units are Bytes) For each contact interval, a range (OWLT) value	
Static Routes	Set of static routes in CGR. Static routes are pairings between destination node #s and the node #s of the gateway nodes responsible for ultimate forwarding to the destination(s).	
Current Time	Current time at the node (according to CGR, including any offset from the time returned by the OS)	

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Management Information for SSI Nodes: Bundle Protocol Security

Category	Item	BSP Draft Section
Hop-by-Hop Authentication	Number of bundles with invalid Bundle Authentication Blocks (BAB blocks) encountered Number of BAB-authenticated bundles that passed authentication Number of failed BAB authentications	2.2
Payload Integrity	Number of bundles with invalid Payload Integrity Blocks (PIBs) encountered Number of bundles that passed PIB integrity checks Number of bundles that failed Payload Integrity Checks	2.3
Payload confidentiality	Number of bundles with invalid payload confidentiality blocks encountered Number of bundles that passed payload confidentiality decryption (can we know this?) Number of bundles that failed payload confidentiality decryption (can we know this?)	2.4
Errors	Number of bundles containing invalid security combinations (e.g. nonsensical combinations of security extension blocks) Number of bundles with bad fragment ranges and security extensions Number of bundles dropped due to policy exceptions Number of bundles dropped due to security path overlap	2.8 2.6 3.1 3.3

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SISG

IP Network Management

IOAG
Interagency Operations Advisory Group

Category	Item	
IP	RFC4293 – Management Information Base for the Internet Protocol (IP) RFC4292 – IP Forwarding Table MIB	
IP QoS	RFC3747 – Diffserv Configuration Management MIB RFC2213 – Integrated Services Management Information Base using SMIv2	
Security	RFC4301 – Security Architecture for the Internet Protocol (IP) RFC4302 – IP Authentication Header (AH) RFC4303 – IP Encapsulating Security Header (ESP) RFC4305 – Cryptographic Algorithm Implementation Requirements for Encapsulating Security Payload (ESP) and Authentication Header (AH) RFC4309 – Using Advanced Encryption Standard (AES) CCM Mode with IPSec Encapsulating Security Payload (ESP)	
Key Management	RFC4306 – Internet Key Exchange (IKEv2) RFC4307 – Cryptographic Algorithms for use in the Internet Key Exchange Version 2 (IKEv2)	
Transport Protocols	RFC2959 – Real Time Protocol MIB RFC4113 – Management information base for User Datagram Protocol (UDP) RFC4022 – Management Information Base for Transmission Control Protocol (TCP)	

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Slide 30

SISG

Service Level Agreement

IOAG

- Service Level Agreements (SLA) document the services to be provided to a mission by SSI providers
  - negotiated on behalf of a mission by an SSI-ISP
- The Service Level Agreement contains information that characterizes the resources and level of commitment that supporting SSI providers agree to supply to a mission
  - includes details of the types of service, frequency and duration of services, quality of service, and essential information required to assess the level of support required by the mission
  - This information is used by Agency service providers to determine the resources needed to support the mission (e.g., RF equipment, data storage, terrestrial network bandwidth)
    - spacecraft communication characteristics (e.g., frequencies, modulation)
    - Traffic requirements (e.g. volumes, quality of service)
    - Protocol profile (e.g., IP vs. BP)
    - mission planning information (e.g., mission timeline, trajectories)
- Documents a preliminary plan outlining the communications support that Agency providers have agreed to make available to the mission

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Network Bootstrapping / Recovery Mechanisms

- In the SSI, some spacecraft may depend on networked communications and may not be directly accessible from Earth
- Low-level commands to bootstrap a particular spacecraft may need to be delivered via another spacecraft (as opposed to direct-from-Earth)
  - A class of ‘last-hop commanding/telemetry’ applications on the penultimate spacecraft will support this function

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SISG

Wikipedia Definition of Network Management

IOAG

- **Network management** refers to the activities, methods, procedures, and tools that pertain to the operation, administration, maintenance, and provisioning of networked systems.
  - Operation deals with keeping the network (and the services that the network provides) up and running smoothly. It includes monitoring the network to spot problems as soon as possible, ideally before users are affected.
  - Administration deals with keeping track of resources in the network and how they are assigned. It includes all the "housekeeping" that is necessary to keep the network under control.
  - Maintenance is concerned with performing repairs and upgrades—for example, when equipment must be replaced, when a router needs a patch for an operating system image, when a new switch is added to a network. Maintenance also involves corrective and preventive measures to make the managed network run "better", such as adjusting device configuration parameters.
  - Provisioning is concerned with configuring resources in the network to support a given service. For example, this might include setting up the network so that a new customer can receive voice service.
- A common way of characterizing network management functions is FCAPS—Fault, Configuration, Accounting, Performance and Security.
  - Functions that are performed as part of network management accordingly include controlling, planning, allocating, deploying, coordinating, and monitoring the resources of a network, network planning, frequency allocation, predetermined traffic routing to support load balancing, cryptographic key distribution authorization, configuration management, fault management, security management, performance management, bandwidth management, route analytics and accounting management.
  - Data for network management is collected through several mechanisms, including agents installed on infrastructure, synthetic monitoring that simulates transactions, logs of activity, sniffers and real user monitoring.

May 26, 2010 Version 1.3 Link to Wikipedia 32

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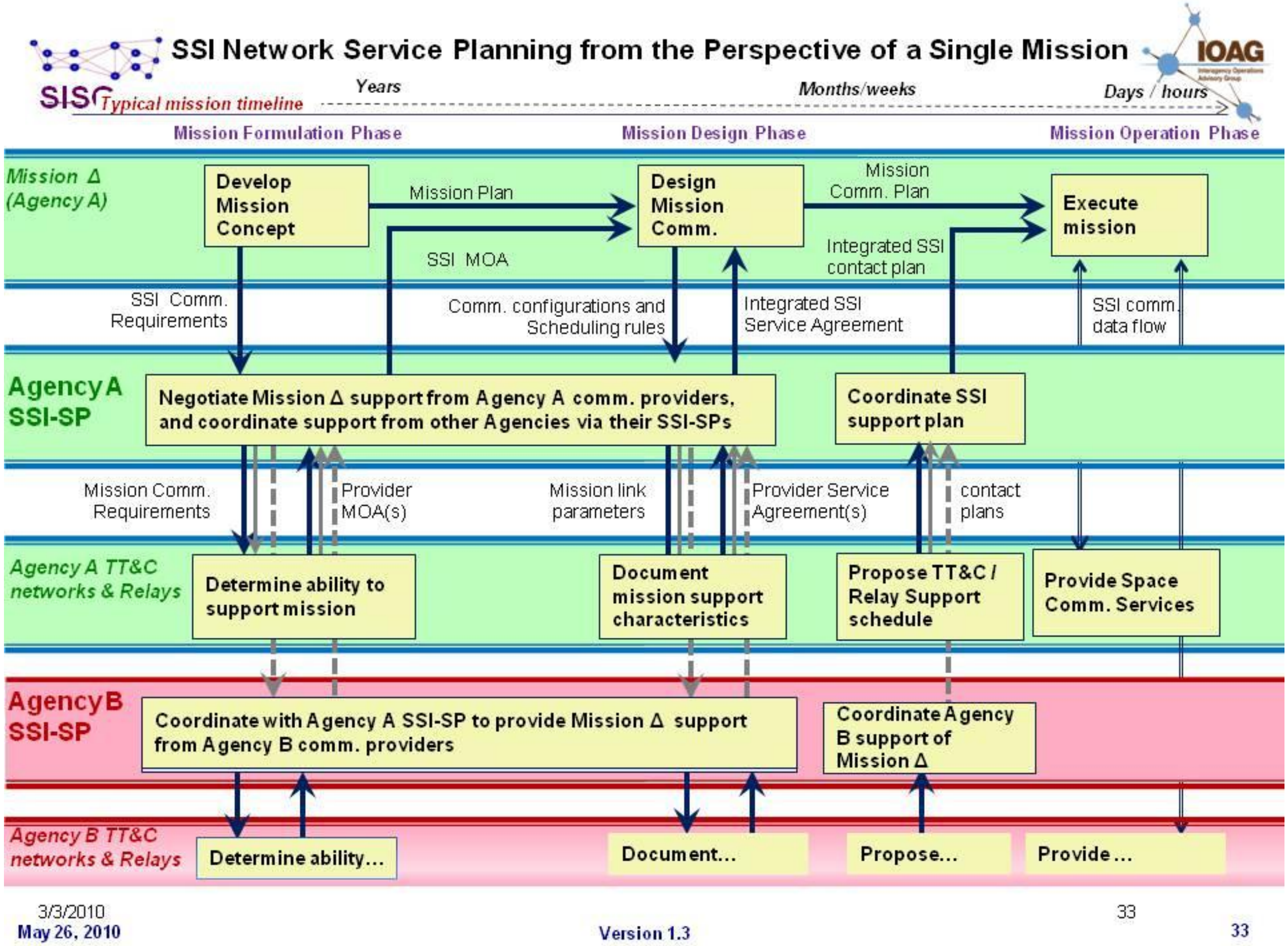
SSI Network Service Planning from the Perspective of a Single Mission
SISG
IOAG
Typical mission timeline
Years
Months/weeks
Days / hours
Mission Formulation Phase
Mission Design Phase
Mission Operation Phase
Mission Δ (Agency A)
Develop Mission Concept
Mission Plan
Design Mission Comm.
Mission Comm. Plan
Execute mission
SSI MOA
Integrated SSI contact plan
SSI Comm. Requirements
Comm. configurations and Scheduling rules
Integrated SSI Service Agreement
SSI comm. data flow
Agency A SSI-SP
Negotiate Mission Δ support from Agency A comm. providers, and coordinate support from other Agencies via their SSI-SPs
Coordinate SSI support plan
Mission Comm. Requirements
Provider MOA(s)
Mission link parameters
Provider Service Agreement(s)
contact plans
Agency A TT&C networks & Relays
Determine ability to support mission
Document mission support characteristics
Propose TT&C / Relay Support schedule
Provide Space Comm. Services
Agency B SSI-SP
Coordinate with Agency A SSI-SP to provide Mission Δ support from Agency B comm. providers
Coordinate Agency B support of Mission Δ
Agency B TT&C networks & Relays
Determine ability…
Document…
Propose…
Provide …
3/3/2010
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33

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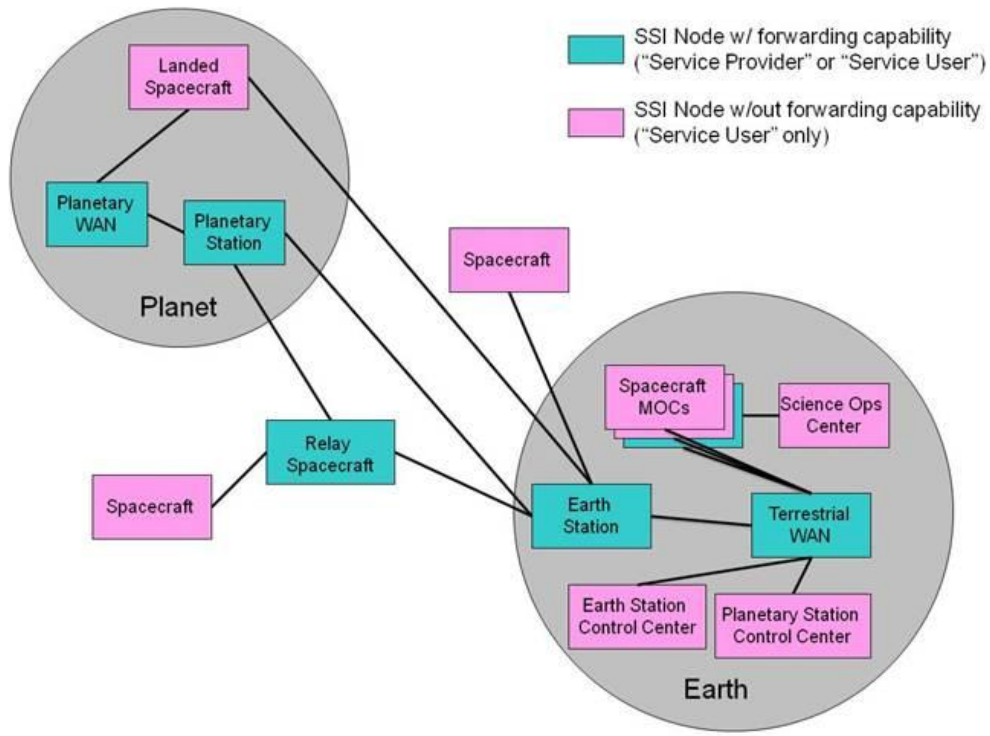
SISG

Definitions of SSI Nodes (From the Operations Concepts Document)

IOAG



May 26, 2010 | Version 1.3 | 34

Appendix C. Issue 4 Supplementary Material

Slide 1

Slide 2

SISG

Draft Requirements

- Provide "last hop" delivery services in the forward and return directions
  - Forward service: "emergency commanding", legacy (non-networked) mission commanding, Proximity link time service
  - Return service: "essential" telemetry, legacy (non-networked) mission telemetry, open loop recording (EDL & emergency), Proximity link radiometric & time service
- "Last hop" delivery service is an application level service residing on the node that provides the delivery service, described as a Delivery Agent
- Agreed conceptual approach to support this application service consists of a specification for the service request, Proximity link configuration parameters, the data to be transferred, and the reports to be generated
- Nominally designed to operate over SSI networked end-to-end services
  - May also be used to operate with transitional file relaying, hop-by-hop services, or even with legacy mission configurations
- Operate over end to end services, i.e. user to delivery end-point, or over "CSTS File Relay" service

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 2

Slide 3

SISG

Draft Requirements, contd

- Service Agreement is used to establish the agreement to provide services and the nature of the required services and possible link characteristics
- Service management parameters to configure the link for any specific instance of service are provided in the delivery package metadata
- In forward direction user is responsible for providing a “delivery package” containing a file with the necessary contents, pre-formatted, and metadata instructions as to how those data are to be delivered
- Forward Delivery Agent extracts data according to instructions and configures the “last hop” node to deliver those data over the link to the end node
- In return direction user is responsible for providing data acquisition “service request”
- Return Delivery Agent configures the “last hop” node to acquire the data as requested, packages the data as instructed, and returns the data and any associated metadata as a delivery package

5/25/2010 SISG SSI “Last Hop” Delivery Services **PS, et al 3**

Slide 4

SISG

Assumptions

- This discussion presumes that there is in place a service agreement of some form between the user and the provider to deliver these services
- These materials assume deployment of new, standardized, forward / return "last hop" delivery services on the Orbiters
  - The Delivery Agent is defined as an application that has a file interface, and the agent is defined separately from the means of transferring that file to/from the agent
  - Nominal configuration assumes implementation of a Delivery Agent on the Orbiter and use of SSI protocols to transfer the requests, associated data and reports between the Lander MOC and the Orbiter
  - Configurations where the Orbiter MOC implements the Delivery Agent functions and retains responsibility for full control of the data transfer and radio configurations are also possible
  - The same standard specification for the service request, Proximity link configuration parameters, the data to be transferred, and the report, is is to be used at the service provision interface to the Lander MOC
  - The same service production operations are to be performed over the "last hop" Proximity link, regardless of where the Delivery Agent is actually implemented
- Proximity link / radio configuration must be handled as a part of the "Forward Delivery Package" and the "Return Service Request"
  - This is a service management request describing how the Proximity link is to be configured
  - The same information must be conveyed for "emergency" service configurations and for "normal" legacy or SSI communications
  - One common approach should be used for all these link configurations
  - This link configuration information might be a part of the "Request Package" or it might be defined and stored on the orbiter (or in the Orbiter MOC) and then re-used.

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 4

Slide 5

SISG

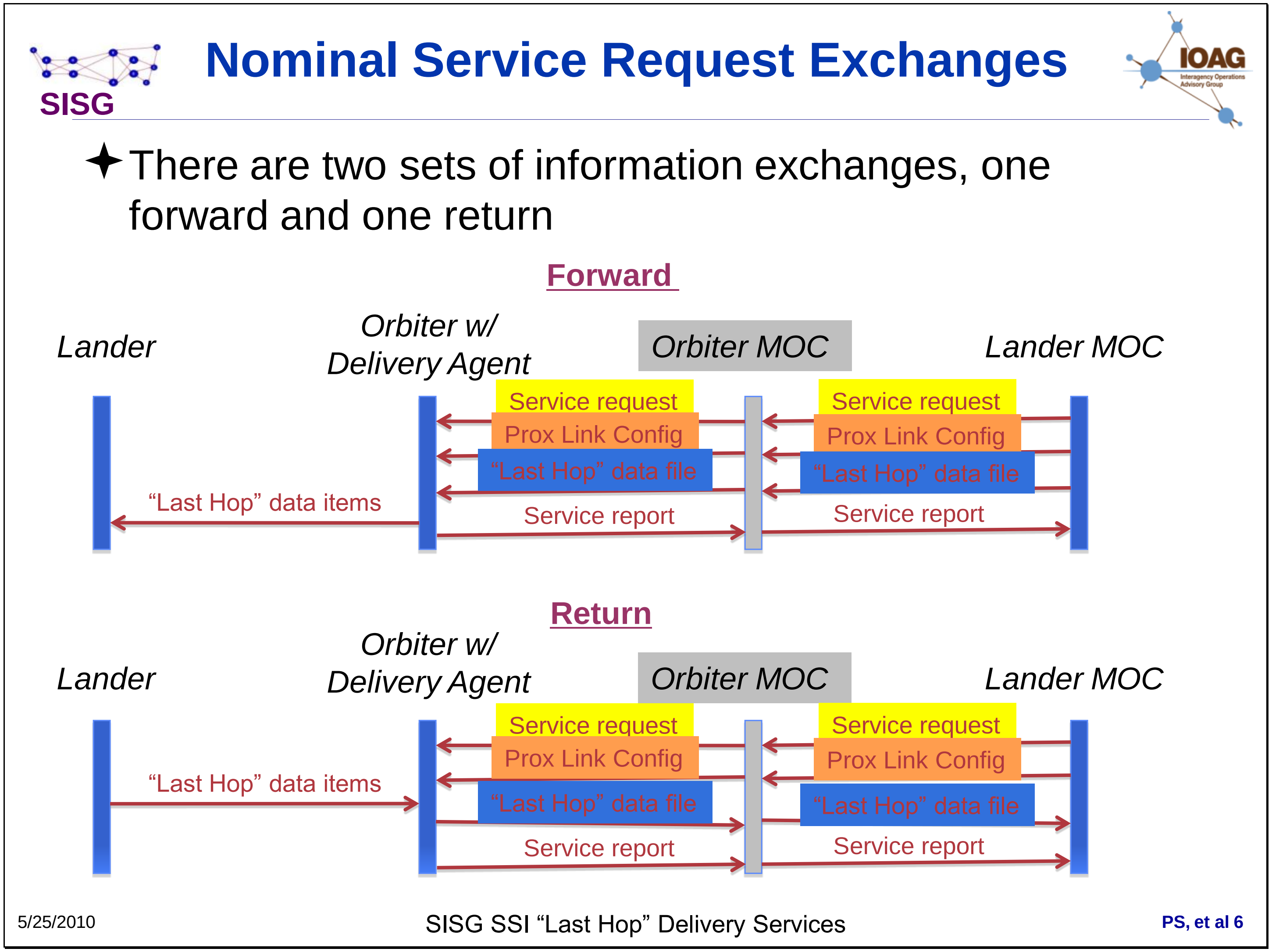
Assumptions, contd

IOAG

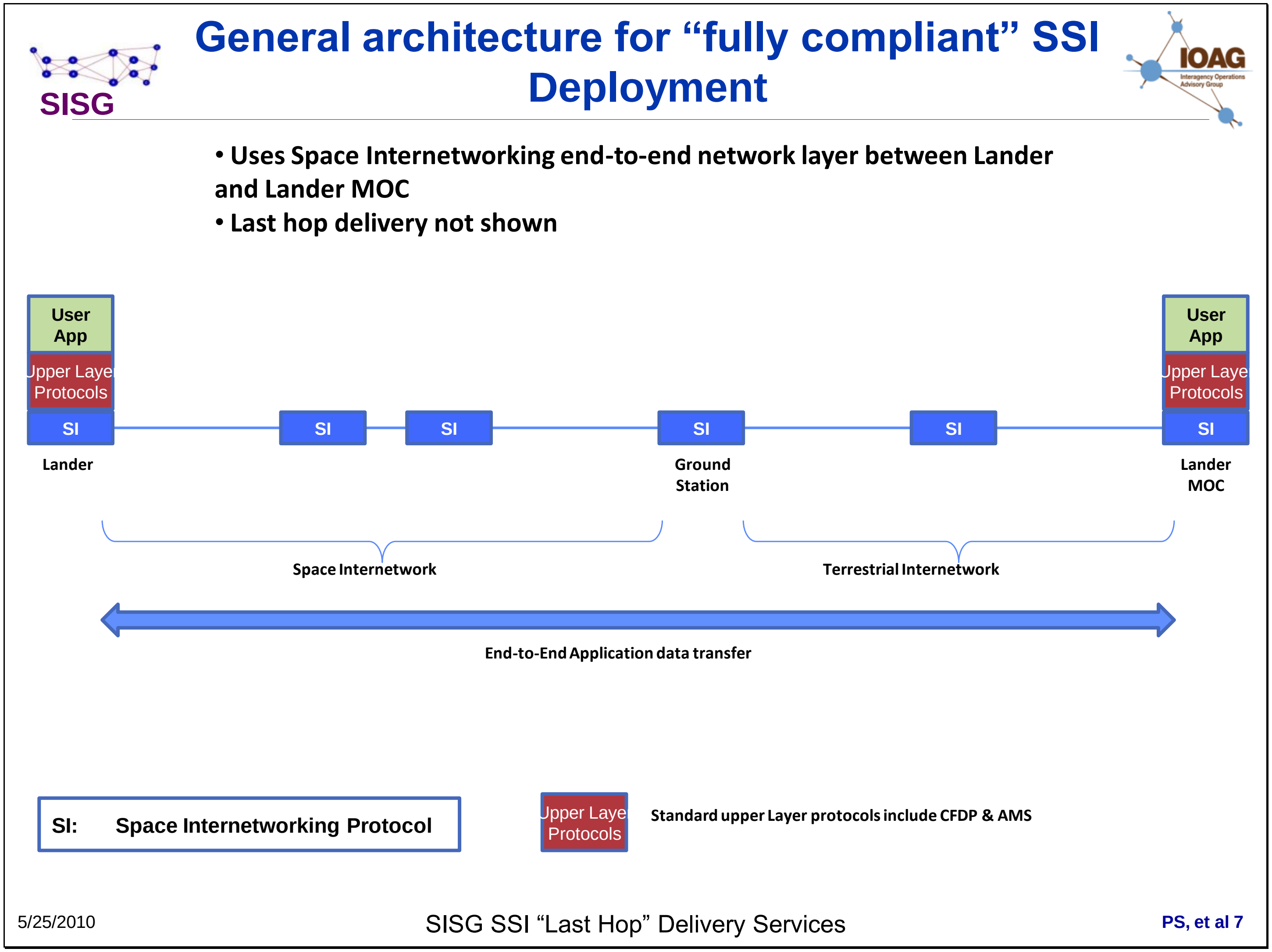
- The defined Forward cross supported service will standardize the request and configuration information is sent to the Delivery Agent and the format of the forwarded file data
  - Service request states what services are required of the Orbiter and when they are to be delivered
  - Proximity link configuration parameters state what is required to configure the Proximity link and radio
  - Format of the data to be transferred from the Orbiter to the Lander and how it is to be transferred
  - Format of the reports to be generated by the Orbiter on the status of the requested service
- The defined Return cross supported service will standardize the request and configuration information sent to the Delivery Agent, and the format of the returned file data
  - Service request states what services are required of the Orbiter and when they are to be performed
  - Proximity link configuration parameters state what is required to configure the Proximity link and radio
  - Format of the data to be returned from the Orbiter to the Lander MOC and how it is to be acquired
  - Format of the reports to be generated by the Orbiter on the status of the requested service
- The exact mechanisms for requesting, delivering and reporting on these services are TBS. A nominal approach using a file that packages this information is provided here.
- Standard mechanisms for reporting request status and service completion is required. This is not yet addressed in these materials.
- Details of various possible ground communications configurations are being addressed separately.
  - These materials assume a nominal SSI networked configuration, but an interim configuration, compliant with SISG Catalog 1 services, is also described for reference
- Network management is responsible for configuring the SSI network layer elements, routing, contacts, policies, and the like. It will be addressed separately.

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 5

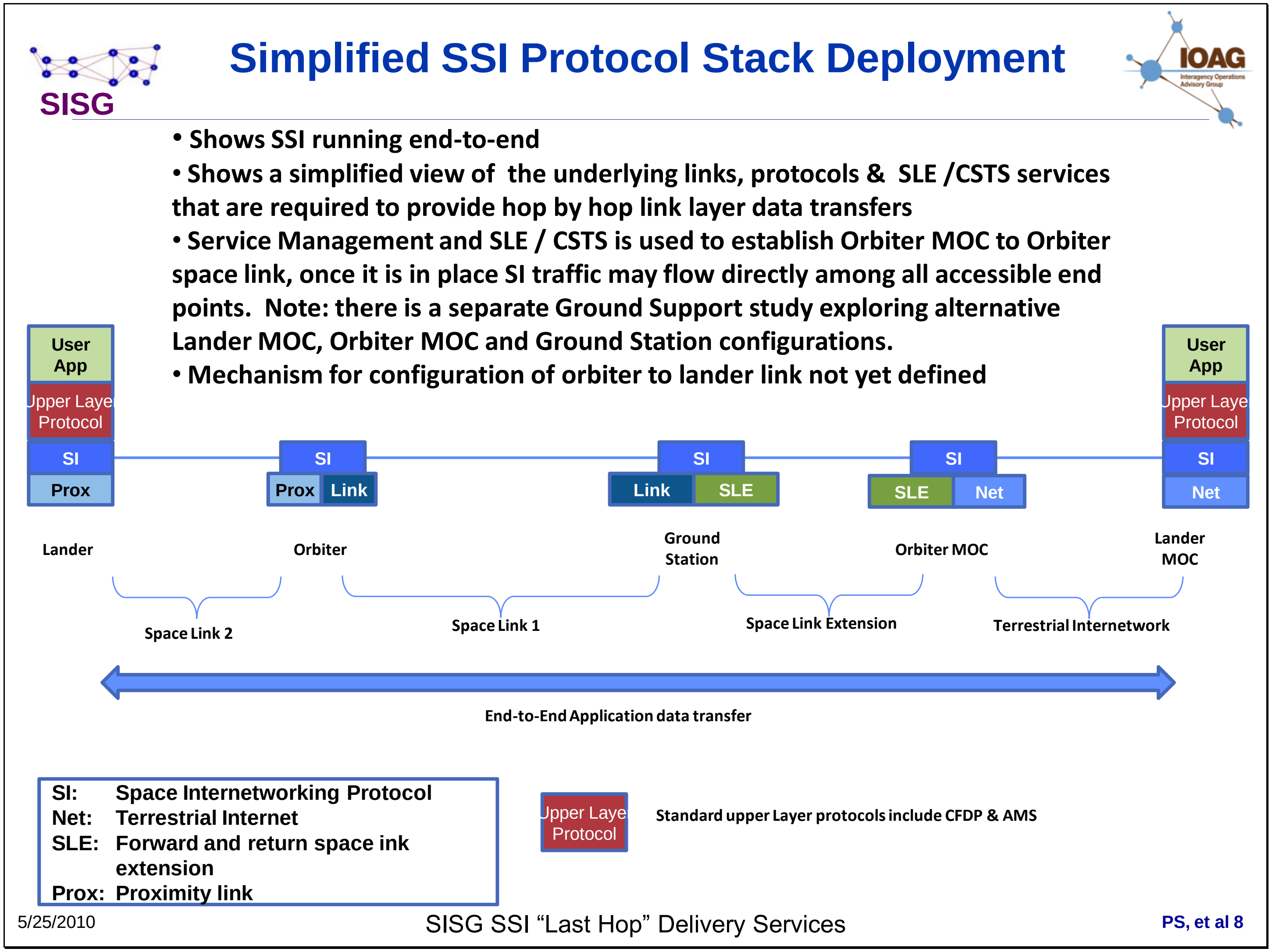
Slide 6


SISG
Nominal Service Request Exchanges
IOAG
There are two sets of information exchanges, one forward and one return
Forward
Lander
Orbiter w/ Delivery Agent
Orbiter MOC
Lander MOC
Service request
Prox Link Config
"Last Hop" data file
"Last Hop" data items
Service report
Service request
Prox Link Config
"Last Hop" data file
Service report
Return
Lander
Orbiter w/ Delivery Agent
Orbiter MOC
Lander MOC
Service request
Prox Link Config
"Last Hop" data items
"Last Hop" data file
Service report
Service request
Prox Link Config
"Last Hop" data file
Service report
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 6

Slide 7


SISG
General architecture for "fully compliant" SSI Deployment
IOAG
• Uses Space Internetworking end-to-end network layer between Lander and Lander MOC
• Last hop delivery not shown
User App
Upper Layer Protocols
SI
Lander
SI
SI
SI
Ground Station
SI
User App
Upper Layer Protocols
SI
Lander MOC
Space Internetwork
Terrestrial Internetwork
End-to-End Application data transfer
SI: Space Internetworking Protocol
Upper Layer Protocols
Standard upper Layer protocols include CFDP & AMS
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 7

Slide 8


SISG
Simplified SSI Protocol Stack Deployment
IOAG
• Shows SSI running end-to-end
• Shows a simplified view of the underlying links, protocols & SLE /CSTS services that are required to provide hop by hop link layer data transfers
• Service Management and SLE / CSTS is used to establish Orbiter MOC to Orbiter space link, once it is in place SI traffic may flow directly among all accessible end points. Note: there is a separate Ground Support study exploring alternative Lander MOC, Orbiter MOC and Ground Station configurations.
• Mechanism for configuration of orbiter to lander link not yet defined
User App
Upper Layer Protocol
SI
Prox
Link
SLE
Net
Lander
Orbiter
Ground Station
Orbiter MOC
Lander MOC
Space Link 2
Space Link 1
Space Link Extension
Terrestrial Internetwork
End-to-End Application data transfer
SI: Space Internetworking Protocol
Net: Terrestrial Internet
SLE: Forward and return space ink extension
Prox: Proximity link
Standard upper Layer protocols include CFDP & AMS
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 8

Slide 9

SISG

Forward Delivery Package

- **Two main elements packaged within a file**
  - **Data to be delivered**
  - **Delivery metadata (service management for prox link configuration and delivery instructions to last hop delivery agent)**

Data to be delivered	Delivery metadata
May be TC frames, BCH code blocks, space packets, AOS frames or other well defined link artifacts Constructed by the user to conform to required inputs for target spacecraft hardware command decoder	Parameters defining how to configure the "last hop" link (UDD or packet SAP, bit rate, channel, port) Instructions as to when to deliver data (next pass or pass #), how to extract data (data structures), how to deliver the data (once, continuously), and when to terminate (# of retries, time out, signal)

- Formats for the Delivery Package to be defined and agreed
- Standard report on service as delivered to be defined and agreed
- See following discussion for return delivery package and process

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 9

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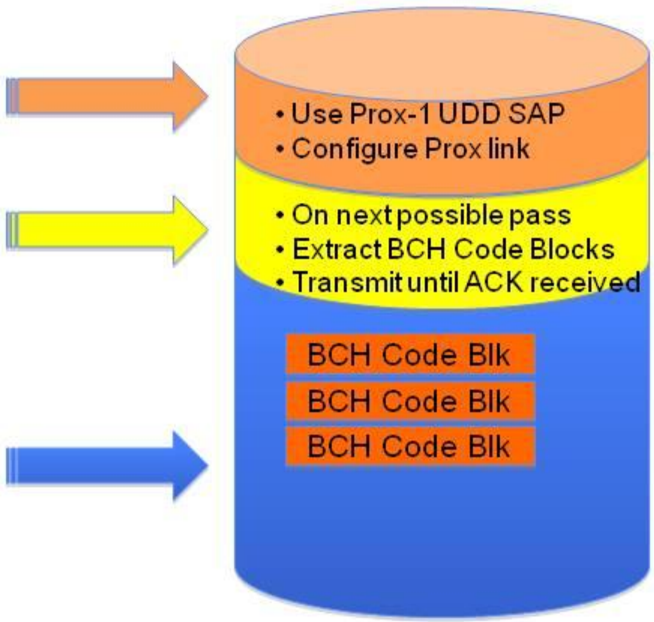
SISG

Forward Delivery Package Contents

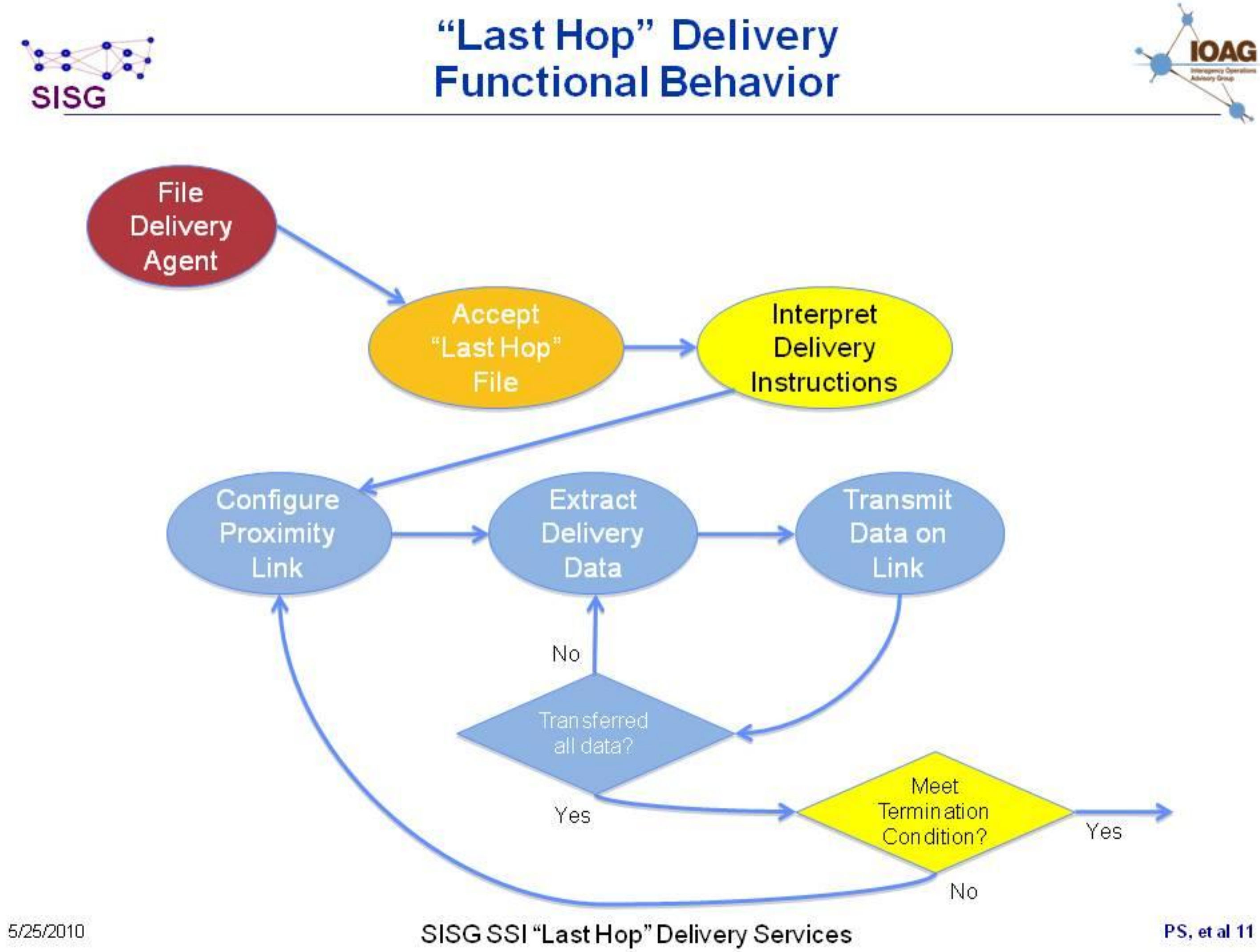
IOAG

- Delivery metadata
  - Instructions on which link to use and how to configure the “last hop” link (UDD or packet SAP)
  - Instructions on when to provide the service, how to extract data (data structures), how to deliver the data (once, continuously), and when to terminate (# of retries, time out, signal)
- Data to be delivered
  - Could be TC frames, BCH code blocks, space packets, AOS frames or other well defined link artifacts

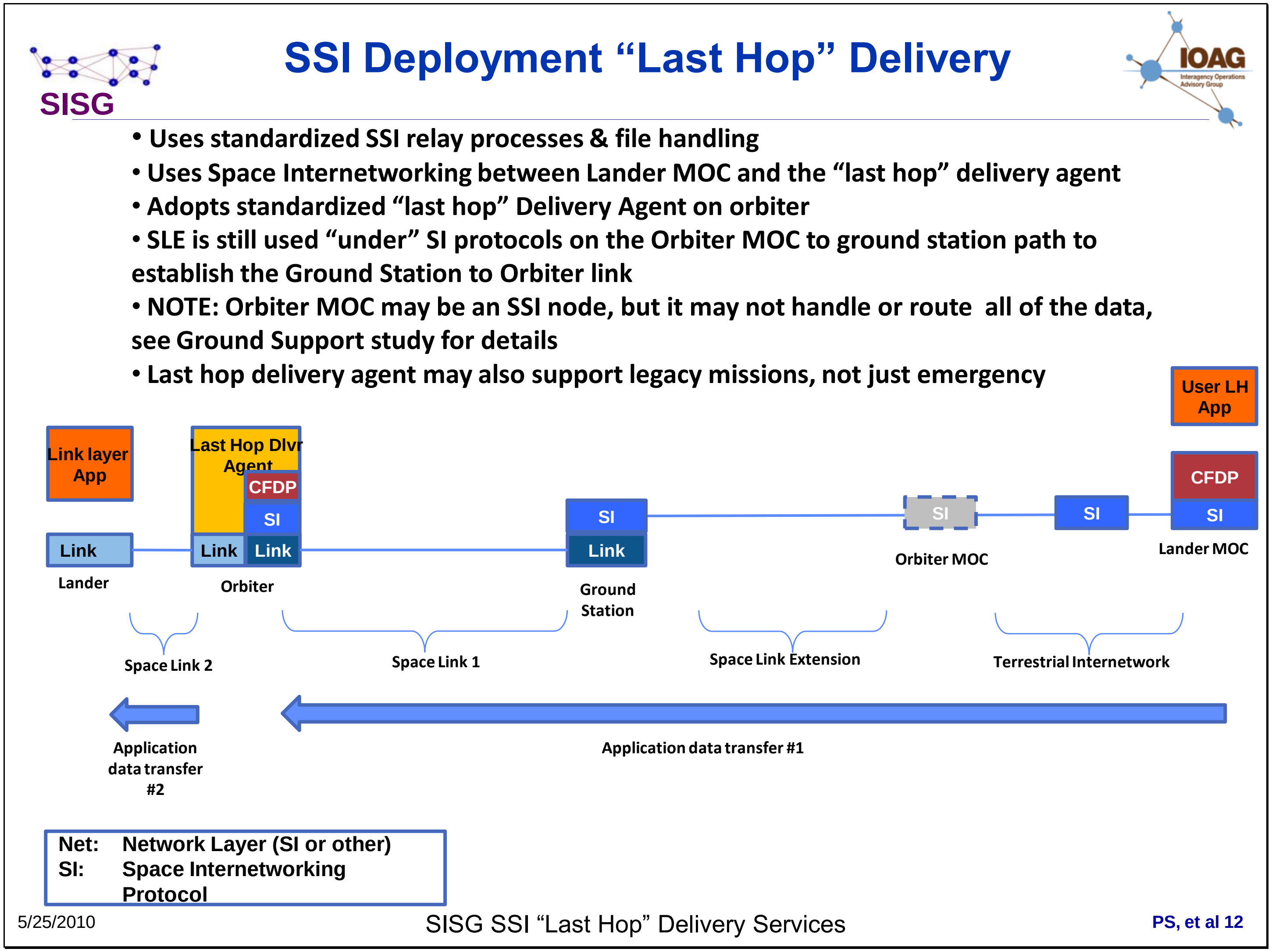


5/25/2010 SISG SSI “Last Hop” Delivery Services PS, et al 10

Slide 11


SISG
"Last Hop" Delivery
Functional Behavior
IOAG
File Delivery Agent
Accept "Last Hop" File
Interpret Delivery Instructions
Configure Proximity Link
Extract Delivery Data
Transmit Data on Link
No
Transferred all data?
Yes
Meet Termination Condition?
Yes
No
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 11

Slide 12


SISG
SSI Deployment "Last Hop" Delivery
IOAG
• Uses standardized SSI relay processes & file handling
• Uses Space Internetworking between Lander MOC and the "last hop" delivery agent
• Adopts standardized "last hop" Delivery Agent on orbiter
• SLE is still used "under" SI protocols on the Orbiter MOC to ground station path to establish the Ground Station to Orbiter link
• NOTE: Orbiter MOC may be an SSI node, but it may not handle or route all of the data, see Ground Support study for details
• Last hop delivery agent may also support legacy missions, not just emergency
User LH App
Link layer App
Last Hop Dlvr Agent
CFDP
SI
Link
Link
Lander
Orbiter
SI
Link
Ground Station
SI
Orbiter MOC
SI
CFDP
SI
Lander MOC
Space Link 2
Space Link 1
Space Link Extension
Terrestrial Internetwork
Application data transfer #2
Application data transfer #1
Net: Network Layer (SI or other)
SI: Space Internetworking Protocol
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 12

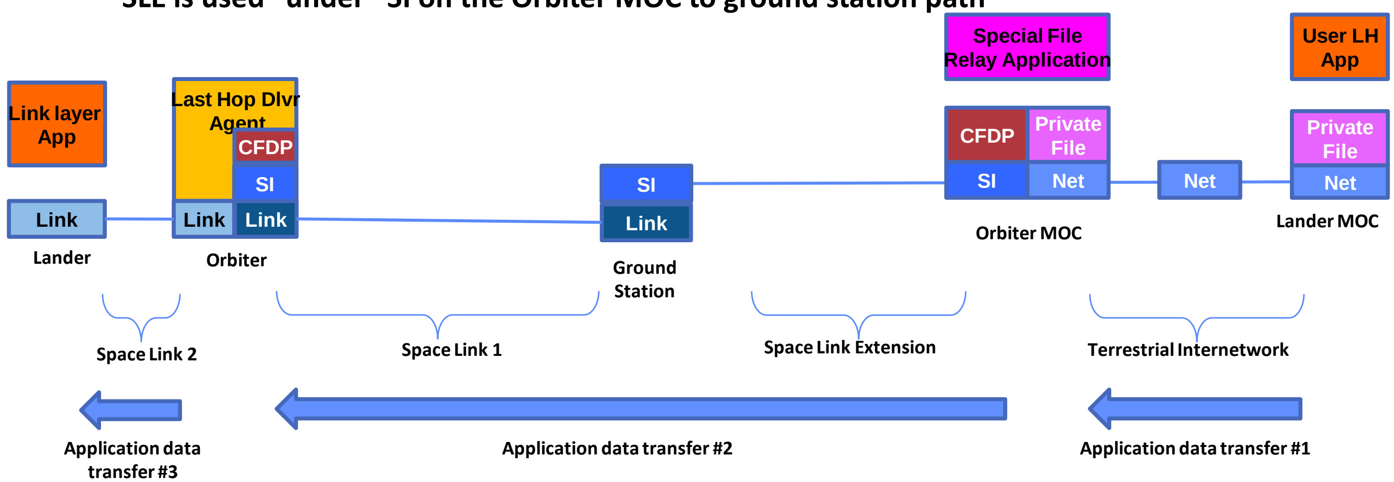
Slide 13

SISG

IOAG

Evolving "mixed mode" SSI Deployment "Last Hop" Delivery

- Uses evolving SSI relay processes & file handling
- Uses Space Internetworking between orbiter MOC and the "last hop" delivery agent
- Retains existing Lander MOC to Orbiter MOC private file procedures
- Orbiter MOC handles all of the data
- Adopts "last hop" delivery approach on orbiter
- "Private File" transfer terrestrially might use some future standardized file transfer, see Service Catalog 1 discussion
- SLE is used "under" SI on the Orbiter MOC to ground station path



Net: Network Layer (SI or other)
SI: Space Internetworking Protocol

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 13

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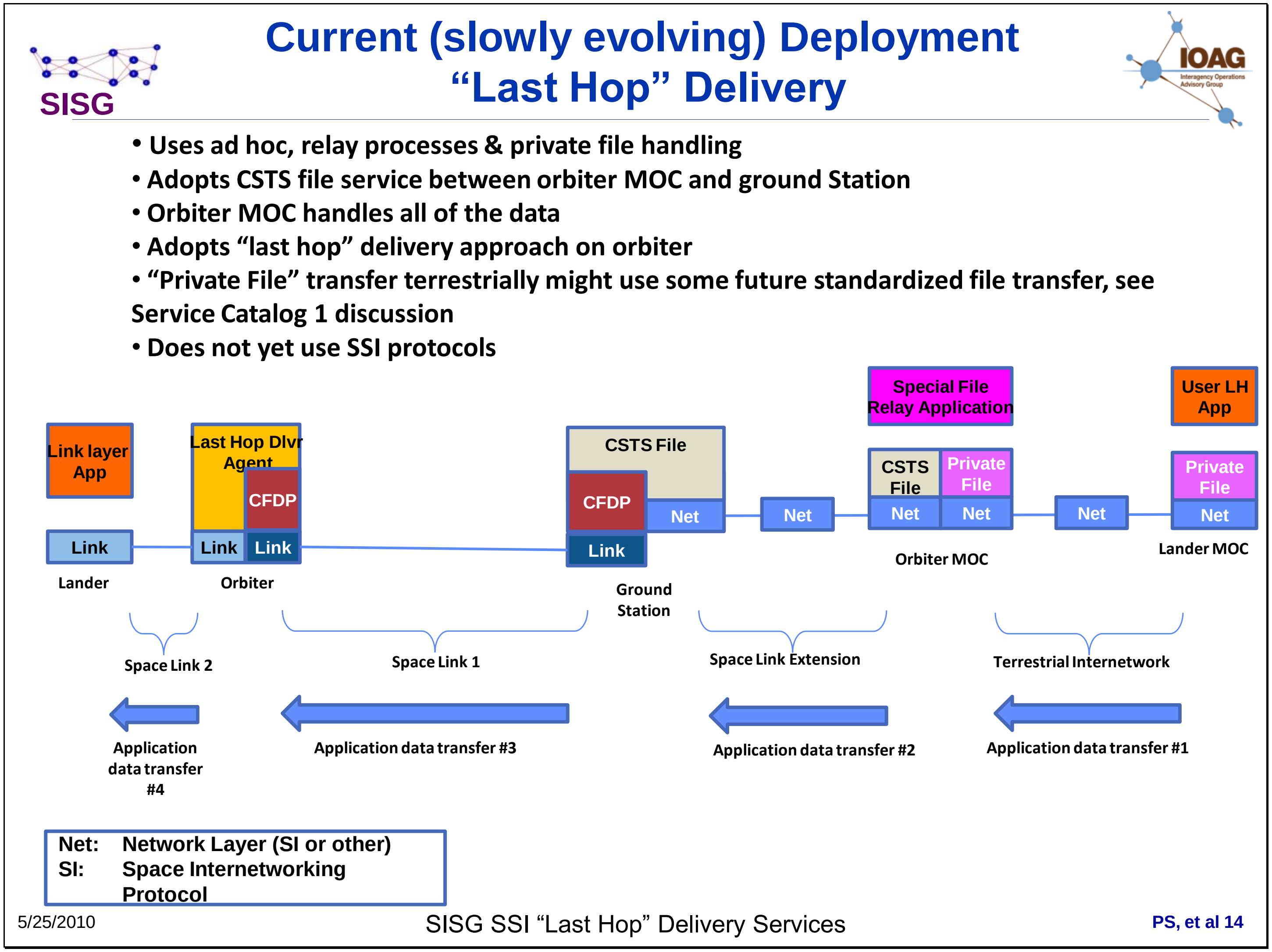
SISG
Current (slowly evolving) Deployment
"Last Hop" Delivery
IOAG
• Uses ad hoc, relay processes & private file handling
• Adopts CSTS file service between orbiter MOC and ground Station
• Orbiter MOC handles all of the data
• Adopts "last hop" delivery approach on orbiter
• "Private File" transfer terrestrially might use some future standardized file transfer, see Service Catalog 1 discussion
• Does not yet use SSI protocols
Special File Relay Application
User LH App
Link layer App
Last Hop Dlvr Agent
CFDP
CSTS File
CFDP
CSTS File
Private File
Private File
Net
Net
Net
Net
Net
Net
Link
Link
Link
Link
Lander
Orbiter
Ground Station
Orbiter MOC
Lander MOC
Space Link 2
Space Link 1
Space Link Extension
Terrestrial Internetwork
Application data transfer #4
Application data transfer #3
Application data transfer #2
Application data transfer #1
Net: Network Layer (SI or other)
SI: Space Internetworking Protocol
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 14

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SISG

Return Delivery Package

- Return service: "essential" telemetry, open loop recording (EDL and emergency support), proximity link tracking & time data return, legacy (non-networked) mission telemetry
- Return service has to be initiated and/or configured
  - Defines a standard "service request" for delivery of this service, Instructions as to how to configure the "last hop" link (UDD or packet SAP)
- Two main elements packaged in a file
  - Data to be delivered
  - Delivery metadata (documentation to delivery target)

Data to be delivered	Delivery metadata
• May be TM frames, space packets, open loop recording, tracking or time data, or other well defined link artifacts • Constructed by the return agent according to the agreed process	• Link configuration parameters • Processing instructions

- Formats for the Delivery Package to be defined and agreed
- Standard report on service as delivered to be defined and agreed

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 15

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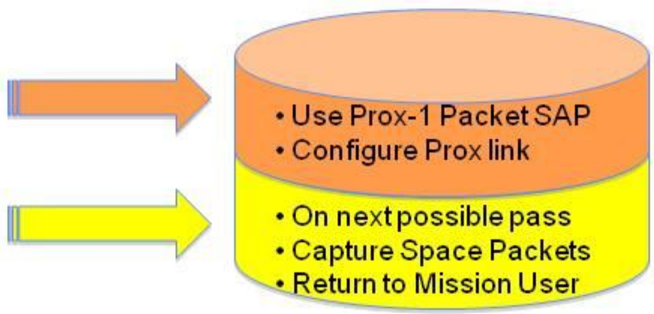
SISG

Return Service Request

IOAG

- Service Request to "Last Hop" return agent
  - Instructions on which link to use, and how to configure the "last hop" link (UDD or packet SAP)
  - Instructions on when to provide the service, what data to return (data structures), how to process the data and how/where to deliver the data



5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 16

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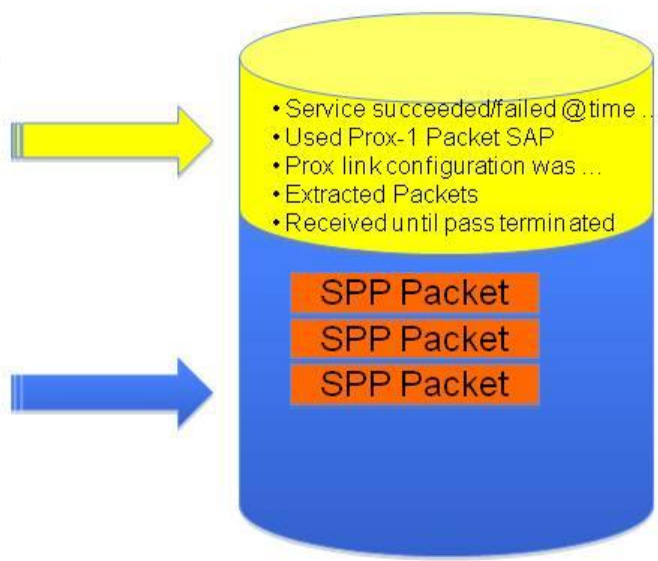
SISG

Return Delivery Package Contents

IOAG

- Delivery metadata
  - Description of when the service was performed, how the "last hop" link (UDD or packet SAP) was configured, time of service, and report on what processing was performed (may be separate)
- Data that was processed
  - Could be TM frames, space packets, AOS frames, open loop wideband digitized bandpass data, radiometric or time data derived form the Proximity link, or other well defined link artifacts



5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 17

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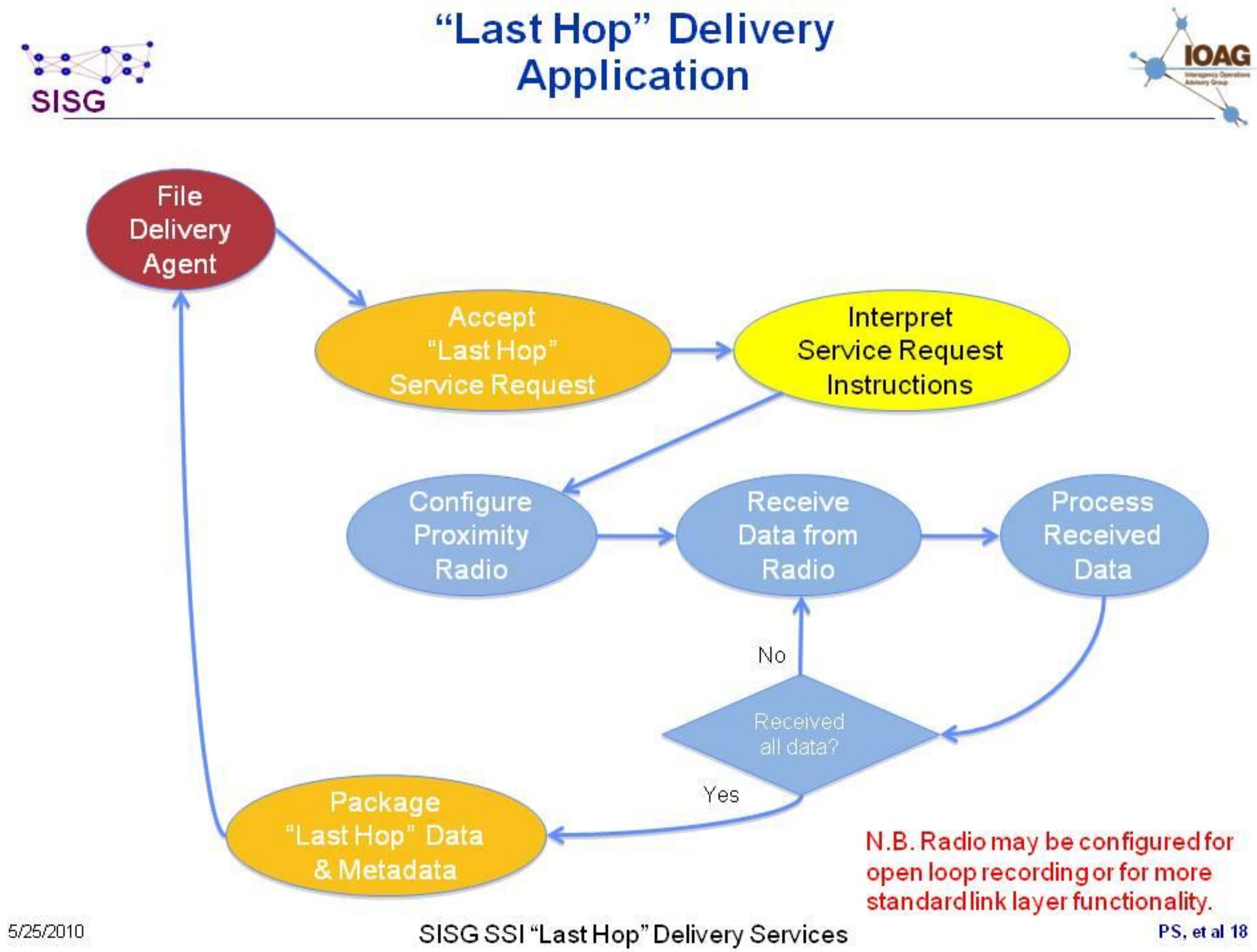
SISG
"Last Hop" Delivery Application
IOAG
File Delivery Agent
Accept "Last Hop" Service Request
Interpret Service Request Instructions
Configure Proximity Radio
Receive Data from Radio
Process Received Data
No
Received all data?
Yes
Package "Last Hop" Data & Metadata
N.B. Radio may be configured for open loop recording or for more standard link layer functionality.
5/25/2010
SISG SSI "Last Hop" Delivery Services
PS, et al 18

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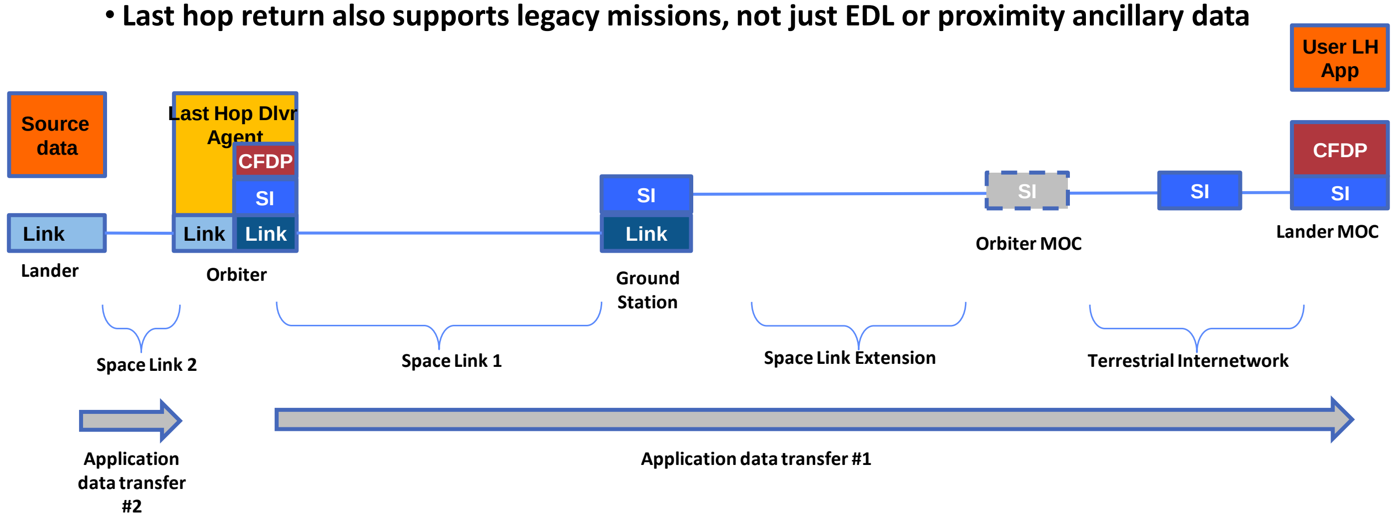
SISG

SSI Deployment "Last Hop" Return Delivery

IOAG

- Uses standardized evolved SSI relay processes & file handling
- Implements "last hop" return approach on orbiter
- Uses Space Internetworking between "last hop" return agent and the Lander MOC
- SLE is still used "under" SI protocols on the ground station to Orbiter MOC path to establish the Ground Station to Orbiter link
- Orbiter MOC may be an SSI node, but it does not need to handle & route all of the data
- Last hop return also supports legacy missions, not just EDL or proximity ancillary data



Net: Network Layer (SI or other)
SI: Space Internetworking Protocol

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 19

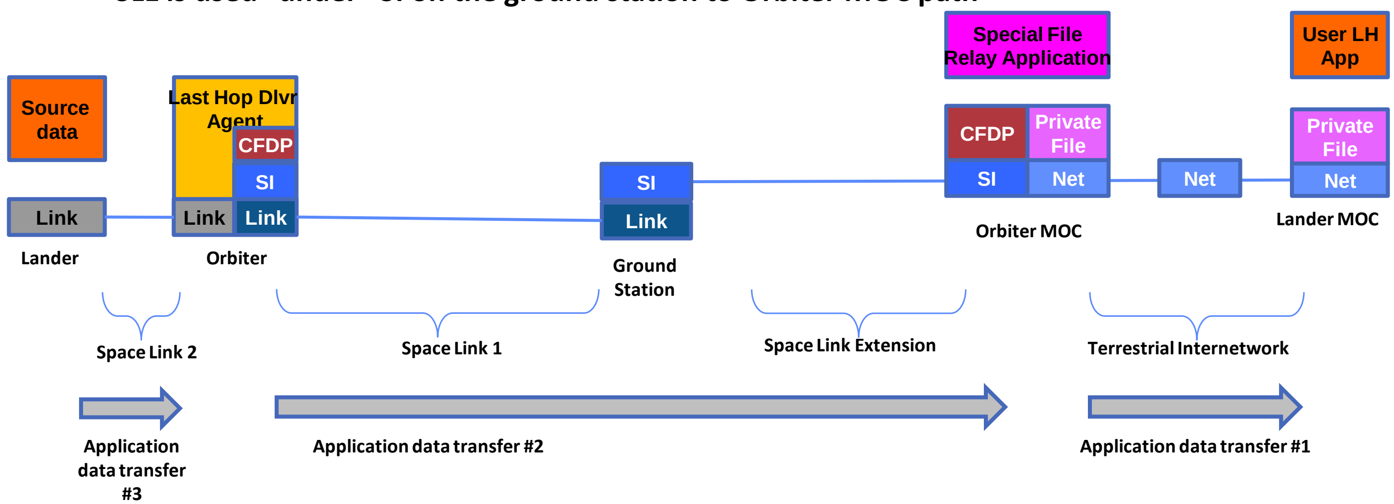
Slide 20

SISG

Evolving "mixed mode" SSI Deployment "Last Hop" Return Delivery

IOAG

- Uses evolving SSI relay processes & file handling
- Uses Space Internetworking between the "last hop" return agent and the Orbiter MOC
- Retains existing Lander MOC to Orbiter MOC private file procedures
    - "Private File" transfer terrestrially might use some future standardized file transfer, see Service Catalog 1 discussion
- Adopts "last hop" return approach on orbiter
- SLE is used "under" SI on the ground station to Orbiter MOC path



Net: Network Layer (SI or other)
SI: Space Internetworking Protocol

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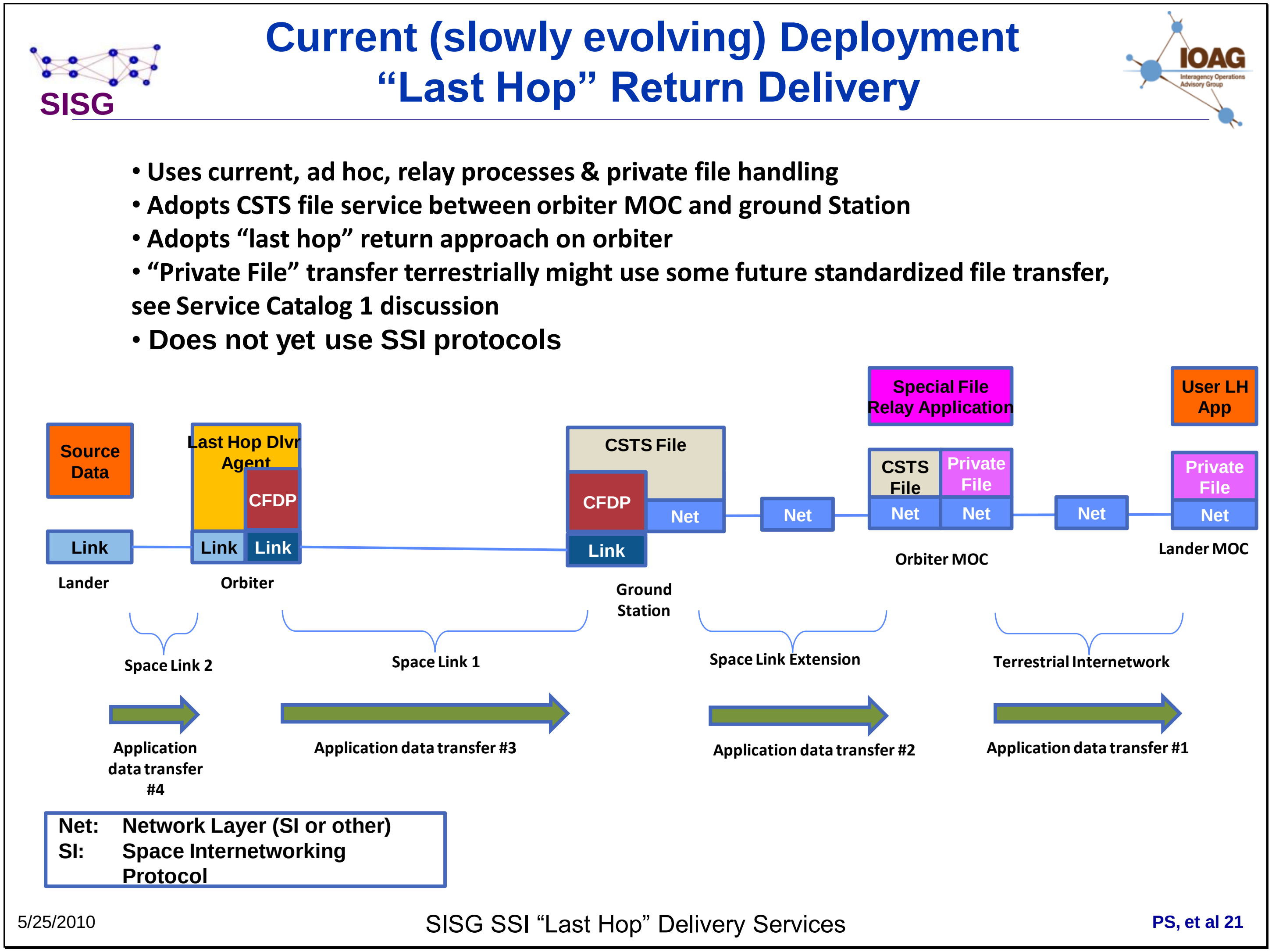
SISG
Current (slowly evolving) Deployment
"Last Hop" Return Delivery
IOAG
Interagency Operations Advisory Group
• Uses current, ad hoc, relay processes & private file handling
• Adopts CSTS file service between orbiter MOC and ground Station
• Adopts "last hop" return approach on orbiter
• "Private File" transfer terrestrially might use some future standardized file transfer, see Service Catalog 1 discussion
• Does not yet use SSI protocols
Source Data
Link
Lander
Last Hop Dlvr Agent
CFDP
Link
Link
Orbiter
CSTS File
CFDP
Net
Link
Ground Station
Net
Special File Relay Application
CSTS File
Private File
Net
Net
Orbiter MOC
Net
User LH App
Private File
Net
Lander MOC
Space Link 2
Space Link 1
Space Link Extension
Terrestrial Internetwork
Application data transfer #4
Application data transfer #3
Application data transfer #2
Application data transfer #1
Net: Network Layer (SI or other)
SI: Space Internetworking Protocol
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SISG SSI "Last Hop" Delivery Services
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SISG

Other Notes

IOAG

- There is a wide variety of possible orbiter MOC to ground station and Lander MOC to Orbiter MOC configurations. Many of these are being analyzed separately in a different study call "Ground Support Considerations".
- This approach assumes the nominal case of a standard Delivery Agent on the Orbiter and the use of SSI protocols to transfer the Delivery Package to the Orbiter.
- This also assumes that the Delivery Agent accepts Proximity link configuration parameters and locally performs the necessary radio and link commanding.
- It is possible, in legacy or evolving / hybrid mission configurations, for the service provision part of the Delivery Agent to be implemented in the Orbiter MOC. In these cases the Orbiter handles all of the data, transfers it to the Orbiter, possibly by private means, and sends explicit commands to the Orbiter that are used locally to configure the radio.
- As long as the agreed service is delivered at the two interfaces, ground and space, either of these will be considered compliant approaches.
- To reiterate, the specific details for how a Delivery Package is to be defined, or for the service request, link configuration parameters, data package, or reports is yet to be agreed.

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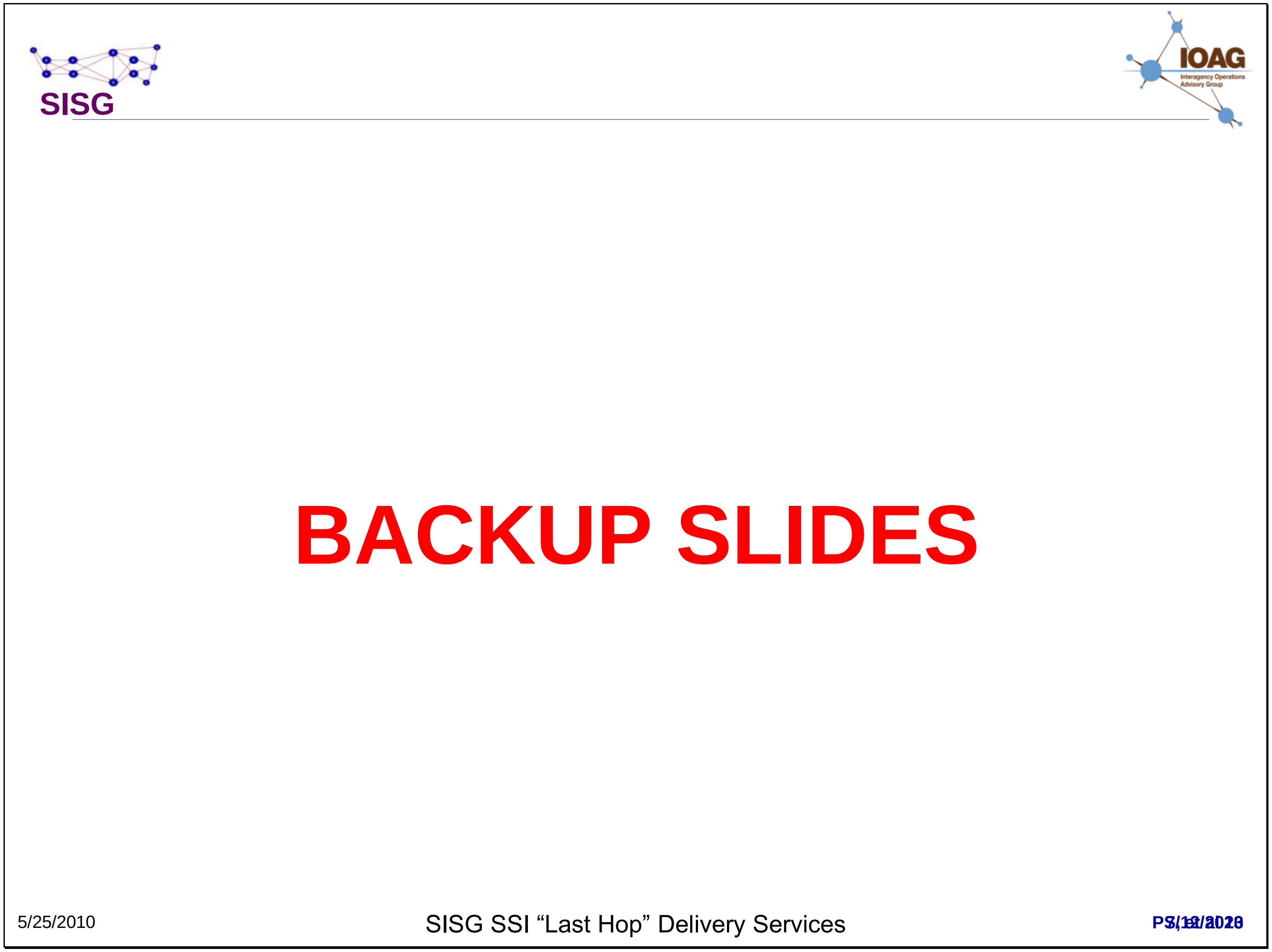
SISG
IOAG
BACKUP SLIDES
5/25/2010
SISG SSI "Last Hop" Delivery Services

Slide 24

SISG

Notes on Backup Materials

- The following two slides were developed during team discussions, but were removed from the final package
- They represent a use of the defined Last Hop Delivery Agent approach applied to the ground station in an “ABA” Orbiter MOC to Ground Station to Orbiter configuration
- This has the advantage of re-use of this new capability and may reduce the implementation costs of an Orbiter MOC that has already adopted use of SSI
- However, since this configuration offers no additional capability for emergency commanding and essential telemetry than is already provided by SLE, and most MOCs already are using normal TT&C based on SLE, these possible configurations have been eliminated from the baseline approach

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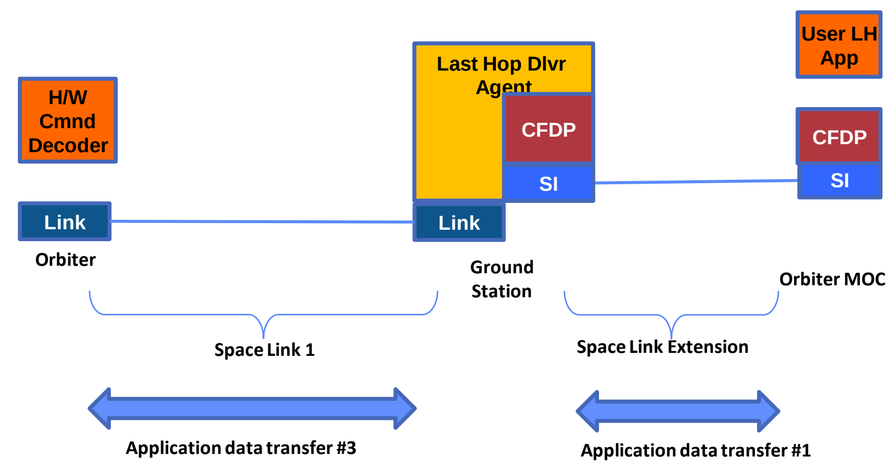
Slide 25

SISG

Evolved "fully compliant" SSI Deployment "Last Hop" Delivery to Orbiter

IOAG

- Uses evolved SSI relay processes & file handling
- Uses Space Internetworking between Lander MOC and the "last hop" delivery agent
- Adopts "last hop" delivery approach on orbiter
- Could also be handled as direct commands from Orbiter MOC via SLE, w/o "Last Hop"
- SLE is used "under" SI on the Orbiter MOC to ground station path



Net: Network Layer (SI or other)
SI: Space Internetworking Protocol

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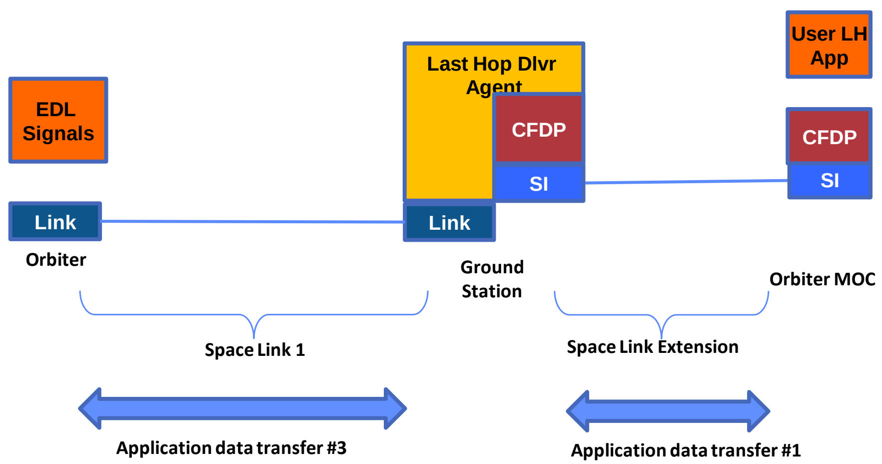
Slide 26

SISG

Evolved "fully compliant" SSI Deployment "Last Hop" Return From Orbiter

IOAG

- Uses evolved SSI relay processes & file handling
- Implements "last hop" return approach on orbiter
- Uses Space Internetworking between the "last hop" return agent and Lander MOC
- Could also handled "essential telemetry" direct to Orbiter MOC via SLE, w/o "Last Hop"
- SLE is used "under" SI on the ground station to Orbiter MOC path



Net: Network Layer (SI or other)
SI: Space Internetworking Protocol

5/25/2010 SISG SSI "Last Hop" Delivery Services PS, et al 26

Appendix D. Issues 6 and 8 Supplementary Material

File-Based Operations Requirement	Incorporated	DTN GB Requirement(s)	Additional notes
General Requirements			
REQ.GEN.1 Communications shall be supported directly from Earth to a spacecraft.	Yes	4.2.2.1.1 Communications shall be supported to a spacecraft via zero or more intermediate relays.	
REQ.GEN.2 Communications shall be supported to a spacecraft via an intermediate spacecraft relay.		Covered by 4.2.2.1.1	
REQ.GEN.3 Other entities which may perform the role of relays shall include ground facilities, earth stations, data relay satellites, orbiters, landers and internal spacecraft nodes.		Covered by 4.2.2.1.1	
REQ.GEN.4 Deployed networks on planetary surfaces shall be supported.	Yes	4.2.2.1.2 It shall be possible to use local, in-situ networking technologies different from the end-to-end space internetwork technology.	
REQ.GEN.5 Both file and message based operations shall be supported.	Yes	4.2.2.1.3 The system shall support a general class of applications, including at least file transfer and messaging.	
REQ.GEN.6 International standards shall be respected at cross support points.			Motherhood and apple pie. Alternatively, this precludes support for PUS packet transport across cross support points.
REQ.GEN.7 Management information relating to data transfer shall be collected in all nodes and shall be made available to network operators as well as management facilities.	Yes	4.2.2.1.4 Management information relating to data transfer shall be collected in all nodes.	
REQ.GEN.8 Network operators and management facilities shall be able to manipulate management information in all nodes.	Yes	4.2.2.1.5 Management information relating to data transfer shall be made available to network operators.	
REQ.GEN.9 Routing shall be managed with no requirement for autonomous route discovery.			This is an explicit NON-requirement (no requirement for autonomous routing). Routing (via manual and/or autonomous means) is of course required.
REQ.GEN.10 Autonomous switching to pre-planned redundancy routes shall be provided.	Yes	4.2.2.1.7 It shall be possible to configure routing to automatically fail over to redundant routes if such routes are available.	

REQ.GEN.11 A minimum of protocols to support the requirements shall be adopted.			A good goal, but not a good requirement. E.g. I can do everything with one protocol, if it's monolithic.
REQ.GEN.12 Techniques for interoperability between areas of responsibility shall be rationalised (e.g. use similar procedures between user and ESA segments as between ESA and NASA centres).			A good goal, but beyond scope of the SIS-DTN WG. We can define such mechanisms (we are), but we can't enforce them.
REQ.GEN.13 Communications firewalls shall be implemented at interoperability points to guarantee mission security.	Yes	4.2.2.1.8 Communications firewalls shall be implemented at interoperability points to guarantee mission security.	
REQ.GEN.14 Methods for user authentication shall be incorporated with authenticated users having associated levels of permission and resource allocation.	Yes	4.2.2.1.9 Methods for user authentication shall be incorporated with authenticated users having associated levels of permission and resource allocation.	
REQ.GEN.15 Data privacy between users shall be provided.	Yes	4.2.2.1.10 Data privacy between users shall be provided.	
REQ.GEN.16 It shall be possible to use multiple ground stations for a mission with some ground stations providing downlink capability only.	Yes	4.2.2.1.11 It shall be possible to use multiple ground stations to communicate with a single space asset with some ground stations providing downlink capability only.	
REQ.GEN.17 It shall be possible to transmit science data from the ground station directly to the payload data centre without routing via the control centre. Note: This could be advantageous in the case that capacity of the ground station control centre link is too low to send all the data via the control centre within an acceptable time frame.	Yes	4.2.2.1.12 It shall be possible to route data from the ground station directly to destinations without routing via the control center.	
REQ.GEN.18 Application layer firewalls shall be implemented at interoperability points to guarantee mission safety.	Yes	4.2.2.1.13 It shall be possible to implement application layer firewalls at interoperability points to guarantee mission safety.	
	Yes	4.2.2.1.14 'Hardware commanding' of spacecraft by embedding special command sequences in either frames or packets shall be supported.	
Data Transport Requirements			

REQ.TP.1 deleted			
REQ.TP.2 deleted			
REQ.TP.3 deleted			
REQ.TP.4 deleted			
REQ.TP.5 deleted			
REQ.TP.6 deleted			
REQ.TP.7 deleted			
REQ.TP.8 It shall be possible to initiate data relaying either by autonomous methods within the network or managed by mission/infrastructure network management or a combination of both.	Yes	4.2.2.2.1 It shall be possible to send a file to an application on board a spacecraft that can, either by autonomous methods or managed by mission / infrastructure management or a combination of both, convey the file to a second spacecraft.	
REQ.TP.9 deleted			
REQ.TP.10 deleted			
REQ.TP.11 deleted			
REQ.TP.12 deleted			
REQ.TP.13 deleted			
REQ.TP.14 deleted			
REQ.TP.15 It shall be possible to multiplex data belonging to file transfer with other types of forward and return data (e.g. TM/TC packets).			
REQ.TP.16 It shall be possible to segregate the data belonging to file transfer from other data exchanged on the space link.			Covered by 'General class of applications' and 'demultiplex to specific application instance' requirements.
REQ.TP.17 The end-to-end infrastructure and protocols shall be capable of transferring, as Service Data Units (SDUs), the Protocol Data Units (PDUs) of the CCSDS File Delivery Protocol	Yes	4.2.2.2.2 The end-to-end infrastructure and protocols shall be capable of transferring, as Service Data Units (SDUs), the Protocol Data Units (PDUs) of the following CCSDS protocols: CCSDS File Delivery Protocol (CFDP), Space Packet Protocol (SPP), Encapsulation Packet Protocol (EP), Telemetry (TM), Telecommand (TC), and Asynchronous Messaging System (AMS).	
REQ.TP.18 deleted			

REQ.TP.19 The end-to-end infrastructure and protocols shall be capable of transferring, as Service Data Units (SDUs), the Protocol Data Units (PDUs) of the Packet Utilisation Standard			
REQ.TP.20 The end-to-end infrastructure and protocols shall be capable of supporting these protocols simultaneously.			Covered by other requirements.
REQ.TP.20 The end-to-end infrastructure and protocols shall provide the service specified as required of the underlying layer by the above protocols.	Yes	4.2.2.2.3 The end-to-end infrastructure and protocols shall provide the services specified as required of the underlying layers of the CFDP, SPP, EP, Telemetry, Telecommand, and AMS protocols.	
REQ.TP.21 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting qualities of service with respect to data completeness.	Yes	4.2.2.2.4 The end-to-end infrastructure and protocols shall be capable, under the direction of users and/or mission/infrastructure network management, of supporting qualities of service with respect to data completeness.	
REQ.TP.22 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting qualities of service with respect to data errors.	Yes	require it. 4.2.2.2.5 The end-to-end infrastructure and protocols shall be capable, under the direction of users and/or mission/infrastructure network management, of supporting qualities of service with respect to data errors.	
REQ.TP.23 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting qualities of service with respect to data sequencing (depends on tolerance to out of sequence PDUs of upper layer protocols).	Yes	4.2.2.2.6 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting qualities of service with respect to data sequencing (depends on tolerance to out of sequence PDUs of upper layer protocols).	
REQ.TP.24 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting QoS with respect to data priority.	Yes	4.2.2.2.7 The end-to-end infrastructure and protocols shall be capable, under the direction of the application and mission/infrastructure network management, of supporting QoS with respect to data priority.	

REQ.TP.25 The end-to-end infrastructure and protocols shall be capable, under the direction of mission/infrastructure network management, of supporting qualities of service with respect to data availability (via e.g. alternate routes).	Yes	4.2.2.2.8 The end-to-end infrastructure and protocols shall be capable, under the direction of users and/or mission/infrastructure network management, of supporting qualities of service with respect to data availability (via e.g. alternate routes).	
REQ.TP.26 Compatibility with the CCSDS space packets shall be ensured for all data exchanged between the ground and the space segment and between space segments.	Yes	4.2.2.2.9 The Space Internetworking Protocols (e.g. BP and IP) shall be capable of operating over the CCSDS Encapsulation Protocol.	
REQ.TP.22 Compatibility with the CCSDS packet based space data link protocols shall be ensured on the ground-to-space and space to space links (telemetry space link, telecommand space link, AOS downlink, Proximity-1).			Covered by 4.2.2.2.11
Data Transfer Requirements			
REQ.TF.1 The transfer protocols shall be capable of transferring files completely (reliable) or incomplete (best effort).	Yes	4.2.2.3.1 The transfer protocols shall be capable of transferring application data units completely (reliably) when required by applications. If an application does not require complete delivery, the transfer protocols may deliver incomplete data (data with holes).	
REQ.TF.2 Individual messages shall always be transferred error free.			This is subsumed by the previous requirement and a messaging protocol that requests unerrored delivery.
REQ.TF.3 The transfer protocols shall be capable of transferring complete sequences of messages	Yes	4.2.2.3.2 The transfer protocols shall be capable of transferring complete sequences of messages.	
REQ.TF.4 The transfer protocols shall be capable of transferring sequences of messages in-sequence	Yes	4.2.2.3.3 The transfer protocols shall be capable of transferring sequences of messages in-sequence.	
REQ.TF.5 It shall be possible to transfer a file over a disrupted link, retaining the state of the file transfer between contact periods.	Yes	4.2.2.3.4 It shall be possible to transfer a file over a disrupted link, retaining the state of the file transfer between contact periods.	
REQ.TF.6 It shall be possible to 'hand-over' the transmission of a file from one intermediate hop to another (e.g. transmission starts using ground station A, A looses visibility and hands-over to ground station B).	Yes	4.2.2.3.5 It shall be possible to 'hand-over' the transmission of a file from one intermediate hop to another (e.g. transmission starts using ground station A, A looses visibility and hands-over to ground station B).	

REQ.TF.7 File and message transfer shall be capable of operating over simplex links (with limited QoS).	Yes	4.2.2.3.6 Data transfer shall be capable of operating over simplex links (with limited QoS).	
REQ.TF.8 File and message transfer shall be capable of operating over links with widely differing capacities (up to the order of 10,000:1)	Yes	4.2.2.3.7 Data transfer shall be capable of operating over network paths with widely differing capacities (up to 10,000:1)	
REQ.TF.9 File and Message Transfer protocols shall be independent of file and message contents.	Yes	4.2.2.3.8 Data Transfer protocols shall be independent of application data content.	
REQ.TF.10 File transfer may be initiated by the sender of a file, the receiver of a file or a third party.	Yes	4.2.2.3.9 File transfer may be initiated by the sender of a file, the receiver of a file or a third party.	
REQ.TF.11 File transfer shall take place between file stores under the control of file service user entities.	Yes	4.2.2.3.10 File transfer shall take place between file stores under the control of file service user entities.	
REQ.TF.12 Message transfer shall take place between message service user entities	Yes	4.2.2.3.11 Message transfer shall take place between message service user entities.	
REQ.TF.13 Data transfer shall be possible over multiple concatenated heterogeneous data transport layers.	Yes	4.2.2.3.12 Data transfer shall be possible over multiple concatenated heterogeneous data transport layers.	
REQ.TF.14 It shall be possible to verify completeness of the data transfer and to notify the data transfer originator about this. This shall be possible regardless of other QoS attributes (e.g. completeness).	Yes	4.2.2.3.13 Given suitable QoS attributes when data is submitted and suitable network connectivity, it shall be possible to verify completeness of the data transfer and to notify the data transfer originator about this. This shall be possible regardless of other QoS attributes (e.g. completeness).	
REQ.TF.15 Data transfer shall support priority and pre-emption mechanisms in all nodes.	Yes	4.2.2.3.14 Data transfer shall support priority and pre-emption mechanisms in all nodes.	
REQ.TF.16 It shall be possible to transfer file metadata as part of the file transfer protocol or using a messaging protocol.	Yes	4.2.2.3.15 It shall be possible to transfer file metadata as part of the file transfer protocol or using a messaging protocol.	
REQ.TF.17 Data transfer protocols shall not require simultaneous availability of the communication link between all nodes involved in the data delivery/routing.	Yes	4.2.2.3.16 Data transfer protocols shall not require simultaneous availability of the communication link between all nodes involved in the data delivery/routing.	
REQ.TF.18 It shall be possible to use the same data transfer protocol in the Ground-to-Space link, in the Space-to-Space link and between ground nodes (Ground-to-Ground).	Yes	4.2.2.3.17 It shall be possible to use the same data transfer protocol in the Ground-to-Space link, in the Space-to-Space link and between ground nodes (Ground-to-Ground).	

REQ.TF.19 Data retransmission strategy shall be flexible to allow opportunistic (automated) retransmission of data when links become available while still respecting quality of service conditions.	Yes	4.2.2.3.18 Data retransmission strategy shall be flexible to allow opportunistic (automated) retransmission of data when links become available while still respecting quality of service conditions.	
REQ.TF.20 Retransmitted data shall, by default, assume the same priority as the original data but priority and queue position may be modified by local or remote data management entities.	Yes	4.2.2.3.19 Retransmitted data shall, by default, assume the same priority as the original data.	
REQ.TF.21 It shall be possible to specify causality in data exchanges such that a dependent data exchange is not commenced until completion of another exchange.	Yes	4.2.2.3.21 It shall be possible to demultiplex the SDUs contained in network layer PDUs to specific upper-layer entities.	
REQ.TF.22 The protocols shall allow files or messages to be associated with a specified user entity.	Yes	4.2.2.3.22 The data transfer protocols shall be able to operate in a communications environment characterized by large transmission delays.	
REQ.TF.23 The data transfer protocols shall be able to operate in a communications environment characterised by large transmission delays.	Yes	4.2.2.3.23 The data transfer protocols shall be able to operate in a communications environment characterized by unreliable, noisy communication links.	
REQ.TF.24 The data transfer protocols shall be able to operate in a communications environment characterised by unreliable, noisy communication links.	Yes	4.2.2.3.24 The data transfer protocols shall be able to operate in a communications environment characterized by interrupted visibility between communication nodes due to predictable causes (e.g. orbital visibility)	
REQ.TF.25 The data transfer protocols shall be able to operate in a communications environment characterised by interrupted visibility between communication nodes due to predictable causes (e.g. orbital visibility)	Yes	4.2.2.3.25 The data transfer protocols shall be able to operate in a communications environment characterized by unpredictable disruptions due to failures.	
REQ.TF.26 The data transfer protocols shall be able to operate in a communications environment characterised by unpredictable disruptions due to failures.	Yes	4.2.2.3.26 The protocol shall have a mechanism for carrying a priority field that may be affected by the user and/or management/policy at the sending node.	
REQ.TF.27 The control and data units shall be distinguished such that control units can be transmitted with higher priority.	Yes	4.2.3.27 Management / policy at intermediate nodes (nodes other than the source) may override the priority treatment indicated in the priority field of a space internetworking PDU.	

REQ.TF.28 It shall be possible for the File Transfer protocol to perform multiple file transfer transactions in parallel (e.g. in order to initiate the delivery of file 'n+1' before receiving confirmation of successful transfer of file 'n'). This is essential in order to optimise the use of the available bandwidth.	Yes	4.2.2.3.28 It shall be possible for the File Transfer protocol to perform multiple file transfer transactions in parallel (e.g. in order to initiate the delivery of file 'n+1' before receiving confirmation of successful transfer of file 'n'). This is essential in order to optimize the use of the available bandwidth.	
Data Management Requirements			
REQ.MAN.1 It shall be possible to observe the progress of file transfers by local or remote data management entities.	Yes	4.2.2.4.1 It shall be possible to observe the progress of data transfers by local or remote data management entities.	
REQ.MAN.2 It shall be possible to observe the state of data transfer queues (file or message) by local or remote data management entities.	Yes	4.2.2.4.2 It shall be possible to observe the state of data transfer queues (file or message) by local or remote data management entities.	
REQ.MAN.3 It shall be possible to control the progress of file transfers with respect to stop (cancel), suspend and resume (global or individual files) by local or remote data management entities. [This is possible wherever the file transfer application is transmitting the file.]	Yes	4.2.2.4.3 It shall be possible to control data transfer queues by reordering, deleting, suspending/resuming transmission of queued items by local or remote data management entities.	
REQ.MAN.4 It shall be possible to control data transfer queues by reordering or deleting queued items by local or remote data management entities.	Yes	4.2.2.4.4 It shall be possible to control the actions of file transfer applications with respect to stop (cancel), suspend and resume (global or individual files) by local or remote data management entities.	
REQ.MAN.5 It shall be possible to pre-empt file transfers either locally to the sending entity or remotely from a remote manager. [This is possible wherever the file transfer application is transmitting the file.] This is a requirement on CFDP or the thing above CFDP.			Subsumed by individual network management commands (stop 1, start 2)

REQ.MAN.6 Suspension and Resumption of transfer at transmitting or receiving ends may be initiated by a local management entity in response to an anticipated or unanticipated outage. [This is possible wherever the file transfer application is transmitting the file.] This is a requirement on CFDP or the thing above CFDP.			It's not a requirement, it's rationale for who/why might invoke the previous requirement.
REQ.MAN.7 It shall be possible to establish primary and backup routes through the end-to-end data path at a network planning facility and to distribute this information to the nodes concerned.	Yes	4.2.2.4.5 It shall be possible to pre-empt data transfers either locally to the sending entity or remotely from a remote manager.	
REQ.MAN.8 Synchronisation of route changes must be managed in the end-to-end network.	Yes	4.2.2.4.6 Suspension and resumption of transfer at transmitting or receiving ends may be initiated by a local management entity in response to an anticipated or unanticipated outage. [This is possible wherever the file transfer application is transmitting the file.] This is a requirement on CFDP or the CFDP user.	
REQ.MAN.9 File segmentation should be implemented and managed to arrange that data segments are sized so that they can be completely transferred within contact periods. [And this is a requirement on the file transfer application.]	Yes	4.2.2.4.7 It shall be possible to establish primary and backup routes through the end-to-end data path at a network planning facility and to distribute this information to the nodes concerned.	
REQ.MAN.10 It shall be possible to terminate file transmission from a relay node, delete the data buffered and resume data transmission using another relay, if necessary.	Yes	4.2.2.4.8 Synchronization of route changes must be managed in the end-to-end network.	
REQ.MAN.11 It shall be possible for data to be delivered and stored with metadata indicating the time of data transmission and reception.	Yes	4.2.2.4.9 It shall be possible to terminate data transmission via a relay node A, delete the data buffered at A, and resume data transmission via another next-hop relay, if necessary.	
REQ.MAN.12 The on-board and ground systems shall support the management of files as a basic container for spacecraft command, housekeeping and science data.	Yes	4.2.2.4.10 The data transfer protocols shall provide to the destination the time of transmission and receipt of the ADU being delivered.	Very file-specific. Not included as Green Book requirement.

REQ.MAN.13 The on-board and ground systems shall support the management of files as a basic container for spacecraft command, housekeeping and science data.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.14 Files shall be stored persistently.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.15 It shall be possible to segregate files in hierarchical or non hierarchical containers (i.e. directories and other associations).			Very file-specific. Not included as Green Book requirement.
REQ.MAN.16 A given file system shall be able to manage multiple physical data storages (e.g. disks, memory devices).			Very file-specific. Not included as Green Book requirement.
REQ.MAN.17 Files shall be associated to attributes such as the name, creation time, last update time, size, status.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.18 A file shall be uniquely identified by its name and directory path within a given file system.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.19 All ground and space systems shall support the basic operations of a typical file system e.g. create, open, close, rename, move, copy, delete files.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.20 It shall be possible to create and delete file directories and associations.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.21 It shall be possible to copy, move and rename file directories.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.22 It shall be possible to delete multiple files with one single operation (e.g. all files in a directory).			Very file-specific. Not included as Green Book requirement.
REQ.MAN.23 It shall be possible to read and write from/to an open file.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.24 It shall be possible to restrict the operations affecting a file (e.g. a read-only file cannot be written, a ‘locked’ file cannot be deleted).			Very file-specific. Not included as Green Book requirement.
REQ.MAN.25 deleted			Very file-specific. Not included as Green Book requirement.
REQ.MAN.26 It shall be possible to read and write at the same time from/to an open file.			Very file-specific. Not included as Green Book requirement.

REQ.MAN.27 It shall be possible to append data to an open file.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.28 All file operations (including reading and appending data) shall be accessible by local applications (e.g. on-board applications) as well as by remote applications e.g. by using ground commands.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.29 The available data storage resources shall be allocated dynamically to files (it shall not be necessary to fix the exact file size at creation time).			Very file-specific. Not included as Green Book requirement.
REQ.MAN.30 A maximum file size may be imposed by a particular deployment of a file system implementation			Very file-specific. Not included as Green Book requirement.
REQ.MAN.31 Deleted requirement.			Very file-specific. Not included as Green Book requirement.
REQ.MAN.32 It shall be possible to browse a file system by requesting the catalogue of all files/directories belonging to a given directory.			Very file-specific. Not included as Green Book requirement.
Utilization Requirements			
Requirement from SISG Requirements Document		SIS-DTN Green Book Requirement	Additional Notes
REQ.UTI.1 Data shall be delivered and stored with metadata indicating the time of data creation.			
REQ.UTI.2 Contents of files or messages for onward transmission to a spacecraft may be examined and checked for mission critical effects at a mission control entity and blocked if necessary. Notification of blocking shall be delivered to the sending entity.	Yes	4.2.2.5.1 Application-layer content (e.g. files, messages) for onward transmission to a spacecraft may be examined and checked for mission critical effects at a mission control entity and blocked if necessary.	
REQ.UTI.3 The last hop relay node may extract TCs from an immediate or delayed TC file and radiate them as TCs to their destination (typically orbiter to lander).	Yes	4.2.2.5.3 An application on the last hop relay node may extract TCs from an immediate or delayed TC file and radiate them as TCs to their destination (typically orbiter to lander).	
REQ.UTI.4 The first hop relay node may assemble TM packets received from another entity and assemble them into a TM file for further transmission.	Yes	4.2.2.5.4 An application on the first hop relay node may assemble TM packets received from another entity and assemble them into a TM file for further transmission.	

REQ.UTI.5 It shall be possible to manage "TC Files" i.e. files which contain TC Packets which are to be delivered to the final application. This is meant to be used e.g. to upload time-tagged commands for the On-board Scheduler.		Not applicable to DTN (SISG designation)	
REQ.UTI.6 It shall be possible to execute all commands within a TC File as soon as the file is completely received on-board. These are referred to as "Immediate TC Files".		Not applicable to DTN (SISG designation)	
REQ.UTI.7 Immediate TC files shall be automatically deleted following execution.		Not applicable to DTN (SISG designation)	
REQ.UTI.8 It shall be possible to store on-board a TC File for delayed execution triggered by ground command. These are referred to as "Delayed TC Files".		Not applicable to DTN (SISG designation)	
REQ.UTI.9 Ground shall be able to request the execution of a "Delayed TC File" by command.		Not applicable to DTN (SISG designation)	
REQ.UTI.10 It shall be possible to request the execution of a "Delayed TC File" multiple times.		Not applicable to DTN (SISG designation)	
REQ.UTI.11 Deleted requirement		Not applicable to DTN (SISG designation)	
REQ.UTI.12 The ground commands requesting storage and execution of TC Files shall be acknowledged at execution completion (i.e. when all contained TCs have been delivered to the end application);		Not applicable to DTN (SISG designation)	
REQ.UTI.13 It shall be possible to record the values of specified on-board parameters or lists of parameters in a file for subsequent transmission.		Not applicable to DTN (SISG designation)	
REQ.UTI.14 It shall be possible to apply and activate a patch of the on-board S/W contained within a file.		Not applicable to DTN (SISG designation)	
REQ.UTI.15 It shall be possible to organise the on-board storage in "TM files" (i.e. files containing spacecraft housekeeping data in the form of telemetry packets) matching a specified filter for a specified time range.		Not applicable to DTN (SISG designation)	

REQ.UTI.16 It shall be possible to request the storage of the same data in multiple TM files by copying, simultaneous creation or appending .		Not applicable to DTN (SISG designation)	
REQ.UTI.17 The creation of TM files shall be autonomously managed by the relevant on-board application within a specified directory.		Not applicable to DTN (SISG designation)	
REQ.UTI.18 It shall be possible to upload the definition of an On-Board Control Procedure by means of a file.		Not applicable to DTN (SISG designation)	
REQ.UTI.19 It shall be possible to store the product data generated by a given on-board instrument in a given time range in a file available for delayed downlink. This is meant to support the capability to organise 'data takes' (e.g. images, observations) in individual "data files";		Not applicable to DTN (SISG designation)	
REQ.UTI.20 It shall be possible to request the closure/opening of the file collecting product data of a given instrument by command or by definition of an on-board event.		Not applicable to DTN (SISG designation)	
REQ.UTI.21 The on-board instrument generating the product data shall be able to manage the opening/closing of the data files.		Not applicable to DTN (SISG designation)	
REQ.UTI.22 It shall be possible to configure the downlink of on-board stored data by identifying the directories containing files to be down-linked and the associated priorities. Within a given directory, the order of transfer of files on the return link shall be initiated in creation time order informed by file meta-information.		Not applicable to DTN (SISG designation)	
REQ.UTI.23 It shall be possible to request the immediate downlink of a specified file, by increasing to highest priority or pre-empting existing transfers.		Not applicable to DTN (SISG designation)	
REQ.UTI.24 It shall be possible to request the immediate downlink of all files belonging to a given directory and matching file meta-information criteria (e.g. all files whose creation time falls within a specified time range).		Not applicable to DTN (SISG designation)	

REQ.UTI.25 It shall be possible to initiate multiple parallel file downlinks.			Already covered / function of the file transfer protocol.

Appendix E. Issue 9 Supplementary Material

Slide 1

Closure Briefing :
SISG Issue 9: SSI Evolutionary Path

C. Edwards, W. Hell,
S. Burleigh, G. P. Calzolari

Dec 15, 2009

Slide 2

Background

- **Issue 9:** Identify FOM and analyze various mission scenario alternatives to determine the best SSI evolutionary path, due 15 Dec 2009.
  - SISG has committed to an internetworked architecture in the 2020+ time frame
  - This action seeks opportunities in the 2015-2020 time frame to make incremental steps towards this internetworked end state

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Slide 3

Selected Mission Opportunities

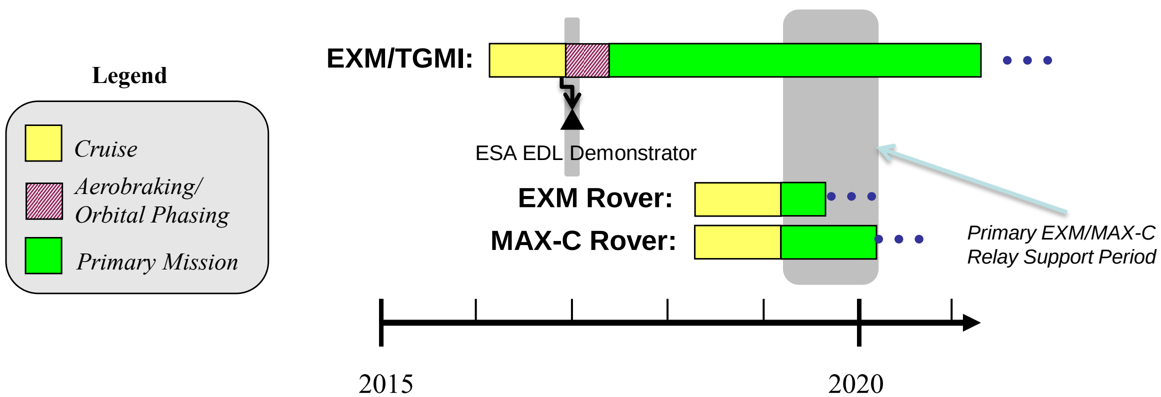
- Study effort focused on the ESA/NASA Mars Exploration Joint Initiative (MEJI)

*2016: ESA/NASA ExoMars/Trace Gas Mapper-Imager (*TGMI) Science/Relay Orbiter Mission

- ESA-provided orbiter mission with NASA/ESA science instruments
- NASA-provided UHF relay payload
- ESA-provided EDL Demonstrator (released on approach to Mars)

2018: NASA/ESA Mars Astrobiology Explorer-Cacher (MAX-C)/ExoMars Joint Rover Mission

- NASA-provided MSL-heritage EDL system delivering two rovers to a single site:
  - NASA MAX-C rover (1 Earth yr nominal mission duration)
  - ESA ExoMars rover (180 sol nominal mission duration)



3

Slide 4

Mission Characteristics

- This mission set offers a number of interesting characteristics for the purposes of the requested study:
  - Store-and-forward relay operations
  - Collocated landed assets
  - Potential for more complex network topology
  - Falls in the desired 2015-2020 time frame
  - Just entering formulation phase, so design not frozen (but moving forward quickly!)
  - De facto multi-agency cross-support and interoperability considerations

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Slide 5

Selected Figures of Merit

Figure of Merit	FOM Definition
QQCL	
Quantity	Quantity is defined as the volume of "acceptable" data units delivered by the service
Quality	Quality is defined as the "error rate" for the delivered data units over the end-to-end path
Continuity	Continuity is defined as the number of gaps in the set of data units delivered to a customer during a service
Latency	Latency is defined as the delay between a data unit's reception at a specified point and its delivery to another point where it becomes accessible to a customer
Cost	
Implementation	Sum of flight and ground implementation cost to achieve the selected option
Operations	Impact of the selected option on mission operations costs
Risk	
Implementation	Technical risk associated with implementing the selected option
Operations	Extent to which the selected option increases or decreases mission risk during flight operations
Programmatics	
Interoperability with Legacy Assets	Ability of the selected option to accommodate existing missions
Extensibility to SSI Final State	Extent to which the selected option moves towards the desired SSI final state, characterized by a functional BP/IP network layer

cde-5

Slide 6

SSI Evolution Options

- Options for the 2016-2018 Mars missions:
  1. Current baseline
  2a. CFDP between Relay MOC and S/C only
  2b. CFDP store-and-forward overlay, end-to-end
  3a. DTN option "A": upgraded Electra, DTN operating at ESOC
  3b. DTN option "B": upgraded Electra, DTN operating at DSN ground stations
- For each option, consider each of these scenarios:
  – Orbiter operations
  – ESA lander nominal operations
  – ESA lander emergency commanding
  – NASA lander nominal operations
  – NASA lander emergency commanding

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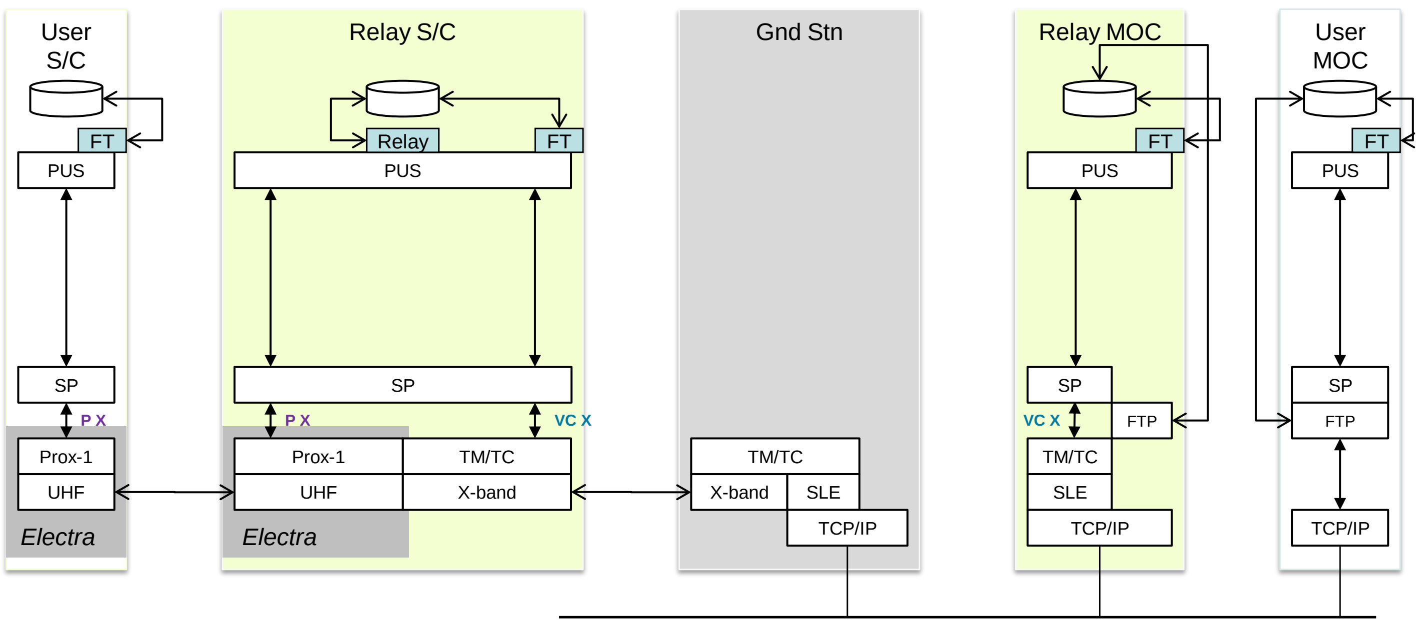
Slide 7

Baseline Configuration



Note: "VC X" is a notional virtual channel which in practice might be implemented by a set of virtual channels.

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Slide 8

Option 1 Features

- No change from current plans
- Minimum development cost and risk
- PUS service 13 for reliable data transfers over deep space links (uplink and downlink)
- FTP-based interface between MOCs

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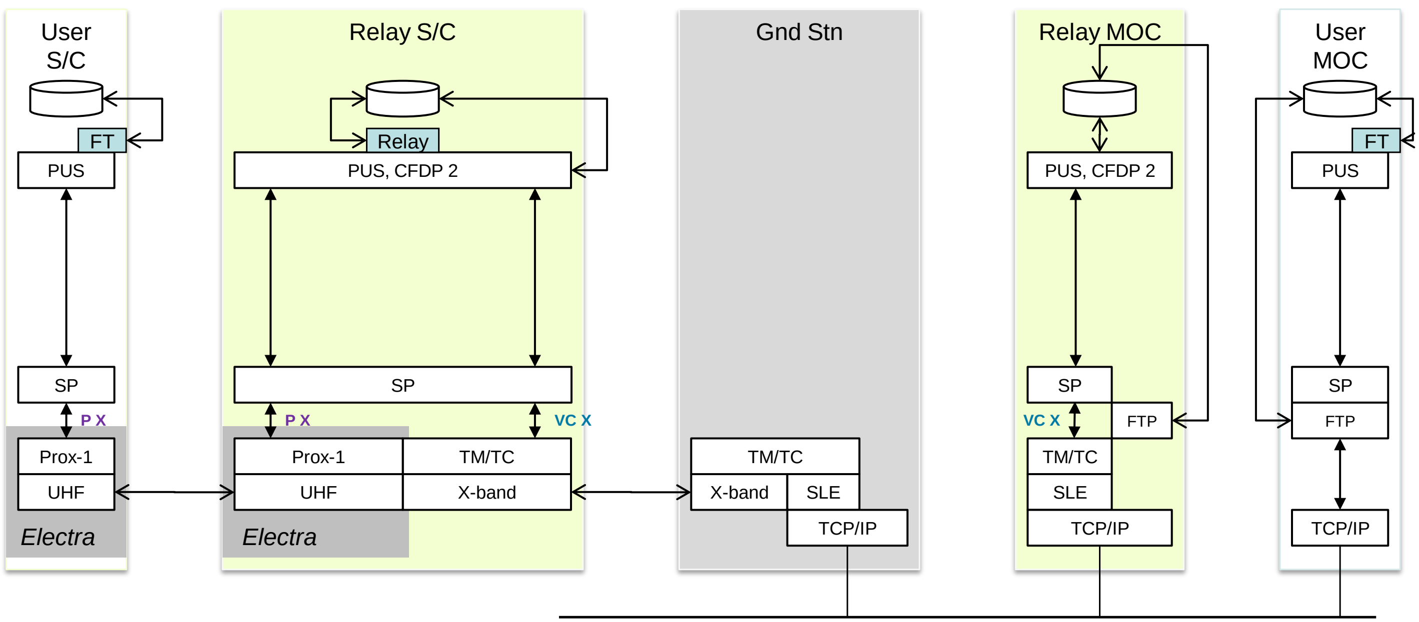
Slide 9

CFDP DS Configuration



9

Slide 10

Option 2a Features

- Small change from current plans
- Acknowledged CFDP for reliable data transfers over deep space links
- FTP-based interface between MOCs

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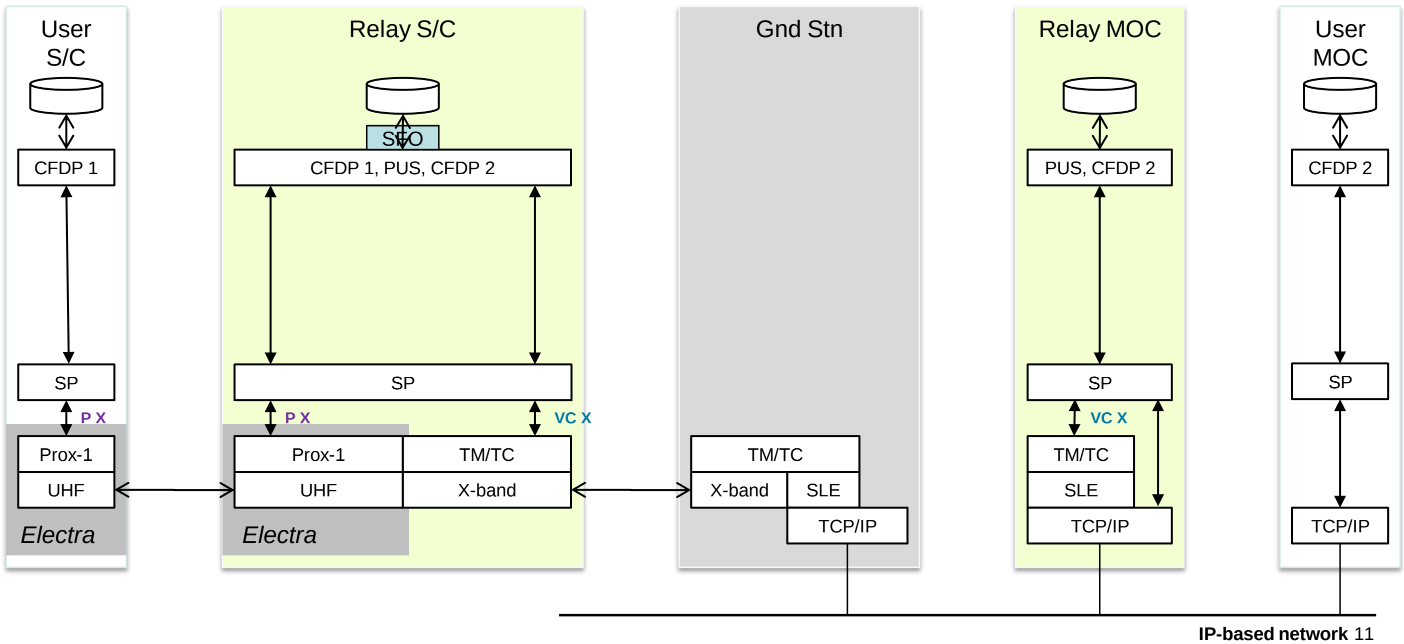
Slide 11

CFDP SFO Configuration



Slide 12

Option 2b Features

- CFDP-based file transfer at all interfaces, including between MOCs
  - Unacknowledged CFDP over reliable Proximity-1
  - Acknowledged CFDP over deep space links
- Forwarding automated by SFO

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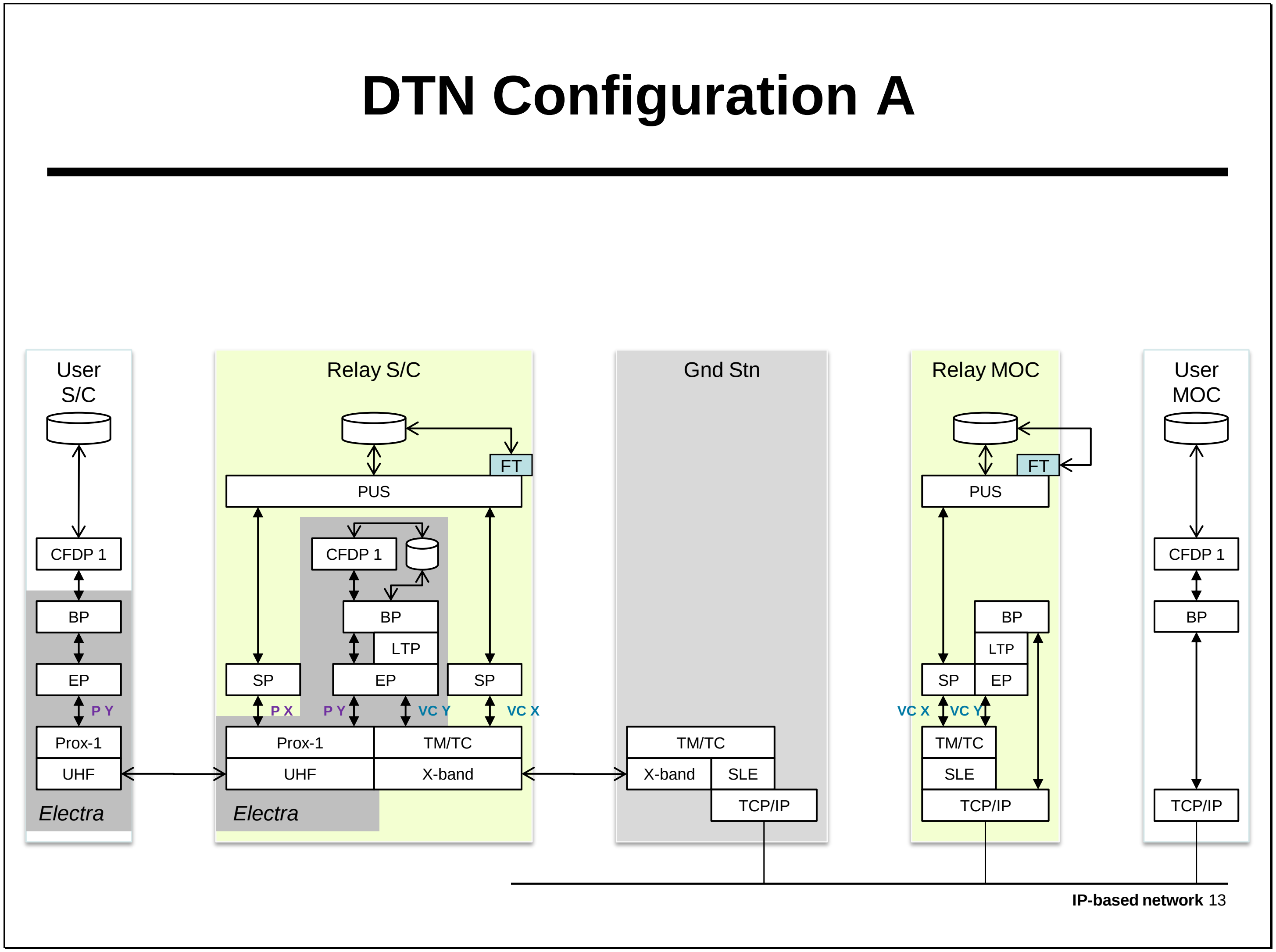
DTN Configuration A
User S/C
CFDP 1
BP
EP
P Y
Prox-1
UHF
Electra
Relay S/C
FT
PUS
CFDP 1
BP
LTP
SP
EP
SP
P X
P Y
VC Y
VC X
Prox-1
TM/TC
UHF
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
FT
PUS
BP
LTP
SP
EP
VC X
VC Y
TM/TC
SLE
TCP/IP
User MOC
CFDP 1
BP
TCP/IP
IP-based network
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Slide 14

Option 3a Features

- ESA operations are the same as in the baseline approach
- NASA operations are based on DTN end-to-end, including class-1 CFDP over DTN
- A DTN node is added at the Orbiter MOC; the Orbiter s/c team continues to handle all uplink traffic
- Interface between MOCs is streaming, not file-based, for DTN-enabled user

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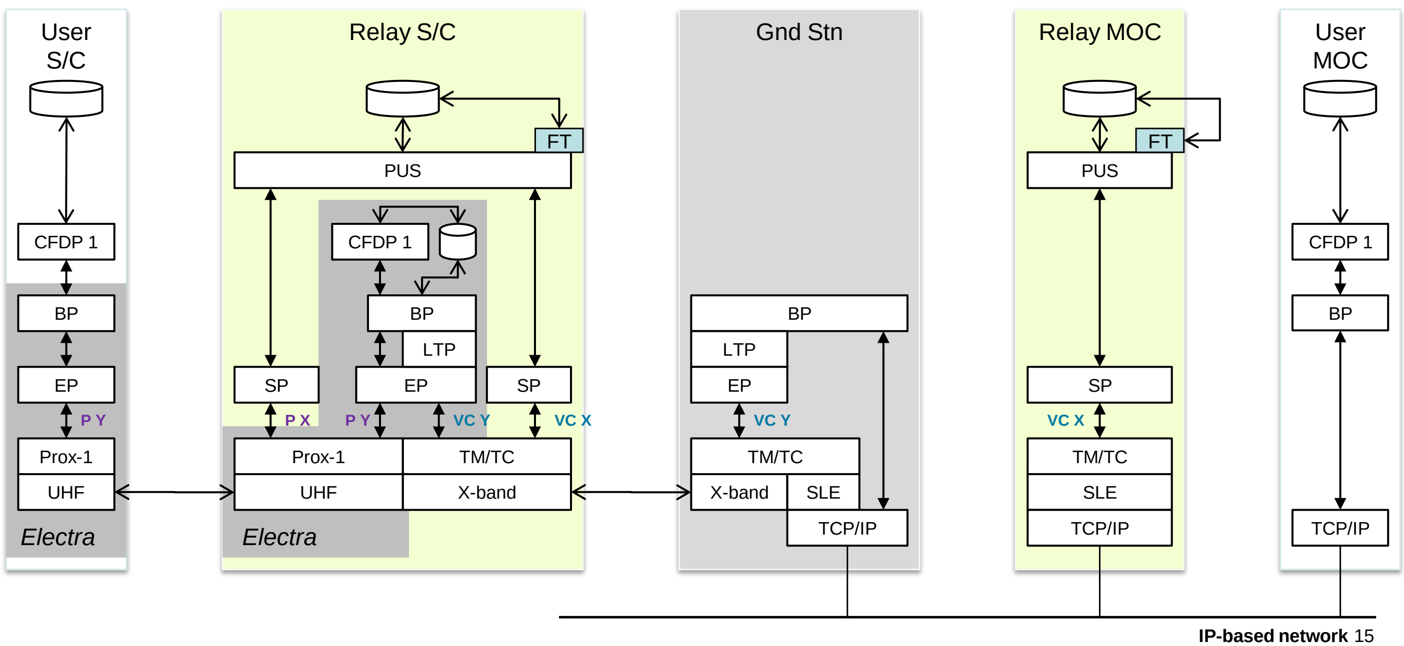
DTN Configuration B



Slide 16

Option 3b Features

- ESA operations are the same as in the baseline approach
- No DTN node needed at ESOC; minimum cost
- NASA operations are based on DTN end-to-end, including class-1 CFDP over DTN
- Interface between MOCs is removed: NASA traffic – both downlink and uplink – streams directly between the User MOC and the ground station

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FOM Scoring Process

- Consensus group conducted interactive telecon to negotiate consensus FOM scores
  - Wolfgang Hell, Gian Paolo Calzolari, Scott Burleigh, and Chad Edwards
- Additional offline interviews held to broaden inputs
  - Peter Schmitz (ESA; 2016 ExoMars/Trace Gas Orbiter)
  - Chris Taylor (ESTEC)
  - Tom Komarek (NASA; 2016 ExoMars/Trace Gas Orbiter
  - Chris Salvo (NASA; 2018 MAX-C/ExoMars Rovers)
- Score each FOM across five levels
  - Major strength (+2)
  - Minor strength (+1)
  - Non-factor (0)
  - Minor weakness (-1)
  - Major weakness (-2)

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FOM Scoring

- The consensus group established relative weights for the various FOMs, with each scored on a scale of 0-10
- FOM scores were then linearly scaled from 0 to 1, and weights linearly scaled to sum to 100
- Product of scaled FOM score and scaled weight, summed over FOMs, provided the final score for each option, with a maximum possible score of 100

Figure of Merit	Consensus Weights
QQCL	
Quantity	4
Quality	2
Continuity	2
Latency	6
Cost	
Implementation	6
Operations	3
Risk	
Implementation	5
Operations	7
Programmatics	
Interoperability with Legacy Assets	7
Extensibility to SSI Final State	7

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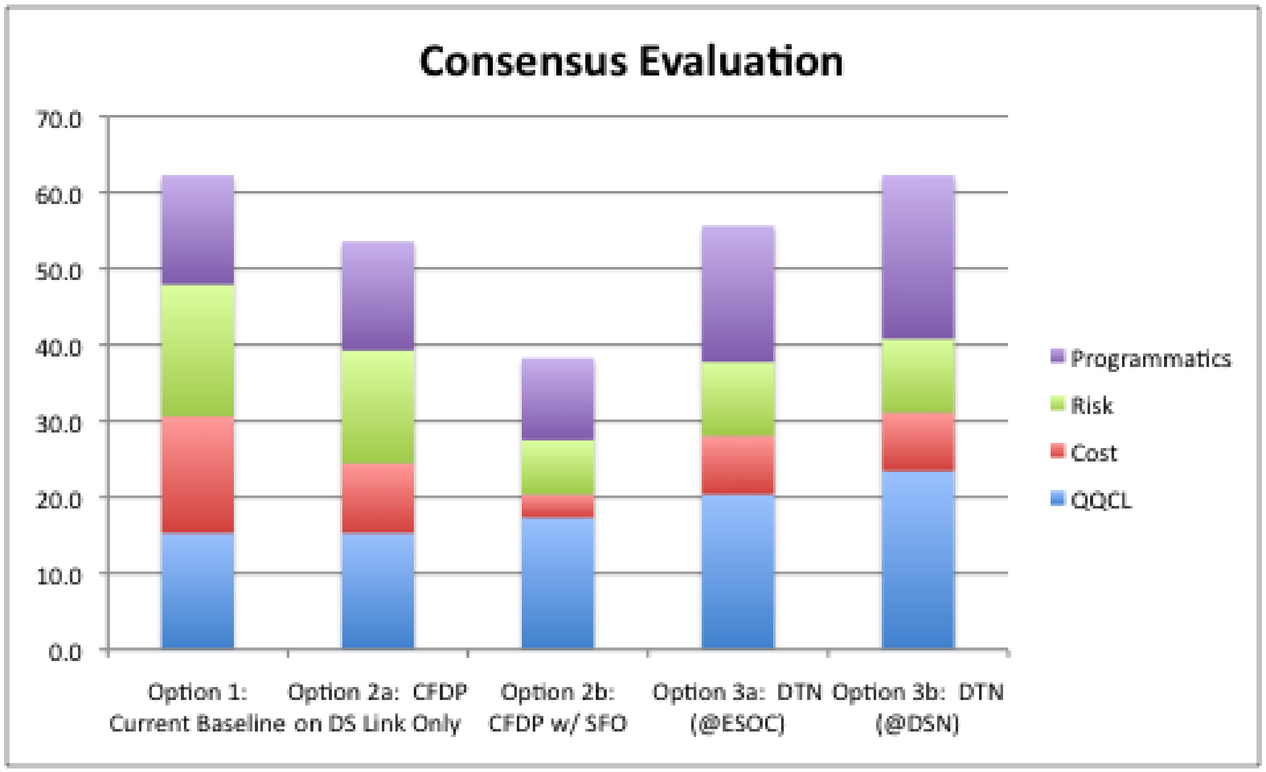
Slide 19

FOM Results (1/2)



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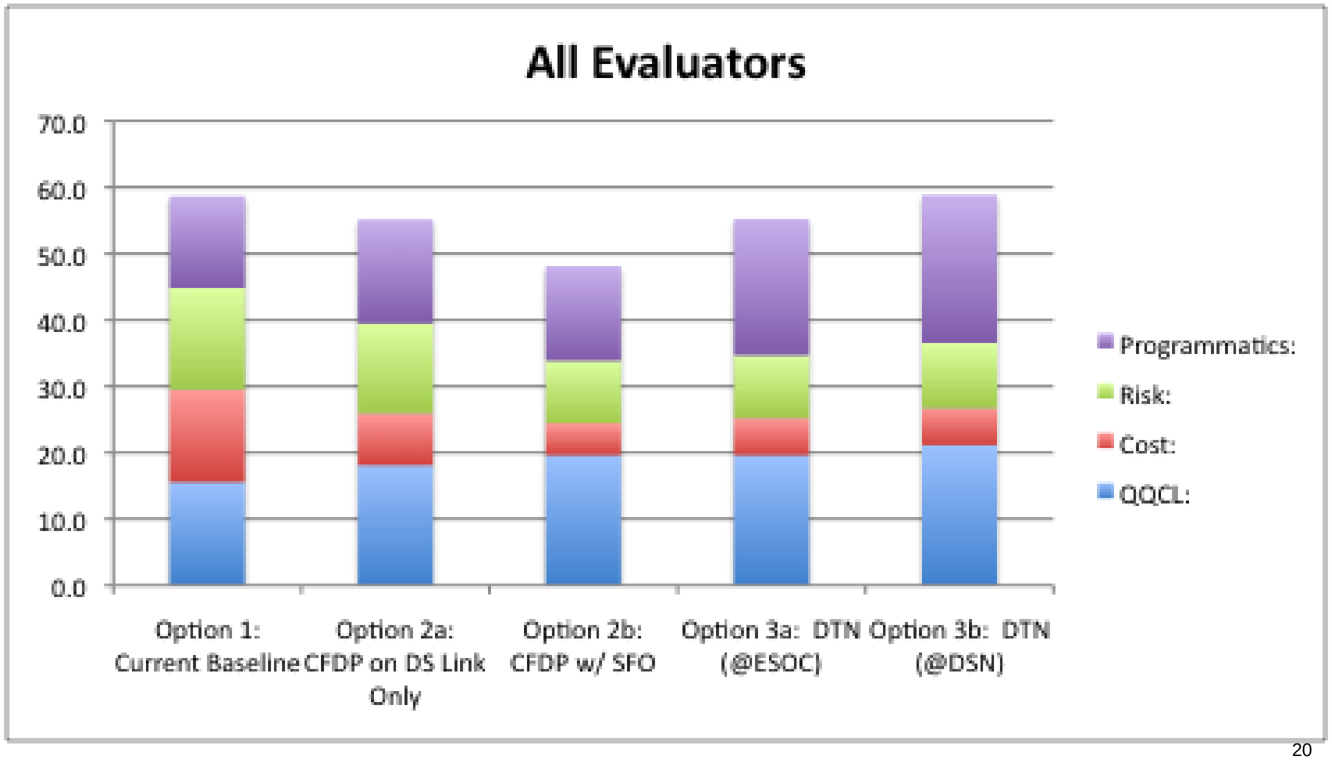
FOM Results (2/2)



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Comments During FOM Scoring (1/4)

- QQCL
  - Quantity:
    - "Retransmission mechanisms for reliable transfer enable operating links at higher rates, with less margin"
    - "PUS Service 13 in current baseline option could offer benefits comparable to CFDP on the deep space link; other options offer the additional benefit of alternate data paths"
  - Quality:
    - "Strong channel codes already deliver effectively error-free data"
  - Continuity:
    - "ExoMars plans to use PUS Service 13 on u/l and d/l, providing gap-free delivery"
  - Latency:
    - "DTN options offer advantages in closing retransmission loops as early as possible"

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Comments During FOM Scoring (2/4)

- Cost:
  - Implementation:
    - “Current baseline has max heritage”
    - “Existing NASA implementation exists for CFDP DS option”
    - “CFDP SFO would require extensive new s/w dev”
    - “DTN options can leverage NASA heritage solutions (DINET and ISS demonstrations)”
  - Operations:
    - “DTN offers further advantages in ops efficiency for large file transfers through multiple paths”

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Comments During FOM Scoring (3/4)

- Risk:
  - Implementation:
    - "Current baseline option is minimum implementation risk based on maximum reuse of existing heritage software"
    - "CFDP w/ SFO option may be the least-well understood option – significant implementations and/or prototyping exist for other options"
  - Operations:
    - "DTN Option B (w/ direct data flow from user MOC to relay S/C) would represent a significant change from current paradigm (where the orbiter MOC is always in the uplink data path)"

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Comments During FOM Scoring (4/4)

- Programmatics:
  - Interoperability w/ legacy assets:
    - "Proposed DTN options also support legacy ESA PUS operations"
  - Extensibility to SSI final state:
    - "DTN options clearly offer best alignment with desired network layer-enabled SSI final state"
    - "CFDP w/ SFO option represents a major investment that could be an impediment to implementing DTN"

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Conclusions

- First a caveat: the FOM analysis should not be considered “the answer”, but rather a useful exercise to explore various aspects of the option trade space
- The favored options (with nearly equivalent scores) were:
  - Current Baseline (w/ PUS Service 13)
  - DTN Option B (modified Electra, DTN @ DSN)
- CFDP w/ SFO was lowest-rated option
- The analysis clearly shows the dynamic tension between reuse of heritage solutions (with advantages of low cost and risk) vs. moving aggressively towards the desired DTN-enabled end-state (with programmatic and QQCL advantages)
  - Ultimately, the decision on the path forward is critically dependent on the relative importance of these two factors

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BACKUP

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Quick Reference to Diagrams

	Configuration	Orbiter ops	ESA lander Nominal ops	ESA lander Emergency cmd	NASA lander Nominal ops	NASA lander Emergency cmd
1. Baseline	7	29	30	31	32	33
2a. CFDP	9	35	36	37	38	39
2b. SFO	11	41	42	43	44	45
3a. DTN ‘A’	13	47	48	49	50	51
3b. DTN ‘B’	15	53	54	55	56	57

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Option 1: Baseline Configuration Operating Scenarios

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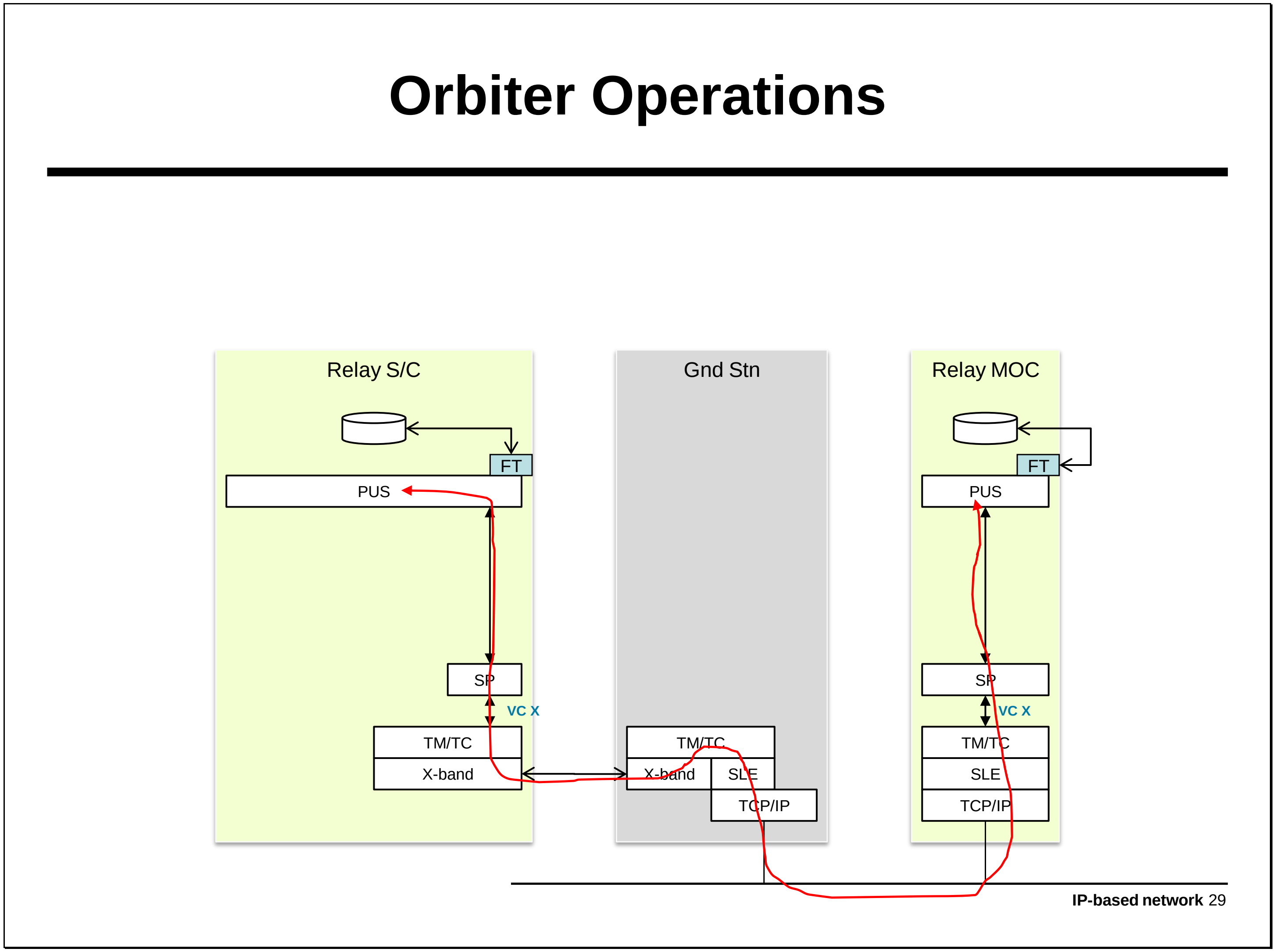
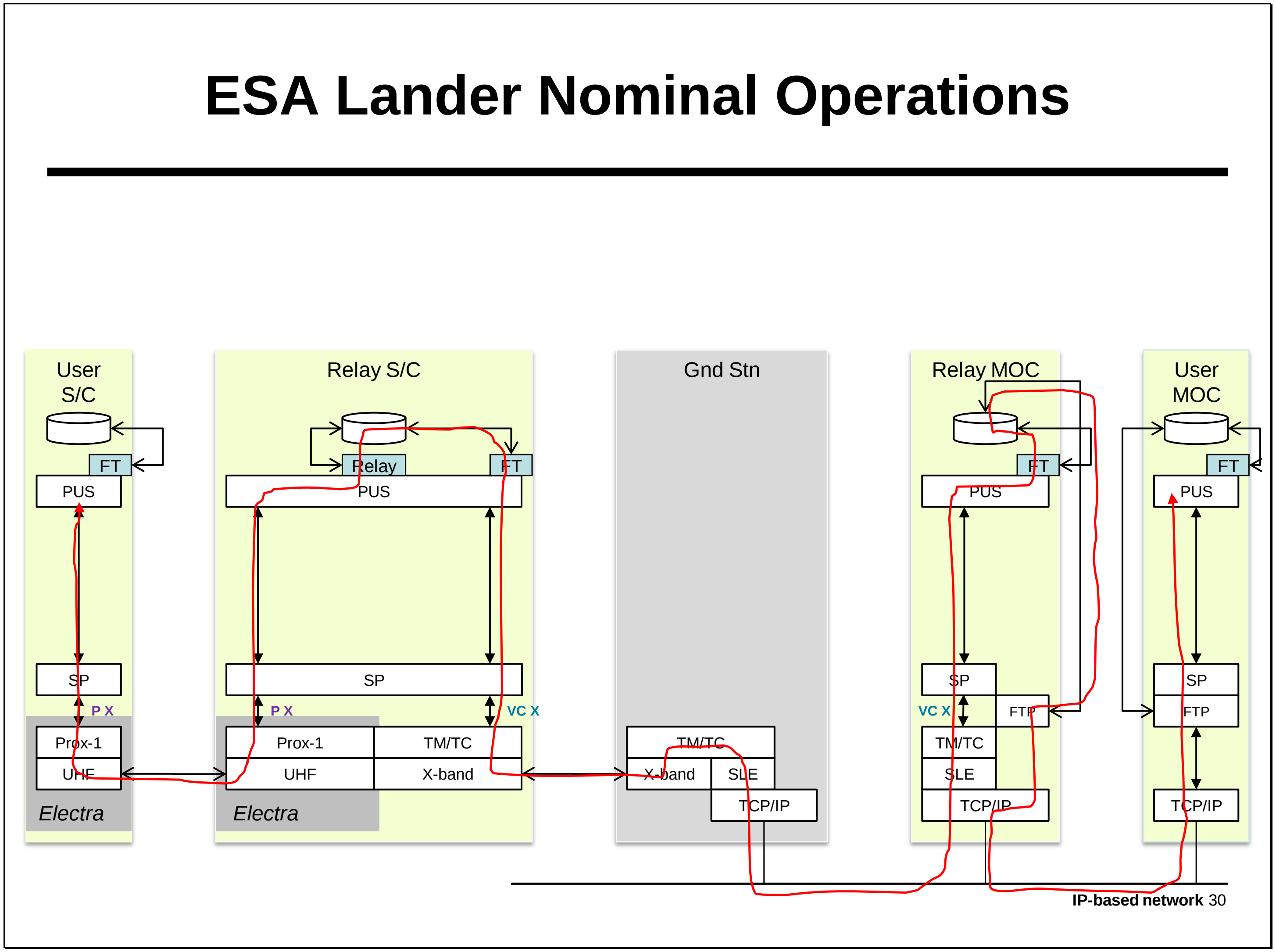
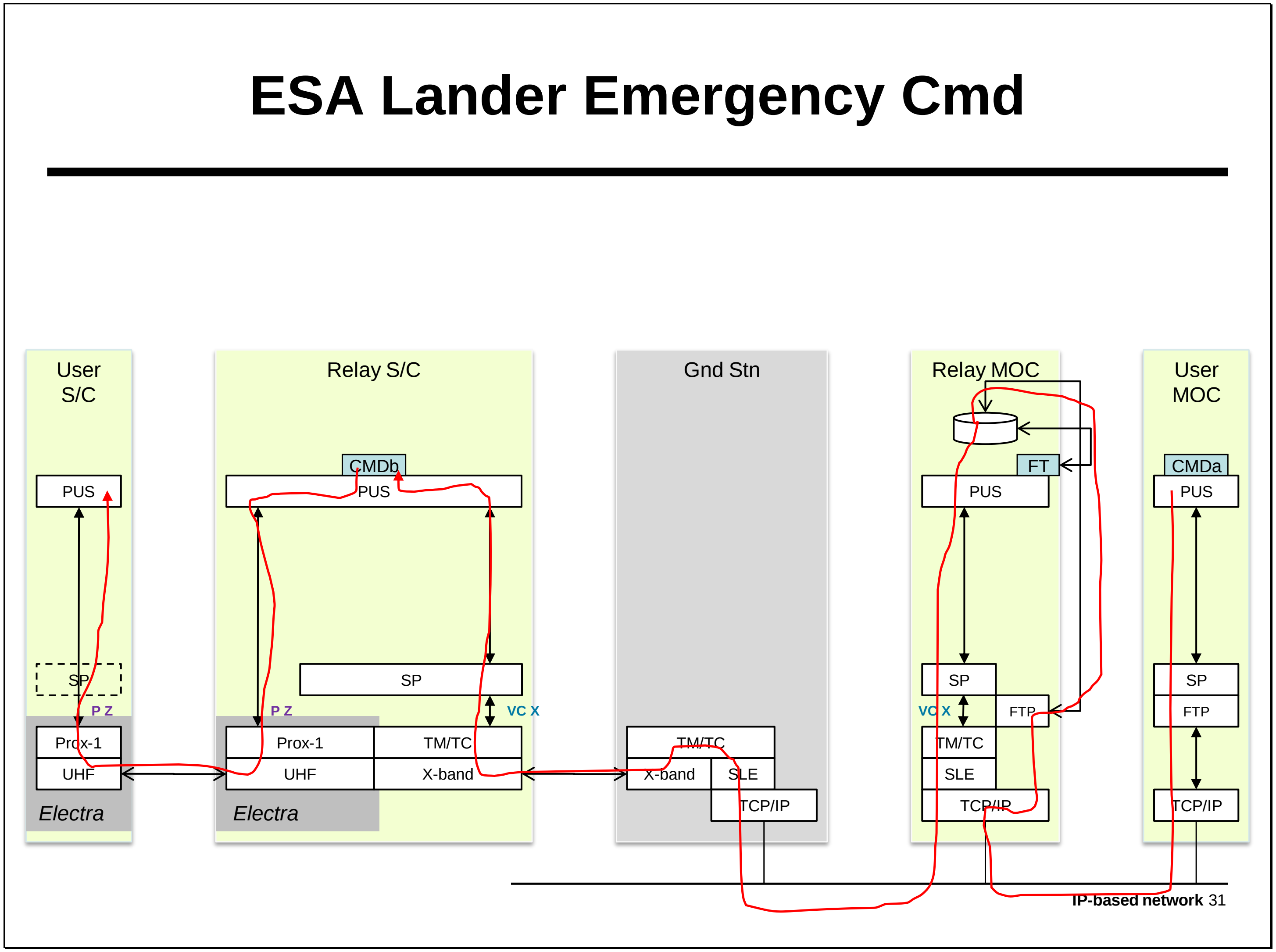

Orbiter Operations
Relay S/C
FT
PUS
SP
VC X
TM/TC
X-band
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
FT
PUS
SP
VC X
TM/TC
SLE
TCP/IP
IP-based network 29

Slide 30

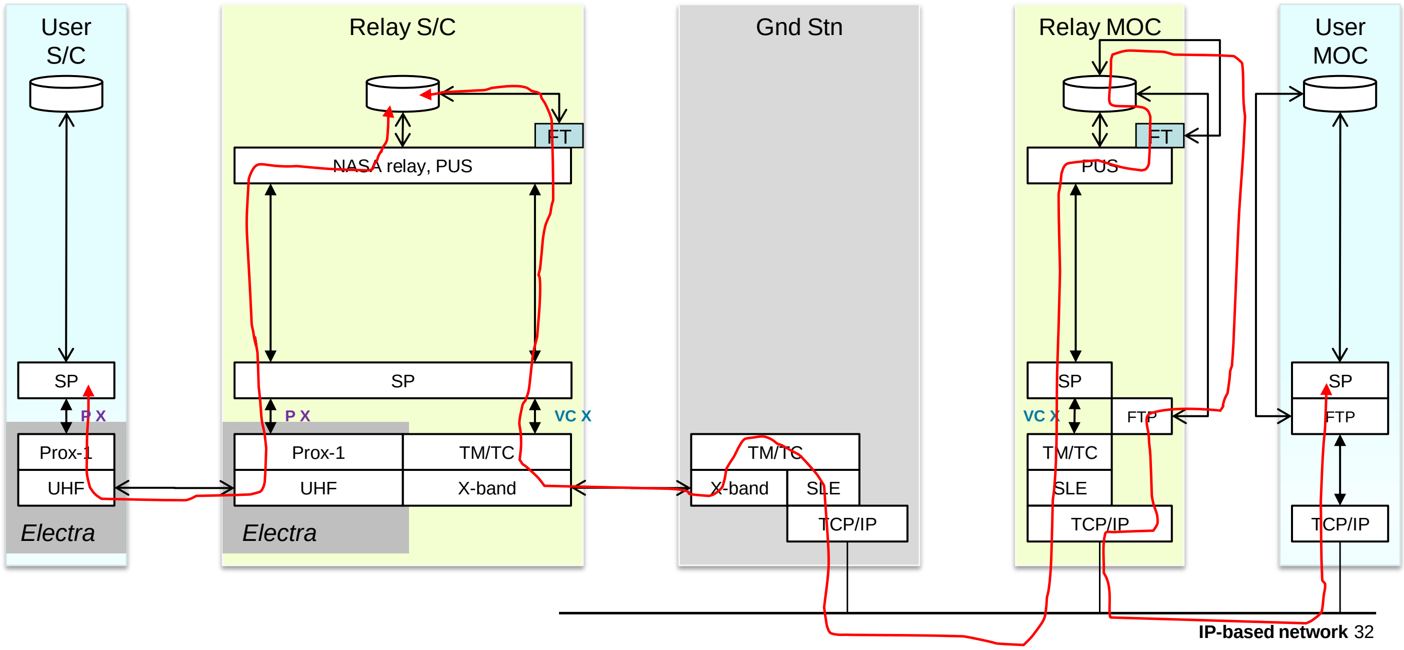

ESA Lander Nominal Operations
User S/C
FT
PUS
SP
P X
Prox-1
UHF
Electra
Relay S/C
Relay
FT
PUS
SP
P X
VC X
Prox-1
TM/TC
UHF
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
FT
PUS
SP
VC X
FTP
TM/TC
SLE
TCP/IP
User MOC
FT
PUS
SP
FTP
TCP/IP
IP-based network
30

Slide 31

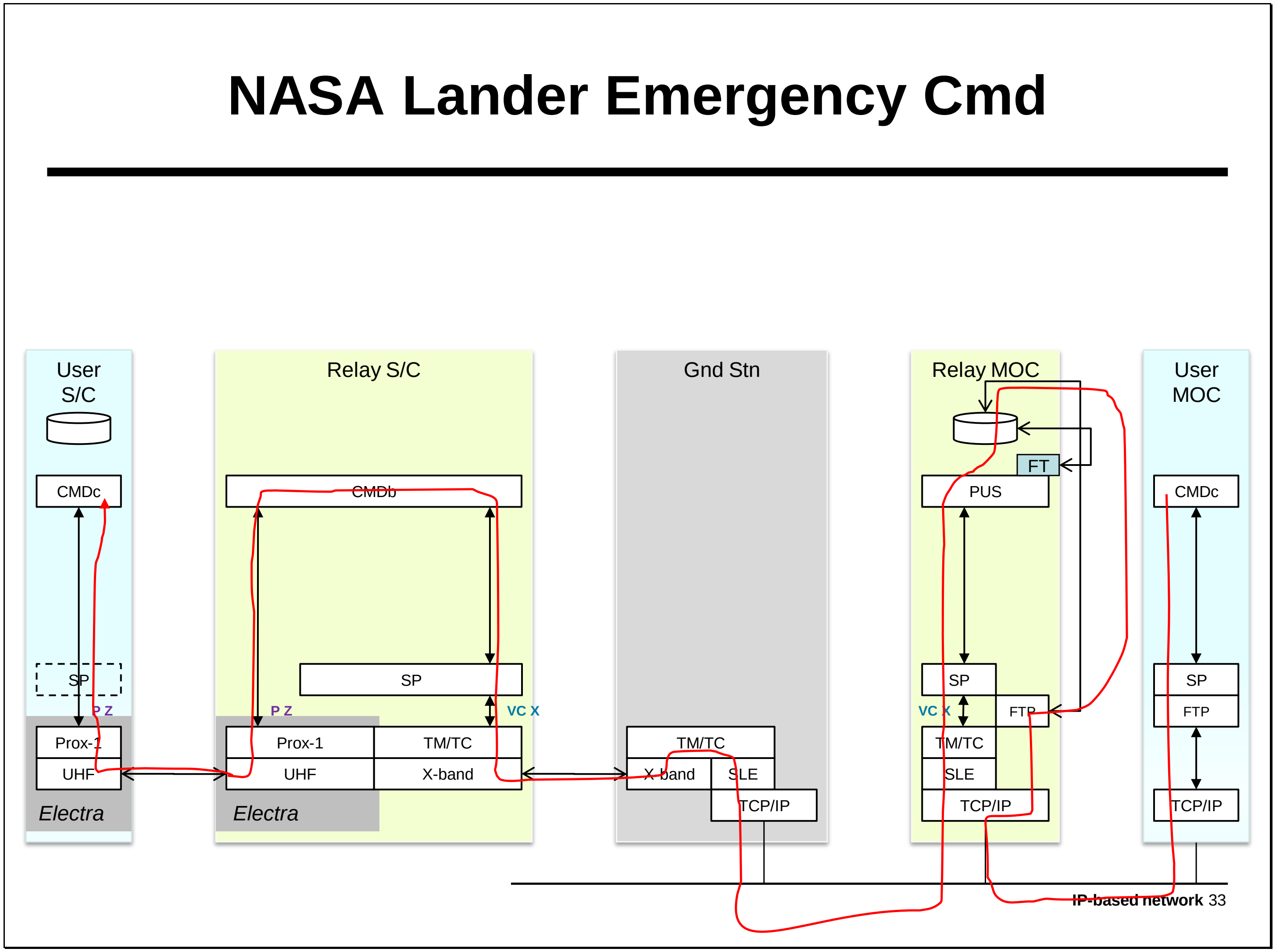

ESA Lander Emergency Cmd
User S/C
Relay S/C
Gnd Stn
Relay MOC
User MOC
PUS
CMDb
CMDa
FT
SP
P Z
VC X
Prox-1
UHF
TM/TC
X-band
SLE
TCP/IP
FTP
Electra
IP-based network 31

Slide 32

NASA Lander Nominal Ops



Slide 33


NASA Lander Emergency Cmd
User S/C
CMDc
SP
P Z
Prox-1
UHF
Electra
Relay S/C
CMDb
SP
P Z
VC X
Prox-1
TM/TC
UHF
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
FT
PUS
SP
FTP
VC X
TM/TC
SLE
TCP/IP
User MOC
CMDc
SP
FTP
TCP/IP
IP-based network 33

Slide 34

Option 2a: CFDP SFO Configuration Operating Scenarios

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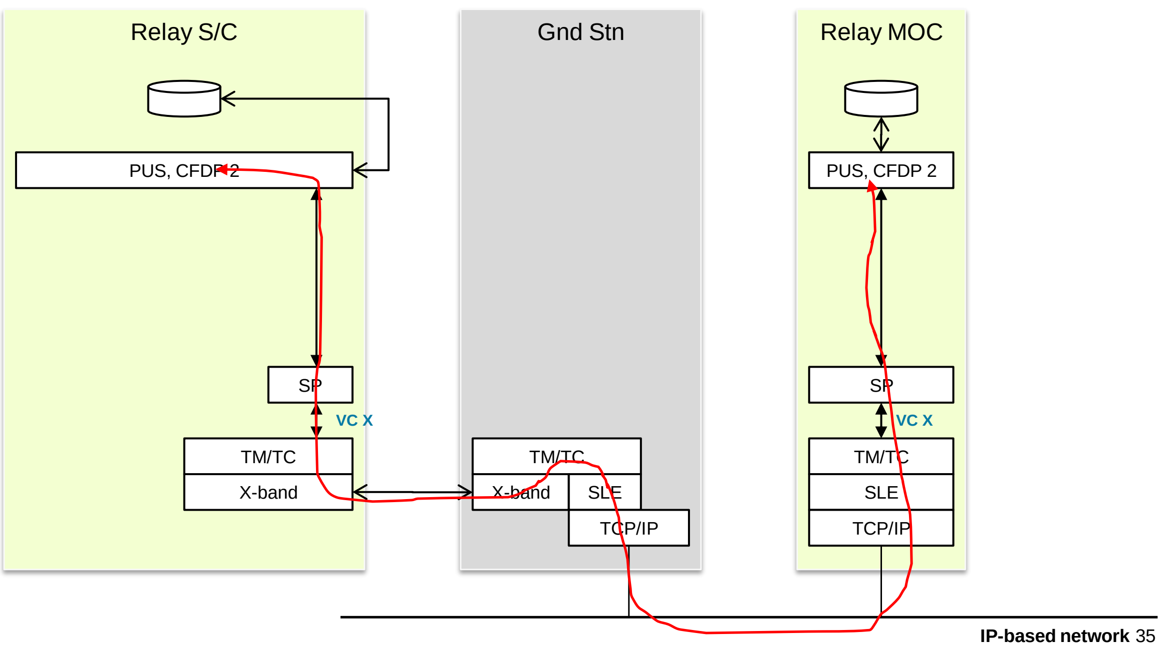
Orbiter Operations



35

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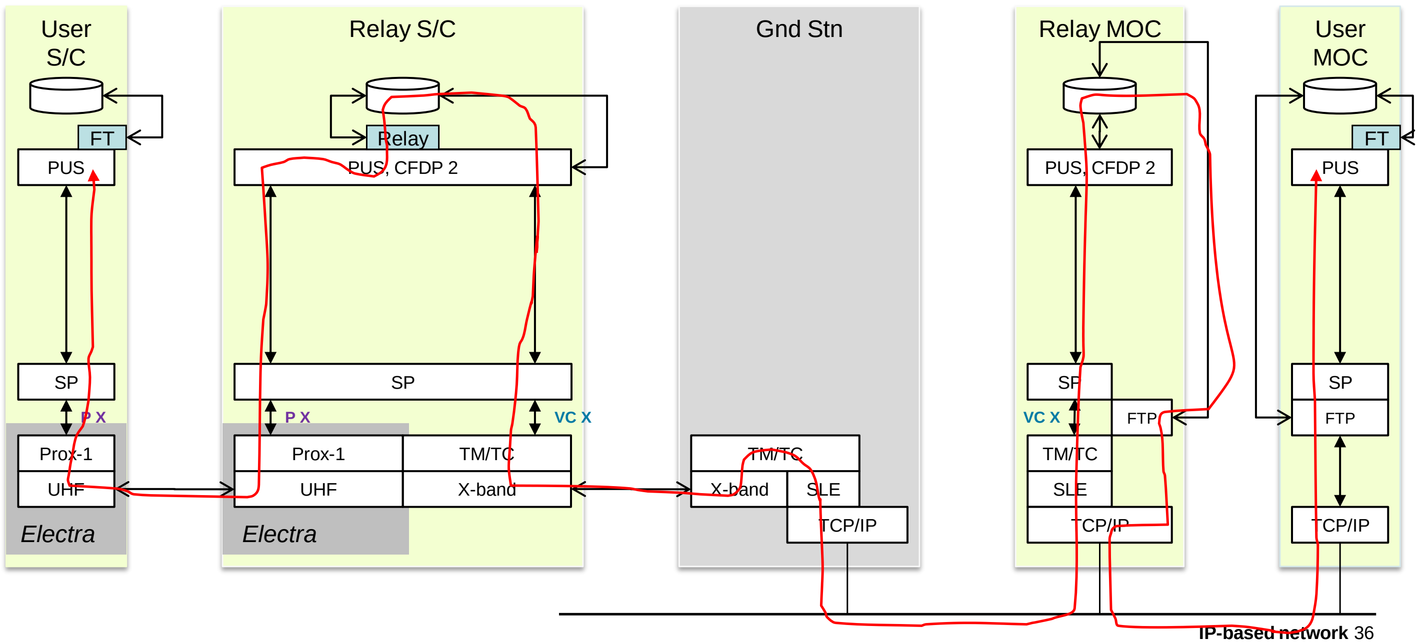
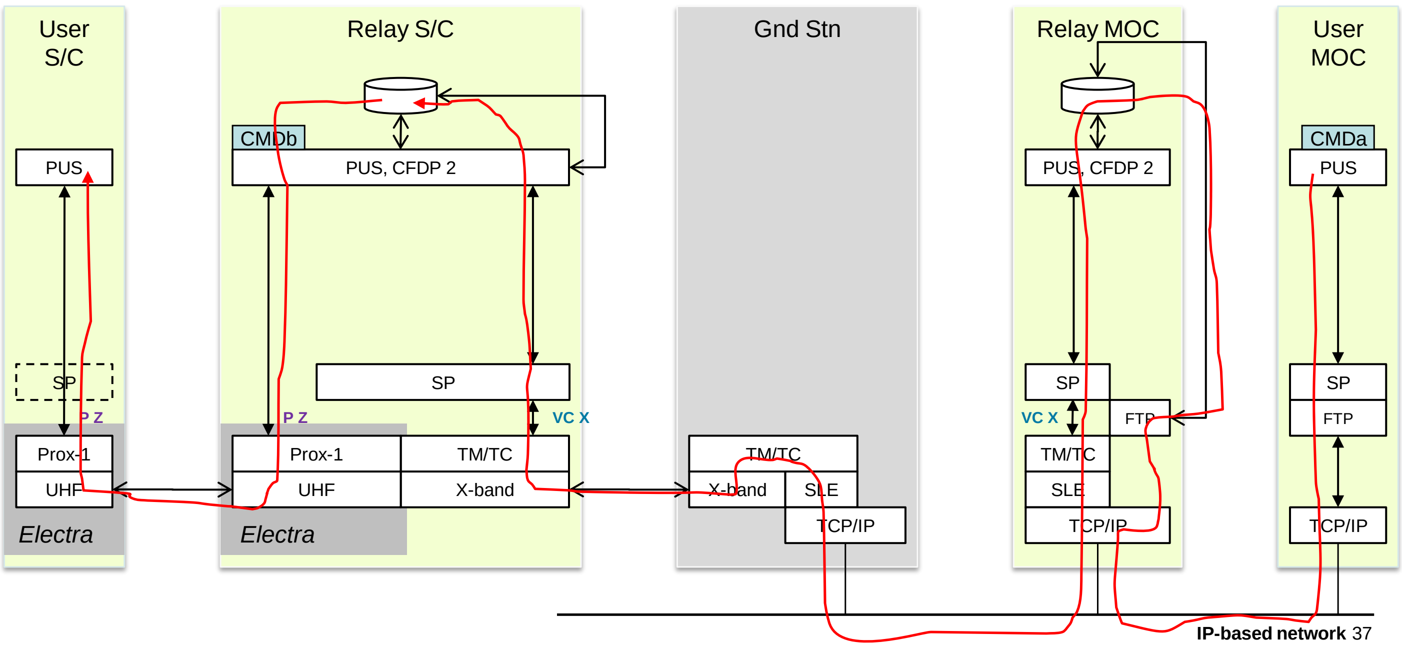
ESA Lander Nominal Operations



Slide 37

ESA Lander Emergency Cmd



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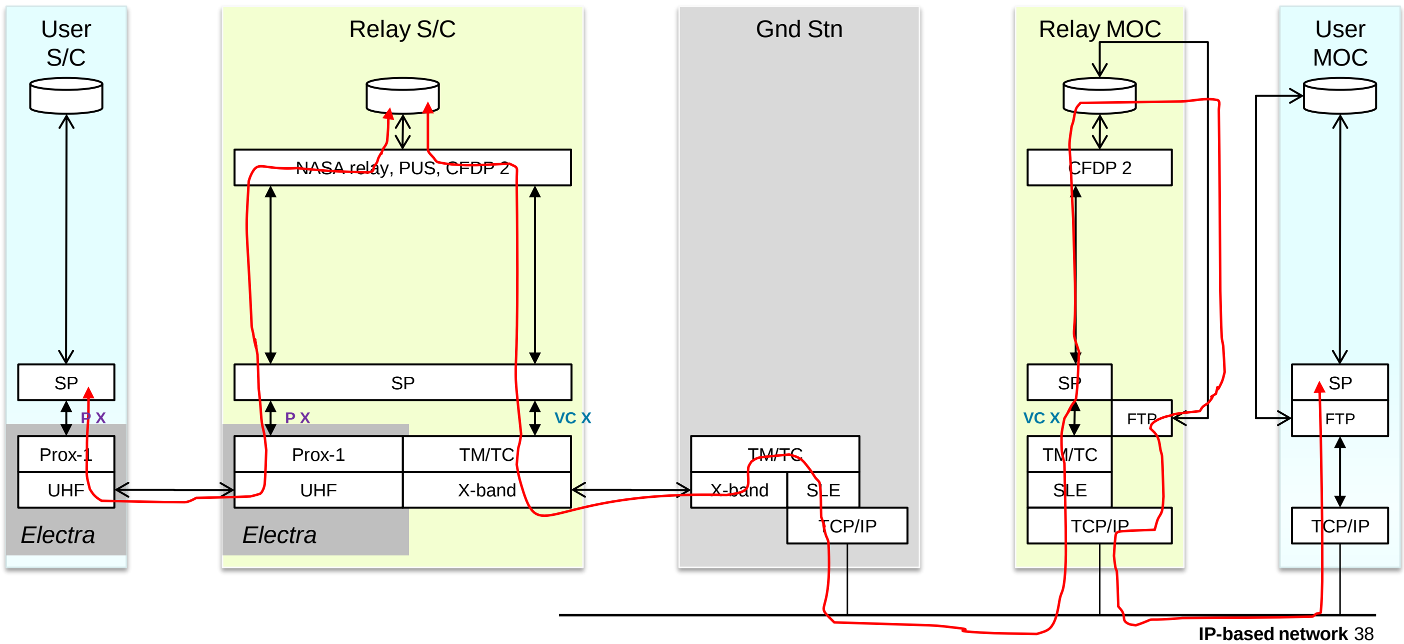
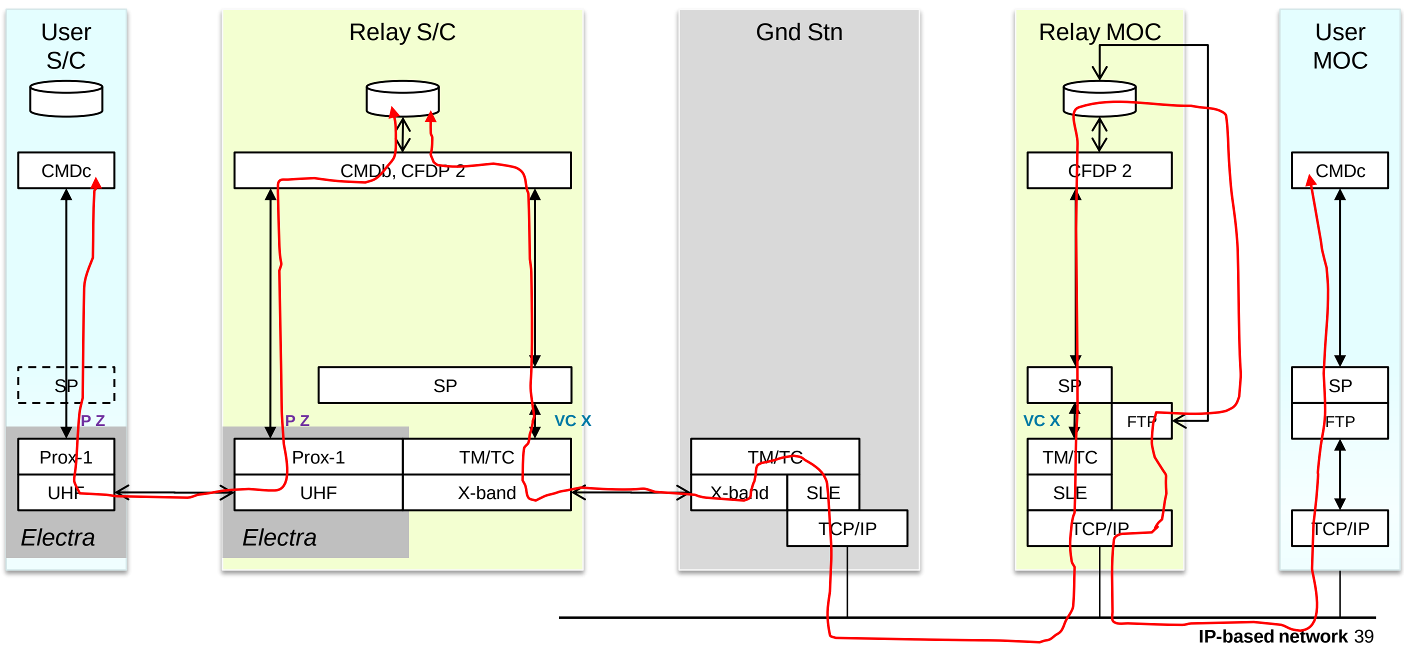
NASA Lander Nominal Ops



Slide 39

NASA Lander Emergency Cmd



Slide 40

Option 2b: CFDP SFO Configuration Operating Scenarios

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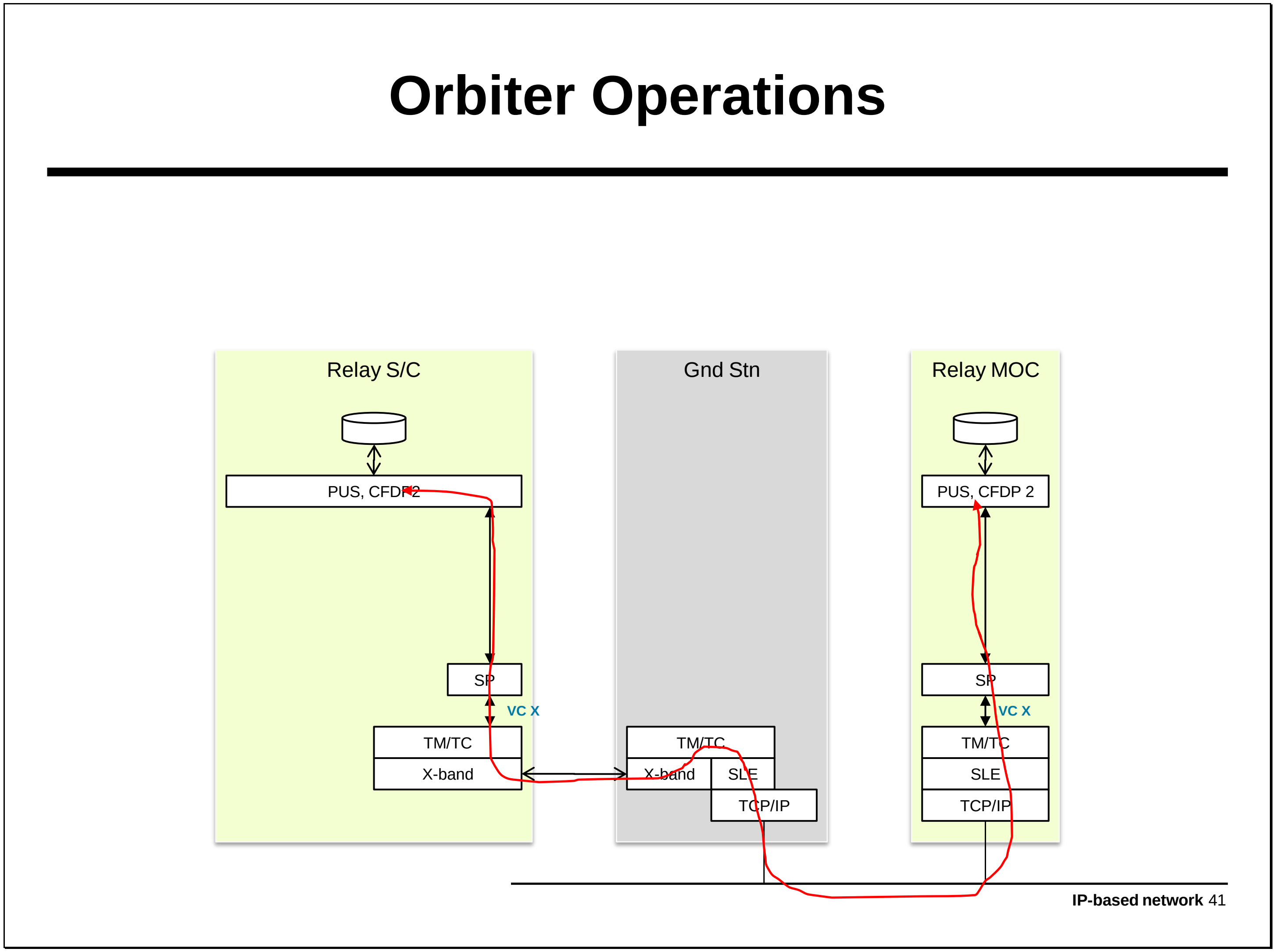
Orbiter Operations
Relay S/C
Gnd Stn
Relay MOC
PUS, CFDP 2
SP
VC X
TM/TC
X-band
TM/TC
X-band
SLE
TCP/IP
PUS, CFDP 2
SP
VC X
TM/TC
SLE
TCP/IP
IP-based network 41

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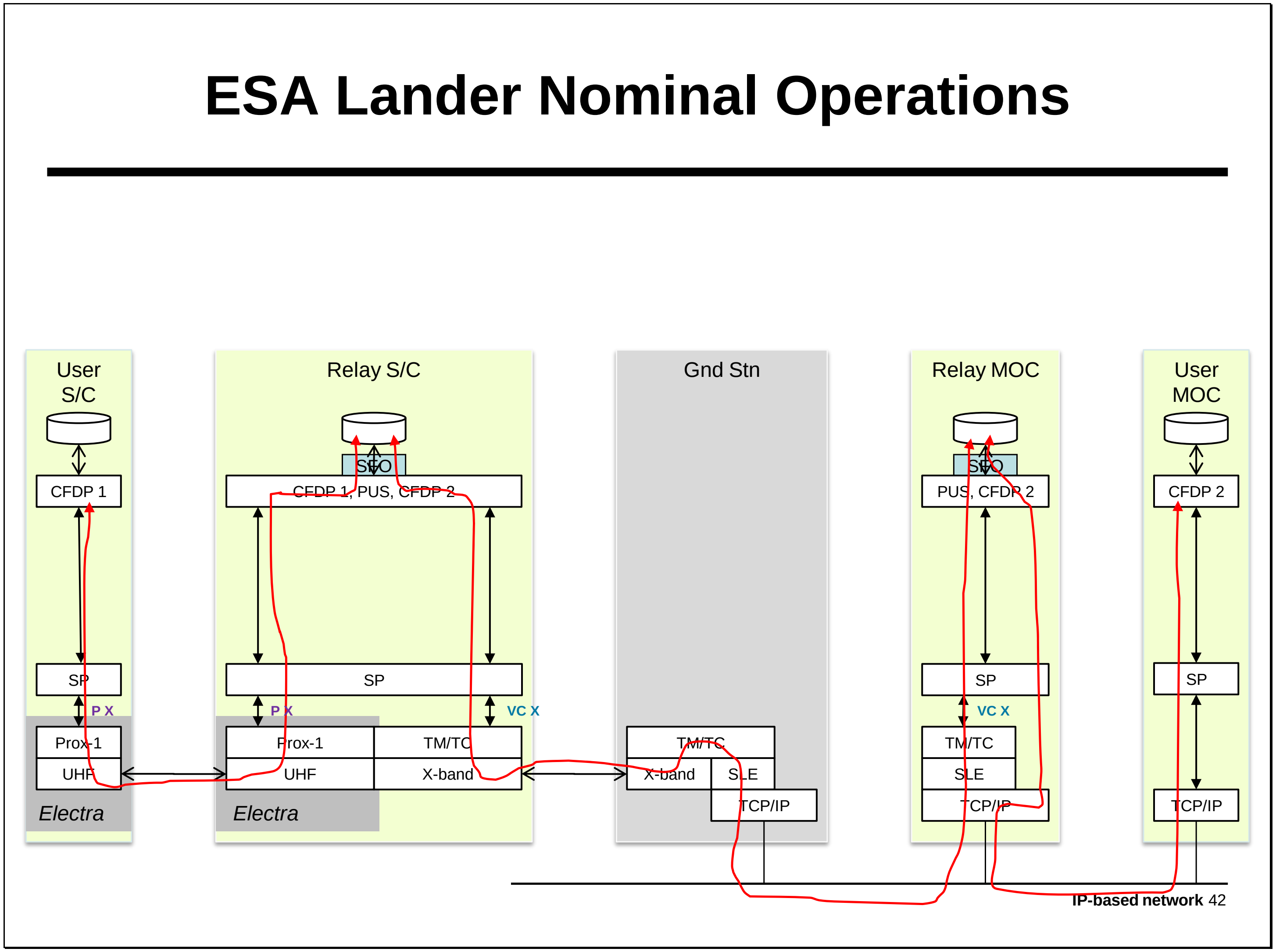
ESA Lander Nominal Operations
User S/C
CFDP 1
SP
P X
Prox-1
UHF
Electra
Relay S/C
SFO
CFDP 1, PUS, CFDP 2
SP
P X
VC X
Prox-1
TM/TC
UHF
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
SFO
PUS, CFDP 2
SP
VC X
TM/TC
SLE
TCP/IP
User MOC
CFDP 2
SP
TCP/IP
IP-based network
42

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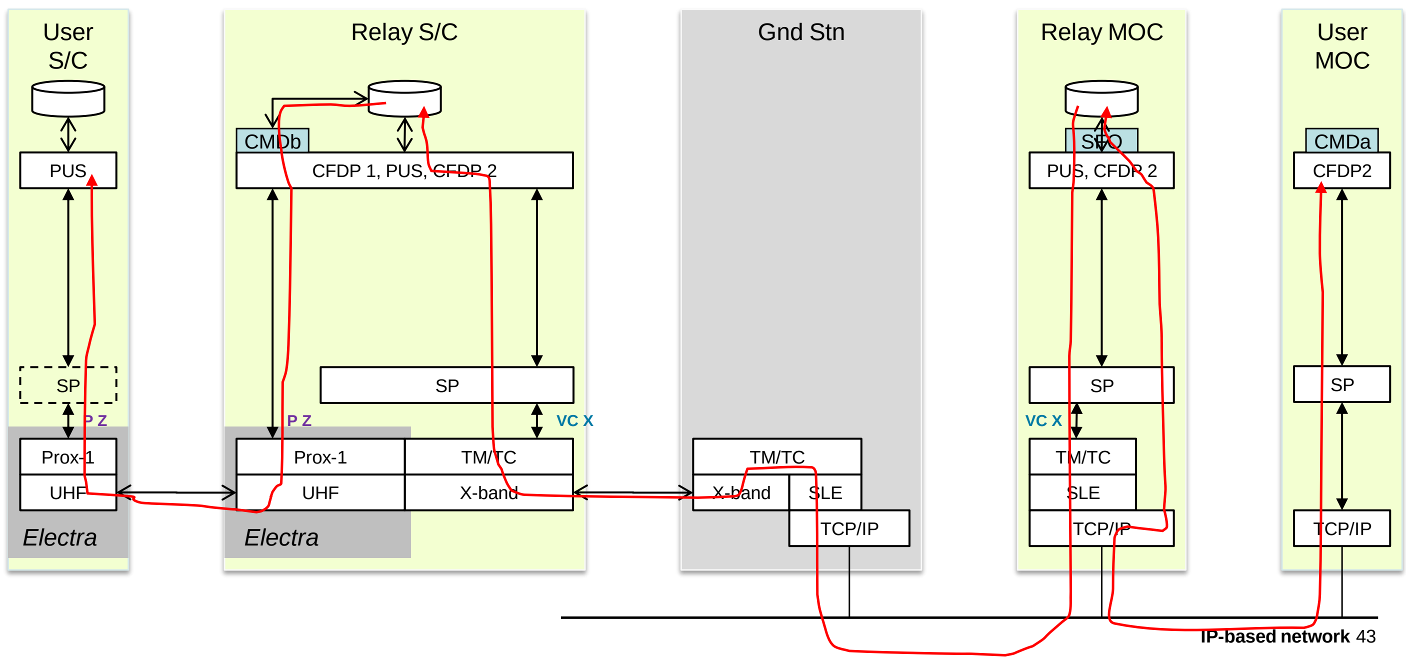
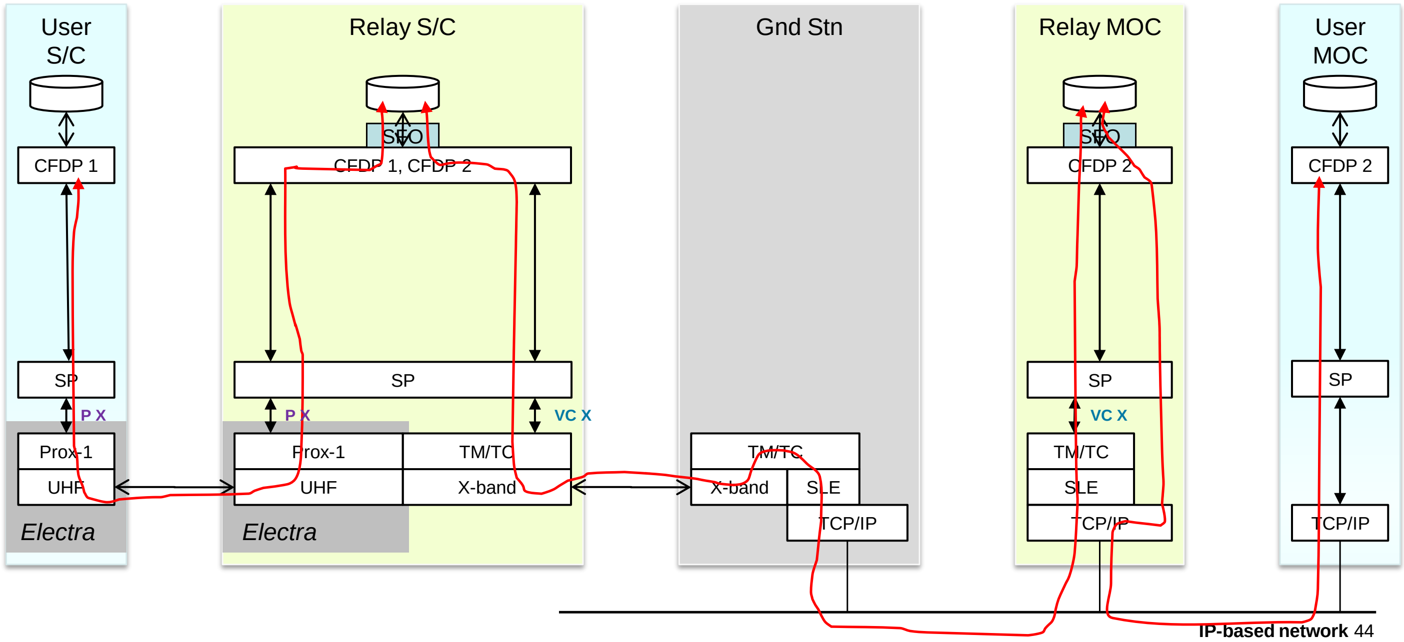
ESA Lander Emergency Cmd

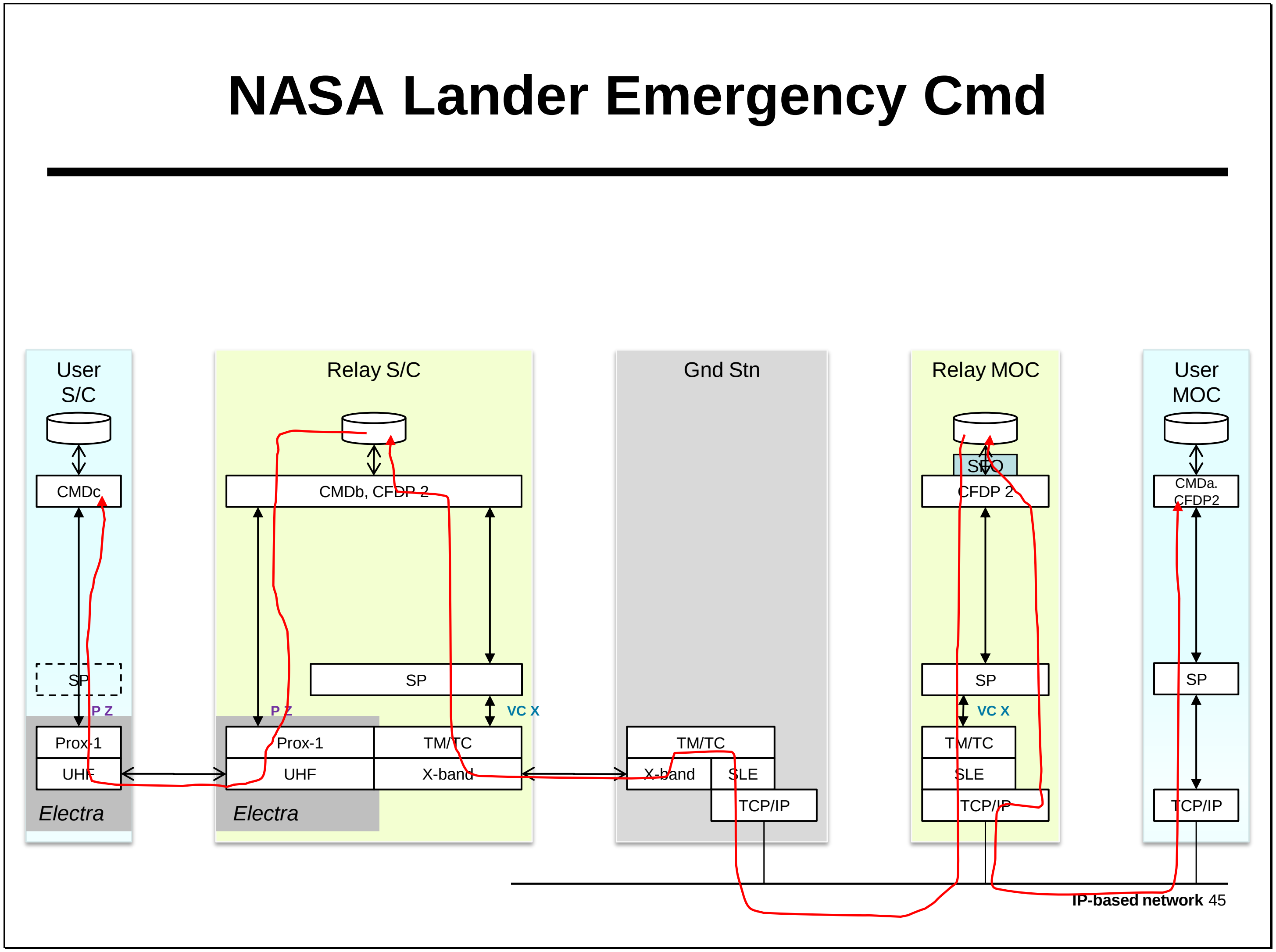


Slide 44

NASA Lander Nominal Operations



Slide 45


NASA Lander Emergency Cmd
User S/C
CMDc
SP
P Z
Prox-1
UHF
Electra
Relay S/C
CMDb, CFDP 2
SP
VC X
P Z
Prox-1
TM/TC
UHF
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
SFO
CFDP 2
SP
VC X
TM/TC
SLE
TCP/IP
User MOC
CMDa. CFDP2
SP
TCP/IP
IP-based network 45

Slide 46

Option 3a: DTN Configuration A Operating Scenarios

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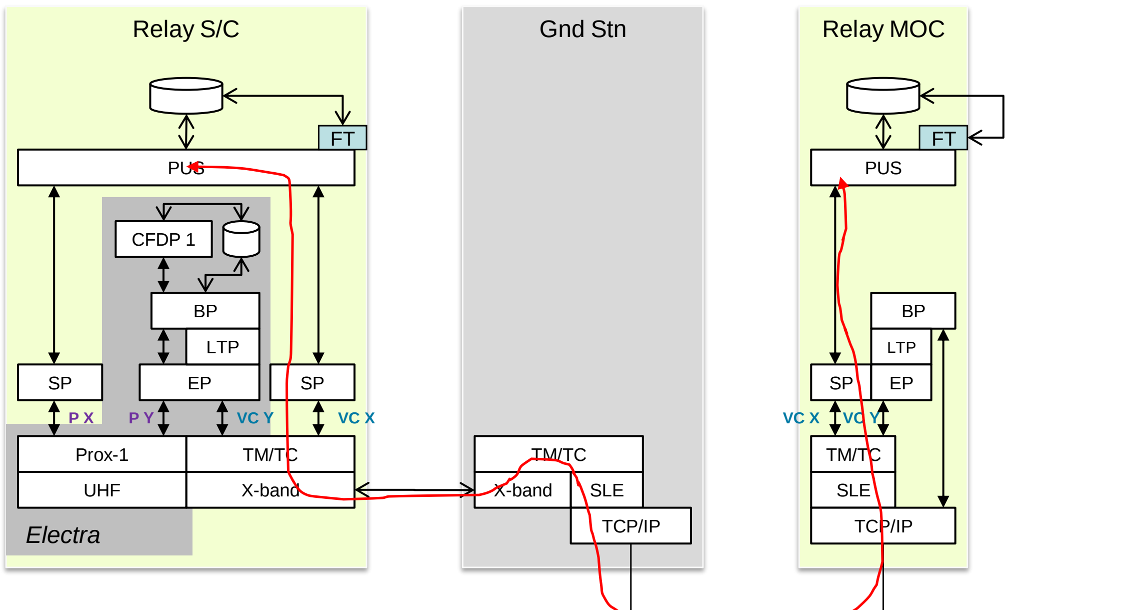
Slide 47

Orbiter Operations



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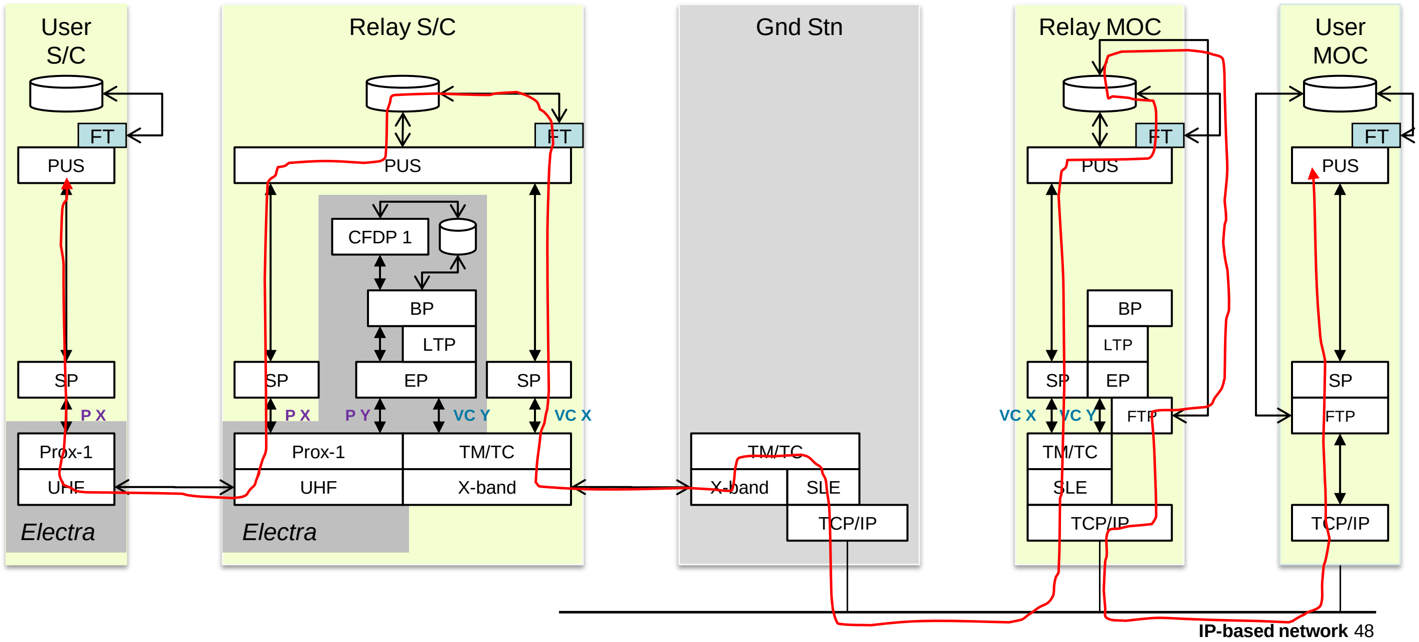
ESA Lander Nominal Operations



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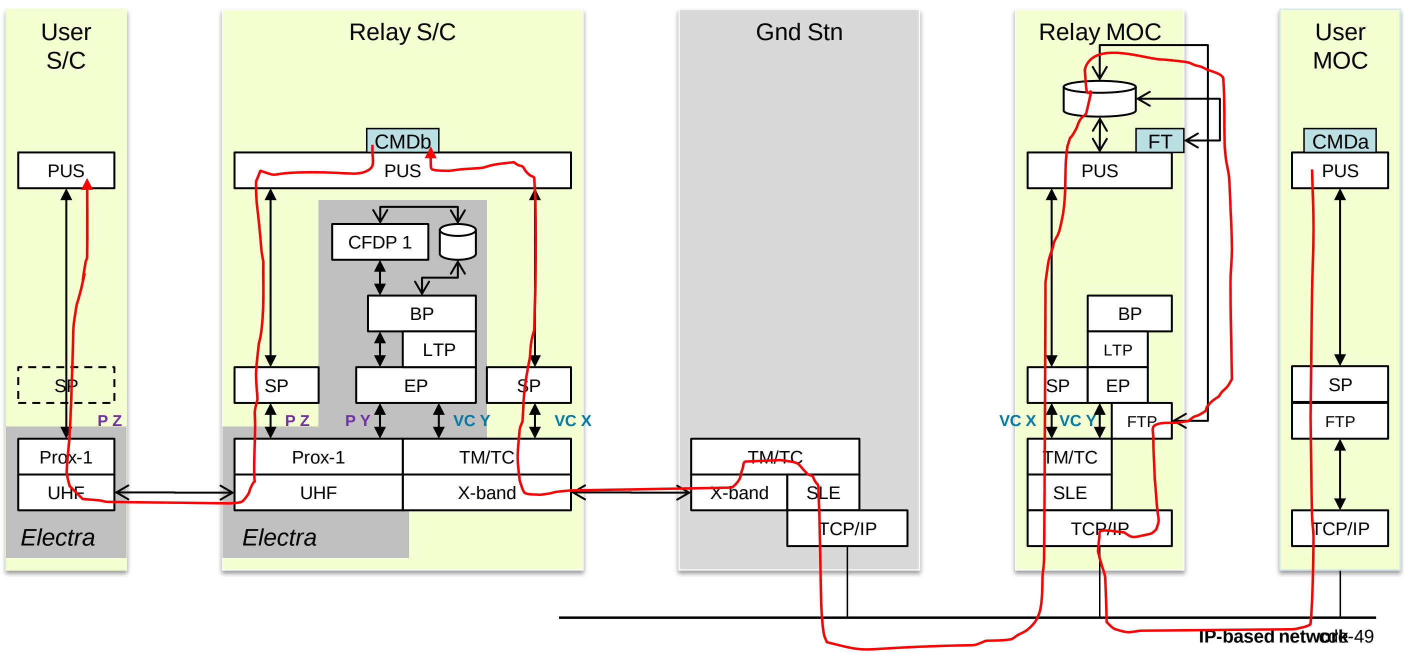
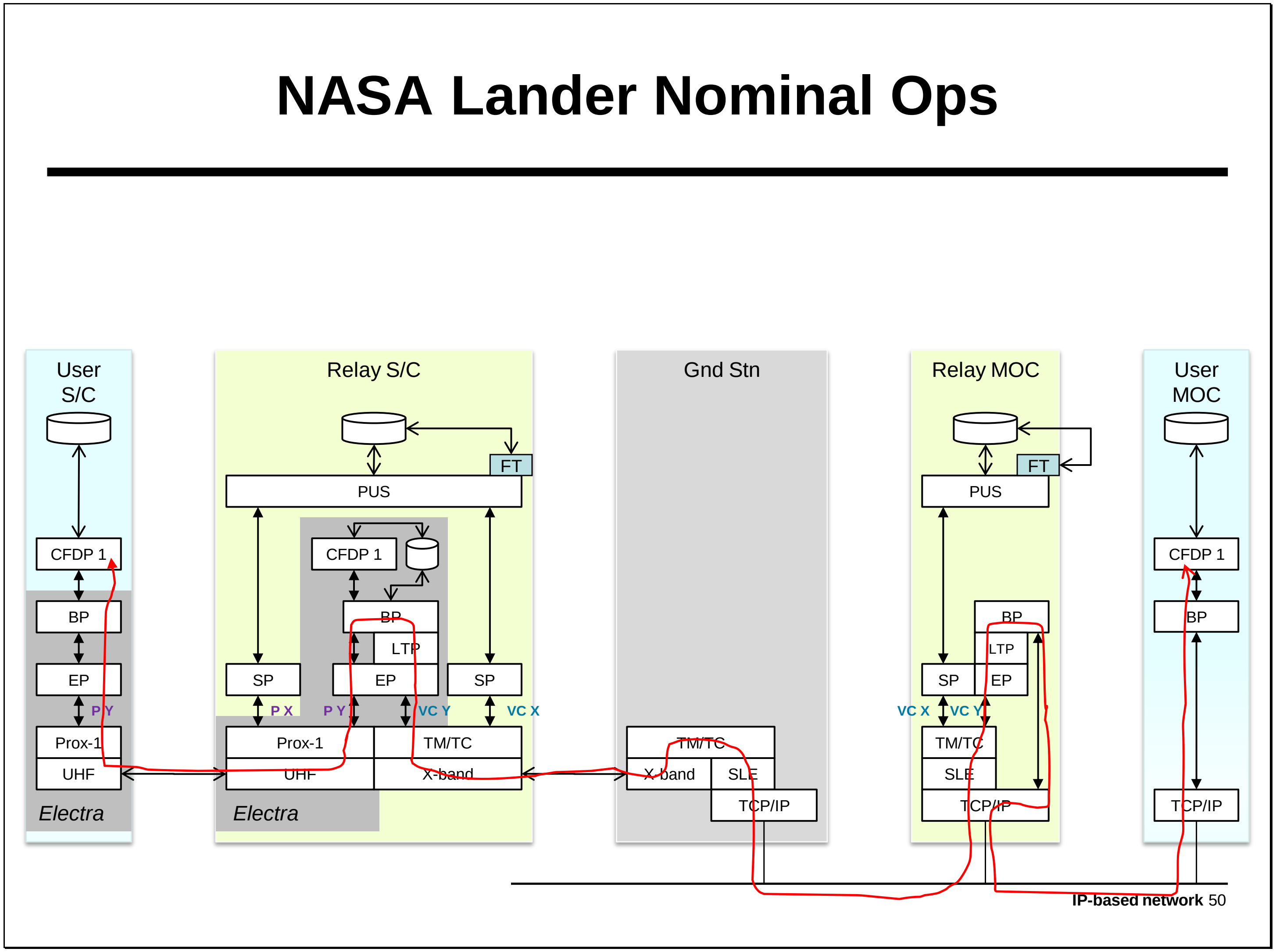
Slide 49

ESA Lander Emergency Cmd

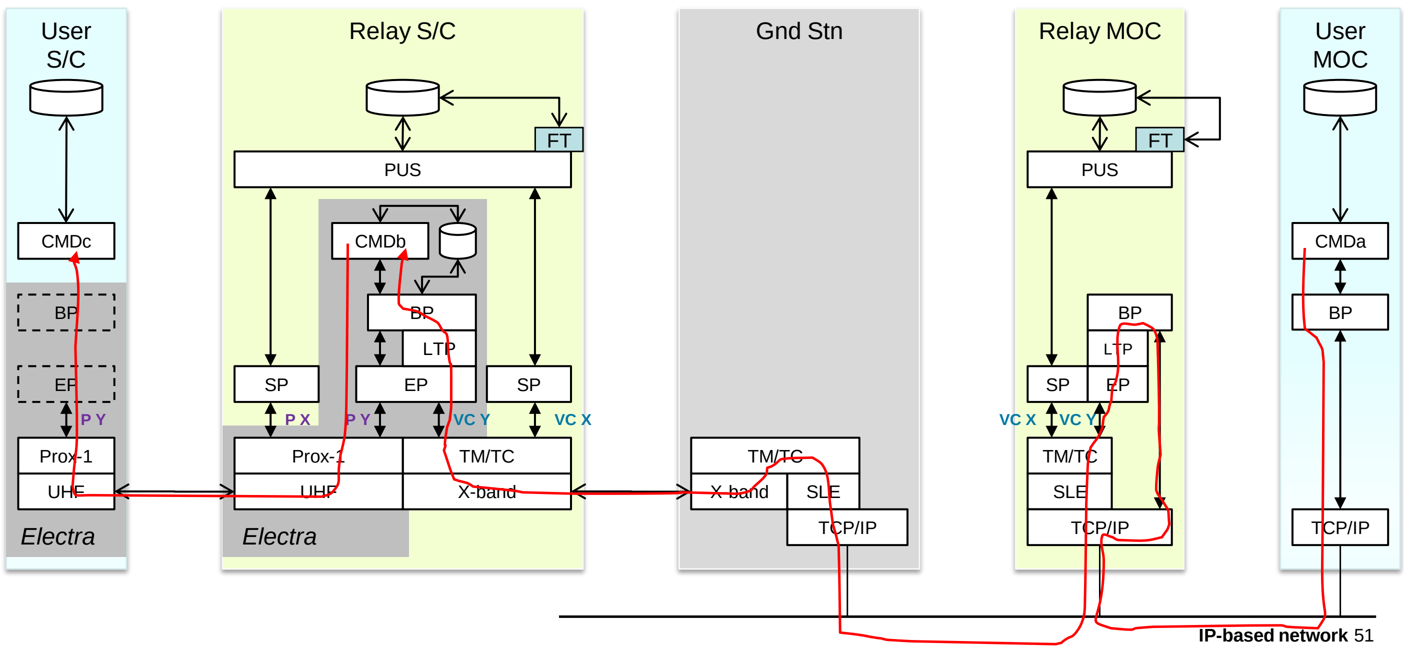


Slide 50


NASA Lander Nominal Ops
User S/C
CFDP 1
BP
EP
P Y
Prox-1
UHF
Electra
Relay S/C
FT
PUS
CFDP 1
BP
LTP
SP
EP
SP
P X
P Y
VC Y
VC X
Prox-1
UHF
TM/TC
X-band
Electra
Gnd Stn
TM/TC
X-band
SLE
TCP/IP
Relay MOC
FT
PUS
BP
LTP
SP
EP
VC X
VC Y
TM/TC
SLE
TCP/IP
User MOC
CFDP 1
BP
TCP/IP
IP-based network 50

Slide 51

NASA Lander Emergency Cmd



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Option 3b: DTN Configuration B Operating Scenarios

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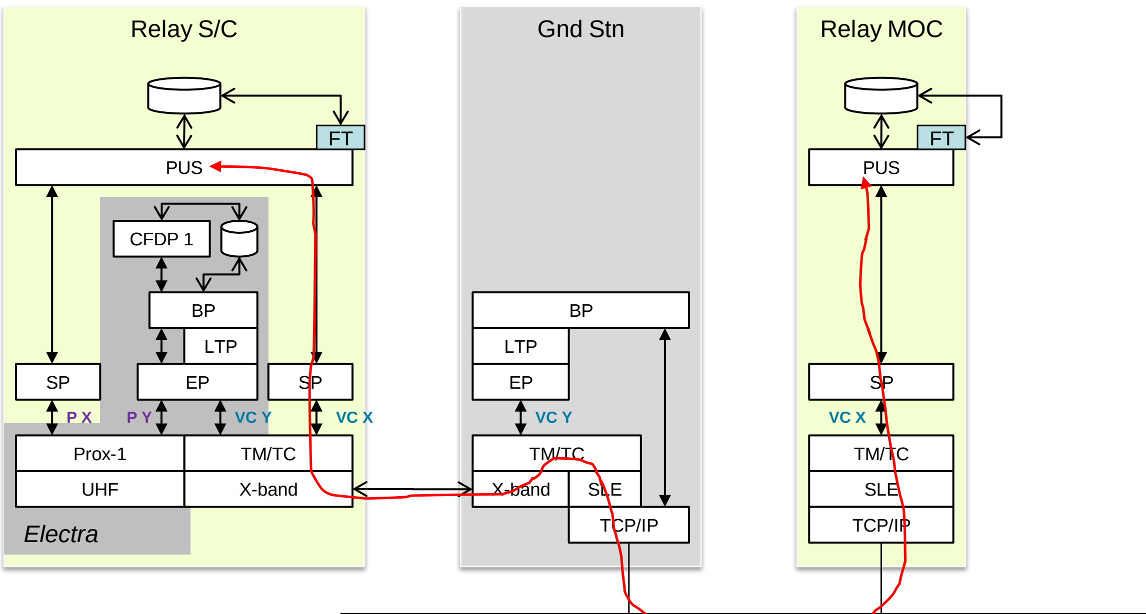
Orbiter Operations



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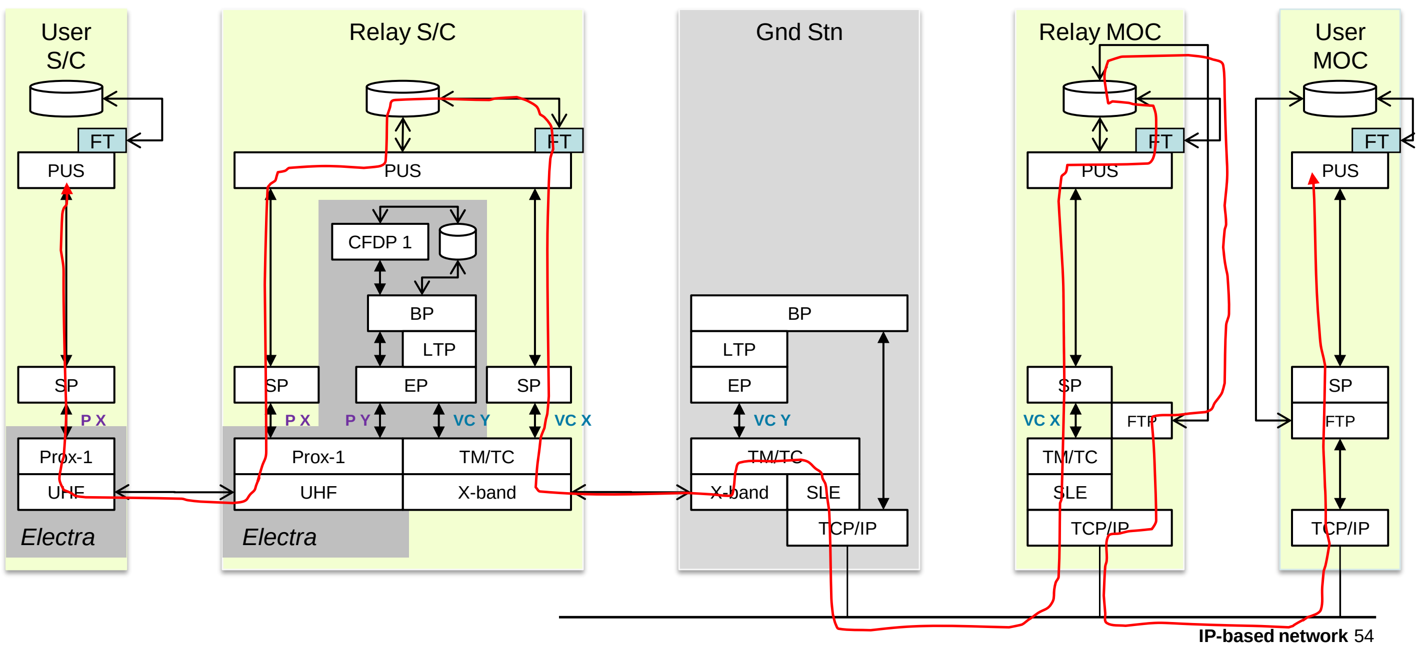
ESA Lander Nominal Operations



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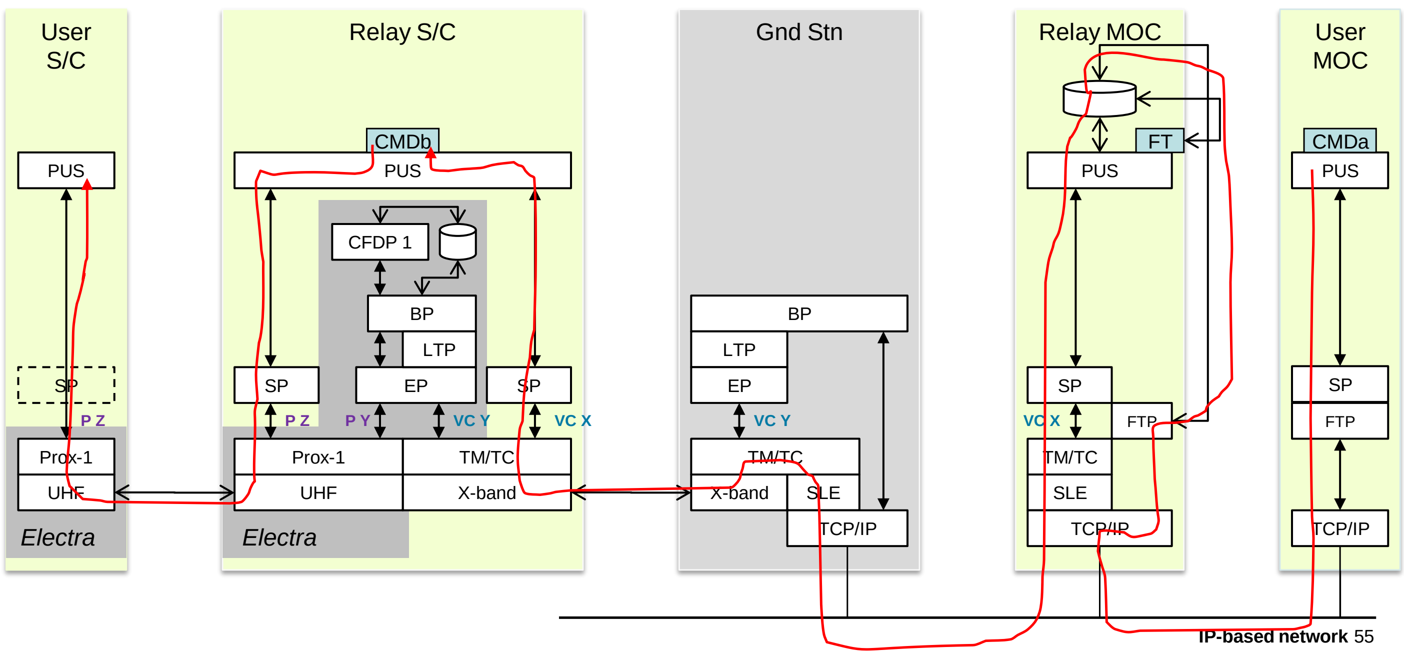
ESA Lander Emergency Cmd



55

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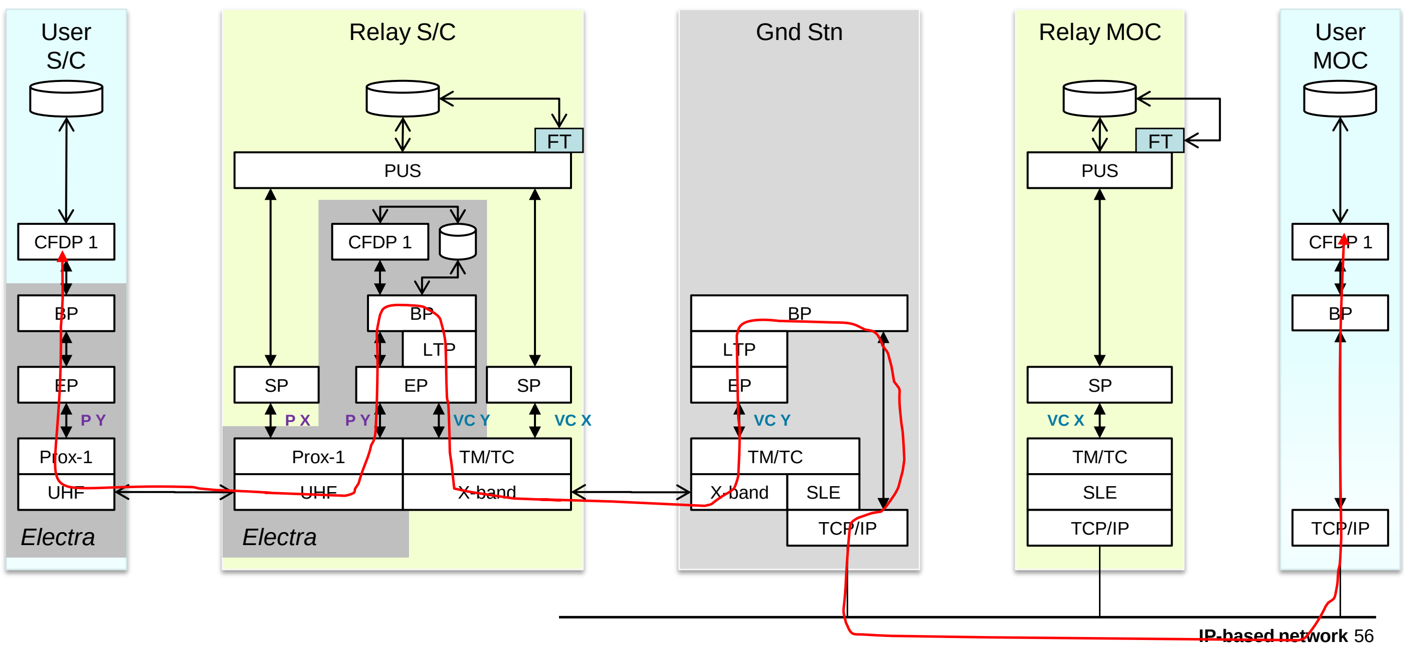
NASA Lander Nominal Operations



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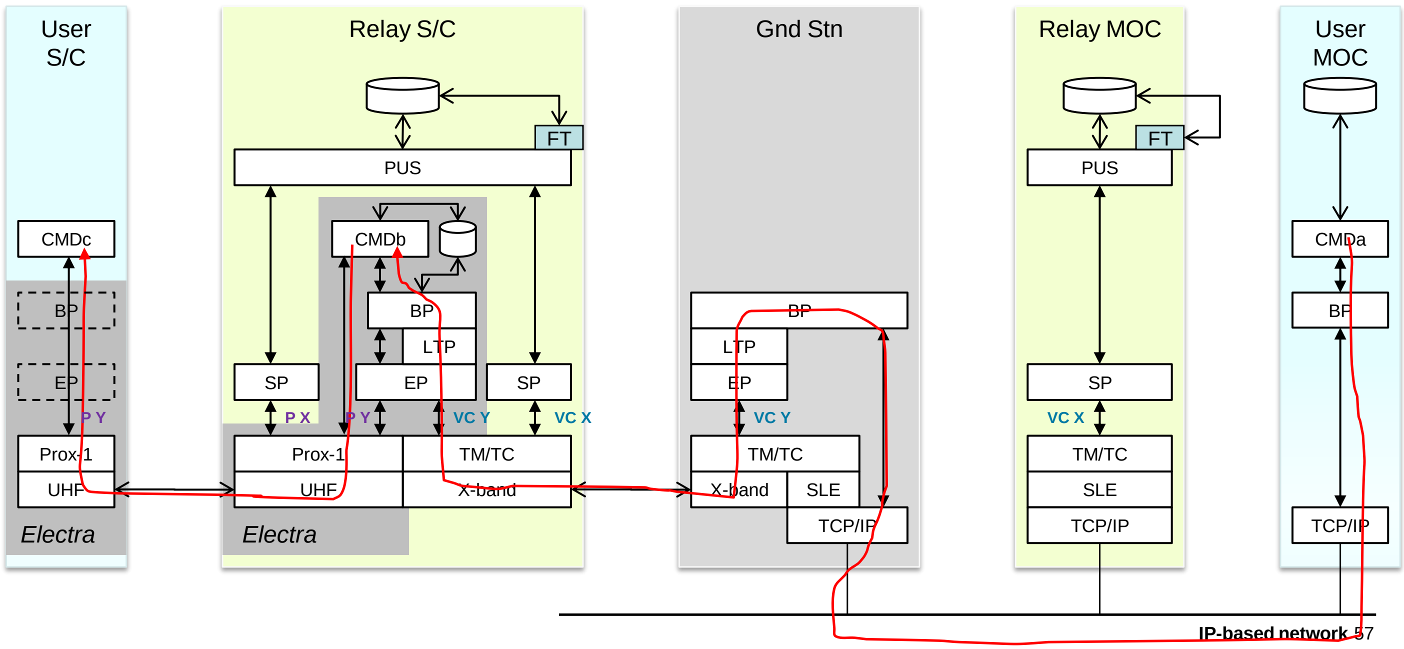
NASA Lander Emergency CMD



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Consensus Group Scoring

		Options				
Figure of Merit	**FOM Definition**	**Option 1: Current Baseline**	**Option 2a: CFDP on DS Link Only**	**Option 2b: CFDP w/ SFO**	**Option 3a: DTN (@ESOC)**	**Option 3b: DTN (@DSN)**
QQCL		*15.3*	*15.3*	*17.3*	*20.4*	*23.5*
Quantity	Quantity is defined as the volume of "acceptable" data units delivered by the service	0	0	1	1	1
Quality	Quality is defined as the "error rate" for the delivered data units over the end-to-end path	0	0	0	0	0
Continuity	Continuity is defined as the number of gaps in the set of data units delivered to a customer during a service	1	1	1	1	1
Latency	Latency is defined as the delay between a data unit's reception at a specified point and its delivery to another point where it becomes accessible to a customer	0	0	0	1	2
Cost		*15.3*	*9.2*	*3.1*	*7.7*	*7.7*
Implementation	Sum of flight and ground implementation cost to achieve the selected option	2	0	-2	-1	-1
Operations	Impact of the selected option on mission operations costs	0	0	0	1	1
Risk		*17.3*	*14.8*	*7.1*	*9.7*	*9.7*
Implementation	Technical risk associated with implementing the selected option	2	1	-2	-1	-1
Operations	Extent to which the selected option increases or decreases mission risk during flight operations	0	0	0	0	0
Programmatics		*14.3*	*14.3*	*10.7*	*17.9*	*21.4*
Interoperability with Legacy Assets	Ability of the selected option to accommodate existing missions	0	0	0	-1	0
Extensibility to SSI Final State	Extent to which the selected option moves towards the desired SSI final state, characterized by a functional BP/IP network layer	0	0	-1	2	2
Final FOM Score:		**62.2**	**53.6**	**38.3**	**55.6**	**62.2**

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Combined Scoring
(Consensus Group + 4 Add'l Stakeholders)

Figure of Merit	FOM Definition	Options Option 1: Current Baseline	Option 2a: CFDP on DS Link Only	Option 2b: CFDP w/ SFO	Option 3a: DTN (@ESOC)	Option 3b: DTN (@DSN)
QQCL:		***15.6***	***18.1***	***19.6***	***19.6***	***21.2***
Quantity	Quantity is defined as the volume of "acceptable" data units delivered by the service	0.125	0.625	1.25	0.875	0.875
Quality	Quality is defined as the "error rate" for the delivered data units over the end-to-end path	0.125	0.375	0.5	0.125	0.125
Continuity	Continuity is defined as the number of gaps in the set of data units delivered to a customer during a service	0.5	1	1.125	0.75	0.75
Latency	Latency is defined as the delay between a data unit's reception at a specified point and its delivery to another point where it becomes accessible to a customer	0.125	0.375	0.375	0.875	1.375
Cost:		***14.0***	***7.8***	***4.8***	***5.5***	***5.5***
Implementation	Sum of flight and ground implementation cost to achieve the selected option	1.75	-0.625	-1.625	-1.5	-1.5
Operations	Impact of the selected option on mission operations costs	-0.375	0.375	0.375	0.625	0.625
Risk:		***15.3***	***13.6***	***9.4***	***9.5***	***9.8***
Implementation	Technical risk associated with implementing the selected option	1.5625	0	-1.625	-1.25	-1.125
Operations	Extent to which the selected option increases or decreases mission risk during flight operations	-0.25	0.375	0.375	0.125	0.125
Programmatics:		***13.8***	***15.6***	***14.3***	***20.5***	***22.3***
Interoperability with Legacy Assets	Ability of the selected option to accommodate existing missions	0.25	0.25	0	-0.25	0.25
Extensibility to SSI Final State	Extent to which the selected option moves towards the desired SSI final state, characterized by a functional BP/IP network layer	-0.375	0.125	0	2	2
Final FOM Score:		**58.7**	**55.2**	**48.2**	**55.2**	**58.9**

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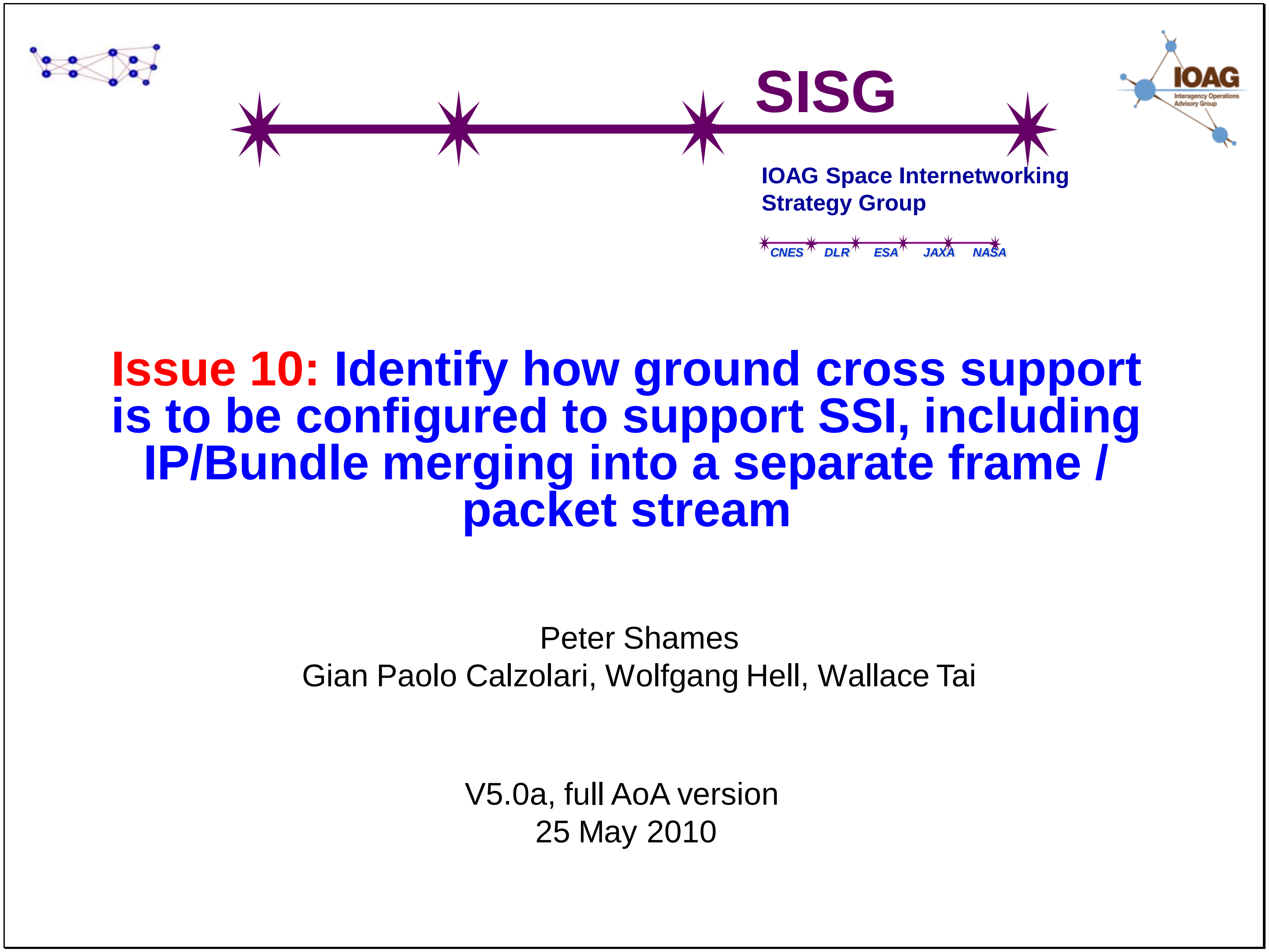
Appendix F. Issue 10 Supplementary Material

Slide 1



Slide 2

SISG

Assumptions

IOAG

- Orbiter MOC is assumed to be responsible for the ground to Orbiter link, configured using SM
- Orbiter MOC is assumed to have its own frame / packet flows to / from the Orbiter
- SLE/CSTS is assumed between the Orbiter MOC and Ground Station, forward and return, where Service Management is assumed to cover also any novel SLE / CSTS services used on that interface
- Monitoring of space link related parameters is provided via SLE/CSTS services not shown in the figures
- SSI traffic may flow either through the Orbiter MOC or direct to the Ground Station
- All NASA operations are assumed to be DTN end-to-end (except for specific last hop delivery needs)
- Spacecraft (Orbiter or Lander) operations may be either DTN based, file based, or space link based, and all will be supported by the ground installations
- It is assumed that the Orbiter always supports DTN (e.g. either natively or via enhanced ELECTRA)
- F-CLTU, R-AF and R-CF are baseline services assumed to be available by each Agency
- Application of link layer security is assumed to be performed by the user to avoid need to share keys

5/25/10 SISG SSI Ground Support Considerations PS, et al 2

Slide 3

SISG

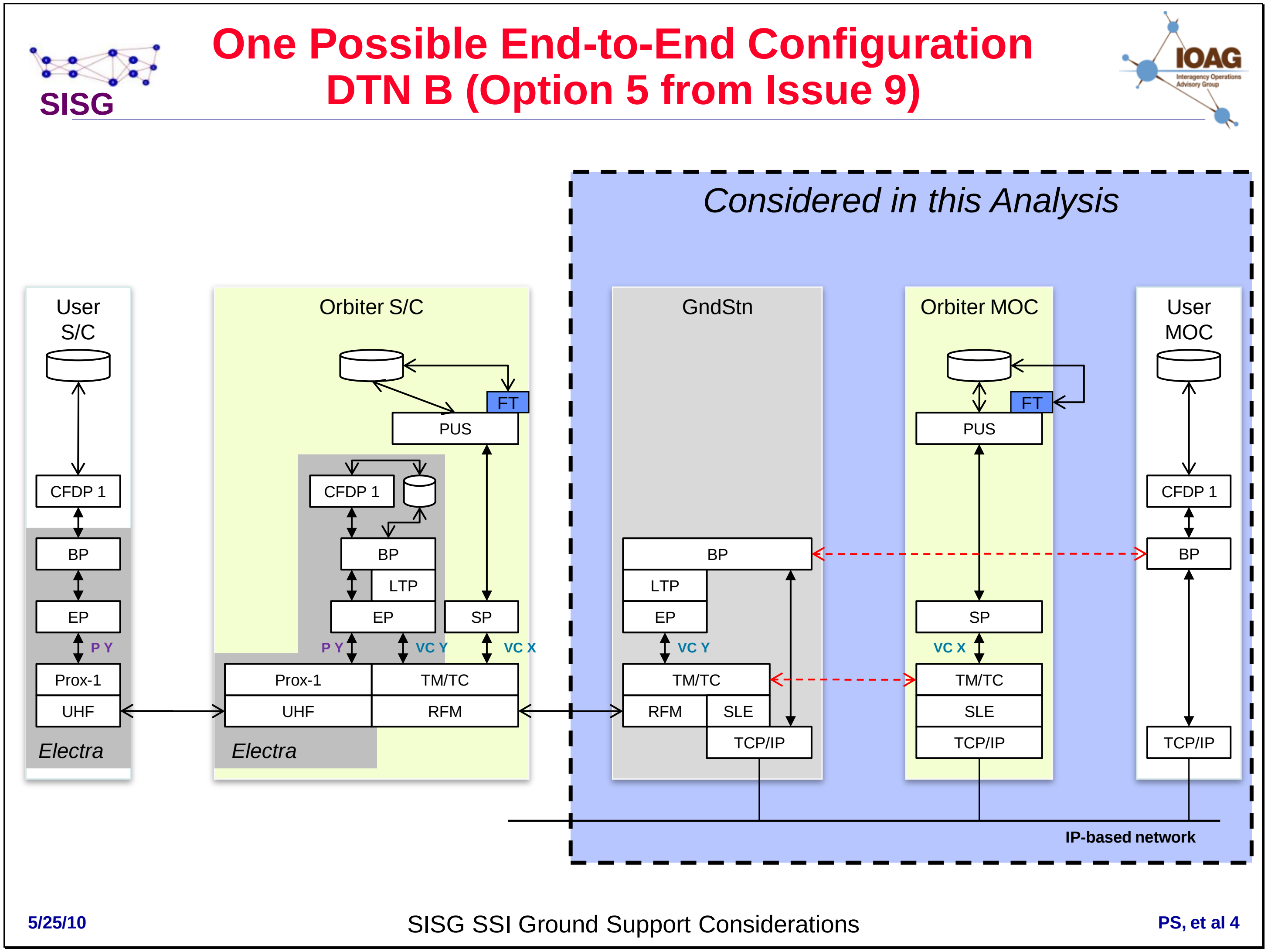
Some Conventions

IOAG

- C&S = Coding & Synchronization layer [forward/return]
- RFM = RF & Modulation layer [forward/return]
- Even if the functionalities belong to SLE/CSTS services, separate Multiplexing and C&S boxes are often shown to make diagrams easier to understand.
- Simplification: some boxes are side-to-side even when not belonging to same layer.
- Simplification: the packet extraction/insertion is not shown explicitly. Boxes with TC/AOS and TM/AOS labels are supposed to include it.

5/25/10 SISG SSI Ground Support Considerations PS, et al 3

Slide 4


SISG
One Possible End-to-End Configuration
DTN B (Option 5 from Issue 9)
IOAG
Considered in this Analysis
User S/C
Orbiter S/C
GndStn
Orbiter MOC
User MOC
FT
PUS
CFDP 1
BP
LTP
EP
SP
P Y
VC Y
VC X
Prox-1
UHF
TM/TC
RFM
SLE
TCP/IP
Electra
IP-based network
5/25/10
SISG SSI Ground Support Considerations
PS, et al 4

Slide 5

SISG

Ground Support Scenario

IOAG Interagency Operations Advisory Group

- All spacecraft options that have been considered in Issue 9 study can be supported by any of the identified ground support options
- For each option, consider each of these scenarios:
  - Nominal Orbiter operations, fwd & ret, DTN
  - Nominal Lander operations, fwd & ret, DTN
  - Orbiter emergency commanding
- Lander emergency commanding (it is assumed that ELECTRA can also transmit/receive non DTN data streams despite this is not explicitly shown in the figure “One Possible End-to-End Configuration ”)

5/25/10 SISG SSI Ground Support Considerations PS, et al 5

Slide 6

SISG

New Definitions (1 of 2)

IOAG Interagency Operations Advisory Group

- F-SEF (**Forward Synchronous Encoded Frame**) service is defined in IOAG Catalog #1: This Service enables a mission to send Frames to a spacecraft by allowing a Control Center to provide - in an asynchronous manner - a Ground Tracking Asset with encoded frames for uplink to a spacecraft in a synchronous manner. The Ground Tracking Asset will undertake to insert predefined idle frames in the absence of user supplied data. No encoding capabilities are required to the Ground Tracking Asset. This service is specifically intended to support - but is not limited to - uplinking CCSDS Version-2 Transfer Frames (i.e. AOS Frames).
- F-Frame (**Forward Frame**) service is new. This Service provides a forward frame service for AOS. It also implements multiplexing, frame fill and coding in the provider and implements the full stack down to the physical layer.
  - For consideration by CCSDS: F-Frame is intended to support AOS insert zone (i.e. adding non encrypted data to the received frame before encoding). Additional interfaces may be required to accomplish this.
  - For consideration by CCSDS: F-Frame may be configured to additionally behave as the previous F-CLTU/F-ESF services and provide a uniform forward frame service for TC and AOS. This may be useful for frame oriented encryption.
  - For consideration by CCSDS: F-Frame should be renamed “F-AOS Frame” if only AOS is supported.

5/25/10 SISG SSI Ground Support Considerations PS, et al 6

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SISG

New Definitions (2 of 2)

IOAG

- F-SP2 is a new version of the current SLE F-SP with the following (main) modifications:
  - accepts Enc. Packets (in addition to Space Packets)
  - multiplexes either SP or EP or both packet types on a single VC or on several VCs
  - runs on top of AOS protocol (in addition to TC protocol) [in this case without using the COP]
  - implements the full stack down to the physical layer.
- R-SP2 will be a new version of the SLE R-SP that was defined only conceptually in the SLE Reference Model. It:
  - delivers Encapsulation Packets (in addition to Space Packets)
  - de-multiplexes either SP or EP or both packet types on a single VC or on several VCs (Note: VC Demux is done before/outside R-SP2).
  - runs on top of TM and AOS protocols

5/25/10 SISG SSI Ground Support Considerations PS, et al 7

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SISG

SSI Ground Support Options

IOAG

Conf. #	Forward	Return	Notes
1	SLE F-CLTU or F-SEF	R-CF	Orbiter MOC handles all data including DTN. DTN installed at Orbiter MOC.
2	SLE F-CLTU or F-SEF	R-AF or R-CF	Orbiter MOC handles all data excluding DTN. User MOC implements DTN. This is ESA legacy Orbiter MOC.
3	SLE F-SP2	R-SP2	Ground Station interface is multiple packet streams, DTN installed at User MOC
4	SLE F-SP2	R-SP2	Ground Station interface is multiple packet streams, DTN installed at Ground Station
5	F-Frame	R-CF	Ground Station interface is multiple frame streams, DTN installed at Ground Station
6	F-Frame	R-CF	Ground Station interface is multiple frame streams, DTN installed at User MOC

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SISG

Management of VC Multiplexing

IOAG Interagency Operations Advisory Group

- **In the configurations shown forward or return data flows are often multiplexed on Virtual Channels (VCs).**
- **Such multiplexing shall be managed and this capability shall be considered in Catalog #2.**
- **On ground Management of multiplexing is likely to be included in SLE/CSTS.**
- **Orbiter Mux shall be agreed among agencies but may not imply a standardized service management.**

Forward	Return
1 TC / AOS VCs @ Orbiter MOC	1 TM/AOS VCs @ Orbiter
2 TC / AOS VCs @ Orbiter MOC	2 TM/AOS VCs @ Orbiter
3 TC / AOS VCs @ GndStn	3 TM/AOS VCs @ Orbiter
4 TC / AOS VCs @ GndStn	4 TM/AOS VCs @ Orbiter
5 TC / AOS VCs @ GndStn	5 TM/AOS VCs @ Orbiter
6 TC / AOS VCs @ GndStn	6 TM/AOS VCs @ Orbiter

In the Return link the multiplexing is always performed @ Orbiter.

5/25/10 SISG SSI Ground Support Considerations PS, et al 9

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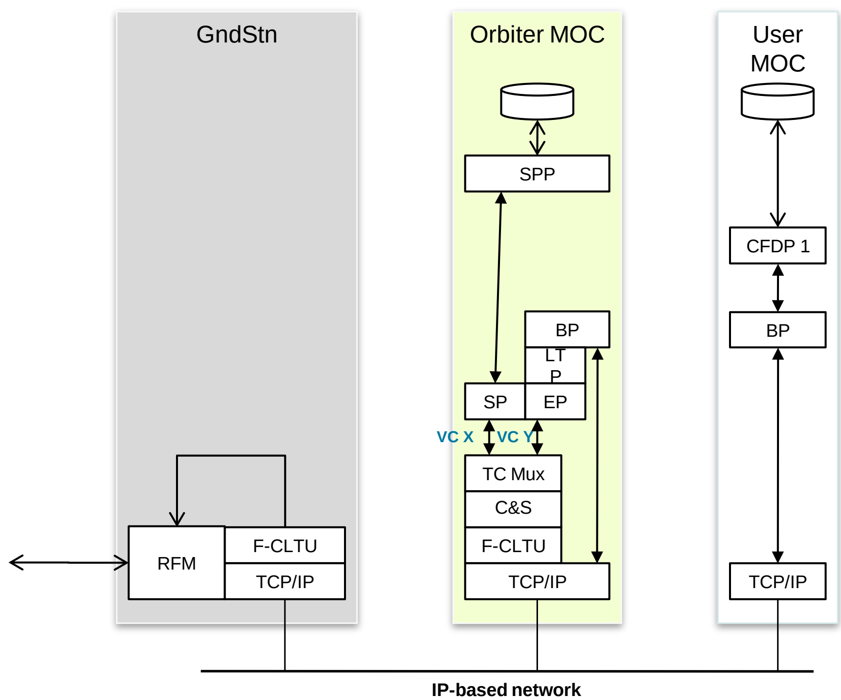
Configuration 1, Forward TC
(Current SLE F-CLTU, DTN at Orbiter MOC)



5/25/10 SISG SSI Ground Support Considerations PS, et al 10

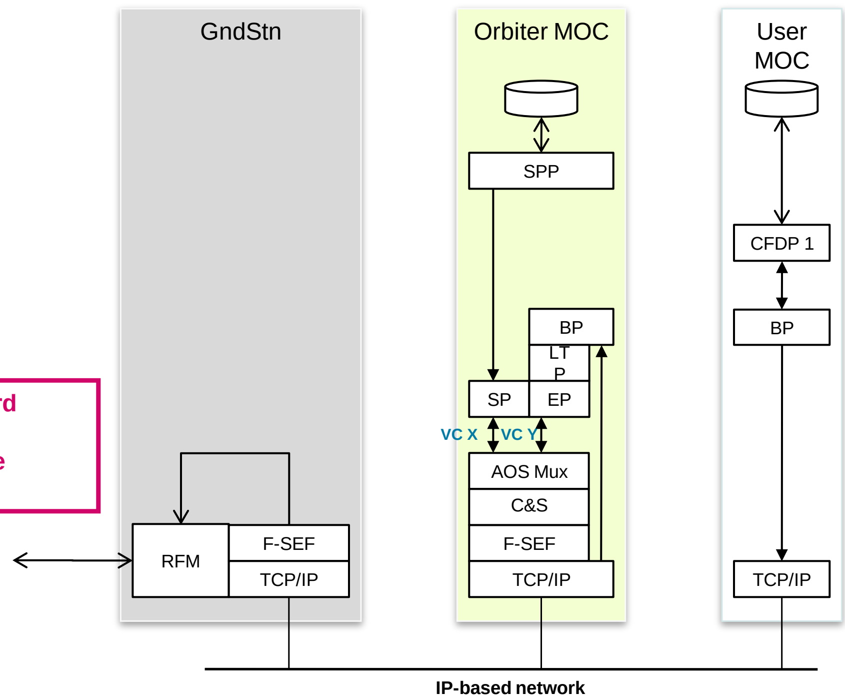
Slide 11

SISG

Configuration 1, Forward AOS (New SLE F-SEF, DTN at Orbiter MOC)

IOAG

F-SEF = Forward Synchronous Encoded Frame service.



5/25/10 SISG SSI Ground Support Considerations PS, et al 11

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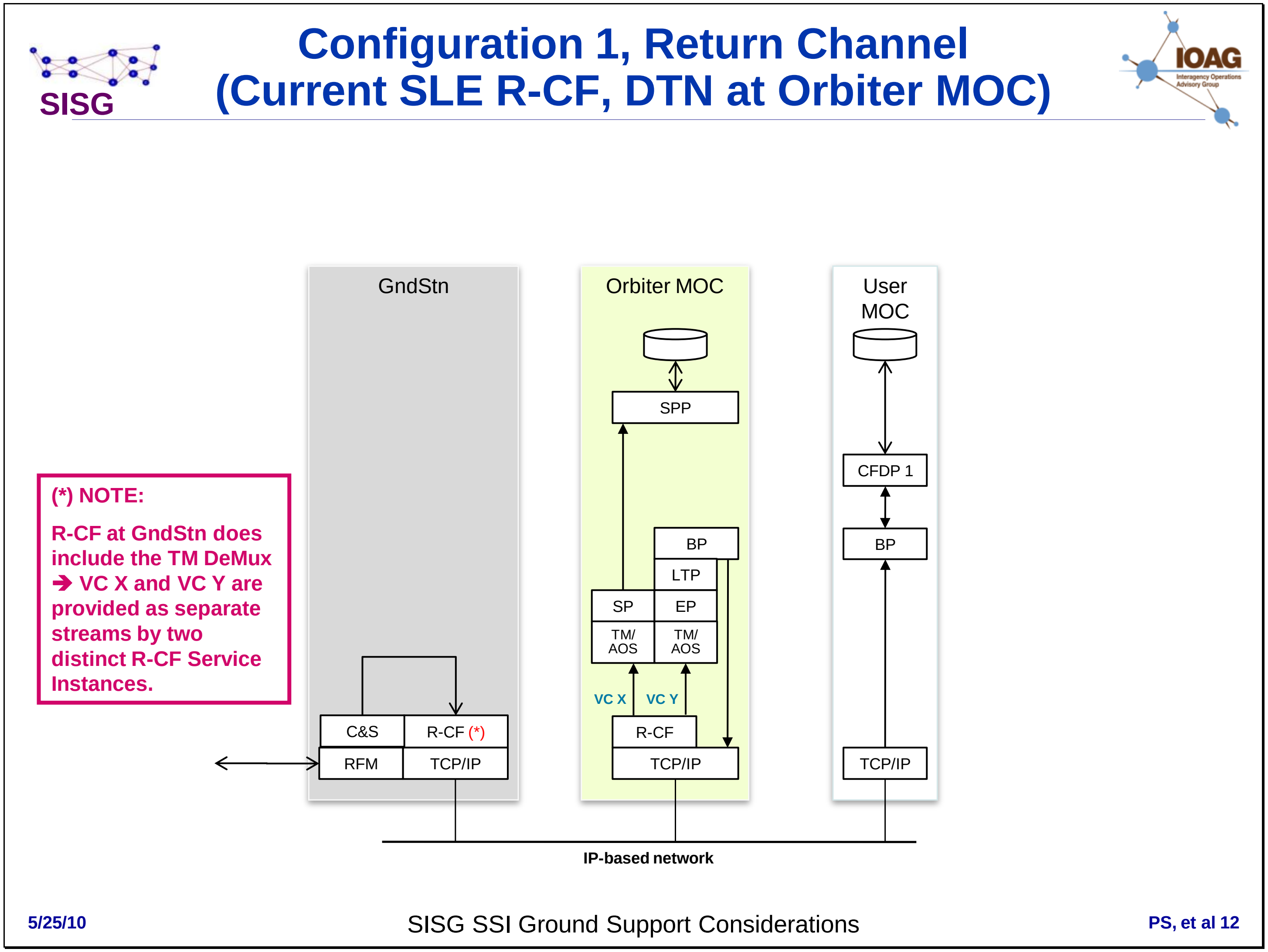
SISG
Configuration 1, Return Channel
(Current SLE R-CF, DTN at Orbiter MOC)
IOAG
Interagency Operations Advisory Group
GndStn
Orbiter MOC
User MOC
SPP
CFDP 1
BP
LTP
SP
EP
TM/ AOS
TM/ AOS
BP
VC X
VC Y
R-CF
TCP/IP
C&S
R-CF (*)
RFM
TCP/IP
TCP/IP
IP-based network
(*) NOTE:
R-CF at GndStn does include the TM DeMux ➔ VC X and VC Y are provided as separate streams by two distinct R-CF Service Instances.
5/25/10
SISG SSI Ground Support Considerations
PS, et al 12

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SISG

Configuration 1 Features

IOAG

<table>
<tr><th>Forward</th><th>Return</th></tr>
<tr><td>SLE F-CLTU (existing) or SLE F-SEF (new)</td><td>R-CF (existing) supports also AOS (excepted the optional header protection)</td></tr>
<tr><td colspan="2">The Ground Station does not support DTN directly so the functions need to be implemented in the Orbiter MOC supporting the SSI; i.e. DTN node is located at the Orbiter MOC.
LTP is closed between the Orbiter MOC and the Orbiter. REMARK: There is interaction at Orbiter MOC between Return and Forward because of LTP; i.e. when needed the “LTP return entity” can ask the “LTP forward entity” to generate Encapsulation Packets to be uplinked.</td></tr>
<tr><td colspan="2">Orbiter MOC operations are responsible for all data flows across the space link</td></tr>
<tr><td colspan="2">Interface between MOCs is a stream of bundles over TCP for DTN-enabled user</td></tr>
<tr><td>The Orbiter S/C team handles all uplink traffic.
The Orbiter MOC merges all traffic flows at the VC or frame level into the space link</td><td>The Orbiter MOC handles all downlink traffic and performs packet extraction.
GndStn (R-CF) demux all traffic flows at VC level from the space link.</td></tr>
<tr><td>TC/ AOS Frame mux, ASM, uplink coding, is done in the Orbiter MOC.
AOS fill frames insertion in the GndStn (by F-SEF).</td><td>TM/AOS Frame synch & decoding is done at the Ground Station.</td></tr>
</table>

5/25/10 SISG SSI Ground Support Considerations PS, et al 13

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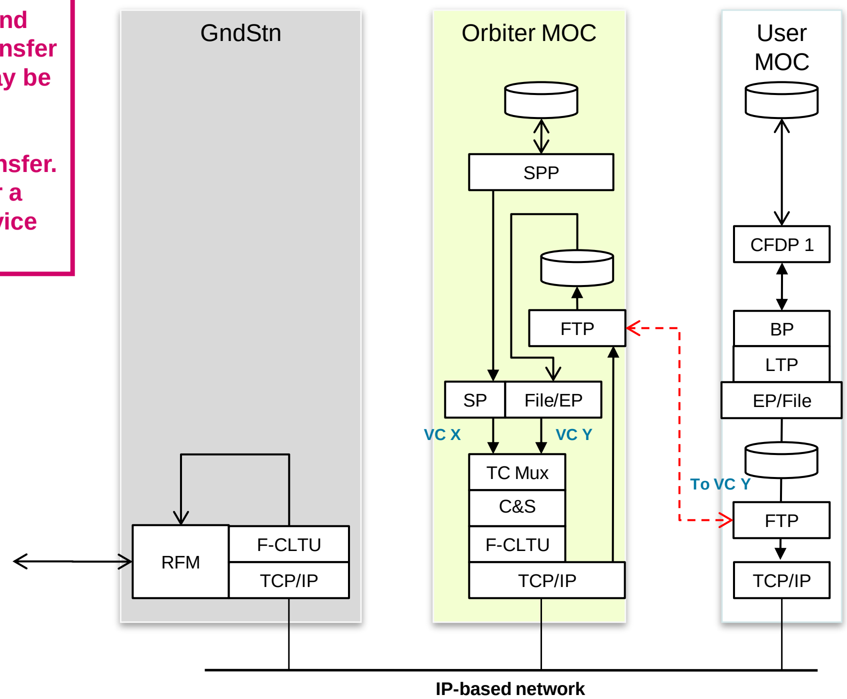
SISG

Configuration 2, ESA Legacy Forward TC (Current SLE F-CLTU, DTN at User MOC, file transfer to Orbiter MOC)

IOAG

This is an ESA legacy operational configuration and requires file transfer (FTP) which may be replaced by a standard cross support file transfer. Not relevant for a NASA DTN service provider.



EP/File and File/EP are local adaptations that allow a file of EP to be sent and decomposed for transfer by Orbiter MOC.

5/25/10 SISG SSI Ground Support Considerations PS, et al 14

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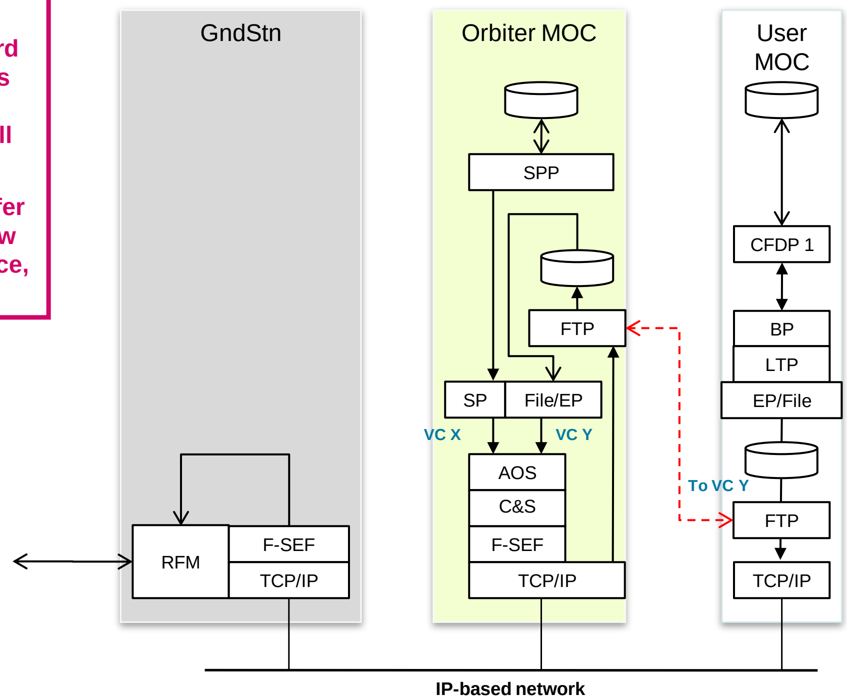
SISG

Configuration 2, ESA Legacy Forward AOS (New SLE F-SEF, DTN at User MOC,file transfer to Orbiter MOC)

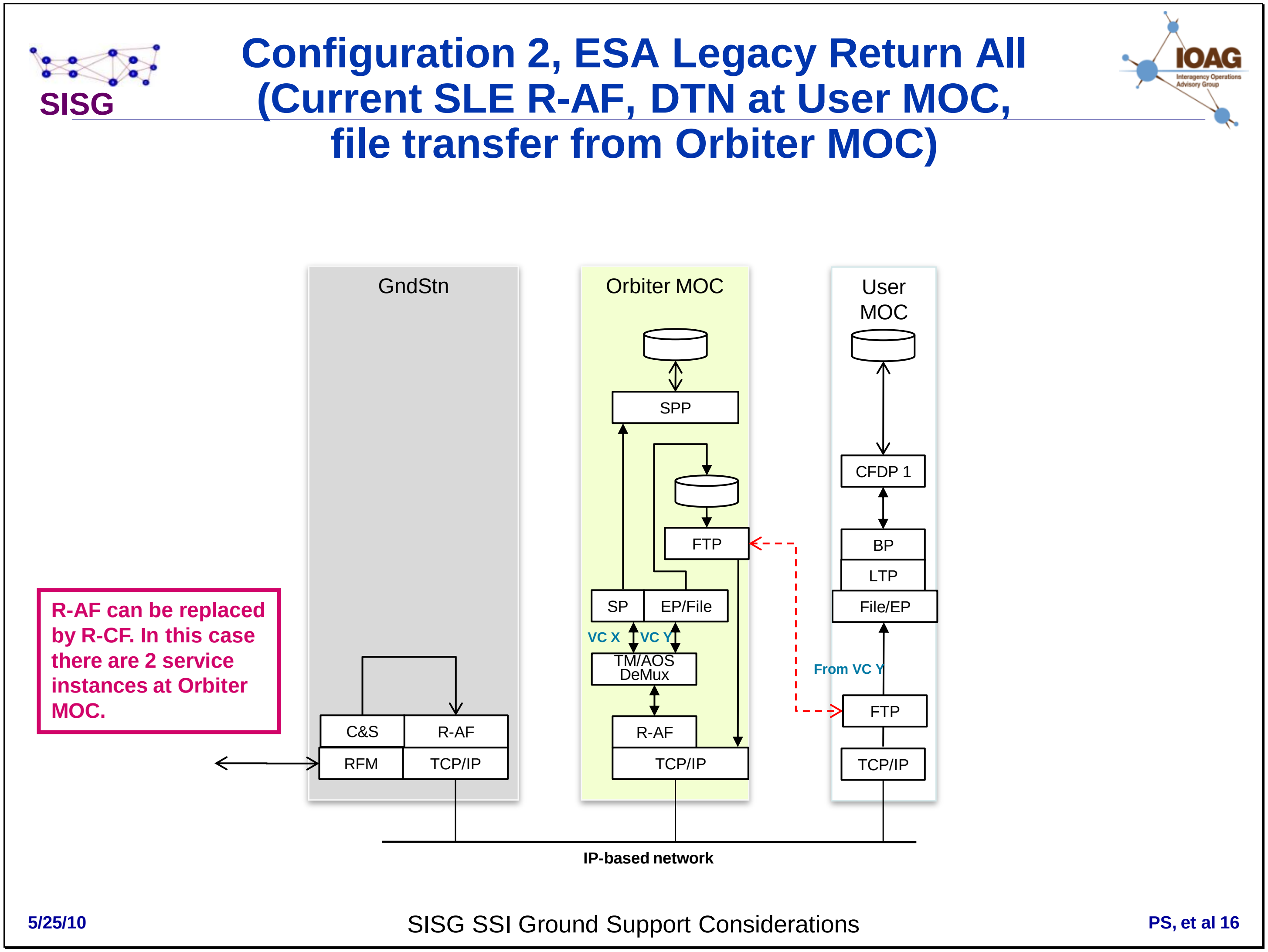
IOAG

ESA does not plan to support synchronous encoded forward uplink, but does see an external mission that will require it.

ESA would prefer to adopt the new F-FRAME service, see Config 5



Slide 16


SISG
IOAG
Interagency Operations Advisory Group
Configuration 2, ESA Legacy Return All
(Current SLE R-AF, DTN at User MOC,
file transfer from Orbiter MOC)
GndStn
Orbiter MOC
User MOC
SPP
FTP
SP
EP/File
VC X
VC Y
TM/AOS DeMux
R-AF
TCP/IP
CFDP 1
BP
LTP
File/EP
From VC Y
FTP
TCP/IP
C&S
R-AF
RFM
TCP/IP
R-AF can be replaced by R-CF. In this case there are 2 service instances at Orbiter MOC.
IP-based network
5/25/10
SISG SSI Ground Support Considerations
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SISG

Configuration 2 Features

IOAG
Interagency Operations Advisory Group

<table>
<tr><th>Forward</th><th>Return</th></tr>
<tr><td>SLE F-CLTU (existing) or SLE F-SEF (new)</td><td>R-AF or R-CF (existing), they support also AOS (excepted the optional header protection)</td></tr>
<tr><td colspan="2">The Ground Station <u>and the Orbiter MOC</u> do not support DTN directly so the functions need to be implemented in the User MOC supporting the SSI; i.e. DTN node is located at the User MOC.
LTP is closed between the User MOC and the Orbiter (ELECTRA). REMARK: There is interaction at User MOC between Return and Forward because of LTP; i.e. when needed the “LTP return entity” can ask the “LTP forward entity” to generate Encapsulation Packets to be uplinked.</td></tr>
<tr><td colspan="2">Orbiter MOC operations are responsible for all data flows across the space link (but NOT DTN) , may use any legacy means (space packets, CFDP, or even PUS Svc 13) to deliver the User data to the Orbiter</td></tr>
<tr><td colspan="2">Interface between MOCs is a stream of EP sent in a file using FTP over TCP</td></tr>
<tr><td>The Orbiter MOC handles all uplink traffic.
The Orbiter MOC merges all traffic flows at the VC or frame level into the space link</td><td>The Orbiter MOC handles all downlink traffic and performs packet extraction.
Orbiter MOC demux all traffic flows at the VC or frame level from the space link</td></tr>
<tr><td>TC/ AOS Frame mux, ASM, uplink coding, is done in the Orbiter MOC.
AOS fill frames insertion in the GndStn (by F-SEF).</td><td>TM/AOS Frame synch & decoding is done at the Ground Station.</td></tr>
</table>

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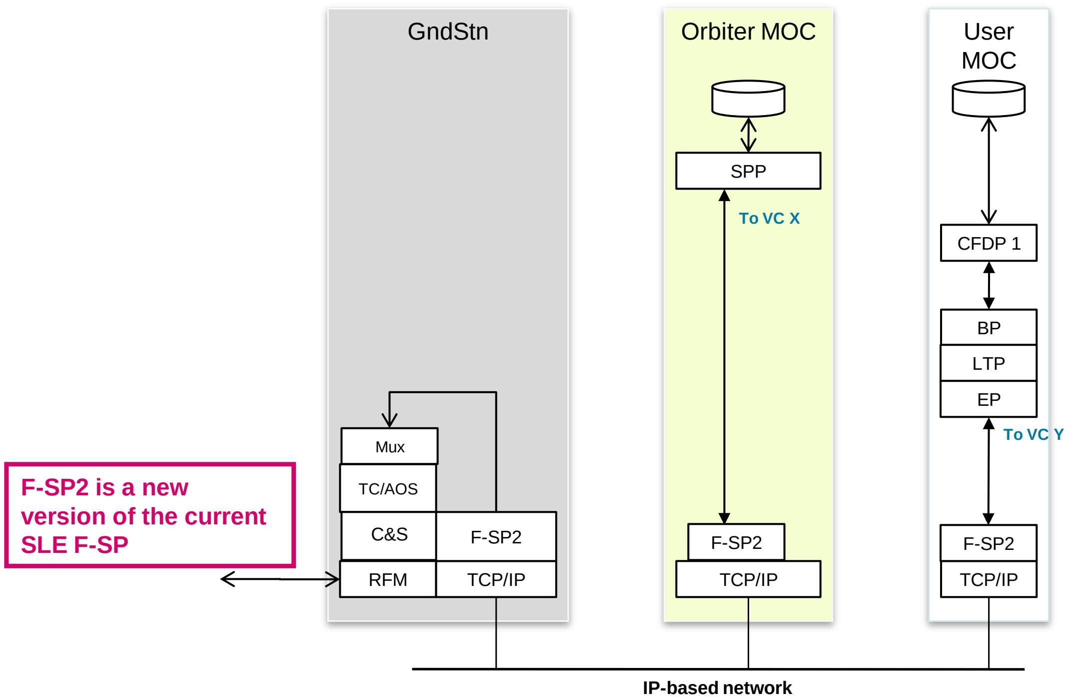
SISG

Configuration 3, Forward (New SLE F-SP2, packet multiplex, DTN at User)

IOAG



5/25/10 SISG SSI Ground Support Considerations PS, et al 18

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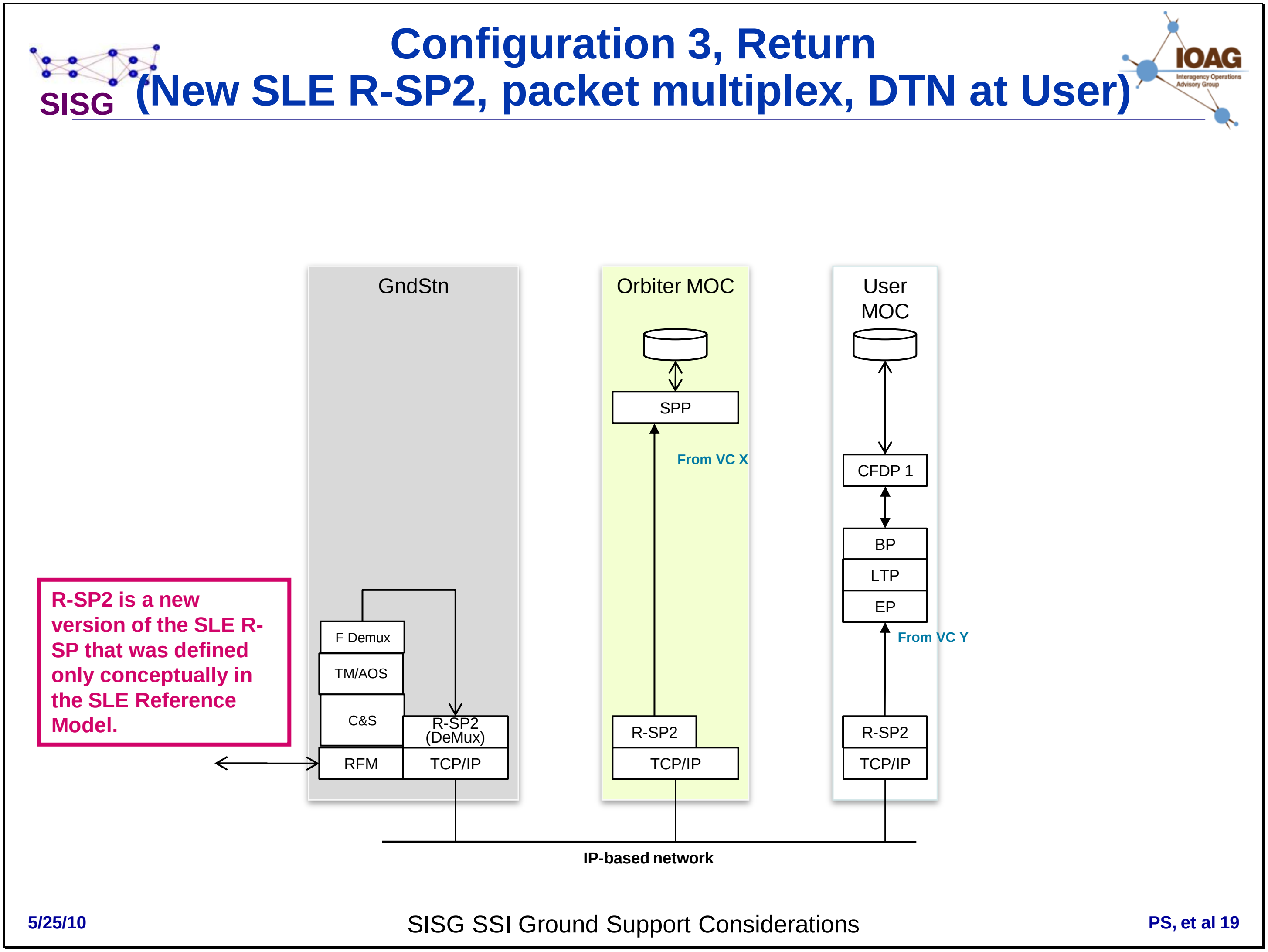
SISG
Configuration 3, Return
(New SLE R-SP2, packet multiplex, DTN at User)
IOAG
GndStn
Orbiter MOC
User MOC
SPP
From VC X
CFDP 1
BP
LTP
EP
From VC Y
R-SP2 is a new version of the SLE R-SP that was defined only conceptually in the SLE Reference Model.
F Demux
TM/AOS
C&S
R-SP2 (DeMux)
RFM
TCP/IP
R-SP2
TCP/IP
R-SP2
TCP/IP
IP-based network
5/25/10
SISG SSI Ground Support Considerations
PS, et al 19

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SISG

Configuration 3 Features

IOAG Interagency Operations Advisory Group

<table>
<tr><th>Forward</th><th>Return</th></tr>
<tr><td>SLE F-SP2 (new). Note: F-SP2 (a modified F-SP) service supports both EP and SP multiplexing function from multiple sources.</td><td>R-SP2 (new). Note: R-SP2 (a modified R-SP) service supports both EP and SP de-multiplexing function for multiple destinations.</td></tr>
<tr><td>VC/Packet Multiplexing in GndStn (and it shall be “managed”), i.e. the Ground Station merges all traffic flows into the space link.</td><td>VC/Packet De-Multiplexing in GndStn (and its <u>multiplexing</u> shall be “managed” in the Orbiter).</td></tr>
<tr><td>The Ground Station interface accepts multiple packet streams.</td><td>The Ground Station interface delivers multiple packet streams.</td></tr>
<tr><td colspan="2">Orbiter MOC operations are responsible only for their data flows across the space link, do not see the User traffic. There is no direct interface between the two MOCs.</td></tr>
<tr><td colspan="2">A DTN node is located only at the User MOC and LTP is closed between the User MOC and the Orbiter.
REMARK: when needed, the “LTP return entity” can ask the “LTP forward entity” to generate Encapsulation Packets to be uplinked.</td></tr>
<tr><td>TC/AOS frame generation, AOS fill frames insertion, uplink coding & ASM, is done in the Ground Station.</td><td>TM/AOS Frame synch, decoding, packet extraction & demuxing is done at the Ground Station.</td></tr>
<tr><td colspan="2">GENERAL REMARK: Since this configuration offers services at packet level, frame level services cannot be supported, e.g.
AOS frame insert zone (for e.g. voice support) or
Security Data Header for encryption at frame level (unless encryption is delegated to the Ground Station).
Note: Require frame level service to DEAL WITH THESE CASES. For voice support even frame services may not be enough.</td></tr>
</table>

5/25/10 SISG SSI Ground Support Considerations PS, et al 20

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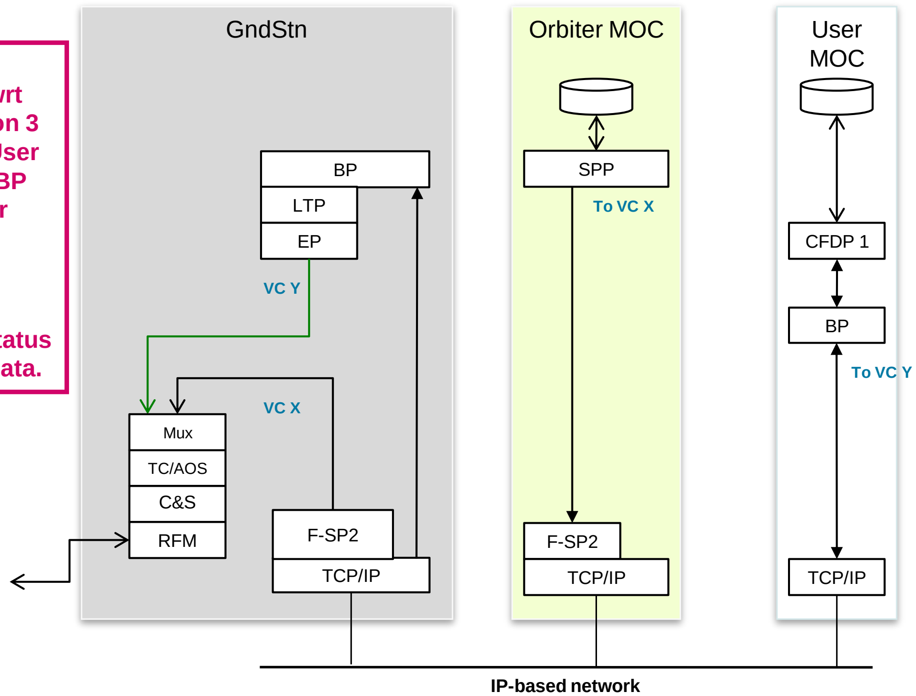
Configuration 4, Forward (SLE, F-SP, packet multiplex, DTN IN Ground Station)

The big difference wrt configuration 3 is that the User MOC runs BP directly over TCP/IP, not using FSP.

This loses access to status & monitor data.



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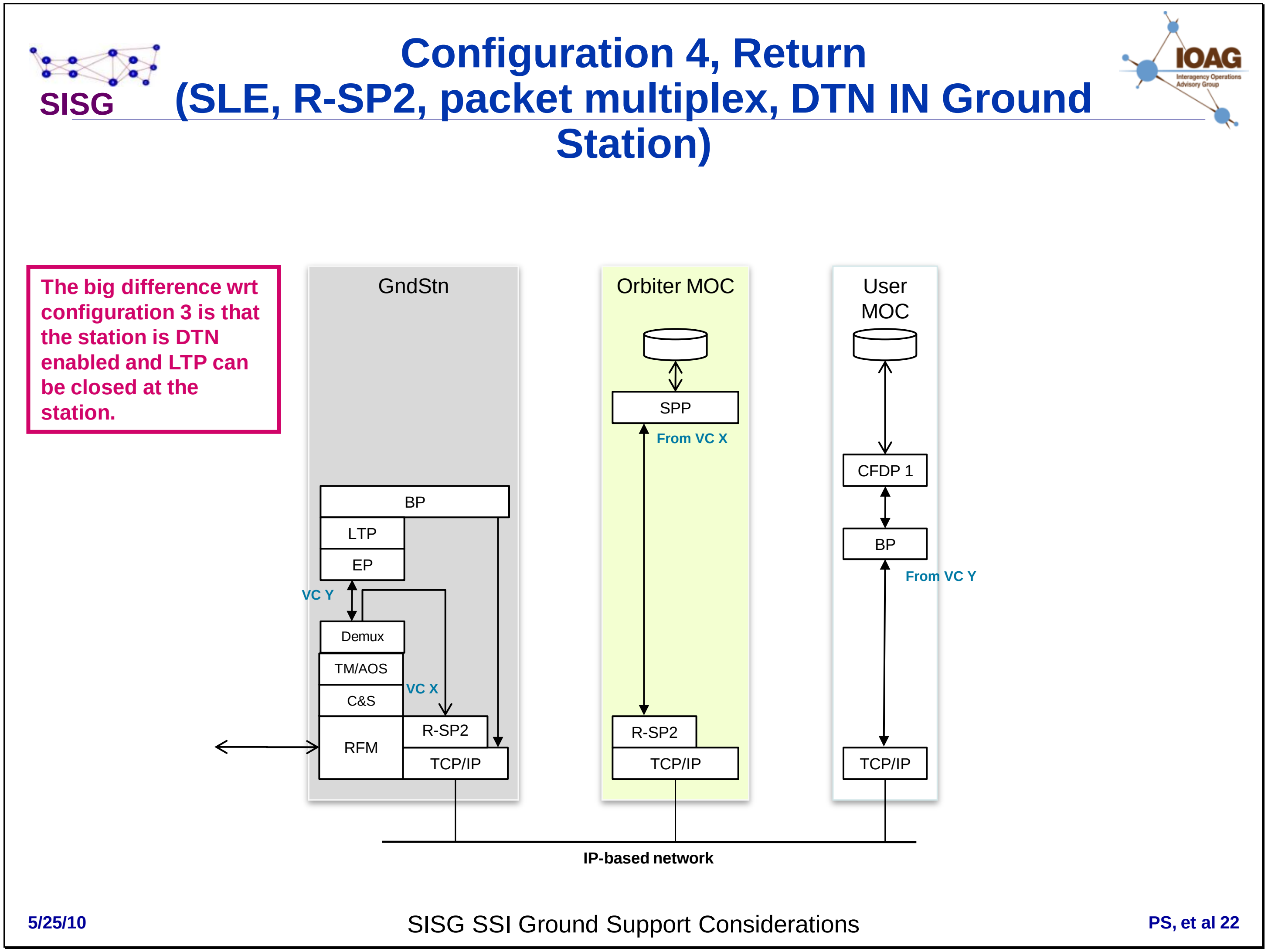
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Configuration 4, Return
(SLE, R-SP2, packet multiplex, DTN IN Ground Station)
The big difference wrt configuration 3 is that the station is DTN enabled and LTP can be closed at the station.
GndStn
Orbiter MOC
User MOC
SPP
From VC X
CFDP 1
BP
LTP
EP
BP
From VC Y
VC Y
Demux
TM/AOS
VC X
C&S
R-SP2
RFM
TCP/IP
R-SP2
TCP/IP
TCP/IP
IP-based network
5/25/10
SISG SSI Ground Support Considerations
PS, et al 22

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Configuration 4 Features

IOAG

<table>
<tr><th>Forward</th><th>Return</th></tr>
<tr><td>SLE F-SP2 (new). Note: F-SP2 (a modified F-SP) service supports both EP and SP multiplexing function from multiple sources.</td><td>R-SP2 (new). Note: R-SP2 (a modified R-SP) service supports both EP and SP de-multiplexing function for multiple destinations.</td></tr>
<tr><td>VC/Packet Multiplexing in GndStn (“managed” by Orbiter MOC), i.e. the Ground Station merges all traffic flows into the space link.</td><td>VC/Packet De-Multiplexing in GndStn (and its multiplexing shall be “managed” in the Orbiter).</td></tr>
<tr><td>The Ground Station interface accepts multiple packet streams.</td><td>The Ground Station interface delivers multiple packet streams.</td></tr>
<tr><td colspan="2">Orbiter MOC operations are responsible only for their data flows across the space link, do not see the User traffic. There is no direct interface between the two MOCs.</td></tr>
<tr><td colspan="2">A DTN node is located only at the Ground Station and LTP is closed between the Ground Station and the Orbiter. REMARK: when needed, the “LTP return entity” can ask the “LTP forward entity” to generate Encapsulation Packets to be uplinked.</td></tr>
<tr><td colspan="2">Bundles are transferred directly over TCP/IP between the User MOC and the Ground Station.</td></tr>
<tr><td>TC/AOS frame generation, AOS fill frames insertion, uplink coding & ASM, is done in the Ground Station.</td><td>TM/AOS Frame synch, decoding, packet extraction & demuxing is done at the Ground Station.</td></tr>
<tr><td colspan="2">GENERAL REMARK: Since this configuration offers services at packet level, frame level services cannot be supported, e.g.
AOS frame insert zone (for e.g. voice support) or
Security Data Header for encryption at frame level (unless encryption is delegated to the Ground Station).
Note: Require frame level service to DEAL WITH THESE CASES. For voice support even frame services may not be enough.</td></tr>
</table>

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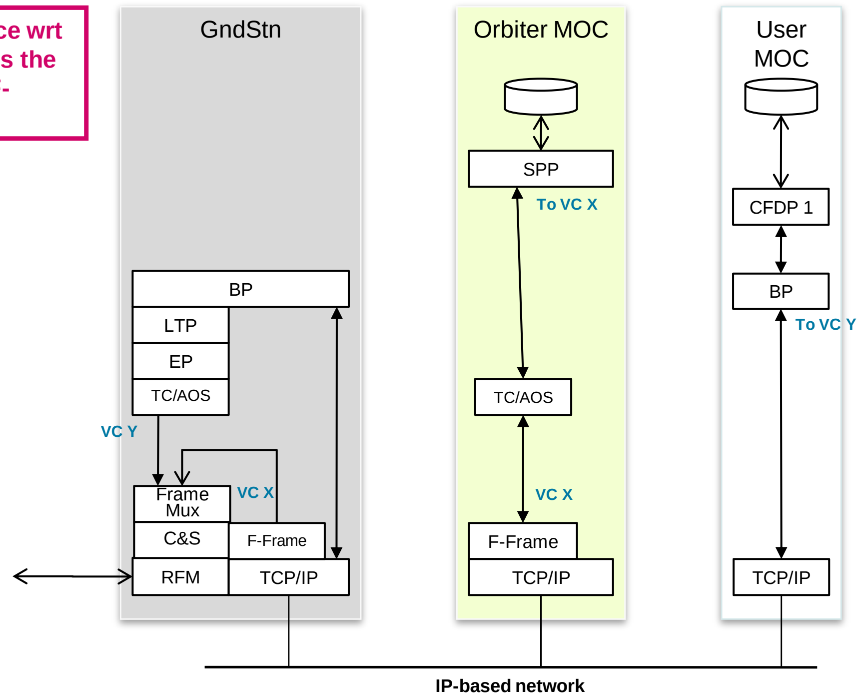
Configuration 5, Forward (SLE, F-Frame, frame multiplex, DTN IN Ground Station)

The big difference wrt configuration 4 is the use of the new F-Frame service.



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Configuration 5, Return (SLE, R-CF, frame multiplex, DTN IN Ground Station)

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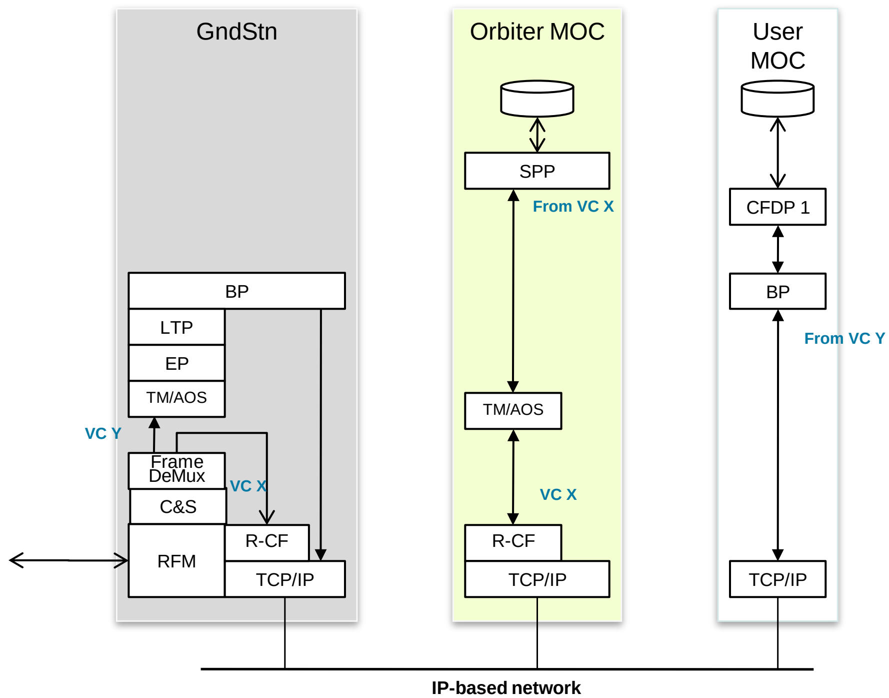

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Configuration 5 Features

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Forward	Return
SLE F-Frame (new). It supports frame multiplexing function from multiple sources. It permits use of insert zone (TBC).	R-CF return
VC/Frame Multiplexing in GndStn ("managed" by Orbiter MOC), i.e. the Ground Station merges all traffic flows into the space link.	VC/Frame De-Multiplexing in GndStn (and its multiplexing shall be "managed" in the Orbiter).
The Ground Station interface accepts multiple frame streams & DTN.	The Ground Station interface delivers multiple frame streams & DTN.
Orbiter MOC operations are responsible only for their data flows across the space link, do not see the User traffic. There is no direct interface between the two MOCs .	
A DTN node is located only at the Ground Station and LTP is closed between the Ground Station and the Orbiter. **REMARK**: when needed, the "LTP return entity" can ask the "LTP forward entity" to generate Encapsulation Packets to be uplinked.	
Frame muxing, AOS fill insertion, uplink coding & ASM, is done at Ground Station.	Frame synch, decoding, demuxing is done at Ground Station.
DTN installed at Ground Station. Any mission may choose to use either DTN or frame services, the Ground Station supports both.	

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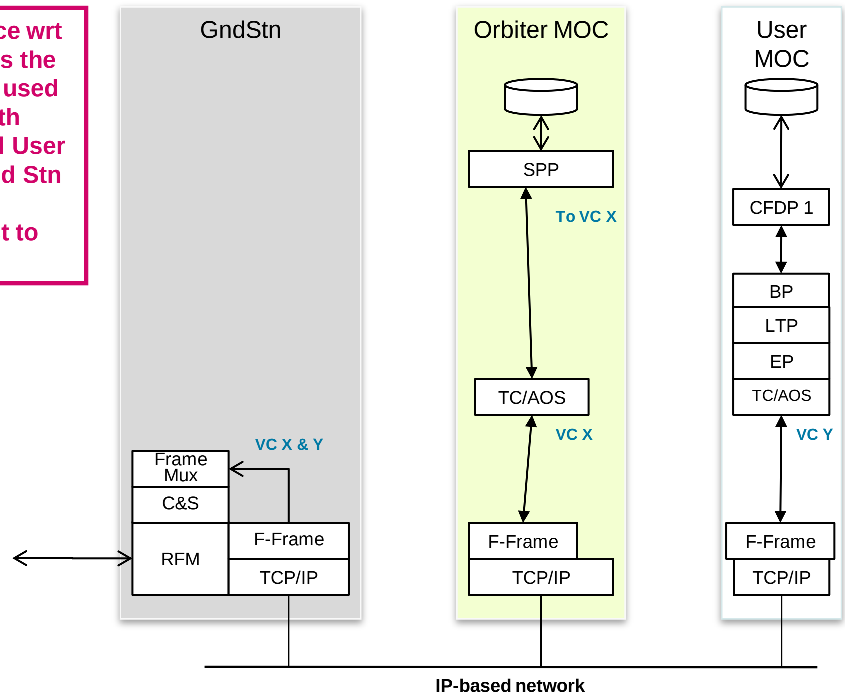
Configuration 6, Forward (SLE, F-Frame, frame multiplex in Ground Station, DTN in User MOC)

The big difference wrt configuration 5 is the F-Frame service used uniformly for both Orbiter MOC and User MOC and the Gnd Stn is considerably simplified at cost to the User MOC.



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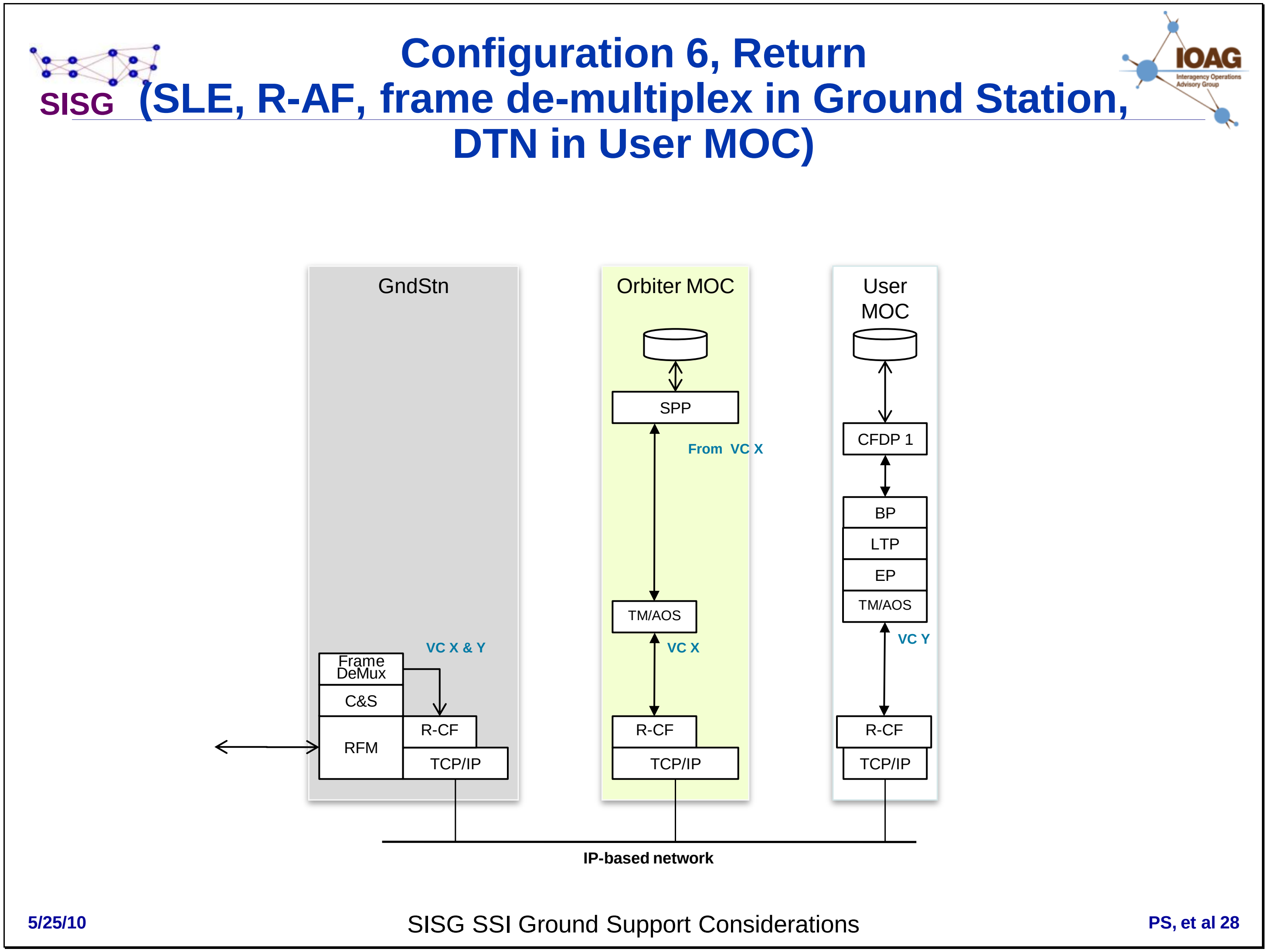
Configuration 6, Return
(SLE, R-AF, frame de-multiplex in Ground Station,
DTN in User MOC)
SISG
IOAG
GndStn
Orbiter MOC
User MOC
SPP
From VC X
CFDP 1
BP
LTP
EP
TM/AOS
TM/AOS
VC X & Y
VC X
VC Y
Frame DeMux
C&S
RFM
R-CF
TCP/IP
R-CF
TCP/IP
R-CF
TCP/IP
IP-based network
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Configuration 6 Features

IOAG

Forward	Return
SLE F-Frame (new). It supports frame multiplexing function from multiple sources. It permits use of insert zone (TBC).	R-CF return
VC/Frame Multiplexing in GndStn ("managed" by Orbiter MOC), i.e. the Ground Station merges all traffic flows into the space link.	VC/Frame De-Multiplexing in GndStn (and its multiplexing shall be "managed" in the Orbiter).
The Ground Station interface accepts multiple frame streams (but not DTN).	The Ground Station interface delivers multiple frame streams (but not DTN).
Orbiter MOC operations are responsible only for their data flows across the space link, do not see the User traffic. There is no direct interface between the two MOCs.	
A DTN node is located only at the User MOC and LTP is closed between the User MOC and the Orbiter. **REMARK**: when needed, the "LTP return entity" can ask the "LTP forward entity" to generate Encapsulation Packets to be uplinked.	
Frame muxing, AOS fill insertion, uplink coding & ASM, is done at Ground Station.	Frame synch, decoding, demuxing is done at Ground Station.
DTN installed at User MOC.	

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Enhanced Configurations

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- Next diagrams are examples to show how configurations 1-fwd, 3-fwd and 5-rtn can be enhanced to allow the Orbiter MOC to also use the DTN data flow for its own purposes and not only for cross support. The added elements are shown in red.
- For simplicity all of the baseline diagrams show DTN only in the User MOC and ISO Layer 2 functions (or SPP) used in the Orbiter MOC
  - Based upon assumption that the Orbiter MOC will wish to have direct TC/TM access to the Orbiter for monitor & control functions
- With most of these options it is also possible to deploy DTN (and CFDP) in the Orbiter MOC in parallel with the Layer 2 functions
- In all of these options it is also possible to deploy the CFDP file protocol or AMS message protocol on top of either DTN or SPP
- Three alternative configurations 1 Forward, 3 Forward, and 5 Return are shown as examples of alternative parallel CFDP /DTN configurations. The "opposite" (return or forward direction) will need a corresponding change as per added red parts.

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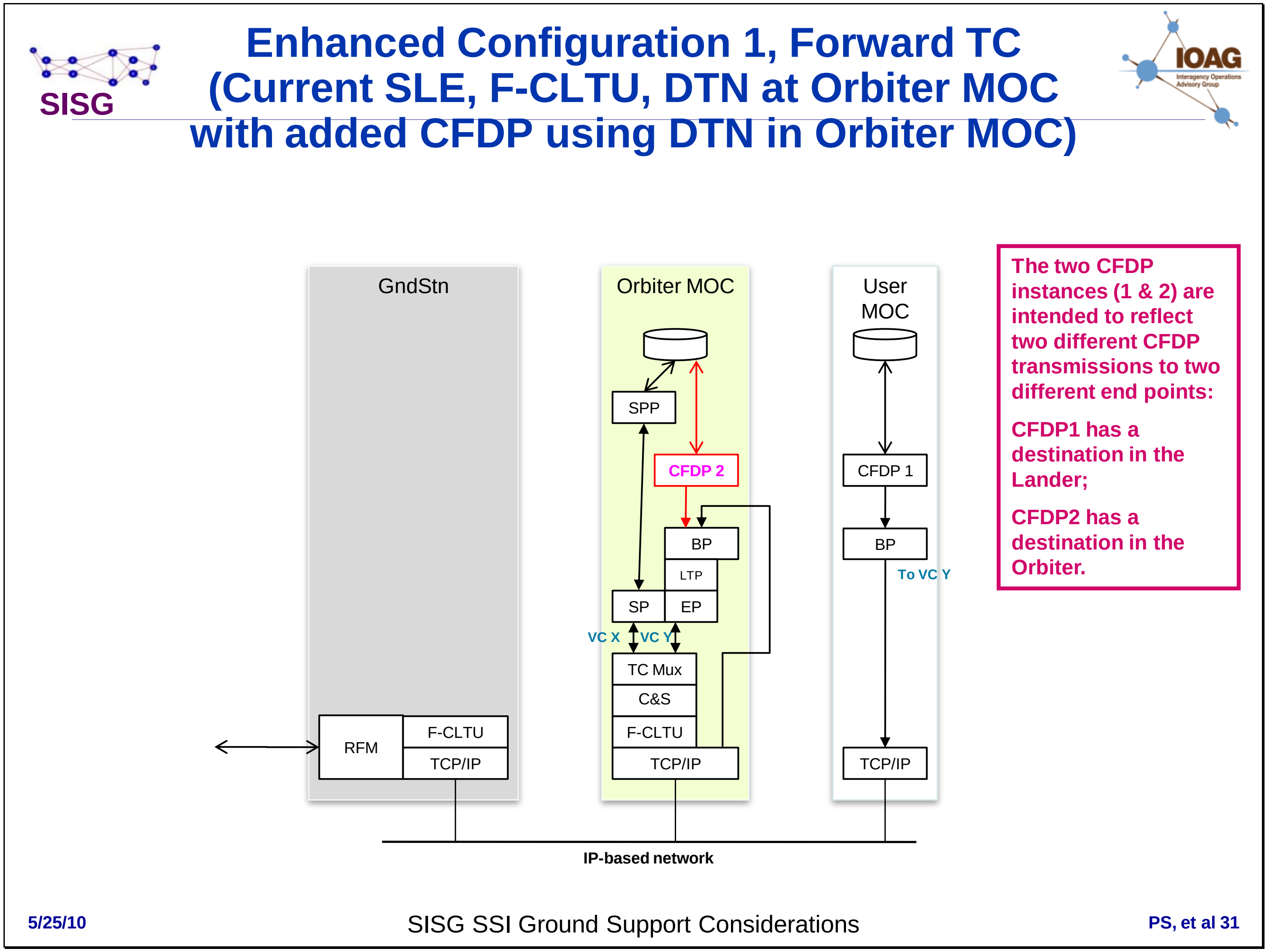
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Enhanced Configuration 1, Forward TC (Current SLE, F-CLTU, DTN at Orbiter MOC with added CFDP using DTN in Orbiter MOC)
GndStn
Orbiter MOC
User MOC
SPP
CFDP 2
CFDP 1
BP
LTP
SP
EP
BP
To VC Y
VC X
VC Y
TC Mux
C&S
F-CLTU
TCP/IP
RFM
F-CLTU
TCP/IP
TCP/IP
IP-based network
The two CFDP instances (1 & 2) are intended to reflect two different CFDP transmissions to two different end points:
CFDP1 has a destination in the Lander;
CFDP2 has a destination in the Orbiter.
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Enhanced Configuration 3, Forward (SLE, F-SP, packet multiplex, DTN at User, with added CFDP using DTN in Orbiter MOC)

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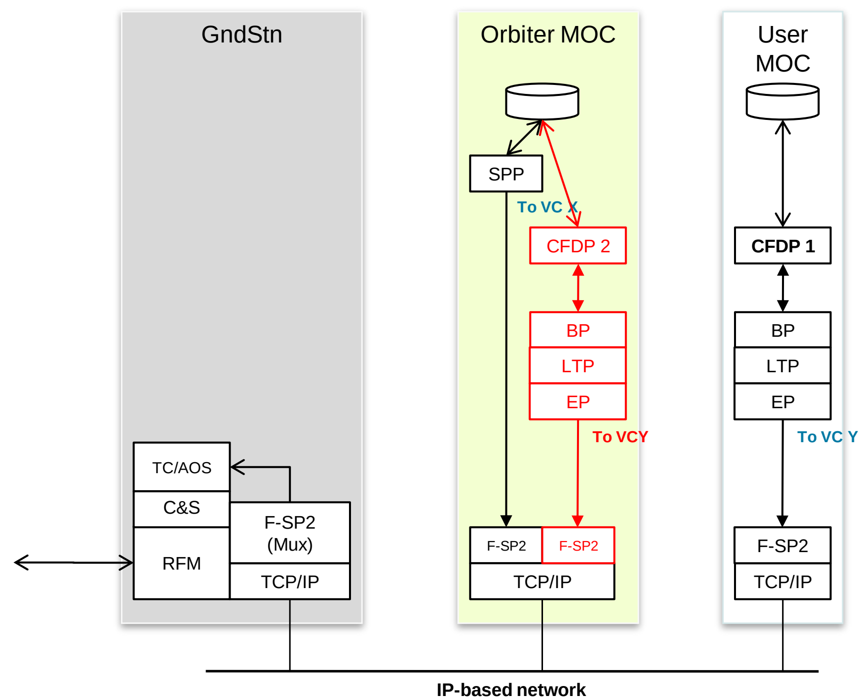

The two CFDP instances (1 & 2) are intended to reflect two different CFDP transmissions to two different end points:

CFDP1 has a destination in the Lander;

CFDP2 has a destination in the Orbiter.

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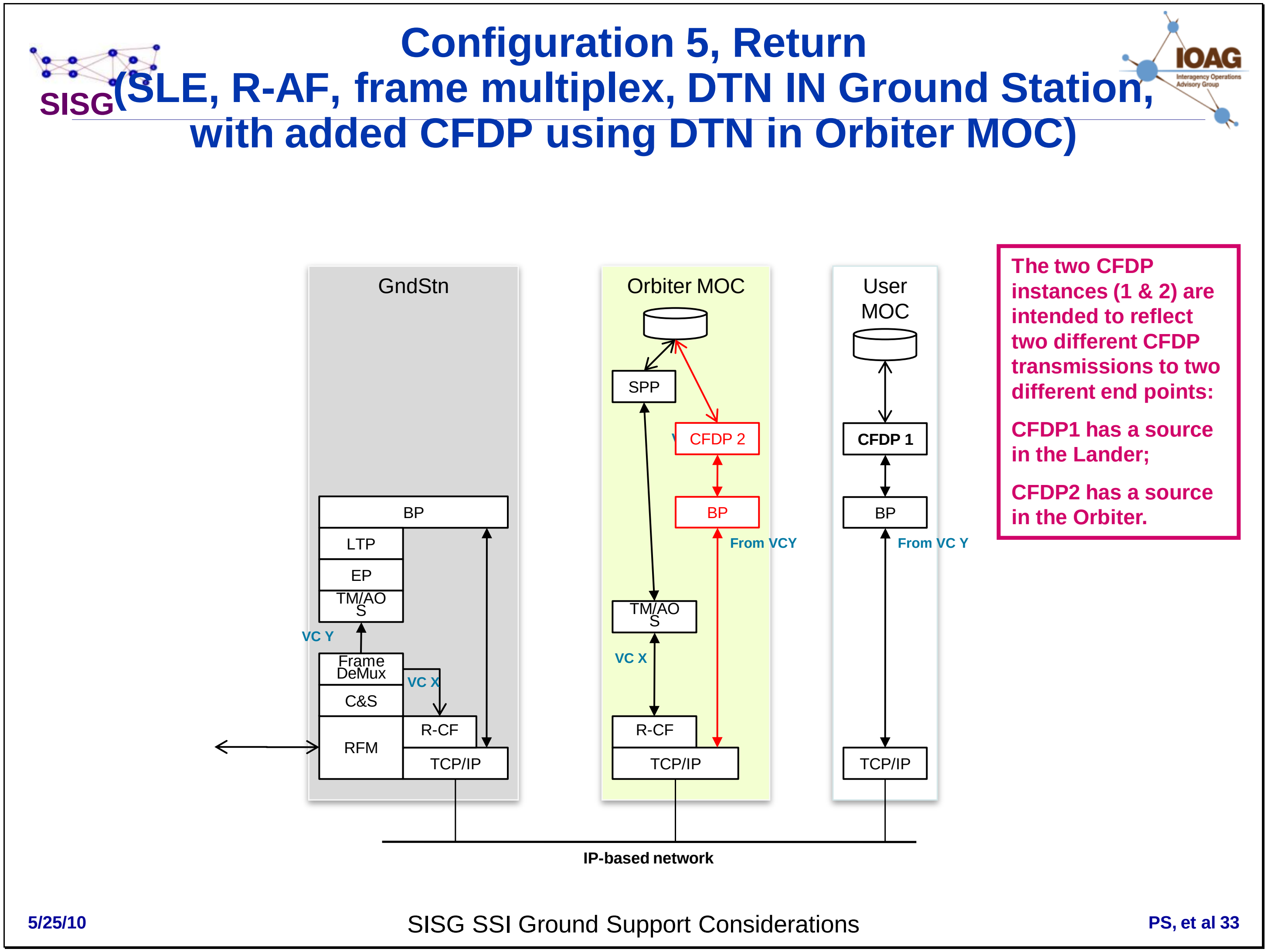
Configuration 5, Return
(SLE, R-AF, frame multiplex, DTN IN Ground Station, with added CFDP using DTN in Orbiter MOC)
SISG
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GndStn
Orbiter MOC
User MOC
BP
LTP
EP
TM/AOS
VC Y
Frame DeMux
VC X
C&S
RFM
R-CF
TCP/IP
SPP
CFDP 2
BP
From VCY
TM/AOS
VC X
R-CF
TCP/IP
CFDP 1
BP
From VC Y
TCP/IP
IP-based network
The two CFDP instances (1 & 2) are intended to reflect two different CFDP transmissions to two different end points:
CFDP1 has a source in the Lander;
CFDP2 has a source in the Orbiter.
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Initial Analysis (1 of 5)

1. **Current SLE: SLE F-CLTU or F-SEF, R-CF, Orbiter MOC handles all data including DTN**
   - Requires the least amount of changes in the Ground Station: two services (F-CLTU and R-CF) exist.
   - F-SEF service is to be defined and to be implemented.
   - Requires the Orbiter MOC to implement the full DTN stack on top of the (almost) full TC/TM/AOS stack.
   - Requires the Orbiter MOC to manage forward multiplexing and to handle all the data for the Orbiter and for ALL the Users.
   - The User MOC only needs a bundle connection to some next hop node (Orbiter MOC in this case).
   - Support for forward AOS over standard FCLTU is weak and may introduce longer latency, jitter, and a requirement to do fill in the Orbiter MOC.
   - This is one of the least extensible of the options because of the traffic flows through the Orbiter MOC.
2. **ESA Legacy Mode: F-CLTU, R-AF for R-CF return. Orbiter MOC handles all data as files, DTN in User MOC transferred via files**
   - Requires the least amount of changes in the Ground Station: two services (F-CLTU and R-CF) exist.
   - F-SEF service is to be defined and to be implemented.
   - It does not require the Orbiter MOC to implement the full DTN stack.
   - It requires the Orbiter MOC and the User MOC to implement some sort of transfer of files containing Encapsulation Packets.
   - Requires the Orbiter MOC to manage forward multiplexing and to handle all the data for the Orbiter and for ALL the Users.
   - The User MOC has a bundle/LTP connection only to the end User Node but without an end-to-end network layer .
   - Support for forward AOS over standard FCLTU is weak and may introduce longer latency, jitter, and a requirement to do fill in the Orbiter MOC.
   - This is the least extensible of the options because of the anomalous end to end configurations.

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Initial Analysis (2 of 5)

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3. SLE Packet: **SLE F-SP2 forward, R-SP2 return**, Ground Station interface is multiple packet streams, DTN installed at User MOC
   - Requires a greater amount of implementation effort in the Ground Station (frame generation and coding) and in the User MOC (to implement the full DTN stack & FSP2/RSP2).
   - F-SP2 and R-SP2 are new services to be defined and to be implemented in Ground Stations and in MOCs. (The existing F-SP is implemented only by ESA).
   - The Orbiter MOC no longer has to handle all of the data, it does not implement DTN and it only has to produce packets.
   - Does permit multiple individual missions to access the space link at the packet level, but does not provide straightforward means for handling certain link features such as frame secondary headers & insert zones.
   - Requires the Ground Station to manage forward multiplexing.
   - The User MOC has a bundle/LTP connection only to the user node without an end-to-end network layer .
   - Support for forward AOS may be good if it is included in F-SP2 design, with lower latency, jitter, and fill in the Ground Station.
   - More extensible than Options 1 & 2, with increased costs for the User MOC and the Ground Station.

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Initial Analysis (3 of 5)

4. **SLE Packet: SLE F-SP2 forward, R-SP2 return, Ground Station interface is multiple packet streams, DTN installed at Ground Station**
   - Requires a significantly greater amount of implementation effort in the Ground Station (full DTN stack as well as frame generation and coding). The User MOC has to implement only the basic DTN stack.
   - F-SP2 and R-SP2 are new services to be defined and to be implemented in Ground Stations and in the Orbiter MOCs. (The existing F-SP is implemented only by ESA).
   - The Orbiter MOC no longer has to handle all of the data, it does not implement DTN and it only has to produce packets.
   - The User MOC has to implement no SLE/CSTS service.
   - Does permit multiple individual missions to access the space link at the packet level, but does not provide straightforward means for handling certain link features such as frame secondary headers & insert zones.
   - Requires the Ground Station to manage forward multiplexing.
   - The User MOC has a bundle connection to the user node through an end-to-end network layer with LTP in Ground Station.
   - Support for forward AOS may be good if it is included in F-SP2 design, with lower latency, jitter, and fill in the Ground Station.
   - Much more extensible than Options 1, 2 & 3, at the expense of increased costs for the Ground Station.

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Initial Analysis (4 of 5)

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5. **CSTS F-Frame, R-CF, Ground Station interface is multiple frame streams, DTN installed at Ground Station**
   - In the Ground Station, this configuration requires a moderate amount of changes with respect to SLE/CSTS services (i.e. R-CF service exists while F-Frame service is to be defined and to be implemented) and a significantly greater amount of effort with respect to implementation for the full DTN stack.
   - The User MOC has to implement only the basic DTN stack.
   - The Orbiter MOC does not handle all of the data and it produces frames.
   - Permits multiple individual missions to access the space link at the frame level and provides straightforward means for giving access to space link features such as frame secondary headers & insert zones.
   - Requires the Ground Station to manage forward multiplexing at the frame level.
   - The User MOC has a bundle connection to the user node through an end-to-end network layer with LTP in Ground Station.
   - Support for forward AOS will be excellent since it is explicitly included in F-Frame design, with lower latency and jitter, and with fill in the Ground Station.
   - Probably the most extensible option since it allows multiple streams of frame or bundle traffic to be merged at modest cost to each user. It does this at increased cost for the Ground Station.

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Initial Analysis (5 of 5)

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6. CSTS F-Frame, R-CF, Ground Station interface is multiple frame streams, DTN installed at User MOC

- Requires a moderate amount of changes in the Ground Station: R-CF service exists while F-Frame service is to be defined and to be implemented.
- The User MOC has to implement the full DTN stack and SLE/CSTS services as user.
- The Orbiter MOC does not handle all of the data and it produces frames.
- Permits multiple individual missions to access the space link at the frame level and provides straightforward means for giving access to space link features such as frame secondary headers & insert zones.
- Requires the Ground Station to manage forward multiplexing.
- The User MOC has a bundle connection to the user node through an end-to-end network layer, but with LTP closed in the User MOC.
- Support for forward AOS will be excellent since it is explicitly included in F-Frame design, with lower latency and jitter, and with fill in the Ground Station.
- Very extensible option since it allows multiple streams of frame or bundle traffic to be merged.
- In comparison with Configuration 5, it uses simpler Ground Station, but it has a more complex User MOC.

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Comparison Table for Initial Analysis

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#	Gnd Stn	Orb. MOC	User MOC	Notes
1	FCLTU+RCF old, FSEF new	FSEF new, DTN + LTP, Full CCSDS stack, Mux manager, frame generation	Basic DTN, No SLE/CSTS	FCLTU weak for AOS, Least-1 extensible
2	FCLTU+RCF old, FSEF new	FSEF new, NO DTN stack, Full CCSDS stack, Mux manager, File xfer for EP, frame generation	File xfer for EP, DTN+LTP	FCLTU weak for AOS, Least extensible
3	FSP2+RSP2 new, Full CCSDS stack, Mux manager	FSP2+RSP2 new, NO DTN stack, packet generation	FSP2+RSP2 new, DTN+LTP	FSP2 good for AOS (TBC), More extensible than 1 & 2: more cost for GS + User MOC
4	FSP2+RSP2 new, DTN+LTP, Full CCSDS stack, Mux manager	FSP2+RSP2 new, NO DTN stack, packet generation	Basic DTN, No SLE/CSTS	FSP2 good for AOS (TBC), More extensible than 1 & 2 & 3: more cost for GS
5	RCF old, F-Frame new, DTN+LTP , Mux manager	RCF old, F-Frame new, frame generation	Basic DTN, No SLE/CSTS	F-Frame excellent for AOS (TBC), Most extensible: costs moderate for users, more for GS
6	RCF old, F-Frame new, Mux manager	RCF old, F-Frame new, frame generation	RCF old, F-Frame new, DTN+LTP	F-Frame excellent for AOS (TBC), Very extensible, wrt #5 simpler GS but more complex User MOC

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FOM Scoring Process (1 of 2)

- Analysis of Alternative (AoA) Process used *
  - Semi-quantitative approach
- FOM scores were arrived at via a consensus process
  - NASA: Shames, Tai, Burleigh
  - ESA: Hell, Calzolari
- Separate FOM weighting and scoring was done for Technical FOMs and Cost / Risk FOMs
- Score each FOM across five levels
  - Major strength (+2)
  - Minor strength (+1)
  - Non-factor (0)
  - Minor weakness (-1)
  - Major weakness (-2)

***** An Analysis of Alternatives (AoA) is a study intended to aid decision making by illuminating the risk, uncertainty, and the relative advantages and disadvantages of alternatives being considered to satisfy a mission need. The AoA shows the sensitivity of each alternative to possible changes in key assumptions (e.g., threat) or variables (e.g., performance capabilities). The analysis is intended to aid in decision-making by showing relative advantages and disadvantages of the considered alternatives. It aids in the discussion of issues. Although the AoA is a quantitative document, disagreements arise over key assumptions or variables. The analysis should show the sensitivity of each alternative to possible changes in key assumptions (e.g. threat) or variables (e.g., selected performance capabilities). Source: DoD Acquisitions Web site: https://acc.dau.mil

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FOM Scoring Process (2 of 2)

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- IMPLEMENTATION EFFORT for Services: stated wrt the novelty of services; e.g.
  - F-CLTU/R-AF/R-CF = assume no impact
  - F-SEF/F-Frame = small effort
  - F-SP2/R-SP2 = moderate effort
  - Full DTN stack = big effort, but all configurations include it, so not a great discriminator

- IMPLEMENTATION EFFORT for DTN @ USER MOC: stated wrt the additions; e.g.
  - F-SP2/R-SP2 = moderate effort
  - Basic DTN Stack = moderate effort
  - LTP = small effort
  - Additional mechanisms = moderate/big effort

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FOM Weighting & Scoring Approach

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- The consensus group established relative weights for the various FOMs, with each scored on a scale of 0-10
- FOM scores were then linearly scaled from 0 to 1, and weights linearly scaled to sum to 100
- Product of scaled FOM score and scaled weight, summed over FOMs, provided the final score for each option, with a maximum possible score of 100

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Selected Technical Figures of Merit

Figure of Merit	FOM Definition
Complexity	
Complexity of User MOC	Measure of complexity of the User MOC based upon the number of different separate layers of protocols and PDUs required
Complexity of Orbiter MOC	Measure of complexity of the Orbiter MOC based upon the number of different separate layers of protocols and PDUs required
Complexity of Ground Station	Measure of complexity of the Ground Station based upon the number of different separate layers of protocols and PDUs required
Capabilities	
Support for heterogeneous environment	Measure of how well the selected option can handle a heterogenous mix of user / service configurations (files, messages, packets, voice, security, etc)
Ease of handling multiple data sources	Extent to which the selected option provides the ability to simultaneously handle data from / to multiple sources
Mission emergency	Measure of how well the selected option can handle mission and Orbiter spacecraft emergencies
Robustness	
Dependencies	Measure of the interdependencies among different elements in the selected option, vulnerability to element failure or priorities
Functionality	
Interoperability with Legacy assets	Ability of the selected option to accommodate existing missions using the ground station directly
Extensibility to SSI final state	Extent to which the selected option moves towards the desired SSI final state, with a fully functional DTN capability

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Technical FOM Weighting

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Figure of Merit	FOM Weights	Rationale
Complexity		
Complexity of User MOC	8	More User MOCs than Orbiter MOCs or ground stations
Complexity of Orbiter MOC	6	Fewer Orbiter MOCs than ground stations
Complexity of Ground Station	4	Fewer ground stations, but they are more critical to operations & represent reusable infrastructure
Capabilities		
Support for heterogeneous environment	6	Heterogeneous environment, supporting different MOC modes, is important
Ease of handling multiple data sources	4	Need to be able to merge data from multiple sources into space link
Mission emergency	8	Must be able to support missions during emergency conditions
Robustness		
Dependencies	8	Reducing dependencies among elements is essential for robustness
Functionality		
Interoperability with Legacy assets	6	Essential that the system continue to support legacy missions while moving to SSI end state
Extensibility to SSI final state	10	Achieving the SSI end state with interoperable services is the primary goal of this effort

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Graded Scoring of Technical FOMs

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Figure of Merit	Config #1: Current F-CLTU, R-CF, DTN Orbiter MOC	Config #2: ESA Legacy, Current F-SEF, R-CF, DTN User MOC	Config #3: F-SP2, R-SP2, DTN User MOC	Config #4: F-SP2, R-SP2, DTN GndStn	Config #5: F-Frame, R-CF, DTN GndStn	Config #6: F-Frame, R-CF, DTN User MOC
Complexity						
Complexity of User MOC	2	0	-2	2	2	-1
Complexity of Relay MOC	-2	-1	1	1	2	2
Complexity of Ground Station	2	2	0	-2	-1	1
Capabilities						
Support for heterogeneous environment	0	-2	-1	1	2	1
Ease of handling multiple data sources	-1	-2	0	0	2	1
Mission emergency	0	-1	-2	-2	2	1
Robustness						
Dependencies	-2	-2	0	-1	1	2
Functionality						
Interoperability with Legacy assets	2	2	-1	-1	1	1
Extensibility to SSI final state	1	-2	-1	1	2	0
Raw sums	2	-6	-6	-1	13	8
Graded scores	**47.08**	**26.67**	**27.29**	**43.13**	**78.96**	**70.00**

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Selected Cost / Risk Figures of Merit

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Figure of Merit	FOM Definition
Cost to Implement	
Ground Station	The cost to implement and deploy at ground stations
Orbiter MOC	The cost to implement and deploy at Orbiter MOCs (re-use is assumed)
User MOC	The cost to implement and deploy at User / Lander MOCs (re-use is assumed)
Standards	The cost to design and specify new (or revised) standards
Cost to Operate	
Ground Station	The cost to operate at ground stations
Orbiter MOC	The cost to operate at Orbiter MOCs (implied multiplier for multiple MOCs)
User MOC	The cost to operate at User / Lander MOCs (implied multiplier for multiple MOCs)
Design & Implementation Risk	
Ground Station	The risk associated with design and implementation at ground stations
Orbiter MOC	The risk associated with design and implementation at Orbiter MOCs (re-use is assumed)
User MOC	The risk associated with design and implementation at User / Lander MOCs (re-use is assumed)
Standards	The risk associated with design and implementation of new or revised standards

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Cost / Risk FOM Weighting

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Figure of Merit	FOM Weights	Rationale
Cost to Implement		
Ground Station	6	Each ground station is more complex because it provides all services and services many different missions and users, assumes re-use
Orbiter MOC	4	There may be a few Orbiter MOCs, but they are typically less complex than a ground station, assumes re-use
User MOC	4	There will be more User MOCs, and they may be similarly complex as the Orbiter, assumes re-use
Standards	3	Standards are not as costly to produce as formal flight qualified implementations
Cost to Operate		
Ground Station	4	Each ground station services many different missions and users
Orbiter MOC	6	There may be a few Orbiter MOCs, weight is higher to reflect this
User MOC	8	There may be several User MOCs, weight is higher to reflect this
Design & Implementation Risk		
Ground Station	8	Ground stations service many users, and implementations must service all users, therefore are likely to be more complicated
Orbiter MOC	4	Orbiter MOC may service more than one user, re-use of implementations is assumed
User MOC	4	In some cases User MOC is as complicated as Orbiter MOC, but less so than Ground Station, re-use is assumed
Standards	3	The risk for design and validating standards is lower than for formal flight qualified implementations

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Graded Scoring of Cost / Risk FOMs

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Figure of Merit	Config #1: Current F-CLTU, R-CF, DTN Orbiter MOC	Config #2: ESA Legacy, Current F-SEF, R-CF, DTN User MOC	Config #3: F-SP2, R-SP2, DTN User MOC	Config #4: F-SP2, R-SP2, DTN GndStn	Config #5: F-Frame, R-CF, DTN GndStn	Config #6: F-Frame, R-CF, DTN User MOC
Cost to Implement						
Ground Station	2	2	-1	-2	-1	0
Orbiter MOC	-2	-1	1	1	0	0
User MOC	0	-1	-2	0	0	-1
Standards	2	0	-2	-2	-1	-1
Cost to Operate						
Ground Station	2	2	1	-1	0	1
Orbiter MOC	-2	-2	2	2	2	2
User MOC	1	-2	-1	1	1	-1
Design & Implementation Risk						
Ground Station	2	2	0	-2	-1	1
Orbiter MOC	-2	-1	0	0	1	1
User MOC	0	-2	-2	0	0	-1
Standards	2	1	-2	-2	-1	-1
Raw sums	5	-2	-6	-5	0	0
Graded scores	**62.96**	**45.83**	**39.81**	**40.74**	**51.85**	**52.78**

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Conclusions

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- This analysis is largely qualitative, although relative quantitative estimates have been applied to reflect and normalize the quality, complexity and cost of the different configurations for each FOM
- Accurate cost estimates for the service users and service providers should ultimately be used to provide solid validation for the outcome
- The costing assumptions included considerations of adopting common standards and of each agency doing a single implementation of both user and service provider that would be re-used
- For the Technical FOMs Configurations 5 & 6 were heavily favored, largely because they provided the greatest flexibility and interoperability
  - Configuration 5 was selected because it has the higher scores, provided the greatest flexibility, and subsumes the features of option 6, where users can still provide their own local implementations running over a frame service
  - A sensitivity analysis, that altered the weights to favor user complexity over simpler ground stations did not change the relative rankings (see backup)

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Conclusions, contd

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- For the Cost / Risk FOMs Configuration 1 was strongly favored, but this is not a surprise, it is essentially “do nothing”, thus the lowest cost
- Selecting among the remaining Cost / Risk FOMs Configurations 5 & 6 were moderately strongly favored
  - Configuration 5 was selected because it has an almost identical score to 6, provided the greatest flexibility, and subsumes all the features of option 6. Higher capability for roughly the same cost is to be preferred.
  - A sensitivity analysis, that altered the weights to favor user complexity in exchange for simpler ground stations ranked 5 the highest of all, followed by 1 and 6 (see backup)
- In all cases where movement toward an SSI final state was a strong consideration Configurations 5 & 6 were favored or strongly favored.
- The consensus is to select Configuration #5, which, while it increases Ground Station and provider costs, has the greatest generality and extensibility and also the least cost and complexity for both the Orbiter and the users.

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Backup Slides:
FOM Scoring, Weighting & Sensitivity Analysis

Used the same scores as consensus set, but re-weighted to emphasize reduction in ground station complexity instead of users

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Alternate Technical FOM Weighting (Sensitivity Analysis)

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Figure of Merit	FOM Weights	Rationale
Complexity		
Complexity of User MOC	4	Missions will pay for what they think they need & User MOCs get to reuse implementations
Complexity of Orbiter MOC	6	Missions will pay for what they think they need & Orbiter MOCs have greater complexity
Complexity of Ground Station	8	Minimize need to investment in Ground Station, maximize possibility that Ground Stations will be part of SSI
Capabilities		
Support for heterogeneous environment	6	Heterogeneous environment, supporting different MOC modes, is important
Ease of handling multiple data sources	4	Need to be able to merge data from multiple sources into space link
Mission emergency	8	Must be able to support missions during emergency conditions
Robustness		
Dependencies	8	Reducing dependencies among elements is essential for robustness
Functionality		
Interoperability with Legacy assets	6	Essential that the system continue to support legacy missions while moving to SSI end state
Extensibility to SSI final state	10	Achieving the SSI end state with interoperable services is the primary goal of this effort

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Alternate Graded Scoring of Technical FOMs (Sensitivity Analysis)

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Figure of Merit	Config #1: Current F-CLTU, R-CF, DTN Orbiter MOC	Config #2: ESA Legacy, Current F-SEF, R-CF, DTN User MOC	Config #3: F-SP2, R-SP2, DTN User MOC	Config #4: F-SP2, R-SP2, DTN GndStn	Config #5: F-Frame, R-CF, DTN GndStn	Config #6: F-Frame, R-CF, DTN User MOC
Complexity						
Complexity of User MOC	2	0	-2	2	2	-1
Complexity of Relay MOC	-2	-1	1	1	2	2
Complexity of Ground Station	2	2	0	-2	-1	1
Capabilities						
Support for heterogeneous environment	0	-2	-1	1	2	1
Ease of handling multiple data sources	-1	-2	0	0	2	1
Mission emergency	0	-1	-2	-2	2	1
Robustness						
Dependencies	-2	-2	0	-1	1	2
Functionality						
Interoperability with Legacy assets	2	2	-1	-1	1	1
Extensibility to SSI final state	1	-2	-1	1	2	0
Raw sums	2	-6	-6	-1	13	8
Graded scores	**47.08**	**30.00**	**30.63**	**36.46**	**73.96**	**73.33**

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Alternate Cost / Risk FOM Weighting (Sensitivity Analysis)

Figure of Merit	FOM Weights	Rationale
Cost to Implement		
Ground Station	4	Each ground station services many different missions and users
Orbiter MOC	6	There may be a few Orbiter MOCs, weight is higher to reflect this
User MOC	6	There may be several User MOCs, weight is higher to reflect this
Standards	3	Standards are not as costly to produce as formal flight qualified implementations
Cost to Operate		
Ground Station	4	Each ground station services many different missions and users
Orbiter MOC	6	There may be a few Orbiter MOCs, weight is higher to reflect this
User MOC	8	There may be several User MOCs, weight is higher to reflect this
Design & Implementation Risk		
Ground Station	4	Ground stations service many users, but implementations must service all users, therefore are likely to be more complicated
Orbiter MOC	6	Orbiter MOC may service more than one user, also more than one Orbiter MOC is needed, thus higher weight
User MOC	6	There may be several User MOCs, weight is higher to reflect this
Standards	3	The risk for design and validating standards is lower than for formal flight qualified implementations

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Alternate Graded Scoring of Cost / Risk FOMs (Sensitivity Analysis)

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Figure of Merit	Config #1: Current F-CLTU, R-CF, DTN Orbiter MOC	Config #2: ESA Legacy, Current F-SEF, R-CF, DTN User MOC	Config #3: F-SP2, R-SP2, DTN User MOC	Config #4: F-SP2, R-SP2, DTN GndStn	Config #5: F-Frame, R-CF, DTN GndStn	Config #6: F-Frame, R-CF, DTN User MOC
Cost to Implement						
Ground Station	2	2	-1	-2	-1	0
Orbiter MOC	-2	-1	1	1	0	0
User MOC	0	-1	-2	0	0	-1
Standards	2	0	-2	-2	-1	-1
Cost to Operate						
Ground Station	2	2	1	-1	0	1
Orbiter MOC	-2	-2	2	2	2	2
User MOC	1	-2	-1	1	1	-1
Design & Implementation Risk						
Ground Station	2	2	0	-2	-1	1
Orbiter MOC	-2	-1	0	0	1	1
User MOC	0	-2	-2	0	0	-1
Standards	2	1	-2	-2	-1	-1
Raw sums	5	-2	-6	-5	0	0
Graded scores	**53.57**	**36.16**	**38.39**	**47.32**	**55.36**	**50.00**

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Appendix G. Referenced Documents

"Operations Concept for a Solar System Internetwork (SSI)." Interagency Operations Advisory Group's (IOAG) Space Internetworking Strategy Group (SISG). Publication date TBD.