Plug and Play - Technologies for Robotic Operations

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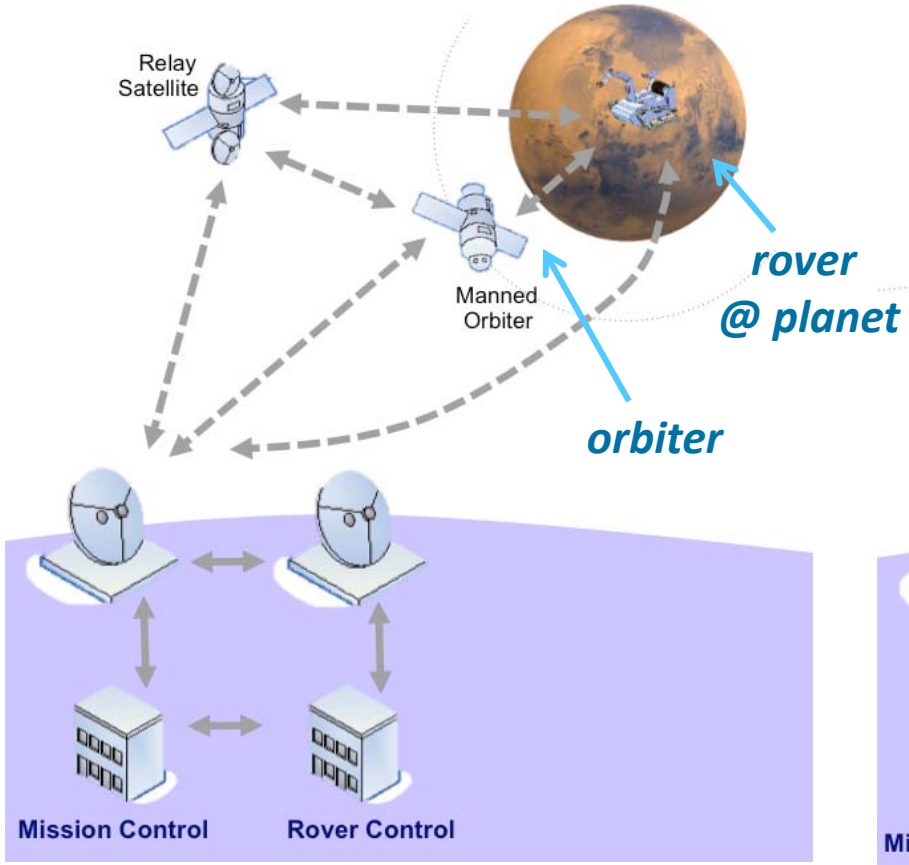
European Space Agency

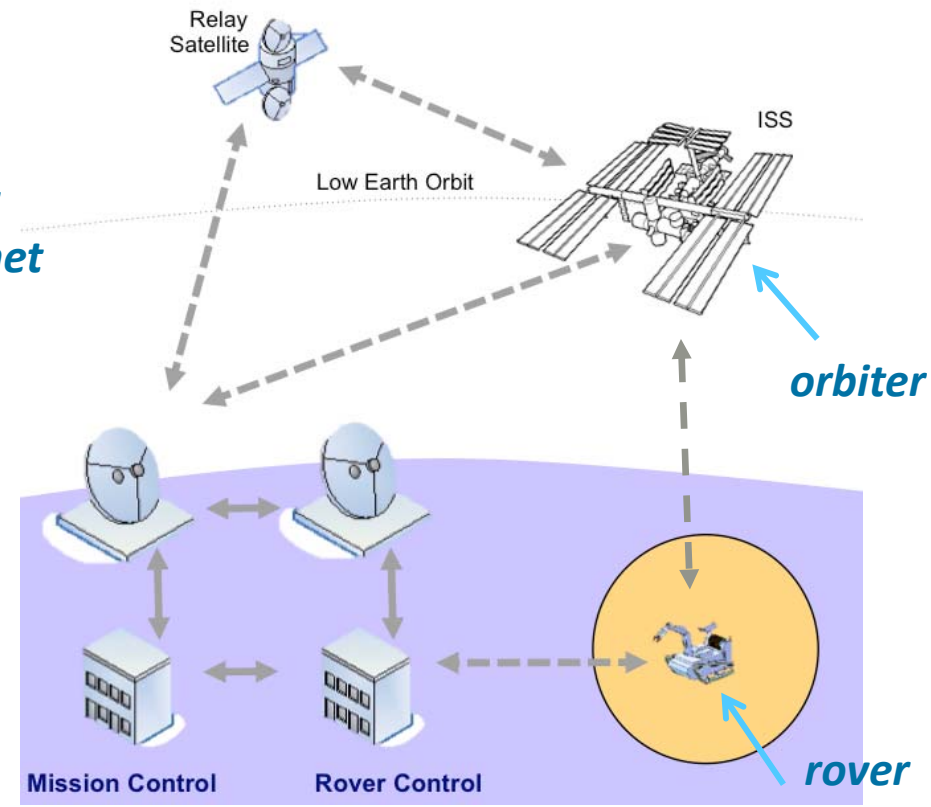
METERON =

Multi-Purpose **E**nd-**T**o-**E**nd **R**obotic **O**perations **N**etwork

Reference scenario



International Space Station as test bed



monitoring @ Earth

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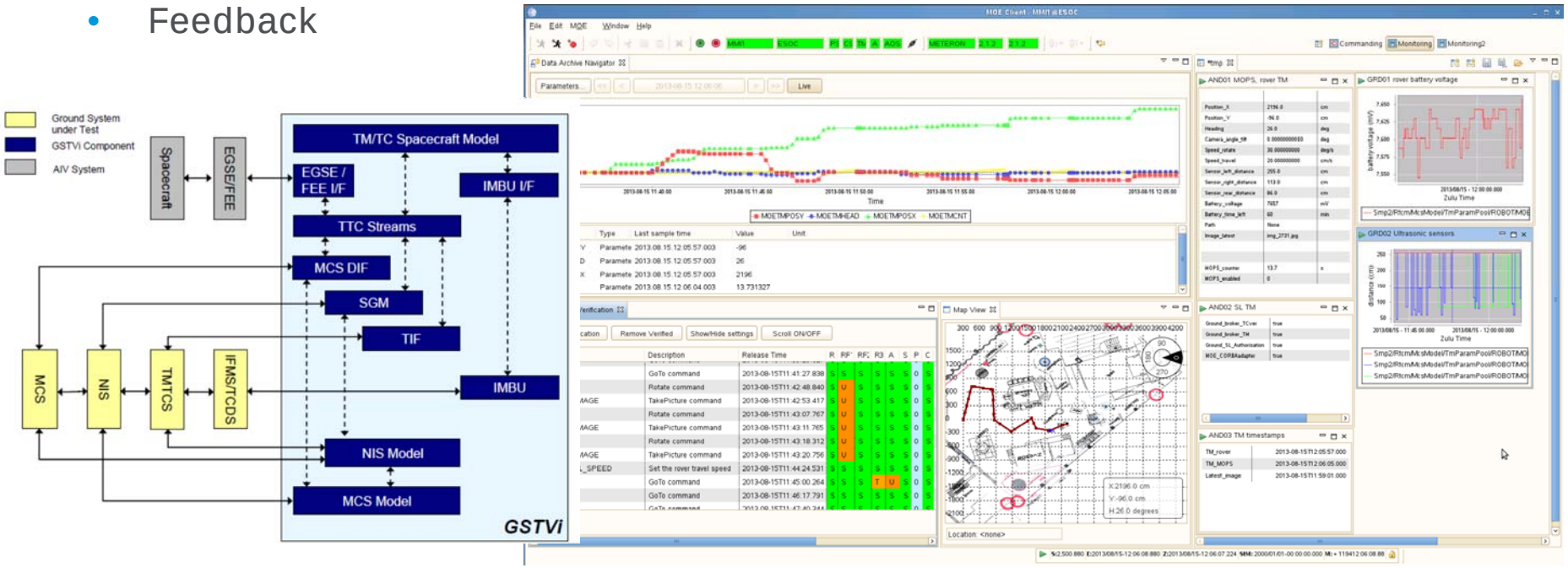
How to compare technologies

- Re-use modular reference simulator and control system

Ground Systems Test and Validation Infrastructure **GSTVi** -> METERON Operations Environment **MOE**

- Agnostic software hosted on virtual machines
- Develop APIs
- Feedback



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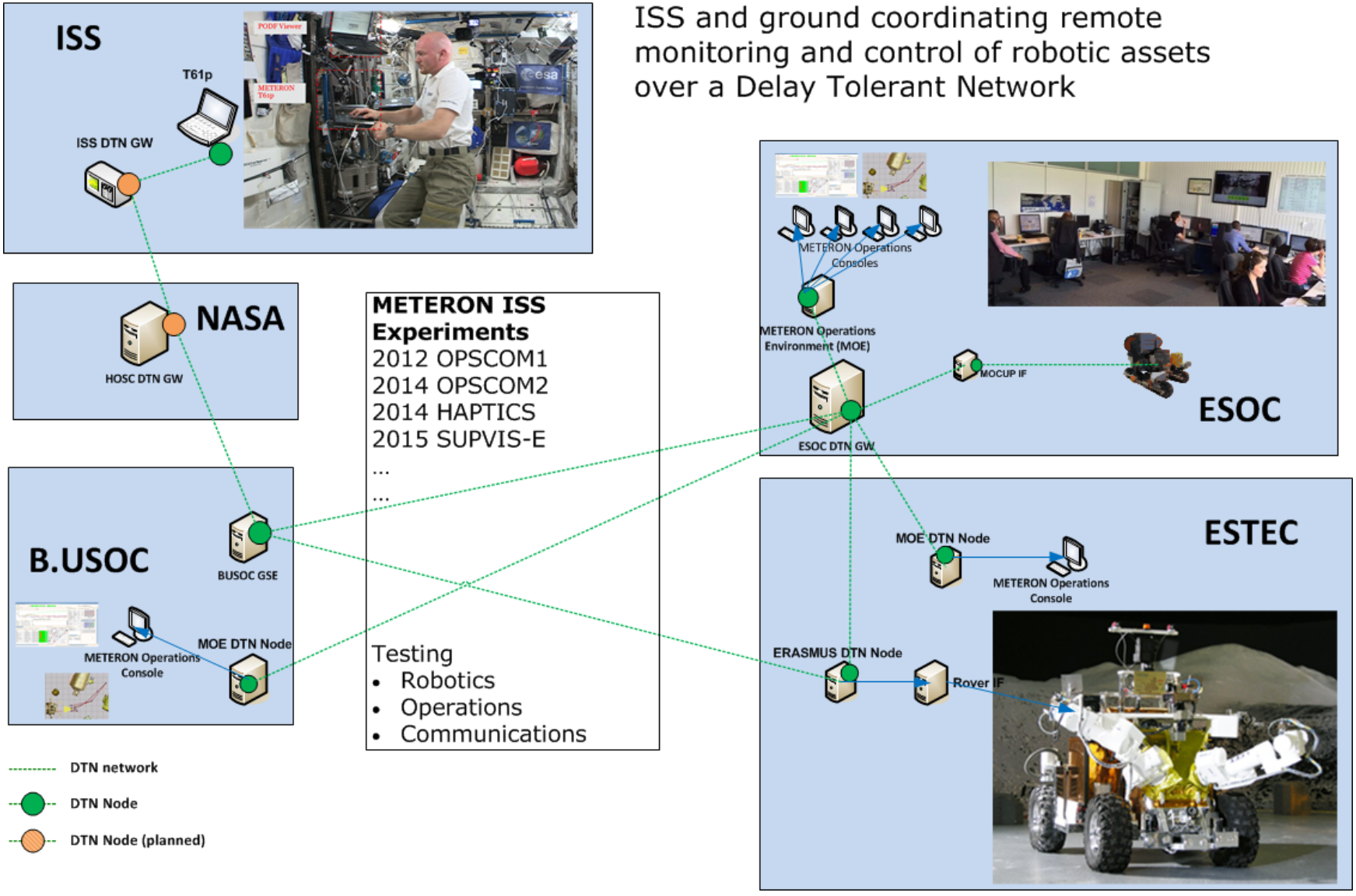
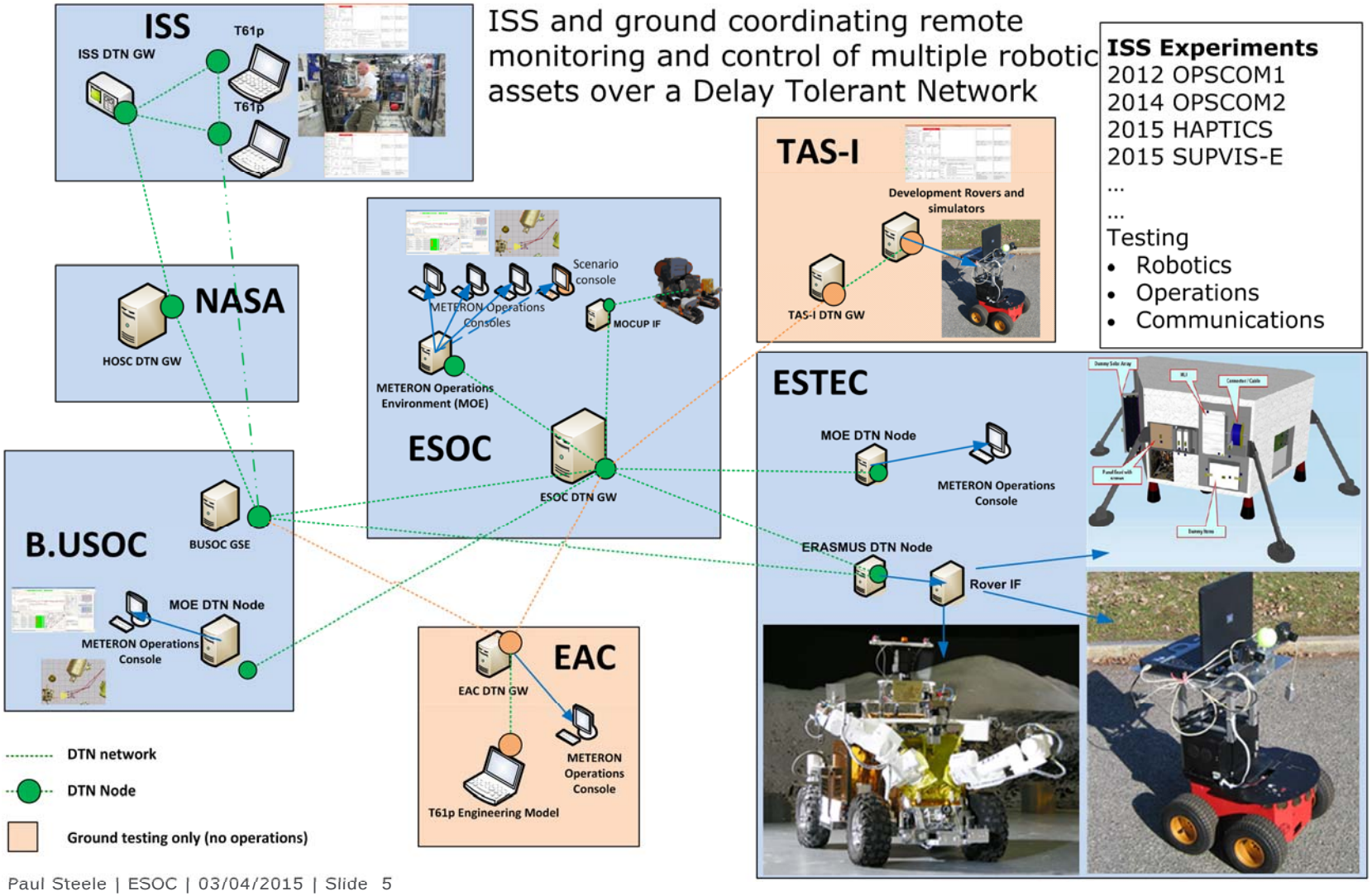
Operations and Communications (OPSCOM-2)

ISS and ground coordinating remote monitoring and control of robotic assets over a Delay Tolerant Network



Supervisory Control (SUPVIS-E)



ISS and ground coordinating remote monitoring and control of multiple robotic assets over a Delay Tolerant Network

ISS Experiments
2012 OPSCOM1
2014 OPSCOM2
2015 HAPTICS
2015 SUPVIS-E
…
…
Testing
- Robotics
- Operations
- Communications

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Enabling technologies and standards

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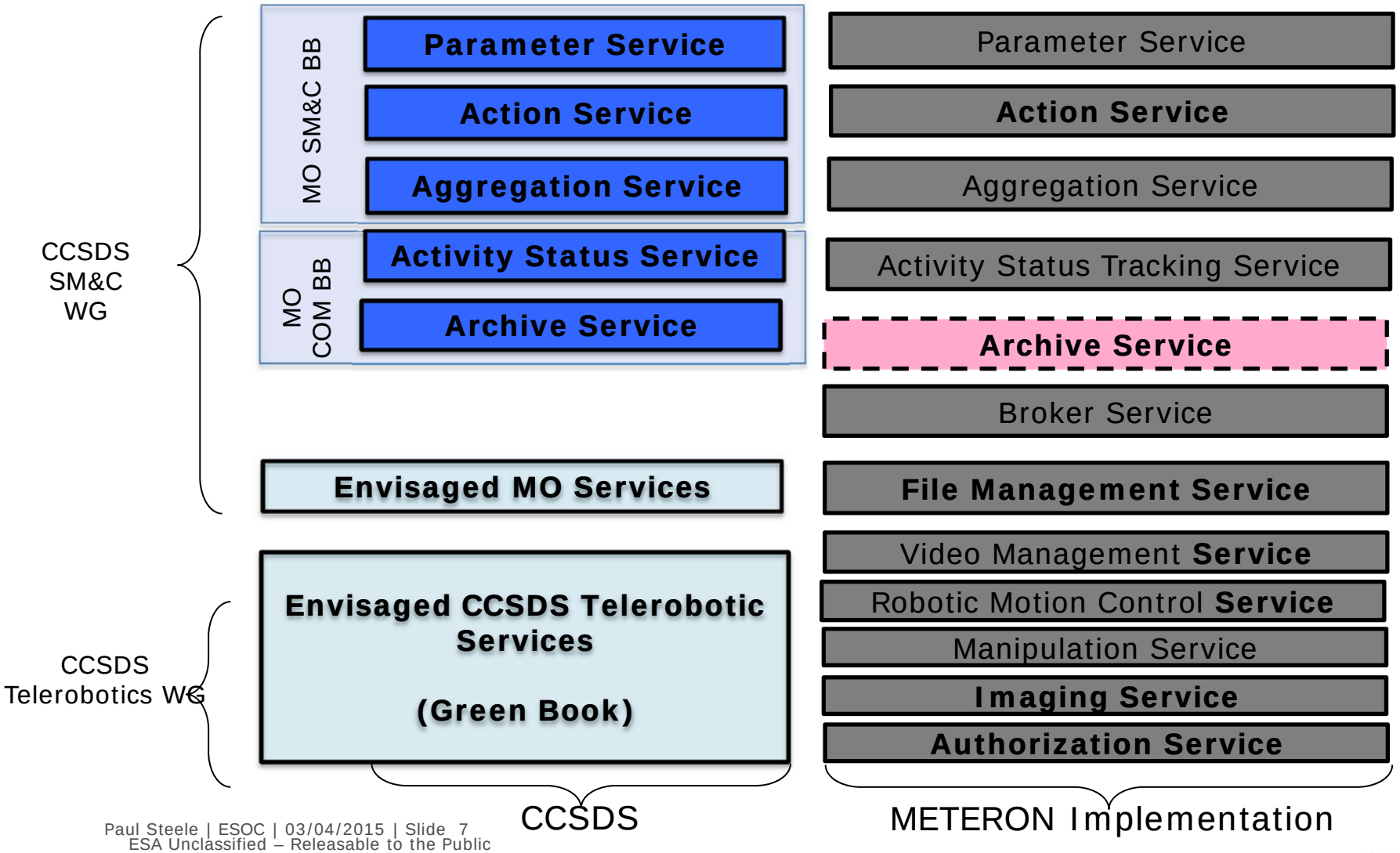
Relation to CCSDS Standards



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CCSDS Mission Operations Services

The METERON Robotic Services can be grouped as follows:

Generic services

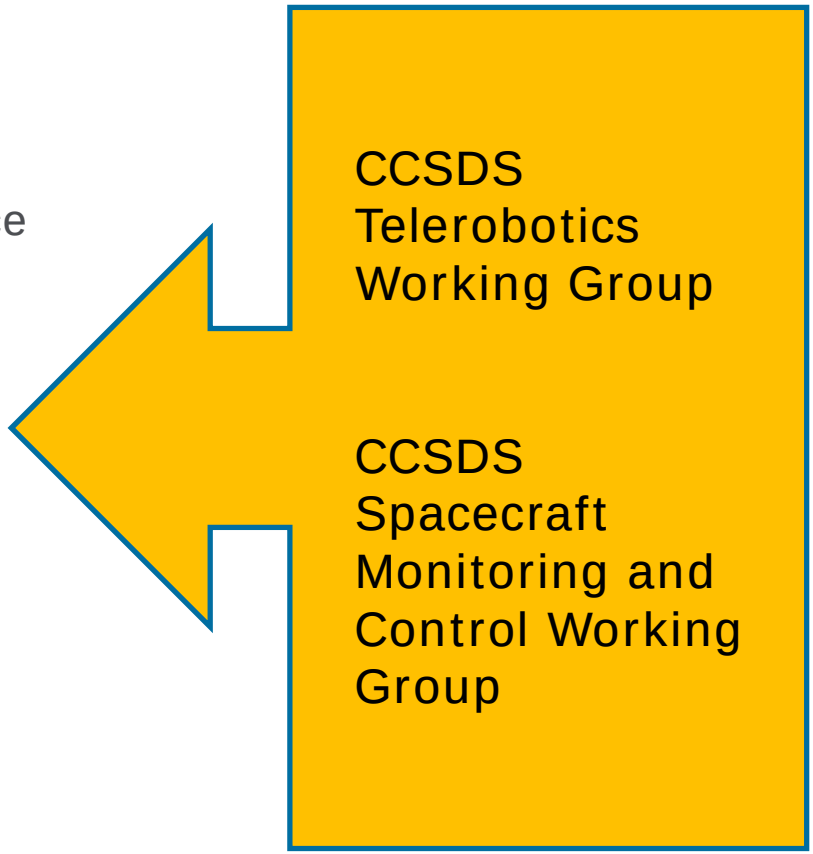
a. Parameter Service
b. Action Service
c. Activity Status Tracking Service

Utility Services

a. Authorisation Service
b. File Management Service

Telerobotic Operations Specific Services

a. Motion Control Services
b. Imaging Service
c. Manipulation Service
d. Localisation Service



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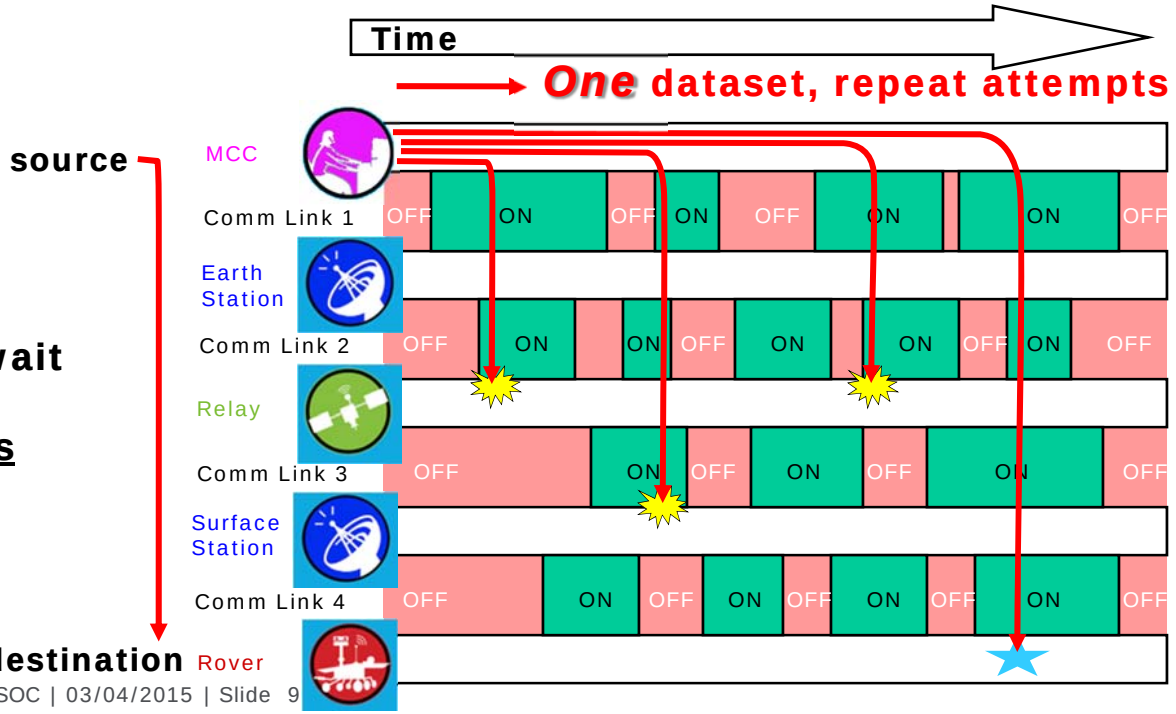
CCSDS Delay/Disruption Tolerant Network - Why not use Internet Protocols?

Compared to Internet, efficient space protocols need to overcome:

A: Asymetric bit data rates
B: Bit error rates (high in space from radiation and sun bursts)
C: intermittent link Connectivity (not always a line of sight)
D: long transmission Delay



With IP:
User must wait for a continuous end-to-end path.

Data are discarded by IP routers if next hop is not available

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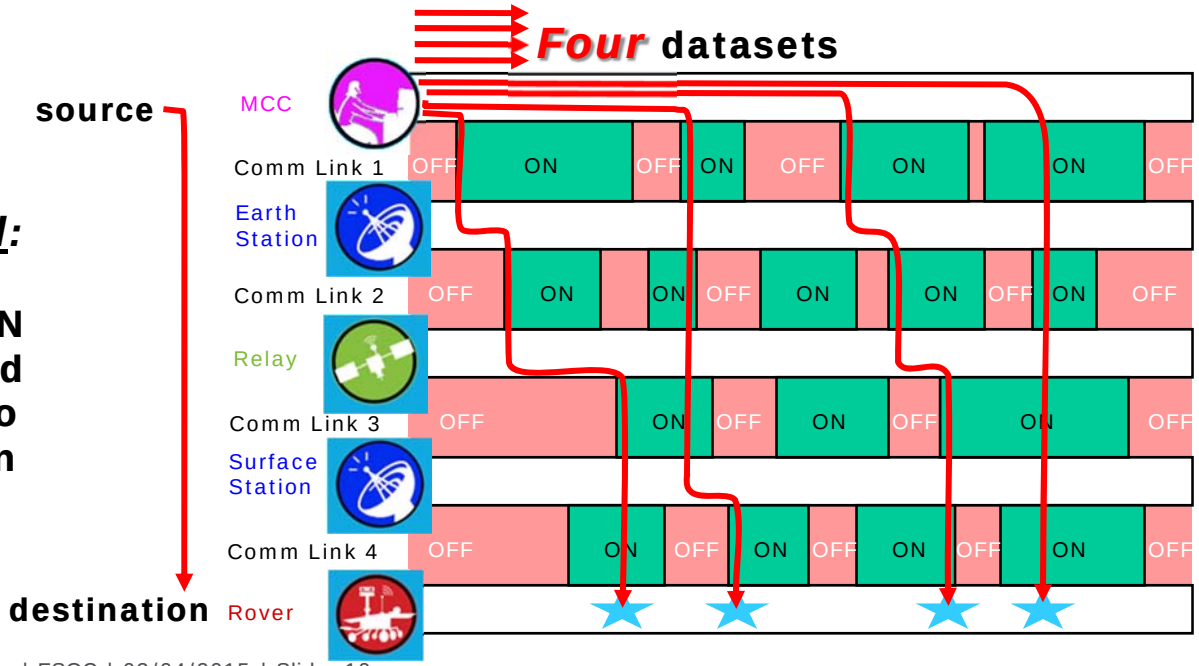
CCSDS DTN with intermittent connections

- Store and Forward with Custody Transfer (hop-by-hop): Delegation of retransmission responsibility to an accepting node
- DTNs overcome the “Internet assumptions” of intermittent connectivity, long or variable delay, asymmetric data rates - utilising store-and-forward messaging (“ABCD-problems”)

With DTN:
Data are held at DTN routers and continue to destination when next hop is available.



In stressed communications environments:

Increased VOLUME of data, delivered FASTER, i.e. higher GOODPUT and lower LATENCY

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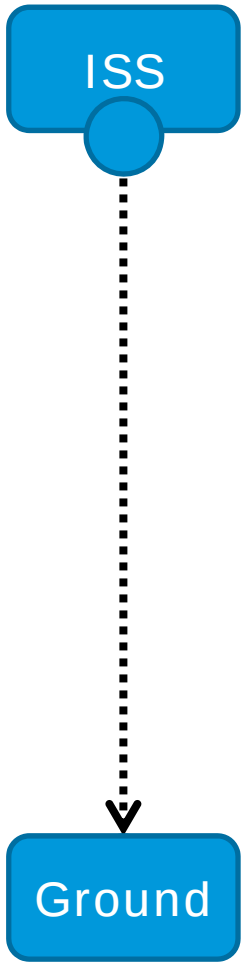
b) Custody transfer (1 / 3)



Bundle sent space to ground,

custody signal returned to previous node

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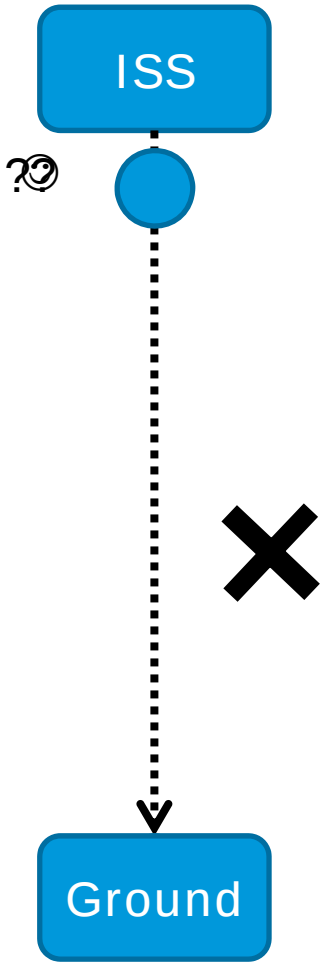
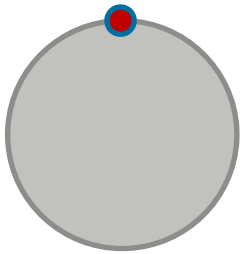
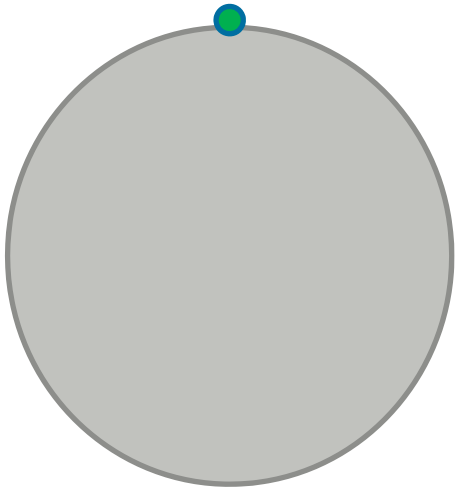
b) Custody transfer (2/3)



Bundle sent space to ground but lost on transfer



Custody timeout



Packet lifetime

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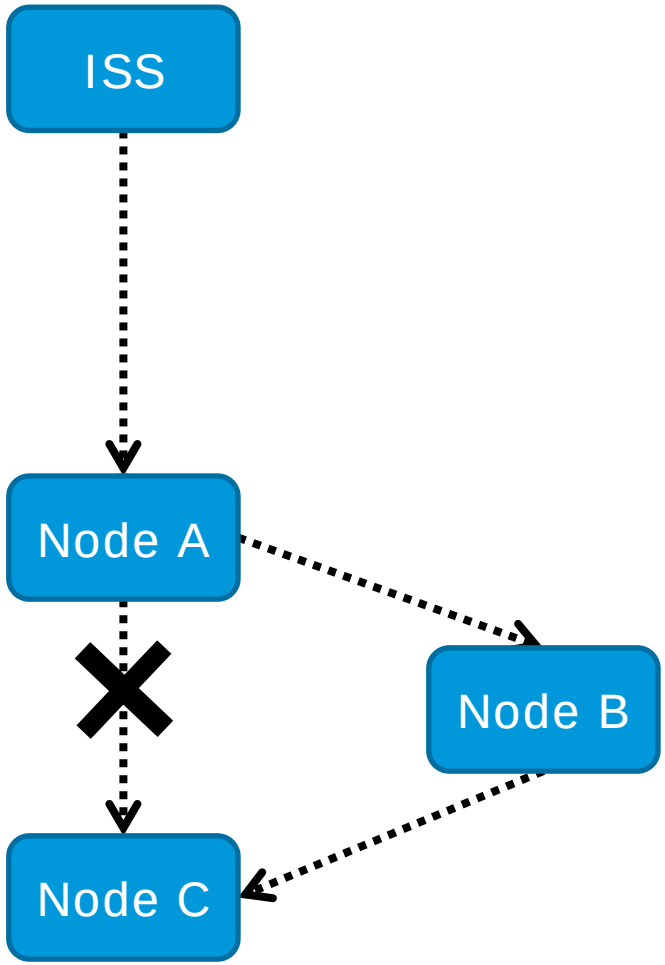
c) Multipath routing (1/3)



Bundle taking alternative route based on:

- ***Physical availability of route***
- ***Estimated transport time on route***
- ***Contact graph routing***

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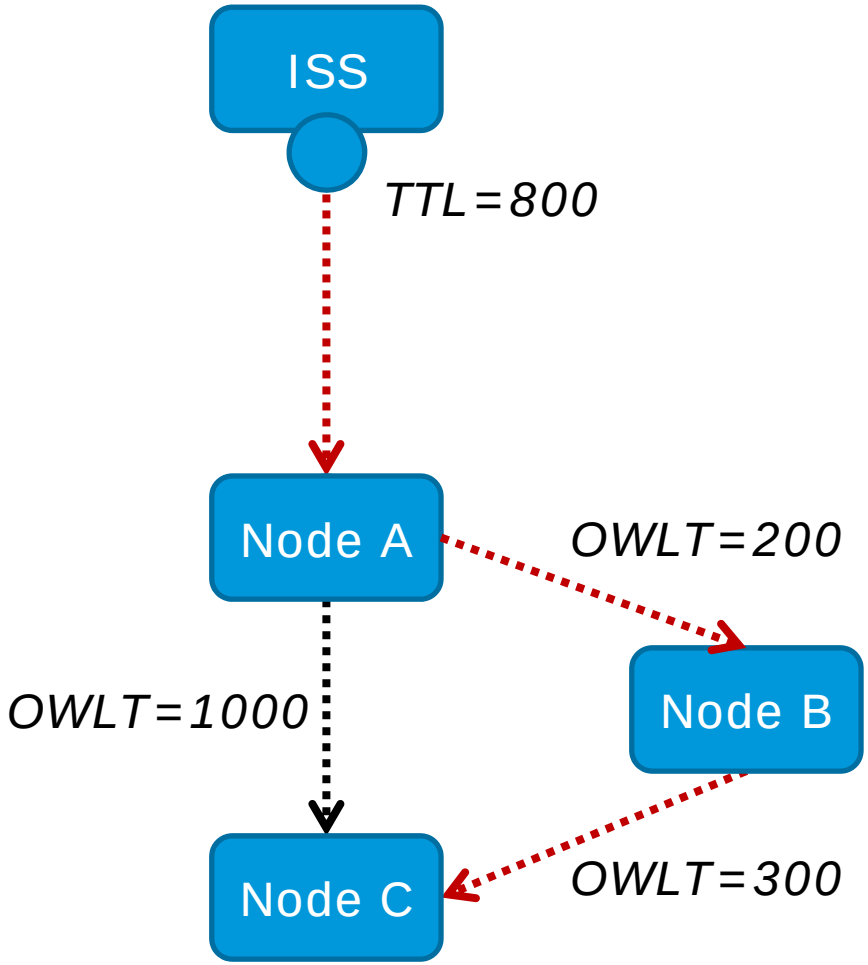
b) Multipath routing (2/3)



Bundle taking alternative route based on:

- ***Physical availability of route***
- ***Estimated transport time on route***
- ***Contact graph routing***

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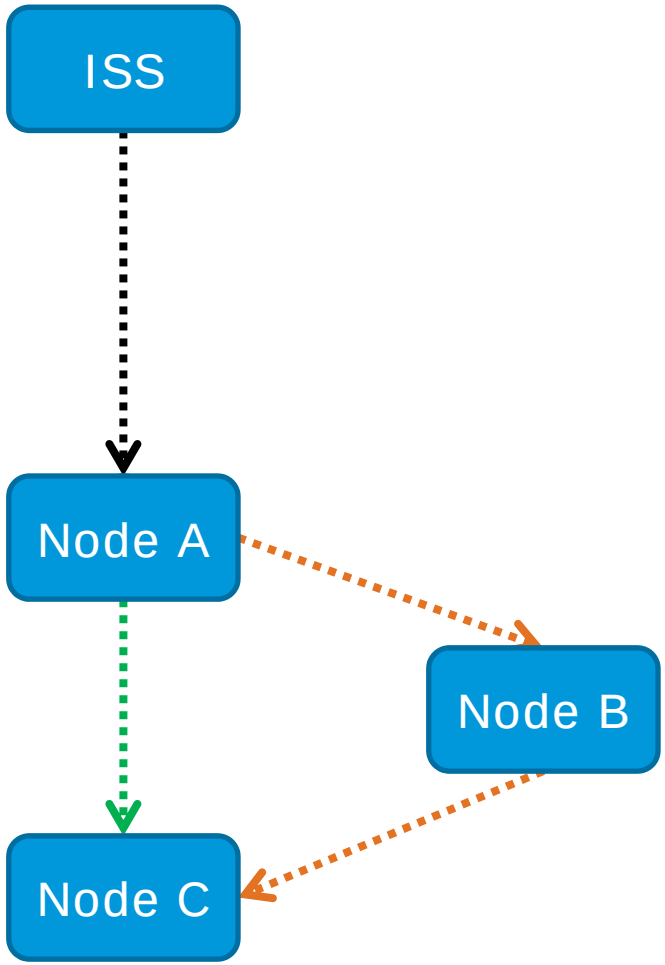
c) Multipath routing (3/3)



Bundle taking alternative route based on:

- ***Physical availability of route***
- ***Estimated transport time on route***
- ***Contact graph routing***

A <-> C available from GMT xxx

A <-> B <-> C available from GMT yyy

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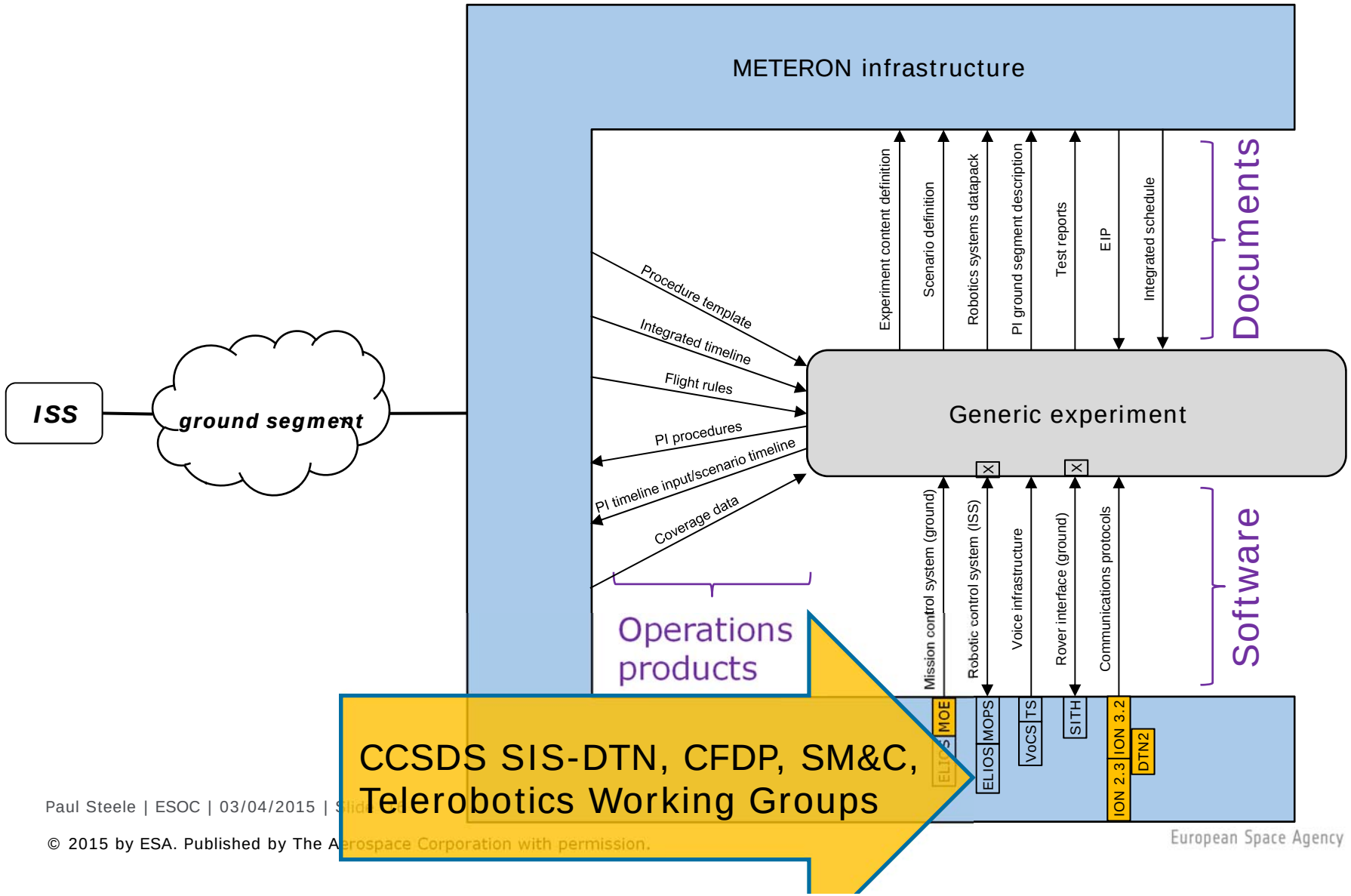
Plug and play



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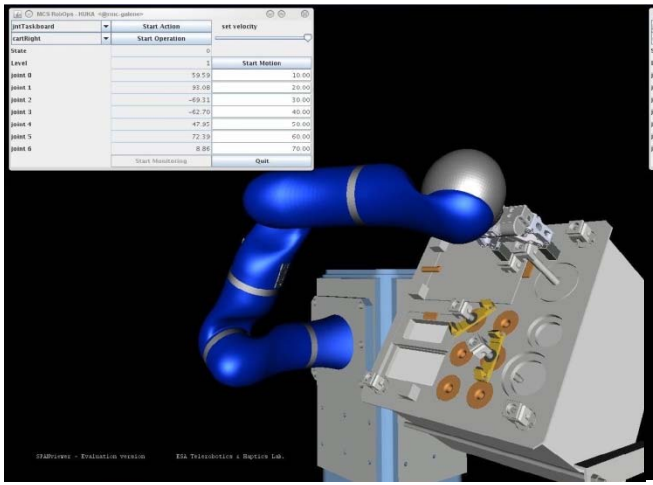
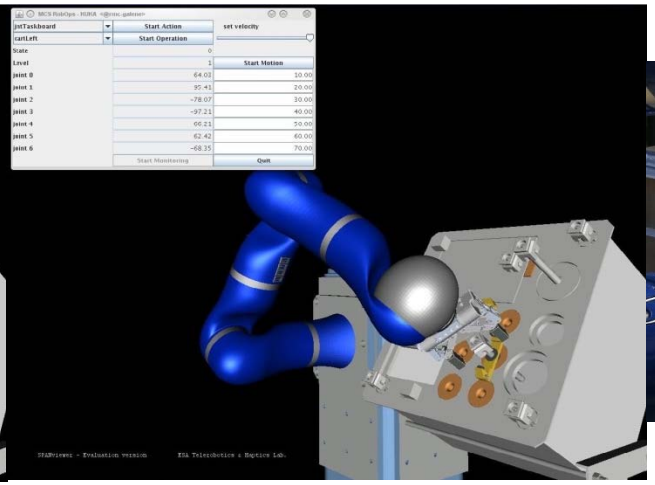
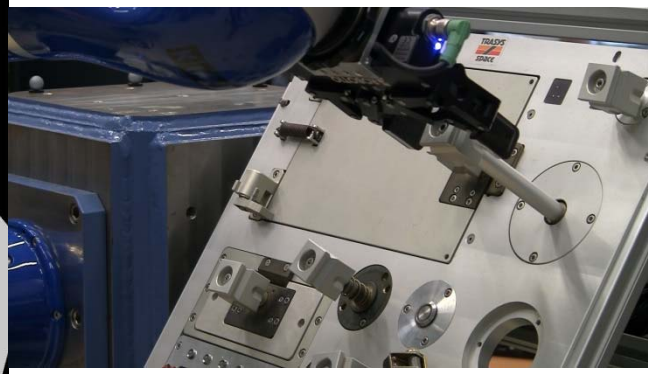
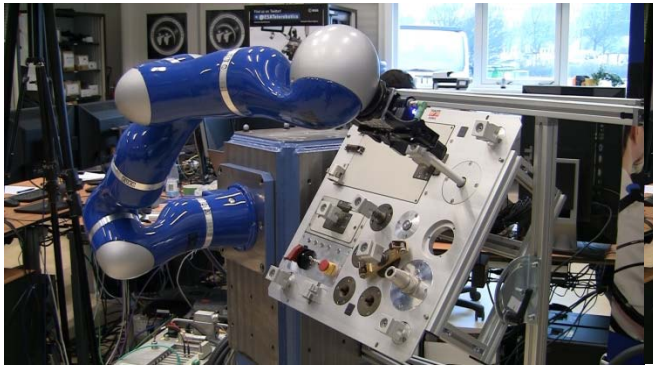
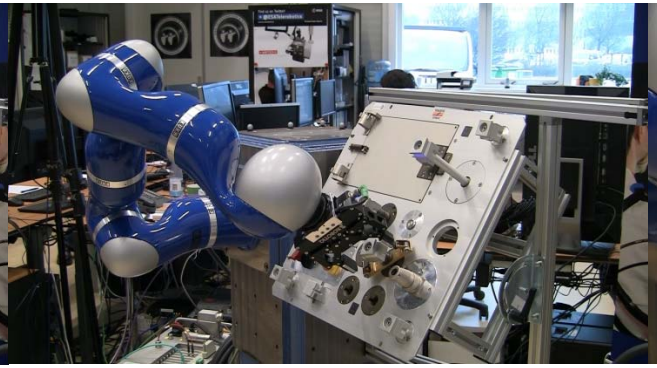
Kuka operations using services

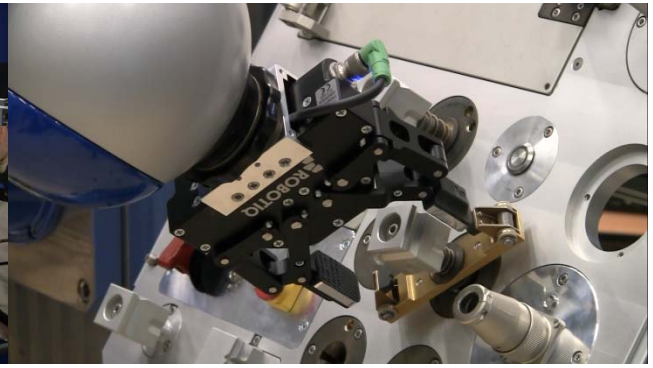












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Key Points

1. Enabling technologies and standards for human/robotic missions
    a. DTN (various implementations), RAPID, Prox-1, CFDP, ROS …
    b. Services (various implementations but CCSDS based)
    c. GSTVi customised as METERON Operations Environment
        – System of systems
        – Deployable
        – Reconfigurable
        – Ingest network data, HNS from orbiter/other assets
        – Multiple rovers/landers
2. Goal based commanding, telerobotics, distributed ops, interoperability
3. OPSCOM-1 (2012), OPSCOM-2 (2014), SUPVIS-E (2015)…

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Questions?

Backup slides:

a. DTN stack
b. Service adapter
c. METERON future experiments

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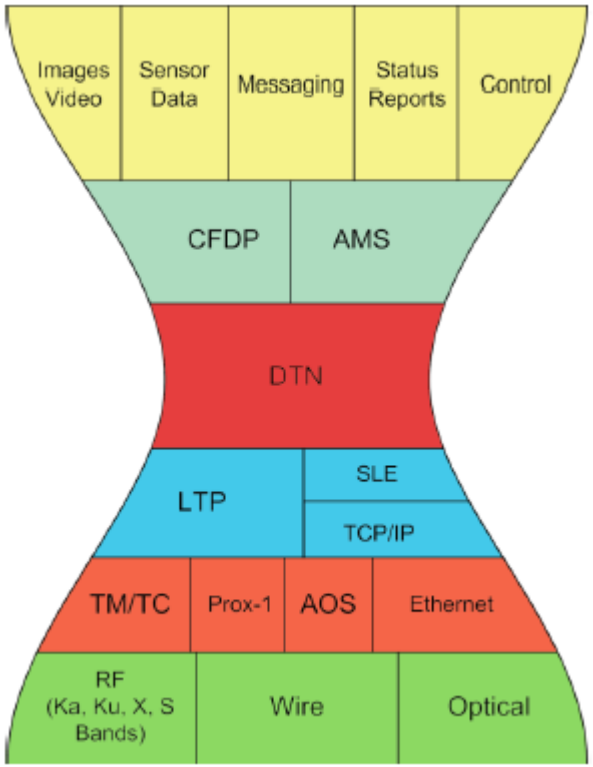
DTN Stack



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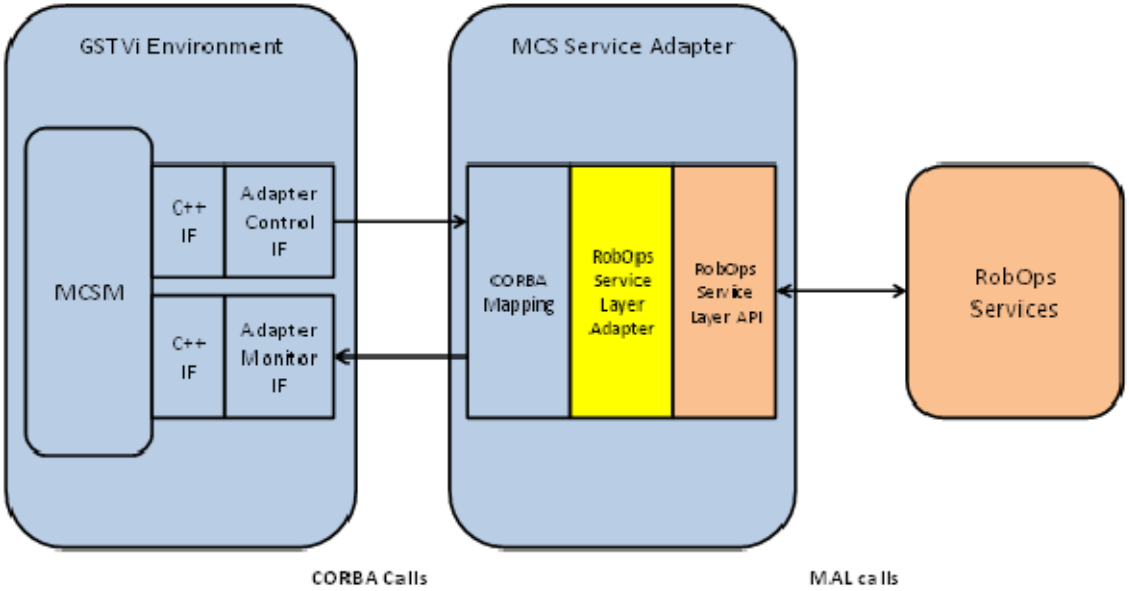
Service adapter



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METERON Experiment Series

Short Title of Experiment	Summary Description
OPSCOM-1	Communications set-up and first DTN flight demo (COMPLETED)
OPSCOM-2	Validation of communications and operations systems (utilising Eurobot) via DTN, using specific ground infrastructure (COMPLETED)
SUPVIS-E	Supervisory control of Eurobot, enhanced network capabilities
HAPTICS-1	First-time demonstration of force-reflection to take place within a microgravity experiment. In-orbit calibration of Exo joints, body-grounded tests
OPSCOM-3	Use of European DTN / MPCC for sequential Eurobot operation
HAPTICS-2	First time demonstration of a closed bilateral control loop with real-time force-reflection between the ISS and a small robotic joint located on Earth by the Astronaut, with real-time video feedback. Demonstration of suitability of the Russian Kontur System (low-latency link)
INTERACT	Haptics control of arm and rover; development of control strategies and algorithms
SUPVIS-JUSTIN	Supervisory control of Justin
COM4HAP-1	Demonstration of ESTRACK + Kontur comms links
COM4HAP-2	Demonstration of complete comms chain
EXO-1	Exo control of LWR in TRH lab
EXO-2	Exo control of Justin (inclu. Supervisory tasks)
EXO-3	Exo control of ISS-based Robonaut (TBC)
ANALOG-1	End-to-end exploration scenario with Eurobot

The series of experiments will culminate in ANALOG-1 which will consist of the simulation of an end-to-end exploration scenario with Eurobot located at an analogue site, being controlled from the ISS.

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