Plug and Play - Technologies for Robotic Operations

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METERON = Multi-Purpose End-To-End Robotic Operations Network

Reference scenario

International Space Station as test bed

monitoring @ Earth

rover @ “planet” (Earth)
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
ISS and ground coordinating remote monitoring and control of robotic assets over a Delay Tolerant Network.

**METERON ISS Experiments**
- 2012 OPSCOM1
- 2014 OPSCOM2
- 2014 HAPTICS
- 2015 SUPVIS-E

Testing:
- Robotics
- Operations
- Communications

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**Operations and Communications (OPSCOM-2)**
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
Relation to CCSDS Standards

CCSDS SM&C WG
- Parameter Service
- Action Service
- Aggregation Service
- Activity Status Service
- Archive Service

CCSDS Telerobotics WG
- Envisaged MO Services
- Envisaged CCSDS Telerobotic Services (Green Book)

CCSDS
- File Management Service
- Video Management Service
- Robotic Motion Control Service
- Manipulation Service
- Imaging Service
- Authorization Service

METERON Implementation
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
Compared to Internet, efficient space protocols need to overcome:

A: Asymmetric 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.
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
b) Custody transfer (1/3)

Bundle sent space to ground, custody signal returned to previous node
b) Custody transfer (2/3)

Bundle sent space to ground but lost on transfer

ISS

Ground

Custody timeout

Packet lifetime
c) Multipath routing (1/3)

Bundle taking alternative route based on:
- **Physical availability of route**
- **Estimated transport time on route**
- **Contact graph routing**
b) Multipath routing (2/3)

Bundle taking alternative route based on:
- **Physical availability of route**
- **Estimated transport time on route**
- **Contact graph routing**
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
Plug and play

ISS ground segment

METERON infrastructure

- Experiment content definition
- Scenario definition
- Robotics systems datapack
- PI ground segment description
- Test reports
- EIP
- Integrated schedule

Documents

- Mission control system (ground)
- Robotic control system (ISS)
- Voice infrastructure
- Rover interface (ground)
- Communications protocols

Software

- Operations products
- CCSDS SIS-DTN, CFDP, SM&C, Telerobotics Working Groups

ELIOS
MOPS
VoCS
SITH
DTN2
ION 2.3
ION 3.2

ELIOS
MOE
Kuka operations using services
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

Questions?

Backup slides:

a. DTN stack
b. Service adapter
c. METERON future experiments
Service adapter
## METERON Experiment Series

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<tr>
<th>Short Title of Experiment</th>
<th>Summary Description</th>
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<td><strong>OPSCOM-1</strong></td>
<td>Communications set-up and first DTN flight demo (COMPLETED)</td>
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<tr>
<td><strong>OPSCOM-2</strong></td>
<td>Validation of communications and operations systems (utilising Eurobot) via DTN, using specific ground infrastructure (COMPLETED)</td>
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<td><strong>SUPVIS-E</strong></td>
<td>Supervisory control of Eurobot, enhanced network capabilities</td>
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<td><strong>HAPTICS-1</strong></td>
<td>First-time demonstration of force-reflection to take place within a microgravity experiment. In-orbit calibration of Exo joints, body-grounded tests</td>
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<td><strong>OPSCOM-3</strong></td>
<td>Use of European DTN / MPCC for sequential Eurobot operation</td>
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<td><strong>HAPTICS-2</strong></td>
<td>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)</td>
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<tr>
<td><strong>INTERACT</strong></td>
<td>Haptics control of arm and rover; development of control strategies and algorithms</td>
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<td><strong>SUPVIS-JUSTIN</strong></td>
<td>Supervisory control of Justin</td>
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<td><strong>COM4HAP-1</strong></td>
<td>Demonstration of ESTRACK + Kontur comms links</td>
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<td><strong>COM4HAP-2</strong></td>
<td>Demonstration of complete comms chain</td>
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<td><strong>EXO-1</strong></td>
<td>Exo control of LWR in TRH lab</td>
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<tr>
<td><strong>EXO-2</strong></td>
<td>Exo control of Justin (incl. Supervisory tasks)</td>
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<tr>
<td><strong>EXO-3</strong></td>
<td>Exo control of ISS-based Robonaut (TBC)</td>
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<td><strong>ANALOG-1</strong></td>
<td>End-to-end exploration scenario with Eurobot</td>
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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.