JAXA Status Report Part 1

Design guideline and software tools for deterministic SpaceWire network using SpaceWire-D

Takayuki Yuasa, Tadayuki Takahashi (JAXA)

Collaborators:
Hiroaki Takada, Mitsutaka Takada, Yang Chen (Nagoya University)

20th SpaceWire Working Group meeting
at ESTEC

Japan Aerospace Exploration Agency
Institute of Space and Astronautical Science

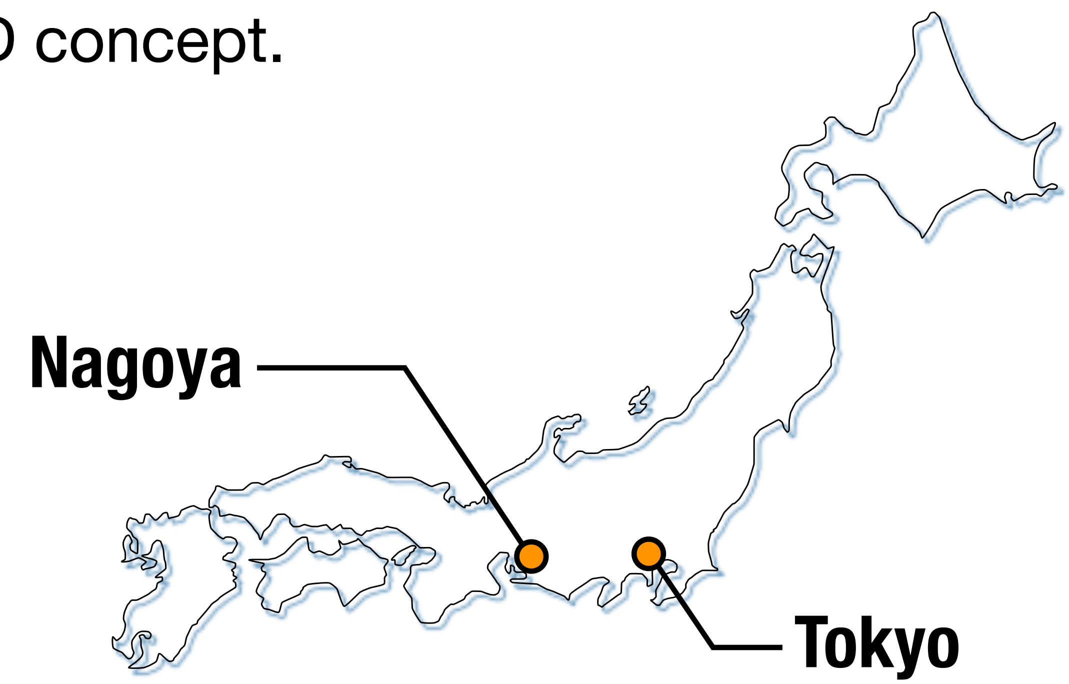
Brief introduction

Takayuki Yuasa

- High-energy astrophysicist.
- Institute of Space and Astronautical Science (ISAS) of JAXA.
- Working for ASTRO-H X-ray observatory satellite (2015-).
- Practical aspects of SpaceWire-related developments in JAXA with Tad Takahashi (JAXA) and Masaharu Nomachi (Osaka U.)
- Conferences: 2007, 2008, 2010, 2011

Purpose of this presentation

- To report SpaceWire-related R&D activities in Japan, especially concentrating the JAXA-Nagoya U. joint activities for deterministic property of SpaceWire.
  - Design guideline based on the SpaceWire-D concept.
  - Tools for scheduling.
  - SpaceWire Middleware on RTOS.



Reference

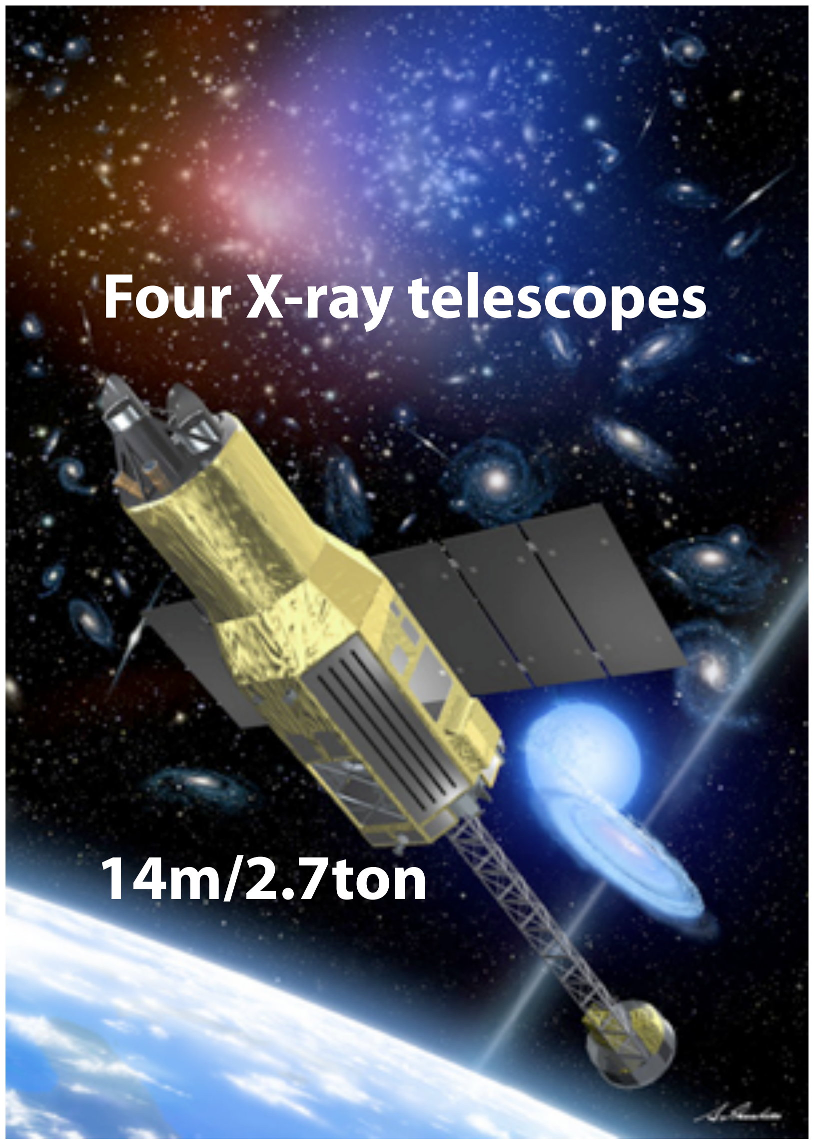
- Hiroaki Takada, "**Guaranteeing real-time property of SpW network based on SpW-D**", 18th SpaceWire WG meeting proceedings
- Nagoya University and JAXA, "**SpaceWire Real-Time Property Guarantee Methods Guideline**", available as a support document of 20th SpaceWire WG meeting
- Mitsutaka Takada et al., "**Development of software platform supporting a protocol for guaranteeing the real-time property of SpaceWire**", SpaceWire Conference 2013
- Yang Chen et al., "**A scheduling method of RMAP transactions for SpaceWire-D**", SpaceWire Conference 2013

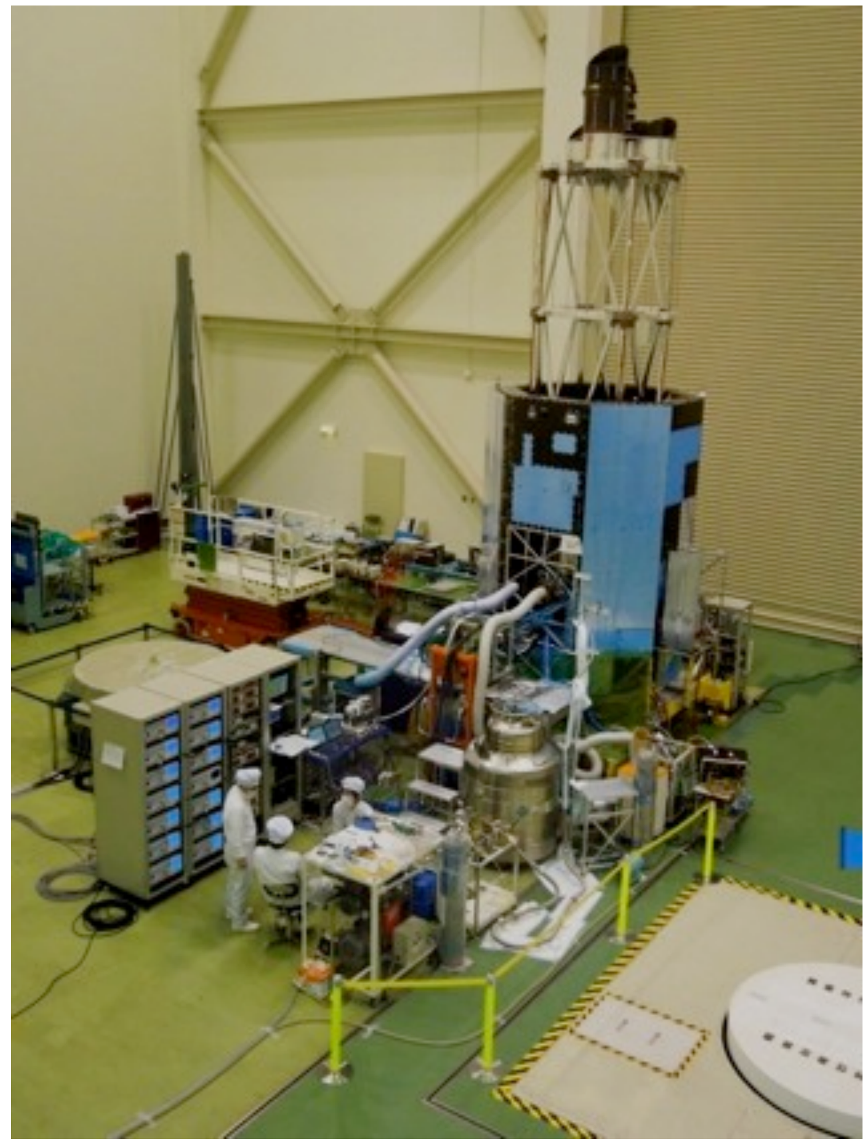
Why deterministic/real-time SpaceWire network?

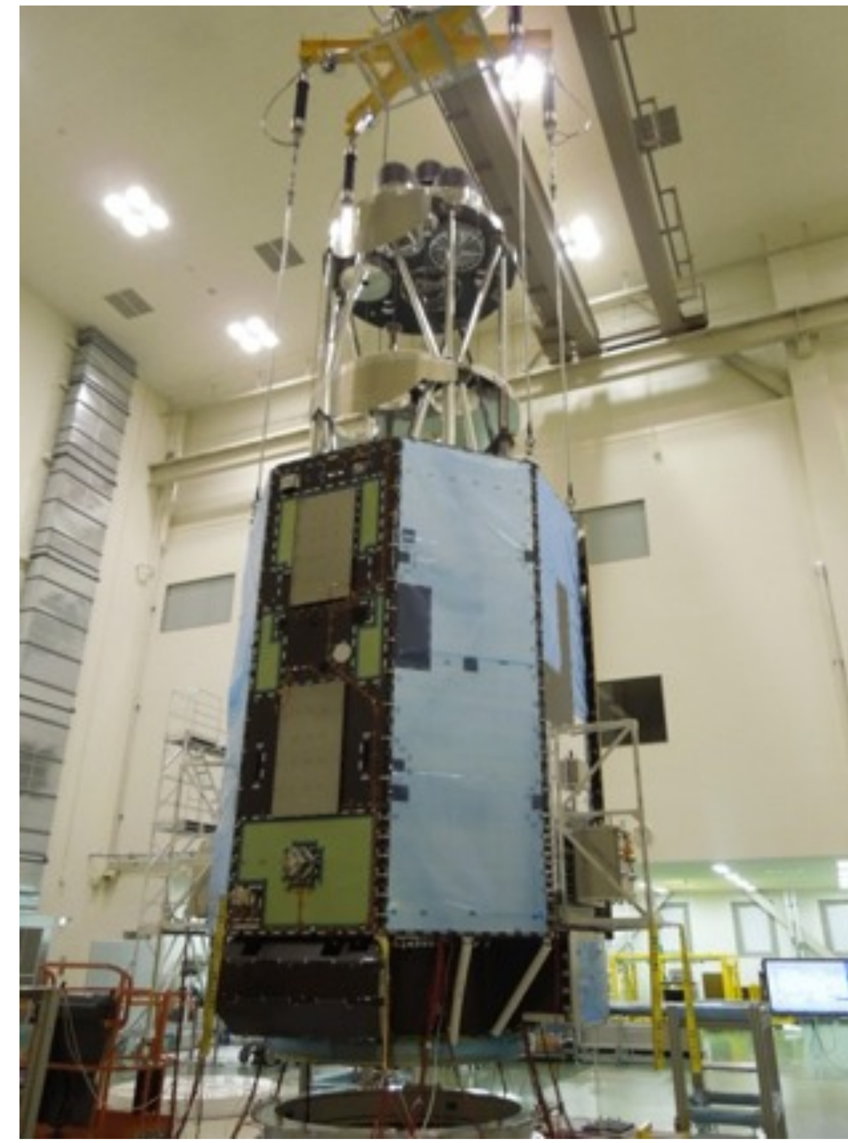
Why deterministic/real-time SpaceWire network?

ASTRO-H X-ray Observatory
(2015-)

MTM in JAXA's Tsukuba Space Center
March -May 2013







ASTRO-H is the first large satellite, in Japan, that fully adopts SpaceWire network for mission DH, C&C including AOCS.
(no MIL-1553, RS422, CAN, ...)

Why deterministic/real-time SpaceWire network?

Because determinism was/is essential for a large-scale network to operate successfully, transferring mission data and C&C data.

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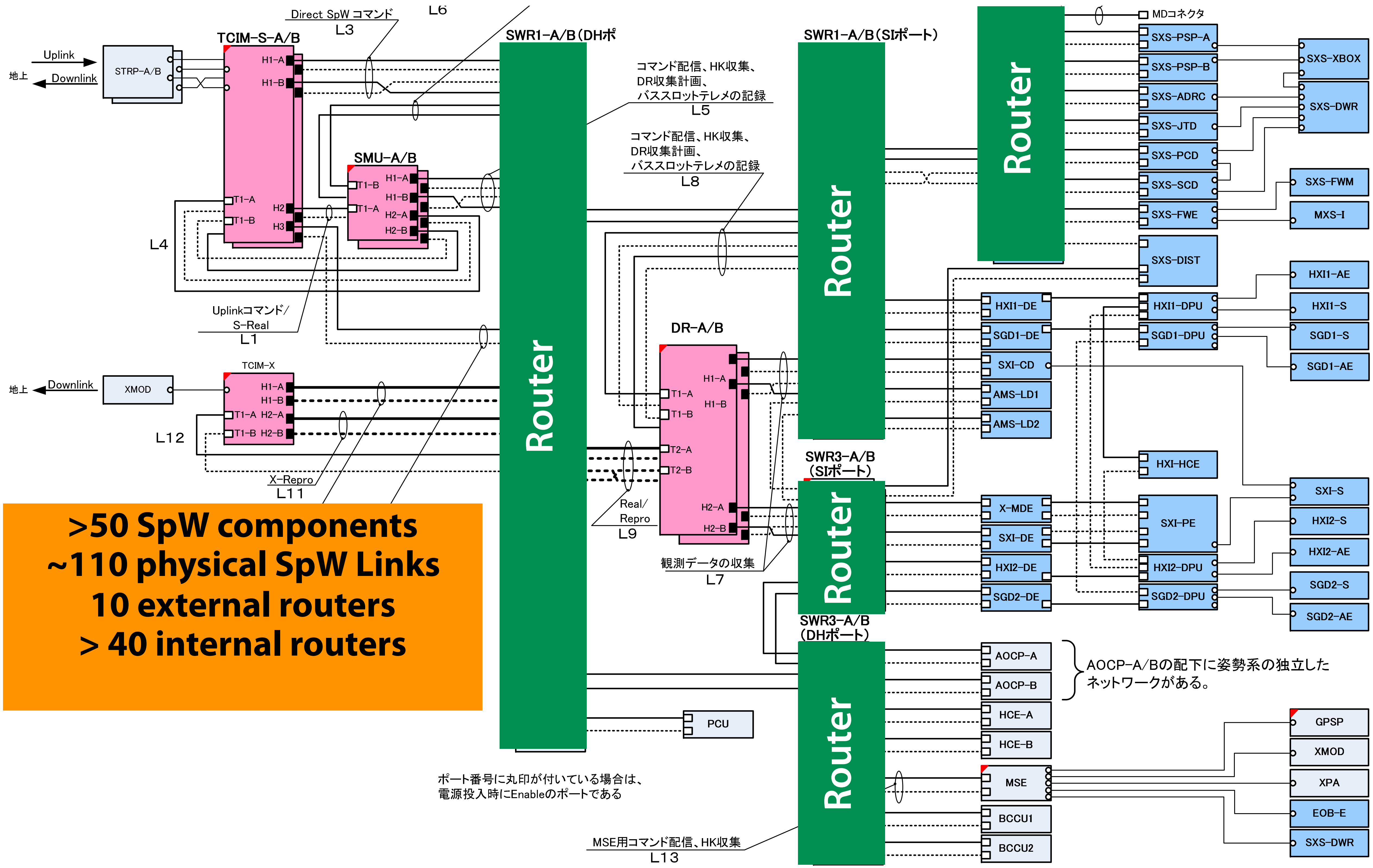

>50 SpW components
~110 physical SpW Links
10 external routers
> 40 internal routers

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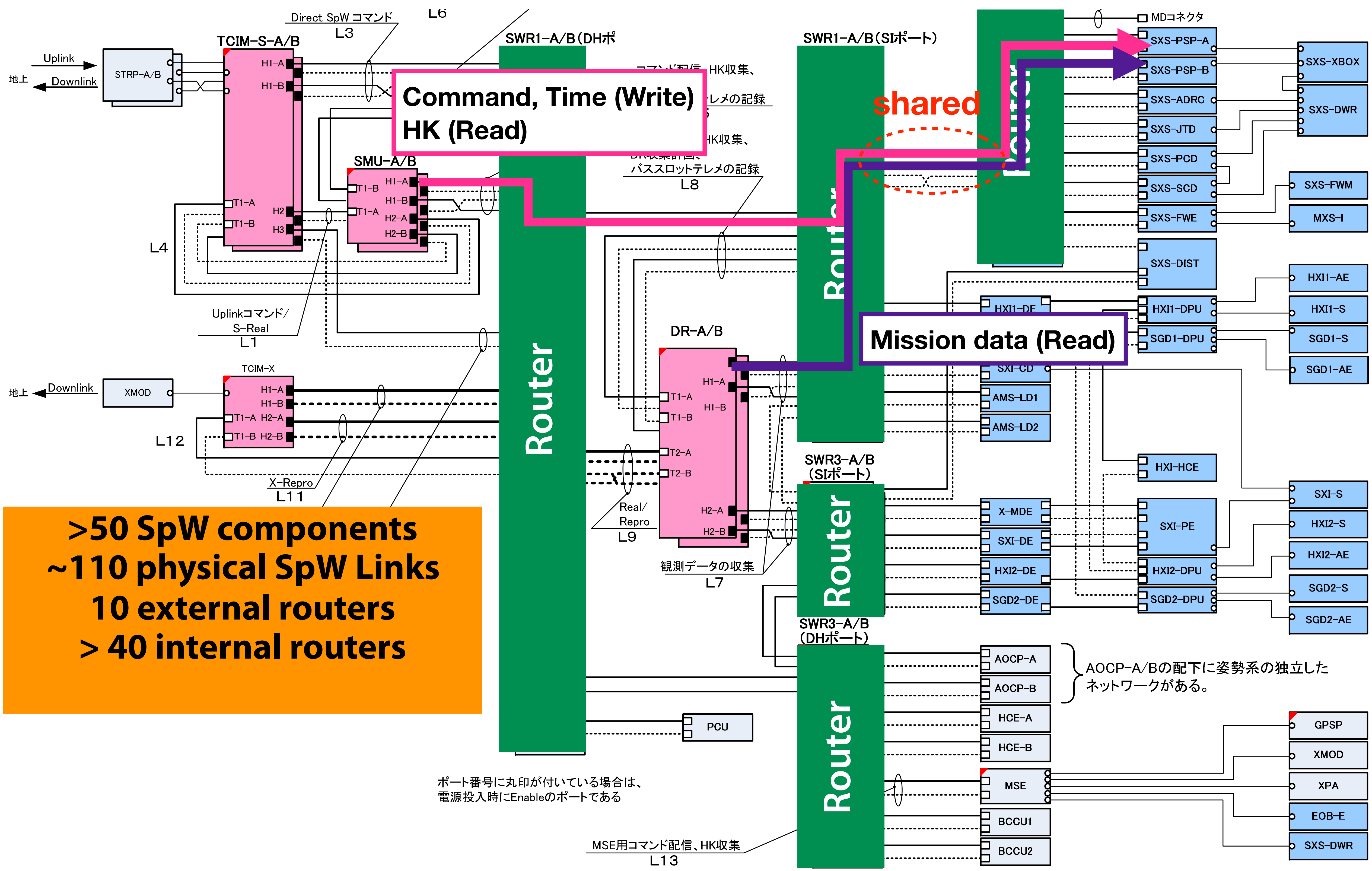

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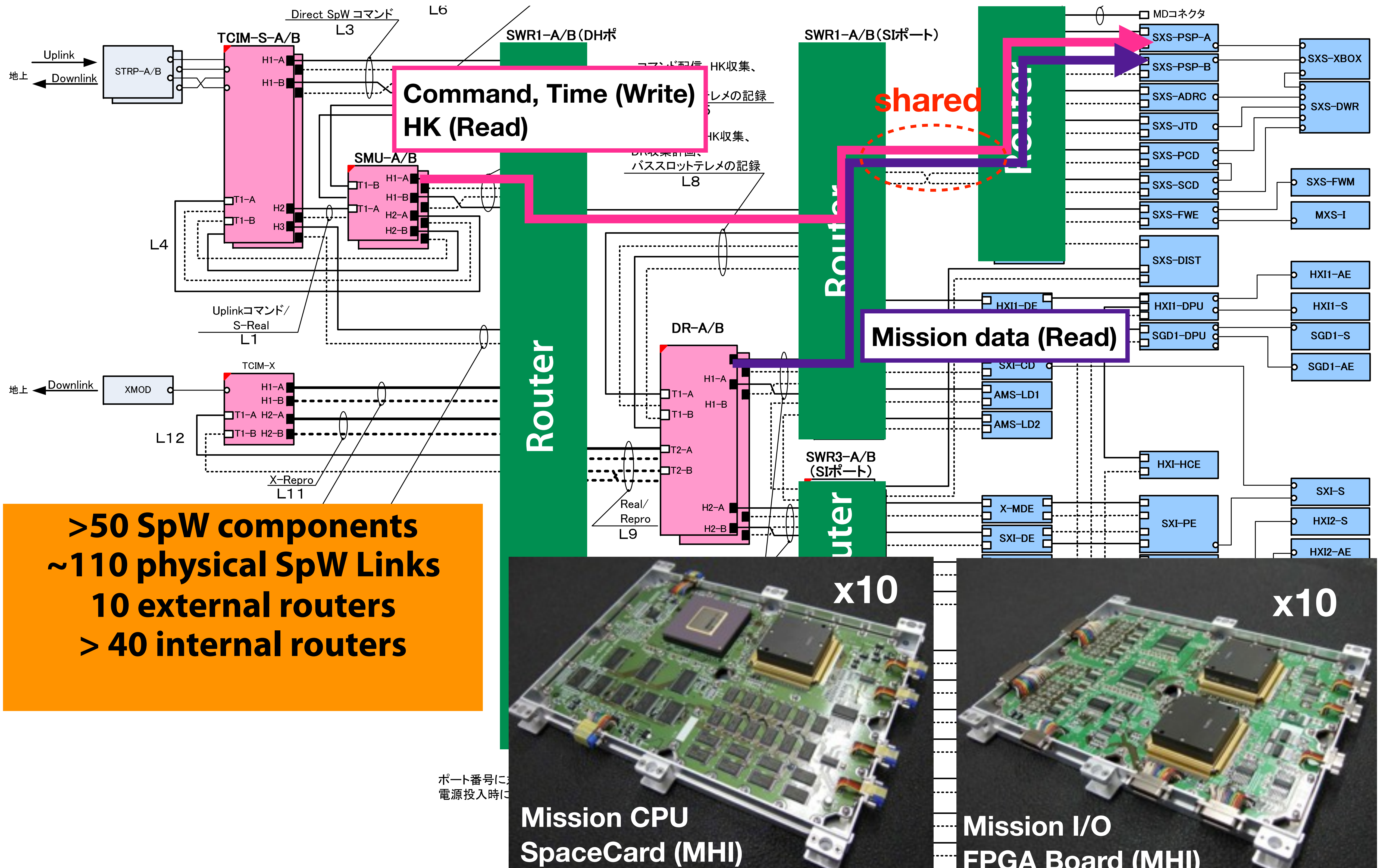

>50 SpW components
~110 physical SpW Links
10 external routers
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Constraints for determinism (see Yuasa et al. SpW Conference 2011)

- ***SpaceWire-D did not exist when the project started.***
  We had intensive discussion with NEC/MHI for determinism.
- RMAP-only data transfer (cargo size <1kB).
- Time slicing with 64-Hz timecode.
- All transactions are performed within pre-allocated time slots (see below).
- Every transaction should be completed within 5 ms.
- Multiple transactions for better throughput with 64-Hz timecode.
  (see S. Parkes: SpW-D Proposed Contents of Standard, 17th WG meeting)

Time-slot allocation (manually designed)

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63

"Spacecraft Bus slots" used for
- command distribution
- house-keeping data collection
- polling of request flags

Time and auxiliary data distribution from the SMU to components.

Mission instrument data collection by the DR according to the schdule provided by the SMU.

Collection of house-keeping data of SpaceWire Routers.

Collaboration between JAXA/ISAS and Nagoya U.

It was considered valuable to standardize and deepen experience gained in the ASTRO-H development for future missions including earth observation/communication satellites.

Joint R&D activities on real-time aspects of SpaceWire

- Between Q4 2010 - Q1 2013 (completed in March 2013).
- To construct a flexible methodology for guaranteeing the real-time property of SpW network based on SpW-D.
- To develop a software platform supporting the proposed framework.
- JAXA and NCES host a study group with Japan SpW Users Group (NEC, MELCO, MHI, etc) for:
  - Gathering requirements on “SpW real-time property”, and
  - Investigating the experience and problems obtained from the development of ASTRO-H.

- Resulting products:
  1. Design guideline document based on the SpaceWire-D concept.
  2. Software tools for time-slot scheduling.
  3. Open-source real-time OS and SpW Middleware for a flight computer.
     API that supports SpaceWire-D and the guideline.

Design Guideline for deterministic SpaceWire network

Starting points

- ASTRO-H SpaceWire Network Design Criteria (2008-).
- SpW-D standard under discussion.
  - [1] P. Armbruster: SpW-D Overview and Trade-offs, 16th SpW WG meeting.
  - [2] S. Parkes: SpW-D Proposed Contents of Standard, 17th SpW WG meeting.

Gathering additional requirements

- Regular meeting to collect inputs from spacecraft system industries (NEC, MELCO).
- Experience obtained from the development of ASTRO-H was also considered.

Concepts/functions added to SpW-D

- Some additional concepts/functions are added to SpW-D for satisfying the additional requirements.

Additional items considered in the guideline

Extended schedule table structure

- Each node in a scheduled network holds a schedule table defined *a priori*.
- Non-RMAP packets could be also transferred in a scheduled manner.
- Schedule tables should be designed carefully so as to all packet transfer complete within a single time slot. (or allocated time slots if multi-slot scheduling is used)
- Practically, it can be a complex task to construct schedule tables.
  We developed a software tool based on data transfer requests defined as an XML file.

Example schedule table for a certain initiator node.

Time slot	Packet type	Target node list	Total packet size	RMAP reply size (if any)
0	RMAP Write with Reply	11, 12, 13, 14	1024	20
1	Others	16	2000	---
2	RMAP Read	11, 12, 13, 14	40	1024
	RMAP Write with Reply	5, 6, 7	16	20
	Others	17	2000	---
3	RAMP Read	11, 12, 13, 14	40	1024
...	...	...	...	...
63	Others	21	2000	---

Additional items considered in the guideline

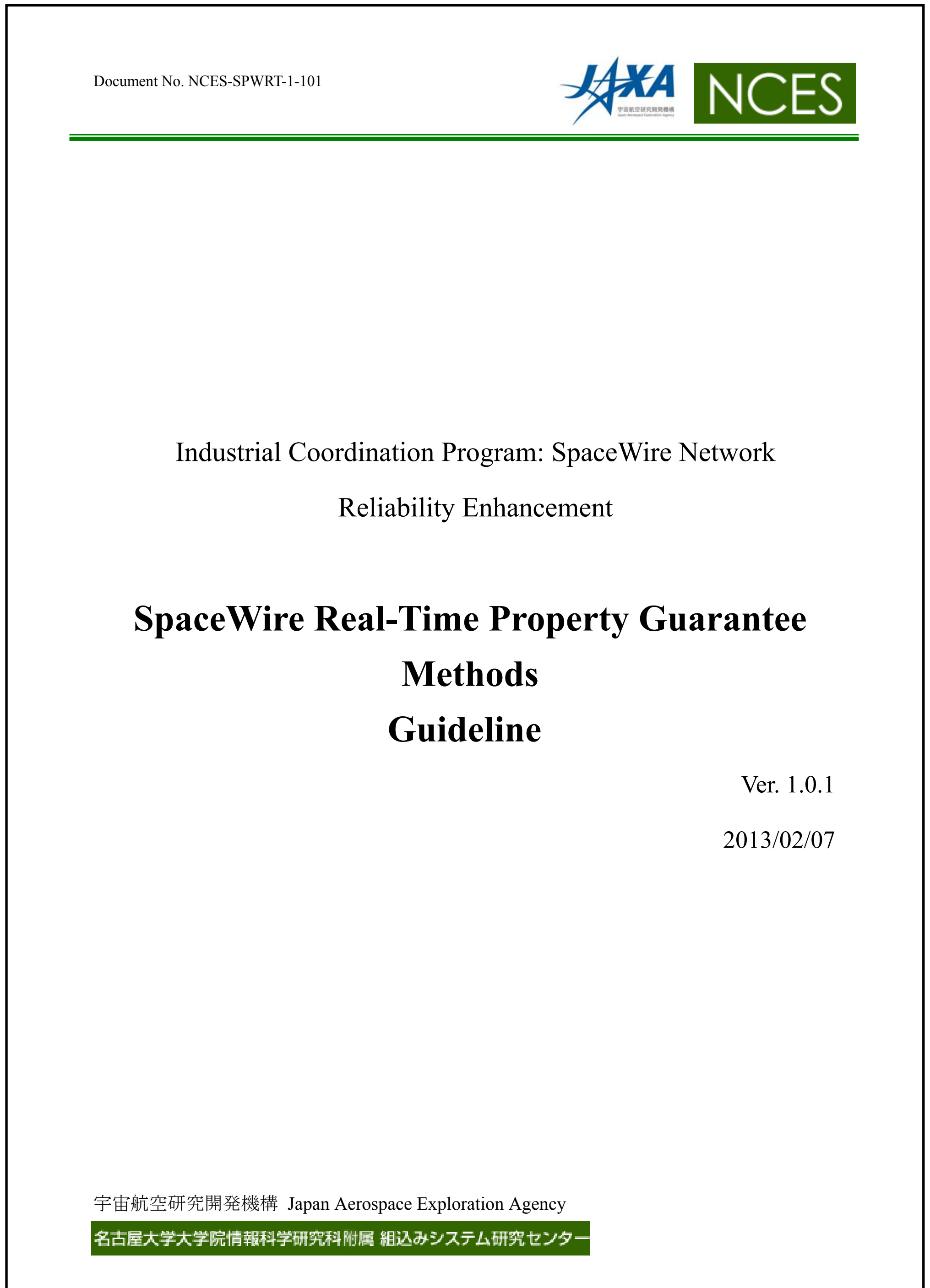
FDIR

- Behavior of initiators and targets is defined (as option) against erroneous events such as:
    - A packet resides beyond the time slot.
    - A packet that does not match the schedule is sent.
    - RMAP command is not delivered.
    - RMAP Reply is not returned.
    - A packet is lost.
        - A bit error occurs on the link, and the link is reset with an error due to a parity error or others.
    - The timecode is not received at the correct time.
        - This includes failure of the node that sends the timecode.
    - A packet exceeding the subnet is sent.

- The SpaceWire Middleware implements some of these FDIR procedures, and notify the event to user tasks.

Guideline document

- Intended to be used with SpaceWire-D when designing an onboard network.
- Containing additional consideration items and FDIR behavior.
- Will be publicly released from Nagoya U. and JAXA shortly.
  (after coordination with JAXA IP office...)



Document No. NCES-SPWRT-1-101

Industrial Coordination Program: SpaceWire Network

Reliability Enhancement

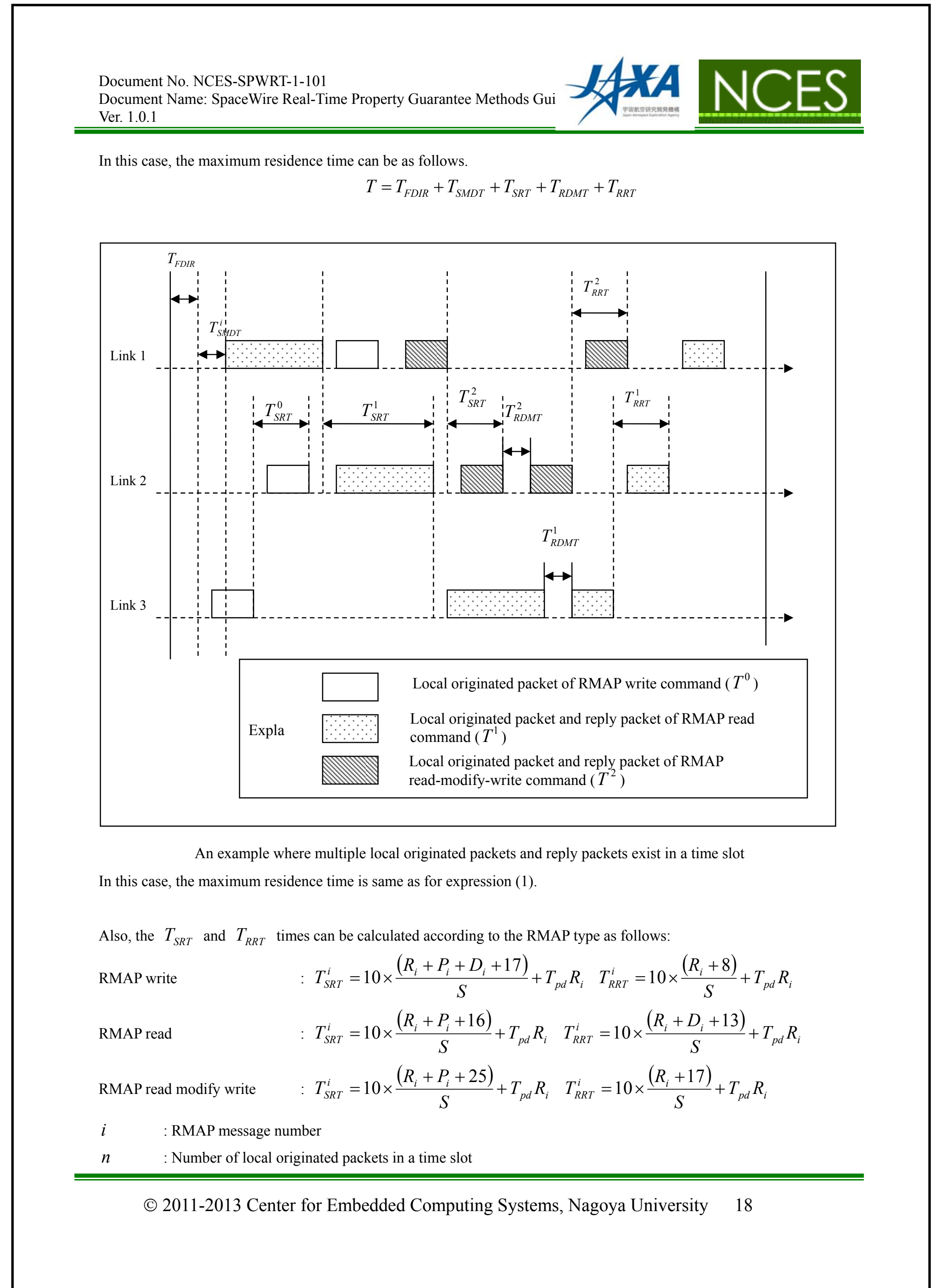
SpaceWire Real-Time Property Guarantee Methods Guideline

Ver. 1.0.1

2013/02/07

宇宙航空研究開発機構 Japan Aerospace Exploration Agency

名古屋大学大学院情報科学研究科附属 組込みシステム研究センター



Document No. NCES-SPWRT-1-101
Document Name: SpaceWire Real-Time Property Guarantee Methods Gui
Ver. 1.0.1

In this case, the maximum residence time can be as follows.

$$T = T_{FDIR} + T_{SMDT} + T_{SRT} + T_{RDMT} + T_{RRT}$$

An example where multiple local originated packets and reply packets exist in a time slot

In this case, the maximum residence time is same as for expression (1).

Also, the T_{SRT} and T_{RRT} times can be calculated according to the RMAP type as follows:

RMAP write : $T^i_{SRT} = 10 \times \frac{(R_i + P_i + D_i + 17)}{S} + T_{pd} R_i \quad T^i_{RRT} = 10 \times \frac{(R_i + 8)}{S} + T_{pd} R_i$

RMAP read : $T^i_{SRT} = 10 \times \frac{(R_i + P_i + 16)}{S} + T_{pd} R_i \quad T^i_{RRT} = 10 \times \frac{(R_i + D_i + 13)}{S} + T_{pd} R_i$

RMAP read modify write : $T^i_{SRT} = 10 \times \frac{(R_i + P_i + 25)}{S} + T_{pd} R_i \quad T^i_{RRT} = 10 \times \frac{(R_i + 17)}{S} + T_{pd} R_i$

i : RMAP message number

n : Number of local originated packets in a time slot

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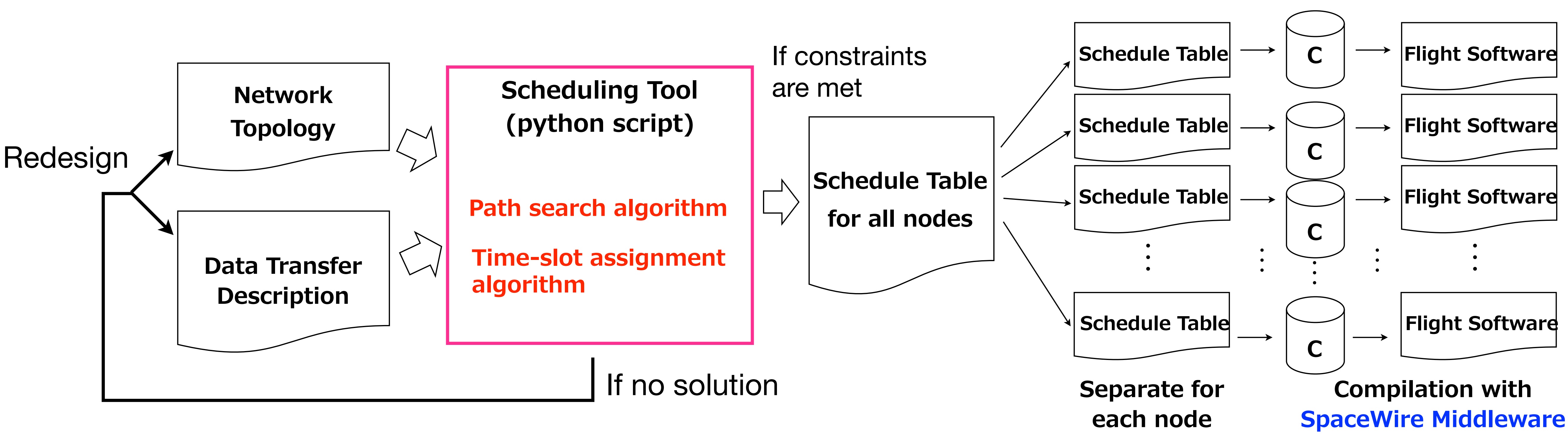
Design workflow with our software tools

Scheduling tool

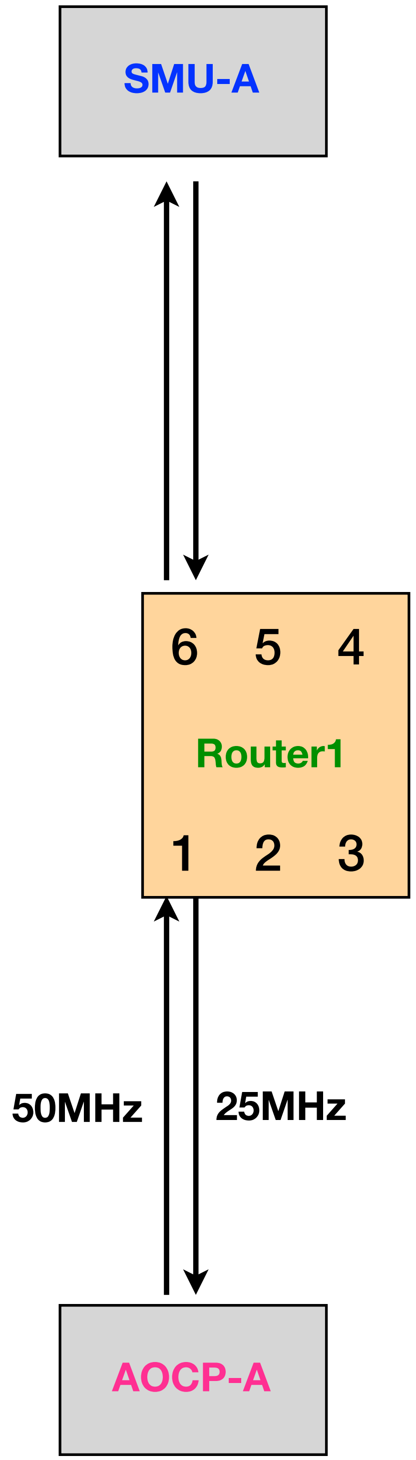
- Helps to resolve complex time-slot allocation (scheduling).
- Iteratively calculates possible time-slot allocation based on a given data transfer description and network topology (input as XML files).
- Searches nominal/redundant communication paths automatically.
- Generates schedule tables for each node in XML and/or C source code. The source code can be imported by SpaceWire Middleware.

SpaceWire Middleware

- APIs for SpaceWire-D packet transfer and RMAP initiator/target protocol stack.
- Runs on TOPPERS Real-time OS with SpaceCard flight computer (Mitsubishi Heavy Industry).
- User applications can easily perform scheduled data transfer by providing a schedule table calculated/generated by the scheduling tool.
- Includes FDIR functions and automatic RMAP retry (as requested from user application).



Topology in XML



Topology in XML

```
<SpaceWireNetworkTopology>
    <Subnet>
        <FDIR IntervalTime="5"/>
        <Timeslot Number="64" SlotTime="15625"/>

        <Router Id="Router1" NetworkPropagationDelay="2">
            <Port Number="1"/>
            <Port Number="2"/>
            ...
            <Port Number="6"/>
        </Router>
            ...
```
Router definition

```
        <Node Id="AOCP-A" LogicalAddress="0x37"/>
        <Node Id="HCE-A" LogicalAddress="0x39"/>
        <Node Id="HXI-HCE" LogicalAddress="0x3B"/>
            ...
```
Node definition

```
        <Link Id="Router1-AOCP-A"
            Speed="50" NetworkPropagationDelay="0">
            <Endpoint1 Id="Router1" Port="1"/>
            <Endpoint2 Id="AOCP-A" Port="1"/>
        </Link>
        <Link Id="AOCP-A-Router1"
            Speed="25" NetworkPropagationDelay="0">
            <Endpoint1 Id="AOCP-A" Port="1"/>
            <Endpoint2 Id="Router1" Port="1"/>
        </Link>
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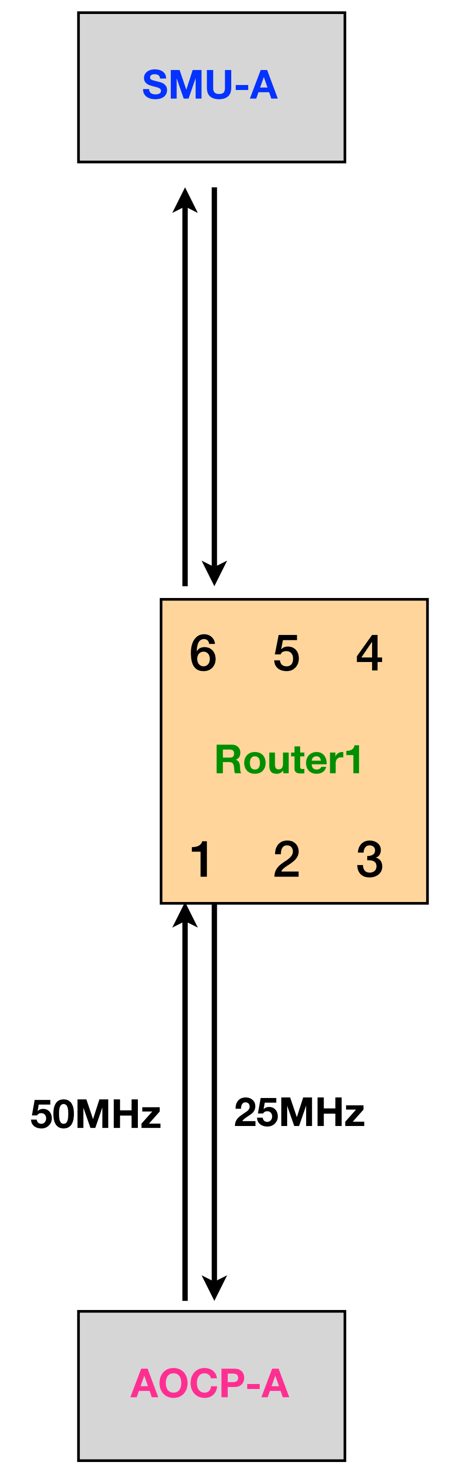

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        </Link>
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            Speed="25" NetworkPropagationDelay="0">
            <Endpoint1 Id="AOCP-A" Port="1"/>
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        </Link>
            ...
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```

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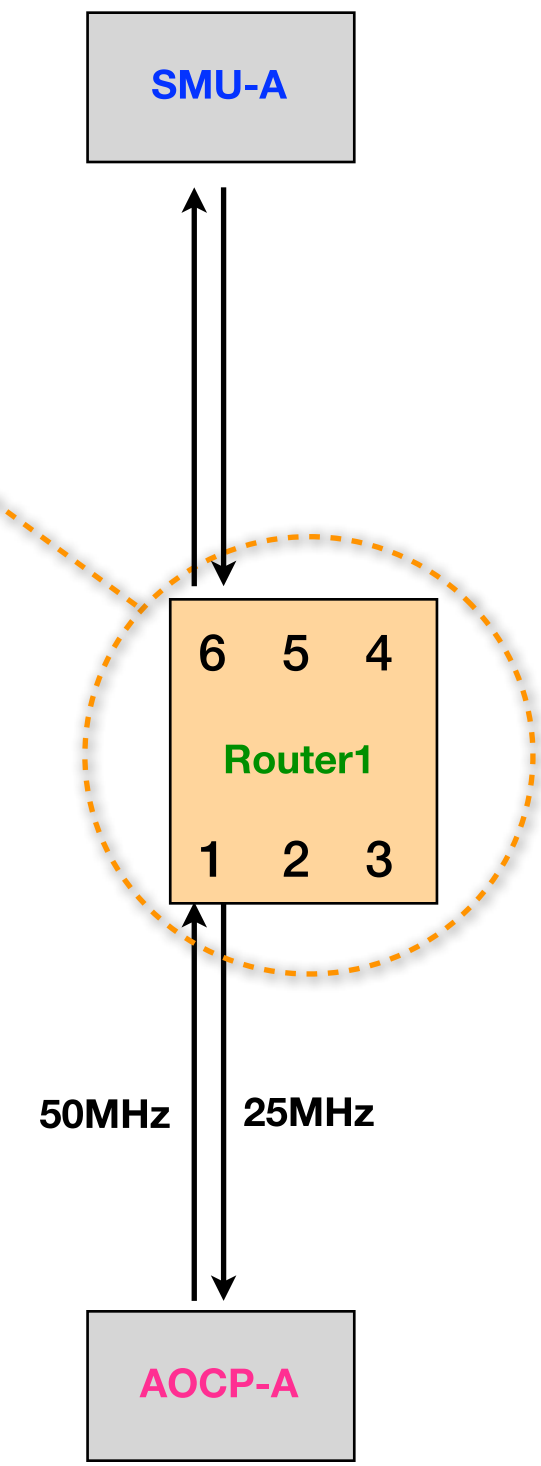

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            <Port Number="6"/>
        </Router>
            ...
                                                Router definition
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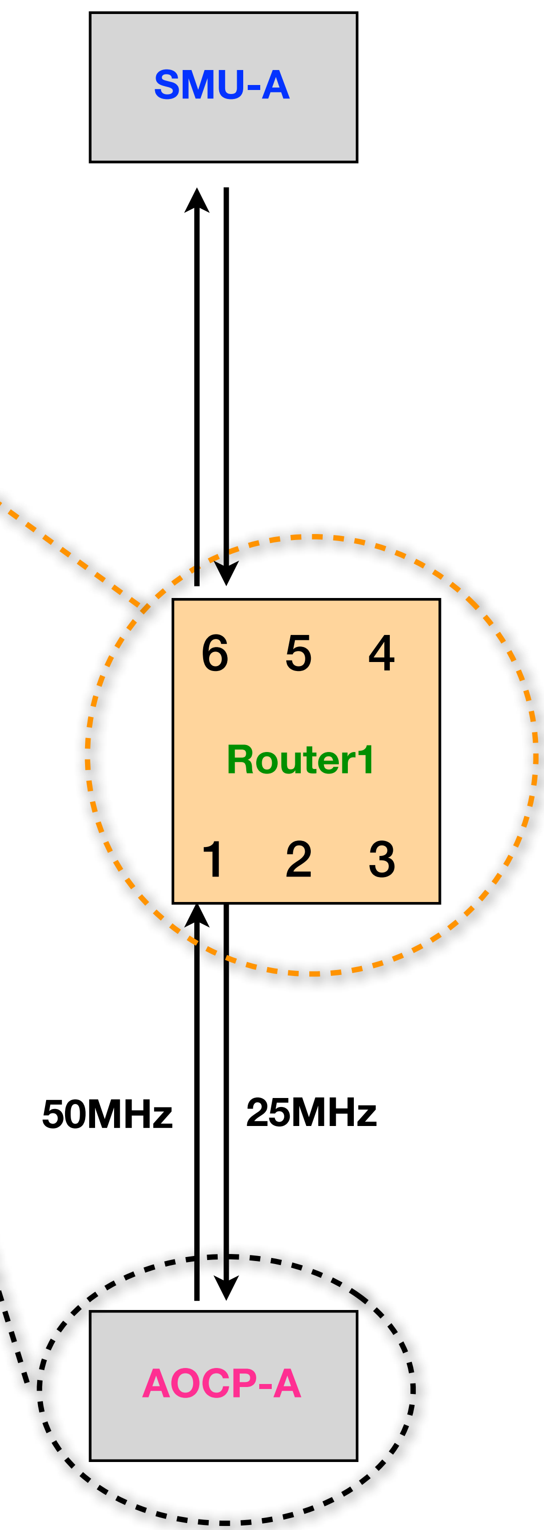
            ...
                                                Node definition
        <Link Id="Router1-AOCP-A"
            Speed="50" NetworkPropagationDelay="0">
            <Endpoint1 Id="Router1" Port="1"/>
            <Endpoint2 Id="AOCP-A" Port="1"/>
        </Link>
        <Link Id="AOCP-A-Router1"
            Speed="25" NetworkPropagationDelay="0">
            <Endpoint1 Id="AOCP-A" Port="1"/>
            <Endpoint2 Id="Router1" Port="1"/>
        </Link>
            ...
                                                Link definition
    </Subnet>
</SpaceWireNetworkTopology>
```



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        </Link>
            ...
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</SpaceWireNetworkTopology>
```
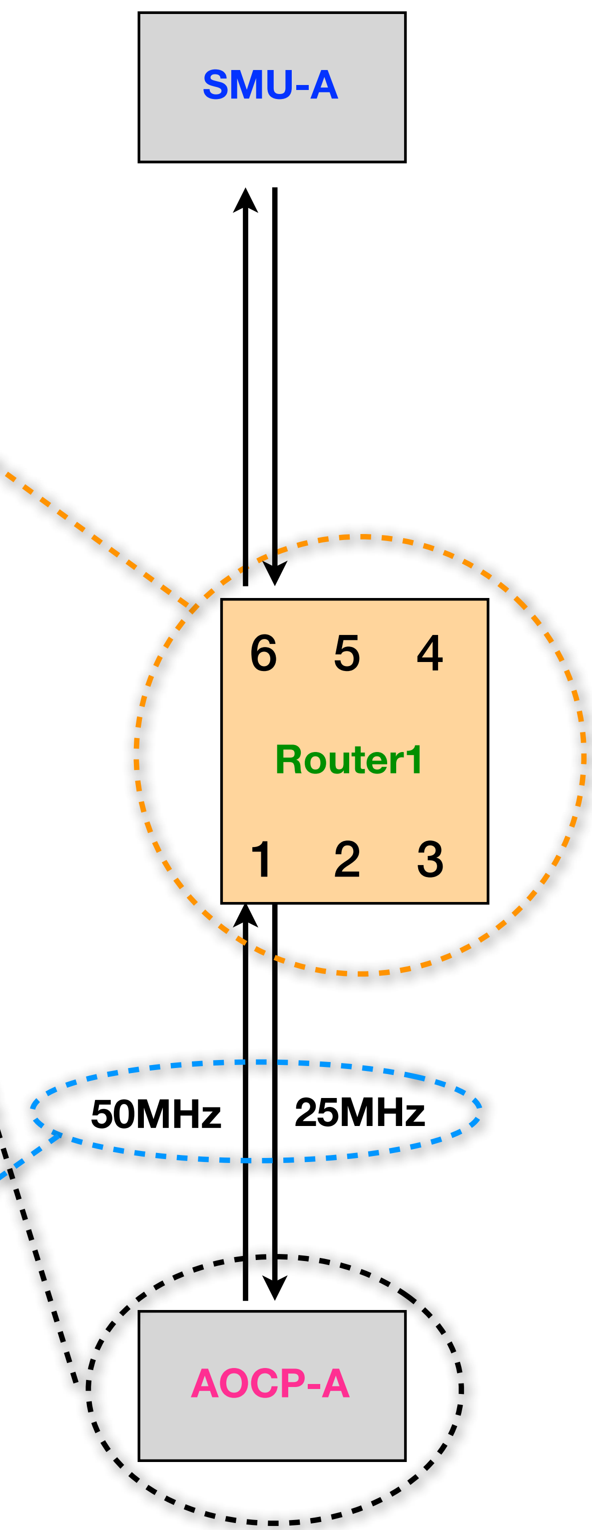
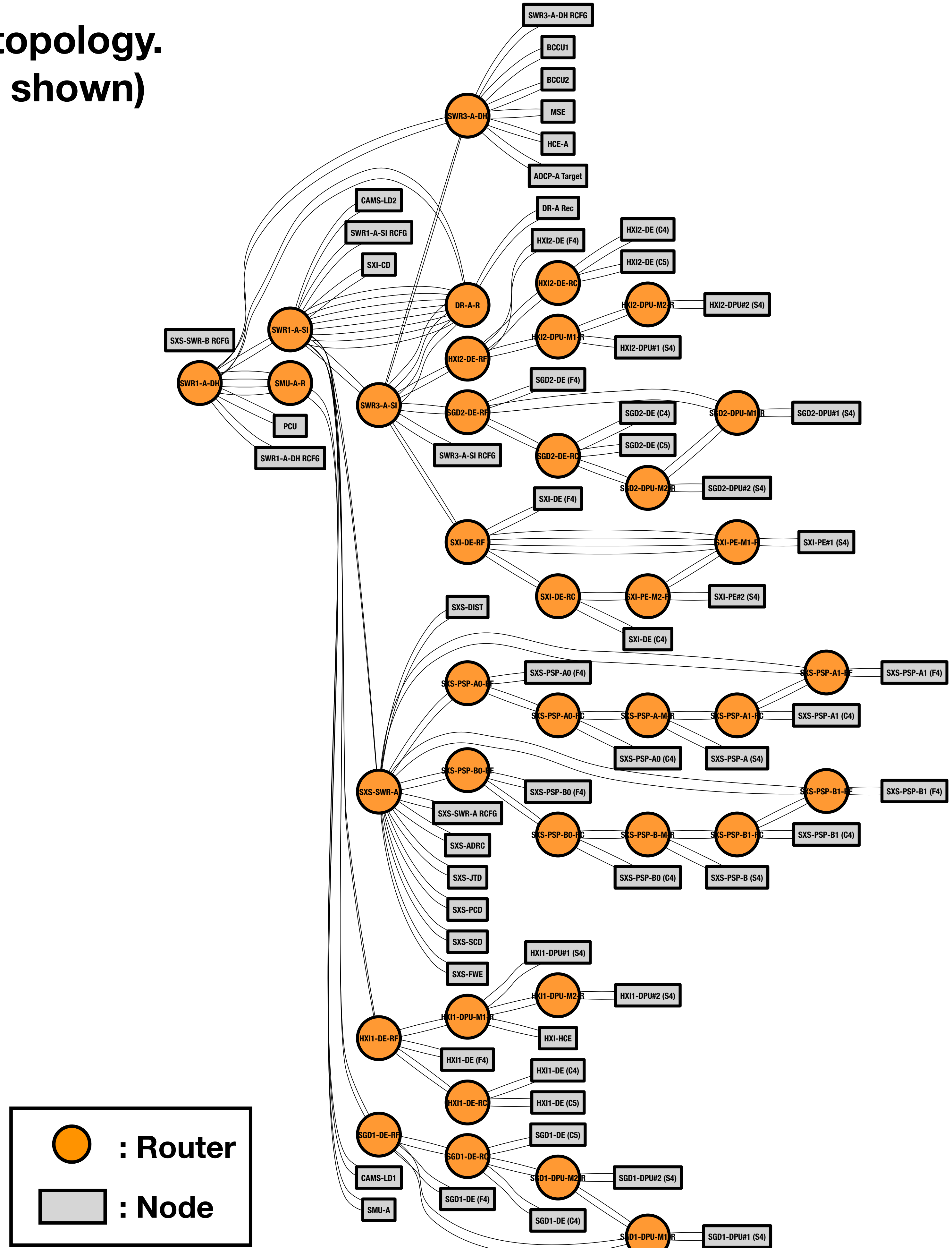

Link definition

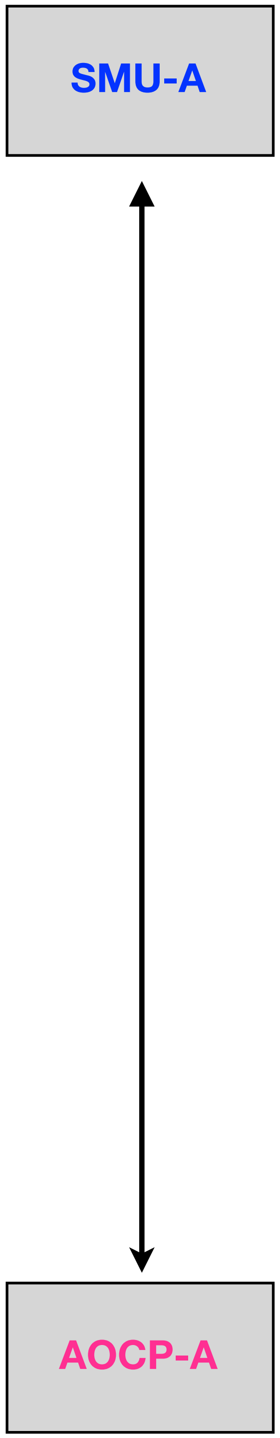


Example of ASTRO-H topology.
(redundant routers not shown)



Data Transfer Description in XML

- List of all data transfer occurring in a network:
- Initiator(source)/targets, packet type, packet length, redundancy, and frequency.
- Node IDs should be ones defined in the topology file.
- Used as an input to the scheduling tool.



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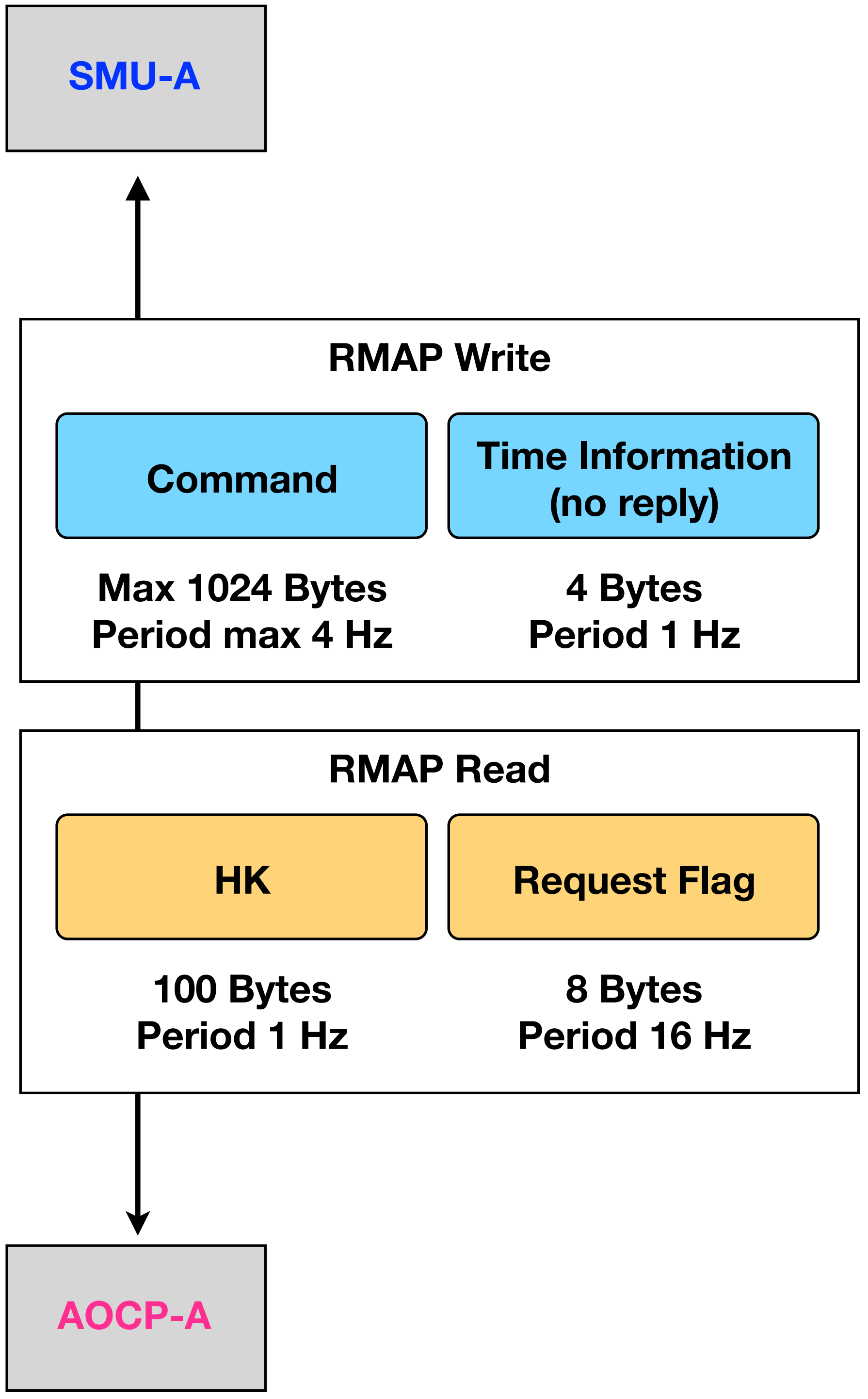

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- Initiator(source)/targets, packet type, packet length, redundancy, and frequency.
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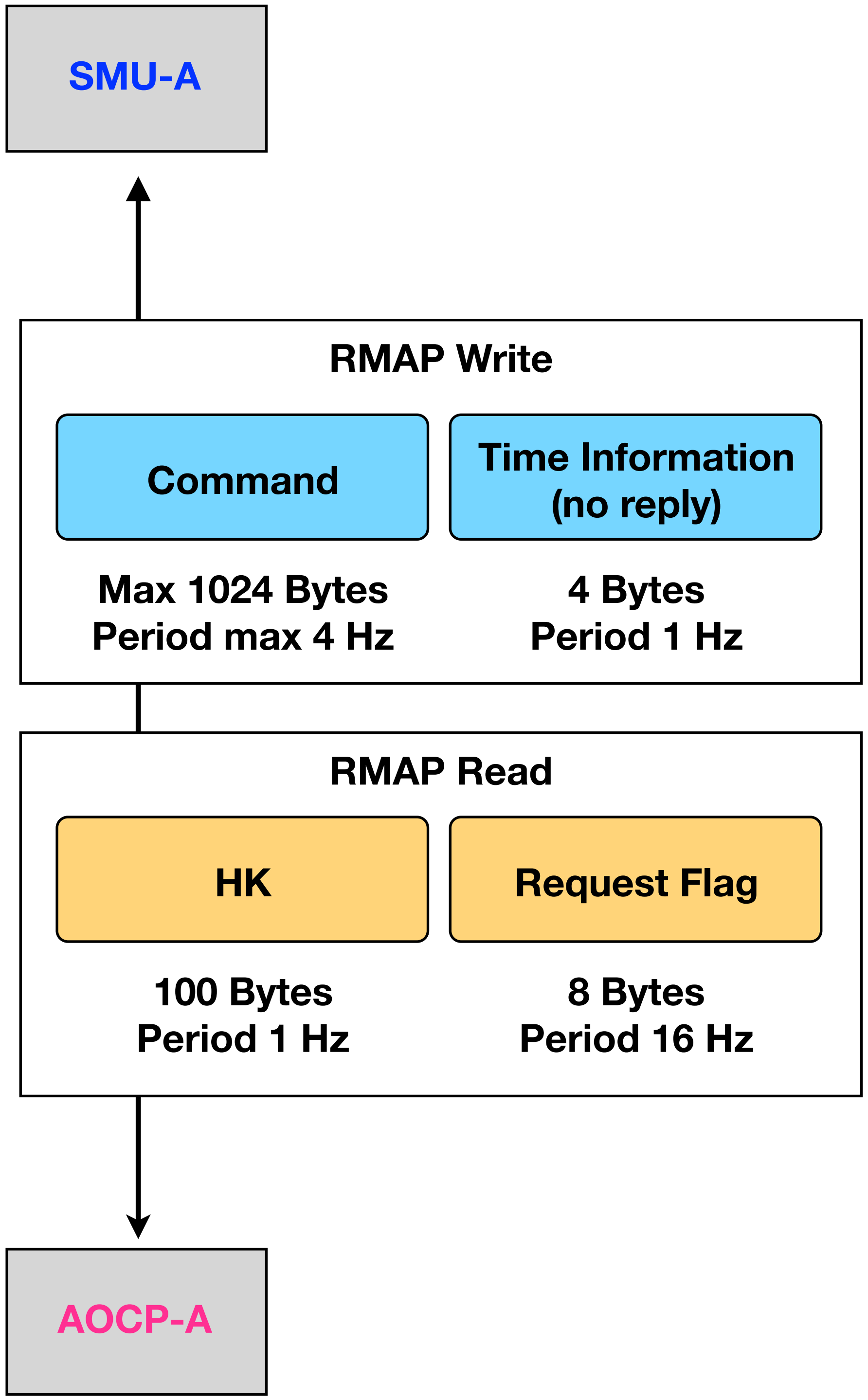
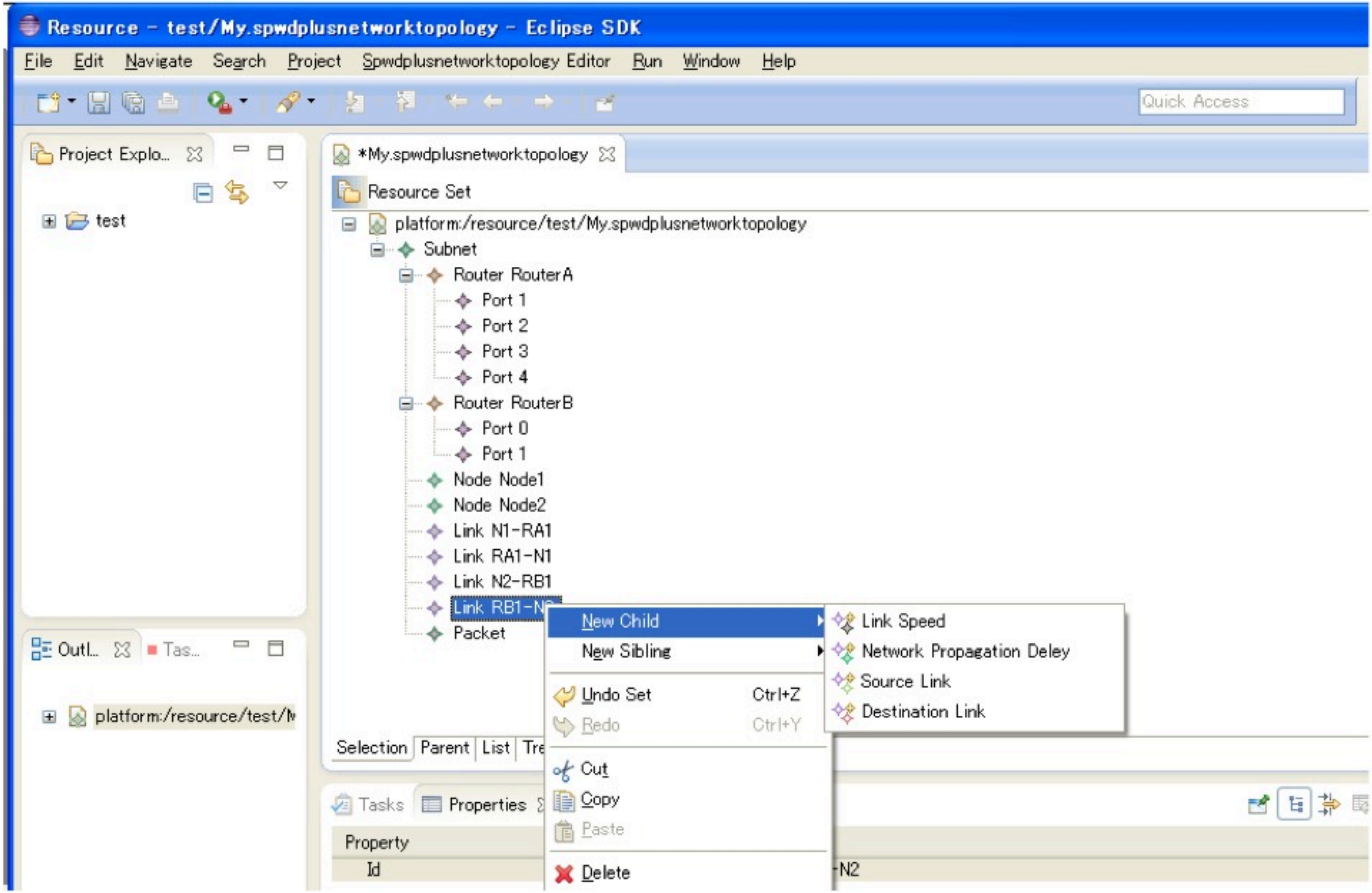
- Used as an input to the scheduling tool.

```xml
<SpaceWireChannelsInfo>
...
<Channel Id="SMU-A_AOCP-A">

    <Source Id="SMU-A"/>
    <Destination Id="AOCP-A" Redundancy="2"/>

    <Packet Id="Command_Write" Type="RMAP-W"
        Reply="True" Cargosize="1024" Period="16" />

    <Packet Id="TimeInformation_Write" Type="RMAP-W"
        Reply="False" Cargosize="4" Period="64" />

    <Packet Id="HK_Read" Type="RMAP-R"
        Reply="True" Cargosize="100" Period="64" />

    <Packet Id="RequestFlag_Read" Type="RMAP-R"
        Reply="True" Cargosize="8" Period="4" />

</Channel>
...
```



Eclipse XML editor will be available



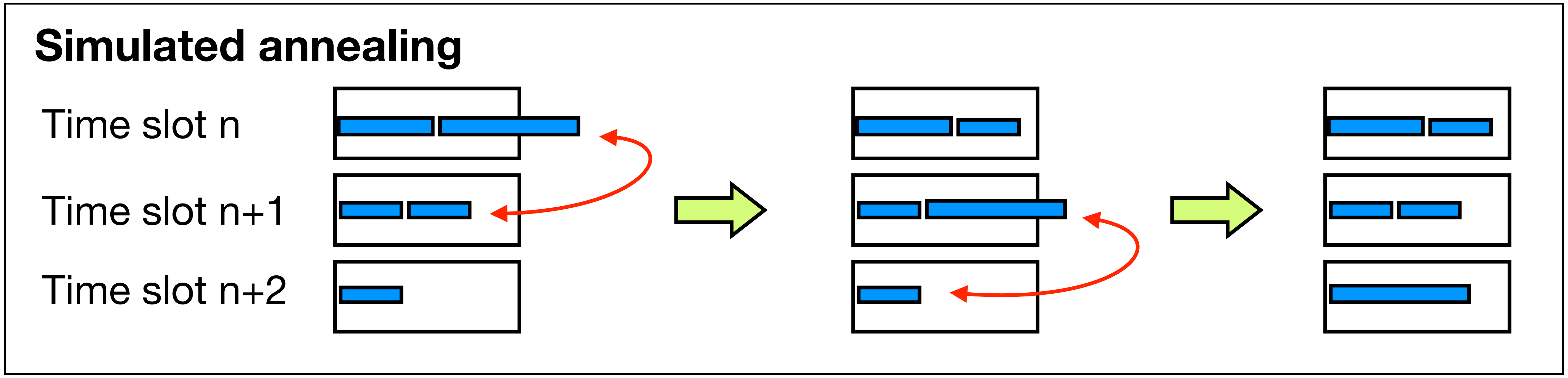
Algorithms

Path search

- Simple search over a tree starting from a source node to a destination node.

Scheduling algorithm

1. All packets are tentatively filled to time slots.
2. Maximum packet transfer latency is calculated for each packet.
3. If maximum latencies for all time slots are within time slot period (i.e. all packet transfer is contained within a time slot), allocation is completed.
4. When a certain time slot is over subscripted, *Simulated Annealing* method (random exchange of time slot allocation) is applied to minimize an evaluation function.
5. Return to 3.



(actual evaluation function:
see Chen+13 in SpW Conference for details

$$OF(S) = (N_{\phi} + 1)\sum_{J \in \phi_o} U_J^S + N_{\phi_u} + \prod_{I \in \phi_u} U_I^S$$
)

Implementation of scheduling algorithm

- A set of Python scripts.
- Practical calculation, e.g. on ASTRO-H network, completes within a few minutes.
- The tool outputs result as an XML file for each packet with:
    - Communication paths.
    - Allocated time slot.

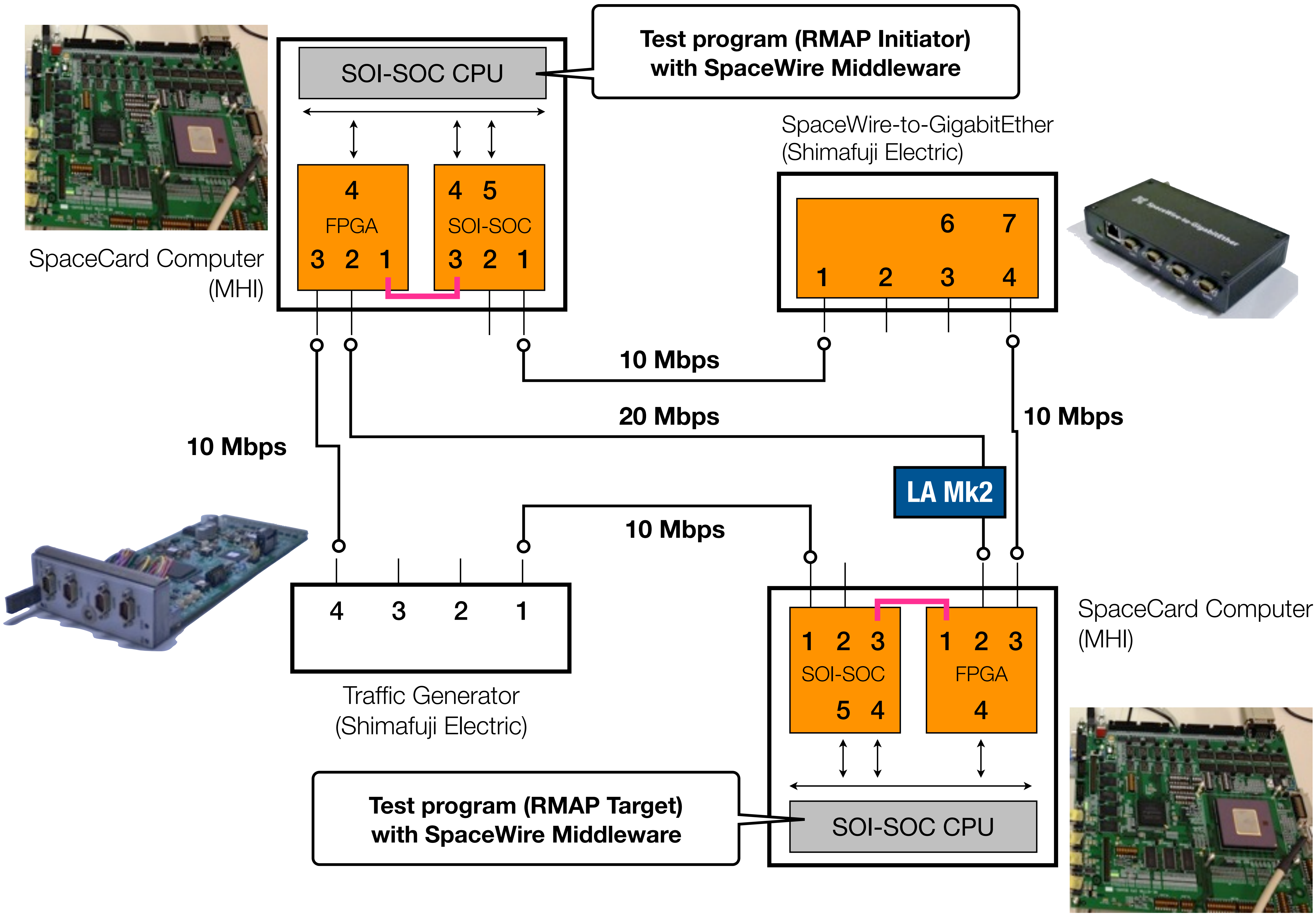
Example result of time-slot assignment

```
<SpaceWireChannelsInfo>
<Channel Id="SMU-A_AOCP-A">
    <Source Id="SMU-A" />
    <Destination Id="AOCP-A" Redundancy="2">
        <Path Id="SMU-A-AOCP-A">
            <Link Id="SMU-A-Port1-Router1-Port6" />
            <Link Id="Router1-Port6-AOCP-A-Port1" />
        </Path>
        ...
    </Destination>
...
    <Packet Cargosize="8" Id="RequestFlag_Read" Jitter="0"
       Period="4" Reply="true" ReplyInterval="0"
       Requirement="Constraint" Type="RMAP-R">
            <Timeslot Number="3" />
            <Timeslot Number="7" />
            <Timeslot Number="11" />
            <Timeslot Number="15" />
            <Timeslot Number="19" />
            ....
```

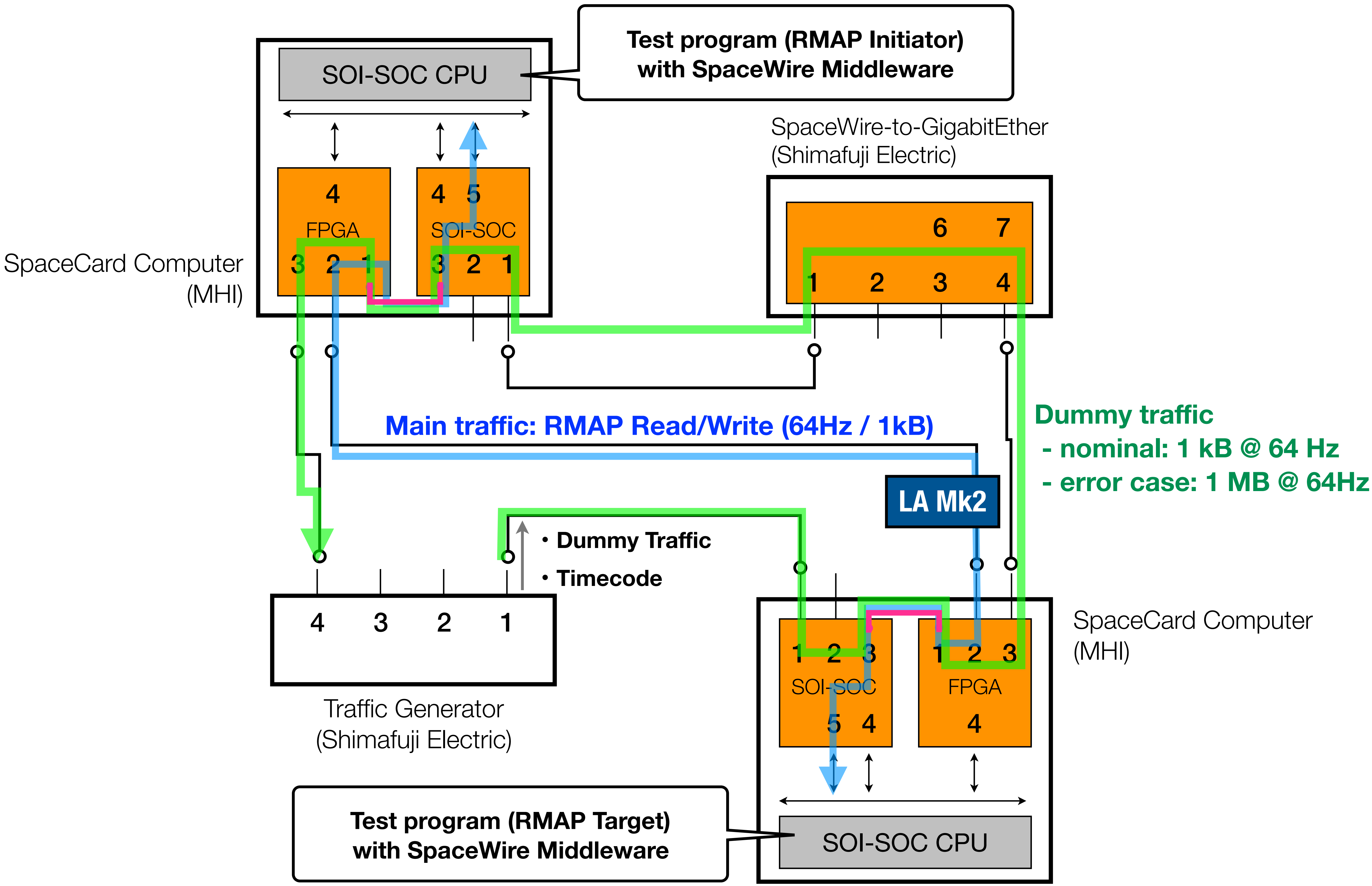
Possible paths from SMU-A to AOCP-A

Time slots that SMU-A can initiate an RMAP Read transaction to AOCP-A for “RequestFlag_Read”.

Demonstration - topology

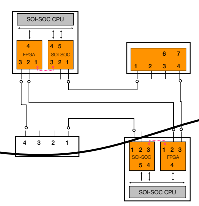


Demonstration - traffic



Demonstration - result

Network Topology



Data Transfer Description
64Hz / 1kB
+ Traffic Generator

Scheduling Tool (python script)

Path search algorithm

Time-slot assignment algorithm

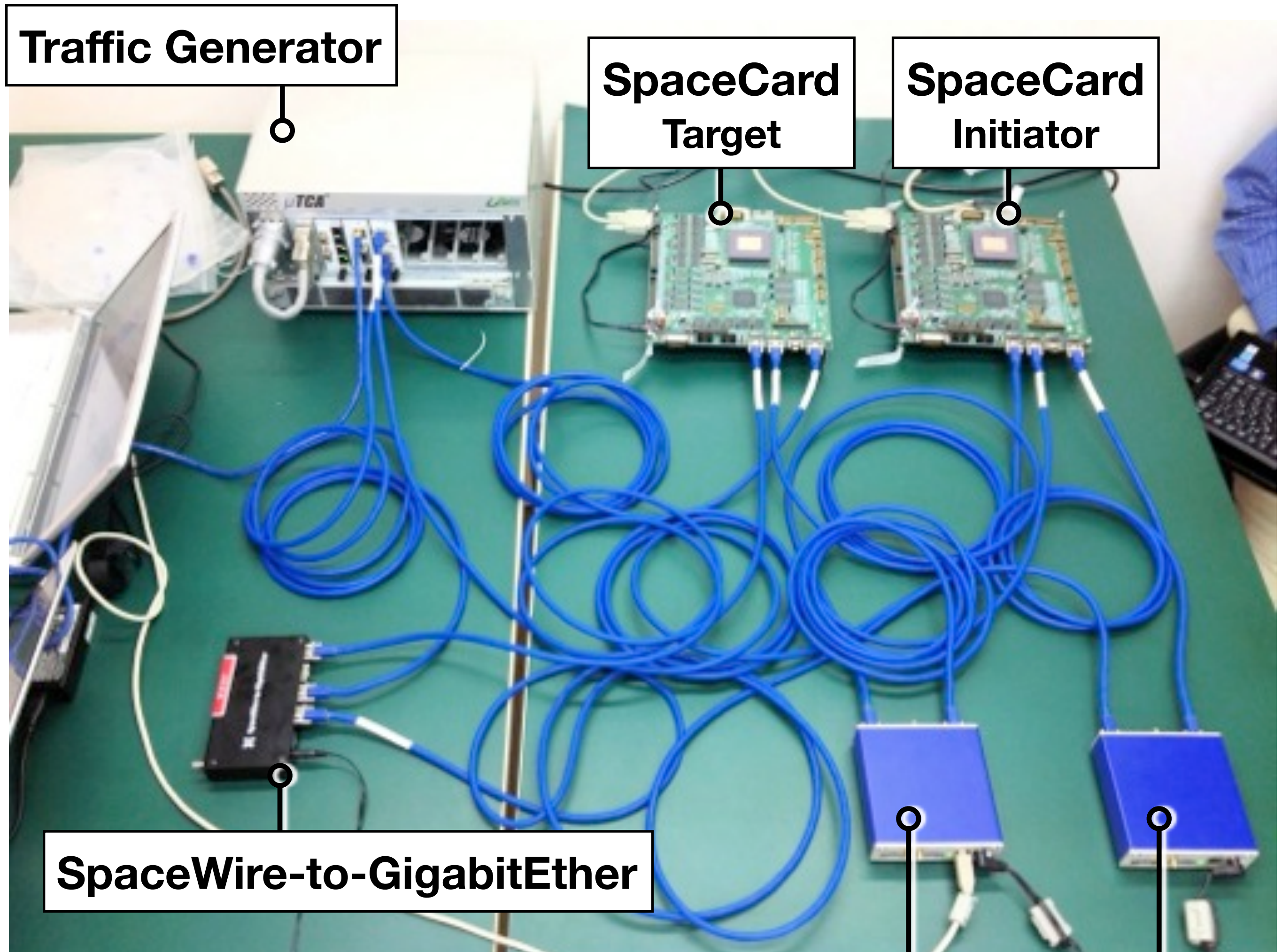
Schedule Table for all nodes

Schedule Table → Test Program (RMAP Initiator)

Schedule Table → Test Program (RMAP Target)

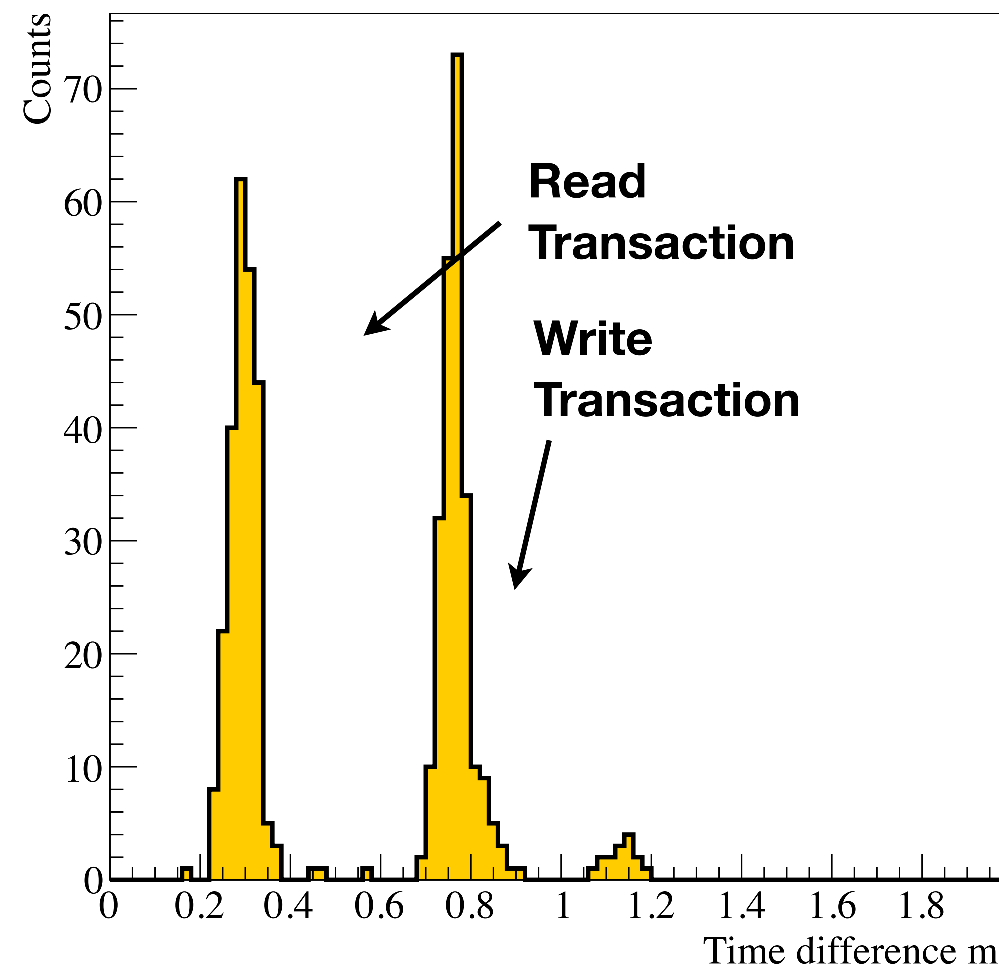
Separate for each node

Compilation with SpaceWire Middleware



March 2013
SpaceWire Test Center

Time difference between RMAP Command and Reply packets



- Packets were transferred in assigned time slots.
- Reply latency well below time-slot period (15.625ms)

Summary and near future plans

Summary

- JAXA-Nagoya U. joint R&D for deterministic SpaceWire network design guideline.
- Scheduling tool that could be also used in SpaceWire-D design.
- SpaceWire Middleware that supports SpaceWire-D.

Near future plans

- Publicly release the products (after coordination with JAXA IP office...)
  - Design guideline document
  - Scheduling tool
  - SpaceWire Middleware (C source code)
  - TOPPERS Realtime OS (C source code)

- Leon CPU support (Nagoya U.)
  - Porting TOPPERS RTOS and SpaceWire Middleware to LEON CPU.

- JAXA Design Guideline
  - JAXA-wide activity to standardize the guideline as one of JAXA Design Guideline series has been started.
  - Expecting use in earth observation/communication satellites not only in scientific satellites.

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