SPACEWIRE DRIVEN ARCHITECTURE FOR THE ASTRO-H SATELLITE

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Long Paper

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ABSTRACT

ASTRO-H is a very large scale and complicated spacecraft as a scientific mission. In order to realize the project with limited resources, SpaceWire is used as the information network base, and many elements such as the network architecture, standard nodes and ground support equipments have been designed. The design is adaptive for not only ASTRO-H but other missions: in JAXA, the small satellites project will use the common design architecture.

1 INTRODUCTION

ASTRO-H[1] is the 6th Japanese X-ray astronomy satellite, which is scheduled to be launched in 2014. The requirements for the satellite controlling units, such as of

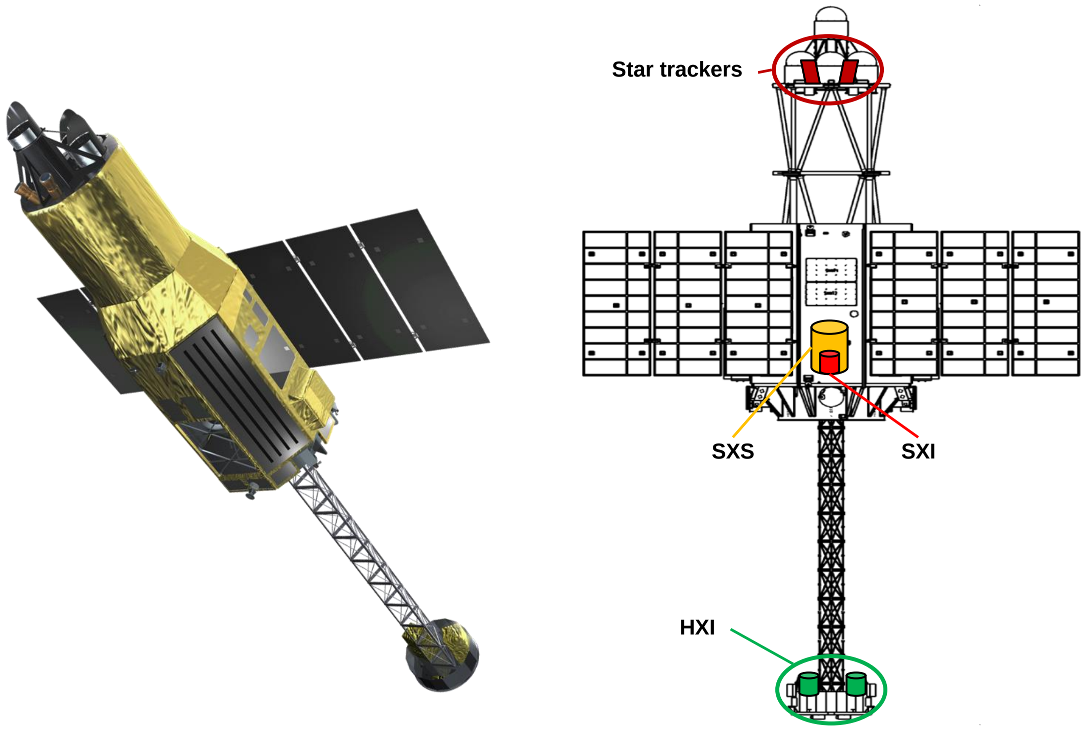

Figure 1: A CG image (left) and a schematic frame drawing (right) of the ASTRO-H satellite. The SpW network covers not only the main body but also the extendable optical bench (EOB) plate and the fixed optical bench (FOB) top plate.

system management, telemetry-and-command handling and attitude controlling, are more complicated than for past scientific satellites. In addition to this, the satellite carries 4 different kinds of scientific payloads, X-ray micro calorimeter (SXS), X-ray CCD camera (SXI), hard X-ray imaging spectrometer (HXI) and soft gamma-ray detector (SGD), each of which has different type of sensor and on-board data processing scheme from others. They make the satellite structure complex and force multiple companies to be deeply involved in the interface coordination, which usually introduces long negotiation, development and integration phases and lead the project to a cost-consuming way.

SpW[2] motivated us to define new system architecture to solve these problems, which is applicable not only to ASTRO-H but also to other projects. We thus build up a new standard that defines network protocol, router, the standard computer architecture and the standard I/O module, which are constructed on the SpW standards and can be implemented by multiple companies. In addition to them, we also defined a handling scheme of the CCSDS Space Packet on the network. In parallel to the standard definition process, we organized a SpW user community with other JAXA satellite projects, which works as the technical forum among the standard developers, component developers and users.

2 ON-BOARD ARCHITECTURE

The ASTRO-H information-exchange framework is wholly SpW base. This consists of the network, the data format and each component (i.e., SpW node).

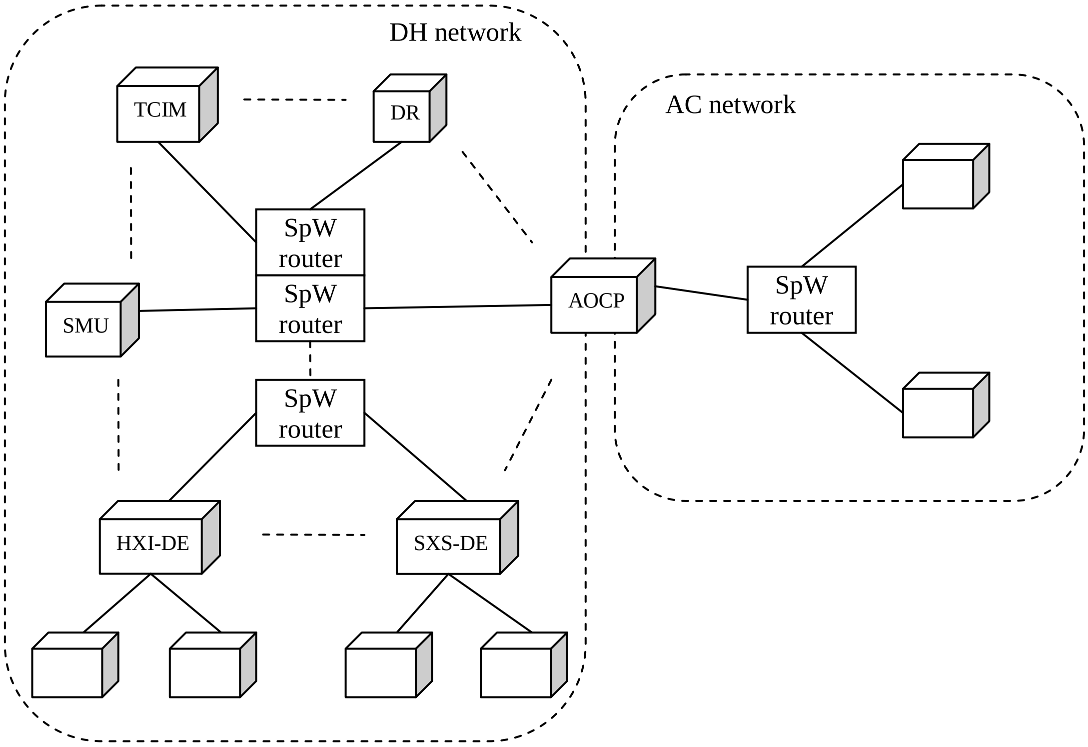

Figure 2: A schematic diagram of the physical network topology. There are two independent star topology networks.

2.1 REQUIREMENTS

The ASTRO-H observatory is expected to generate about 12Gb of data par day, which corresponds to about 140 kbps, which is not very large value for a modern data transfer line. This is, however, a result of on-board data reduction process, and the original data generation rate is 10-100 times larger than this. In order to handle the original data without any loss, the network must have a well-designed topology.

2.2 NETWORK

The SpW network covers whole the satellite, whose length is about 14 m on orbit and the core part shapes octagonal column inside which most of the components are attached. On the base panel inside the column, SXS, SXI and the fixed optical bench that supports the X-ray mirrors, the star trackers and the optical alignment system are settled. The extendable optical bench is attached at the backside of the base panel and supports HXIs. SGDs are placed at the outside of two panels. Figure 1 shows a schematic drawing of the satellite structure.

2.2.1 TOPOLOGY AND DIRECTION

The ASTRO-H SpW network consists of two physically-independent subnets: one is the DH (data handling) network that is controlled by the satellite management unit (SMU) and includes data recorders (DRs) and telecommunication components, and the other is the AC (attitude control) network that is controlled by the attitude and orbit control processor (AOCP). AOCP is also connected to the DH network, but no SpW packet, even TI packet, is forwarded between two networks. All the AC network components other than AOCP are sensors or actuators, and all the traffic in the

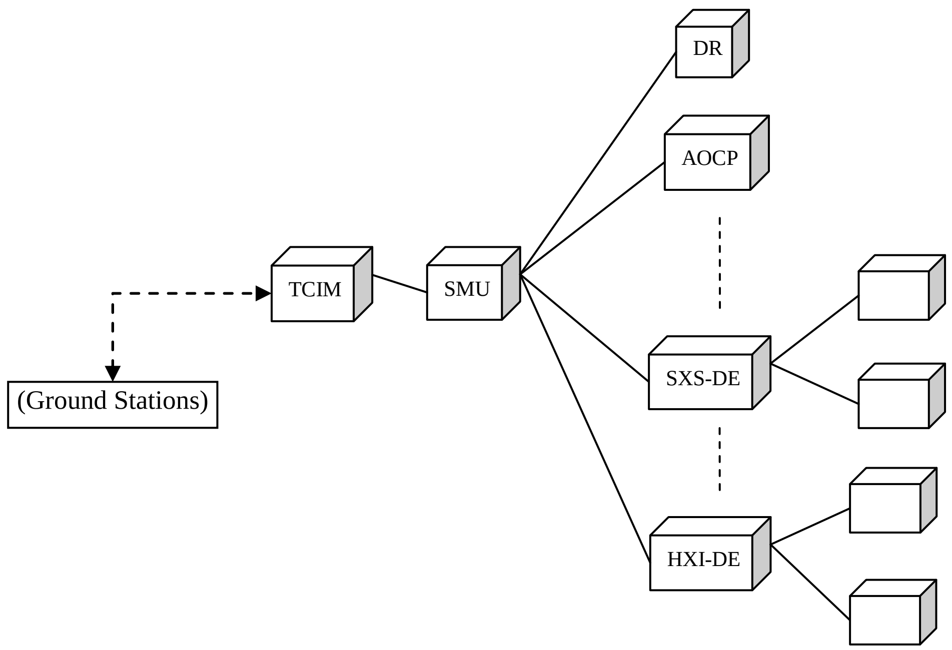

Figure 3: A schematic diagram of the logical topology of the DH network. The network has tree topology, and the communication is basically held between a parent and a child in normal operation.

network is initiated by AOCP. Figure 2 shows schematic diagram of physical network topology.

The components of each network are basically connected to the SpW routers that are based on the crossbar switch technology and form the physical networks of star topology: multiple SpW communication thus can be held simultaneously with no packet collision. All the SpW components are connected to two or more different SpW components or routers, and single failure of any connection can be substituted by an alternative path. The link speed from SpW routers and SMU is 25 MHz.

The logical structure of the ASTRO-H SpW network is, on the other hand, tree topology starting from the telemetry command interface module (TCIM), and all the SpW transaction are initiated from the root-side of the network. TCIM communicates with SMU, and SMU sends out all the commands to other components in normal operation. Most of the communication except for diagnostic or initialization ones are held between parent and child nodes and initiated from the parent: other kind of communication is physically possible, but forbidden except for ones between SMU and TCIM or DR and other components. The reason of the latter exception is that most of the telemetry data generated by payload instruments are not edited by SMU and can be transferred to the ground stations directly. Figure 3 shows schematic diagram of logical network topology.

All the traffic between SMU and other components in the DH network is thus initiated by SMU. The traffic is categorized into command and telemetry in the application layer: the former contents flow from SMU to other components, and it is natural that SMU initiate the transaction. The latter are, on the other hand, generated from other components in most cases. In order to transfer such contents, we chose the architecture that the destination side (SMU or DR) collects each component’s output with periodic polling by SMU.

2.2.2 Time code

The TI packet of the DH network is generated by SMU. SMU receives the reference clock and time information from a GPS receiver via an exclusive line and SpW, respectively. The TI packet frequency is 64 Hz.

2.3 Protocols

All the SpW communication inside ASTRO-H uses RMAP[3]. With this protocol, all the components can have network-transparent accessibility, which is quite useful for diagnostic and initialization not only in R&D phase but also even on orbit. The contents carried by the RMAP access is classified into two: Space Packets[4] and raw data.

2.3.1 CCSDS on RMAP

Commands to all the components and telemetry from major instruments such as scientific payloads are transferred as Space Packets on RMAP. All the command packets are sent out from SMU, and the telemetry packets are generated by multiple components. The latter ones are sent out to SMU or DR, and transferred to the ground stations at the end.

Each command packet is transferred by independent RMAP transaction. Multiple telemetry packets, on the other hand, can be transferred by one RMAP transaction.

2.3.2 PIM on SpW

In case of non-intelligent components that cannot generate Space Packets, the telemetry data are generated as raw binary data on the RMAP memory space. The memory map is based on that of the peripheral interface module (PIM) that has been used for previous Japanese scientific satellites[5]. The data are periodically read and assembled as Space Packets by SMU.

2.4 Components

As described in Section 1, the main motivation of introducing SpW to the ASTRO-H project is to make the satellite system as simple as possible. We accordingly developed several kinds of SpW devices that can handle not only the physical layer but also up to RMAP level. The largest component is SpaceCube, which is a computer architecture that can handle RMAP/SpW and work as a stand alone machine. Another group consists of embedded devices that bridge between components' internal bus and RMAP memory space: they cannot work without other devices such as memories or sensors, but make old architecture payloads as SpW components.

In all cases, the signal ground of all the SpW devices in all the components are connected to the satellite body explicitly because the LVDS devices, which are used in the physical layer of SpW, generally have low tolerance to over voltage on the I/O pins and it is essential to align the signal ground levels among all the SpW components.

2.4.1 SpaceCube

SpaceCube is a computer architecture for spacecraft information system, and has following features: (1) open architecture based on T-Engine, (2) SpW connection, (3) source-code level compatibility in the application layer between different implementation and (4) small, low mass, low power consumption and low cost by introducing recent results from commercial products. The original SpaceCube, which is sometimes called as SpaceCube1, is developed by Shimafuji and JAXA. The ASTRO-H on-board computers connected to the SpW network are its derivatives or successors, which are implemented by NEC and MHI independently.

2.4.2 Embedded RMAP Devices

For small components such as simple sensors or actuators, a CPU-based system such as SpaceCube is too complicated in most cases. In order to connect such components to the SpW network, we developed IPs that can be implemented in an FPGA and ASICs. They can handle not only SpW connection and network but also RMAP, and are embedded in many components, such as the power control unit and SpW I/O boards used for the scientific payloads. They are also implemented by multiple companies independently, as the SpaceCube computers do.

3 Supports for Development

As SpW is on the cutting edge of the spacecraft information technology, we are taking both technical and social approach to make use of it. Both are depending to each other and difficult to be separated clearly, but we can pick up some prominent cases: the ground support equipments (GSE) supplied by the system integrator and the user community.

3.1 GSE

As the spacecraft information system is not only an aggregation of communication channels but a highly organized system managed by SMU, a GSE that act as the network manager is essential for the payload instrument development. For this purpose, the satellite integrator (NEC) and JAXA are preparing two kinds of SMU simulators. The minimum simulator is called “SMU Sim Light” and has abilities to send out Space Packet commands, collect raw binary data from target components and receive Space Packet telemetry data. The simulator consists of a commercial grade SpaceCube computer, the on-board software and a PC that works as the console.

The full configuration simulator is called “SMU Sim”. This system contains whole the ground control system equivalent to that used for the real spacecraft control, and can emulate not only SMU but also the control system used in the integration test phase. The component developers thus can carry out interface tests in the development phase independently before the system integration test.

3.2 Community

In order to develop SpW based system, we formed a SpW user group in Japanese space community where the members share the basic knowledge such as the startup procedure of the SpW system development and a reference implementation of SpW and RMAP software on SpaceCube. The member is not limited to JAXA and aerospace companies, and the group works as a gateway to commercial base SpW instruments and ground-based applications.

The ASTRO-H SpW components are designed as adaptive for other missions. In ISAS/JAXA, the small satellites project is running in parallel to ASTRO-H, and many of the DH and AC network components will be used in that.

4 CONCLUSION

We are developing the ASTRO-H satellite with using the SpW technology as the main information framework, and many elements such as the network architecture and the standard components are designed. They will also used for other Japanese future scientific space missions.

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