High-performance Heterogeneous and Flexible Computing Architecture for Spacecraft Internet Protocol Communication and Payload Processing

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Overview

NASA and other space agencies have identified the need to improve the processing and communication capabilities onboard remote space platforms to support the complexity of future space exploration missions. Increasing amounts of collected data coupled with limited downlink speeds make the need to improve in-situ processing critical. In addition, both military and civilian space agencies have determined spacecraft flexibility is a key design strategy necessary to meet divergent mission objectives with minimal cost and risk. To address these needs, SEAKR has developed a flexible heterogeneous computing architecture for spacecraft that has been applied to several disperate missions including Internet Protocol (IP) routing and waveform processing for satellite communications and real-time image processing and compression for tactical missions. This presentation will provide an overview of SEAKR's heterogeneous architecture and describe missions in which the architecture has been deployed with an emphasis on system performance and fault tolerance.

IP-based Satellite Communications

Providing flexible satellite communications through frequency- and waveform-agile onboard processing is an emerging trend for missions such as the US Air Force's Operationally Responsive Space (ORS). Onboard data packet routing features that seek to improve network flexibility and performance by going beyond traditional "bent pipe" platforms are being leveraged to meet the objectives of ORS [1]. SEAKR Engineering's Programmable Space Internet Protocol Modem (PSIM) is an integral part of the Cisco Space Router on the Intelsat 14 spacecraft as part of the Internet Routing in Space (IRIS) Joint Capabilities Technology Demonstration (JCTD) with the US Department of Defense set to launch September 2009. The PSIM provides data processing for interfacing to existing ground terminal waveforms and recovers the datagrams for on-board routing. Component interfaces include a standard Layer-2 Gigabit Ethernet and a modified Layer-1 physical interface that is radiation-tolerant for the mission's 10-year geosynchronous orbit. The PSIM mission seeks to extend Internet communication capability to users who are currently "off the grid" in remote areas where extending landline connectivity is cost prohibitive.

PSIM Architecture

The first-generation PSIM payload provides increased performance and flexibility beyond currently deployed space-based IP-centric systems by routing onboard all signals captured between all of the bands and beams. The platform is composed of two enclosures that include the PSIM and the Space IP Router (SIPR). Signals from the C-band and the two Ku-band antennas are routed to the PSIM which manages physical interconnectivity within the system for all bi-directional waveform and intra-spacecraft links.

The architecture supports flexible processing by coupling compute-intensive FPGAs with a powerful PowerPC-based general-purpose processor. This adaptable architecture provides flexibility when tailoring the system design to meet the needs of various missions and allows for in-situ reconfigurability to vastly improve system fault tolerance. The PSIM flight configuration is shown in Figure 1. Waveform processing is performed on the FPGA modules and each module does so in a triple-redundant, majority voted fashion. Space-qualified Gigabit Ethernet interconnects the SIPR and PSIM components and the PowerPC single board computer (SBC) manages this interconnection among other tasks.

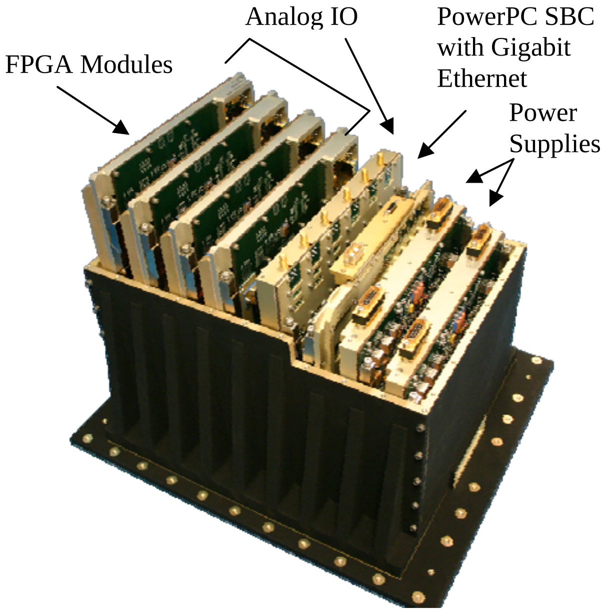

Figure 1: PSIM Flight Module.

IP-enabled Payload Interconnect Architecture

While the PSIM has been designed to support IP-enabled satellite communications, a synergistic technology being developed at SEAKR Engineering seeks to translate legacy satellite component interconnects to Gigabit Ethernet, and used in combination with the PSIM, could greatly improve spacecraft component interconnect performance and scalability. Spacecraft device interconnects have traditionally included a mixture of custom or aerospace-specific standards that make system integration and test challenging. As the variety and performance requirements of sensors and related components increases, it will become

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increasingly difficult to find space-qualified components that both meet mission objectives and can be readily interconnected.

IP and related communication protocols have become the de facto standard for terrestrial networking systems and leveraging the success of decades of commercial development for use in aerospace systems has the potential to reduce development costs while improving system performance. The Reprogrammable Space Network Interface Controller (RSNIC) is a Naval Research Lab funded project to build the infrastructure to provide IP datagram connectivity between components within the spacecraft to reduce system integration costs. RSNIC primarily performs IP encapsulation of data transferred between instruments, onboard processors and solid-state recorders [2]. RSNIC strips off or adds the IP packetization of command data destined for onboard systems. RSNIC endpoints are modular and customizable interface cards that couple FPGA and general-purpose processors to allow new and existing payloads to easily integrate within the IP-based interconnect as provided by PSIM and shown in Figure 2.

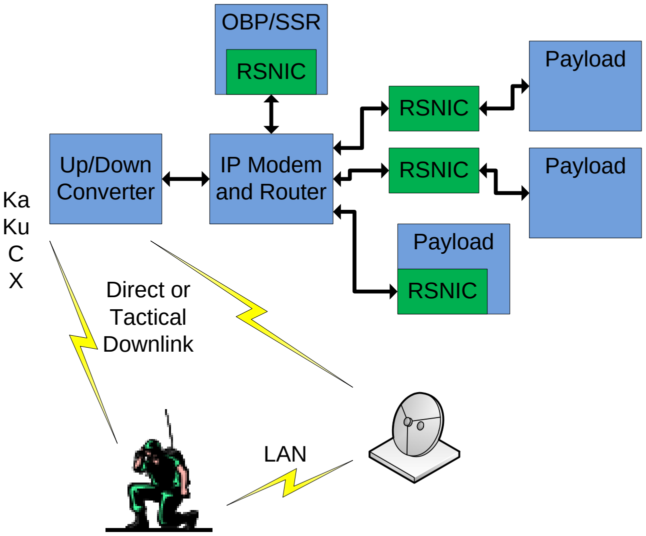

Figure 2: Example RSNIC and PSIM Enhanced Mission.

Real-time Imaging through ARTEMIS

The Hyperspectral Imaging (HSI) payload onboard TacSat-3 consists of a telescope, an imaging spectrometer, and a high resolution imager that combine to produce raw high resolution images. HSI allows for spectral match indication and identification which provides anomaly detection within a given scene that allows the warfighter to distinguish man-made materials from natural materials among other benefits as shown in Figure 3. The payload unit on TacSat-3 is known as the Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS). A fundamental capability of the ARTEMIS payload is to autonomously process HSI data and produce tactically relevant data for dissemination directly to the warfighter in the form of text or imagery as the situation requires. The HSI data collected from the sensor is processed by a SEAKR designed and developed sensor processor based on SEAKR's flexible and heterogeneous processing architecture previously described [3].

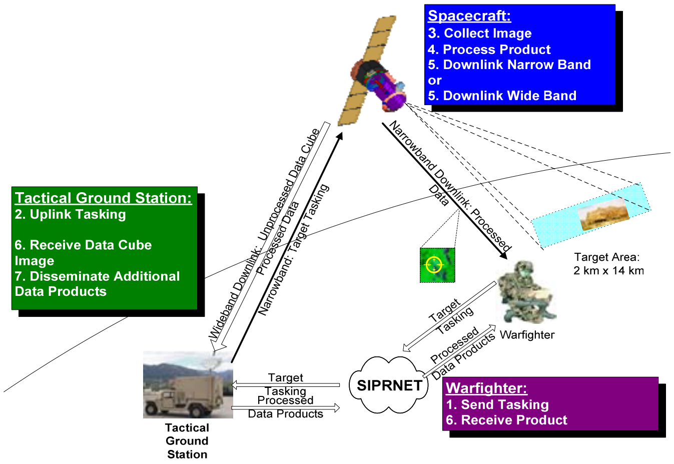

Figure 3: TacSat-3 HSI Mission Summary.

ARTEMIS provides a foundation for high-performance and flexible payload system design that meets the TacSat development program's responsive space objectives. An innovative aspect used to control cost and schedule is to decouple payload processing capabilities from the spacecraft sensors. The ARTEMIS processor employs mezzanine connectors with flexible hardware interfacing to connect sensors to processing resources. This flexibility allows the payload to be deployed on divergent spacecraft architectures and support numerous sensors by only re-spinning the interface card. Also, decoupling processor and sensor allows for a smooth transition when future versions of the processing or sensor boards are developed. Such flexibility will allow future missions to quickly augment sensors and processing capabilities around the core payload architecture deployed on TacSat-3. The ARTEMIS payload processor is a key technology that enables the responsive space mission and is actively being investigated for additional missions. The TacSat-3 spacecraft was successfully launched on May 19, 2009.

Conclusions

SEAKR Engineering has developed a flexible heterogeneous computing architecture for spacecraft that has been applied to several diverse missions from onboard Internet Protocol (IP) routing and waveform processing for satellite communications to real-time image processing and compression for tactical missions. This presentation will provide an overview of SEAKR's heterogeneous architecture and will emphasize the system's performance capability and fault tolerance considerations over several distinct missions.

References

[1] W. Buerkle, M. Trefz, "Fast-Packet vs. Circuit Switch and Bent Pipe Satellite Network Architectures," *Proc. Ka-Band Utilization Conf.*, Sorrento, Italy, Sept. 15-18, 1997.

[2] I. Troxel, M. Fehringer, and P. Murray, "Unifying Spacecraft Payload Interconnects Using the Reprogrammable Space Network Interface Controller," *Proc. Military and Aerospace Programmable Logic Devices (MAPLD) Conference*, Annapolis, MD, September 15-18, 2008.

[3] I. Troxel, M. Fehringer, and M. Chenoweth, "Achieving Multipurpose Space Imaging with the ARTEMIS Reconfigurable Payload Processor," *Proc. Aerospace Conference*, Big Sky, MT, March 1-8, 2008.