Towards a Unified, Scalable, and Highly Capable Next Generation Avionics Interconnect: The NEXUS Approach

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Outline

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• Objectives
• NEXUS Technology
• NEXUS Testbed: Hardware and Software
• An Standardization Effort
• Summary
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Motivations

So, why are we here?

And what should we do in the future?

- High-speed instruments of a Gbps-bandwidth
  - SARs and hyper-spectrometers;
- On-board multi-core computing paradigm;
- Guaranteed real-time determinism with sub-microsecond latency/jitter for tight control loops;
- Fractionated spacecraft and sample return missions that requires separability and scalability
- More suitable physical layer technology such as wireless and fiber optics.
Objectives

- **NEXUS (NEXt bUS)**
  - A research task funded by JPL R&TD program
  - Develop a common highly-capable, highly-scalable next generation avionics interconnect with the following features:
    - Transparently compatible with wired, fiber-optic, and RF physical layers
    - Scalable fault tolerant (sub-microsecond detection/recovery latency)
    - Scalable bandwidth from 1 Kbps to 10 Gbps
    - Guaranteed real-time determinism with sub-microsecond latency/jitter
    - 20% - 50% wire mass reduction
    - Low power (< 100mW per Gbps)
    - Light-weight (< 5000 logic gate footprint)
    - A clear and feasible path-to-flight to ensure infusion into future NASA/JPL missions
1. Survey past, current, and future space missions
2. Develop a set of spacecraft avionics interconnect requirements
3. Assess the state-of-the-art existing protocols with respect to the developed requirements and decide the design approach
4. Develop the NEXUS protocol specification
5. Design and Implement the NEXUS protocol
Survey Findings

• 15 past, current, and future space missions were surveyed with respect to its interconnect requirements

• Key findings
  – Aggregate bandwidth is orders of magnitude greater than traditional avionics “backbone” buses such as 1553B
  – Instrument are the biggest drivers on bandwidth, and are expected to be even more so in the future
  – Missions with complex operation scenarios are big drivers in C&DH and ACS
  – Need to accommodate physical separation events is a large driver for many future S/Cs
  – Hybrid ad-hoc solutions lead to a overwhelming interconnect maze that complicates design, integration, and testing, and increase wire mass and power consumption
  – Instruments requiring coordinated precision is the biggest driver in real-time performance
NEXUS Requirements

- A detailed set of 94 NEXUS desirements has been developed and reviewed
- It is divided into 20 categories

<table>
<thead>
<tr>
<th>No.</th>
<th>Requirement Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Physical Layer Compatibility</td>
</tr>
<tr>
<td>2.0</td>
<td>Operational Mode</td>
</tr>
<tr>
<td>3.0</td>
<td>Protocol</td>
</tr>
<tr>
<td>4.0</td>
<td>Topology</td>
</tr>
<tr>
<td>5.0</td>
<td>Scalability</td>
</tr>
<tr>
<td>6.0</td>
<td>Reconfiguration</td>
</tr>
<tr>
<td>7.0</td>
<td>Modularity</td>
</tr>
<tr>
<td>8.0</td>
<td>Commercial Standard Compatibility</td>
</tr>
<tr>
<td>9.0</td>
<td>Legacy System Compatibility</td>
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<tr>
<td>10.0</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>11.0</td>
<td>Real-Time Operation and Control</td>
</tr>
<tr>
<td>12.0</td>
<td>Fault Tolerance Level</td>
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<td>13.0</td>
<td>Fault Detection</td>
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<td>Fault Response</td>
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<tr>
<td>15.0</td>
<td>Testability</td>
</tr>
<tr>
<td>16.0</td>
<td>Electrical Isolation</td>
</tr>
<tr>
<td>17.0</td>
<td>Power/Bandwidth Management</td>
</tr>
<tr>
<td>18.0</td>
<td>Radiation Level</td>
</tr>
<tr>
<td>19.0</td>
<td>EMI Sensitivity</td>
</tr>
<tr>
<td>20.0</td>
<td>Temp Range Op &amp; Non-Op</td>
</tr>
</tbody>
</table>

Notes:

1. The categories are listed from high-level to low-level; i.e., from generic to specific

2. The ordering does not reflect the importance of the categories
NEXUS Architecture

NEXUS – next generation avionics bus
- High bandwidth: 1 to 10 Gbps
- Low Latency: 1 to 10 us
- Low Jitter: < 100 ns
- Guaranteed determinism
- Scalable and inherent fault tolerance
- Parallel traffic classes of different QoS levels

NEXUS-SYS (System Layer)

NEXUS-NET (Network Layer)

NEXUS-PA (Physical Abstraction Layer)

Wired Copper PHY  Wireless PHY  Wired Fiber Optical PHY
Protocol Survey

• An evaluation matrix was developed based on the requirements
• 13 commercial and avionics protocols were assessed against the evaluation matrix
• 13 protocols were down-selected to four protocols
  – tt-GbE
  – Ring Bus
  – SpaceWire
  – Serial RapidIO
• A depth assessment was conducted and the final working baseline protocol was chosen
  – Serial RapidIO
Key Driving Differentiators

• Serial RapidIO has the following salient features among four protocols:
  – Transparent compatibility with wired and fiber-optic
  – Applicable to chip-to-chip, board-to-board, and box-to-box
  – Light-weight and modular (features are configurable)
  – Low power with less than 192 mW per node
  – Scalable fault tolerance with link-level error detection
  – Scalable bandwidth up to 3.125 Gbps per lane
  – Real-time with sub-microsecond latency and jitter
  – Switch-based flexible topology
  – Built-in shared-memory support with low S/W overhead
  – Embedded provisions allow backward-compatible protocol extension
Key Enhancements for Serial RapidIO

• Enhancements are being made by exploiting existing SRIO provisions without breaking backward compatibility
  – Guaranteed real-time determinism
  – Complete testability using in-band maintenance packets
  – Reduced bandwidth of 1 kbps using slow clock
  – Links with hybrid bandwidths within a network
  – Scalable fault tolerance level
  – Multiple power operational modes
• NEXUS Bus Interface Units (BIU)
  – Can be integrated into 4 types of NEXUS nodes in terms of front end types
    • C-Node: Interfaces with the flight computer
    • I-Node: Interfaces with instrument detector (camera, radar ADC boards, etc)
    • S-Node: Interfaces with storage disk array
    • M-Node: Interfaces with any other types of front end
  – Is capable of providing scalability of performance/power consumption
  – Can serve as design templates as reference design
NEXUS Hardware Testbed - BIU

- NEXUS BIU
  - Developed the NEXUS BIU based on Xilinx Serial RapidIO IP core
### NEXUS Hardware Testbed - Configurations

<table>
<thead>
<tr>
<th>HW Testbed</th>
<th>Testbed 1</th>
<th>Testbed 2</th>
<th>Testbed 3</th>
<th>Testbed 4</th>
<th>Testbed 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Nodes</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Topology</td>
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<td>Switch-based</td>
<td>Switched</td>
<td>Point-to-point</td>
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<td>Components</td>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Endpoints + Switch</td>
<td>Endpoints + Switch</td>
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<td>Chipscope</td>
<td>Chipscope</td>
<td>RapidFET</td>
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<tr>
<td>PHY</td>
<td>Copper</td>
<td></td>
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<td>Fiber</td>
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</table>

![Testbed Images]

![Hologram Images]

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**NEXUS – 2011 ReSpace/MAPLD Conference**
NEXUS Software Testbed

- Based on a sophisticated modeling and simulation tool VisualSim by Mirabilis Design, Inc
- Allow implementation and evaluation of identified enhancements
Next Generation Spacecraft Interconnect Standard

- A next generation spacecraft interconnect standardization organization is formed
- It consists of representatives from USAF, NASA, NRO and other space agencies
- It will also include representatives from stakeholders in government, industry and academia.
- Currently it is a Working Group (WG) under the Computer Systems Technical Committee in AIAA
Summary

• A unified interconnect such as NEXUS can be used to meet performance, power, size, reliability requirements of all ranges of equipment/sensors/actuators at chip-to-chip, board-to-board, box-to-box boundary.

• It is designed in a modular and configurable fashion under a common interconnect standard and is used via adaptation.

• Serial RapidIO provides a viable baseline.
Acknowledgement

• JPL Colleagues

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