Integrating Gen-Z with RISC-V

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The Motivation for a Gen-Z Fabric
Compute-Memory Balance is Degrading

Normalized Properties of Typical Server Processors

Processor memory and I/O technologies are being stretched to their limits
The Motivation for a Gen-Z Fabric
Memory and Storage are Converging

Memory Operations (Byte Addressable)
- Processor 1ns
- SRAM 5ns
- DRAM 100ns
- SCM

Block Operations (Rich Data Services)
- Flash 200,000ns
- Hard Disk 10,000,000ns
- Tape 40,000,000ns

With memory/storage convergence, memory semantic operations become predominant (volatile & non-volatile)

Byte-addressable persistent memory delivered using DRAM + Flash or SCM
The Solution: Scalable Memory Fabric – Gen-Z!

- **High Performance**
  - Very high bandwidth (16 GT/s to 112 GT/s signaling), low latency
  - Delivers 32 GB/s to 400+ GB/s per memory module

- **Reliable**
  - Flattens memory / storage hierarchy w/integrated resiliency, multipath, aggregation, etc.
  - No stranded resources or single-point-of-failures

- **Secure**
  - Provides strong hardware-enforced isolation and security

- **Flexible**
  - Multiple topologies, component types, etc.
  - Supports legacy and new high-capacity form factors. Multiple media types can be physically co-located.
  - Scales from co-packaged to single motherboard to rack-scale

- **Compatible**
  - Use existing physical layers, unmodified OS support

- **Futuristic**
  - Breaks processor-memory interlock enabling innovative solutions.
  - Built from the “ground up” to support persistent memory semantics
So What’s an Example of How Gen-Z Helps Us?

- Media specific logic integrated into memory module
- Tight coupling of SoC and memory technology evolution
- Limits the types of memory that can be supported

Gen-Z Memory Interconnect

- Media specific logic integrated into memory module
- Independent SoC and memory technology evolution
- Accelerates innovation, enables variety of memory support

Traditional

- SoC & memory are in generational lock-step
- Limited memory types
## Gen-Z + DDR: High Bandwidth

<table>
<thead>
<tr>
<th>Gen-Z Signaling Rate</th>
<th>Gen-Z</th>
<th>8 DDR 6400 Channels</th>
<th>Aggregate Memory Application Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 GT/s 64 Tx / Rx Lanes</td>
<td>320 GB/s</td>
<td>400 GB/s</td>
<td>720 GB/s</td>
</tr>
<tr>
<td>25 GT/s 128 Tx / Rx Lanes</td>
<td>640 GB/s</td>
<td>400 GB/s</td>
<td>1.04 TB/s</td>
</tr>
<tr>
<td>32 GT/s 64 Tx / Rx Lanes</td>
<td>400 GB/s</td>
<td>400 GB/s</td>
<td>800 GB/s</td>
</tr>
<tr>
<td>32 GT/s 128 Tx / Rx Lanes</td>
<td>800 GB/s</td>
<td>400 GB/s</td>
<td>1.2 TB/s</td>
</tr>
<tr>
<td>56 GT/s 64 Tx / Rx Lanes</td>
<td>700 GB/s</td>
<td>400 GB/s</td>
<td>1.1 TB/s</td>
</tr>
<tr>
<td>56 GT/s 128 Tx / Rx Lanes</td>
<td>1.4 TB/s</td>
<td>400 GB/s</td>
<td>1.8 TB/s</td>
</tr>
<tr>
<td>112 GT/s 64 Tx / Rx Lanes</td>
<td>1.4 TB/s</td>
<td>400 GB/s</td>
<td>1.8 TB/s</td>
</tr>
<tr>
<td>112 GT/s 128 Tx / Rx Lanes</td>
<td>2.8 TB/s</td>
<td>400 GB/s</td>
<td>3.2 TB/s</td>
</tr>
</tbody>
</table>
Network addressing
16-bit subnet IDs + 12-bit component IDs + [64-bit memory address]
A theoretical maximum of $2^{28}$ (~268M) components
Memory-semantic datagram packets independent of fabric scale
No performance degradation to communicate across subnets
Does not require multiple component IDs to support multipath
Flexible destination and packet relay tables to support nearly any routing topology

Advanced Operations
Multiple buffer put / get variations
Collectives + Collective Acceleration
Signaled writes / Write MSG (send) with Receive Tags and Embedded Read

Virtual Channels
32 VCs
Remove cyclic resource dependencies for routing deadlock avoidance.
Reduce head-of-line blocking and / or cross path blocking.
Segregate traffic classes for performance isolation.
VC remapping to support components with different number of VCs

Packet Injection / Relay
Robust congestion management with automatic packet injection rate
Common source node adaptive / dispersive packet injection and switch adaptive / dispersive packet relay

Traffic Classes
Set of VCs for user-defined purposes
Performance within a TC is not affected by other TCs, e.g., TCs separate:
  – Latency Sensitive (e.g., SHMEM)
  – Bandwidth Sensitive (e.g., check point)
  – Noise Sensitive (e.g., collectives)
  – High-priority Applications

Multi-plane Support
All planes can be co-packaged within a single switch
A single cable can be used to connect to all planes
A single interface can be drive all planes
Adaptive / dispersive routing enables load balancing, resiliency, etc.

Low-latency FEC
2 ns per link hop
Gen-Z : A RISC-V should take
What RISC-V should do to take advantage of Gen-Z

– Should support Gen-Z in addition to DDR natively to differentiate from processors supporting only DDR natively.

– Should support 52 bit physical addressing.

– Cache Management Challenges (Support for Memory consistency models across fabric)

– Should support a minimum of 64 Gen-Z lanes of the PCIe Phy at 32 GT/s.

– Should support a minimum of 1K outstanding transactions on the coherency interface to support inherent SCM media latencies.

– Memory Mapping using ZMMU for Gen-Z

– LPD Support for PCIe compatibility

– Implement Far Atomics

– Take advantage of Gen-Z Security Features

– Protection/Translation architecture for a secure fabric
ZMMU Implementation: Page-Grid based ZMMU

- Gen-Z supports Page-table based ZMMU and Page-grid based ZMMU
- A Page Table-based ZMMU is analogous to a processor page table MMU.
- A page-table based ZMMU should be integrated into processor MMU or page table caching should be implemented for performance reasons.
- Recommend RISC-V to use page grid not page table technology as it is simpler and easier to integrate compared to trying to integrate into a SMMU
Gen-Z : Trust and Security

- Multiple Access Control Techniques including:
  - Access Keys (component group level access)
  - Access Request and Access Response (fine-grain component-level access)
  - R-Keys (page-level access control)
  - R-Key Domains (Requester R-Key filtering)
  - Switch Packet Filtering (control plane, leaf component)
  - Peer Component Authorization (whitelist)
  - Peer Nonce to detect rogue component insertion while in low-power state
- Packet authentication with Anti-replay Tags
  - Hashed Message Authentication Code (HMAC)
  - Uses transaction integrity key (TIK)
    - Only devices sharing TIK can communicate
- Packets dropped due to authentication violations
  - Configurable interface / component containment
- Violations reported to management
- Currently, developing new component authentication, page-level encryption, and data authentication

• **RISC-V could add capabilities support to augment Gen-Z security features.**
• **Recommend RISC-V add a trust zone like capability to build on what Gen-Z enables to provide more page level security** (Who configures the ZMMU – do you trust the node?)
Gen-Z : I/O with PCIe compatibility

Gen-Z Logical PCI Devices (LPDs)

- Gen-Z devices can be discovered/configured
  - Via standard PCI / PCIe system software
- LPDs can fully exploit Gen-Z Architecture
  - Low-latency switching
    - Gen-Z 30 ns vs. PCIe 130-150 ns translates to 200-240 ns savings per read operation
  - Memory-speed CPU-to-device communication
  - Security and fine-grain hardware-enforced isolation (any-to-any communication without compromise)
  - Supports all x86 / ARM / Power architecture Atomics
  - Simplified single and multi-host I/O virtualization and sharing capabilities
  - Multipath—aggregation / resiliency / robust topologies
  - PCIe 2.5-32 GT/s PHY and 25-112 GT/s 802.3 Electrical
  - Legacy plus New Gen-Z Scalable Connector and Scalable Form Factors
  - CPU-based data movers to enable new software paradigms
  - Scale-up and scale-out connectivity and performance
  - Simplified software—any mix coherent and non-coherent operations
  - And much more…

- **RISC-V should support a PECAM through the Requestor ZMMU for LPD support**
Gen-Z Transforms Performance

- Modify existing frameworks
- New algorithms
- Completely rethink

- In-memory analytics: 15x faster
- Similarity search: 20x faster
- Large-scale graph inference: 100x faster
- Financial models: 8,000x faster
Gen-Z: Broad Industry and Component Support

Consortium Members

- Alpha Data
- AMD
- Amphenol
- ARM
- Avery Design
- Broadcom
- Cadence
- Cavium
- Cisco
- Cray
- Dell EMC
- ETRI
- (Research)
- Everspin
- Foxconn
- Interconnect
- Google
- HPR
- Hirose Electric
- Huawei
- IBM
- IDT
- IntelliProp
- Jess-Link
- Keysight
- Lenovo
- Lots
- LUXSHARE-ICT
- Mellanox
- Micron
- Microsemi
- Mobiveil
- Molex
- NetApp
- Nokia
- Oak Ridge National
- Labs
- PLDA
- Qualcomm
- Red Hat
- Samsung
- Seagate
- Senko
- Simula Research
- SK hynix
- Smart Modular
- Spin Transfer
- Technologies
- TE Connectivity
- Teledyne
- LeCroy
- Toshiba Memory
- Tyco Electronics
- UNH
- VMware
- WDC
- Xilinx
- YADRO
- Yonsei
- University

Component Categories

- GenZ Components
- GenZ Intellectual Property
- GenZ Connectors
- GenZ Subsystems
- GenZ Systems
- GenZ Software

- CPUs
- GPUs
- Special Purpose Processors
- Storage Controllers
- Switches/Gateways
- FPGAs
- Volatile Memory
- Storage Class Memory
Gen-Z Consortium Milestones

– Significant milestones over the past year
  – Multi-vendor Proof-of-Concept Demonstrated (FMS’17 / SC’17)
    – New demonstrations at HPE Discover / FMS’18 / SC’18
  – Multiple draft and final specifications publicly available (core architecture, multiple mechanicals, PHY, scalable connector including new high-power and cabling, etc.)
  – 40+ tutorials publicly available, YouTube channel, etc.
  – Expanded membership (including academic & government agencies)

– Key Upcoming Objectives
  – Expand Gen-Z security to support component authentication and page-level data encryption / authenticated
  – Deliver design guides covering:
    – DRAM / SCM, LPD, Storage, eNIC, and high-speed messaging
  – Complete ZSFF and PECFF mechanical form factor specifications
    – PECFF (September) and ZSFF (4Q2018)
  – Release Gen-Z PHY specification with support:
    – PCIe 16 GT/s and 802.3 electrical 25 GT/s (September)
    – 802.3 electrical 56 GT/s PAM 4 (4Q2018)
    – PCIe 32 GT/s and 802.3 electrical 112 GT/s PAM 4 (2Q2019)
  – Develop compliance testing
**RISC-V: Building on Gen-Z Basics**

**Figure 1 – Storage Class Memory**

- Supports DRAM, Flash, Memristor, PCRAM, MRAM, 3D-Xpoint... **Universal Interconnect**
- Decouples CPU/memory design
- Enables independent innovation

**Figure 2 – GPU or FPGA**

**Figure 3 – Multiple resources enabled by Universal Interconnect**
Thank you
Contact information