Pre-Conference Seminar D
Flash Storage Networking

Rob Davis, Ilker Cebeli, J Metz, Motti Beck, Curt Beckmann, Peter Onufryk, and Alan Weckel
Why Network Flash Based Storage?

- There are advantages to shared storage
  - Better utilization:
    - capacity, rack space, power
  - Scalability
  - Manageability
  - Fault isolation
- Shared storage requires a Network
Agenda

- **Networked Flash Storage Overview** – 8:30 to 8:45
  - Rob Davis, Mellanox, VP Storage Technology

- **PCIe** Networked Flash Storage – ~8:45 to 9:05
  - Peter Onufryk, Microsemi(Microchip), NVM Solutions Fellow

- **InfiniBand** Networked Flash Storage – ~9:05 to 9:25
  - Motti Beck, Mellanox, Sr. Dir. Enterprise Market Development

- **Fibre Channel** Networked Flash Storage – ~9:25 to 9:45
  - Curt Beckmann, Principal Product Architect, Brocade(Broadcom)

- **Ethernet** Networked Flash Storage – ~9:45 to 10:05
  - J Metz, Cisco, R&D Engineer, Advanced Storage, Office of the CTO, UCS Systems Group
Agenda (cont.)

- Conference Break – 10:15 to 10:30
- How Networking Affects Flash Storage Systems – 10:30 to 10:50
  - Ilker Cebeli, Samsung, Sr. Dir. Product Planning
- Flash Storage Networking, How the market is evolving – ~10:50 to 11:10
  - Alan Weckel, Technology Analyst/Co-Founder at 650 Group
- Q/A and Panel Discussion – ~11:10 to 12:00
  - All Presenters
Flash Makes Networking More Difficult
Faster Storage Needs a Faster Network

Flash SSDs move the Bottleneck from the Disk to the Network
What is the solution?

Networked Storage

Protocol and Network

Storage Media

Access Time (micro-sec)

Faster Wire Speeds

Storage
Protocol (SW)
Network

HDD
SSD
NVM

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Faster Network Wires are Available

Ethernet & InfiniBand – 100Gb, going to 200 and 400Gb…
PCIe – Gen3(8Gb/lane), going to Gen4(16Gb/lane)…
FC – 32Gb, going to 128Gb…
Importance of Network Latency

Network hops multiply latency
Faster Network Components Solves Some of the Problem…
Faster Protocols

- NVMe-oF
  - RDMA(RoCE, IB)
  - Fibre Channel
  - PCIe
  - Coming soon TCP
- RDMA
  - SMB Direct
  - iSER
Where best to plug in?
Flash Storage – Closer to Servers
The Solution will often drive the protocol and the network technology

- All technologies support Block
- All technologies do not support File and Object

Technologies can be layered:
- Block behind File

Flash based solutions will almost always improve performance with a faster network and protocol.
Conclusions

- There are tried and true reasons for networking your storage
- Networking flash requires special considerations
  - Faster Storage needs Faster Networks!
  - And protocols
- For the next few hours this team will present the different options and trade offs
- Then you get to question us
Peter Onufryk

- Peter is a Fellow in the Data Center Solutions Business Unit, where he is responsible for architecture and validation of storage products. He received a Ph.D. in Electrical and Computer Engineering from Rutgers University, has been granted over 40 patents.
PCIe® Networked Flash Storage

Peter Onufryk
Microsemi Corporation
PCI Express® (PCIe®)

- Specification defined by PCI-SIG®
  - www.pcisig.com
- Packet-based protocol over serial links
  - Software compatible with PCI and PCI-X
  - Reliable, in-order packet transfer
- High performance and scalable from consumer to Enterprise
  - Scalable link speed (2.5 GT/s, 5.0 GT/s, 8.0 GT/s, 16 GT/s, and 32 GT/s)
    - Gen5 (32 GT/s) is still being standardized
  - Scalable link width (x1, x2, x4, ..., x32)
- Primary application is as an I/O interconnect
PCIe Characteristics

- Scalable speed
  - Encoding
    - 8b10b: 2.5 GT/s (Gen 1) and 5 GT/s (Gen 2)
    - 128b/130b: 8 GT/s (Gen 3), 16 GT/s (Gen4) and 32 GT/s (Gen5)
- Scalable width: x1, x2, x4, x8, x12, x16, x32

<table>
<thead>
<tr>
<th>Generation</th>
<th>Raw Bit Rate</th>
<th>Bandwidth Per Lane Each Direction</th>
<th>Total x16 Link Bandwidth</th>
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</thead>
<tbody>
<tr>
<td>Gen 1*</td>
<td>2.5 GT/s</td>
<td>~ 250 MB/s</td>
<td>~ 8 GB/s</td>
</tr>
<tr>
<td>Gen 2*</td>
<td>5.0 GT/s</td>
<td>~500 MB/s</td>
<td>~16 GB/s</td>
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<tr>
<td>Gen 3*</td>
<td>8 GT/s</td>
<td>~ 1 GB/s</td>
<td>~ 32 GB/s</td>
</tr>
<tr>
<td>Gen 4</td>
<td>16 GT/s</td>
<td>~ 2 GB/s</td>
<td>~ 64 GB/s</td>
</tr>
<tr>
<td>Gen 5</td>
<td>32 GT/s</td>
<td>~4 GB/s</td>
<td>~128 GB/s</td>
</tr>
</tbody>
</table>

Note
* Source – PCI-SIG PCI Express 3.0 FAQ
NVM Express™ (NVMe™)

- Two specifications
  1. NVM Express (PCIe)
  2. NVM Express over Fabrics (RDMA and Fibre Channel)
- Architected from the ground up for NVM
  - Simple optimized command set
  - Fixed size 64 B commands and 16 B completions
  - Supports many-core processors without locking
  - No practical limit on the number of outstanding requests
  - Supports out-of-order data deliver

PCIe SSD = NVMe SSD
## Ideal NVM Fabric

<table>
<thead>
<tr>
<th>Property</th>
<th>Ideal Characteristic</th>
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<tbody>
<tr>
<td>Cost</td>
<td>Free</td>
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<tr>
<td>Complexity</td>
<td>Low</td>
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<tr>
<td>Performance</td>
<td>High</td>
</tr>
<tr>
<td>Power consumption</td>
<td>None</td>
</tr>
<tr>
<td>Standards-based</td>
<td>Yes</td>
</tr>
<tr>
<td>Scalability</td>
<td>Infinite</td>
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</table>
PCIe Fabric

PCIe Switch

NVMe SSD
NVMe SSD
NVMe SSD
NVMe SSD

NVMe Host 1

PCIe Switch

NVMe SSD
NVMe SSD
NVMe SSD
NVMe SSD

NVMe Host 2

NVMe SSD
NVMe SSD
NVMe SSD
NVMe SSD

NVMe Host 3

NVMe SSD
NVMe SSD
NVMe SSD
NVMe SSD

NVMe Host 4

NVMe SSD
NVMe SSD
NVMe SSD
NVMe SSD
Non-Transparent Bridging (NTB)
Dynamic Partitioning

Physical View

Functional View
Multi-Host I/O Sharing
### PCIe Fabric

**Storage Functions**
- Dynamic partitioning (drive-to-host mapping)
- NVMe shared I/O (shared storage)
- Ability to share other storage (SAS/SATA)

**Host-to-Host Communications**
- RDMA
- Ethernet emulation

**Manageability**
- NVMe controller-to-host mapping
- PCIe path selection
- NVMe management

**Fabric Resilience**
- Supports link failover
- Supports fabric manager failover
A high performance fabric means:
- High bandwidth
- Low latency

Increasing bandwidth is easy
- Aggregate parallel links
- Increase link speed (fatter pipe)

Reducing latency is hard
- Transfer latency is typically a small component of overall latency
- Other sources of latency:
  - Software (drivers)
  - Complex protocols
  - Protocol translation
  - Fabric switches/hops
Latency

- Media Access Time
  - Hard drive – Milliseconds
  - NAND flash – Microseconds
  - Next-gen. NVM – Nanoseconds
The PCIe Advantage

Other Flash Storage Networks

PCIe Fabric
The PCIe Latency Advantage

Latency data from Z. Guz et al., "NVMe-over-Fabrics Performance Characterization and the Path to Low-Overhead Flash Disaggregation" in SYSTOR '17
# PCIe Fabric Characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Ideal Characteristic</th>
<th>PCIe Fabric</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Free</td>
<td>Low</td>
<td>• PCIe built into virtually all hosts and NVMe drives</td>
</tr>
</tbody>
</table>
| Complexity     | Low                  | Medium      | • Builds on existing NVMe ecosystem with no changes  
• PCIe fabrics are an emerging technology  
• Requires PCIe SR-IOV drives for low-latency shared storage                                    |
| Performance    | High                 | High        | • High bandwidth  
• The absolute lowest latency                                                                                                         |
| Power consumption | None              | Low         | • No protocol translation                                                                                                              |
| Standards-based | Yes                | Yes         | • Works with standard hosts and standard NVMe SSDs                                                                                  |
| Scalability    | Infinite             | Limited     | • PCIe hierarchy domain limited to 256 bus numbers  
• PCIe has limited reach (cables)  
• PCIe fabrics have limited scalability (less than 256 SSDs and 128 hosts)                                                               |
Persistent Memory & Next Gen. NVM

**Traditional Memory**
- Volatile
- Byte addressable
- Memory load/store operations
- Memory bus

**Traditional Storage**
- Non-volatile (persistent)
- Block, file, or object addressable
- I/O operations
- Storage interconnect

**Next Generation NVM**
- Non-volatile (persistent)
- Byte, block, file, or object addressable
- Memory load/store operations and I/O operations

**Examples:** phase-change memory (PCM), resistive RAM (RRAM), spin-transfer-torque magnetic RAM (STT_MRAM), ferroelectric RAM (FRAM)
NVMe and Memory Operations

• Controller Memory Buffer (CMB)
  • PCI memory space exposed to host (byte addressable)
  • May be used to store commands & data
  • Contents do not persist across power cycles and resets

• Persistent Memory Region (PMR)
  • PCI memory space exposed to host (byte addressable)
  • May be used to store data
  • Content persist across power cycles and resets
Storage is Not Just About CPU I/O Anymore

- NVMe together with a PCIe fabric allow direct network to storage and accelerator to storage communications

Example:

1. Data transferred from network to NVMe CMB
2. NVMe block write operation initiated from CMB to NVM
3. NVMe block read operation initiated from NVM to CMB
4. GPU/Accelerator transfers data from NVMe CMB for processing
Putting it All Together

- NVMe Storage Functions
  - Dynamic partitioning (drive-to-host mapping)
  - NVMe shared I/O (shared storage)
- Direct accelerator-to-NVMe and network-to-NVMe transfers
- Byte addressable persistent memory
Summary

• PCIe fabrics build on the existing PCIe and NVMe ecosystem
  • Work with standard NVMe SSDs, OS drivers, and PCIe infrastructure

• PCIe fabrics support both byte addressable memory and traditional storage operations

• PCIe fabrics are well suited for applications that require low cost, the absolute lowest latency, and limited scalability
  • NVMe SSD sharing inside a rack and small clusters

• PCIe fabrics are not well suited for long reach applications or where a high degree of scalability is required
  • NVM Express over Fabrics (NVMe-oF™) is well suited for these applications
Motti Beck

Motti Beck is Sr. Director of Marketing, Enterprise Data Center market segment at Mellanox Technologies, Inc. Before joining Mellanox, Motti was a founder of several start-up companies including BindKey Technologies that was acquired by DuPont Photomask (today Toppan Printing Company LTD) and Butterfly Communications that was acquired by Texas Instrument. Prior to that he was a Business Unit Director at National Semiconductors. Motti hold B.Sc in computer engineering from the Technion - Israel Institute of Technology.
InfiniBand Networked Flash Storage

Superior Performance, Efficiency and Scalability

Motti Beck – Sr. Director Enterprise Market Development, Mellanox Technologies
The Need for Intelligent and Faster Interconnect

Faster Data Speeds and In-Network Computing Enable Higher Performance and Scale

CPU-Centric (Onload)

Data-Centric (Offload)

Onload Network

In-Network Computing

Must Wait for the Data Creates Performance Bottlenecks

Analyze Data as it Moves! Higher Performance and Scale
In-Network Processing Enables Higher Efficiency

- Higher Scalability
- Lower latency
- Higher ROI
InfiniBand Technical Overview

- **What is InfiniBand?**
  - InfiniBand is an open standard, interconnect protocol developed by the InfiniBand® Trade Association: [http://www.infinibandta.org/home](http://www.infinibandta.org/home)
  - First InfiniBand specification was released in 2000

- **What does the specification includes?**
  - The specification is very comprehensive
  - From physical to applications

- **InfiniBand SW is open and has been developed under OpenFabrics Alliance**
  - [http://www.openfabrics.org/index.html](http://www.openfabrics.org/index.html)
InfiniBand Protocol Layers

- Application
- Presentation
- Session
- Transport
- Network
- Link
- Physical

InfiniBand Node

- Packet relay
- PHY

InfiniBand Switch

- Packet relay
- PHY
- PHY

InfiniBand Router

- Packet relay
- Link
- PHY
- PHY
- Physical

Presentation
Session
Transport
Network
Link
Physical

Packet Format

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InfiniBand Architecture Highlights

- Reliable, lossless, self-managed fabric
- Hardware based transport protocol - Remote Direct Memory Access (RDMA)
- Centralized fabric management – Subnet Manager (SM)
Reliable, Lossless, Self-Managed Fabric

- Credit-based link-level flow control
  - Link Flow control assures **NO packet loss** within fabric even in the presence of congestion
  - Link Receivers grant packet receive buffer space credits per Virtual Lane
  - Flow control credits are issued in 64 byte units

- Separate flow control per Virtual Lanes provides:
  - Alleviation of head-of-line blocking
  - Virtual Fabrics – Congestion and latency on one VL does not impact traffic with guaranteed QOS on another VL even though they share the same physical link
Remote Direct Memory Access RDMA

- Transport offload
- Kernel bypass
10X Better Performance with GPUDirect™ RDMA

- Purpose-built for Acceleration of Deep Learning
- Lowest communication latency for acceleration devices
- No unnecessary system memory copies and CPU overhead
- Enables GPUDirect™ RDMA and ASYNC, ROCm and others
- InfiniBand and RoCE
Scaling HPC and ML with GPUDirect over InfiniBand on vSphere 6.7

Figure 3: Testbed virtual cluster architecture showing the no-GPUDirect RDMA vs. GPUDirect RDMA data path with DirectPath I/O on vSphere 6.7

Source: Scaling HPC and ML with GPUDirect RDMA on vSphere 6.7
Subnet Management

Each Subnet must have a Subnet Manager (SM)

Every entity (HCA, Switch or Router) must support a Subnet Management Agent (SMA)

Topology Discovery
Fabric Initialization
Fabric Maintenance

Initialization uses Directed Route MADs:

Management uses unreliable datagrams (MAD)

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InfiniBand Superior Performance*

Network Throughput and Latency

(a) Throughput

CPU Overhead for Network Operations

(a) Client

(b) Latency

(b) Server

* Source: Brown University Research: "The End of Slow Networks: It’s Time for a Redesign"
InfiniBand Enables Most Cost Effective Database Storage

Exadata X5-2 Product Components

- **Scale-Out Database Servers**
  - Two 18-core x86 Processors (36 cores)
  - Oracle Linux 6
  - Oracle Database Enterprise Edition
  - Oracle VM (optional)
  - Oracle Database options (optional)

- **Fastest Internal Fabric**
  - 40 Gb/s InfiniBand
  - Ethernet External Connectivity

- **Scale-Out Intelligent Storage**
  - High-Capacity Storage Server
  - Extreme Flash Storage Server
  - Exadata Storage Server Software

Source: Oracle
InfiniBand Networking Storage enables Higher Efficiency

PDW* V1 Reference: The Basic Full Rack

- 160 cores on 10 compute nodes
- 1.28 TB of RAM on compute
- Up to 30 TB of temp DB
- Up to 150 TB of user data

Parallel Data Warehouse
10X Faster & Lower Capital Cost

Per RACK details
- 128 cores on 8 compute nodes
- 2TB of RAM on compute
- Up to 168 TB of temp DB
- Up to 1PB of user data

*Parallel Data Warehouse
Source: Big Data Integration with SQL Server PDW 2012

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RDMA enables Higher Scalability with IBM DB2 pureScale

Scale-out Throughput – DB2 pureScale on LE POWER Linux

- 3.5x scaling on RDMA Ethernet, 1-4 members
- 3.1x scaling on TCP sockets, 1-4 members

- 80% read / 20% write OLTP workload
- POWER9 4c/32t, 160 GB LBP
- 10 Gb RoCE RDMA Ethernet / 10 Gb TCP sockets

Source: IBM
Teradata BYNET® V5 Performance

- BYNET’s basic link performance enhanced with InfiniBand
  - Dual InfiniBand links provide 10GB per second
  - 10X higher than previous BYNET®

- Message delays decreased
  - Latency in interconnect reduced by 2/3
InfiniBand Unleashed the Power of Flash

Hadoop HDFS Architecture

Hadoop GPFS Architecture

Source: Driving IBM BigInsights Performance Over GPFS Using InfiniBand+RDMA
InfiniBand Accelerate Big Data Analytics

Data Analytics Throughput Results
(Based on 1TB of Tensor Test)

DFSIO Write Results

DFSIO Read Results

Source: Driving IBM BigInsights Performance Over GPFS Using InfiniBand+RDMA
TeraSort - Performance Results

Source: #HWCSAIS18

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RDMA Enables Higher Performance SDS Solutions

Traditional Solution

Converged Solution

Hyperconverged Solution

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*Microsoft's Solutions
InfiniBand Cuts SAN Cost by 50%

- Delivers SAN-like functionality from the Windows Stack
  - Using SMB Direct (SMB 3.0 over RDMA)

- Utilize inexpensive, industry-standard, commodity hardware
  - Eliminate the cost of proprietary hardware and software from SAN solutions

Source: Microsoft

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RoCE – RDMA (InfiniBand) over Converged Ethernet

- InfiniBand transport over Ethernet
- API Compatible
- Efficient, light-weight transport, layered directly over
  - Ethernet – RoCE
  - UDP – RoCEv2
- Takes advantage of DCB Ethernet
  - PFC, ETS, and QCN

InfiniBand

- LRH (L2 Hdr)
- GRH (L3 Hdr)
- BTH+ (L4 Hdr)
- IB Payload
- ICRC
- VCRC

RoCE

- MAC
- ET RoCE
- GRH
- BTH+
- IB Payload
- ICRC
- FCS

RoCEv2

- MAC
- ET IP
- IP Proto UDP
- UDP Port=RoCE
- BTH+
- IB Payload
- ICRC
- FCS
DataON WSSD* Hyper-Converged Infrastructure

- Microsoft’s WSSD Certified
- RoCE networking
- Increased efficiency
  - 30X** vs. previous solution

*Windows Server Software-Defined

** Source: DataON

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iSER – iSCSI with RDMA Extensions

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iSER Delivers 3X Higher Efficiency vs. iSCSI

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RDMA enabled Networking Powers Modern Storage Platforms

Higher Performance, Higher Efficiency and Higher Scalability
Principal Architect at Brocade, is recently back to the Bay Area after 2 years in Paris where he held the role of CTO for Brocade Europe and last year wrote the 'NVMe over Fibre Channel for Dummies book'. Prior to that he led the architecture and development of storage virtualization ASICs for Rhapsody Networks, which was central to that firm’s successful acquisition by Brocade. He also led the ASIC/hardware design team for Nortel’s largest-unit-selling network switch. Beckmann’s combination of winning designs and customer-facing experience make him uniquely qualified to evaluate the design considerations of customer needs.
NVMe over Fibre Channel

Curt Beckmann
Principal Architect
Brocade Storage Networking, Broadcom
Today’s Presentation Topics

• Background: The why and how of sharing storage
• Enterprise and other storage categories
• The impact of Flash on Storage protocols
• The current state of NVMe/FC
Storage began as direct-attached. Why share it?

- Stored data as a durable *Information Asset*
  - Not like transient compute artifact (e.g. call stack)
  - Memory v Storage: Error handling? SLA?
- Desire to scale and leverage
  - Want to scale-out compute, re-use assets
- Stranded storage capacity
  - Spare capacity only usable by direct attached CPU
“Traditional” (20th C) shared storage concepts

- **Files:** “NAS”:
  - Enet/IP/L4: NFS, SMB/CIFS…

- **Blocks (structured, strictly consistent, mission critical):** “SAN”
  - Networked SCSI: SAS, FCP…

- **Enduring wish:** Consistency / Availability / Partition (CAP) Theorem
  - Span, cost, performance, availability/reliability, size

- **Ethernet / IP / Layer 4:** Rose to dominance in 1990’s
  - Best-effort/retry, Internet-wide, “converged”, commodity (span/cost)

- **Fibre Channel:** born in Ethernet/IP heyday
  - Lossless, DC-wide, storage-centric, “Enterprise” (performance/availability)
Storage Types

DAS = Direct Attached Storage
NAS = Network Attached Storage
iSCSI – Internet Small Computer Systems Interface
LOM = LAN on Motherboard
NIC = Network Interface Card
HBA = Host Bus Adapter
CNA = Converged Network Adapter

“Recent” (21st C) shared storage concepts

- InfiniBand (and Omni-Path… etc?):
  - Lossless, DC-wide, compute-centric (HPC), popularized RDMA
- “3rd platform”: Mobile + Cloud, IoT
  - Virtualized, commoditized / converged, “shared nothing”, “cattle” v. “pets”
- New use cases, “evolved” choices for CAP theorem
  - Big Data / “SDS” / “Eventual Consistency” / AI-ML / DevOps (flexible) mindset
- Flash broke out of niche: scale, write endurance, $/GB
  - Flash’s disruptive speed has moved focus to various sluggish software
- NVMe stack slims away decades of SCSI baggage
  - “NVMe” is PCI-based, “NVMe-over-Fabrics” (coming slides) for shared use cases
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<th></th>
<th>CapEx*</th>
<th>Performance</th>
<th>Reliability</th>
<th>Maturity</th>
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<tbody>
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<td>Fibre Channel</td>
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<td>High</td>
<td>High</td>
<td>High</td>
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<td>NAS (NFS, etc, over IP)</td>
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<td>iSCSI</td>
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<td>FCoE</td>
<td>0.79</td>
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<tr>
<td>NVMe over Fabrics</td>
<td>n/a</td>
<td>High**</td>
<td>High**</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Normalized to FC Cost/GB in 2016 prices (Ref: IDC)  **Projected
How Fibre Channel differs from Ethernet: Tech

- Technical:
  - Fewer, more coupled layers, limited application
  - Smaller address range, smaller header
  - Addresses assigned (not random or learned)
    - Scales bigger than typical subnet, but smaller than Internet
  - Not much multicast, no flooding
  - Always supported fabric topology (not just Spanning Tree)
  - Always built for reliable delivery (v. best effort)
  - Credit-based flow control is “always on”
  - Fabric provides fabric-resident services: Name server, etc
How Fibre Channel differs from Ethernet: Industry

- **Industry:**
  - Focus in critical “always on” use cases
    - Nearly always redundant fabrics dedicated to storage
  - Few switch / HBA firms mostly selling through storage vendors
  - Storage vendors certify products, mark them up, provide support
  - Interoperability driven by storage vendors
  - Vendor arrays loaded w enterprise features, virtualization
    - Rarely expose raw media
  - **Upshot:** most benchmarks are based on full featured arrays
    - With SSDs getting so fast, software features now a large fraction of the latency
    - When tested on raw media (Linux JBOFs), FC latency comparable to PCI-attached Flash Memory Summit 2018
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Enterprise Flash Growing Well

Enterprise Storage Dynamics

Source: IDC September 2015 WW Quarterly Disk Storage Systems Forecast
NVMe over Fabrics Concepts

• NVMEExpress.org defined specs
  • PCIe-based NVMe (1.0 in 2011, currently at 1.3)
  • NVMe-over-Fabrics (1.0 in 2016)

• Four early fabrics, one newcomer
  • (RDMA-based) InfiniBand, iWARP, RoCE(v2)
  • (no RDMA) Fibre Channel
  • (no RDMA, iSCSI-like newcomer) NVMe-over-TCP
FC-NVMe Spec Status

• Why move to NVMe/FC?
  • It’s like SCSI/FC tuned for SSDs and parallelism
  • Simpler, more efficient, and (as we’ll see) faster
• FC-NVMe standard effort is overseen by T11
  • T11 and INCITS finalized FC/NVMe early 2018
• Several vendors are shipping GA products
• FCIA plugfest last week: XX participants
Dual Protocol SANs lower risk, help NVMe adoption

• 80% of today’s Flash arrays connect via FC
  • This is where most vital data assets (still!) live today

• High-value Assets require protection
  • Storage Teams avoid risk…part of job description
  • How can Storage Teams adopt NVMe with low risk?
    • Use familiar, trusted infrastructure, vendors and support
    • Dual protocol SAN offers that, and NVMe performance too…
Dual protocol SANs enable low risk NVMe adoption

- Get NVMe performance benefits while migrating incrementally “as-needed”

- Migrate application volumes 1 by 1 with easy rollback options

- Interesting dual-protocol use cases

- Full fabric awareness, visibility and manageability with existing Brocade Fabric Vision technology
Summary of Demartek Report

- **Purpose:** Credibly document performance benefit of NVMe over Fibre Channel (NVMe/FC) is relative to SCSI FCP on vendor target

- **Audited by:** Demartek
  - Performance Benefits of NVMe™ over Fibre Channel – A New, Parallel, Efficient Protocol

- **Audit Date:** May 1, 2018
  - PDF available at: [www.demartek.com/ModernSAN](http://www.demartek.com/ModernSAN)

- **Results of testing both protocols on same hardware:**
  - Up to 58% higher IOPS for NVMe/FC
  - From 11% to 34% lower latency with NVMe/FC

Note: The audit was *not* intended as a test of max overall array performance
Results: 4KB Random Reads, full scale and zoomed in

This image highlights how NVMe/FC gives 53% / 54% higher IOPS with 4KB random read I/Os.
Summary

• Shared storage
  • Data asset has value independent of any application
  • Need more protection!
    • Even if it adds some access time
• With slight inefficiency, SCSI has dominated
• SSDs are so fast, SCSI burden no longer slight
  • NVMe command set o
J Metz is R&D Engineer, Office of the CTO, at Cisco, where he focuses on examining and deploying directions for storage strategy. He was previously Strategic Product Manager, Storage and Unified Fabric. With Cisco since 2010, he has previous experience with QLogic and Apple. He has also been President at Communiweb Communications and an Assistant Professor at the University of Central Florida. He holds a PhD from the University of Georgia, an MA from the University of South Dakota, and a BA from the University of Rhode Island.
Ethernet-Networked Flash Storage

J Metz, Ph.D
R&D Engineer, Advanced Storage
Cisco Systems

@drjmetz
Agenda

• Ethernet Background and Roadmap
• Storage Use Cases
• Goodness of Fit
Planting a Flag

- Is there anyone who thinks Ethernet will not play a role in storage?
Then the Question Is…

…how best to use Ethernet for Storage?
Storage Perspective

- There is a “sweet spot” for storage
  - Depends on the workload and application type
  - No “one-size fits all”
- What is the problem to be solved?
  - Deterministic or non-deterministic?
  - Highly scalable or highly performant?
  - Level of manageability?
- Understanding “where” the solution fits is critical to understanding “how” to put it together
Network Determinism

- **Non-Deterministic**
  - Provide any-to-any connectivity
  - Storage is unaware of packet loss – relies on ULPs for retransmission and windowing
  - Provide transport w/o worrying about services
  - East-West/North-South traffic ratios are undefined

- **Examples**
  - NFS/SMB
  - iSCSI
  - iSER
  - iWARP
  - (Some) NVMe-oF

Fabric topology and traffic flows are highly flexible

Client/Server Relationships are not pre-defined
Network Determinism (cont.)

- **Deterministic Storage**
  - Goal: Provide 1:1 Connectivity
  - Designed for Scale and Availability
  - Well-defined end-device relationships (i.e., initiators/targets)
  - Only north-south traffic; east-west mostly irrelevant

- **Examples**
  - Fibre Channel
  - Fibre Channel over Ethernet
  - InfiniBand
  - RoCE
  - (Some) NVMe-oF
Big Picture

• Many ways to solve a problem
  • No “one-size-fits-all”

• Lots of overlap
  • Can easily get confused about which to choose

• If two different approaches can do the same thing, how do you know what to do?
Big Picture

- When you miss the sweet spot, you risk major problems
  - Careful of the “Danger Zones”
Scope Comparison

PCIe

Fibre Channel

Ethernet (FCoE, iSCSI, iSER, NVMe-oF)

InfiniBand

Ethernet (NFS, SMB, Object)
Ethernet Enhancements

Ability to support different forwarding behaviours, e.g. QoS, MTU, … queues within the “lanes”
Congestion Notification: BCN/QCN

- **Principles**
  - Push congestion from the core towards the edge of the network
  - Use rate-limiters at the edge to shape flows causing congestion
  - Tune rate-limiter parameters based on feedback coming from congestion points
- Inspired by TCP
- Self-Clocking Control loop
- Derived from FCC (Fire Channel Congestion Control)
DCTCP
Data Center TCP

- Congestion indicated quantitatively (reduce load prior to packet loss)
- React in proportion to the extent of congestion, not its presence
  - Reduces variance in sending rates, lowering queuing requirements

<table>
<thead>
<tr>
<th>ECN Marks</th>
<th>TCP</th>
<th>DCTCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 1 1 1 0 1 1 1</td>
<td>Cut window by 50%</td>
<td>Cut window by 40%</td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0 0 1</td>
<td>Cut window by 50%</td>
<td>Cut window by 5%</td>
</tr>
</tbody>
</table>

- Mark based on instantaneous queue length
  - Fast feedback to better deal with bursts
Leaf-Spine DC Fabric

Approximates ideal output-queued switch

- How close is Leaf-Spine to ideal OQ switch?
- What impacts its performance?
  - Link speeds, oversubscription, buffering
### Comparison

<table>
<thead>
<tr>
<th></th>
<th>Ethernet</th>
<th>PCIe</th>
<th>Fibre Channel</th>
<th>InfiniBand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-Host</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Direct Attached (DAS)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Network Attached (NAS)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Storage-Area Network (SAN)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Deterministic Capability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Non-Deterministic Capability</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Block Storage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>File Storage</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Object Storage</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Global Distance</td>
<td>Yes</td>
<td>Hell no</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Summary

• Ethernet
  • General Purpose network designed to solve many, many problems and do it well
  • Flexible for all but the most extreme conditions
  • Largest ecosystem of developers, vendors, and users
  • From the smallest system to the largest, there is no other networking technology more suited, or best understood
Ilker Cebeli

Ilker is a Senior Director of Product Planning at Samsung. He is responsible for leading the emerging memory, SSD, and all-flash-array related storage solutions and technologies. He has spent 25 years in enterprise computing, storage and networking working in various roles. Prior to joining to Samsung, Ilker worked at Micron, and was leading and directing emerging memory projects in memory division. Ilker also spent 15 years at Intel and he was responsible for Intel's Xeon™ product planning and server platform architecture definition.
NVMe over Fabrics

High Performance SSDs networked over Ethernet

Ilker Cebeli
Senior Director of Product Planning, Samsung

August 8th, 2017
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NVMe Technology – Background

• Optimized for flash
  ● Traditional SCSI designed for disk
  ● NVMe bypasses unneeded layers
  ● Dramatically reducing latency
NVMe Design Advantages

• Lower latency
  • Direct connection to CPU’s PCIe lanes
• Higher bandwidth
  • Scales with number of PCIe lanes
• Best in class latency consistency
  • Lower cycles/IO, fewer cmds, better queueing
• Lower system power
• No HBA required
• NVMe outperforms SATA SSDs
  ● 5X-6X more bandwidth,
  ● 40-50% lower latency
  ● Up to 8x more IOPS
What is NVM Express Over Fabrics?

- A protocol interface to NVMe that enable operation over other interconnects (e.g., Ethernet, InfiniBand™, Fibre Channel).
- Shares the same base architecture and NVMe Host Software as PCIe.
- Enables NVMe Scale-Out and low latency (<10µS latency) operations on Data Center Fabrics.
- Avoids protocol translation (avoid SCSI).

![Diagram showing NVMe-oF architecture and latency comparison]
Some of the use cases for NVMe Over Fabrics

1. Software-Defined Storage (SDS)
2. Hyper-Converged

Disaggregated JBOF Storage

Direct Attached JBOF
SAS DAS Replacement
Performance Test Configuration – 2016

- **1x NVMe-oF target**
  - 24x NVMe 2.5” SSDs
  - 2x 100GbE NICs
  - Dual x86 CPUs

- **4x initiator hosts**
  - 2x25GbE NICs each

- **Open Source NVMe-oF kernel drivers**
Local vs. Remote Latency Comparison – 2016

<table>
<thead>
<tr>
<th></th>
<th>Read Gap</th>
<th>Write Gap</th>
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<tbody>
<tr>
<td></td>
<td>~17 us</td>
<td>~9 us</td>
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</tbody>
</table>
Performance Test Configuration – 2017

- **1x NVMe-oF target**
  - 36x NF1 SSDs
  - 2x 100GbE NICs, 2x 50GbE NICs
  - Dual x86 CPUs

- **6x initiator clients**
  - 2x25Gb/s each

- **Open Source NVMe-oF kernel drivers**
  - Ubuntu Linux 16.04/4.9 on Target
Local vs. Remote Latency Comparison - 2017

Flash Memory Summit 2018
Santa Clara, CA
SSDs Will Continue to get Faster

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<thead>
<tr>
<th></th>
<th>2016 Tests</th>
<th>2017 Tests</th>
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<tbody>
<tr>
<td>Read Gap</td>
<td>~17 us</td>
<td>~14 us</td>
</tr>
<tr>
<td>Write Gap</td>
<td>~9 us</td>
<td>~10 us</td>
</tr>
</tbody>
</table>

Flash Memory Summit 2018
Santa Clara, CA
THANK YOU

Sessions to Follow:

Forum W-32: NVMe over Fabrics (NVMe-oF) (NVMe over Fabrics (NVMe-oF) Track)

Session 204-C: Flash in Big Data Applications (Data Management Track)

Forum B-11: Flash-Memory Based Architectures: A Technical Discussion, Part 1 (Architectures Track)
Alan Weckel is Technology Analyst/Co-Founder at 650 Group, where he is in charge of Ethernet switch, Cloud and data center research. He has written many articles for the trade and technical press, and is frequently quoted in such leading publications as Bloomberg, Businessweek, Forbes, Network World, and the Wall Street Journal. Before co-founding 650 Group, he was VP/analyst at Dell’Oro Group and had engineering and software development experience at Raytheon, General Electric Power Systems, and Cisco. He holds a BSEE and an MS in Management from Rensselaer Polytechnic Institute.
Flash Storage Networking,
How the market is evolving

Alan Weckel (alan@650group.com)
Trends changing how compute and storage are consumed
Storage: How and Where We Store Data is Changing

- Enterprise Storage Systems Market is Shrinking
  - Enterprises continue to buy systems
  - Enterprise market for converged and hyperconverged is growing

- Cloud Market is Growing
  - Hyperscalers buy components
  - Hyperscalers build their own software

- Areas of growth in Storage Systems Market
  - Cloud
  - All Flash Arrays
  - Hyperconverged
Server Shipments: Shipments into the Cloud

- Cloud servers will dominate compute
  - Higher-end processor
  - Smart NIC
  - Better software
  - Different type of storage
- Enterprise servers are being deployed in colocation facilities
- East/West traffic is no longer limited to one data center
  - Ethernet Based Architectures
  - Large amounts of data being moved across the world
Workloads:
Installed Base by Deployment

- Enterprise workloads continue to grow
  - More workloads per server
  - Type of application is changing
  - Colocation becoming common

- Cloud workload growth exploding
  - All types of applications are growing
  - IoT will be a major driving of workload growth
Server and Smart NICs:
Server Installed Base

- Cloud is the new leader in technology transitions
  - Entire Telco market is smaller than Amazon
  - Cloud is moving from 2-3 to 3-4 technology generations ahead of the enterprise

- Tier 2 and 3 Clouds are increasingly riding on top of Tier 1 Cloud Infrastructure

- Clouds uses different architecture and buys different equipment than the enterprise
Ethernet Switch – Data Center
Ethernet Switch – Data Center: Total Market Revenue

Revenue in Billions ($)

- 1 Gbps
- 10 Gbps
- 25 Gbps
- 50 Gbps
- 800 Gbps
- 200 Gbps
- 400 Gbps
- 100 Gbps
- 40 Gbps
- 25 Gbps
- 10 Gbps
- 40 Gbps
- 1 Gbps

Years:
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022
Ethernet Switch – Data Center: Total Market Revenue

Revenue In Billions ($)

US Top 5 Cloud Providers: Amazon, Apple, Facebook, Google, Microsoft
Chinese Tier 1 Cloud Providers: Alibaba, Baidu, Tencent
2017 saw 3rd consecutive year of almost identical Y/Y change

- Revenue down 7% to ~$1.5B
- Shipments down 11% to ~4.1M ports

2H17 did improve 2% probably due to 32Gb product ramping
Crehan IB Data

- 2017 saw revenue up and post shipments down
  - Revenue up 7% to ~$460M
  - Shipments down 9% to ~1.5M ports
- HDR/200Gb products announced but not yet shipping
Merchant Silicon – Data Center Switching: ASIC Usage in the Tier 1 Cloud

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<td>1.3 Tbps</td>
<td>10 Gbps</td>
<td>10 Gbps</td>
<td>10/40 Gbps</td>
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<td>1.8 Tbps</td>
<td>25 Gbps</td>
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<td>3.2 Tbps</td>
<td>25 Gbps</td>
<td>25/50 Gbps</td>
<td>100 Gbps</td>
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<td>6.4 Tbps</td>
<td>25 Gbps</td>
<td>25/50 Gbps</td>
<td>100/200 Gbps</td>
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<td>7.2 Tbps</td>
<td>100 Gbps</td>
<td>100 Gbps</td>
<td>400 Gbps</td>
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<tr>
<td>12.8 Tbps</td>
<td>50 Gbps</td>
<td>50/100 Gbps</td>
<td>200/400 Gbps</td>
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<td>12.8 Tbps</td>
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<td>400 Gbps</td>
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<td>25.6 Tbps</td>
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- Two waves of 400 Gbps
  - 8 X 50 Gbps
  - 4 X 100 Gbps
- Pace of Innovation Increasing
  - Four major silicon cycles in five years
  - Some technologies will get orphaned
Conclusion

- Speed of technology advancement is more rapid
- Ethernet is expanding into the Storage connectivity and Data Center transport markets at a rapid pace
- Cloud customers have different architectures and use different equipment than the enterprise
- 2019 will usher in Smart NICs and 200/400 Gbps which will expand the market for Ethernet
Thank You
Panel Q/A

Rob Davis, Ilker Cebeli, J Metz, Motti Beck, Curt Beckmann, Peter Onufryk, and Allen Weckel