Benefits of RDMA In Accelerating Ethernet Storage Connectivity

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SNIA™
Ethernet Storage Forum

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Agenda

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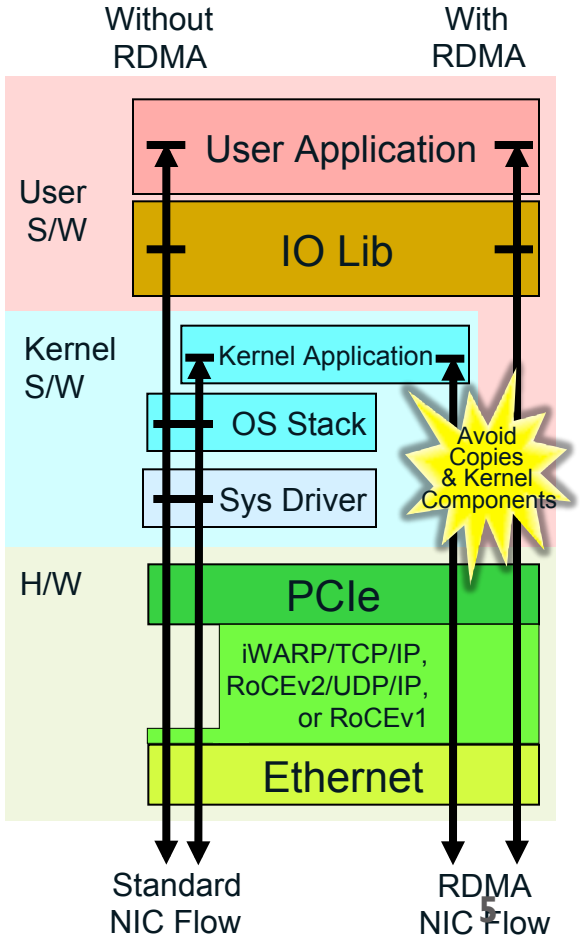
- What is RDMA?
- Overview of key RDMA protocols for storage
- Where is RDMA used in storage?
- Deep Dive on SMB Direct

What Is Remote Direct Memory Access (RDMA)?

- RDMA increases bandwidth while lowering latency, jitter, and CPU utilization – great for networked storage!
- RDMA bypasses system software stack components that processes network traffic
  - For user applications, RDMA bypasses the kernel altogether
  - Kernel applications that support RDMA get the same benefits as user applications, e.g. SMB Direct in Windows® Server 2012



What Is Remote Direct Memory Access (RDMA)?

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- RDMA can deliver direct data placement of data from one machine (real or virtual) to another machine -- without copies
  - Applications can write directly into the memory space of another application or to a storage target
  - A storage system can write to an application's memory space or to a storage target
- RDMA enables header/data separation by preserving message boundaries

What Are RDMA Verbs?

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- RDMA defines an asynchronous “verbs” programming interface (traditional sockets are synchronous)
- For applications to take advantage of RDMA, they have to be written to verbs
- However, verbs can be hidden “under the hood,” i.e., below the application APIs, to avoid the requirement of rewriting applications
  - HPC MPI libraries have been re-written to verbs so applications written to MPI can take advantage of RDMA without having to be rewritten
- The Open Fabrics Alliance maintains verbs and libraries of code written to them

OPENFABRICS ALLIANCE

Where Can I Find RDMA?

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- RDMA is in production today in InfiniBand* fabrics and in two Ethernet fabrics, iWARP and RoCE
  - An application should not care what wire, transport, or network is delivering its traffic
- RDMA is supported today in Linux and Microsoft Windows® Server

iWARP and RoCE Are Different "RDMA over Ethernet" Technologies

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- Both can deliver RDMA storage over Ethernet
- Applications shouldn't care between them
- iWARP
  - 2007 Internet Engineering Task Force (IETF) standard
  - Runs on top of TCP/IP
- RDMA over Converged Ethernet (RoCE)
  - 2010 InfiniBand Trade Association (IBTA) standard
    - Uses an InfiniBand transport on an Ethernet wire
    - Requires Data Center Bridging to establish a lossless L2 fabric
  - 2014 IBTA update for routable "RoCEv2"
    - Adds a UDP/IP ecapsulation in support of routability

Under The Hood: iWARP and RoCE

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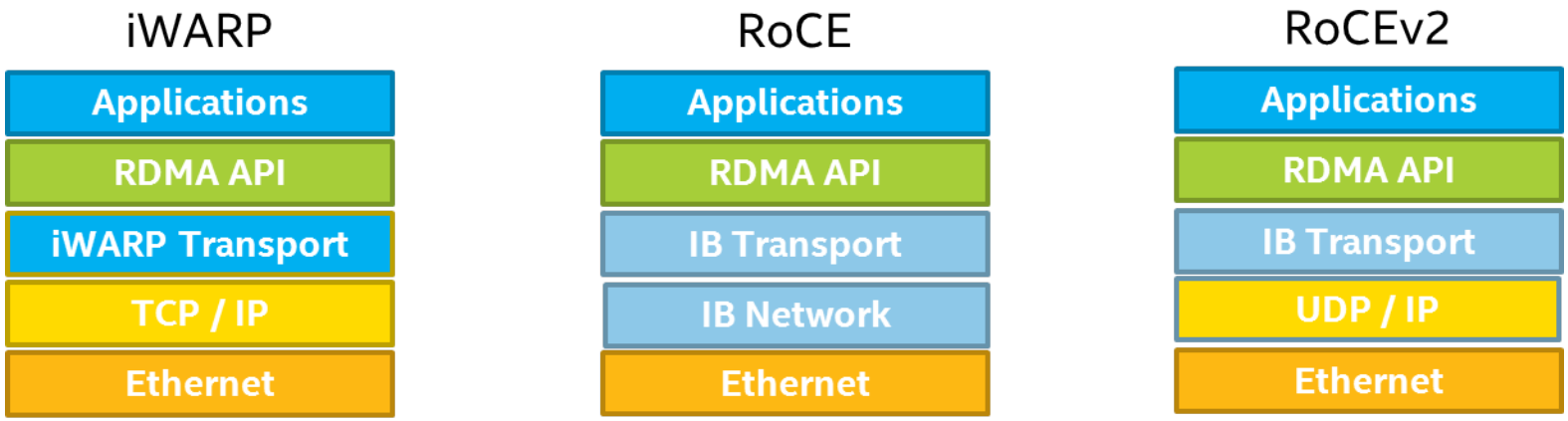
- iWARP and RoCE cannot talk RDMA to each other because of L3/L4 differences
  - iWARP adapters can talk RDMA only to iWARP adapters
  - RoCE adapters can talk RDMA only to RoCE adapters



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Overview of RDMA storage protocols

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- SMB 3 with SMB Direct
  - RDMA-enabled network protocol for file sharing
  - In production. Broad ecosystem including Windows Server 2012 and Windows Server 2012 R2
  - Deep dive by Microsoft later in this presentation
- NFS/RDMA
  - RDMA-enabled Remote Procedure Call (RPC) layer for NFS
  - Defined in RFC 5532, RFC 5666, RFC 5667 (2009-2010)
  - In open source distros for many years, but not widely used
  - Server OS support
    - Linux kernel NFS/RDMA client and server (recent industry effort to reanimate)
    - Oracle Solaris 11 NFS/RDMA client and server, for InfiniBand only

Overview of RDMA storage protocols

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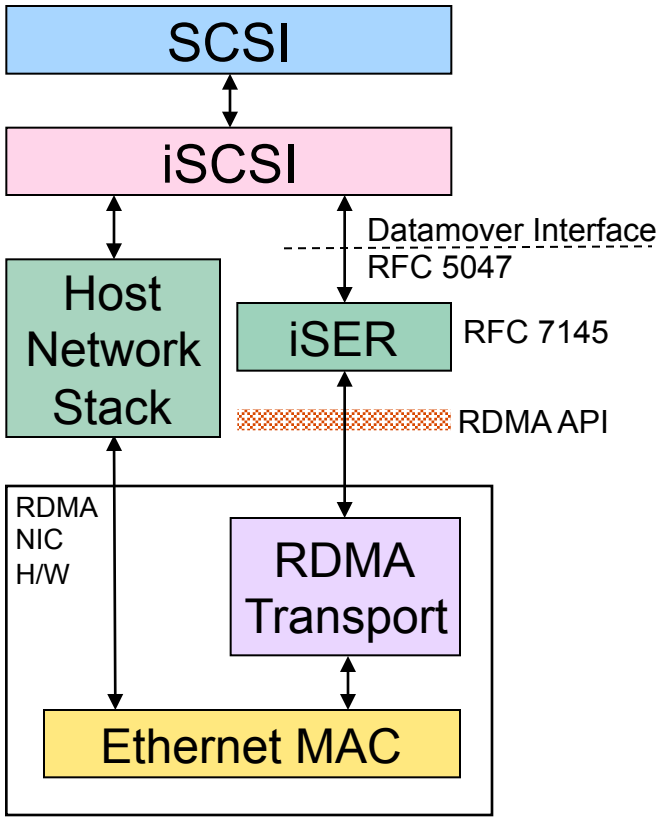
- iSCSI Extensions for RDMA (iSER)
  - Extends iSCSI with an RDMA-enabled Datamover service
  - Defined in RFC 5047 (2007), and RFC 7145 (2014)
  - In production. Growing interest by users and storage vendors
  - Server OS support
    - Linux kernel iSER initiator (kernel-integrated)
    - Linux kernel targets supporting iSER: LIO (kernel-integrated), SCST
    - Linux userspace target supporting iSER: TGT
    - Oracle Solaris 11 iSER initiator/target, for InfiniBand only

iSER Architecture

- iSER provides iSCSI with a Datamover service, which offloads data transfers (Data-In, Data-Out, etc.) to an RDMA NIC
- iSER maintains the existing iSCSI management infrastructure including MIB definition, bootstrapping, negotiation, naming and discovery, and security
- If iSER is not supported by initiator or target, then traditional iSCSI data transfer mode is used
- iSER enables a general-purpose RDMA NIC to handle iSCSI with the efficiency and performance of an iSCSI host bus adapter



Drawing adopted from Chadalapaka 2004, slide 8:
www.ietf.org/proceedings/60/slides/ips-1/ips-1.ppt

Overview of RDMA storage protocols

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- SCSI RDMA Protocol (SRP)
  - Maps SCSI initiator to target using RDMA
  - Defined in T10 (ANSI INCITS 365-2002)
  - Requires out-of-band management for e.g. target discovery
  - Only used with InfiniBand. On Ethernet, iSER is preferred.
- NVMe over Fabrics
  - Proposed open standard for remote block access to NVMe SSDs across an RDMA-enabled fabric
  - Proposed standard currently in definition in the NVM Express Work Group
  - Detailed in another SNIA-ESF webcast available on demand: *The Performance Impact of NVMe and NVMe over Fabrics*

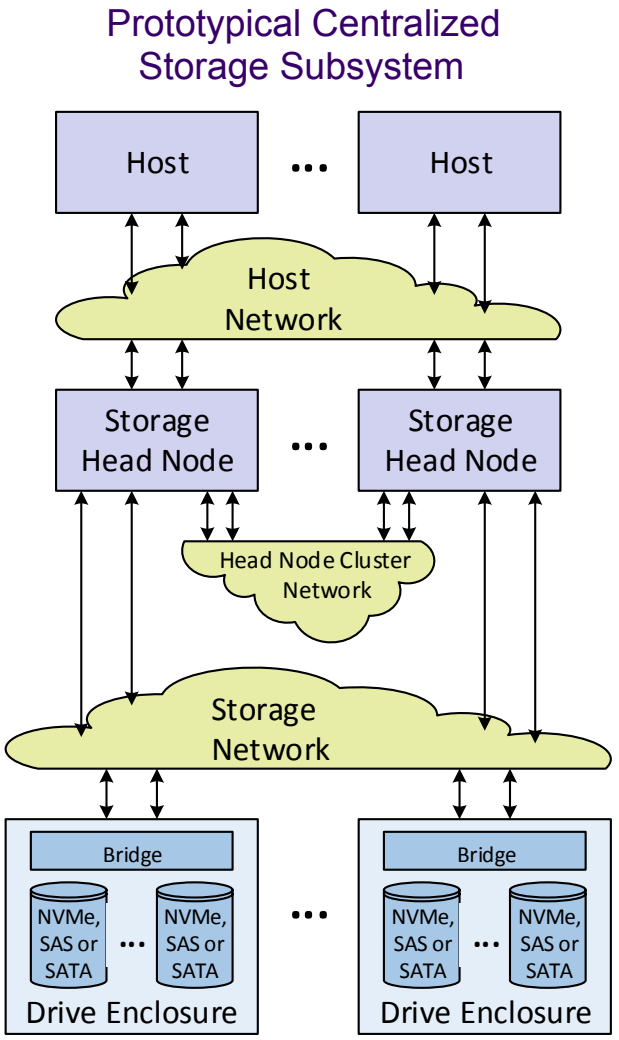
Overview of RDMA storage protocols

- Future topics, out-of-scope for this presentation
  - RDMA-enabled distributed filesystems
    (e.g. Lustre, GPFS, HDFS, Ceph, etc.)
  - RDMA-enablement of scale-out distributed SAN or caching
    (e.g. EMC ScaleIO, VMware Virtual SAN, Dell Fluid Cache, etc.)

SMB 3 with SMB Direct, NFS/RDMA, iSER, and NVMe over Fabrics are designed to work with either iWARP or RoCE

Where is RDMA Used In Storage?

- Prototypical Centralized Storage Subsystem
  - Hosts are storage clients
  - Storage Head Nodes serve files, blocks, objects, or combinations
  - Drive enclosure could be
    - A typical JBOD
    - A server with direct-attached storage
    - A single network-connected NVMe, SAS, or SATA device



Where is RDMA Used In Storage?

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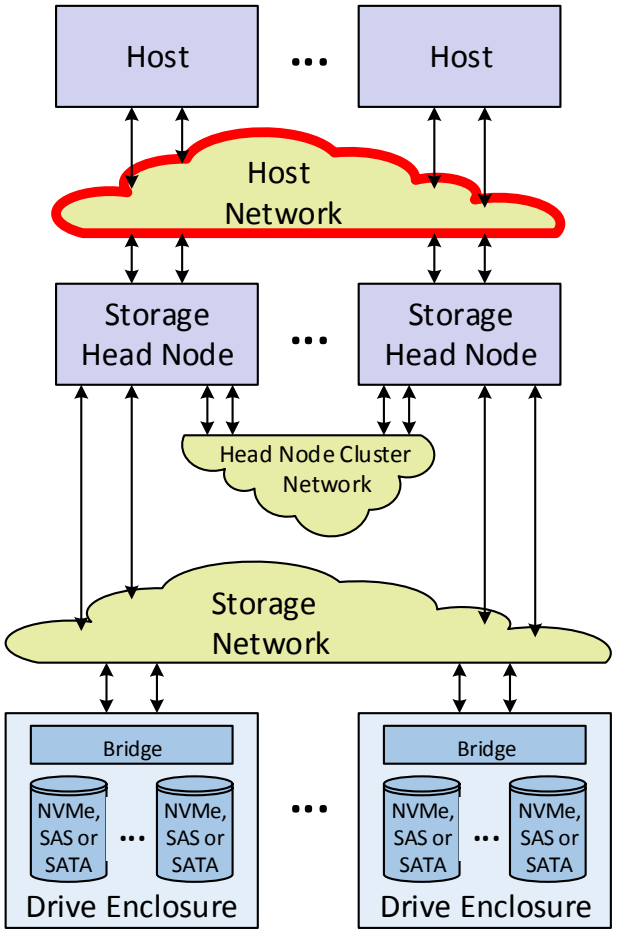
Host Network

As RDMA-enabled Hosts become common, Host Network protocols will shift to take advantage :

- File Storage protocols will shift from SMB or NFS on Ethernet towards *SMB Direct* or NFS/RDMA.
- Block Storage will shift from Fibre Channel, iSCSI, or FCoE towards iSER or *NVMe over Fabrics* for high-performance all-flash storage.

Prototypical Centralized Storage Subsystem



Where is RDMA Used In Storage?

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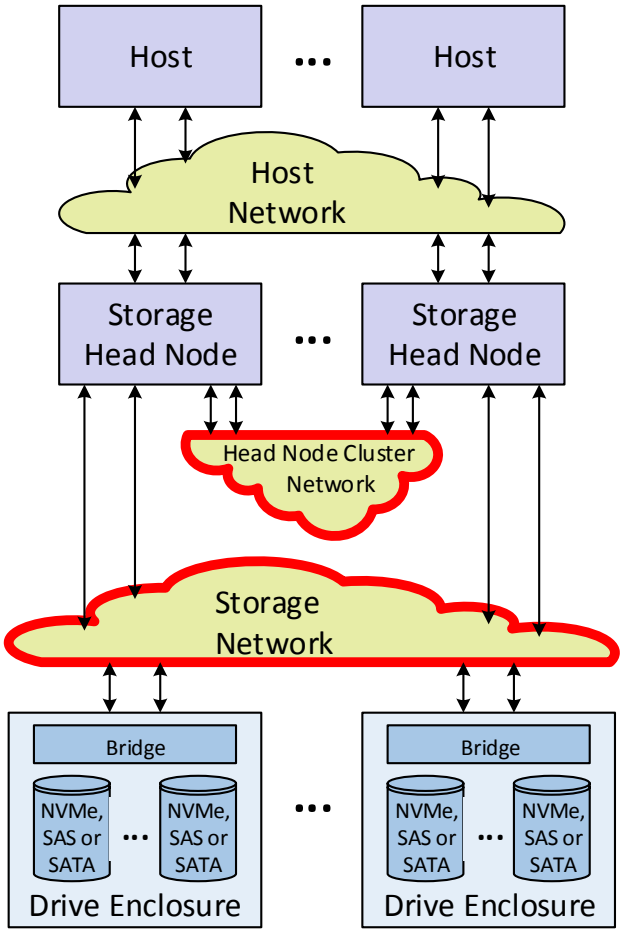
- Head Node Cluster Network
  - Wide variety of networking technologies in use: Ethernet, Fibre Channel, PCIe non-transparent bridging, RapidIO, InfiniBand, etc.
  - Some use RDMA, but storage protocols on this network are typically vendor-specific.
- Storage Network
  - Today, this is SAS, Fibre Channel, or a PCIe fabric with high-performance all-flash storage
  - Industry momentum to transition the Storage Network to Ethernet
  - RDMA protocols are well-suited to this transition
    - iSER, *NVMe over Fabrics*, or combination
  - As the Drive Enclosure Bridge becomes more intelligent/autonomous, other RDMA protocols may emerge

Prototypical Centralized Storage Subsystem



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The Origins of SMB3

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- Enterprise-Class Storage Features with Much Simpler Management
- File sharing semantics (rather than block semantics)
  - Increased flexibility, easier provisioning and management
  - Easy deployment of encryption & signing
- Enterprise class RAS
  - No application downtime for planned maintenance or unplanned failures
  - Extremely fast failover (<10 sec)
- Excellent Performance
  - Near line rate performance for both small and large IOs with RDMA
  - Very low CPU utilization with RDMA
- Work with existing storage investments
- Work on existing and next generation network infrastructure

SMB3 Features

- Remote File Protocol
  - Full file semantics
  - Read/write/metadata
    - Caching, leasing, locking
    - Access control, sharing
  - Enterprise Application-ready
- Performance
  - Scale-Out (scalable server)
  - SMB Direct (RDMA)
  - Multichannel (trunking for bandwidth)
  - Directory Leasing (metadata caching)
  - BranchCache™ V2
  - Server Copy Offload
- Availability
  - Transparent Failover
  - Witness (fast failover)
  - Multichannel (path redundancy)
- Strong Security
  - Encryption – AES-CCM/GCM
  - Signing - AES-CMAC
- Backup
  - Volume Shadow Copy (VSS) for SMB File Shares
- Management
  - PowerShell™ over WS-Man
  - SMI-S File

SMB3 Multichannel

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Full Throughput

- Bandwidth aggregation with multiple NICs
- Multiple CPUs cores engaged when NIC offers Receive Side Scaling (RSS) or Remote Direct Memory Access (RDMA)

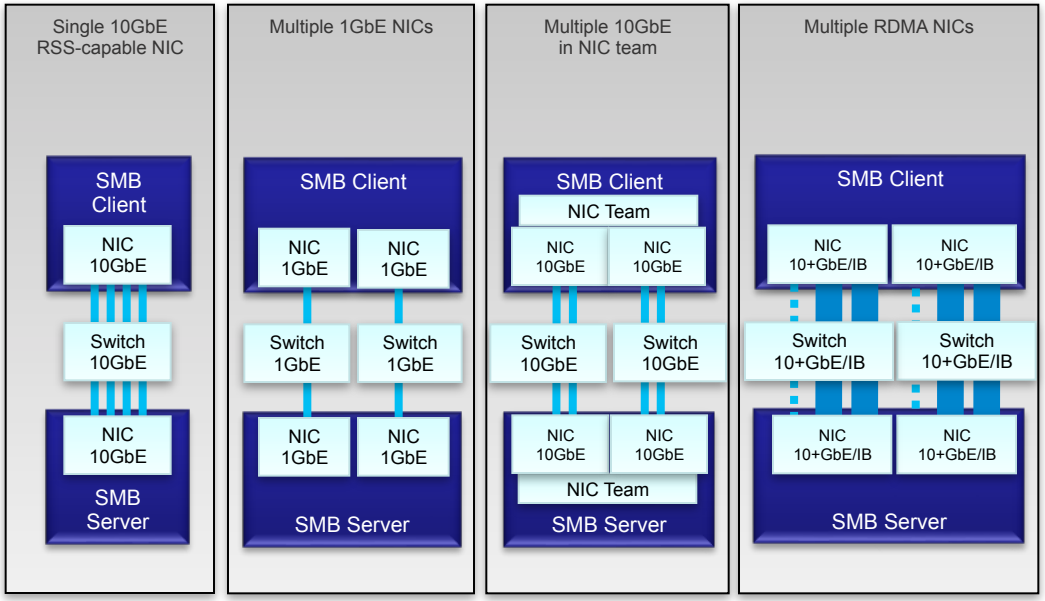
Automatic Failover

- SMB Multichannel implements end-to-end failure detection
- Leverages NIC teaming if present, but does not require it

Automatic Configuration

- SMB detects and uses multiple paths
- Discovers and “steps up” to RDMA

Sample Configurations



SMB Direct

Advantages

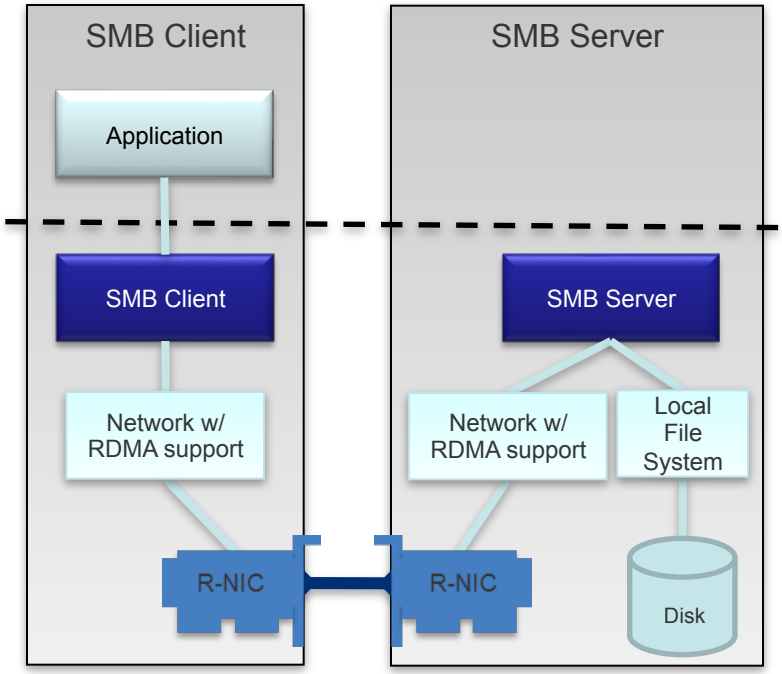
- Scalable, fast and efficient storage access
- High throughput with low latency
- Minimal CPU utilization for I/O processing
- Load balancing, automatic failover and bandwidth aggregation via SMB Multichannel

Scenario

- High performance remote file access for application servers like Virtualization and Databases

Required hardware

- RDMA-capable network interface (R-NIC)
- Three types: iWARP, RoCE and InfiniBand



SMB Direct Protocol Basics

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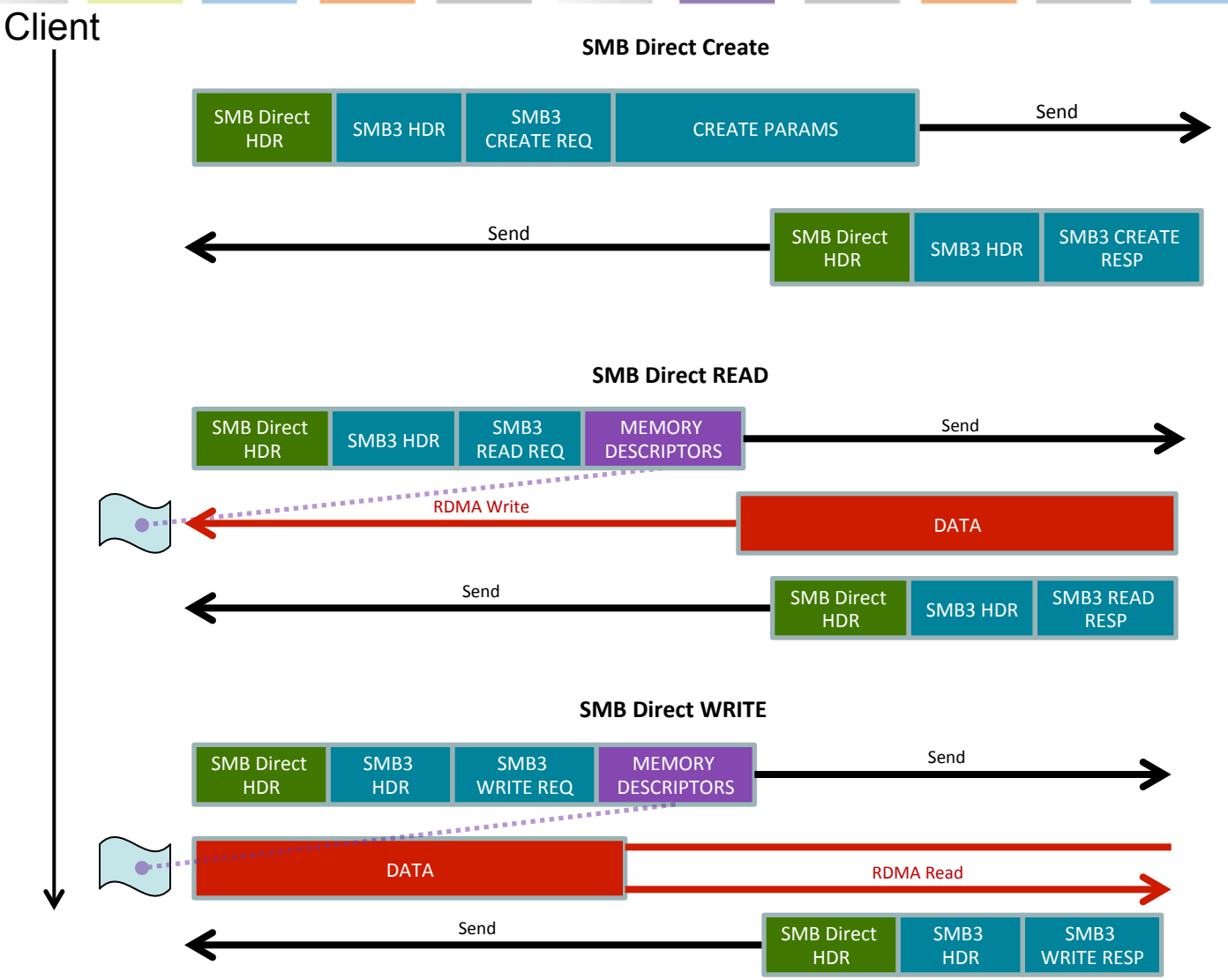
- SMB Direct is a *transport framing*
  - Only 3 message types
- 2-way full duplex transport which supports:
  - Datagram-type send/receive exchange
    - With fragmentation/reassembly for “large” messages (~2KB and up)
  - Direct RDMA Read/Write
    - Bulk data transfer from 4KB to 8MB per operation
- Secure RDMA transfer model:
  - Client buffer advertisement for READ and WRITE
  - Server RDMA buffer access (push/pull)

SMB Direct Transfers

RDMA in RED



SMB3 and SMB Direct Workloads

SMB3 Workloads

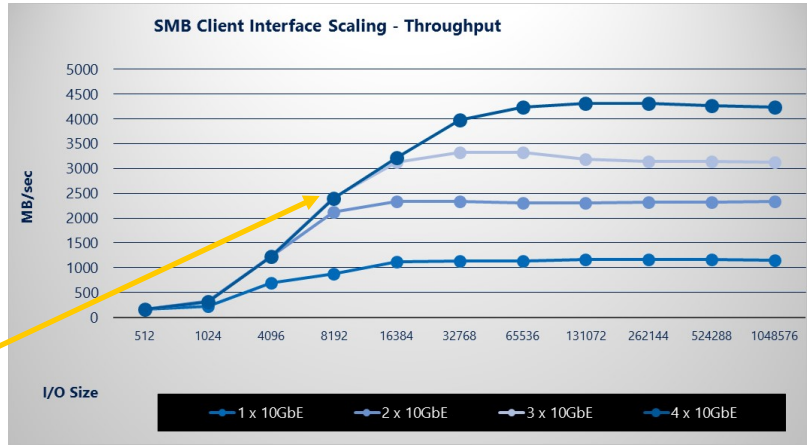
- Storage for Virtualization, database, HPC
- Storage for desktops/laptops/slates (LAN/ WAN)
- Virtual Machine Live Migration between hosts

The Design Point is Private Cloud

- Almost all IOs are small (<64 KB)
  - TCP throughput is significantly **less** due to **CPU saturation**
- SMB Direct (SMB3 support for RDMA)
  - **RDMA enables near line rate** with small IOs

SMB3 Multi-Channel Enables Linear Scaling

- Linear 10GbE scaling with TCP/IP (no RDMA)
- 4300 Mbps with 4x10GbE



Source: Microsoft Sept 2012 white paper provides full details
See http://go.microsoft.com/fwlink/p/?LinkId=227841

SMB3 as Virtual Machine Storage

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- File-based containers
  - Natively support high availability, replication, snapshot/backup
  - Remote file protocols increasingly supported by hypervisors
  - SMB3 Continuous Availability features fully supported by Microsoft Hyper-V
- Workload:
  - 4KB-8KB Random, broad read/write mix
  - Very high **aggregate** IOPS
    - Example rack scaling: 1000 IOPS/VM x 32 VM/U x 32U =~ 1M IOPS
- Low overhead of SMB Direct
  - Less overhead to serve I/O -> more CPU for compute, higher IOPS -> more VM's per rack

SMB3 Storage with RDMA on 40GbE

PRELIMINARY

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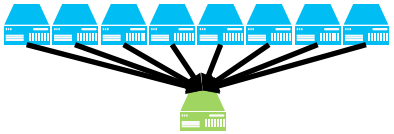
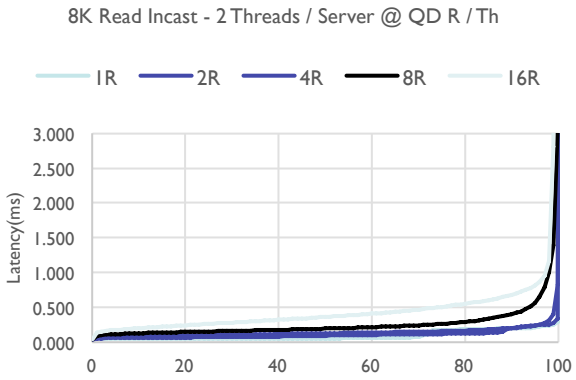
8 KB IOPs* and Latency (ms)
Single client, 8 file servers

QD *R* / Thread	Read IOPs	Latency 50th Read	Latency 99th Read
1	163,800	0.056	0.249
2	291,000	0.094	0.270
4	440,900	0.129	0.397
8	492,400	0.195	1.391
16	510,200	0.363	2.810

Incast Performance



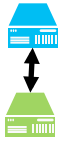
Near line-rate with small IOs
- 33.4 Gbps at 8 KB IO
- Excellent latency variance



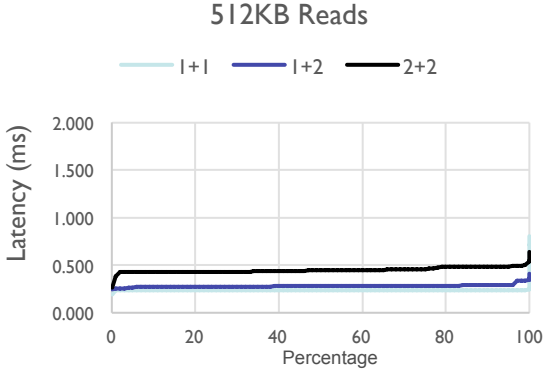
Large IOPs* (512 KB) in Gbps

512KB	Read BW	Write BW
1 Thread		
1 IO	17.82	16.14
2 IO	29.74	23.13
2 Thread		
2 IO/t	37.21	30.61

Client-to-Server Performance



Near line-rate with large IOs
- 37.2 Gbps with 2 threads



Excellent Log Write Performance

- 7.2M Read IOPs*, 512 Byte, single outstanding IO
- 3.3M Write IOPs*, 512 Byte, single outstanding IO

*IOs are not written to non-volatile storage
iWARP used for these results
Test configuration details in backup

Other SMB Uses

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- SMB as a Transport
  - Provides transparent use of RDMA
- Example: Virtual Machine Live Migration
  - Peer-to-peer memory image transfer
- Bulk data transfer, ultimate throughput
  - Memory-to-memory “unconstrained by disk physics”
  - Very low CPU with RDMA – more CPU to support **live migration**
    - Minimal VM operational blackout
- Other SMB3 benefits to migration:
  - SMB3 availability provides transparent storage failover after migration
    - Minimal VM operational blackout, maximum VM availability and load balancing

VM Live Migration Performance

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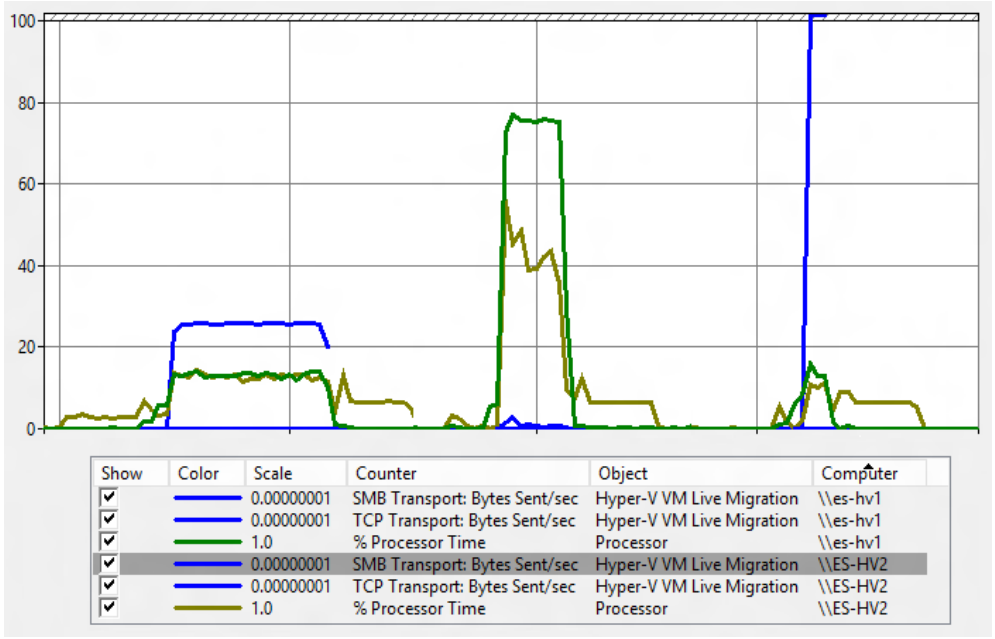
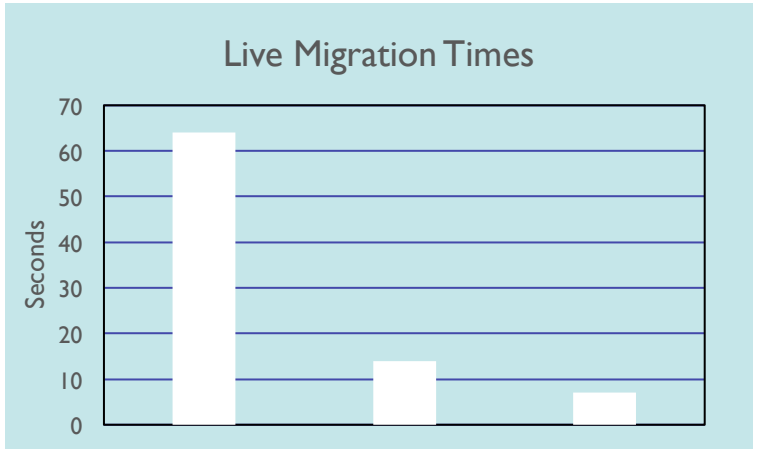
TCP/IP | Compression | SMB+RDMA



- TCP for Live Migration
  - CPU core-limited, long migration time
- TCP with Compression for Live Migration
  - Even more CPU-intensive, reduced migration time
- SMB Direct for Live Migration
  - Minimal CPU, 10x better migration time
  - Greatly increased VM live availability

Live Migration
2x10 GbE RoCE



SMB3 / SMB Direct / RDMA Resources

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- Protocol documentation
  - http://www.microsoft.com/openspecifications
- SNIA education SMB3 tutorial
  - http://www.snia.org/education/tutorials/FAST2015
- SNIA SDC 2014
  - http://www.snia.org/events/storage-developer/presentations14#smb
- Jose Barreto's blog
  - http://smb3.info/
- SNIA-ESF webcast on NVMe over fabrics
  - https://www.brighttalk.com/webcast/663/132761

After This Webcast

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- This webcast and a PDF of the slides will be posted to the SNIA Ethernet Storage Forum (ESF) website and available on-demand
  - http://www.snia.org/forums/esf/knowledge/webcasts
- A full Q&A from this webcast, including answers to questions we couldn't get to today, will be posted to the SNIA-ESF blog
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Thank You

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