The Evolution of iSCSI

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The Journey to Modern iSCSI

- A brief history of iSCSI
- How iSCSI works
  - The basics
  - What makes iSCSI attractive today
- IETF enhancements to iSCSI
- Enhancing iSCSI performance with iSER and RDMA
  - Ethernet
iSCSI History

- SCSI originally designed for communication with storage
- Fibre Channel drove separation of device vs. transport
  - Commands for devices vs. how the commands are transmitted
- iSCSI approach: Use TCP/IP as basis for transport
  - Only mainstream SCSI transport that does no hardware definition
- Defined in IETF RFC 3720 in 2002-2004 (& RFC 7143 in 2014)
  - By IBM, Cisco, HP and others
- Defined block storage over a standard (TCP/IP) network
How iSCSI works

- Encapsulates SCSI commands in TCP/IP packet

- Delivery of iSCSI Protocol Data Unit (PDU) for SCSI

- Reliable data transport and delivery (TCP Windows, ACKs, etc)
- Demux within node (port numbers)

- IP routing capability so packet finds its way through the network
SCSI Concepts

- **Request / Response protocol**
  - There can be no response until there is a request
  - INITIATORS are where requests are created
  - TARGETS are where requests are serviced and responses created

- **SCSI INITIATORS are usually hosts**
  - Compute equipment, like servers or workstations
  - But hosts can also be targets
  - iSCSI initiators can maintain multiple parallel connections to multiple targets
iSCSI Concepts

- **SCSI TARGETS** are usually storage devices
  - But storage devices can also be initiators
  - iSCSI Targets can maintain multiple parallel connections to multiple targets

- **iSCSI** defines several identifiers to enable this:
  - iSCSI names
  - iSCSI initiator session identifiers (ISID)
  - iSCSI connection identifiers (CID)
  - iSCSI target portals (TPGT)
iSCSI is a client-server SCSI transport protocol

iSCSI can run on any physical network that TCP/IP can run on – Ethernet, InfiniBand, ...

Any type of SCSI device can be accessed over iSCSI

Block Storage is the most typical (and the only supported on Windows Server)

Original protocol spec is RFC 3720

RFC 5048 corrects/clarifies the original
RFC 7143 replaces the original
iSCSI Names

- iSCSI names are globally unique
- iSCSI nodes have names
  - Similar to Node World Wide Names (WWN) in Fibre Channel
- iSCSI Qualified Name
  - Used everywhere
- EUI iSCSI Name
  - EUI is the IEEE EUI-64 format (Extended Unique Identifier)
  - EUI-48 and EUI-64 define first 24 bits as the Company ID
  - Example name: eui.02004567A425678D
  - Used few places
- iSCSI Alias
  - “Friendly,” internally viewable, only
1. Initiator
2. Target
3. Initiator Port
4. iSCSI Network Portal
5. iSCSI Session
6. iSCSI Connection
I_T nexus & multi-connection sessions

- iSCSI has native protocol support for combining multiple reliable transport connections into a single iSCSI session
  - “Connection allegiance” for each I/O
  - Scaling throughput with multiple NICs
  - Load balancing and connection failure resiliency for I/Os in progress

- iSCSI is a “SCSI transport protocol”
  - iSCSI in turn relies on a different transport protocol unrelated to SCSI semantics
iSCSI Discovery

- **Static Discovery**
  - Connect using IP address and iSCSI name

- **Dynamic Discovery via SendTargets**
  - Requests all iSCSI names and IP address

\[
\text{SessionType} = \text{Discovery}, \\
\text{SendTargets} = \text{All}
\]

<table>
<thead>
<tr>
<th>Initiator</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>TargetName=iqn.fred</td>
<td></td>
</tr>
<tr>
<td>TargetIP=10.10.10.1,3260,1</td>
<td></td>
</tr>
<tr>
<td>TargetName=iqn.andy</td>
<td></td>
</tr>
<tr>
<td>TargetIP=10.10.10.2,3260,1</td>
<td></td>
</tr>
</tbody>
</table>
iSCSI Discovery, Continued

- **iSNS (Internet Storage Name Service)**
  - Managed by an outside server
  - Similar to DNS
  - Can provide callbacks for changes
  - Rarely used, because storage normally isn’t that dynamic

- **Authentication**
  - IP masking
  - iSCSI name masking
  - Challenge-Handshake Authentication Protocol (CHAP)
  - Target authenticates the initiator
  - Initiator can authenticate the target
**Storage Area Network topology**

- **Initiator**
- IP Storage Area Network (SAN)
- **Target**

**How communication occurs between a target and an initiator**

1. **Discovery of target**
   - Static Configuration
   - Internet Storage Name Service (iSNS)-based discovery
2. **To the discovered iSCSI Target portal**
3. **Security Negotiation**
   - Operational Negotiation
   - Full Feature Phase
   - "I_T nexus"
4. **Starting with INQUIRY and REPORT LUNS**
   - Read, Write, Data transfer, Response
5. **Session Logout**
6. **Ends the “I_T nexus”**
7. **None of the Logical Units (LUs) can be accessed**
8. **Gracefully (TCP FIN) or ungracefully (TCP RST)**
SCSI I/O Mapping onto iSCSI transport

Don’t forget async events that can happen any time….
- Connection drops
- Session drops
- PDU drops
- Application timeouts
- Initiator cluster failovers
- SCSI errors
- Implementation code bugs
- ...

iSCSI spec includes prescriptive Error Recovery semantics – including formal negotiation support for inter-operation between initiator and target implementations with asymmetric capabilities
How iSCSI Changed the Storage Game

- Transport over commodity, established protocols
- Login redirection
- Data readiness modifications
- Software Initiators rule the day
Commodity Transport

- iSCSI defined encapsulation method, nothing else
  - Fibre Channel, SAS define Layers 0-2
- Every win for Ethernet is a win for iSCSI
  - 10Mbit to 100Gbit and beyond with the same standard
  - VLANs provide ZONE fencing that Fibre Channel wrestled with
- Ethernet NIC technology helps out seamlessly
  - LRO, TSO, TOE apply
  - Data Center Bridging added a class for iSCSI, iSCSI didn’t need to add it
- TCP/IP FTW!
  - Resiliency out of the box, with multi-layer flow-control
  - Security (firewalls), In-flight encryption (IPSEC), Routing (you name it)
Data Center Bridging

- Make use of FCoE features for iSCSI
  - iSCSI given its own class
  - Slight performance gain, provide consistent bandwidth
- Priority-based Flow Control – IEEE 802.1Qbb
  - “Lossless” – really less loss
- Enhanced Transmission Selection IEEE 802.1Qaz
  - Assignment of bandwidth for classes
- Congestion Notification – IEEE 802.1Qau
  - End-to-end congestion management
- DCBX IEEE 802.1AB
  - Negotiation of DCB parameters
iSCSI Login Redirection

- iSCSI can temporarily reroute sessions
  - Load balancing
  - Ability to scale out
  - Self healing
  - Rolling upgrades

1. Login iqn.fred, ip 10.1.1.1
2. Target temporarily moved, ip 10.1.1.2
3. Login iqn.fred, ip 10.1.1.2
Data and Status Readiness Improvements

- Eliminates some of the end-to-end traffic for coordination
- Immediate data
  - Allows data to be sent with write commands
  - Size negotiated at login
  - Especially valuable with small writes
- Initial ready to transmit (InitialR2T)
  - First write data PDU to be sent immediately after the command
- Read response included with data
  - An OK status can be returned with the last data PDU for a read
Software Defined iSCSI

- The final benefit of being commodity-based
- Initial push for hardware iSCSI HBAs was short-lived
- Multicore CPUs meant the host could be the initiator
  - Additional cores far cheaper than HBAs
- Scalability comes with core speed and count
- Provides virtual systems with SAN support
  - No need to hand off complete HBA
  - No need to emulate iSCSI HBA
- Supported in every mainstream host base-OS
  - MS, Linux, VMware, Solaris
IETF Enhancements for iSCSI

- New RFCs
- PDU and SCSI Enhancements
- Task Management Updates
- Key Changes
RFC 7143 & 7144: Goals

- **7143: iSCSI spec consolidation**
  - Goal: pulling together about half a dozen older RFCs into one coherent spec, making “minor” modifications to improve interop, and obsoleting a few specific unimplemented features

- **7144: SAM-5 compliance of iSCSI**
  - Goal: Extending iSCSI protocol to be a SAM-5-compliant storage transport protocol, negotiable at a session granularity, fully compatible
SCSI PDU Updates

- **Command Priority**
  - An IN argument to the SAM-5 Execute Command () procedure call model
  - Indicates the relative scheduling importance of this task in comparison to other SIMPLE tasks
  - SCSI Command PDU addition (4-bits)

- **Status Qualifier**
  - An OUT argument to the SAM-5 Execute Command () procedure call model
  - Status qualifier provides additional information about the reason for the status code
  - SCSI Response PDU addition (2 bytes)
Allowance for sense data

- Typically, Sense Data is in DataSegment if the status is CHECK CONDITION
- New draft explicitly allows Sense Data to be present anytime, independent of status
Following new Reason Codes are now allowed in an iSCSI TMF Request PDU

- QUERY TASK (9): is the Referenced Task Tag present in the task set?
- QUERY TASK SET (10): is there a task from “my” I_T_L nexus in the task set?
- I_T NEXUS RESET (11): perform an I_T nexus loss function for all LUs accessible via “my” I_T nexus
- QUERY ASYNCHRONOUS EVENT (12): is there a unit attention condition or a deferred error pending for “my” I_T_L nexus?

New TMF Response “Function succeeded” (equivalent to the FUNCTION SUCCEEDED SAM-4 service response)
New session-scoped (LO) text key
- iSCSIProtocolLevel negotiation decides the iSCSI protocol features that may be used on the session
- Plan is that each new standards-track RFC with protocol features will “claim” a new value
- Higher negotiated value → implicit support for lower numbered values
- Current legal values
  - 0: no version claimed
  - 1: iSCSI Consolidated RFC compliance (7143)
  - 2: iSCSI SAM-4 RFC compliance (7144)
1. Consolidates RFCs 3720, 3980, 4850 and 5048, and made the necessary editorial changes
2. Claims a value for the new iSCSIProtocolLevel
3. Removes Markers and related keys
4. Removes SPKM authentication and related keys
5. Explicitly allows initiator+target implementations, including the composite device naming
6. Clarifies that SLP-based discovery cannot be relied on for interoperability
7. Specifies formal protocol artifact relationships via UML diagrams
Key Change List… (contd)

8. Makes FastAbort implementation a "SHOULD" from the previous "MUST"

9. Requires implementing IPsec, 2400-series RFCs (IPsec v2, IKEv1); and SHOULD implement IPsec, 4300-series RFCs (IPsec v3, IKEv2).

10. Restricts the usage of X#, Y# and Z# name prefixes

11. Provides guidance on minimal number of text negotiation responses

12. Provides guidance on Kerberos authentication, OCSP usage, and extended sequence numbers (ESNs)
iSCSI Extensions for RDMA

- What is iSCSI with RDMA
- How it’s defined
- Read and Write Examples
- Performance comparisons
Remote Direct Memory Access extends DMA across a network

Refresher: Yeah, I’ve heard of DMA

DMA allows a device to directly read or write host memory
  • No copy from device to host memory
  • No context switch
  • Offloads host CPU
Remote DMA

- Extends the concept of DMA to remote devices
- Eliminates the inevitable read/copy when receiving from a network
- Small but measurable win with traditional I/O
- New protocols added to traditional transports
  - iSCSI extensions to TCP/IP for RDMA (iWARP)
  - RDMA over converged Ethernet (RoCE, “rocky”)
**iSER is an Open Standard**

- **IETF Standard** [RFC-7145](#)
- Choice of iSER or iSCSI TCP transparent to the application and user
- Runs on top of InfiniBand, iWARP, and RoCE
RDMA with iSCSI

- iSCSI
  - iSER
  - RDMAP-DDP-MPA
    - TCP
  - RDMAP-DDP-MPA
    - TCP

iSCSI with iWARP acceleration

- iSCSI
  - iSER
  - IB Reliable Transport
    - IB Reliable Transport

iSCSI with IB acceleration

RNIC-offloaded

HCA-offloaded
iSER: Coming of Age

- iWARP continues iSCSI commodity approach
  - Layered on top of tradition TCP/IP, with all the benefits
- ROCe
  - Layered on UDP/IP
- No traditional reads or writes
- New Datamover Interface
  - Defines which end controls memory
- Initiator sends control to target
- Target gets or sends data
- Target returns control to initiator
iSER Read example

Command Request Read  
Send Control  
SCSI Command Read  
RDMA Write  
RDMA Write  
RDMA Write  
SCSI Response  
Control Notify  
Control Notify  
Queue command  
Put Data  
Put Data  
Put Data  
Send Data-in  
Send Data-in  
Send Data-in  
Status and Sense

iSER Write example

iSER Enables More IOPS

Storage IOPs LIO Targets (64)

- **ConnectX-4 100 GbE iSER**: 3,974 IOPS
- **ConnectX-4 100 GbE iSCSI**: 1,500 IOPS
- **ConnectX-4 Lx 25 GbE iSER**: 3,930 IOPS
- **ConnectX-4 Lx 25 GbE iSCSI**: 1,569 IOPS
iSER Reduces Latency

Storage IO Handling Latency  LIO Targets (64)

- Lower is Better

- Latency (us)

- ConnectX-4 100 GbE iSER
- ConnectX-4 100 GbE iSCSI
- ConnectX-4 Lx 25 GbE iSER
- ConnectX-4 Lx 25 GbE iSCSI
iSER Frees Up The CPU

Lower is Better

iSER vs. iSCSI Target Host CPU% LIO Targets (16)

Lower is Better

CPU %

Write Blok size 128KB

- ConnectX-4 Lx 25 GbE iSER
- ConnectX-4 Lx 25 GbE iSCSI

2.32 vs. 10.11
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