NVMe™ Management Interface (NVMe-MI™) and Drivers Update

Sponsored by NVM Express® organization, the owner of NVMe™, NVMe-oF™ and NVMe-MI™ standards
Agenda

• Session Introduction – Uma Parepalli, Marvell (Session Chair)
• NVMe Management Interface - Austin Bolen, Dell EMC and Myron Loewen, Intel
• NVMe Driver Updates
  • NVMe Driver Ecosystem and UEFI Drivers - Uma Parepalli, Marvell
  • Microsoft Inbox Drivers - Lee Prewitt, Microsoft
  • Linux Drivers - Dave Minturn, Intel
  • VMware Drivers - Suds Jain, VMWare
• SPDK Updates - Jim Harris, Intel
NVMe™ Management Interface (NVMe-MI™) Workgroup Update

Austin Bolen, Dell EMC
Myron Loewen, Intel
Agenda

- NVMe-MI™ Workgroup Update
- NVMe-MI 1.0a Overview
- What’s new in NVMe-MI 1.1
  - In-band NVMe-MI
  - Enclosure Management
  - Managing Multi NVM Subsystem Devices
- Summary
NVM Express®, Inc. 120+ Companies defining NVMe™ together

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NVMe Base and NVMe Over Fabrics
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Management Intf. Workgroup
Out-of-band management over SMBus and PCIe® VDM
Chair: Peter Onufryk
Vice Chair: Austin Bolen

Interop (ICC) Workgroup
Interop & Conformance Testing in collaboration with UNH-IOL
Chair: Ryan Holmqvist
NVM Express™ Roadmap

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<th>Year</th>
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**NVM Express (NVMe)**

- **NVMe 1.2 Nov’14**
  - Namespace Management
  - Controller Memory Buffer
  - Host Memory Buffer
  - Live Firmware Update

- **NVMe 1.2.1 May’16**

- **NVMe 1.3 May’17**
  - Sanitize
  - Streams
  - Virtualization

- **NVMe ofF 1.0 May’16**
  - Transport and protocol
  - RDMA binding

- **NVMe ofF (next)**
  - IO Determinism
  - Persistent Memory Region
  - Persistent Event Log
  - Multipathing

- **NVMe MI 1.0 Nov’15**
  - Out-of-band management
  - Device discovery
  - Health & temp monitoring
  - Firmware Update

- **NVMe MI 1.0a April’17**

- **NVMe MI 1.1**
  - In-band Mechanism
  - Enclosure Management
  - Multi NVM Subsystem Devices

- **NVMe MI (next)**
  - Enhanced Discovery
  - In-band Authentication
  - TCP Transport Binding

* Released NVMe specification
* Planned release

* Subject to change
NVMe-MI™ Ecosystem

- Commercial test equipment for NVMe-MI
- NVMe-MI 1.0a compliance testing program has been developed
  - Compliance testing started in the May 2017 NVMe™ Plugfest conducted by the University of New Hampshire Interoperability Laboratory (UNH-IOL)
  - 7 devices from multiple vendors have passed compliance testing and are on the NVMe-MI Integrators List
- Servers are shipping that support NVMe-MI
What is the NVMe™ Management Interface 1.0a?

A programming interface that allows out-of-band management of an NVMe Storage Device Field Replaceable Unit (FRU)
Out-of-Band Management and NVMe-MI™

- **Out-of-Band Management** – Management that operates with hardware resources and components that are *independent of the host operating system control*

- **NVMe™ Out-of-Band Management Interfaces**
  - SMBus/I2C
  - PCIe Vendor Defined Messages (VDM)
NVMe-MI™ Out-of-Band Protocol Layering

- **Management Applications** (e.g., Remote Console)
- **Management Controller** (BMC)
- **NVMe Management Interface**
- **Management Component Transport Protocol (MCTP)**
  - MCTP over SMBus/I2C Binding
  - MCTP over PCIe VDM Binding
- **SMBus/I2C**
- **PCIe**
- **PCIe SSD**

**Layers**
- Application Layer
- Protocol Layer
- Transport Layer
- Physical Layer
NVMe™ Storage Device in 1.0a

- **NVMe Storage Device** – One NVM Subsystem with one or more ports, vital product data (VPD), and an optional SMBus/I2C interface
In-Band Management and NVMe-MI™

- In-band mechanism allows application to tunnel NVMe-MI commands through NVMe™ driver
  - Two new NVMe Admin commands
    - NVMe-MI Send
    - NVMe-MI Receive

- Benefits
  - Provides management capabilities not available in-band via NVMe commands
    - Efficient NVM Subsystem health status reporting
    - Ability to manage NVMe at a FRU level
    - Vital Product Data (VPD) access
    - Enclosure management
NVMe-MI™ over NVMe-oF™

Plumbing in place for NVMe-MI over NVMe-oF
Enclosure Management

- SES Based Enclosure Management
  - Technical proposal developed in NVMe-MI™ workgroup
  - While the NVMe™ and SCSI architectures differ, the elements of an enclosure and the capabilities required to manage these elements are the same
    - Example enclosure elements: power supplies, fans, display or indicators, locks, temperature sensors, current sensors, voltage sensors, and ports
  - Comprehensive enclosure management that leverages SCSI Enclosure Services (SES), a standard developed by T10 for management of enclosures using the SCSI architecture
Multi NVM Subsystem Management
NVMe-MI™ 1.0a NVMe™ Storage Device

- **NVM Storage Device** – One NVM Subsystem with one or more ports and an optional SMBus/I2C interface

![Diagram of NVMe-MI™ 1.0a NVMe™ Storage Device](image)

- Single Ported PCIe SSD
- Dual Ported PCIe SSD with SMBus/I2C
NVMe™ Storage Device with Multiple NVM Subsystems

M.2 Carrier Board from Amfeltec

ANA Carrier Board from Facebook
SMBus Topology for NVMe-MI™ 1.0
Multiple NVM Subsystems on a single SMBus Port

- Describe topology in new VPD MultiRecord
- Add UDID types for additional devices like Mux
Support Expansion Connectors

- New VPD address to avoid conflicts with plugged in devices
- Optional Labels for each connector to assist technicians
A Connection Graph Between Element Types
**Single Port Example (35 bytes of 256B EEPROM)**

<table>
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<tr>
<th>Header</th>
<th>Record: 0Dh</th>
<th>Record Format: 82h</th>
<th>Record Length: 23h</th>
<th>Record Chcksm: 34h</th>
<th>Header Chcksm: 75h</th>
<th>Version Number: 00h</th>
<th>Rsvd: 00h</th>
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<tr>
<td>Element 0</td>
<td>Type: Host 01h</td>
<td>Element Length: 08h</td>
<td>Form Factor: 12h</td>
<td>SMBus Dest: 02h</td>
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<td>Link 0 Start: 00h</td>
<td>Link 0 Dest.: 02h</td>
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<tr>
<td>Element 1</td>
<td>Type: Power 02h</td>
<td>Element Length: 08h</td>
<td>Thermal Load: 0Fh</td>
<td>Vaux Load: 32h</td>
<td>Rail Options: 00h</td>
<td>Rail Voltage: 78h</td>
<td>12V initial: 08h</td>
<td>12V max: 0Fh</td>
</tr>
<tr>
<td>Element 2</td>
<td>Type: NVMe 09h</td>
<td>Element Length: 13h</td>
<td>MCTP Address: 3Ah</td>
<td>SMBus speed: 01h</td>
<td>PCIe Ports: 12h</td>
<td>Port 0 Speed: 0Fh</td>
<td>Port 0 Flags: 01h</td>
<td>Total NVM Capacity (MSB first): 00000000000000000000000000000000h</td>
</tr>
</tbody>
</table>
2 NVM Subsystems with Mux (82)

Dual Port with Expansion Connectors (78)
Summary

- NVMe-MI™ 1.0a is gaining market acceptance and is available in shipping products
- NVMe-MI 1.1 is nearing completion
  - Significant new features
    - In-band mechanism
    - Enclosure management
    - Support for multi NVM subsystem management
- It is time to start thinking about anchor features for NVMe-MI 1.2
Additional Material on NVMe-MI™

• BrightTALK Webinar

• Flash Memory Summit 2017
  o Video:
    o https://www.youtube.com/watch?v=daKL7tIvNII
    o https://www.youtube.com/watch?v=Daqj-XqICo8

• Flash Memory Summit 2015

• Flash Memory Summit 2014

• NVMe-MI Specification
  o https://nvmexpress.org/resources/specifications/
References


MCTP Base Spec: https://www.dmtf.org/sites/default/files/standards/documents/DSP0236_1.3.0.pdf

MCTP SMBus/I2C Binding:
https://www.dmtf.org/sites/default/files/standards/documents/DSP0237_1.1.0.pdf

MCTP PCIe VDM Binding:
https://www.dmtf.org/sites/default/files/standards/documents/DSP0238_1.0.2.pdf

IPMI Platform Management FRU Information Storage Definition:
UEFI NVMe™ Drivers Update

Uma Parepalli, Marvell
NVMe™ Driver Ecosystem

Robust drivers available on all major platforms
NVM Express® Website – Drivers Home Page
UEFI NVMe™ Drivers – What is new

• UEFI drivers available for a while on Intel platforms.

• ARM processor based systems now have built-in NVMe specification compliant UEFI driver and boot to Windows and Linux Operating Systems.
Linux NVMe™ over Fabrics Drivers
Supporting NVMe over RDMA, Fibre Channel, TCP and iWARP

Marvell (former Cavium) contributed the NVMe-oF™ Drivers to the Linux Upstream
Windows Inbox NVMe™ Driver

Lee Prewitt, Microsoft
Agenda

• New Additions for Spring Update (RS4)
• New Additions for Fall Update (RS5)
• Futures
NVMe™ Additions for Spring Update (RS4)

• DMA remapping support for StorNVMe
• F-State stair stepping when not in Modern Standby
New Additions for Fall Update (RS5)

- Asynchronous event request support for Namespace Change Notification
- Device Telemetry
- Support for extended log page
Futures*

• D3 enabled by default on lowest power state
• Support for interface to Host Controlled Thermal Management
• Support for NVM Sets
• Support for Endurance Group Information
• Support for Namespace Management

*Not plan of record
Linux NVMe™ Driver Update

Dave Minturn, Intel Corp.
A Year in the Life of Linux NVMe™ Drivers

Linux Kernel Releases

2017
- Aug 4.13
- Sept 4.14
- Oct 4.15
- Nov
- Dec
- Jan
- Feb
- March
- April
- May
- June
- July
- Aug

2018
- Aug
- Sept
- Oct
- Nov
- Dec
- Jan
- Feb
- March 4.16
- April 4.17
- May 4.18
- June
- July
- Aug 4.19

Key Features:
- 4.13: NSID_ALL, FW activate w/o reset, CMB Fixes
- 4.14: SGLs, Native MP, User-level Notify, Misc. fixes
- 4.15: Many misc. fixes
- 4.16: File backed NS, Misc. fixes
- 4.17: 16K incap data AENs, Buffered I/O, Tracepoints
Projected NVMe™ Driver Features For Next 12 Months

NVMe-oF™ Host/Target Driver functionality based on NVMe-oF 1.1 features
- NVMe/TCP Transport  (available today to NVMe.org Driver WG members)
- Discovery Log AEN
- Flow Control Negotiation
- Authentication
- Transport SGLs and Error Codes

NVMe Host Core and PCIe transport functionality based on NVMe 1.4 features
- Asymmetric Namespace Access (ANA)
- Persistent Memory Region (PMR)
- Determinism and NVM Sets
- Host Memory Buffers
NVMe™ Host Driver Components

NVMe Host Driver Components

NVMe-oF
- Configuration
- Discovery
- Fabrics
- Commands

NVMe Core
- Admin
- Commands
- NVMe I/O
- Commands

PCIe Transport
(Memory based SQ/CCQ)
(Doorbell Registers)

RDMA Transport
(RDMA QP based SQ/CCQ)

Fibre Channel Transport
(FC-NVMe)

TCP Transport
(Coming Soon)

Linux blk-mq interface(s)
queue_rq()
NVMe-oF™ Target Driver Components

[Diagram showing the components of NVMe-oF Target Driver]

- Transport Components:
  - Loopback
  - RDMA Transport (RDMA QP-based SQ/COQ)
  - Fibre Channel Transport (FC-NVMe)
  - TCP Transport (Coming Soon)

- Function Components:
  - Discovery
  - Configuration
  - Fabric Commands
  - Admin Commands
  - NVM I/O Commands
    - File Backed Namespaces
    - Block Backed Namespaces

- Interface Components:
  - Linux File I/O
  - Linux Block I/O
  - Linux ConfigFS
Linux NVMe™ Driver References

• NVMe Specifications and Ratified TPs available publically at:  
  http://nvmexpress.org/resources/specifications/

• NVMe Linux Drivers Sources  
  www.kernel.org (mainline and stable)

• NVMe Linux Driver Reflector (for the latest patches and RFCs)  
  https://lists.infradead.org/mailman/listinfo/linux-nvme

• NVMExpress.org Linux Fabrics Driver Working Group (members only)  
  • Access to NVMe-oF Drivers based on non-public specifications
NVM Express® in vSphere Environment

Sudhanshu (Suds) Jain, VMware
Agenda

• NVMe™ Driver EcoSystem in vSphere 6.7
• Future Direction
NVMe™ Focus @VMWare

**Driver**
- Boot (UEFI)
- Firmware Update
- End-to-end protection
- Deallocate/TRIM/Unmap
- 4K
- SMART, Planned hot-remove

**Core Stack**
- Reduced serialization
- Locality improvements
- vNVMe Adaption layer
- Multiple completion worlds support in NVMe

**Virtual Devices**
- NVMe 1.0e spec
- Hot-plug support
- VM orchestration

**vSphere 6.5**

**vSphere 6.7**
- Performance enhancements
- Extended CLI
- Name space management
- Async event error handling
- Enhance diagnostic logs

**Future Direction**
- NVMe Over Fabric
- Multiple fabric option
- SR-IOV

- Optimized stack - Highly parallel execution for single path local NVMe devices
- Reach target of 90%+ performance of device spec
- NVMe Multi-pathing

- Next Generation Storage Stack with ultra-high IOPS
- End-to-end NVMe Stack

- Rev the specification
- Parallel execution @backend
- 4K Support
- Scatter-gather support
- Interrupt coalescing

**Future Direction**
NVMe™ Performance Boost

Hardware:
- Intel® Xeon® E5-2687W v3 @3.10GHz (10 cores + HT)
- 64 GB RAM
- NVM Express™ 1M IOPS @ 4K Reads

Software:
- vSphere™ 6.0U2 vs. Future prototype
- 1 VM, 8 VCPU, Windows® 2012, 4 VMDK eager-zeroed
- IOMeter: 4K seq reads, 64 OIOs per worker, even distribution of workers to VMDK

The information in this presentation is intended to outline our general product direction and it should not be relied on in making a purchasing decision. It is for informational purposes only and may not be incorporated into any contract.
(Future) NVMe™ Driver Architecture

ESXi Storage Stack

ESXi Next Generation Storage Stack

NVMe Transport Device Driver Framework

PCIe Transport Driver

RDMA Transport Driver (RoCEv1, RoCEv2, iWarp)

Fibre Channel Transport Driver

Stack Interface 1

SCSI NVMe Translation

NVMe Core Functionality

CLI

NVMe-oF Transport Abstraction

Driver Interface

vmknvue
NVMe™ Driver Ecosystem

- Available as part of base ESXi image from vSphere 6.0 onwards
  - Faster innovation with async release of VMware NVMe driver
- VMware led vSphere NVMe Open Source Driver project to encourage ecosystem to innovate
  - [https://github.com/vmware/nvme](https://github.com/vmware/nvme)
- Broad NVMe Ecosystem on VMware NVMe Driver
  - Close to 300 third party NVMe devices certified on VMware NVMe driver
Storage Performance Development Kit and NVM Express®

Jim Harris, Intel Data Center Group
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NVMe™ Software Overhead

- NVMe Specification enables highly optimized drivers
  - No register reads in I/O path
  - Multiple I/O queues allows lockless submission from multiple CPU cores in parallel
- But even best of class kernel mode drivers have non-trivial software overhead
  - 3-5us of software overhead per I/O
  - 500K+ IO/s per SSD, 4-24 SSDs per server
  - <10us latency with latest media (i.e. Intel Optane™ SSD)
- Enter the Storage Performance Development Kit
  - Includes polled-mode and user-space drivers for NVMe
Storage Performance Development Kit (SPDK)

- Open Source Software Project
  - BSD licensed
  - Source code: http://github.com/spdk
  - Project website: http://spdk.io
- Set of software building blocks for scalable efficient storage applications
  - Polled-mode and user-space drivers and protocol libraries (including NVMe™)
- Designed for NAND and latest generation NVM media latencies
NVMe™ Driver Key Characteristics

- Supports NVMe 1.3 spec-compliant devices
- Userspace Asynchronous Polled Mode operation
- Application owns I/O queue allocation and synchronization
- NVMe Features supported include:
  - End-to-end Data Protection
  - SGL
  - Reservations
  - Namespace Management
  - Weighted Round-Robin
  - Controller Memory Buffer
  - Firmware Update
  - Asynchronous Event Requests
NVMe™ Driver Key Characteristics

- Driver Features and Capabilities include:
  - Hotplug
  - Error Injection
  - Open Channel
  - Device Quirks
  - Configurable Timeouts
  - Configurable I/O Queue Sizes
  - Raw Command APIs
  - NVMe™ over Fabrics
  - fio plugin
NVMe™ Driver Performance Comparison

Throughput (Single Intel Xeon® core)

Throughput (Scaling with multiple Intel Xeon® cores)

System Configuration: 2S Intel(R) Xeon(R) Platinum 8180 CPU @ 2.50GHz, 192GB DDR4 Memory, 6x Memory Channels per socket, 1 16GB 2667 DIMM per channel, Fedora 27, Linux kernel 4.15.15-300.fc27.x86_64, BIOS: HT enabled, p-states enabled, turbo enabled, SPDK 18.04, numjobs=1, direct=1, block size 4k 22 Intel® SSD DC P4600 (2 TB, 2.5in PCIe 3.1 x4, 3D1 TLC) 8 on socket 0 and 14 on socket 1.
NVMe-oF™ Initiator

- Common API for local and remote access
  - Differentiated by probe parameters
- Pluggable fabric transport
  - RDMA supported currently (using libibverbs)
  - Allows for future transports (i.e. TCP, FC)
SPDK Architecture

Storage Protocols
- NVMe-oF™ Target
- RDMA
- TCP
- vhost-nvme Target
- iSCSI Target
- vhost-scsi Target
- vhost-blk Target
- Linux nbd

Storage Services
- Block Device Abstraction (bdev)
  - QoS
  - Logical Volumes
  - GPT
  - Encryption
  - virtio (scsi/blk)
  - iSCSI
  - malloc
- NVMe
- Linux AIO
- Ceph
- RBD
- PMDK blk
- virtio
- blk

Drivers
- NVMe Devices
  - NVMe-oF Initiator
  - RDMA
  - TCP
  - NVMe™ PCIe Driver
- virtio
  - virtio-PCIe
  - vhost-user
- Intel® QuickData Technology Driver

SPDK 18.07 In Progress
SPDK Architecture

- **Storage Protocols**
  - NVMe-oF™ Target
  - vhost-nvme Target
  - iSCSI Target
  - vhost-scsi Target
  - vhost-blk Target
  - Linux nbd

- **Storage Services**
  - NVMe
  - Linux AIO
  - Ceph RBD
  - PMDK blk
  - virtio (scsi/blk)
  - iSCSI
  - malloc
  - Logical Volumes
  - GPT
  - Encryption
  - QoS
  - BlobFS
  - Blobstore

- **Drivers**
  - NVMe-oF Initiator
  - NVMe™ PCIe Driver
  - virtio-PCIe
  - vhost-user
  - Intel® QuickData Technology Driver
  - RDMA
  - TCP

- **Drivers (ext)**
  - Intel® QuickData Technology Driver
NVMe-oF™ Target

- Polled-mode userspace NVMe-oF target implementation
  - Pluggable fabric transport (similar to NVMe-oF initiator)
  - Presents SPDK block devices as namespaces
    - Locally-attached namespaces
    - Logical volumes
    - etc.

- SOFT-202-1 – Wednesday 3:20-5:45pm
  - Ben Walker – NVMe-oF: Scaling up with SPDK
Call to Action

- Check out SPDK!
  - Source code: [http://github.com/spdk](http://github.com/spdk)
  - Project website: [http://spdk.io](http://spdk.io)
    - Getting Started Guide (including Vagrant environment)
    - Mailing List
    - IRC
    - GerritHub