15th ANNUAL WORKSHOP 2019

NVME OVER FABRICS OFFLOAD

Tzahi Oved

Mellanox Technologies

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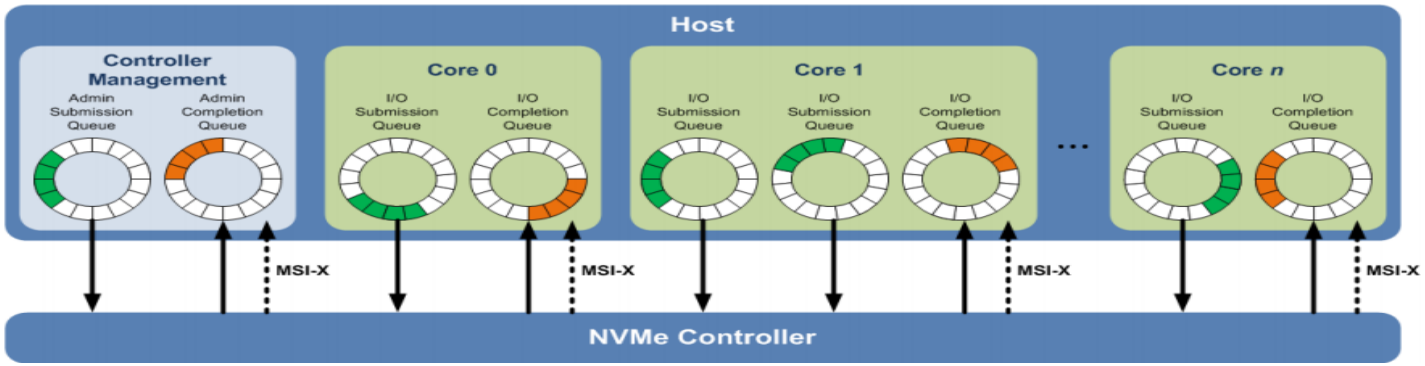
NVME, NVME-OF INTRO

NVME INTRODUCTION

- **Standard PCIe host controller interface for solid-state storage**
  - Driven by industry consortium of 80+ members
  - Standardize feature, command, and register sets
  - Enhance PCIe capabilities: low latency, scalable BW, power efficiency etc.
- **Focus on efficiency, scalability and performance**
  - All parameters for 4KB command in single 64B DMA fetch
  - Simple command set (13 required commands)
  - Supports MSI-X and interrupt steering



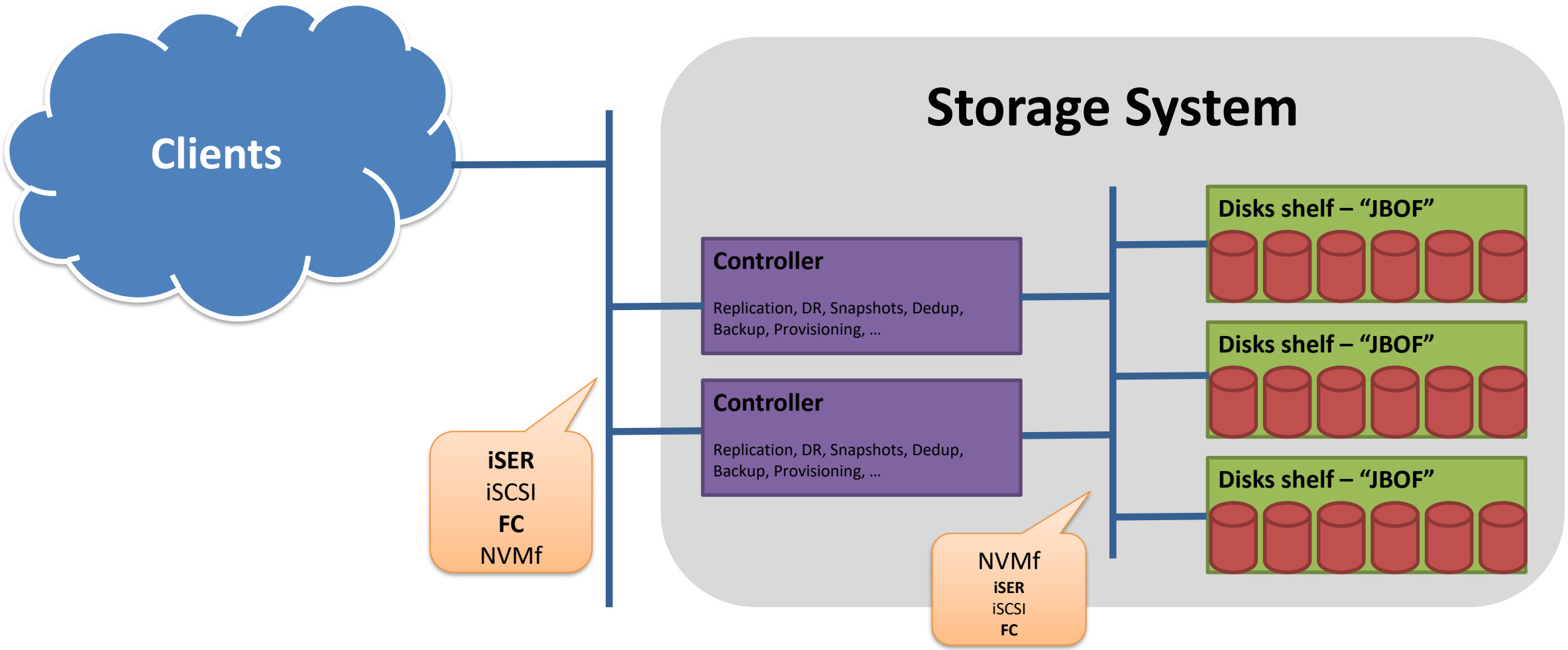
THE NEED FOR NVME OVER FABRICS

- **Regular NVMe Devices "Captive" In the Server**
  - Only supports drives in or near server/storage box
  - Limits number of PCIe-attached devices
- **PCIe, SAS and SATA Don't Support Scale-Out**
  - Distance limitations; Difficult to share
  - Limited robustness and error handling

NVM Express, Inc. solution

- **NVMe Over Fabrics Announced September 2014**
  - Preserves NVMe command set
  - Simplifies storage virtualization, migration, & failover
  - Allows scale-out without SCSI protocol translation
  - Goal: <10µs added latency compared to local NVMe
- **Standard V1.0 done, published June 2016**

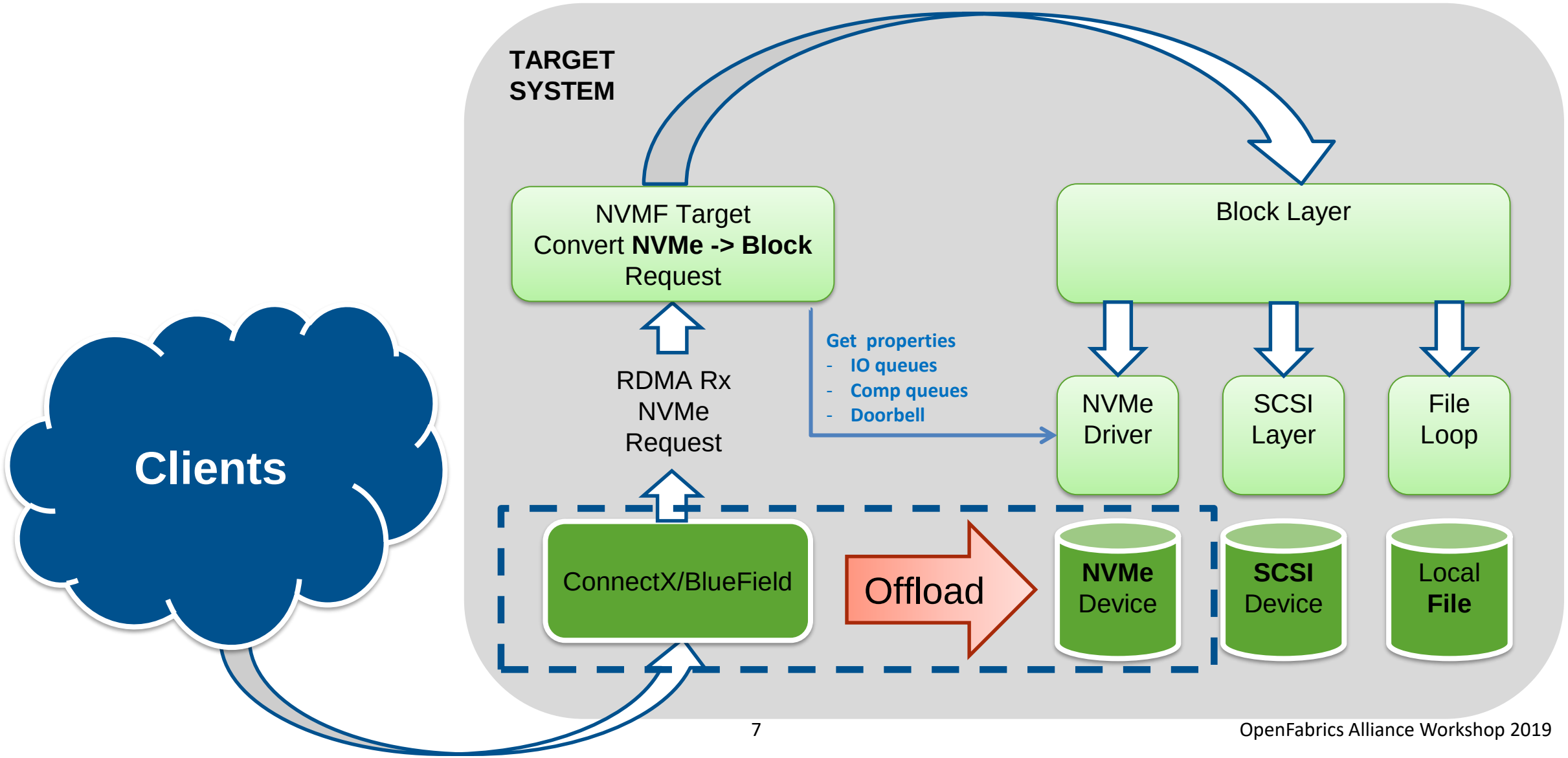
EXAMPLE USE CASE



NVME MAPPING TO FABRICS

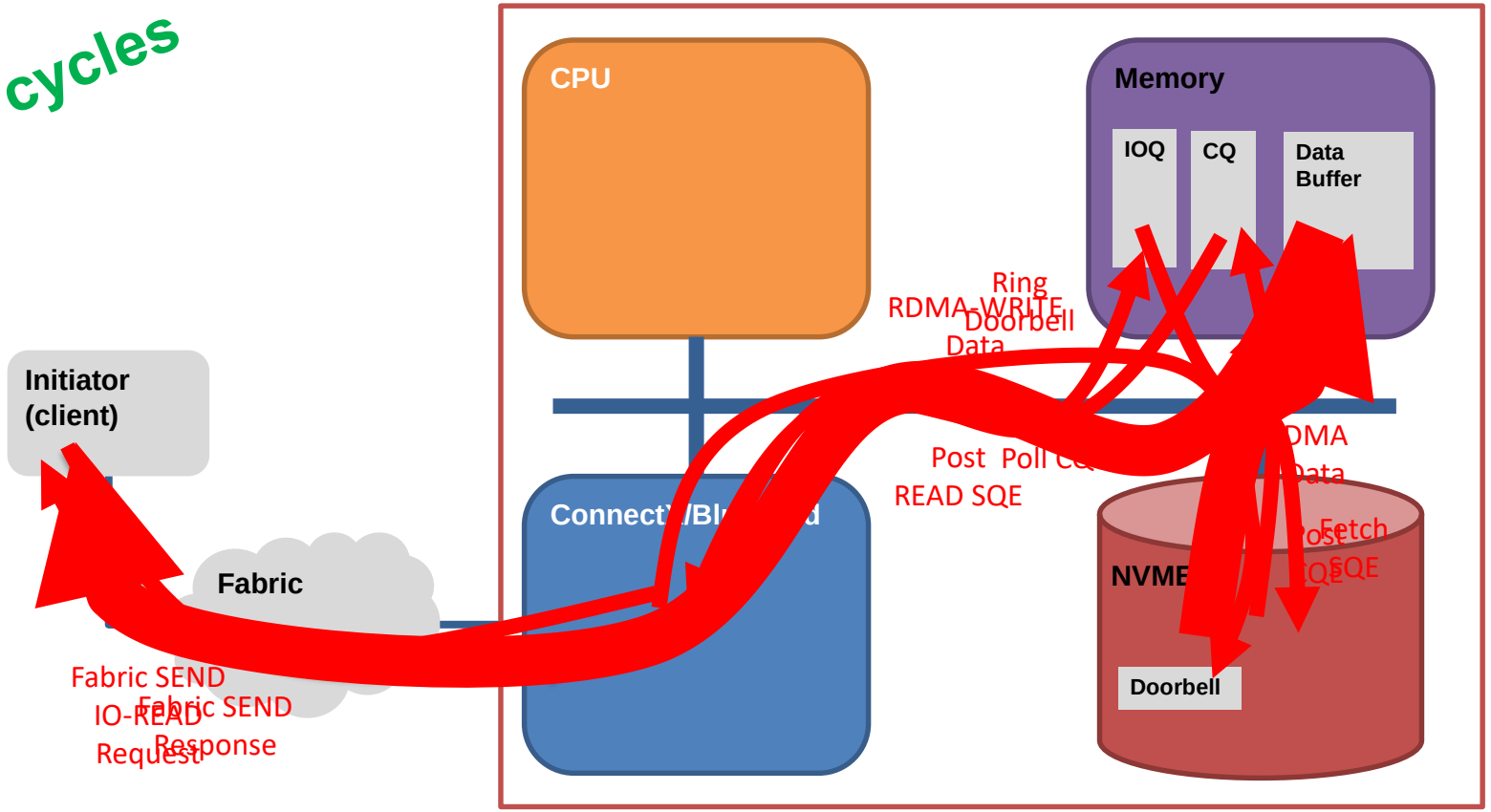
NVMe	NVMe-oF
Submit Queue (SQ)	QP SQ
Completion Queue (CQ)	QP RQ (+CQ)
Host write SQE, ring doorbell	Host SEND SQE capsule, ring doorbell
Device write CQE, interrupt or poll	Target SEND CQE capsule, RX CQE int/poll
PCIe data exchange	RDMA RD/WR, immediate up to 8K

COMMUNITY NVMF TARGET KERNEL



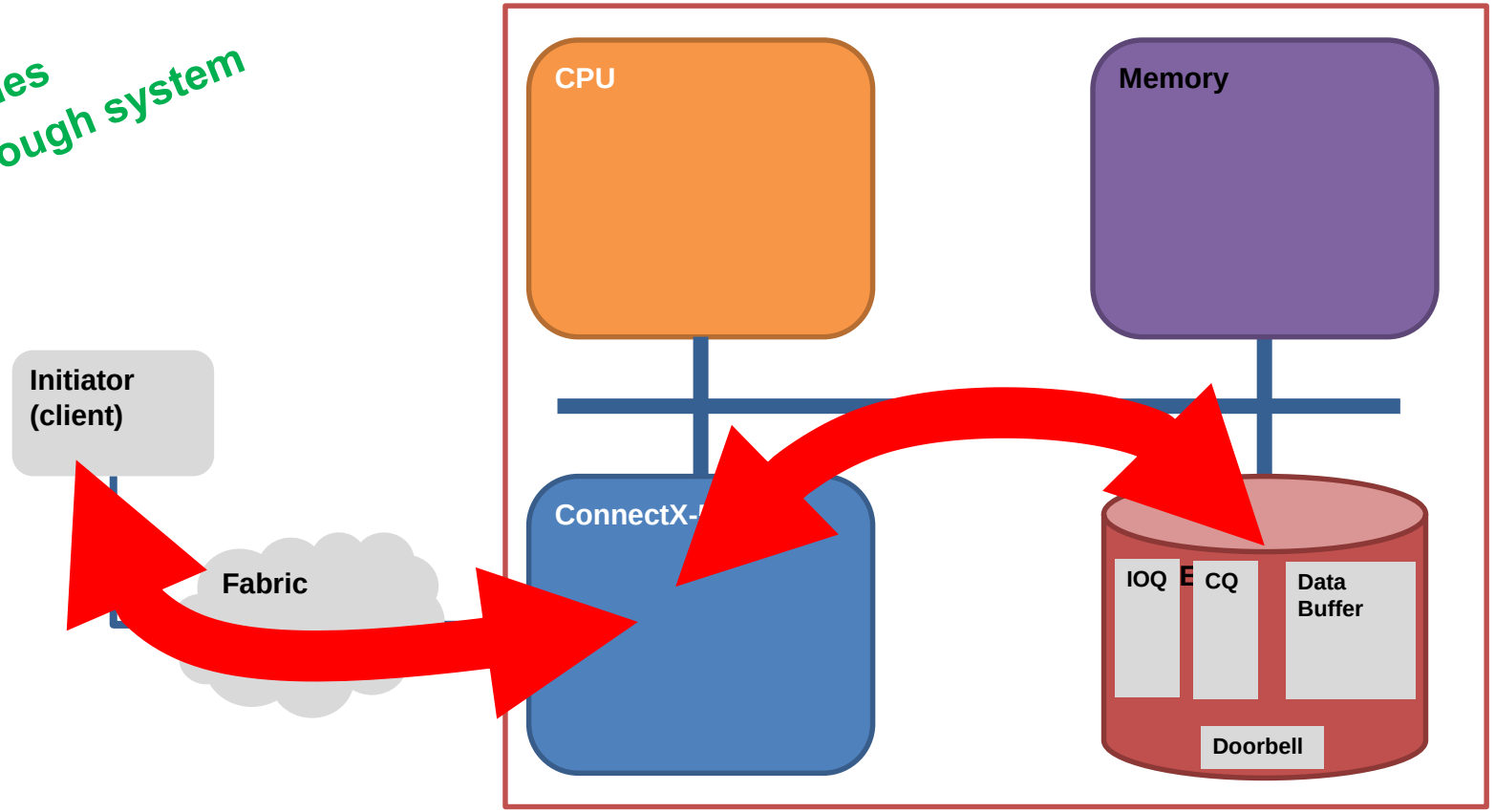
NVME-OF TARGET OFFLOAD FLOW

Zero CPU cycles



NVME-OF TARGET OFFLOAD WITH CMB

Zero CPU cycles
No traffic through system memory



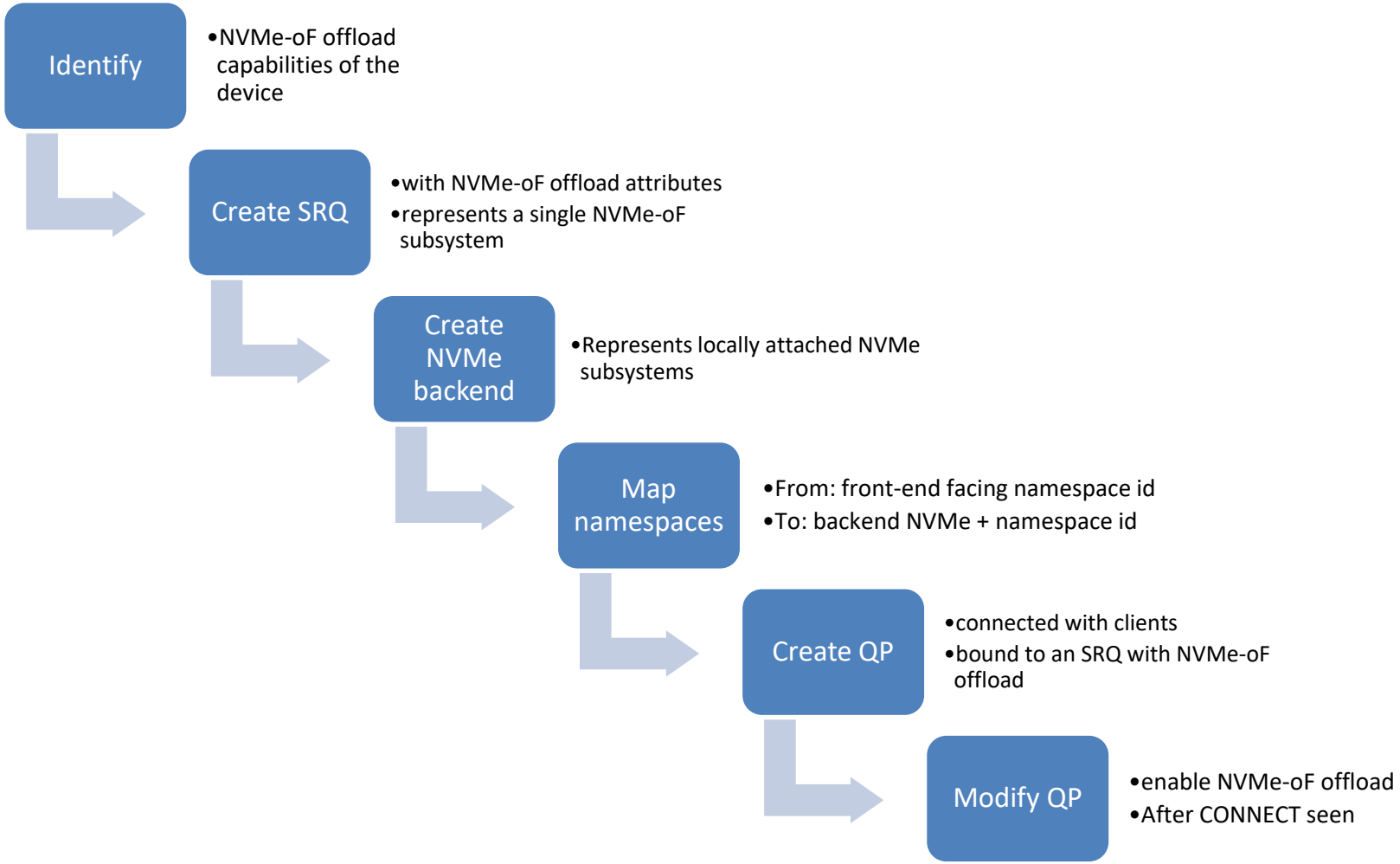
VERBS

STATUS

- **Submitted RFC**
  - https://www.spinics.net/lists/linux-rdma/msg58512.html

- **Added/Updated files**
  - `Documentation/nvmf_offload.md | 172`
  - `libibverbs/man/ibv_create_srq_ex.3 | 48`
  - `libibverbs/man/ibv_get_async_event.3 | 15`
  - `libibverbs/man/ibv_map_nvmf_nsid.3 | 89`
  - `libibverbs/man/ibv_qp_set_nvmf.3 | 53`
  - `libibverbs/man/ibv_query_device_ex.3 | 26`
  - `libibverbs/man/ibv_srq_create_nvme_ctrl.3 | 89`
  - `libibverbs/verbs.h | 107`

VERBS FLOW


Identify
•NVMe-oF offload capabilities of the device
Create SRQ
•with NVMe-oF offload attributes
•represents a single NVMe-oF subsystem
Create NVMe backend
•Represents locally attached NVMe subsystems
Map namespaces
•From: front-end facing namespace id
•To: backend NVMe + namespace id
Create QP
•connected with clients
•bound to an SRQ with NVMe-oF offload
Modify QP
•enable NVMe-oF offload
•After CONNECT seen

IDENTIFY - IBV_QUERY_DEVICE_EX()

- New NVMf caps
- Offload types
- Supported min/max values

```
struct ibv_device_attr_ex {
        ...
        struct ibv_nvmf_caps    nvmf_caps;
};


struct ibv_nvmf_caps {
        enum nvmf_offload_type offload_type;
        uint32_t        max_backend_ctrls_total;
        uint32_t        max_backend_ctrls;
        uint32_t        max_namespaces;
        uint32_t        max_staging_buf_pages;
        uint32_t        min_staging_buf_pages;
        uint32_t        max_io_sz;
        uint16_t        max_nvme_queue_sz;
        uint16_t        min_nvme_queue_sz;
        uint32_t        max_ioccsz;
        uint32_t        min_ioccsz;
        uint16_t        max_icdoff;
};
```

CREATE SRQ - IBV_CREATE_SRQ_EX()

- **Represents a fabric-facing NVMf target**
- **Set params according to caps**
- **Add staging buffer**
  - Use MR!

```
struct ibv_srq_init_attr_ex {
        ...
        struct ibv_nvmf_attrs   nvmf_attr;
};
```

```
struct ibv_nvmf_attrs {
        enum nvmf_offload_type  offload_type;
        uint32_t                max_namespaces;
        uint8_t                 nvme_log_page_sz;
        uint32_t                ioccsz;
        uint16_t                icdoff;
        uint32_t                max_io_sz;
        uint16_t                nvme_queue_sz;
        struct ibv_mr           *staging_buf_mr;
        uint64_t                staging_buf_addr;
        uint64_t                staging_buf_len;
};
```

CREATE NVME BACKEND - IBV_SRQ_CREATE_NVME_CTRL ()

- **ibv_nvme_ctrl belongs to specific SRQ**
- **Attributes are**
  - NVMe SQ
  - NVMe CQ
  - NVMe SQ-DB
  - NVMe CQ-DB
  - NVMe SQ-DB init val
  - NVMe CQ-DB init val
- **SQ, CQ, and DBs are described by**
  - {MR, VA, LEN}
  - Need to ibv_reg_mr()

```
struct ibv_nvme_ctrl *ibv_srq_create_nvme_ctrl(
          struct ibv_srq *srq,
          struct nvme_ctrl_attrs *nvme_attrs);

int                    ibv_srq_remove_nvme_ctrl(
          struct ibv_srq *srq,
          struct ibv_nvme_ctrl *nvme_ctrl);
```

```
struct ibv_mr_sg {
        struct ibv_mr *mr;
        union {
                void     *addr;
                uint64_t offset;
        };
        uint64_t    len;
}
```

```
struct nvme_ctrl_attrs {
        struct ibv_mr_sg      sq_buf;
        struct ibv_mr_sg      cq_buf;

        struct ibv_mr_sg      sqdb;
        struct ibv_mr_sg      cqdb;

        uint16_t              sqdb_ini;
        uint16_t              cqdb_ini;

        uint16_t              timeout_ms;

        uint32_t              comp_mask;
};
```

MAP NAMESPACES - IBV_MAP_NVMF_NSID()

- **New map within the subsystem between**
  - { fe_nsid } -> { nvme_ctrl, nvme_nsid, params }
- **SRQ is available from the nvme_ctrl**
  - It was created for a specific SRQ
- **To map the same NVMe to different SRQ**
  - Meaning to different NVMe-oF subsystems
  - Create different nvme_ctrl with each SRQ
  - Each nvme_ctrl represents exclusive NVMe queues on the same NVMe device

```
int ibv_map_nvmf_nsid(
        struct ibv_nvme_ctrl *nvme_ctrl,
        uint32_t fe_nsid,
        uint16_t lba_data_size,
        uint32_t nvme_nsid);

int ibv_unmap_nvmf_nsid(
        struct ibv_nvme_ctrl *nvme_ctrl,
        uint32_t fe_nsid);
```

ENABLE QP - IBV_QP_SET_NVMF()

- **Create QP – as normal**
  - RDMA-CM in case of NVMf
- **Enable QP for NVMf offload**
  - New verb specifically for NVMf attrs
- **First message is CONNECT**
  - No offload should be done before it
  - Software will enable offload after seeing CONNECT

```
int ibv_modify_qp_nvmf(
        struct ibv_qp *qp,
        int flags);


enum {
        IBV_QP_NVMF_ATTR_FLAG_ENABLE = 1 << 0,
}
```

EXCEPTIONS

- **Non-offloaded operations**
  - Go as normal to SRQ and CQ
  - Software can post responses on QP
- **QP goes to error**
  - Async event IBV_EVENT_QP_FATAL
  - Software may not see CQE with errors…
- **NVMe errors**
  - New async event, nvme_ctrl scope
  - PCI error (when reading CQ)
  - Command timeout
- **Must listen to async events!**

```
struct ibv_async_event {
        union {
                ...
                struct ibv_nvme_ctrl *nvme_ctrl
        } element;
        ...
};
```

```
NVMe controller events:

      IBV_EVENT_NVME_PCI_ERR  NVMe backend controller PCI error

      IBV_EVENT_NVME_TIMEOUT  NVMe backend controller completion timeout
```

NVME EMULATION AND NVME-OF

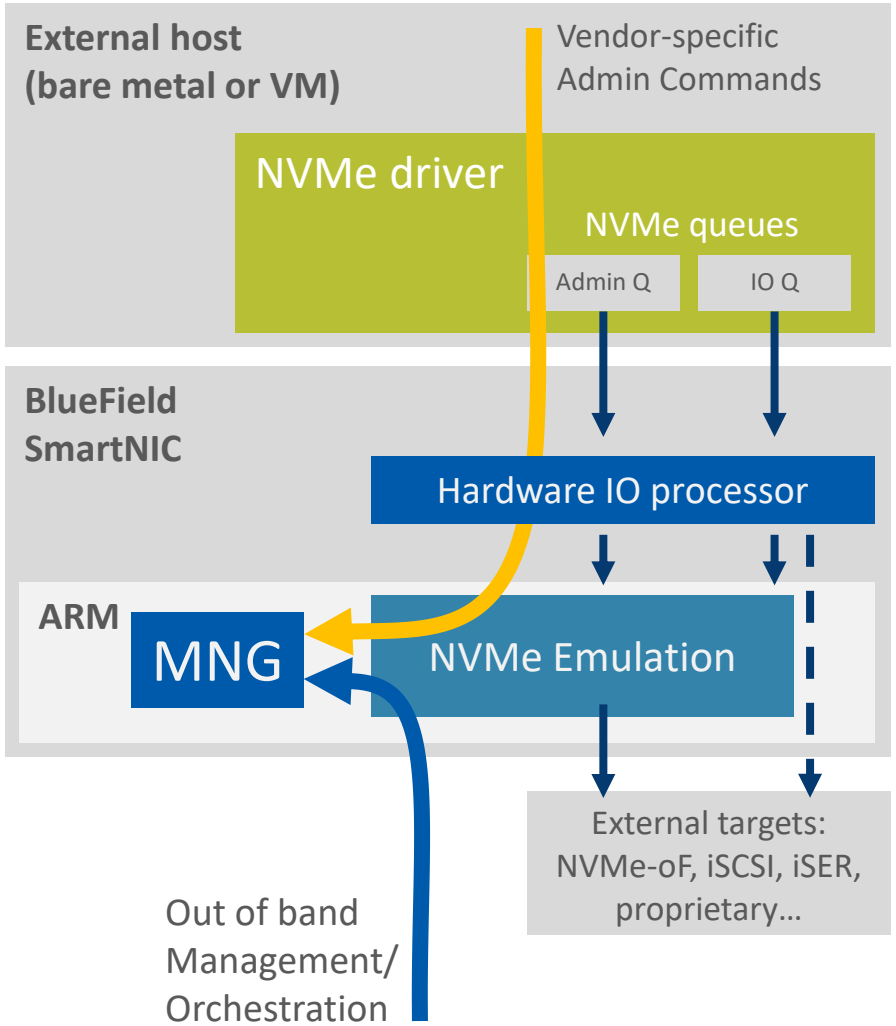
NVME EMULATION - MANAGEMENT

Implemented Out of band

- Connect to Cloud provider management/ orchestration
- Implement any proprietary protocol
- Direct from network, bypassing host
- Utilizing NVMe Emulation SDK

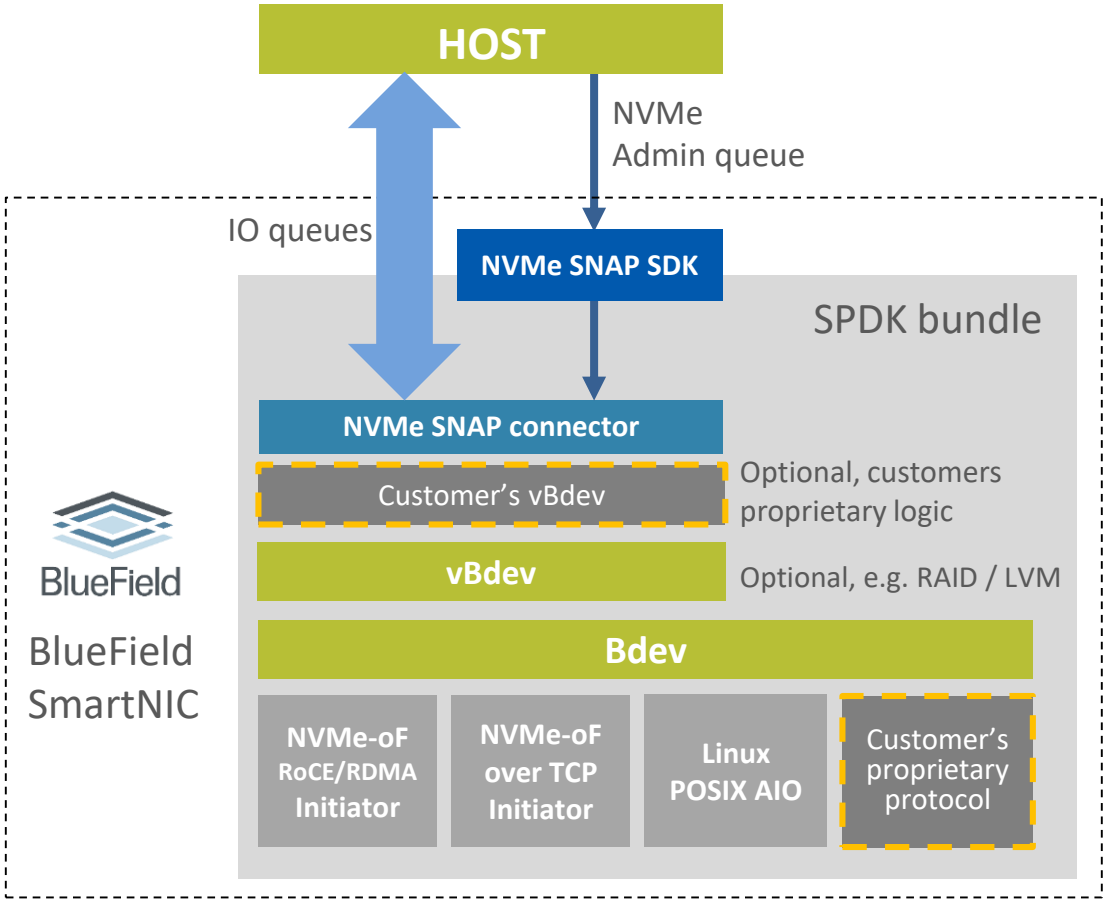
Vendor-specific Admin commands

- Using the NVMe driver
- Limited / controlled capabilities
- Example: allow user to choose QoS policy



NVME EMULATION DATAPATH

- **SDK**
- Handle NVMe registers and admin queue
- Efficient memory management based on SPDK
- Zero-copy all the way
- Full polling
- Multi queues, multi threads, lockless
- Well defined APIs: vBdev, Bdev drivers…



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THANK YOU

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