Extending RDMA for Persistent Memory over Fabrics

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What is Persistent Memory (PM)?

- **Persistent Memory (PM) benefits**
  - Considerably faster than NAND Flash
  - Performance accessible via PCIe or DDR interfaces
  - Lower cost/bit than DRAM
  - Significantly denser than DRAM
For Many Storage Applications PM Needs Network Connectivity

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<td>~100ns</td>
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<td>Write Latency</td>
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Applications Benefitting RPM

- In-Memory application scale-out
- Software Defined Storage
- Big Data & NoSQL workloads
- Machine learning
- Hyperconverged Infrastructure
- Complete compute disaggregation
Compute Disaggregation
Core Requirements for Networked PM

- **PM is really fast**
  - Needs ultra low-latency networking

- **PM has very high bandwidth**
  - Needs ultra efficient protocol, transport offload, high bandwidth networks

- **Remote accesses must not add significant latency**
  - PM networking requires:
    - Predictability, Fairness, Zero Packet Loss
  - Network switches and adapters must deliver all of these

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What is RDMA?

- **Remote**
  - Data transfers between nodes in a network

- **Direct**
  - No Operating System Kernel involvement in transfers
  - Everything about a transfer offloaded onto Interface Card

- **Memory**
  - Transfers between user space application virtual memory
  - No extra copying or buffering

- **Access**
  - Send, receive, read, write, atomic operations
  - Byte or Block Access
RDMA Standards Development

RDMA extensions for RPM being standardized in:
- InfiniBand Trade Association (IBTA): native IB, RoCE
- Internet Engineering Task Force (IETF): iWARP

IBTA/IETF names/terminology may differ:
- Commit : Flush
- Atomic Write : Non-Posted Write

However, extension semantics are similar, such that -
- IETF will use same Verbs extensions as IBTA
Application 1: Database Persistent Log

Replicated log data plus write pointer (wptr) updates, to remote persistent FIFOs

- Logs are remote persistent FIFOs
- Each log entry write: data (~4 KB), followed by write pointer (wptr) update
Application 2: Hot Tier Hyperscale or Hyperconverged Storage

- Storage data writes, replicated for availability: latency-critical, but replicas seldom used
- Great application for emerging NVMe Persistent Memory Regions (PMRs)
  - Target RNIC writes data directly to SSD PMR, bypassing CPU/memory subsystem
- Accompanying metadata may be processed by target CPU
Why Simple RDMA Writes are Not Enough

- Server RNIC acknowledges (ACK) Write as soon as validates it
- At server, there may be multiple volatile intermediate buffers between RNIC and persistent memory
- ACK might race back to complete Write at client, before actual data makes it to persistence
  - Bad news, if Write subsequently fails within server
- Client requirement: explicit confirmation of persistence, to follow Write
The Need for RPM Write Ordering

- Remote persistent FIFO, with data NVDIMM further from RNIC than write pointer NVDIMM
- Without explicit write ordering at RNIC, pointer update may race ahead of data update
- Result upon server failure: corrupt FIFO
RDMA Extensions Summary

- Three new RDMA Messages:
  - Commit Request/Response: confirms prior Writes have been flushed and committed to persistence
  - Atomic Write Request/Response: small (8B) all-or-nothing Write, with explicit response
  - Verify Request/Response (IETF only): hash-based integrity check of persistent data

- New Persistence property for data Memory Regions (MRs)
- New API (Verbs) extensions for Messages and MRs
Accelerating RPM Writes

- New RDMA Messages eliminate one serialized round-trip-time in network
- Commit guarantees persistence (unlike plain Reads on some platforms)
- New Atomic Write guarantees ordering of successive RPM writes
- (Diagram uses IETF terminology)
Matches SNIA NVM PM Model
RDMA to PMEM for High Availability

- **MAP**
  - Memory address for the file
  - Memory address + Registration of the replication

- **SYNC**
  - Write all the “dirty” pages to remote replication
  - FLUSH (IBTA or Commit, IETF) the writes to persistency

- **UNMAP**
  - Invalidate the registered pages for replication
HGST PM Remote Access Demo

- HGST live demo at Flash Memory Summit
- RPM(=PCM) based Key-Value store over 100Gb/s RDMA
PCM is slightly slower than DRAM but … equivalent application perf

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