Storm: a fast transactional dataplane for remote data structures

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What is Remote Direct Memory Access (RDMA)?

• Initiate transfer, hardware executes, async. poll for completions

• Infiniband (IB): specialized network stack for RDMA
  • Fully implemented in hardware (PCIe-based adapters) →
  • Also: IB transport on top of IP and lossless Ethernet

• Key benefits:
  1. one-sided access
  2. user-level w/ minimal instr. footprint
Remote data structures

• Hash tables, graphs, trees, queues, etc
  • Fine-grain accesses
  • High fan-out
  • Pointer-linked
  • Transactional access
  • Throughput (IOPS) bound
  • Latency Service Level Objective (SLO)

• Other (perhaps less interesting) use cases: analytics, VM migration
  • Bulk transfers, bandwidth-bound
What are common concerns?

1. Scalability: network state kept in limited hardware resources

2. Round-trips: pointer-linked data structures
What are common concerns?

1. Scalability: network state kept in limited hardware resources
   - FARM: Use locks to share QP connections (Dragojevic’14)
   - FaSST/eRPC: Don’t use connections (Kalia’19)
   - LITE: Enforce protection in kernel (Tsai’17)

2. Round-trips: pointer-linked data structures
   - FARM: Use Hopscotch algorithm, one RTT common case
   - FaSST/eRPC: Leverage RPCs rather than one-sided reads
Outline

• Problem statement

• Key insights

• Storm design

• Results
Key insights (1/2)

• Hardware has gotten much better!!!
  • ConnectX-4/5 (CX4/5) vs. ConnectX-3 (CX3)
    • 40M IOPS on CX4 → 4x higher than CX3
    • Scales up to 64 machines → on CX3 IOPS collapses for >10 machines
    • CX4 achieves 10M IOPS when zero cache hits → max IOPS for uncontended CX3
    • Break-even point with datagram send/recv currently at ~4k connections

• Possible further improvements with ConnectX-6

• How is HW getting better?
  • More concurrency, better prefetching, larger caches, etc
Key insights (2/2)

• FARM:
  • Locks degrade throughput unnecessarily
  • Large buckets (due to larger keys) wastes throughput

• FaSST/eRPC:
  • Two-sided doesn’t allow for maximum full-duplex throughput
    • Especially for requests larger than a cache line (no inlining)
  • Onloaded congestion control adds overhead

• LITE:
  • Kernel adds overhead (fine-grain accesses)
  • No support for async. operations
Our approach / Storm design principles

1. Use connections but minimal count
   • Lock-free QP sharing if really necessary
   • Offloaded congestion control and retransmissions

2. Use one-sided reads whenever possible
   • First one-sided, then RPC (one-two-sided)
   • RPC also implemented using one-sided writes

3. Leverage abundant memory
   • Cache metadata and/or reduce collisions in hash tables

4. Minimize translation & protection state
   • Use contiguous physical allocation

5. And don’t forget to deploy on new hardware!!!
Storm design

Division of responsibilities:
- Storm DP only understands RDMA connections and memory regions
- Data structure understands data layout and implements metadata caching
Two-sided operations

Storm dataplane

1. op() => fail
2. ev_loop() => success
3. ev_loop() => success

Data structure impl. & metadata

RPC

QP & buffer mngmnt
Event loop
RR

RPC

Event loop
QP & buffer mngmnt
RR

Data structure impl. & metadata
One-sided operations

HW

MEM  CPU  rNIC

SW

Storm dataplane

RPC

QP & buffer mngmnt  Event loop

RR

Data structure impl. & metadata

1  success  success

2

3

Storm dataplane

RPC

Event loop  QP & buffer mngmnt

RR

Data structure impl. & metadata
One-two-sided operations

Storm dataplane

MEM | CPU | rNIC
---|---|---

rNIC | MEM | CPU

HW

SW

op()

ev_loop()

1. success

2. fail

3. Data structure impl. & metadata

Data structure impl. & metadata

RPC

QP & buffer mngmnt

Event loop

RR

Event loop

QP & buffer mngmnt

RR
One-two-sided operations

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**HW**

- MEM
- CPU
- rNIC

**SW**

- Storm dataplane
  - RPC
    - QP & buffer mngmnt
    - Event loop
  - RR
- Data structure impl. & metadata

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**rNIC**

- MEM
- CPU

- Storm dataplane
  - RPC
    - Event loop
    - QP & buffer mngmnt
  - RR
- Data structure impl. & metadata

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**Op**

- ev_loop()

---

**Ev loop**

- ev_loop()

---

**3**

- fail
- success

---

**4**

- success

---

**5**

- success
### Distributed transactions

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| SW  |      |      |      |
|     | Data structure impl. & metadata |      |      |

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**Support for concurrent data structures using transactions**
Data structure API (three callbacks)

• RPC handler
  • Processing two-sided communication
  • Implements complex paths, such as acquiring locks and commits

• Lookup start
  • Check if address is known (cached) or we can guess
  • If yes, leverage RDMA read

• Lookup end
  • Check if data is valid and cache for future use
Storm implementation & exp. setup

• 13k LOC of C++, w/o MICA modifications [Lim’14]

• HPC cluster w/ 32 Dell machines
  • High-speed Infiniband network (100Gbps)
  • Mellanox ConnectX-4 – similar in perf to CX5
  • Emulation of 3-4x larger clusters possible on Storm

• Benchmarks:
  • Key-value transactional micro-benchmark
  • Telecommunication Application Transaction Processing (TATP)
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Baselines

• Emulated FARM (modified: Lock-free_FaRM)
  • No connection sharing, 1KB “neighborhoods”

• eRPC
  • With and without active congestion control

• LITE (modified: Async_LITE)
  • Added support for asynchronous operations
Storm results

- Single-lookup workload
  - 128B KV pairs, 100M items, 20 threads per mn
Storm results

• Single-lookup workload
  • 128B KV pairs, 100M items, 20 threads per mn

• TATP: 11.8 million per node with Storm (oversub)
Does Storm scale well?

- Storm scales well up to 64mn

- Reduce thread count by 2x
  - 2x fewer threads → 2x fewer QPs

- Do we need more than 10 threads?
  - Lock-free QP sharing
Conclusion & future work

• RDMA datacenter users should get a hardware upgrade
  • More scalable hardware available
  • Take advantage of one-sided primitives

• Leverage caching and oversubscription (in hash tables)
  • One-sided read in the common case

• Ongoing research threads:
  • Designing “far” memory data structures (HotOS’19)
  • Memory allocator for repurposing unused memory
  • Lock-free mechanisms for QP sharing