HPNL: A HIGH-PERFORMANCE LIGHT WEIGHTED NETWORK LIBRARY FOR BIGDATA APPLICATION

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AGENDA

- Background and motivation
- RDMA enabling in bigdata software ecosystem
- Transportation agnostic messenger proposals – HPNL
- Optimizing Spark shuffle with HPNL and Persistent Memory
- Summary & Next steps
**BACKGROUND AND MOTIVATIONS**

- **Bigdata analytics software stack requires RDMA for higher performance**
  - Spark is expected to achieve high throughput & ultra-low latency for different workloads like ad-hoc query, real-time streaming, and machine learning
  - There are bottlenecks to be improved in shuffle phase
  - While RDMA networking can lead to orders of magnitude improvement, using VERB interface is a challenge for application development and porting

- **Motivations**
  - A light-weight network library built on Libfabric
  - Protocol-independent networking framework that can easily run on all transportation protocols: TCP, RDMA, IB, OPA etc.
  - Flexible interfaces & abstractions: C/JAVA API and high-level abstraction to let developer easily replace other TCP/IP based network library, like ASIO or Netty
Network interconnects have evolved
- Bandwidth from 1Gbps to 100Gbps
- Message RTT latency reduced by an order of magnitude

BigData Application cannot benefit from new HW
- Network consecutive evolving doesn’t result in application consecutive speedup.

Source
RDMA ENABLING IN BIGDATA ECOSYSTEM
APPROACH 1 – INTEGRATE LIBFABRIC INTO BIGDATA APP CASE BY CASE

- Existing projects for BigData w/ RDMA
  - SparkRDMA.
    - TeraSort benchmark shows 2.63x overall reduced in execution time.*
  - HiDB project from OSU.
    - HiBench PageRank total time reduced by 37%-43% over IPoIB.**
- Pros
  - Easy to integrate to one BigData application
- Cons
  - Hard to benefit all the BigData App, need to integrate case by case.
  - Can’t enable cross-stack optimization.

* [https://github.com/Mellanox/SparkRDMA](https://github.com/Mellanox/SparkRDMA)
** [http://hibd.cse.ohio-state.edu/performance/pagerank/](http://hibd.cse.ohio-state.edu/performance/pagerank/)
Netty* is widely used in BigData application.

However, message transfer is more expensive than RDMA.

- Message RTT time is higher.
- Consumes more CPU.

Pros

- When Netty supports RDMA & Omni-Path, all the BigData App based on Netty will benefit directly.

Cons

- Hard to implement all the interface in Netty transport layer.
- Can’t enable cross-stack optimization.

* https://netty.io/index.html
** https://netty.io/wiki/adopters.html
- Existing projects for BigData by this way.
  - Crail from IBM.
  - FlashNet: Flash/Network Stack Co-Design
  - Octopus: An RDMA-enabled Distributed Persistent Memory File System

- Pros
  - Co-designed storage/network stack optimized to reduce cross-stack overhead between network and flash IO.
TRANSPORTATION AGNOSTIC MESSENGER—HIGH PERFORMANCE NETWORK LIBRARY (HPNL)
WHY LIBFABRIC?

- Libfabric is developed by the OFI Working Group, a subgroup of OFA.
- Goals: to define interfaces that enable a tight semantic map between application and underlying fabric services.
- Libfabric is friendly to application developers, transportation protocol agnostic, easy to port and migrate to new hardware.

*source: https://ofiwg.github.io/libfabric/
WHERE DOES HPNL FIT IN THE BIGDATA STACK?

- HPNL is a general-purpose network library and a appropriated choice to accelerate BigData application with HPC network technology.
PREVIOUS WORK: RDMA IN CEPH

- XIO Messenger.
  - Based on Accelio, seamlessly supporting RDMA.
  - Scalability issue.
  - Merged to Ceph master three years ago, no support for now.

- Async Messenger.
  - Async Messenger is compatible with different network protocol, like Posix, RDMA and DPDK.
  - Current RDMA implementation supports IB protocol.

- We implemented iwrap based RDMA for Ceph and pushed to upstream *
  - Showed 17% performance improvement for 4K random write compared with TCP/IP
  - Connection management: RDMA-CM based RDMA connection management
  - Queue pairs: centralized memory pool for recv queue (RQ)

- Extended the work, build a developer friendly library for bigdata applications

* Accelerating Ceph with RDMA and NVMe-OF: OFA 2018
HPNL ARCHITECTURE

- **Zero-copy approach**
  - The HPNL buffer allowed to be directly used by application without copying data between HPNL buffer and application buffer.
  - Thanks to RDMA, it supporting user-space to kernel-space zero-copy.

- **Threading model**
  - Implements the Proactor model.
  - Interrupt + polling approach to optimize HPNL thread.
  - Supports thread binding to specific core.

- **HPNL interface**
  - C/C++ and Java interface.
  - Supports send, receive, remote read, remote write semantics.
  - Pluggable buffer management interface.
  - Capable of using Persistent memory as RDMA buffer.

- **Open Source**
  - HPNL is Under internal opensource process, expected to be opensourced in Q2.
**Hardware**
- Intel(R) Xeon(R) CPU E5-2699 v4 @ 2.20GHz
- Mellanox ConnectX-4 – RoCE V2
- Arista 7060 CX2-32S

**Software**
- HPNL Java interface with libfabric v1.6.0
- OFED
- CentOS 7

**Micro benchmark Methodology**
- Send/receive based Ping-pong test
- 1 million times transfer of 4K sized message
### Test 1: message size scaling test, single thread
- Shows better performance than Netty or ASIO.

### Test 2: Connection scaling test
- Message size: 65536
  - Hits bandwidth limitation.
- Message size: 4096
  - Send/recv based interface shows round-trip time less than 4 us.

**Peak throughput is 3.8 GB/s**

**lowest message round-trip time is 3.8 us**
OPTIMIZING SPARK SHUFFLE WITH HPNL AND PERSISTENT MEMORY
SPARK SHUFFLE

Input: A HDFS file

Intermediate Data: Each Map's output

Shuffle (Random Partition)

Output: A HDFS file

Write Local, can use shuffle service to cache the data.

1. Serialize obj to off-heap memory
2. Write to local shuffle dir
3. Read from local shuffle dir
4. Send to remote reader through TCP/IP
   - Lots of context switch
   - POSIX buffered read/write on shuffle disk
   - TCP/IP based socket send for remote shuffle read

➢ Lots of context switch
➢ POSIX buffered read/write on shuffle disk
➢ TCP/IP based socket send for remote shuffle read

➢ No context switch
➢ Efficient read/write on DCPMM
➢ RDMA read for remote shuffle read
3 Node cluster

Hardware:
- Intel® Xeon™ processor E5 2699V4 @ 2.2GHz, 558GB Memory
- 1x Mellanox ConnectX-4 40Gb NIC
- 1x 1TB HDD for spark-shuffle
- 4x NVMe for HDFS

Software:
- Hadoop 2.7
- Spark 2.3
- CentOS 7
- HiBench TeraSort 500GB
- **1.5x performance improvement**
  - And much stable!
  - Page cache impact on spark-netty performance
**SYSTEM CONFIGURATION**

**3 Node cluster**

**Hardware:**
- Intel(R) Xeon(R) Gold 6140 CPU @ 2.30GHz
- 1x Mellanox ConnectX-4 40Gb for shuffle
- 384 G MEM
- 1 x X722 for Hadoop
- 4x P4500 for HDFS
- 4x 256GB DCPMM
- 1x HDD/SSD (1x 400Gb DC S3700)/NVMe (1x P4500)/(4x 256GB) DCPMM for Shuffle

**Software:**
- Fedora 27
- Kernal 4.18.19-100.fc27.x86_64
- Hadoop 2.7
- Spark 2.3
- Libfabric 1.6.2
- MLNX_OFED_LINUX-4.5-1.0.1.0-fc27-x86_64

**Workloads:**
- Hibench terasort 1TB
PERFORMANCE SUMMARY

- **PMoF vs. HDD**
  - PMEM and PMEM+RDMA are 9.17x and 9.10x faster than HDD respectively.
  - However, the benefit over NVMe+TCP/IP is not very big.
  - Other opportunities:
    - Lower CPU utilization
    - Latency sensitive workloads – streaming
# Stage 2 Performance Breakdown (HDD+TCP/IP)

## Summary Metrics for 1000 Completed Tasks

<table>
<thead>
<tr>
<th>Metric</th>
<th>Min</th>
<th>25th percentile</th>
<th>Median</th>
<th>75th percentile</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td>Duration</td>
<td>3.7 min</td>
<td>11 min</td>
<td>13 min</td>
<td>14 min</td>
<td>22 min</td>
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<tr>
<td>Scheduler Delay</td>
<td>0 ms</td>
<td>0 ms</td>
<td>2 ms</td>
<td>3 ms</td>
<td>23 ms</td>
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<tr>
<td>Task Deserialization Time</td>
<td>2 ms</td>
<td>3 ms</td>
<td>3 ms</td>
<td>4 ms</td>
<td>1.0 s</td>
</tr>
<tr>
<td>GC Time</td>
<td>4 s</td>
<td>8 s</td>
<td>9 s</td>
<td>11 s</td>
<td>21 s</td>
</tr>
<tr>
<td>Result Serialization Time</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>2 ms</td>
</tr>
<tr>
<td>Getting Result Time</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
</tr>
<tr>
<td>Peak Execution Memory</td>
<td>0.0 B</td>
<td>0.0 B</td>
<td>0.0 B</td>
<td>0.0 B</td>
<td>0.0 B</td>
</tr>
<tr>
<td>Output Size / Records</td>
<td>632.9 MB / 6638259</td>
<td>874.1 MB / 9166014</td>
<td>951.7 MB / 9979334</td>
<td>1035.6 MB / 10658719</td>
<td>1329.5 MB / 13940317</td>
</tr>
<tr>
<td>Shuffle Read Blocked Time</td>
<td>2.5 min</td>
<td>6.5 min</td>
<td>9.7 min</td>
<td>11 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Shuffle Read Size / Records</td>
<td>670.9 MB / 6638259</td>
<td>926.6 MB / 9166014</td>
<td>1008.6 MB / 9979334</td>
<td>1097.7 MB / 10658719</td>
<td>1409.2 MB / 13940317</td>
</tr>
<tr>
<td>Shuffle Remote Reads</td>
<td>596.7 MB</td>
<td>823.5 MB</td>
<td>896.0 MB</td>
<td>976.8 MB</td>
<td>1263.8 MB</td>
</tr>
</tbody>
</table>
# STAGE 2 PERFORMANCE BREAKDOWN (PMEM+RDMA)

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<th>Median</th>
<th>75th percentile</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>36 s</td>
<td>1.0 min</td>
<td>1.1 min</td>
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<td>1.7 min</td>
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<tr>
<td>Scheduler Delay</td>
<td>0 ms</td>
<td>3 ms</td>
<td>3 ms</td>
<td>4 ms</td>
<td>0.2 s</td>
</tr>
<tr>
<td>Task Deserialization Time</td>
<td>2 ms</td>
<td>4 ms</td>
<td>5 ms</td>
<td>6 ms</td>
<td>0.1 s</td>
</tr>
<tr>
<td>GC Time</td>
<td>2 s</td>
<td>9 s</td>
<td>11 s</td>
<td>13 s</td>
<td>26 s</td>
</tr>
<tr>
<td>Result Serialization Time</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>38 ms</td>
</tr>
<tr>
<td>Getting Result Time</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
<td>0 ms</td>
</tr>
<tr>
<td>Peak Execution Memory</td>
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<td>1326.6 MB / 13940317</td>
</tr>
<tr>
<td>Shuffle Read Blocked Time</td>
<td>0 ms</td>
<td>2 ms</td>
<td>3 ms</td>
<td>5 ms</td>
<td>8 s</td>
</tr>
<tr>
<td>Shuffle Read Size / Records</td>
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<tr>
<td>Shuffle Remote Reads</td>
<td>590.3 MB</td>
<td>920.3 MB</td>
<td>895.6 MB</td>
<td>976.8 MB</td>
<td>1256.6 MB</td>
</tr>
</tbody>
</table>
Elastic Deployment with compute and storage disaggregation requires independent shuffle solution

- Shuffle I/O are decoupled from a specific network/storage.
- Shuffle read and write can be implemented using configurable network transports and backend storage

External shuffle cluster

- Lots of on-going efforts making HCFS as shuffle: [Spark-1529, Spark-3685, SPARK-2529]
- And lots of customized solutions
- Independent HPNL library can be integrated with customized solutions
- Opensource version reference design based on HCFS shuffle manager and HDFS will come out soon
SUMMARY
SUMMARY & NEXT STEP

Summary

- Traditional TCP/IP stack can’t benefit more and more Real-time BigData processing even with modern network hardware while RDMA has been proved as an effective way to speedup BigData workload from existing projects.
- HPNL is a transportation Agnostic high performance network library based on libfabric
- HPNL demonstrated significant performance advantage over TCP/IP for bigdata applications
  - 1.5x over TCP/IP for spark terasort
- Spark shuffle with HPNL and pmem delivers up to 9x performance improvement over traditional shuffle solution based on TCP/IP and HDD
- Persistent memory over fabrics with HPNL and pmem enables new workloads and new storage solutions
  - Latency sensitive workloads and external/remote shuffle cluster

Next step

- RPC with HPNL
- RDMA in external shuffle cluster
THANK YOU
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BACKUP
**Terasort 1TB:**
- hibench.spark.master yarn-client
- hibench.yarn.executor.num 12
- yarn.executor.num 12
- hibench.yarn.executor.cores 8
- yarn.executor.cores 8
- spark.shuffle.compress false
- spark.shuffle.spill.compress false
- spark.executor.memory 60G
- spark.executor.memoryoverhead 10G
- spark.driver.memory 80G
- spark.eventLog.compress = false
- spark.executor.extraJavaOptions=-XX:+UseG1GC
- spark.hadoop.yarn.timeline-service.enabled false
- spark.serializer org.apache.spark.serializer.KryoSerializer
- hibench.default.map.parallelism 200
- hibench.default.shuffle.parallelism 1000