Live Migration with Hardware Acceleration

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Agenda

- Project Goals
- Architecture Introduction
- Feature Introduction
- Test Results
- Future Works
Project Goals
Project Goals

• Live migration pain points
  • VMs with memory write intensive workloads are difficult to migrate
  • VMs with large memory size takes long time to migrate
  • May consume large network bandwidth

• Existing solution: compression with CPUs
  • Slow
  • Consumes too many CPUs from host

• Our solution
  • Offload the compression part to Intel QAT with efficient approaches
    • Higher migration throughput
    • Lower CPU utilization
  • A common design ready for future more accelerators to join in
    • Data Streaming Accelerator (DSA) and Intel Analytics Accelerator (IAX) coming on Sapphire Rapids CPUs
    • Smart Selection
Architecture Introduction
Source Machine

- Migration Setup
  - Preparation for migration, including the accelerator device initialization, device polling thread creation
- Page Searching
  - Searching for pages to process and send
- Smart Selection
  - Select an appropriate accelerator based on the history of the acceleration efficiency
- Request Dispatch
  - Dispatch requests to the related accelerator device instance, e.g. in a round robin fashion if there are multiple device instances

- Response Polling
  - Poll for responses from all the devices
  - Blocks when no responses are ready
- Data Transfer
  - Send the compressed data, along with the related header, to network
Destination Machine

- Page Receiving
  - Receive data from the network
  - Parsing the migration protocols, e.g. multi-page
- Accelerator Selection
  - The received data has headers to tell which accelerator to use

- Migration Thread
  - Migration Setup
  - Page Receiving
  - Accelerator Selection
  - Request Dispatch
- Device Polling Thread
  - Response Polling

- QAT Lib & Userspace Driver
- DSA Lib & Userspace Driver
- Other Accelerator Libs & Userspace Drivers
- QAT
- DSA
- Other Accelerators

- Response Polling
  - Poll for decompressed data from each device
  - Blocks when no responses are ready
  - Decompressed data DMA to the QEMU memory
Feature Introduction
Important Features

• Zero-copy
  • Allow the acceleration device to directly access to the guest (QEMU) memory

• Multi-page Processing
  • Support the whole migration flow to process multiple pages each time

• Acceleration Request Caching
  • Caching the acceleration request data structure for efficient memory allocation
Zero-copy

- Migration setup
  - Pre-alloc and pin all the QEMU memory
  - Destination side memory unpinned when migration is done

- Request Composing
  - Source side
    - DMA read buffer points to QEMU memory
    - DMA write buffer allocated via accelerator lib
  - Destination side
    - DMA read buffer allocated via accelerator lib
    - DMA write buffer points to QEMU memory
Acceleration Request Caching

- **Device Setup**
  - Pre-allocate some amount of acceleration requests and fill them into the cache pool

- **Request Composing**
  - Take requests from the cache pool first
  - Initialize the request based on the new pages to send

- **Response Polling**
  - Free the request to the cache pool after it’s processed
Test Results
Test Environment

- **Testbed**
  - CPU: Intel Xeon CPU E5-2699 V4 @2.2GHz
  - QAT: 8960 PCIe card, Gen3
  - DRAM: DDR4, 2666MHz
  - NIC: XL710, 40GB

- **Live migration**
  - Downtime: 300 ms (default)
  - Network bandwidth: No limit (i.e. 40G)
  - Compress level: 1
  - Multi-page: 63 (Max)

- **Guest**
  - 4 vCPUs, 32G RAM, running a workload writing compression-friendly data
  - 4 vCPUs, 32G RAM, running a workload writing sequence numbers
  - 8 vCPUs, 128G RAM, running memcached with reading/writing random numbers
Memory Dirty with Compress-Friendly Data

- Run in guest: ./dirty_workload -t 10 -i 500000 -m 1 1000 -s
  - Write “1”s in specified dirty rate (e.g. 1000 MB/s above)

<table>
<thead>
<tr>
<th></th>
<th>No Compression</th>
<th>16 CPU Compression</th>
<th>QAT Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Throughput</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Pages per Second * 10000)</td>
<td>17 ~ 29</td>
<td>39 ~ 50</td>
<td>133 ~ 138</td>
</tr>
<tr>
<td><strong>Largest Migratable Dirty Rate (MB/s)</strong></td>
<td>1100</td>
<td>1900</td>
<td>5000</td>
</tr>
<tr>
<td><strong>Extra CPU Utilization (%)</strong></td>
<td>No</td>
<td>678</td>
<td>&lt; 40</td>
</tr>
<tr>
<td><strong>Compression Ratio</strong></td>
<td>No</td>
<td>87.6</td>
<td>922</td>
</tr>
</tbody>
</table>

**Normalized Throughput**

- No Compression
- 16-CPU Compression
- QAT Compression

![Normalized Throughput Chart]
Memory Dirty with Sequence Numbers

- Run in guest: `./dirty_workload -t 10 -i 500000 -m 3 1000 -s`
  - Write sequence data in specified dirty rate (e.g. 1000 MB/s above)

<table>
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<th>QAT Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput (Pages per Second * 10000)</td>
<td>17 ~ 29</td>
<td>~19</td>
</tr>
<tr>
<td>Largest Migratable Dirty Rate (MB/s)</td>
<td>1100</td>
<td>700</td>
</tr>
<tr>
<td>Extra CPU Utilization (%)</td>
<td>No</td>
<td>1600</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>No</td>
<td>4.97</td>
</tr>
</tbody>
</table>

**Normalized Throughput**

- No Compression
- 16-CPU Compression
- QAT Compression
Memcached with Random Numbers

- Memcached Server
  - 16 servers, each with 4GB RAM
- Memslap Client
  - 16 threads, 16 concurrency
  - Set/Get ratio 9:1
  - key length 128 bytes, value length 2048 bytes

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<th>QAT Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput (Pages per Second * 10000)</td>
<td>18 ~ 22</td>
<td>7 ~ 10</td>
<td>48 ~ 53</td>
</tr>
<tr>
<td>Migration Time (second)</td>
<td>Infinite</td>
<td>Infinite</td>
<td>60</td>
</tr>
<tr>
<td>Dirty Sync Count</td>
<td>Infinite</td>
<td>Infinite</td>
<td>10</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>No</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- VM fails to be migrated in the “no compression” and “cpu compression” cases, and successfully migrated with QAT acceleration
Future Works
VFIO Driver based Zero-Copy

- Current Zero-copy is implemented based on the UIO based QAT driver
  - Requires QEMU to be root privilege to get VA-to-PA mappings via pagemap
  - Requires QEMU to pin its memory
- VFIO supports the above with QEMU running with non-root privilege
  - QAT’s VFIO based userspace driver and library are work in progress
Smart Acceleration Support

• DSA compares the dirty memory, and sends the “diff” to the destination only
  • Good when the guest only modifies a small part of a page
  • Bad when the entire pages are changed
• Smart Acceleration
  • Dynamically switch to use QAT/IAX compression or DSA diff during live migration using a prediction based on the compression ratio history and diff ratio history
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