TDX Live Migration

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Agenda

• Background Introduction
• TDX Live Migration
• Initial PoC Results
• Status and Plan
Background Introduction
TDX Review

• Intel TDX Module runs in SEAM root mode to manage guest private states
• QEMU/KVM is removed from TCB
  • TD shared memory remains accessible
  • TD private memory is non-accessible
  • TD vCPU states are non-accessible
• KVM manages physical resources and assists TDX Module to virtualize TD via SEAMCALLs
  • E.g. allocate and offer pages to TDX module to build TD's secure EPT
TDX Live Migration Callouts

- Dirty page logging
  - PML isn't supported to log dirty private pages in the first release
  - Seamcall to TDX Module to do write-protection on private pages
- Guest memory copy
  - QEMU doesn't have access to TD private pages
    - Seamcall to TDX module to export/import TD private pages with encryption/decryption
    - SEPTs on the destination need to be set up before importing a TD private page
- Huge page split
  - Not needed for the first release as TD works with 4KB pages only in the first place
- A common framework to abstract TDX migration implementations into the vendor specific layer
TDX Live Migration
Bird’s-eye View

- Pre-migration
  - Migration policy evaluation
  - Compatibility check
  - Security attestation
  - Migration key setup
    - Generated by SrcMigTD and securely transferred to DstMigTD
    - Set to TDX Module on both sides
- Migration data
  - States encrypted/decrypted by TDX Module using the migration key
    - TD private memory states
    - vCPU states
    - TD-scope states
  - States in clear texts
  - TD shared memory states
MigTD

- A service TD to assist the migration of guest TDs
- Perform migration policy evaluation and migration key setup
- Talk to TDX Module using TDCALLs
- No interaction with the guest TD
- VMM binds it to the guest TD that it assists using Seamcalls
- One MigTD can assist the migration of multiple guest TDs at the same time
- Part of the platform TCB, and included in the TD attestation

MigTD communication
- TLS connection between the source and destination MigTDs to keep the info exchange (e.g. migration key) secure
- Use virtio-vsock or TDG.VP.VMCALL based VSOCK transport for Guest-Host communication
- Socat to relay messages from guest to host network

MigTD is vendor specific
- Intel provides a reference design and RUST-based implementation, and cloud vendors can design on their own
Migration Flow

- KVM maintains a per kvm_memory_slot bitmap to indicate if a page is private or shared
  - Bits set/cleared upon EPT violations
  - Private pages go through the export/import steps
  - Shared pages go through the legacy migration path

Pre-migration
Migration Stages

VMM boots a MigTD
VMM binds MigTD to the guest TD: TDH.SERVTD.BIND
MigTD generates a migration key and sets to TDX module: TDG.SERVTD.WR

Create one or multiple migration streams: TDH.MIG.STREAM.CREATE
Start dirty page logging
Huge page split
Write-protection: TDH.EXPORT.BLOCKW TDH.EXPORT.UNBLOCKW

Export TD-scope Immutable states: TDH.EXPORT.STATE.IMMUTABLE
Export memory pages: TDH.EXPORT.MEM
Mark the end at each round by exporting a token: TDH.EXPORT.TRACK
Pause the guest TD: TDH.EXPORT.PAUSE
Export the remaining memory pages
Export mutable TD-scope states: TDH.EXPORT.STATE.TD
Export vCPU states: TDH.EXPORT.STATE.VP
Generate a start token: TDH.EXPORT.TRACK
Migration Flow Con’t

- **In-Order Phase**
  - Source TD is still running
  - Newer version of a page must be imported after the older version of this page has been imported in each round
    - QEMU naturally supports it, as each page gets migrated only once in each round

- **Out-of-Order Phase**
  - Source TD is paused
  - Used by post-copy, which will be supported later
Migration Data Transport

• A migration stream creates a migration device emulated via KVM device
  • QEMU migration thread ioctl on the device fd to send requests, e.g. export states
  • KVM device allocates a piece of memory mapped by the migration thread to transport the exported states
    • The memory is also given to TDX Module to export/import the encrypted states

• Shared Memory
  • MBMD buffer stores the migration bundle metadata
  • Migration buffer stores the exported or imported states
  • MAC list buffer stores a list of MACs corresponding to the TD private pages in the migration buffer
  • GPA list buffer stores a list of GPA entries corresponding to the TD private pages in the migration buffer

• Multifd supports multiple migration streams, so multiple migration devices are created in KVM
  • Each device shares a piece of memory with its multifd iothread
Confidential Guest Migration Framework
Initial PoC Results

Note: Results are from tests of legacy VM live migration with adding the estimated TDX overhead to memcpy (named pseudo-tdx)
Test Environment

• Testbed
  • CPU: Intel(R) Xeon(R) CPU E5-2699 v4 @ 2.20GHz
  • DRAM: DDR4, 2666MHZ
  • NIC: Intel 10-Gigabit X540-AT2
    • Direct cable connection on source and destination’s NICs
• Live migration
  • Downtime: 300 ms (default)
  • Network bandwidth: No limit (i.e. maximum 10G)
• Legacy Guest
  • 8 vCPUs, 32GB RAM
  • No compression, but 0 page optimization is used
• Legacy Guest without 0 page optimization
  • 8 vCPUs, 32GB RAM
  • No compression and no 0 page optimization
• TD Guest, labelled Pseudo-TDX-xxxx
  • 8 vCPUs, 32GB RAM
  • No compression and no 0 page optimization
  • Modelled by adding extra xaaa cycles overhead memory read on SRC and write on DST
    • 2300 cycles = 0.24 * 4096 + 1000 additional transition latency + 300 syscall latency
    • 4000 cycles = 0.63 * 4096 + 1000 additional transition latency + 300 syscall latency
  • Pseudo-TDX-xaaa-multifd: multifd is enabled, with 4 channels (i.e. i/o threads) to send data
**Tests with 600MB/s Memory Dirty Rate**

- Running a workload in guest with 600MB/s memory dirty rate
  - Working set is 600MB

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</thead>
<tbody>
<tr>
<td>Total Migration Time (Seconds)</td>
<td>13.1</td>
<td>30.5</td>
<td>40.6</td>
<td>50.8</td>
<td>34.4</td>
<td>37.1</td>
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<td>Downtime (Milliseconds)</td>
<td>366</td>
<td>355</td>
<td>368</td>
<td>374</td>
<td>372</td>
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<tr>
<td>Dirty Count</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>20</td>
<td>5</td>
<td>6</td>
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<tr>
<td>1st Round Migration Throughput (Pages per Second)</td>
<td>733017</td>
<td>282893</td>
<td>214663</td>
<td>176055</td>
<td>267530</td>
<td>251473</td>
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<tr>
<td>1st Round Network Throughput (Mbps)</td>
<td>52.8</td>
<td>9288.0</td>
<td>7074.8</td>
<td>5780.2</td>
<td>8789.4</td>
<td>8256.8</td>
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<tr>
<td>CPU Usages (%)</td>
<td>23.5% (vCPUs)</td>
<td>100% (Migration)</td>
<td>23.5% (vCPUs)</td>
<td>75% (Migration)</td>
<td>23.5% (vCPUs)</td>
<td>78.2% (Migration)</td>
</tr>
</tbody>
</table>
Maximum Migratable Dirty Rate

- Guest with memory dirty rate larger than the maximum value fails to be live migrated

Guest Memory Dirty Rate: MB/s

- Legacy
- Legacy without Zero-page Optimization
- Pseudo-TDX-2300
- Pseudo-TDX-4000
- Pseudo-TDX-2300-multifd
- Pseudo-TDX-4000-multifd
Status and Plan
Status and Plan

• Pre-copy enabling
  • Draft code ready, pending to test
  • Plan to post out the patches to the QEMU/KVM mailinglists in Q1’2022

• Multi-fd enabling
  • Create multiple migration streams, which allows multiple iothreads to export/import TD private pages in parallel
  • Plan to start support in Q1’2022

• Post-copy enabling
  • Plan to start support in Q2’2022
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End of Presentation – Q&A
Backup
Test 2: Network Throttling – MAX ~3Gbps
### Tests with 300MB/s Memory Dirty Rate

- Running a workload in guest with 300MB/s memory dirty rate
- Working set is 300MB

<table>
<thead>
<tr>
<th></th>
<th>Legacy</th>
<th>Legacy without Zero-page Opt</th>
<th>Pseudo-TDX-2300</th>
<th>Pseudo-TDX-4000</th>
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<tr>
<td><strong>Total Migration Time</strong></td>
<td>15.6</td>
<td>87.3</td>
<td>87.4</td>
<td>87.4</td>
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<tr>
<td>(Seconds)</td>
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<td><strong>Downtime</strong></td>
<td>187</td>
<td>177</td>
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<td>225</td>
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<tr>
<td>(Milliseconds)</td>
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<td><strong>Dirty Count</strong></td>
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<tr>
<td><strong>1st Round Migration</strong></td>
<td>723540</td>
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<td>Throughput</td>
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