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

- 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

- qemu_savevm_state_setup
- qemu_savevm_state_iterate
- qemu_savevm_state_complete_precopy
- qemu_loadvm_state_setup
- qemu_loadvm_state_main

- cgs_mig_savevm_state_setup
- cgs_mig_savevm_state_start
- cgs_mig_savevm_state_ram
- cgs_mig_savevm_state_ram_end
- cgs_mig_savevm_state_end

- tdx_mig_savevm_state_setup
- tdx_mig_savevm_state_start
- tdx_mig_savevm_state_ram
- tdx_mig_savevm_state_ram_end
- tdx_mig_savevm_state_end

- ram_save_iterate
- ram_save_complete

- TDH.MIG.STREAM.CREATE
- TDH.EXPORT.STATE.IMMUTABLE
- TDH.EXPORT.TRACK
- TDH.EXPORT.MEM
- TDH.IMPORT.STATE.TD
- TDH.IMPORT.STATE.VP
- TDH.IMPORT.TRACK
- TDH.IMPORT.MEM
- TDH.IMPORT.END

Legend:
- Existing Migration Logic
- CGS Migration Layer
- Vendor-specific Implementation
- Invocation
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 xxxx 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-xxxx-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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<tr>
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<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>
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<td>Downtime (Milliseconds)</td>
<td>366</td>
<td>355</td>
<td>368</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>78.2% (Migration)</td>
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<td>78.2% (Migration)</td>
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</tbody>
</table>
Maximum Migratable Dirty Rate

- Guest with memory dirty rate larger than the maximum value fails to be live migrated
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>Total Migration Time (Seconds)</td>
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<td>Dirty Count</td>
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<tr>
<td>CPU Usages (%) (vCPUs)</td>
<td>9.6%</td>
<td>100%</td>
<td>9.6%</td>
<td>9.6%</td>
</tr>
<tr>
<td></td>
<td>(migration)</td>
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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