Runtime VM Protection By Intel® Multi-Key Total Memory Encryption (MKTME)

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Agenda

• MKTME Introduction
• MKTME Use Cases
• MKTME Enabling
Background: Trusted VM in Cloud

VM protection by using encryption
• VM encrypted ‘at-rest’, ‘in-transit’ and ‘runtime’.
• There has been existing technologies for ‘at-rest’ and ‘in-transit’ encryption
  • Qemu TLS support for live migration
  • Qemu encrypted image support
• VM runtime encryption requires hardware memory encryption support
  • AMD® SME/SEV
  • Intel® MKTME

Launch VM on ‘Trustiness Verified’ Host
• Trusted hardware/location, etc.
• Trusted Cloud SW stack.

Typical VM Lifecycle in Cloud
Trusted VM w/ OpenCIT -- OpenStack as Example

Intel® Open CIT helps on Host trustiness verification
**TME & MKTME Introduction**

- New AES-XTS engine in data path to external memory bus.
  - Data encrypted/decrypted on-the-fly when entering/leaving memory.
  - AES-XTS uses physical address as “tweak”
    - Same plaintext, different physical address -> different ciphertext.

- TME (Total Memory Encryption)
  - Full memory encryption by TME key (CPU generated).
  - Enabled/Disabled by BIOS.
  - Transparent to OS & user apps.

- MKTME (Multi-key Total Memory Encryption)
  - Memory encryption by using multiple keys.
  - Use upper bits of physical address as keyID (see next)
MKTME KeyIDs

• Repurpose upper bits of physical address as KeyID as shown below.
  • Reduces useable physical address bits.
  • Creates “aliases” of physical memory locations: different keyIDs can refer to the same page.
  • Cache-coherency is not guaranteed for the same page that accessed by different keyIDs.
    • CPU caches are unaware of keyID (still treat keyID as part of PA)

• Architecturally upto $2^{15}-1$ keyIDs (15 keyID bits).
  • Reported by MSR. Configured by BIOS.
  • KeyID 0 is reserved as TME’s key (not useable by MKTME).

• New PCONFIG instruction to program keyID w/ associated key (see next)
MKTME KeyID Programming Overview

New Ring-0 instruction PCONFIG to program the KEYID and associated key

- Package scoped
- Supports programming keyID to 4 modes:
  - Using CPU generated random ephemeral key (invisible to SW)
  - Using SW provided key (tenant’s key)
  - No encryption – plaintext domain
  - Clearing a key (using TME’s key effectively)
- Allows SW to specify crypto algorithms
  - Only AES-XTS-128 for initial server intercept
VM Protection & Isolation With MKTME

- **Protection**
  - Use keyID to encrypt VM memory at runtime

- **Isolation**
  - Use different keyIDs for different VMs

- **Software Enabling**
  - For CPU access, SW sets keyID at PTEs
    - IA page table (host)
    - EPT (KVM)
  - For Device access (DMA)
    - w/ IOMMU: Set keyID to IOMMU page table
    - Physical DMA: Apply keyID to PA directly

![Diagram of keyID management](image_url)
Highlights of MKTME

Guests continue to run “without modifications” in MKTME domains:

• Encrypted with 1) CPU-generated ephemeral key, or 2) the one provided by API (“tenant-controlled keys”)
• Virtio, including optimization (direct access to guest memory by kernel) continues to work
• Direct I/O (including accelerators, FPGA) assignment (including SR-IOV VFs) is available
• Live migration can be supported (among platforms that support MKTME)
• vNVDIMM can be supported w/ limitation (because of physical address “tweak”)
  • Host DIMM configuration cannot be changed cross reboots.
  • Qemu DIMM & vNVDIMM configuration cannot be changed cross VM reboots.
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MKTME Enabled Use Cases

1. **Launch Tenant VMs with in-use protection (CPU generated keys)**
   - Let CSP handle the keys
   - VM image provided by CSP

2. **Launch Tenant VMs with at-rest and in-use protection with full tenant-control**
   - VM image encrypted @rest with tenant-specific keys
   - Keys in tenant control
   - VM memory isolation with tenant-specific keys
   - Trustiness verified host
   - Additional: integrity verification of VM image

*Use-case Extension:*

**KeyID Sharing** for all VMs launched by single tenant with the same tenant-key (or CPU generated key).
VM Launch w/ CPU Generated Keys

- CPU generated key
- CSP provided VM image

Security Properties
- w/ VM runtime protection
- w or w/o at-rest and in-transit protection
- No Host Trustiness Verification

CSP Controlled
VM Launch w/ Tenant Controlled Keys

VM Launch w/
- Tenant provided key
- Tenant provided encrypted VM image
- Tenant controlled key server
- Trustiness verified host
- VM image integrity verified
- Use TPM to wrap/unwrap tenant-key

Security Properties
- w/ VM runtime protection
- w/ VM at-rest protection
- w/ or w/o in-transit protection
- w/ Host trustiness verification
- w/ VM image integrity verification

Tenant Controlled

CSP Controlled
KeyID Sharing Among VMs

Cloud SW makes decision whether to share or not.

<table>
<thead>
<tr>
<th>KeyIDPolicy</th>
<th>KeyID</th>
<th>VMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy1: &lt;tenant1, &quot;ephemeral&quot;&gt;</td>
<td>keyID1</td>
<td>VM1, VM2..</td>
</tr>
<tr>
<td>Policy2: &lt;tenant2, &quot;persistent&quot;, xxxxx&gt;</td>
<td>keyID2</td>
<td>VM3</td>
</tr>
</tbody>
</table>

Example: KeyID sharing is based on KeyIDPolicy: <tenant_id, key_type, tenant_key>

Cloud SW:
- Maintains ‘KeyIDPolicy-to-KeyID’ table
- Makes keyID sharing decision according to the table
- Updates the table on VM launch and teardown

Compute Node

mKey API: MKTME key management API

New VM Launch w/ MktmePolicy

MktmePolicy {
  tenant_id: <UUID>,
  key_type: “ephemeral” | “persistent”,
  key_server: https://...
  allow_to_share: “yes” | “no”
}

Qemu

Apply keyID to VM memory

Launch VM w/ keyID

Launch VM

Cloud SW

Launch VM w/ keyID

mKey API

KVM
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MKTME Enabling High Level

- Host kernel
  - mkey APIs
- Key/KeyID Management
- Core-MM KeyID support
- VFIO/IOMMU KeyID support
- DMA KeyID support
- KVM
  - KeyID setup in EPT
- Qemu
  - Receive KeyID from Cloud SW
  - Apply KeyID to guest memory
MKTME Enabling Current Status

• Specification has been published [1]
• Core kernel enabling status
  • Some preliminary patches have been upstreamed
    • Feature emulation (CPUID, MSR); PCONFIG
  • Proposal of some components have been sent to community for feedback
    • Key management API: Using kernel key retention service
  • Other components WIP internally
    • Core-MM keyID support; IOMMU keyID support; DMA keyID support; ...
• KVM/Qemu enabling status
  • PoC has been done to prove MKTME actually works.
  • Depending on core kernel parts ready for formal patches.

THANKS