Protect Data of Virtual Machines with MKTME on KVM

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Agenda

• Background & MKTME Introduction
• MKTME Use Cases
• MKTME Enabling & Status
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, SW stack, etc.
  - HW based root-of-trust
  - Attestation service

Typical VM Lifecycle in Cloud

1. At-rest
   - VM Image Repo
   - Cloud Orchestrator

2. Runtime
   - Cloud Agent
   - VM Launch
   - Intel® Arch
   - Compute Node

3. In-transit
   - Live Migration
   - Cloud Agent
   - VM Launch
   - Intel® Arch
   - Compute Node
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 supporting 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.
  • Different keyIDs can refer to the same physical address.
• 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)
    - SW can provide entropies for key and tweak, which will be XOR-ed by CPU.
  - 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
Recap -- Highlights of MKTME

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

- 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 runtime protection with CPU generated keys**
   - Let CSP handle the keys
   - VM image provided by CSP

2. **Launch Tenant VMs with at-rest and runtime protection with full tenant-control keys**
   - VM image encrypted at-rest with tenant-specific keys
   - VM memory isolation with tenant-specific keys
   - Keys fully controlled by tenant
   - 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

VM Launch w/
- 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, “ephemeral”&gt;</td>
<td>keyID1</td>
<td>VM1, VM2..</td>
</tr>
<tr>
<td>Policy2: &lt;tenant2, “persistent”, xxxxxx&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

Cloud SW makes decision whether to share or not. New VM Launch w/ MktmePolicy

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

Launch VM w/ keyID

Qemu

Apply keyID to VM memory

Launch VM

KVM

mKey API

Cloud SW
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MKTME Enabling Overview

- **Overall:**
  - Setup the same keyID in both Qemu host page table and EPT/shadow page table
- **Passthrough:**
  - Setup keyID to IOMMU
- **Virtio/vhost-kernel:**
  - `kmap()` w/ keyID
  - DMA w/ keyID
- **Live Migration:**
  - DMA w/ keyID
MKTME Enabling Overview -- Recap

- **Host kernel**
  - Key/keyID Management APIs
    - Use kernel key retention services infrastructure, and add new MKTME key type.
    - Return `key_serial_t` (handle) to userspace instead of actual keyID.
  - Core-MM keyID support
    - VMA, page table keyID manipulation
    - Setup keyID to PTE in #PF
  - New syscall to encrypt process memory region by given MKTME key handle.
    - `encrypt_mprotect(addr, size, prot, key_handle);`
  - VFIO/IOMMU keyID support, DMA keyID support.

- **KVM**
  - Setup keyID in EPT/Shadow MMU

- **Qemu**
  - Receive MKTME key handle from Cloud SW
  - Apply MKTME key handle to all guest memory (by calling new syscall)
MKTME Enabling - Qemu Modification

- New “mktme-guest” object to carry MKTME handle
  - `object mktme-guest,id=mk0,handle=${mktme-handle}`
  - Align with AMD SEV’s “sev-guest” object
- Reuse machine property “memory-encryption” to indicate VM is associated w/ keyID.
  - Consistent with AMD SEV, who introduced ‘memory-encryption’ property

**Example: Launch VM w/ $mktme-handle**

```
#qemu-system-x86_64 ... -machine memory-encryption=mk0 -object mktme-guest,id=mk0,handle=${mktme-handle}
```

**Example: Put into a small script, combined w/ adding MKTME key**

```
#!/bin/bash
serial=`keyctl add mktme k1 “type=cpu algorithm=aes-xts-128” @us`
qemu-system-x86_64 –enable-kvm –cpu host –smp 2 –m 4G –machine memory-encryption=mk0 \
    -object mktme-guest,id=mk0,handle=${serial}
```
MKTME Enabling Current Status

• Specification has been published [1]
• Core kernel enabling status
  • Some preliminary patches have been upstreamed
    • Feature emulation (CPUID, MSR); PCONFIG
  • Some RFCs have been sent to community for feedback
    • New MKTME key type implementation
  • 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