Toward a Virtualization World Built on Mediated Pass-Through

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I/O Virtualization

Software Virtualization

Guest Driver -> Host Driver

Device Model

Guest Driver

Device

Ctrl path

Data path

Direct Pass-Through

Guest Driver -> Guest Driver

Device Model

Host Driver

VF

VF

Mediated Pass-Through

Guest Driver -> Host Driver

Device Model

Guest Driver

√ Performance

√ Scalability

√ Feature
Linux* Mediated Device Framework

• Introduced in kernel 4.10

• Device ops to connect all kinds of mediated devices
  ➢ GPUs, NICs, platform devices, etc.

• Bus ops as the bridge to various UAPIs
  ➢ VFIO, virtio, vhost, etc.

• Life-cycle management through sysfs
Explore More Values beyond Mediate-for-Sharing
Resource Scaling

- **Dynamic queue re-allocation**
  - Load-balancing, queue over-commitment, etc.
  - $\text{maxQ}$ vs. $\text{curQ}$

- **Mdev device driver registers VMA fault handler for re-allocation** *(example)*
  - Guest-transparent way (only see $\#\text{maxQ}$)
  - Guest-cooperated way (see both $\#\text{maxQ}$ and $\#\text{curQ}$)

- **Same technique could also be used for failover**

![Diagram](image-url)
Live Migration

- Mediate for composing device state
- A new migration region on mdev
  - State transition (running, stopped, etc.)
  - GET/SET device state
  - GET dirty page bitmap
- Currently in v8
Generational Compatibility

- Underlying device is incompatible to guest driver
  - Post migration, legacy OS, etc.

- Mediate for compatible device interface

- Useful for small generation jump
  - Incompatible control interface
  - Compatible data path
Memory Footprint

• Mediate for pinning guest DMA pages
  ➢ For efficient memory utilization

• Mdev device driver tracks the status of guest DMA pages
  ➢ E.g. scanning ring descriptors or device mmu page tables, etc.

• vfio_pin_pages for selectively pinning a set of guest PFNs
Innovate the Mediated Device framework
Hardware Assistance

- Example: Intel® Scalable I/O Virtualization
  - For higher density and security

- Device: finer-grained resource isolation
  - ADI: queue, queue pair, or context
  - 4K aligned MMIO ranges
  - Scalable interrupt message storage
  - Independent reset
  - ...

- IOMMU: finer-grained DMA isolation
  - PASID-granular address translation
  - Primary domain vs. Auxiliary (AUX) domain

- VFIO: iommu-capable mdev
Hardware-offloaded Mediation

- Offloading device model to embedded CPU
  - Data path directly routed to embedded device
  - Control path mediated by embedded CPU

- Simplified host software stack
  - State/resource management through the embedded controller
Guest Mediation

- Mediation on assigned PF/VF
  - One-level mediation

- Mediation on assigned mdev
  - Nested mediation

- Additional host support
  - Not required for software-based mediation
  - Required for hardware-assisted mediation
Hardware-assisted Guest Mediation

- Assign a capable PF to the guest
  - E.g. Intel® Scalable IOV

- Expose a capable vIOMMU
  - E.g. Intel® VT-d rev3.0
  - PASID-granular DMA isolation

- Sync vIOMMU to physical IOMMU
  - Nested translation, PASID management, page fault, etc.
  - Part of vSVA effort
Hardware-assisted Guest Mediation (Cont.)

- Remains a gap on IOMMU domain
  - Host maintains only one domain for PF pass-through
  - However, guest creates multiple AUX domains on assigned PF

- Shadow guest AUX domains
  - Guest-initiated AUX domain management
  - Currently under internal exploration
Mediation in User Space

- Need a channel to connect userspace DM to the mdev core
  - When parent device driver is in user space

- Hardware-assisted userspace mediation
  - User-initiated AUX domain management
  - Verify ownership of the parent device

- Currently in prototyping
‘Mediated’ Direct Pass-Through

- Mediation wrapper driver for fixing limitations in direct pass-through
  - Live migration, generational compatibility, etc.

- Based on vfio-mdev
  - Wrap the device into a single mdev
  - Implement mdev_parent_ops

- Based on vfio-pci
  - Directly hook to vfio_pci_ops
  - Under discussion in mailing list
The Future
A World Built on Mediated Pass-Through

Mediation Framework

- Scalability
- Flexibility
- Composability
- Introspection
- Security

SW-based mediation

HW-assisted Mediation

Offloaded Mediation