Hardware-Assisted Mediated Pass-Through with VFIO

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VFIO

• A secure, userspace driver framework

• VFIO physical device
  - PCI endpoints, platform devices, etc.
  - PCI device sharing through PCIe® Single Root I/O Virtualization (SR-IOV)

• VFIO mediated device
  - vGPUs, channel I/O devices, crypto APs, etc.
  - Device sharing through vendor specific resource mediation policy
**PCle® SR-IOV**

- **Hardware-assisted I/O virtualization**
  - Physical Function (PF)
  - Virtual Function (VF)

- **Pros**
  - Software simplicity
  - IOMMU-based DMA isolation

- **Cons**
  - Limited scalability
  - Fixed resource allocation
  - Lack of composability
Mediated Device

- Mediated pass-through architecture
  - Slow-path operations emulated by software
  - Fast-path operations passed through

- Pros
  - Flexible resource allocation
  - Composability

- Cons
  - Software-based DMA isolation (thus increases complexity and limits scalability)
Can we enjoy merits from both sides for hyper-scaled usage?
Goals

Finer-grained resource sharing

Flexible Resource Allocation

Composability

Hardware-enforced DMA Isolation
Assignable Device Interfaces (ADI)

- ADI - represents minimal sharable resource
  - Queues, queue pairs, contexts
  - Enumerated through DVSEC capability (see backup)

- Meets isolation criteria to be ‘assignable’
  - Functional isolation between ADIs
  - ADI MMIO in separate system page size regions
  - Independently resettable
  - Interrupt Message Storage (IMS)
  - …

- Tags DMA with unique PASIDs

Enable maximum possible scalability!
PASID-granular DMA Isolation

- Moves all IOMMU paging structures to per-PASID
  - 1st level translation
  - 2nd level translation
  - Nested translation
  - Pass-through translation

- Enables PASID-granular DMA isolation

- Supports all existing address translation usages
  - IOVA, VA, GPA, GIOVA and GVA

Enable hardware-enforced DMA isolation!
Software Composition

- **Virtual Device Composition Module (VDCM)**
  - Software managed resource remapping between mdev and ADI
  - Composes ADIs into mediated device (mdev)

- **Leverage VFIO mdev framework for**
  - Managing mdev life-cycle
  - Setting up access policy on mdev resources
  - Serving slow-path operations from guest

Enables great flexibility and composability!
Combining them together…
Intel® Scalable I/O Virtualization (Intel® Scalable IOV)

• A hardware-assisted mediated pass-through architecture
  - Device: supports Assignable Device Interfaces (ADIs)
  - Platform: extends Intel® VT-d with PASID-granular DMA isolation (scalable mode)
  - Software: moves infrequent (slow-path) accesses from device to software

• Supports any type of devices
  - e.g. NIC, storage, GPU, accelerators, … (integrated or discrete)

• Supports both VM and bare-metal usages
• Intel® VT-d specification update (Rev 3.0)
  ➢ Documents Intel® VT-d (IOMMU) support for PASID granular address translation

• Intel® Scalable I/O Virtualization Technical Specification (Rev 1.0)
  ➢ Documents the Scalable IOV architecture blueprint and operation, including DVSEC
  ➢ Addresses architecture requirements for devices and drivers
  ➢ Agnostic of type of device or specific implementation
  ➢ Openly published to enable broad device and software ecosystem

• https://software.intel.com/en-us/articles/intel-sdm
What does it mean to VFIO/IOMMU driver?
VFIO: IOMMU-capable Mdev

- IOMMU-capable mdev
  - Allow IOMMU operations on mdev
  - Opt-in by VDCM

- Finer-grained resource management
  - New aggregated type to compose any number of ADIs into a mdev
IOMMU Domains

- One device can attach to one domain, at any time
  - One domain can be attached to multiple devices

- Domain type describes IOMMU policy for device DMAs
  - DMA, UNMANAGED, IDENTITY, and BLOCKED

- Domain is switched when policy changes

"one domain" scheme doesn’t work for IOMMU-capable mdev!
Auxiliary Domain

- One device can attach to multiple domains
  - A primary domain used for DMA-API
  - Multiple auxiliary domains used for mdev instances

- ‘aux’ is a device attribute instead of domain attribute
  - Same domain may represent as ‘primary’ to deviceA and ‘aux’ to deviceB
  - ‘primary’ vs. ‘aux’ is decided at domain attach time
  - Device driver enables ‘aux’ capability on device before attaching domain

- No change to at(de)tach API
  - VFIO attaches domain to mdev’s parent

Avoid mdev awareness in IOMMU layer!
Mdev with vIOMMU

- Ongoing effort to enable VFIO devices with vIOMMU
  - Shadow vIOMMU 2nd level usages (e.g. GIOVA)
  - Nesting vIOMMU 1st level usages (e.g. GIOVA/GVA)
    - Including system-wide PASID management
  - Cache invalidation forwarding (when nesting is in-use)
  - Page request/response handling (for guest SVA)

- Expect common user-space logic for vfio-pci and vfio-mdev
  - Just granularity difference handled within IOMMU driver

- Qemu: emulating new VT-d scalable mode emulation

- For more detail, join below session by Yi & Jacob!
  - “Shared Virtual Addressing in KVM”
Status

• **Key developers**
  - Baolu (Allen) Lu ([baolu.lu@intel.com](mailto:baolu.lu@intel.com))
  - Yi Liu ([yi.l.liu@intel.com](mailto:yi.l.liu@intel.com))
  - Jacob Pan ([jacob.jun.pan@intel.com](mailto:jacob.jun.pan@intel.com))

• **RFC patch progress**
  - [https://lkml.org/lkml/2018/10/7/54](https://lkml.org/lkml/2018/10/7/54) for scalable mode support in intel-iommu driver in v3
  - [https://lkml.org/lkml/2018/10/12/225](https://lkml.org/lkml/2018/10/12/225) for aux_domain and IOMMU capable mdev in VFIO/IOMMU driver in v3
  - Continued hot discussion around vIOMMU/vSVM (in multiple threads)
    - Mdev requirement is being considered gradually
  - [https://www.mail-archive.com/libvir-list@redhat.com/msg173811.html](https://www.mail-archive.com/libvir-list@redhat.com/msg173811.html) for aggregated mdev type in v3
Backup
Enumeration of Intel® Scalable IOV Capability

- Designated Vendor Specific Extended Capability (DVSEC) to discover Intel® Scalable IOV capability
  - A simplified subset of SR-IOV capability

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VT-d Extended Context Mode (Deprecated)
Key Difference: PASID is a global ID space shared by all VMs.
ALL page-table pointers moved to PASID Granular table