vfio-ap: The Perils of the Weird
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KVM Forum 2018
vfio-ap objective: KVM-based, hardware assisted, pass-trough for AP Crypto on IBM z.
Why should anybody care about AP Crypto?

- **Adjunct Processors**, a.k.a. **Crypto Express Features**: crypto cards (PCIe)

- Cool because:
  - Tamper-sensing, tamper-responding HSMs
  - Secure and protected keys
  - Configurable – 3 different FW loads: EP11, CCA, Accelerator
  - Certification (e.g. CEX6C and CEX6P **FIPS 140-2, Level 4**)

- Complementary to **CPACF**

- Designed with virtualization in mind.
Overview – HW Crypto support in IBM Z

Each PU is capable of having the CPACF function.
Names

- AP == adjunct processor == Crypto Express feature == adapter; identified by APID
- Each adapter is partitioned into domains; identified by APQI.
- APID + APQI = APQN; identifies an AP queue, which is, from a functional perspective, the device providing the crypto services, e.g. HSM.
- The functionality is made available to SW via 3 instructions: NQAP, DQAP, PQAP
- NQAP and DQAP act strictly on an AP queue
- PQAP is somewhat special (config info, resets, etc)
Big Machines! Only FW is allowed to run ‘native-native’. Customer workload can be:

- LPAR: Logical Partition, the ‘new native’ (G1)
- KVM guest (G2)
- Nested virtualization (Gn, 2 < n < 8?)

The SIE instruction

- Execute a vCPU based on several control structures in host storage (memory), i.e. State Description (SD) and SD-satellites.
- Keep executing the vCPU until:
  - Hypervisor cooperation is needed
  - The hypervisor wants to intervene
  - Stuff happens
Good news! SIE’s AP virtualization scales beyond G1

- Remember **LPAR** is the **new native**, which is already virtualized. At **LPAR** level, the story is mostly about **partitioning resources**.

- **AP resources** are **partitioned** in the following way. Each **LPAR** has three masks in an **SD-satellite** that control access to **AP queues**:
  - **APM**: if bit corresponding to the **adapter** not set, the guest can do nothing with the adapter
  - **AQM**: if bit not set the guest can not **use** the given **domain** (on any **adapter**)
  - **ADM**: if bit not set the guest can not **control** the given **domain** (on any **adapter**)
- The Cartesian product:
  - **APM x AQM**: authorizes **AP queue use**
  - **APM x ADM**: authorizes **AP queue control**

- For **G2** (and higher), **APM**, **AQM** and **ADM** are effective controls (i.e. **EAPM = G1.APM & G2.APM**); so, KVM only needs to **sub-partition** and almost everything works. Per architecture, on each guest level, **full sized masks** are used **regardless of** what is **installed** or made **available** by lower virtualization layers.
## Example – APM, AQM, ADM (APCB)

<table>
<thead>
<tr>
<th>Domains (AQM)</th>
<th>Adapters (APM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16</td>
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<tr>
<td>1</td>
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<td>15</td>
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<td>16</td>
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</tr>
</tbody>
</table>

**VM “A”**

**VM “B”**
How do we model this in SW?

- **Kernel view:** usually, assignment → vfio
  - Assign a **full device** with plain vfio, or
  - Assign a **uniform part** of a device with vfio-mdev
  - Usually, we do not deal with devices that are not available

- **QEMU view:** usually, model and function in sync

- **AP crypto in Linux (host)**
  - **Card** devices
  - **Queue** devices: Live within the scope of card devices
  - **Zcrypt device:** Provides crypto for user-land, load balanced over AP’s

- **We can’t/don’t want to pass-through:**
  - **Queue** devices: **too fine** grained, SIE can’t do it
  - **Card** devices: **too coarse** grained

- **Design decision:** Regard the whole **AP subsystem** as one device that is **shared** (mdev) between different **guests** and the **host**.
The grand design

Kernel

vfio_ap:module

kvm:module

*:ap_matrix_mdev

APM
AQM
ADM

User-land

Admin

<<instantiates>>

QEMU

<<instantiates>>

VM1: struct kvm

SD

provides struct kvm*

matrix_dev:ap_matrix_dev

regs as mdev parent dev

sets A[PQD]M

1

opens

1
For us vfio-mdev is ...

• ... a good match because, we are almost like a normal mediated device:
  - we kind of do have a host device can be shared scenario
  - we get a host **device that stands for the passed-through resources** (for QEMU)
  - we get a pointer to struct kvm to do our virtualization stuff

• ... not a perfect match because:
  - we deeply **care about what queues** are assigned to what entity (key material)
  - it is **not one size fits all**, like the original mdev design (for vGPUs) implies
    • life-cycle: start empty after **create** and build from there
    • **available_instances is weird** for us
  - there is **no trivial/suitable mdev parent device**
  - **sharing of queues is not allowed**, constraints on the partitioning
  - queues **reserved for host** usage **must not be accessible for guests** and vice-versa, however the admin should decide what is reserved for host
    • not even if **device flickers**
  - we should be able to authorize (assign) queues that are not yet known to the system (system architecture vs mdev architecture)
Enforcing constraints

- **Queues** used by (host) zcrypt vs ‘alternative driver’
  - ap_bus got its own **APM** and **AQM** called apmask and aqmask respectively; can be set via sysfs or via kernel cmd line
  - zcrypt queue drivers bind only to what is specified by the masks, alternative drivers bind only to the complement (vfio-ap is the only alternative driver)

- On each assign_adapter and assign_domain we check whether the resulting queues are:
  - Bound to the vfio_ap driver
  - Not claimed by another vfio_ap_mdev
Life cycle

1) Take care of ap_bus, vfio_ap module

2) Create vfio_ap mdev device:

   $ uuid=$(uuidgen)
   $ echo ${uuid} > /sys/devices/vfio_ap/matrix/mdev_supported_types/vfio_ap-
passthrough/create

3) Assign resources to the mdev device

   $ echo 04 > /sys/bus/mdev/devices/${uuid}/assign_adapter
   $ echo 04 > /sys/bus/mdev/devices/${uuid}/assign_domain
   $ echo 04 > /sys/bus/mdev/devices/${uuid}/assign_control_domain

4) Include the mdev device into a VM

   1) QEMU cmd line:
      qemu -device vfio-ap,sysfsdev=/sys/bus/mdev/devices/${uuid}

   2) open on vfio-ap qdev realization hooks up the vfio_ap_mdev with the struct kvm which makes the
      vfio_ap_mdev immutable (i.e. no (un)assign, remove)
Life cycle challenges 1

• Create
  – Libvirt does not seem to be keen on doing life cycle management of mdev devices, particularly on tying mdev creation to guest life cycle events.
  – OTOH we have persistent configurations where certain elements are mutually exclusive with regards to full instantiation. For example:
    • Guest1: domain 1; adapters 1, 2
    • Guest2: domains 1, 2; adapters 2, 3 conflicts Guest 1 on queue (2,1)
    • Guest3: domain 2; adapter 1 no conflicts (assuming we resolve conflict between G1 and G2)
  – Creating all mdevs on system bring-up is not optimal.
  – Burdening the client of libvirt with ensuring the vfio_ap_mdev referenced by the domain is created before starting the domain does not seem right to me either.
  – Interim solution: Advise against conflicting configs, and make create all on bring-up easy.
Life cycle challenges 2

- Not yet resources.
  - Currently we only allow resources bound to the vfio_ap driver to be assigned. That is IMHO sub-optimal, because we take away functionality provided by lower level hypervisor for no good reason.
  - Resources may go away, so it isn’t an invariant.

- Hot(un)plug
  - Currently hot plug is prohibited, but this is likely to change soon.
  - The assign/unassign interfaces are not best suited for hot plug IMHO.
  - The admin could make ‘alternative’ devices ‘zcrypt’ devices again. React how?

- Migration
  - CPU model guarded, yeah!
  - Currently not supported: vfio-mdev device (QEMU) is a migration blocker
  - Mighty tricky from technical feasibility perspective.
Outlook

- Hot plug!!
- Life cycle management!

- Clean up?
- Intercept and mediate with address virtualization?
  - Performance vs flexibility.
- Intercept and emulate??
- Migration???
Q&A
Learn more

- Learn about vfio-mdev:
  [2016] vGPU on KVM - A VFIO Based Framework by Neo Jia & Kirti Wankhede
  https://www.youtube.com/watch?v=Xs0TJU_sIPc

- Learn about vfio:
  [2016] An Introduction to PCI Device Assignment with VFIO by Alex Williamson
  https://www.youtube.com/watch?v=WFkdTFTOTpA

- More about vfio-mdev: Check out the Documentation and the doc folders in the Linux kernel and the QEMU source tree respectively.