Post-Copy Live Migration on Pass-through Devices

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Live Migration

- Lively migrate the VM state between server nodes
  - CPU state
  - Memory state
  - Device state
  - VM configuration

- Cornerstone capability in data centers and clouds
  - Load balancing, SLA, infrastructure maintenance, etc.

Memory State: Pre-Copy vs. Post-Copy

Pre-Copy

1. Copy the entire guest memory to dest

2. Iteratively copy pages dirtied in previous round

Stop VM on src

3. Copy CPU/device state and remaining dirty pages to dest

Resume VM on dest

Mature and Reliable

Post-Copy

Stop VM on src

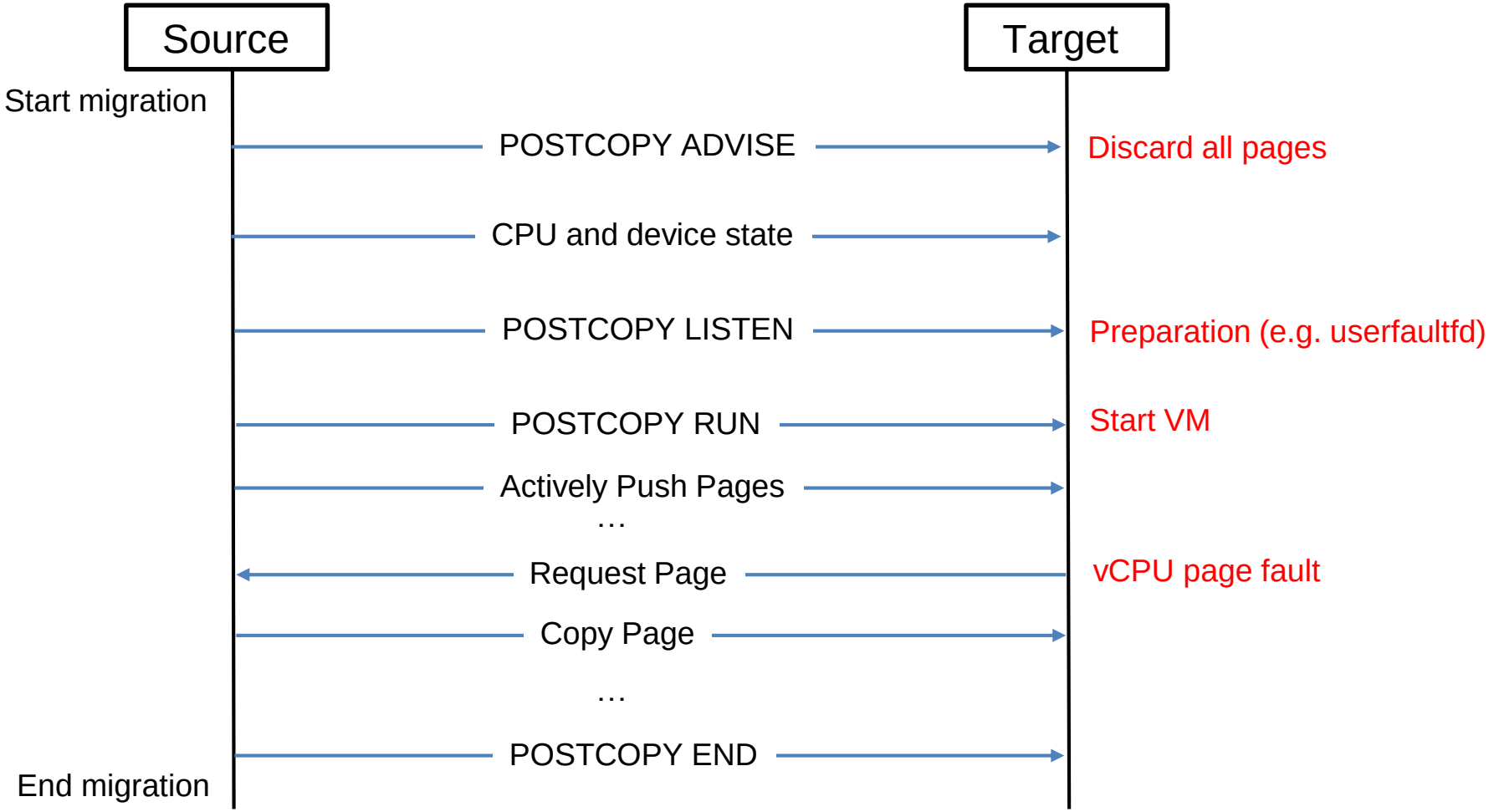
1. Copy CPU/device state to dest

Resume VM on dest

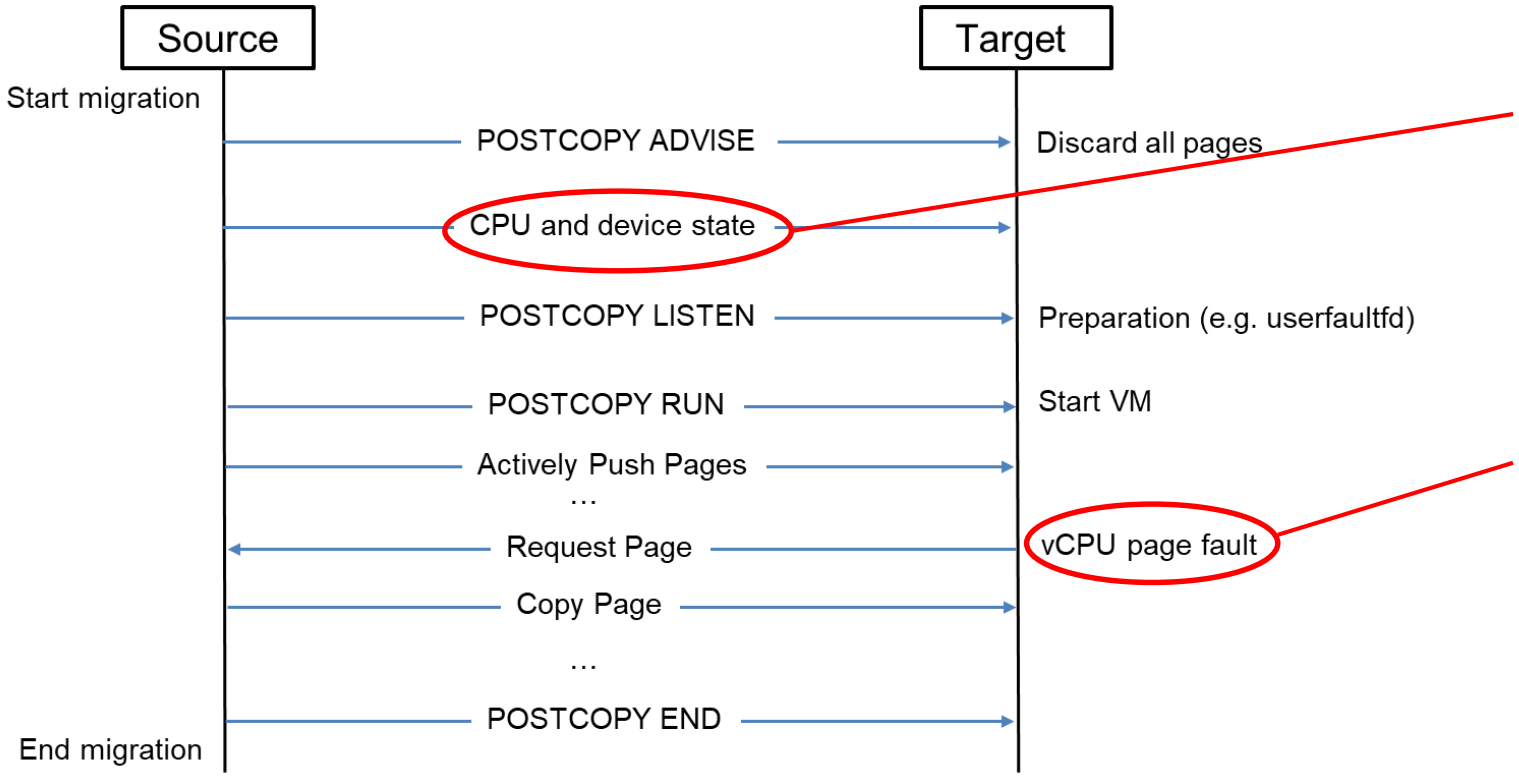
2. Copy the entire guest memory

Predictable and faster

A Detailed Flow of Post-Copy Live Migration



Challenges with Passthrough Devices



Host has no insight of the device state

Most devices don’t support DMA fault

Device State Migration

- Vendor specific definition of ‘device state’
  - Standard PCI resource (config space, MMIO BAR, MSI/MSI-X, etc.)
  - Vendor specific resource (e.g. hidden state, PF-maintained configuration, etc.)

- Use a wrapper driver for poking the device state
  - Use vfio-mdev, by creating a single mdev on top of the device (example)
  - Use vfio-pci, by hooking to specific vfio device ops (under discussion)
  - Getting/setting device state through the migration region (v8)

DMA Page Prefault

- Bear the fact that most devices don’t support DMA fault
- Prefault through device specific mediation
  - Trap any guest operation which may cause DMA access
  - Decode the operation to find out pages that may be used for DMA
  - Prefault the pages to userspace for memory pulling
- Device specific mediation policies
  - E.g. trap guest MMIO accesses, scan workload descriptors, etc.

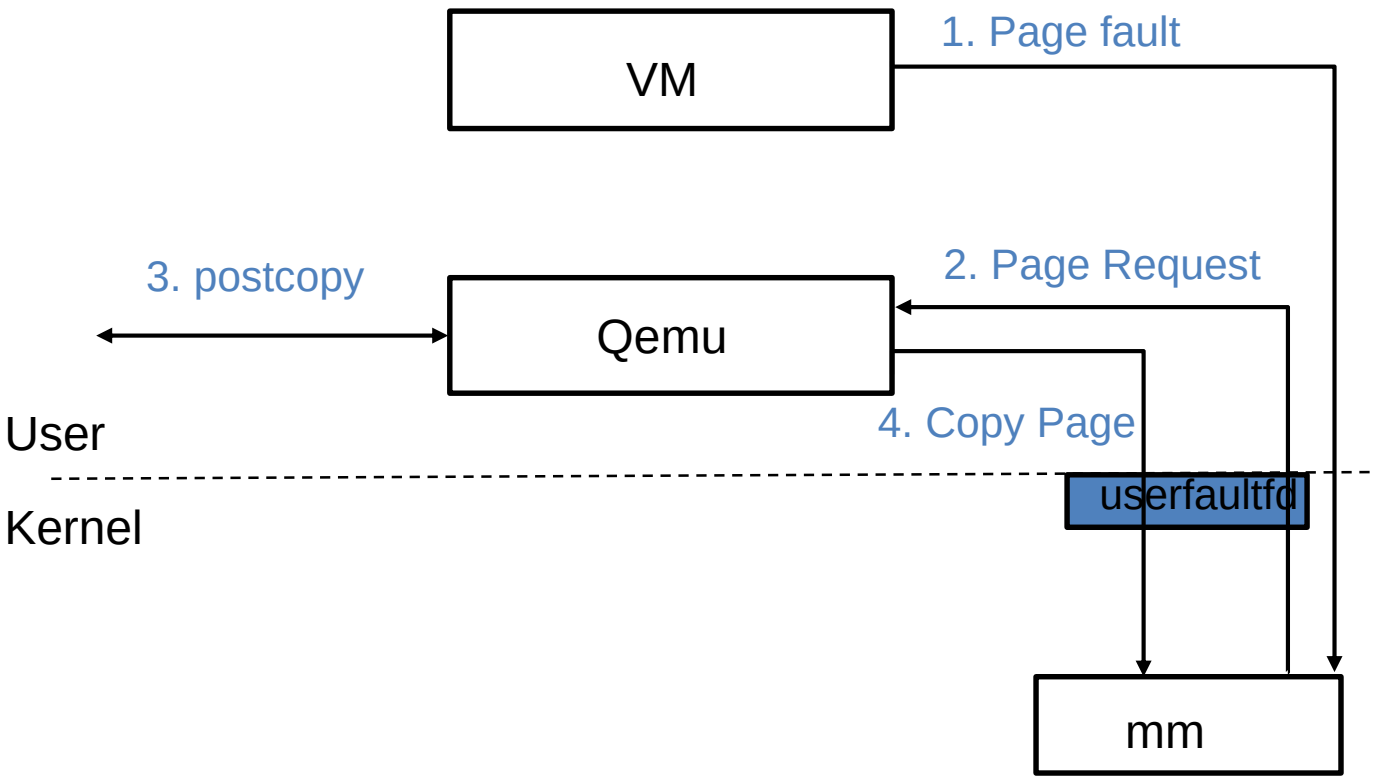
Need the capability of dynamic mediation!

Dynamic Mediation

- Dynamically turn on mediation when migration starts
  - For regions marked as VFIO_REGION_INFO_FLAG_MMAP
  - Re-enable pass-through when migration ends

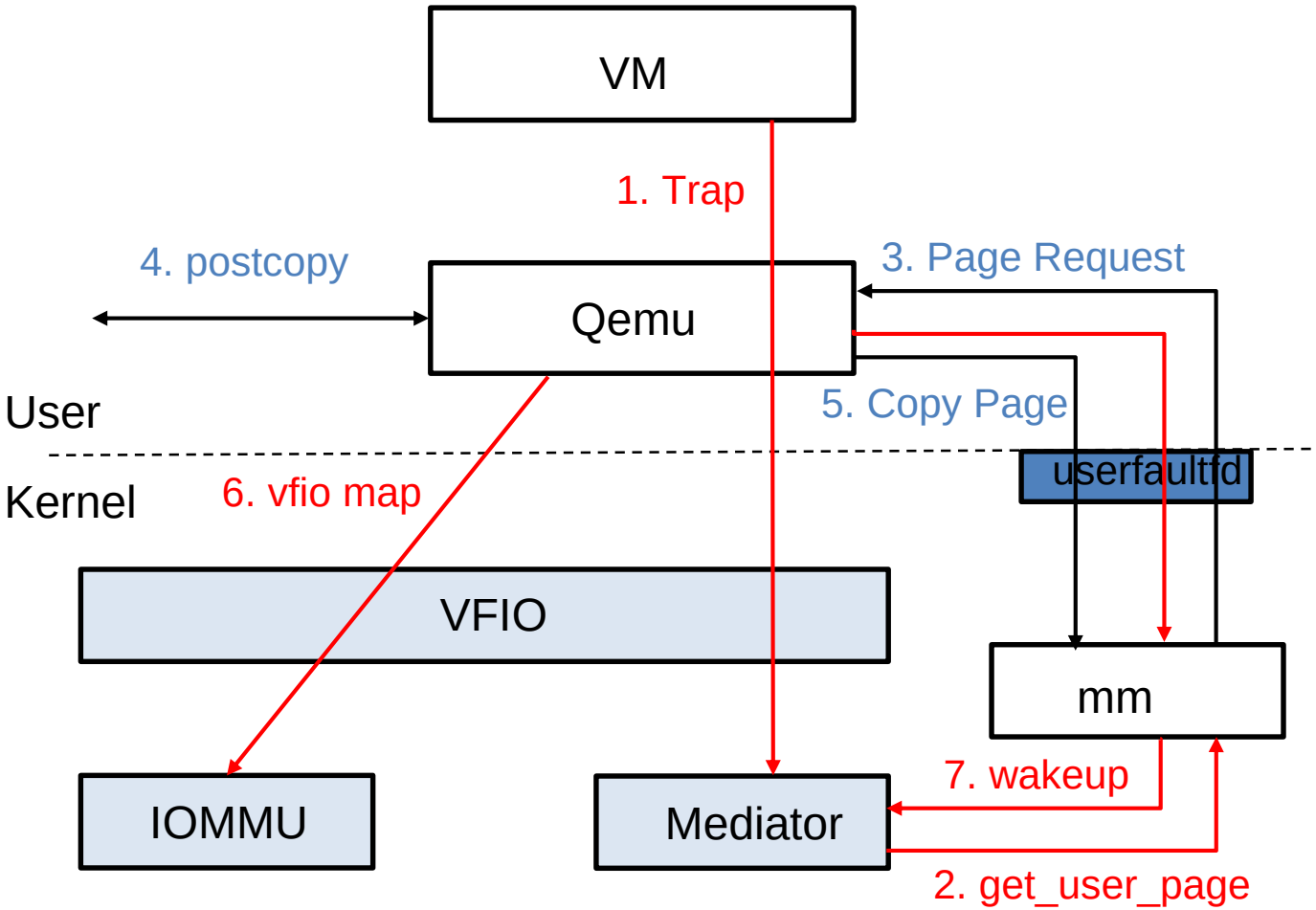
- Introduce a mediation bitmask in migration region
  - Indicate which region should be dynamically mediated when migration starts
  - Currently defined per MMIO region
  - Future
    - Implement a sparse structure for finer-grained mediation control
    - Event-based notification triggered by mediator

Fault-and-Pull



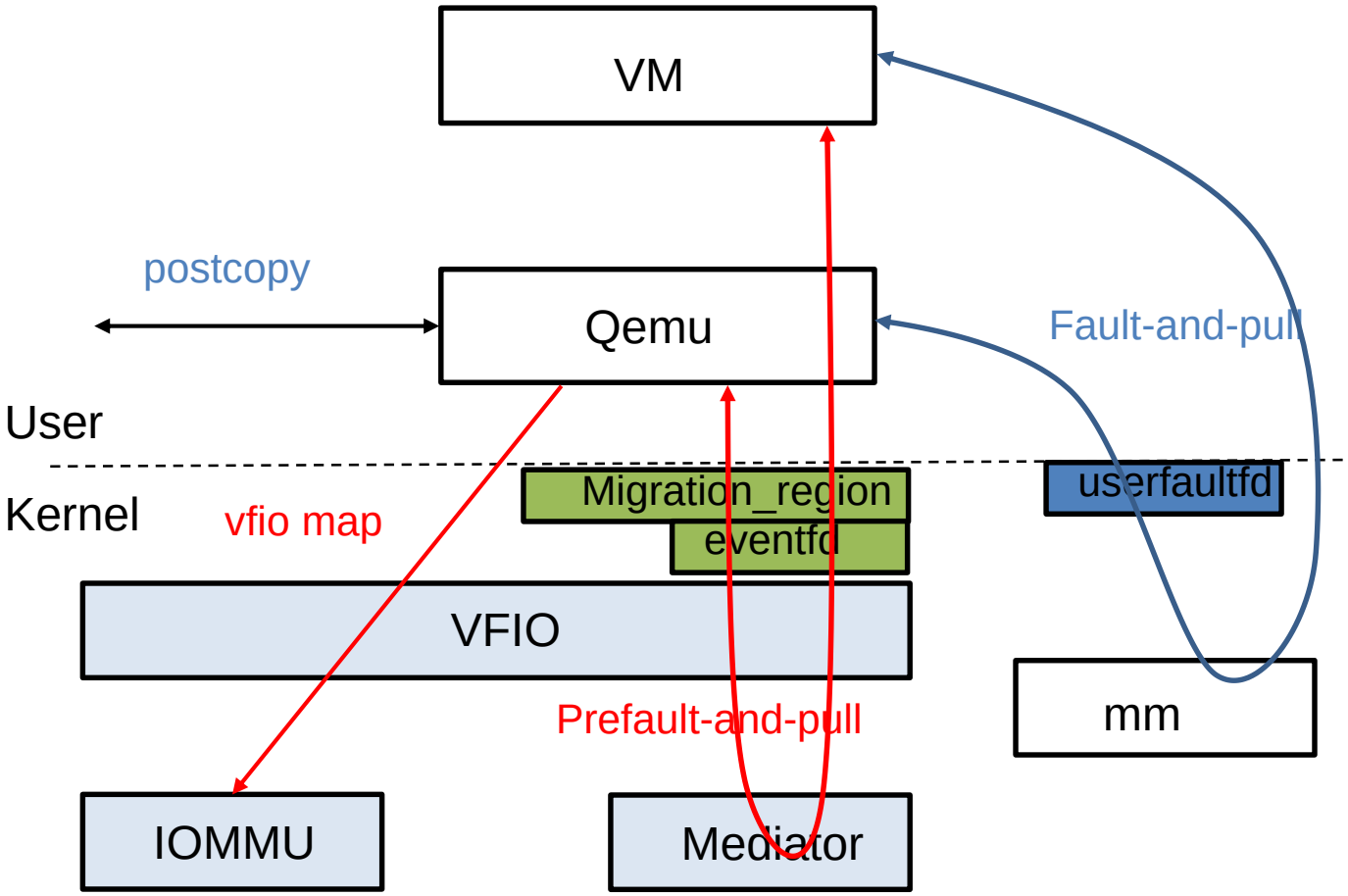
- Based on userfaultfd
  - Introduced in 2015
- For handling vCPU page fault in userspace
- UFFDIO_COPY (step 4)
  - Allocate/copy page and wake up vCPU

Prefault-and-Pull: Ideal Approach



- Leverage userfaultfd interface
  - Triggered by mediator
- Separate page copy and vCPU wakeup
  - UFFDIO_COPY (DONTWAKE) + UFFDIO_WAKE
  - Allow VFIO map in the middle
- Limitations
  - Challenges on finding IOVA->HVA for GUP
    - VFIO mappings have been discarded
    - KVM may provide GPA->HVA (w/o vIOMMU), but what about w/ vIOMMU?
  - No support of device local memory

Prefault-and-Pull: VFIO Approach

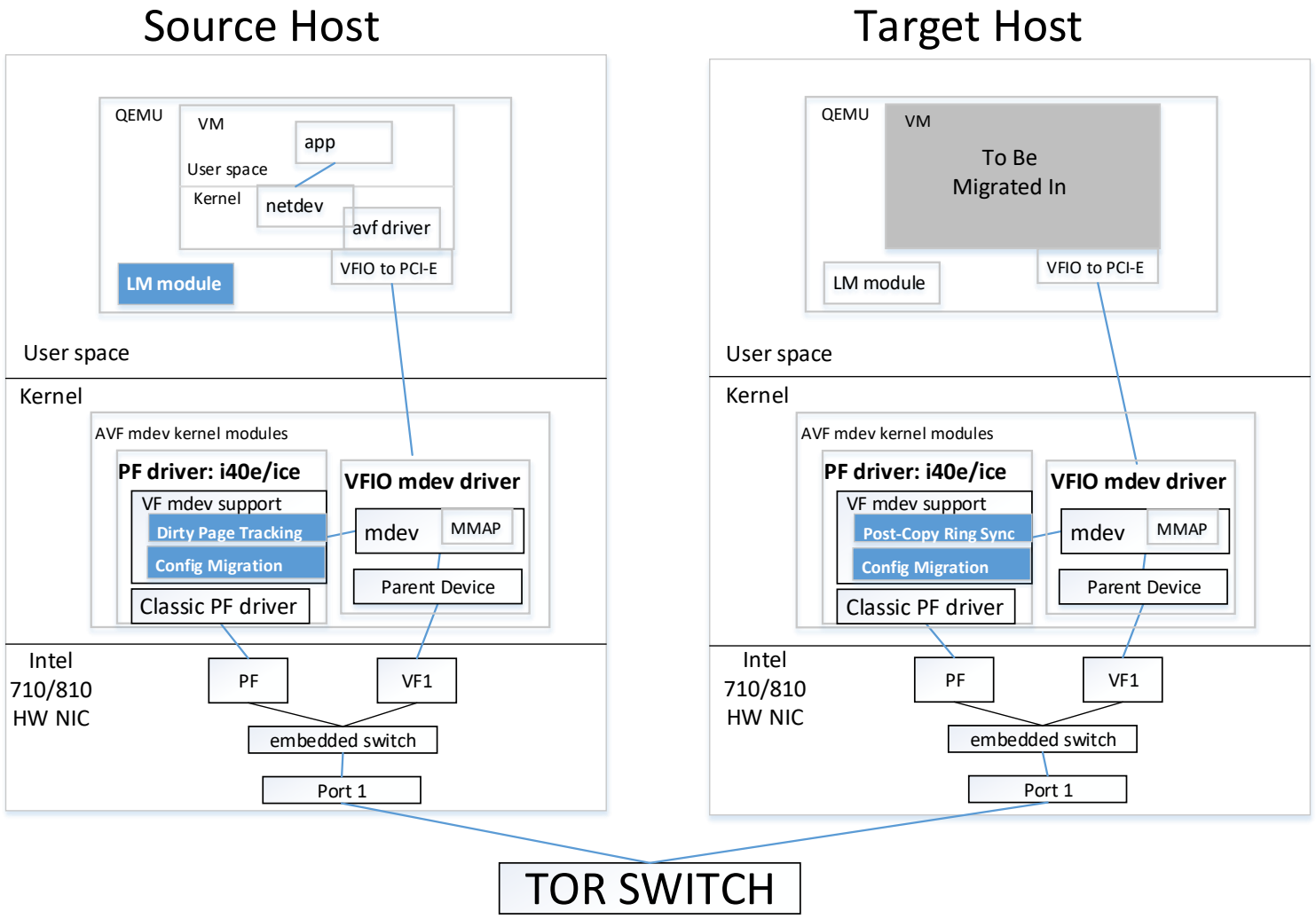


- Built on VFIO migration_region interface
  - A new eventfd for notifying userspace
  - Reuse data_region to carry prefault info
  - Qemu translates from IOVA into GPA
- CPU page fault continues on userfaultfd
- Pros
  - Specifically designed for IOVA-based prefault
  - Easily extended to cover device local memory

Case Study: NIC Passthrough

- Intel xxv710 NIC VF
  - New 25G version of widely used Intel 10G NIC, with RDMA supported
  - VF interface compatible with 10G NIC and later Intel E800 NIC
- Current prototype puts the VF in reset state before migration
  - A quick workaround to avoid copying device state
  - Long-term will follow aforementioned direction by doing state save/restore
- Track DMA pages by scanning ring descriptors in target machine
  - By mediating guest writes to the ring tail register
  - Pull the DMA page from source machine before sending to NIC for DMA R/W

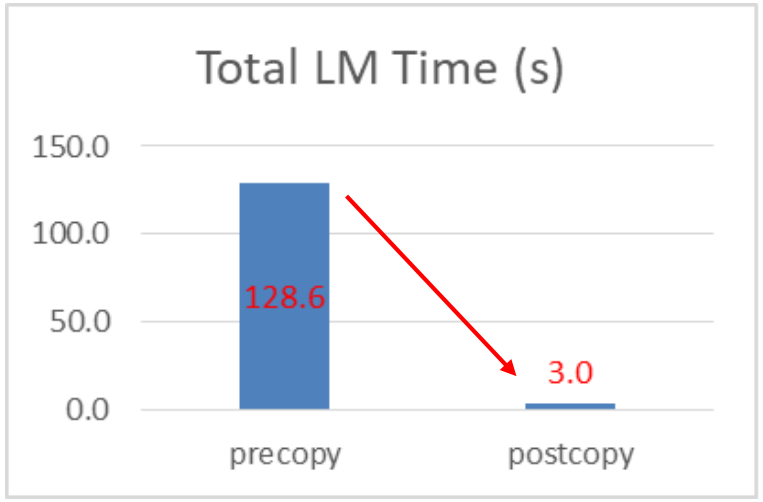
Block Diagram

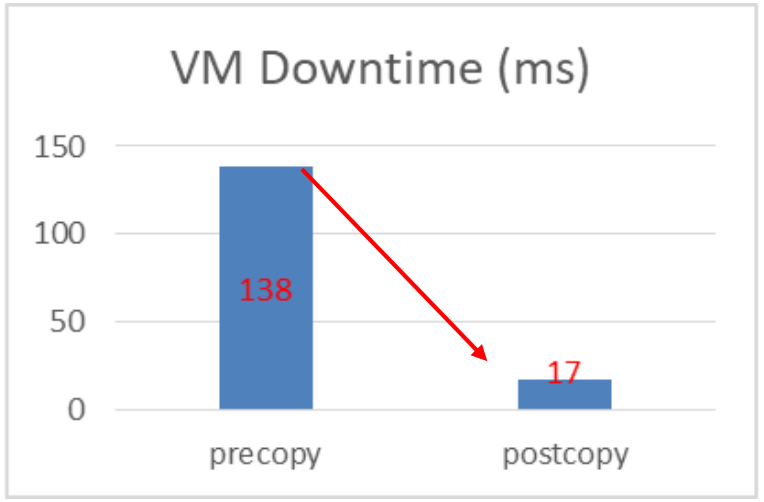


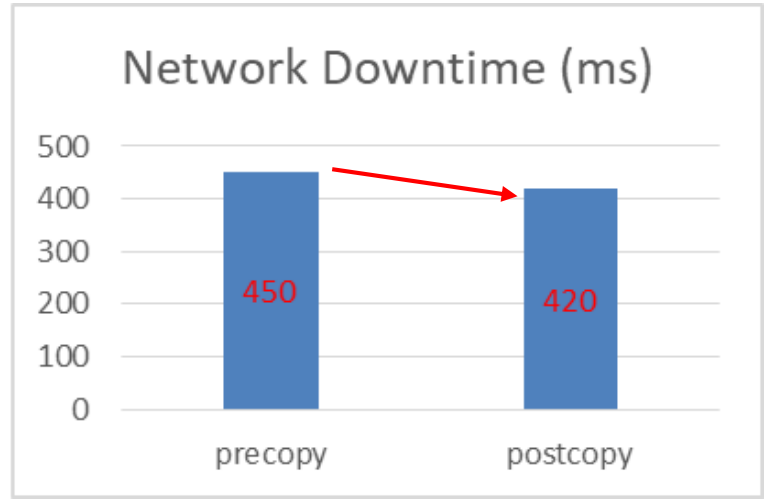
- Same framework for both pre-copy and post-copy
  - Pre-copy: track DMA writes on src
  - Post-copy: track DMA accesses on dest
- Mdev device model in PF driver
  - Manages ring mediation
  - GET/SET VF configuration data
- Easily extended to support migration cross different generations
  - Based on unified interface (AVF)

Performance

- Memory-intensive workload with 2GB guest memory
- 10Gbps migration bandwidth
- Network downtime measured by ping command







- Both include the time of device reset and switch configuration (~300ms)
- Postcopy data is based on optimized VFIO DMA mapping policy

Status and Plan

- Initial prototype work completed
- Future explorations
  - Remove reset
  - Extend userfaultfd or create VFIO-based interface?
  - IOMMU mapping efficiency
  - Huge page support
  - Device local memory
  - Extend to other NICs and device types (e.g. storage)
- Send out precopy RFC first, and then postcopy RFC

Q/A