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Prototyping Live Migration With SR-IOV Supported InfiniBand HCAs

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  - Reallocation of the IB communication resources
  - Handling the outstanding IB operations
  - Reestablishing a remote connection
- Potential approaches for migration of IB SR-IOV VFs
  - The bottom-up approach – IB verbs layer migration
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- Summary

Introduction – Why VM Migration?

- VM migration is a powerful feature in virtualization
  - Server consolidation and workload distribution
  - Service availability
  - Enable greener data centers with resource overcommitment
- VM migration can be categorized as “cold” or “hot”
  - Cold migration is a traditional way to migrate a VM. The VM is shutdown and then booted at the destination host
  - Hot or Live migration is to migrate a running VM from a host to another with a minimal downtime and transparent to the running applications

Introduction – Why SR-IOV?

- IOV: I/O Virtualization
  - The way hypervisors utilize hardware resources and serve them to virtual machines.
  - Common techniques can be emulation, paravirtualization, passthrough, SR-IOV
- SR-IOV: Single Root I/O Virtualization
  - "*I/O Virtualization (IOV) Specifications, in conjunction with system virtualization technologies, allow multiple operating systems running simultaneously within a single computer to natively share PCI Express® devices. The Single Root I/O Virtualization is focused on single root topologies (i.e. a single computer that supports virtualization technology)*" - PCI-SIG Consortium
  - Introducing the idea of Physical Functions (PF) and Virtual Functions (VF)
  - Provide improved performance in virtual machines and less CPU overhead to the hypervisor comparing to other types of IOV

Problem

- Unlike emulated or paravirtualized devices, physical devices cannot be paused to save and restore their hardware states so a consistent device state across live migration is impossible using any kind of device passthrough, including SR-IOV

Live migration of VMs with Ethernet SR-IOV VFs

- The Ethernet VF uses the hot plugging mechanism together with the Linux bonding driver to maintain the network connectivity during the migration [1]
  - The fail-over mechanism is provided by the OS at the TCP layer. E.g. TCP timeout is sufficient
- The CompSC [2] as proposed by Zhenhao Pan et al, suggests an extension to the SR-IOV specification where the internal VF state is cloned and migrated as part of the VM migration

[1] Edwin Zhai et al – Live Migration with Pass-through Device for Linux VM - OLS08

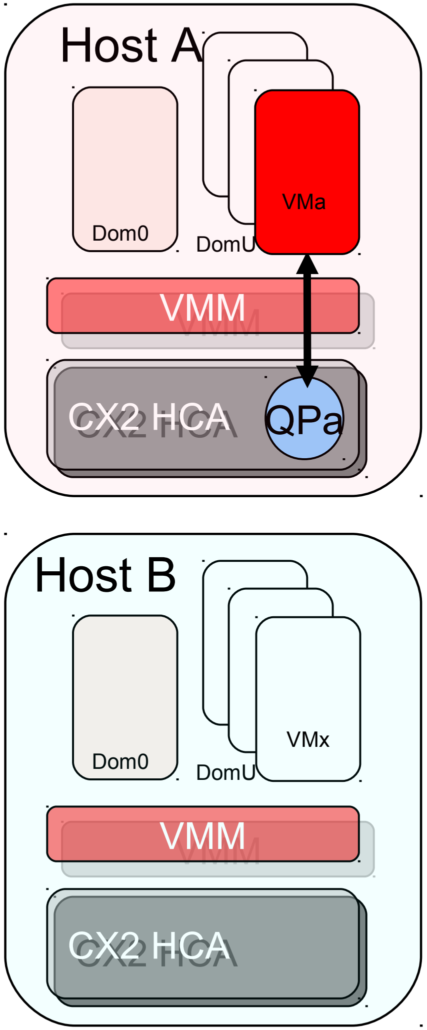
[2] Zhenhao Pan et al – CompSC: Live Migration with Pass-through Devices. ACM VEE 2012.

Live migration of VMs: Ethernet VFs vs IB VFs

- No Linux bonding device available yet for IB native network except bundles with IPoIB (or EoIB)
- Not only need to maintain the hardware state (SR-IOV) but need to keep track of the QP state
- The addressing – LID is assigned by the subnet manager
- With the shared port model*, the QP context cannot be reused after migration. E.g LID, QPN etc.
  - *There are two SR-IOV models for IB HCAs [3]:
    - The shared port model (Mellanox CX2 HCA)
    - The virtual switch model

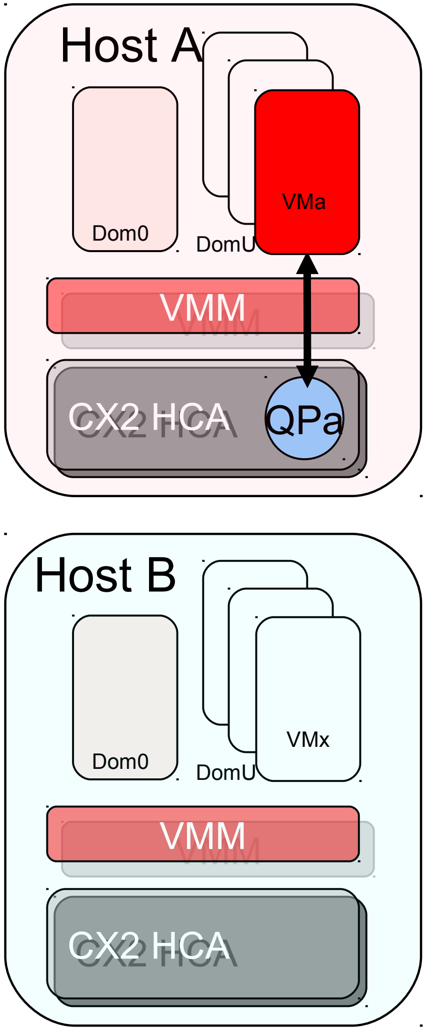
[3]Liran Liss, Mellanox Technologies – InfiniBand and RoCEE virtualization with SR-IOV, OFA workshop 2010.

Hardware and Software



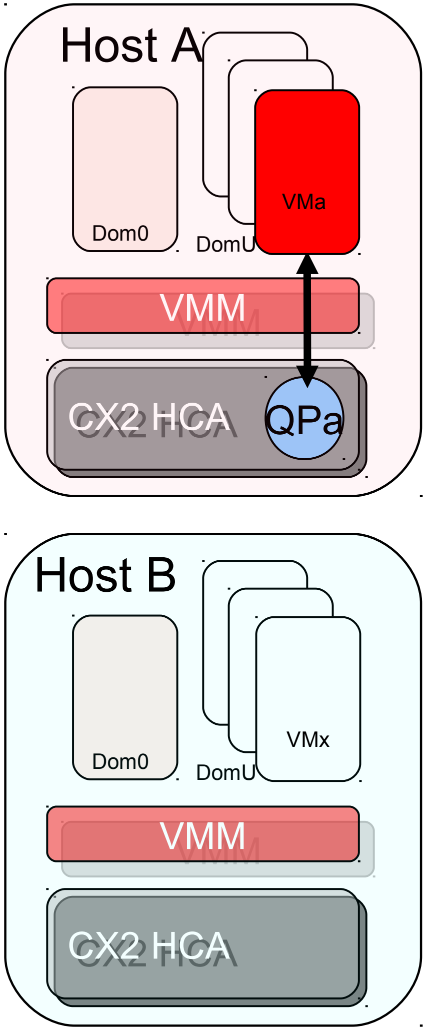
- Experimental setup
  - Two hosts: Host A and B are connected through IB using one IB switch
  - Each host is an Oracle Sun Fire X4170M2 server
    - Oracle VM server (OVS) 3.0 – Xen based VMM (Hypervisor)
    - The Mellanox ConnectX2 QDR HCA with customized firmware to support SR-IOV
    - The OFED software stack that supports SR-IOV
  - Each VM uses 2 vCPUs, 512MB RAM and one IB VF
    - Running ib_rdma_bw bandwidth test

Live migration with an IB VF



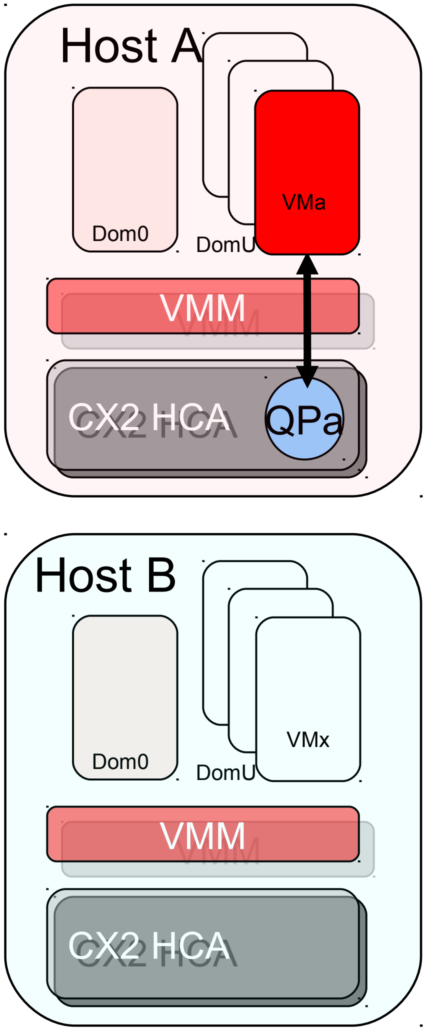
- Migrate VMa from host A to host B
- Problem 1a: The VM migration is not allowed if a VF is attached to the VM
  - This is not an IB problem, but a general prerequisite for the PCIe device that needs to be quiesced before hot-swap
- A workaround for Problem 1a is to detach the VF from VMa

Live migration with an active IB VF



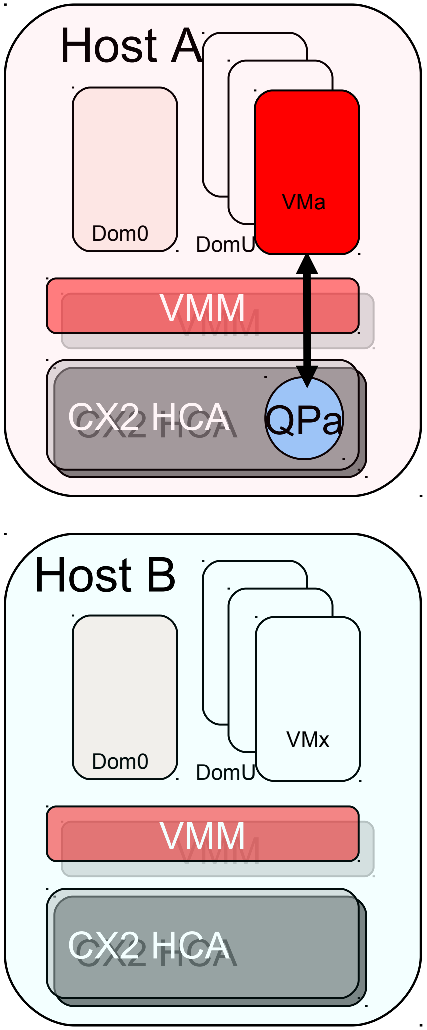
- The dom0 fails to detach the VF of VMa if an active QP exists (QPa)
- Problem 1b : How to detach a VF in order to migrate a VM if an active QP exists

Detaching a VF with an active QP



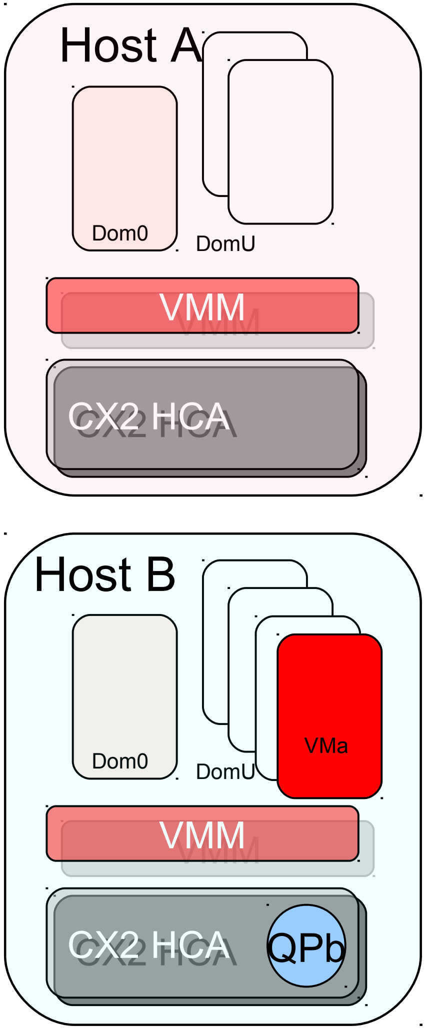
- Most applications are calling the IB user verbs
  - The user space application can operate directly on a QP
  - In contrast, the Ethernet operations require to go through the kernel software stack
- All ib_uverbs contexts need to be released before ib_uverbs module can be unloaded
- If a QP is created by an application, detaching a VF returns with an error because the Xen hot-plug script has timed-out before the uverb's wait_for_complete() completes execution

Detaching a VF with an active QP



- We propose a PID-QPN translation table
- When a QP is created, the PID of the user application is registered in the kernel
- Before ib_uverbs is removed, the kernel signals an event to the user space libmlx4_ib
- The user space libmlx4_ib releases the ib_uverbs contexts
- The kernel uverb’s wait_for_completion() is executed successfully – VF can be detached from VMa
- In order to prevent further operations the communication is halted at the user space libmlx4_ib until a new VF is reattached to VMa

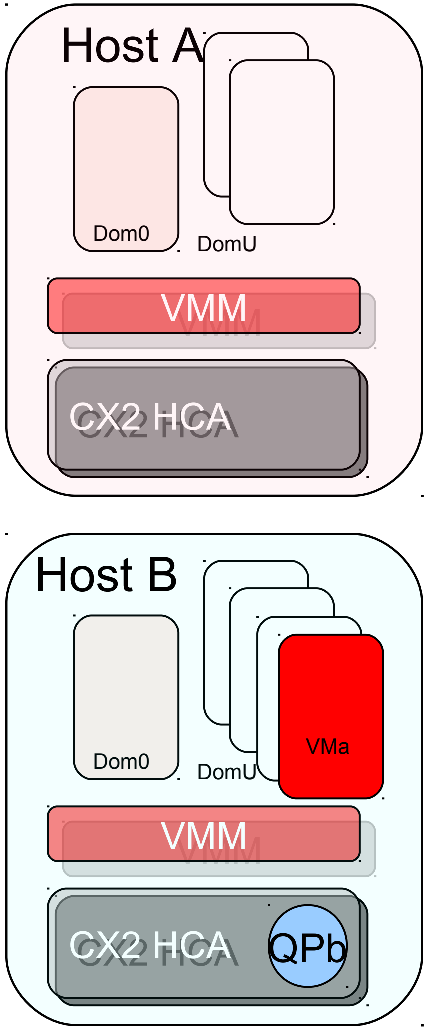
Reallocation of the IB communication resources



- After VMa is migrated from host A to host B and a new VF is reattached to VMa
- The newly attached VF contains a new *vGUID
- The user application continues with an invalid opaque handler that is pointed to Qpa
- In the SR-IOV shared port model, the QP context cannot be reused after migration
- Problem 2: How can the user application continues with QPa (QPb) after the migration?

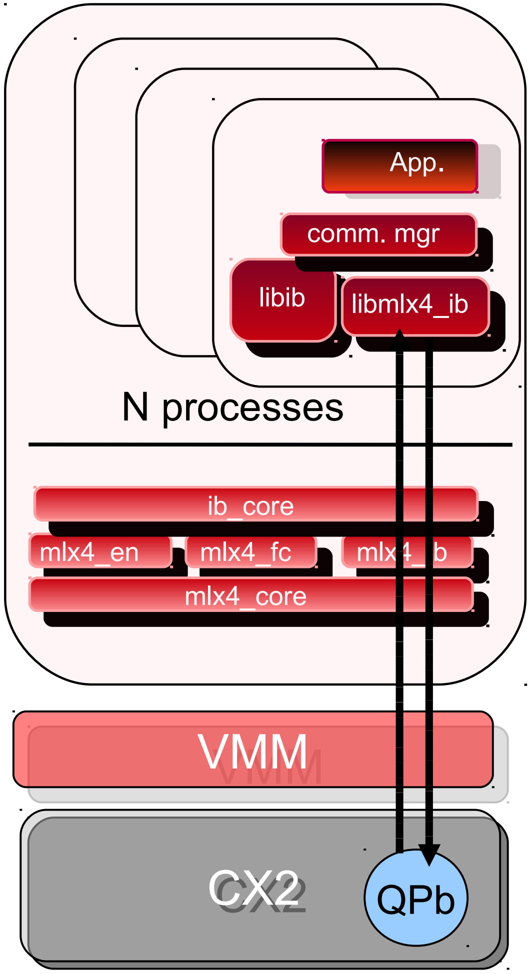
* The vGUID is assigned by the SM to ease the implementation of this prototype. After migration, the associated vGUID to LID mapping may change.

Reallocation of the IB communication resources

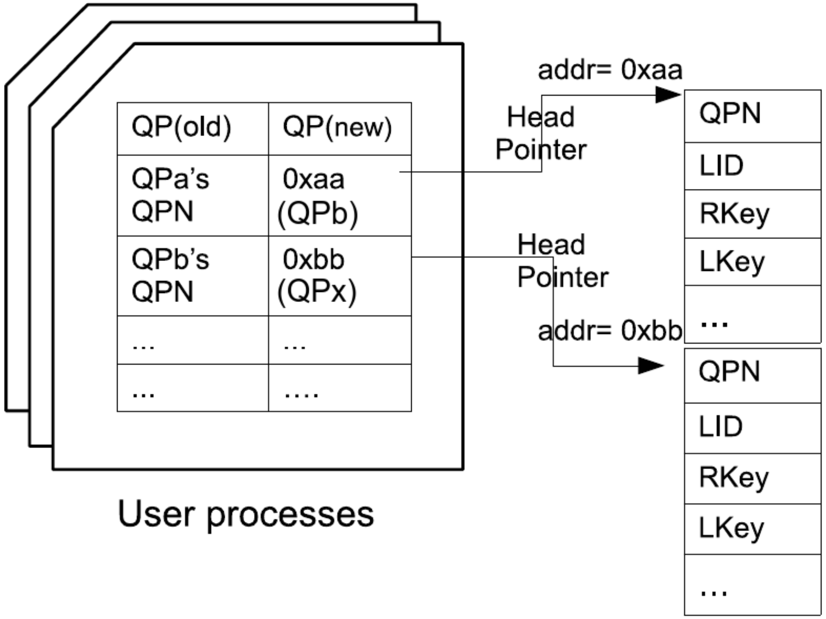


- After a new VF with a new vGUID is reattached, the physical resources such as Memory Region (MR), Completion Queue (CQ), QP must be recreated
  - This includes a user process mapping table to remap the physical resources with QPa’s QPN and to replace the RKEY and LKEY in the posted Work Requests (WR)

User Process Mapping Table

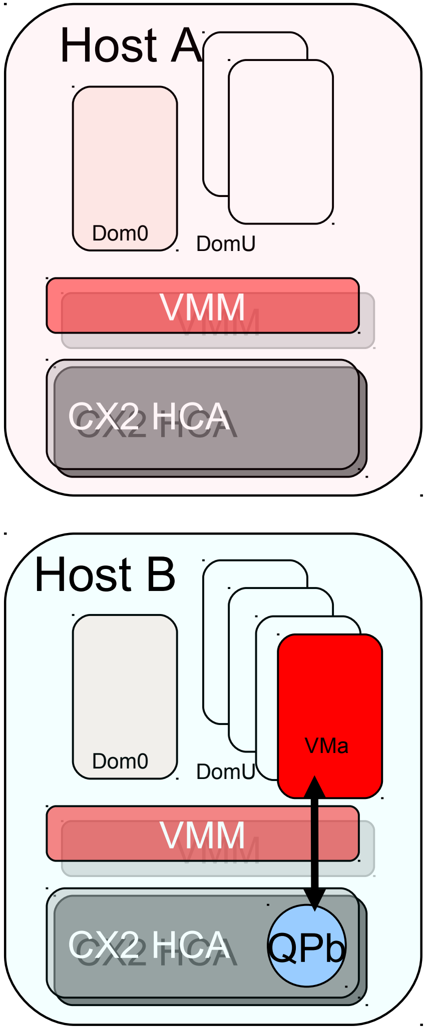


- We propose the translation mechanism as part of the user space libmlx4_ib. Why?
  - The time critical operations do not involve kernel space
  - The same QPN with QPa might exist in Host B. A conflict is avoided if the translation table is only visible per PID.



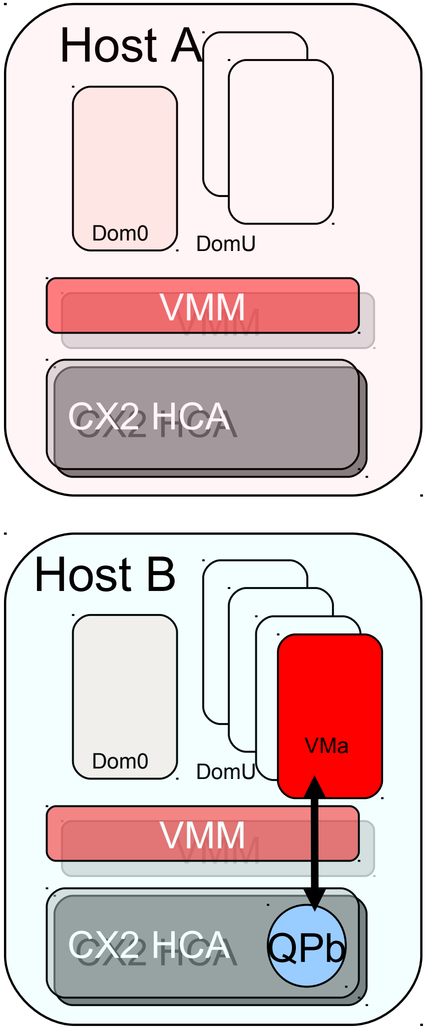
QP(old)	QP(new)
QPa's QPN	0xaa (QPb)
QPb's QPN	0xbb (QPx)
...	...
...	....

Handling the outstanding IB operations



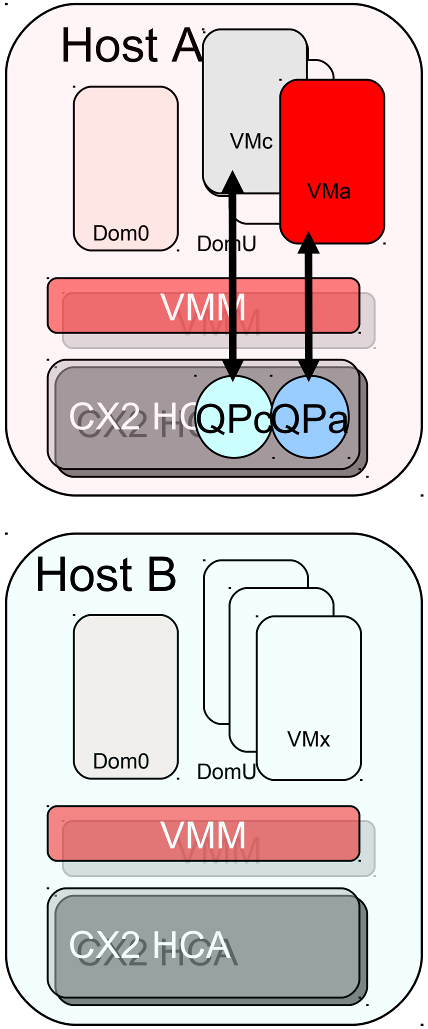
- The user application resumes the send operations with QPb on host B
- If there are outstanding operations before migration and there is no recovery mechanism in the ULP, how to retrieve and resume those Send Queue (SQ) operations in host B?
- Problem 3: How do we handle the outstanding SQ operations after migration?

Handling the outstanding IB operations



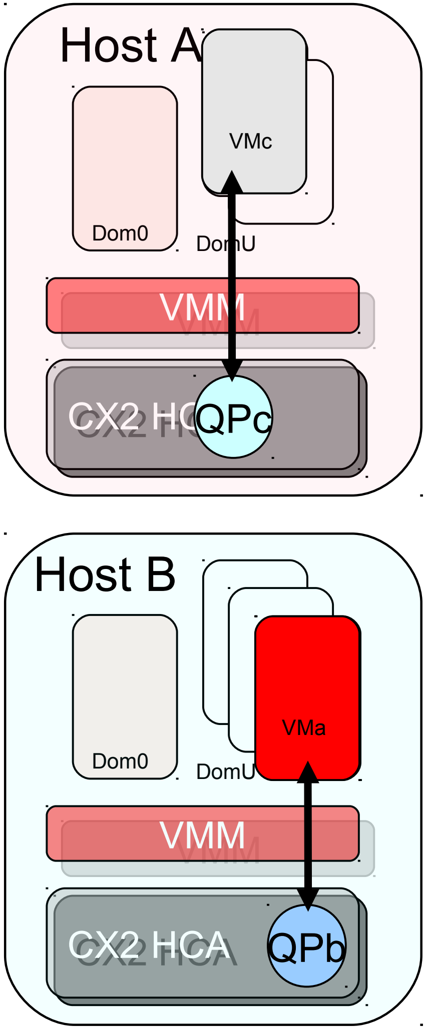
- We propose to use a deterministic state for migration.
- Simulate the SQD-like QP state in software because SQD is not supported by CX2 yet.
  - Work queues are in quiescent state before migration. This is applicable to both sides (QPs) of a connection.
- All the outstanding send operations must be completed (received the CQ) before detaching the VF from host A.
- There are no outstanding operations after the migration.

Reestablishing a remote connection



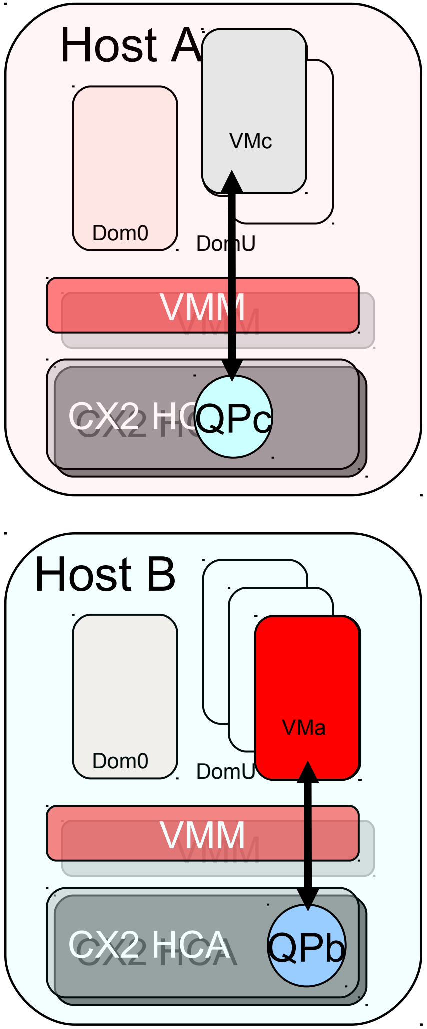
- Looking from the perspective of the peer QP of the migrated VM
- The original QPa (VMa) is communicating with QPc (VMc)

Reestablishing a remote connection



- Looking from the perspective of the peer QP of the migrated VM
- The original QPa (VMa) is communicating with QPc (VMc)
- With the shared port model,
  - After VMa has migrated to host B, QPb is created to resume the remaining operations.
  - However, QPc is not aware that QPa has been replaced by QPb in host B.
- Problem 4: How to maintain the connection with the peer QP after the migration?

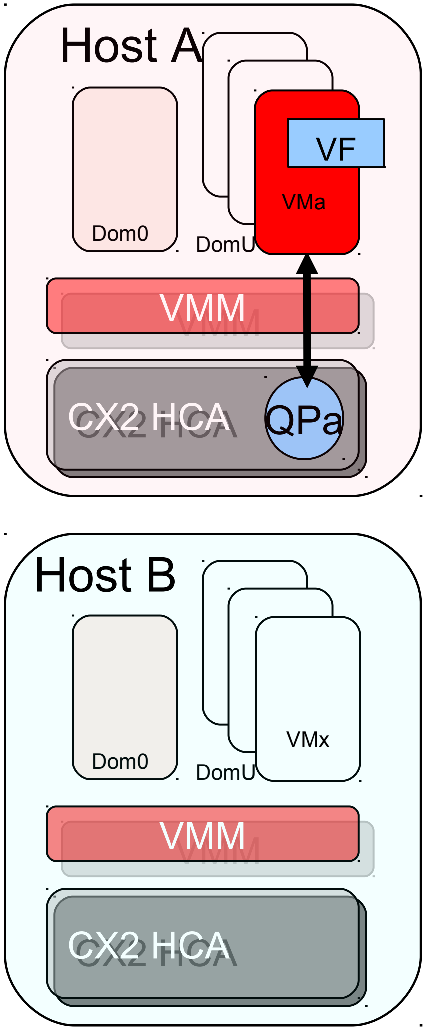
Reestablishing a remote connection



- The Communication Manager (CM) must be tolerant to the device removal fault. E.g do not destroy QPc after the VF is detached from VMa.
- Before VMa releases the uverb, an event is used to notify and suspend QPc. (into the SQD-like state).
  - to avoid QPc transits into the error state by sending to the non-existing QPa.
- Keep track of the Out-Of-Band (OOB) communication (socket address) used by the *CM.
- After a new VF is reattached, QPb is created and a new CM ID is generated to establish a connection with QPc.

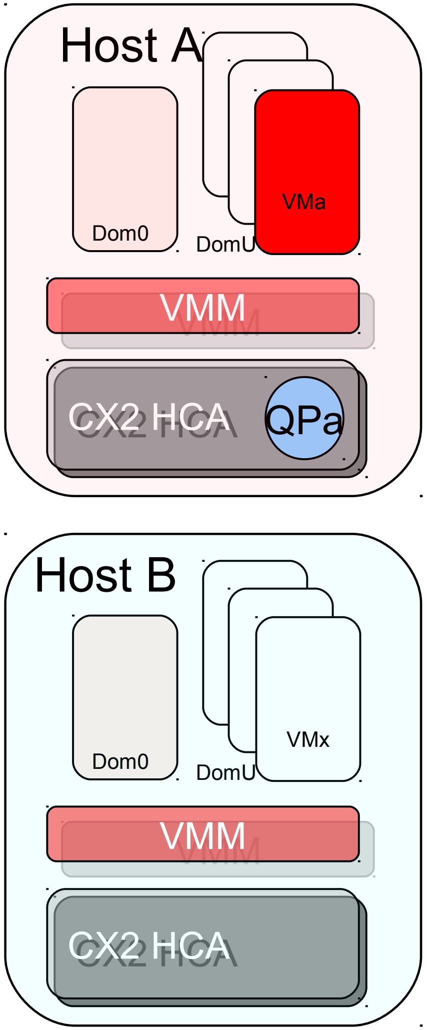
* In the current "workaround" in software, we assume all applications are using RDMA_CM to establish the connection and the reconnection mechanism is part of the user space library.

The VMM level migration process



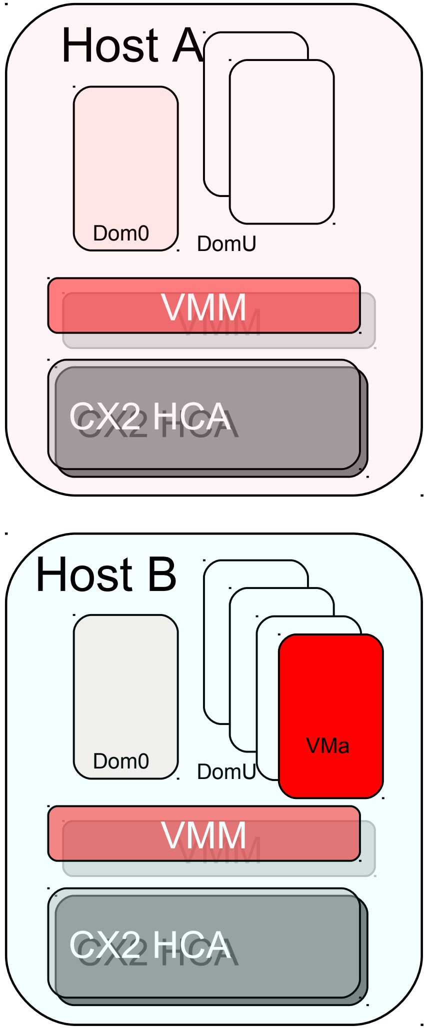
- From the VMM perspective, a three-stage migration process is performed to migrate a VM with an IB VF.

The VMM level migration process



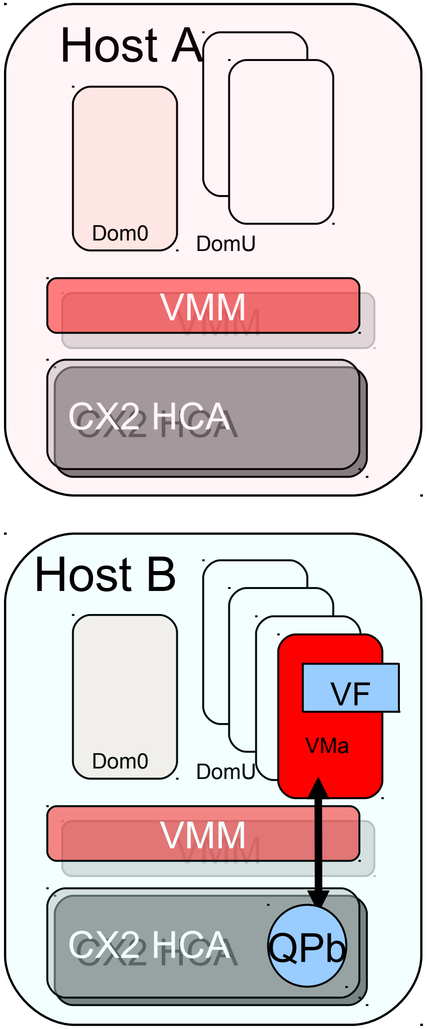
- From the VMM perspective, a three-stage migration process is performed to migrate a VM with an IB VF.
  - Stage 1: Detach the VF.

The VMM level migration process



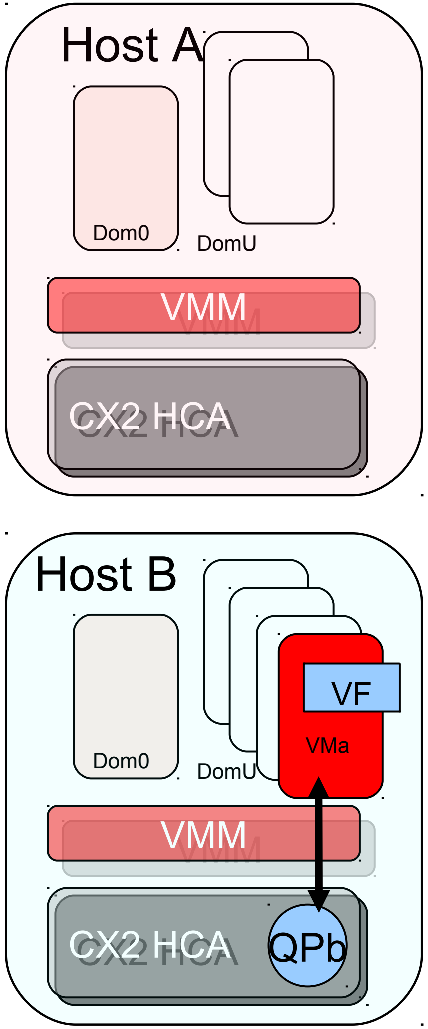
- From the VMM perspective, a three-stage migration process is performed to migrate a VM with an IB VF.
  - Stage 1: Detach the VF.
  - Stage 2: Migrate the VM.

The VMM level migration process



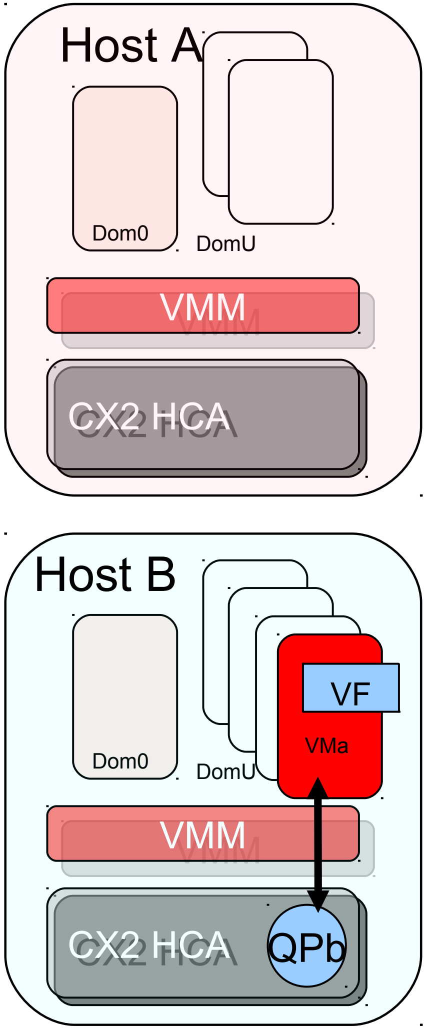
- From the VMM perspective, a three-stage migration process is performed to migrate a VM with an IB VF.
  - Stage 1: Detach the VF.
  - Stage 2: Migrate the VM.
  - Stage 3: Attach a new VF.

The VMM level migration process



- From the VMM perspective, a three-stage migration process is performed to migrate a VM with an IB VF.
  - Stage 1: Detach the VF.
  - Stage 2: Migrate the VM.
  - Stage 3: Attach a new VF.
- Without the Linux bonding driver, the three-stage migration process leads to a long service down-time.
- Problem: How to reduce the service down-time?

Late-detach Migration

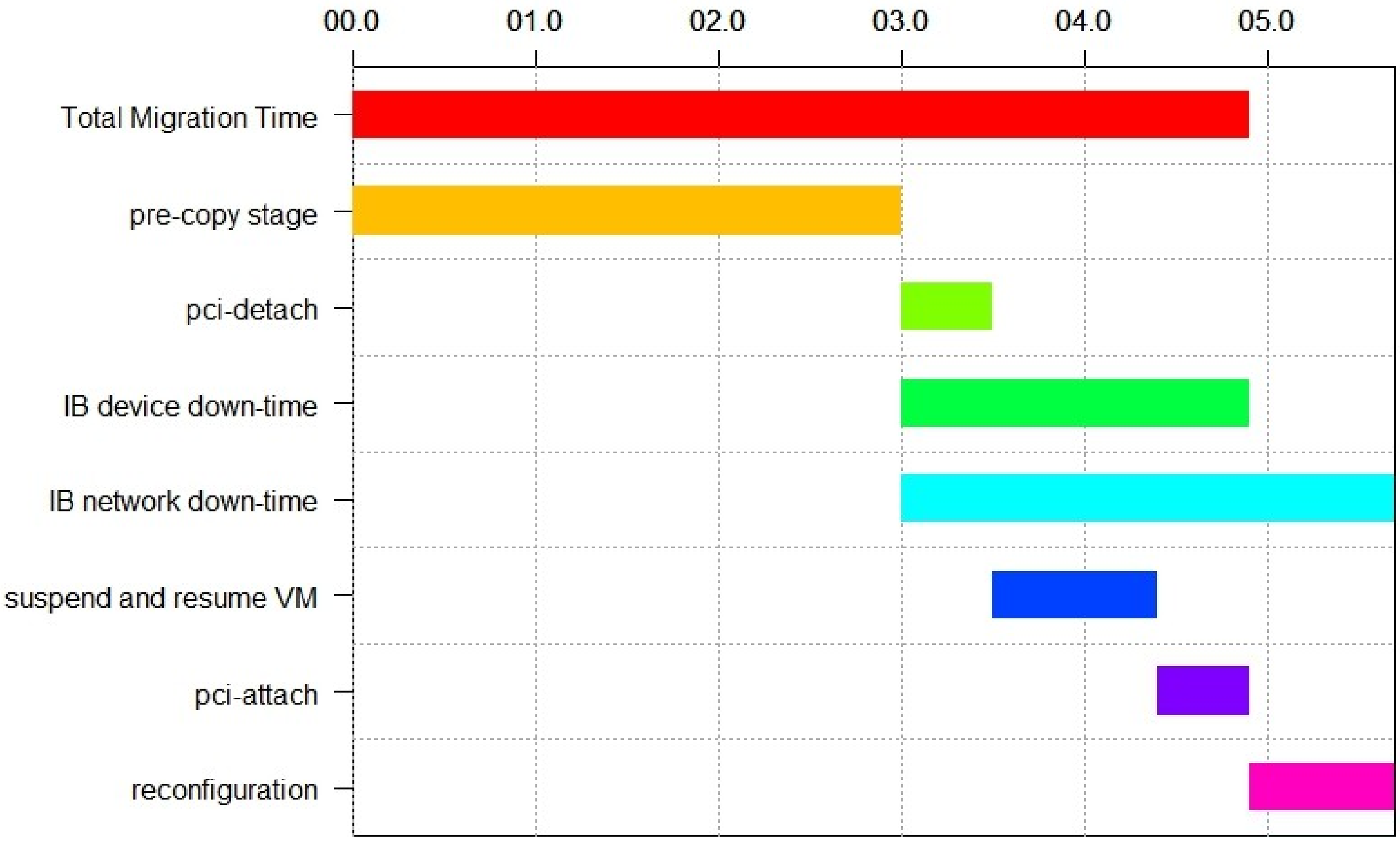


- The Xen migration script is modified to allow migration without detaching the VF during the warm-up stage.
- Dom0 on the migrating source: detach the VF just right before the VM is suspended (stop-and-copy stage).
- Dom0 on the migrating destination: do not initialize the VF during the early restoration, but attach a new VF at the final stage of the restoration.

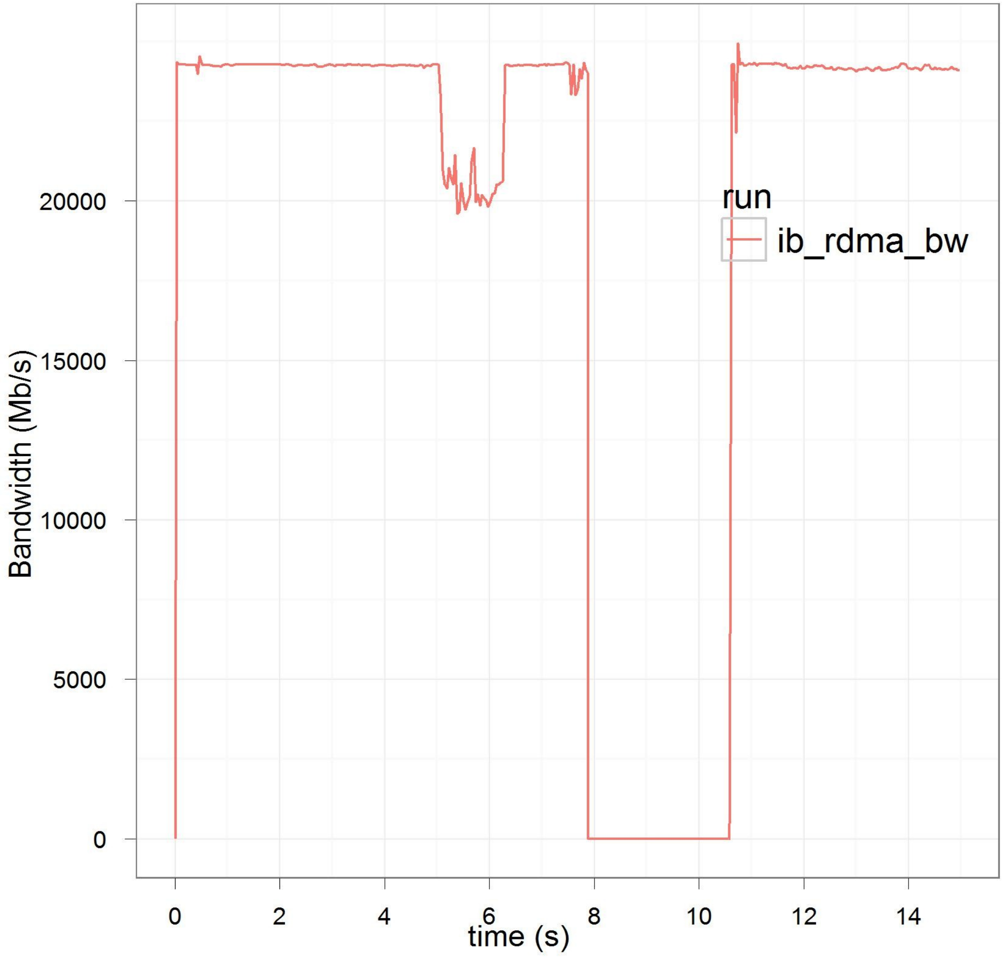
The bottom-*up* approach

- The *bottom-up* approach resolves the above (previous) mentioned challenges.
- The “workarounds” are implemented in both the kernel space and the user space library (libmlx4_ib) to reconfigure the underlying hardware resources during migration.
- The migration model remains the same, it is still based on the three-stage migration process.

The bottom-*up* approach



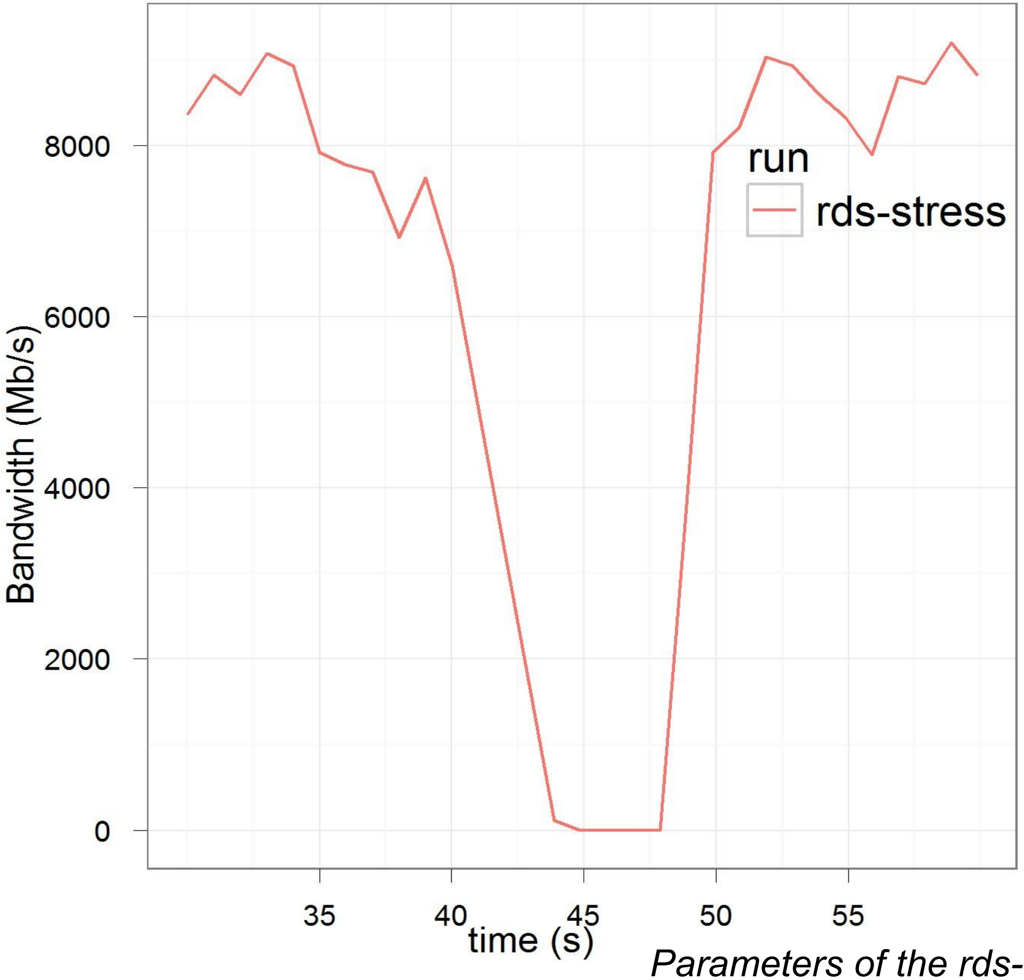
The bottom-*up* approach



The *top-down* approach

- The top-down approach assumes that the complexity of the underlying IB verbs is a black box and the fail-over mechanism is provided by the ULP.
- Reliable Datagram Socket (RDS) as the ULP.
  - RDS is tolerant to fault including the device removal fault.
- The live migration is still based on the three-stage migration process.
  - When a VF is detached, RDS drops the connection.
  - The VM is migrated to the new host.
  - A new VF is reattached and RDS reconnects the connection.
- The top-down approach is not generic because it depends on a dedicated ULP to support live migration.

The *top-down* approach



Parameters of the rds-stress test: -q 4K -a 4K -t 7

Summary

- The bottom-up approach provides a generic solution.
  - The current prototype has a service downtime of 2.7s.
- How to further improve the service downtime and reconfiguration?
  - The *vSwitch* model is a better architecture.
    - The QP namespace is isolated per VF.
    - A better model from networking and routing perspective.
    - How to resolve the scalability issue with the *vSwitch* model?
      - Bloats LID space which is only 16 bits
  - A new state to define suspend?

Questions?