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Hardware vs. Software Routers

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Agenda

1. Why software routers at all ?
2. Technology: hardware routers
3. Technology: software routers
4. Applicability
5. Q&A

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Hardware vs. Software Routers

Why Software Routers ?

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Why Software Routers ?

- In the beginning, there was only routing „in software“ – matched required/available transport link speeds
- Some years later, CPUs simply weren‘t fast enough anymore to „push packets“ reasonably
- Hardware routing with special chipsets was thus the only option for service providers
  - Quite some rounds of development for routing chipsets over time
  - Vendor specific chipsets vs. commercial, off-the-shelf (COTS) chipsets
  - Always a trade between price and performance
- This has changed recently: today‘s CPUs are powerful enough again for commonly used interface speeds
- „High-enough-speed“ network interface cards are available for x86-based servers
- Not everyone anymore also needs the biggest available interfaces in a router (40/100G ?)

Why Software Routers ? (cont‘d)

- Hardware routers are special gear, and thus somewhat inflexible in their applicability
- Today‘s hardware routing chipsets might be „too big“ already for standard enterprise routing (=Internet-routing only, low number of 10G interfaces and some level of BGP)
- Hardware routers do have a bit of cost
- You either need stock, or there might be delivery times

- Can a network operator gain more flexibility and save on costs at the same time by going software-only ?

Hardware vs. Software Routers

Hardware Routers

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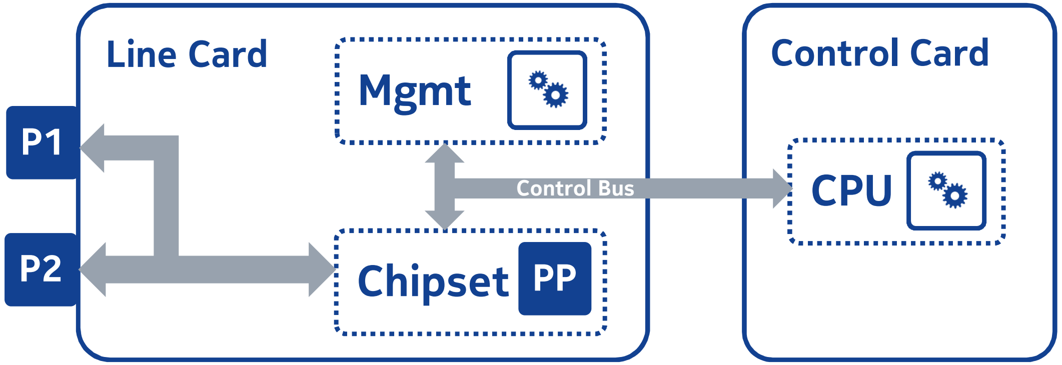
Hardware router flavours: a very simple, fabric-less design



- One control card, and only one single line card
- Control card: runs protocols, keeps lists, tables, state, etc.
- Line card: does all packet processing - lookups, filtering, queueing, forwarding,…
- All traffic stays local within the single line card once it has passed through the ports facing the external world

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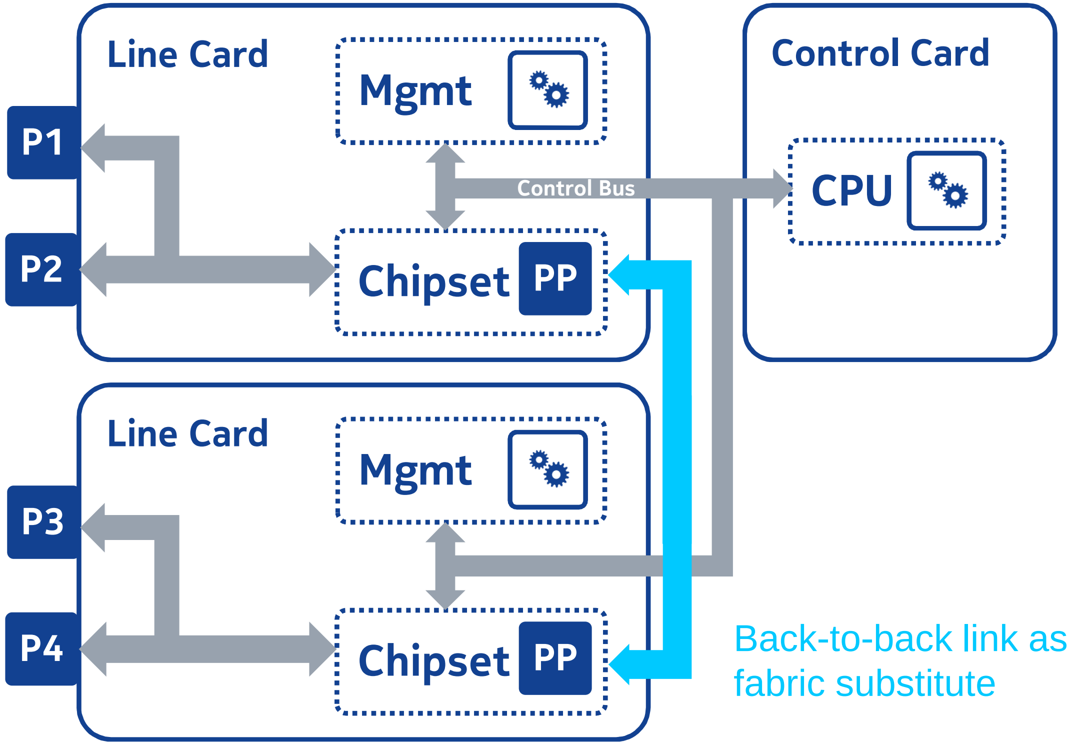
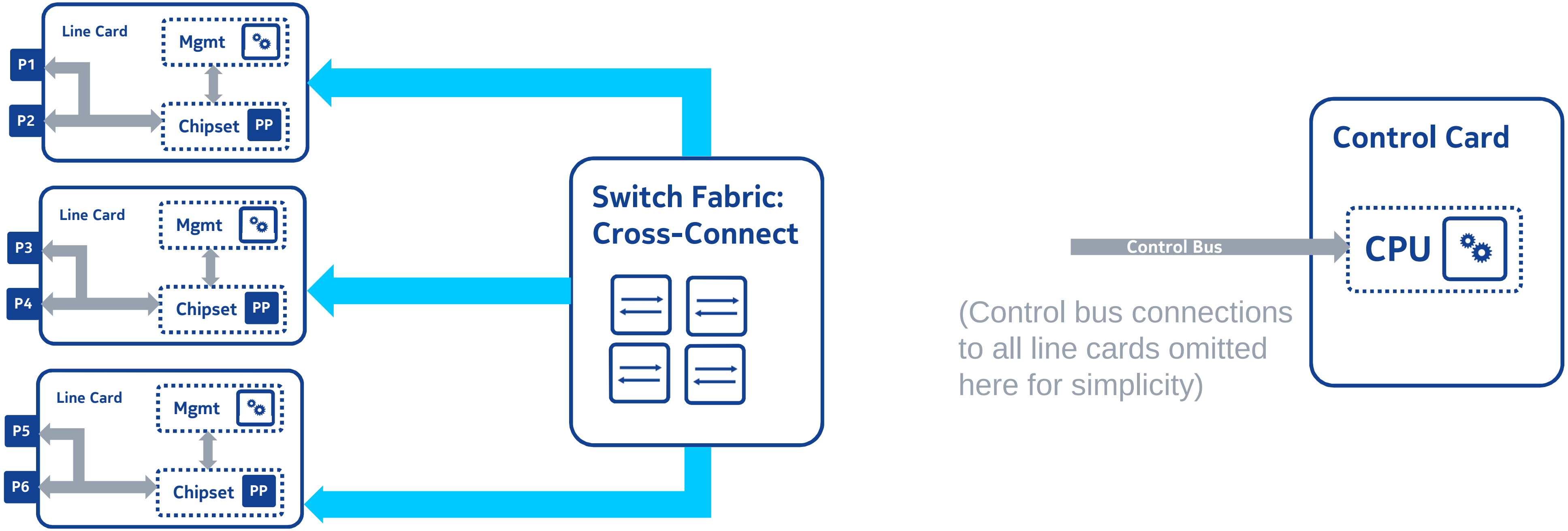
Hardware router flavours: back-to-back line card design



- One control card, and two line cards
- Traffic must have a sufficient bandwidth path between both line cards – basically 100% of the front port speed as worst-case scenario

Hardware router flavours: full fabric design



- One control card, and many line cards
- Traffic must have a sufficient bandwidth path between any two line cards
- You need a lossless, any-to-any cross-connect as your switch fabric

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Hardware vs. Software Routers

Software Routers

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From hardware to software: two approaches

- Take a standard OS, and build some routing software on top of it
  - Start with the hardware you have
  - Install the OS of your choice
  - Create/find suitable routing software that runs on this OS, and does all the protocols you need
  - Your OS will automatically provide the data plane for your software router

- Take existing routing software of a hardware router, and port it onto standard hardware
  - Start with the software you already have: ideally already well-proven and hardened
  - Find ways to make it run on standard hardware instead of special hardware
  - See what OS you have to put in between, if applicable
  - Find a way to „provide“ the hardware router‘s data plane (i.e. hardware chipset) as well…

Option one: standard OS and routing software on top

- Nice, easy, and cheap
- Usually little to no hardware dependencies

- Performance depends on your OS, and it‘s integrated network stack
- Bear in mind your OS might never have been optimized for packet throughput
- With some tweaks, you might be able to improve the situation here
- Is your OS a real-time OS – do you need things to happen at exact intervals (e.g. BFD) ?
- How do you configure this software router – config files and reboot, or well-known CLI ?
- How does it integrate into your NMS/OSS landscape ?
- Is there support for this setup, do you need it, or can you provide it yourself ?

Option two: port routing software from hardware router

- Effort depends on how that routing software was designed originally
  - If it‘s x86-based anyway, should be limited effort
  - If it‘s originally for other CPU flavours, can it be ported ?
- Have the routing software see your server „as close to the real hardware“ as possible
- Where special hardware/chipset functionality is expected, emulate it
- Make sure there is no „stolen CPU cycles“ and the like (real-time behaviour...)
- Apply whatever tricks are necessary to get maximum throughput

- Use your well-known CLI: same look&feel as regular hardware router
- Supported product: your vendor should be able to help you if required
- There will very likely be a cost with this approach

Option two: hardware router OS - virtualize it !

- Best possible hardware abstraction: use as a VM on a hypervisor host
- Configure your VM to look as close as possible to what the routing software expects as underlying hardware - use the hypervisor as a hardware abstraction layer
- Emulate missing hardware in software where required (slow !)
- Have your VM run a different base OS than your hypervisor
- Hypervisor OS and services do not need to be exposed into router data plane (security !)

- However: emulation and abstraction inherently cost performance again...
- Alternative: have the hypervisor „interfere the least possible way“ for critical items
- Especially try to avoid the hypervisor‘s network stack
- But then, you might have a hardware dependency again...

→ There is no free lunch here either !

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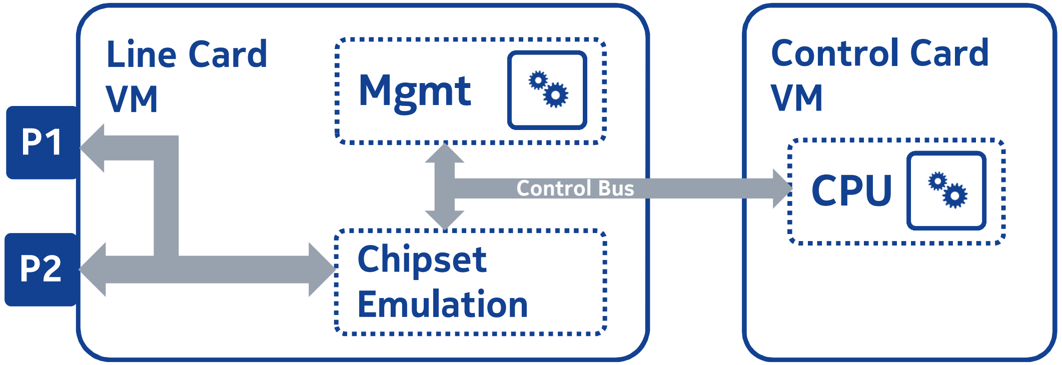
Software router virtualized: a very simple, fabric-less design



- One control card, and only one single line card
- Option one: each of them runs as a separate VM on a common hypervisor
- Option two: have one single, shared VM for both functions
- Control bus needs limited bandwidth only
- All traffic stays local within the single line card VM

Software router virtualized: more than one line card VM ?

In reality, multi-line card software routers quickly come to their limits:

- Any line card VM needs to be able to send worst case up to 100% of the front ports capacity to another line card VM
- Even in a two line card system, you need the same additional port capacity for the line card interconnect as you have on the front ports
- But then, why don‘t you use just ONE line card VM, and ALL available ports „front only“ ?
- „More than two line card systems“ scale even worse in software:
  - You need to emulate the cross-bar switch fabric
  - Either by single point-to-point links → expensive, doesn‘t scale (see above)
  - Or by a real hardware switch as a fabric emulation
  - But then again, didn‘t you originally want a software router WITHOUT any special hardware…?

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Software routers: how far can you go ?

- Remember there was a reason for creating special routing hardware:
  - Highly optimized, built-for-purpose chipsets
  - Special memory types (e.g. TCAM) exist in hardware for a reason – emulation is slow
  - Hardware processing is usually faster than software processing
  - Hardware processing is (should be...) load-independent
  - Assume that where things can be parallelized in hardware, they likely already are

- On a software router, EVERYTHING you do with a packet needs CPU cycles
- The more processing you do on a packet, the more CPU power you need (access lists, Multicast replication,...)
- CPU load goes up with overall throughput

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Software routers: how far can you go ? (cont‘d)

- You need to get packets in and out of your box as well before you can do anything else
- Your server host only has a limited number of PCI slots
- The NICs you can buy have a limited number of ports
- This puts an upper limit to the number of physical ports you can attach to your software router
- If you use external „fan-out switches“, you have special hardware again…

- How fast can you get packets in and out of your line card VM, using all possible tricks ?

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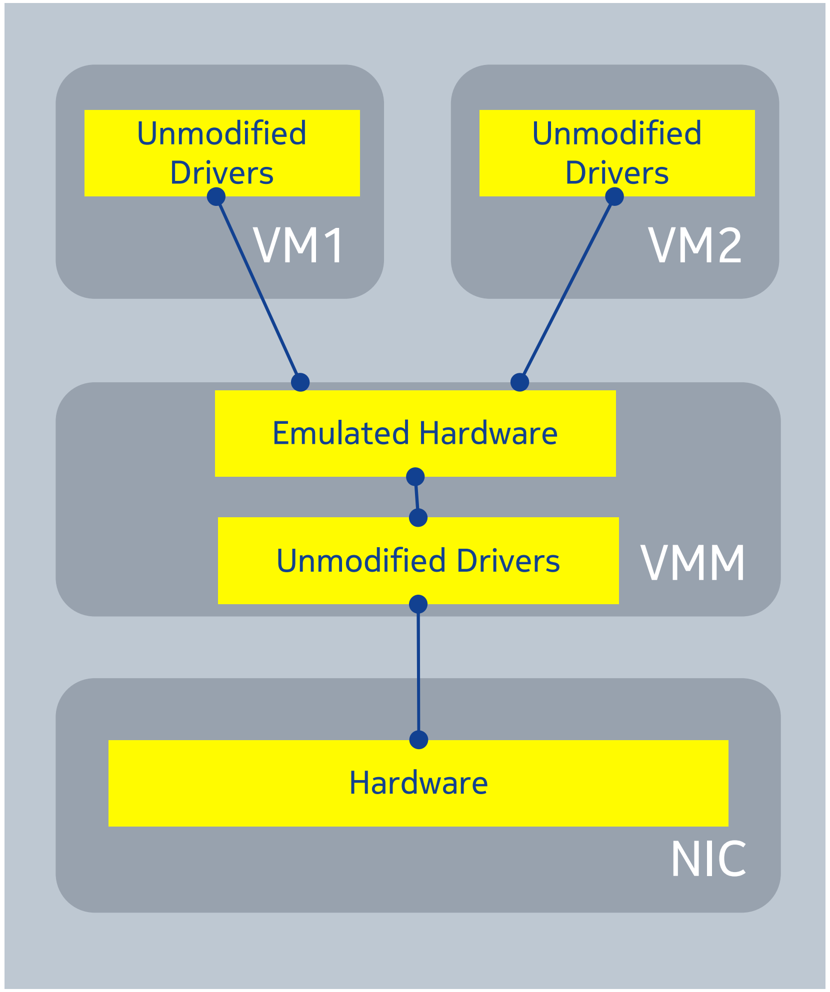
Virtualised I/O: emulated NICs

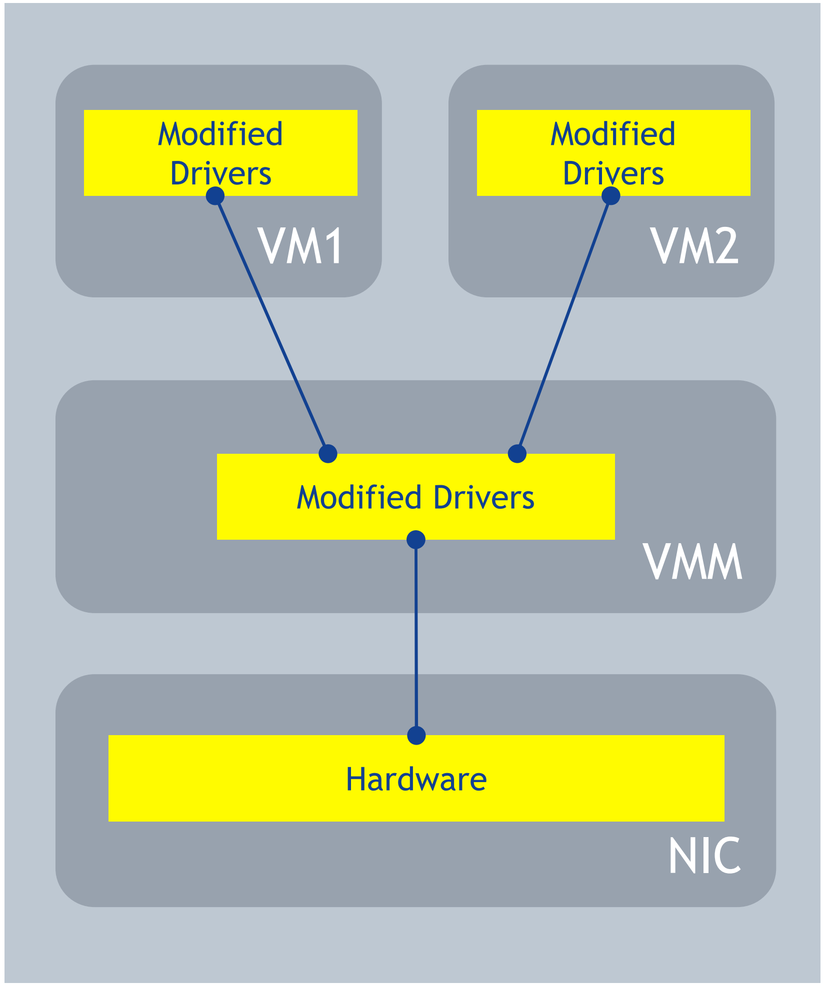
- **Native** device **drivers** in the guest OS
- VMM **emulates** physical **hardware**
- VMM needs to intercept all traffic and convert it for the physical hardware
- **Very slow** operation

- **Hardware** can be **shared** between VMs
- Doesn’t require the guest to have knowledge of the fact that it’s virtualised



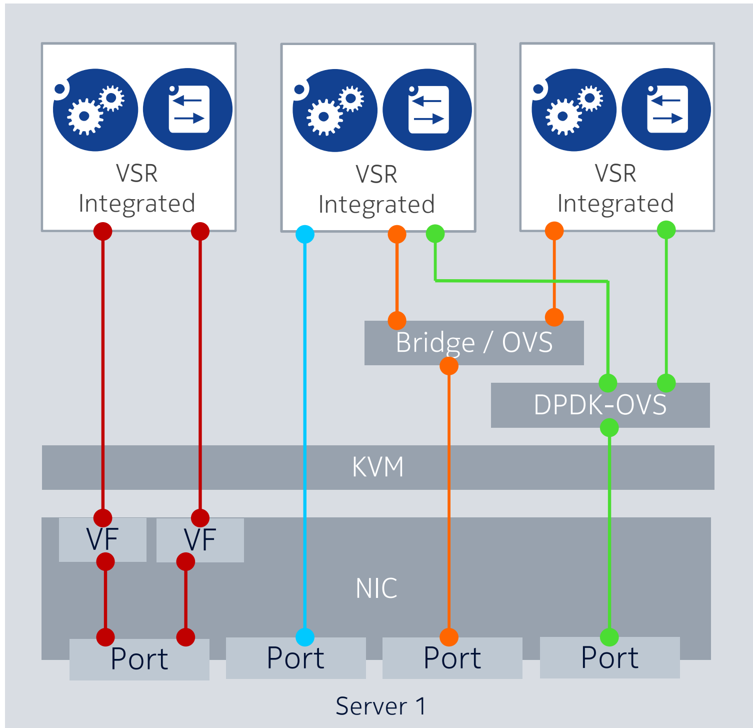
Virtualised I/O: VirtIO NICs

- Para-Virtualised I/O driver
  - The VM is aware of the fact that it is running in an emulated/virtualised environment
- **Requires modifications** to the drivers in both the guest and the host
- Removes the requirement for the hypervisor to have to emulate the hardware
- Guest OS must load the VirtIO driver
- Provides **significantly better performance** than emulated hardware (HVM)



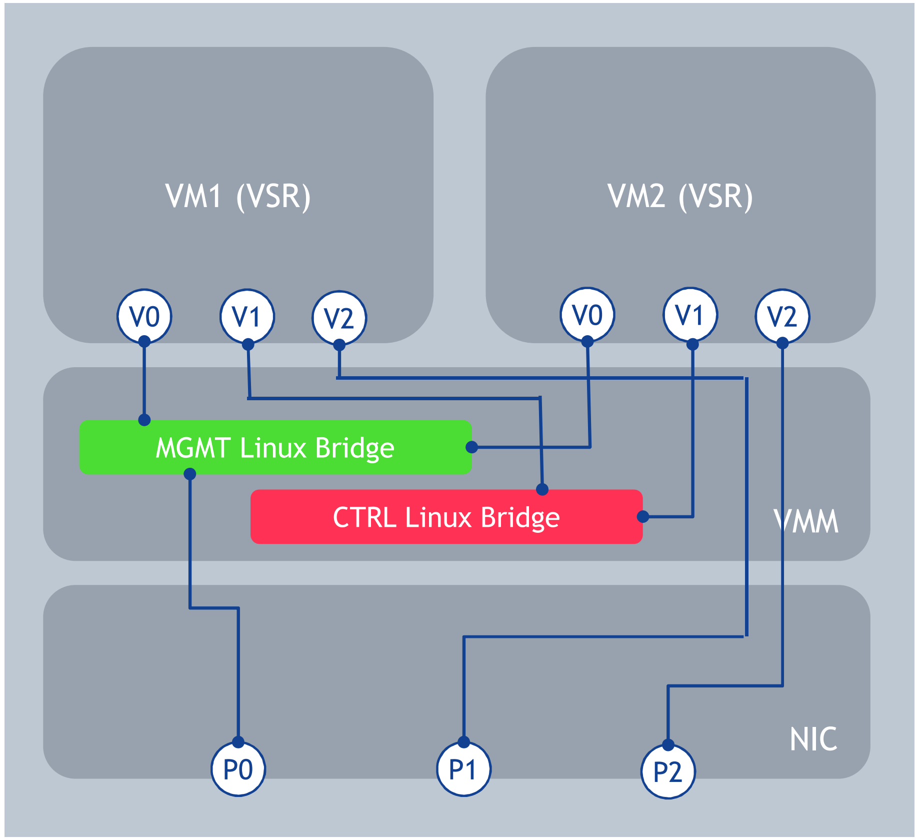
Software routers: virtualised I/O options

- Linux Bridging
  - Most simple option, available everywhere by default
  - Slowest option of all
- Openvswitch (OVS)
  - Flexible, programmable
- OVS with DPDK
  - High throughput with flexibility
- SR-IOV
  - Virtual Functions created in hardware to share ports
  - Highest throughput with some flexibility
- PCI-Passthrough
  - Highest throughput with most flexibility on the virtual router side, but almost no virtualization stack flexibility on the host side



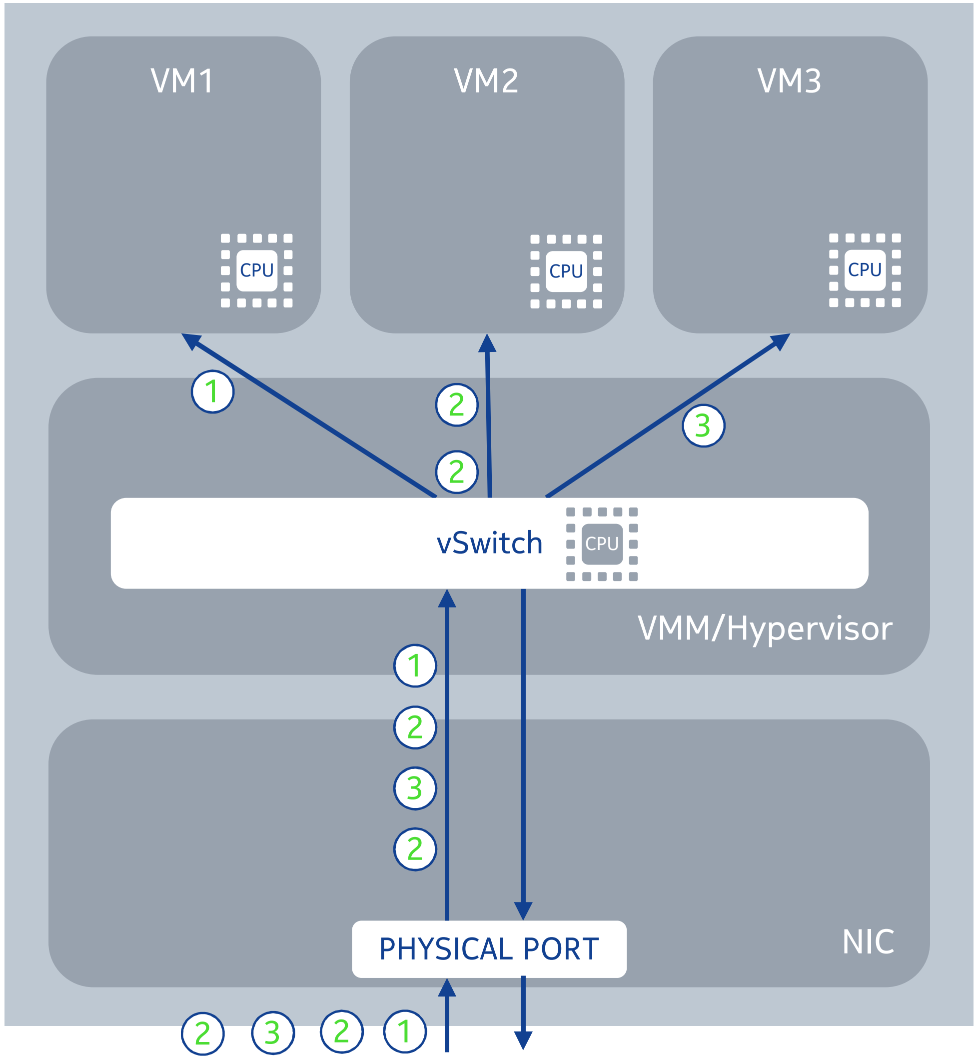
Virtualised I/O: Linux bridging

- **Standard service** available within Linux
- Works within a single physical machine
- The bridge appears like any other Linux Interface
- Multiple virtual and physical interfaces can be connected to it
- Commonly used for the control-interconnects on the VSR within the same physical machine or to share interfaces where **performance is less important**



Virtualised I/O: vSwitch

- If no intelligence provided by the NIC a software switch is required in the VMM (VM Manager)
- vSwitch examines each packet and identifies the destination based on the mac address
- vSwitch then directs the packet to the VM
- **Inefficient** as the hypervisor needs to read, understand and deal with each packet
- Ideally: a **single CPU** core **assigned** to deal with the vSwitch
- Interrupts fired for: Packet arriving on NIC, packet being handled by vSwitch, VM dealing with packet

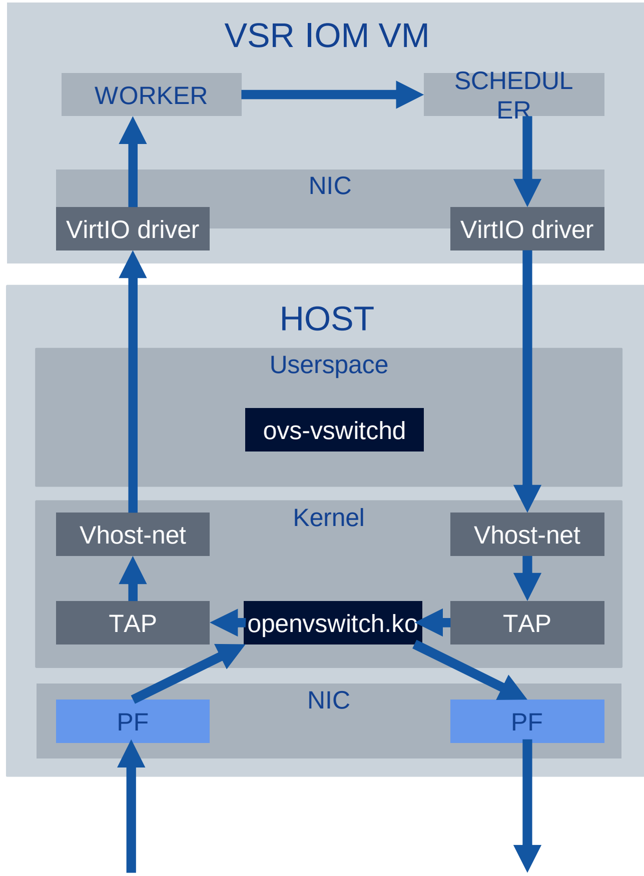


Virtualised I/O: Open vSwitch (OVS)

- Hypervisor connects guest vNIC port to a port of the vSwitch
  - The guest uses a virtualization driver (VirtIO, E1000, VMXNET) for the vNIC port
  - Host implements the other side of the driver in user-space or kernel

- Throughput performance is much lower than pass-through models due to:
  - **Interrupt handling** associated with I/O transfers
  - **Packet copying** between guest and host memory locations

- Possibly relevant for datacenter integration: with Open vSwitch, the packets flowing through the vSwitch can be controlled by Openflow rules for SDN use cases. This includes adding/removing NVO3 encapsulations (VxLAN, GRE, etc.)



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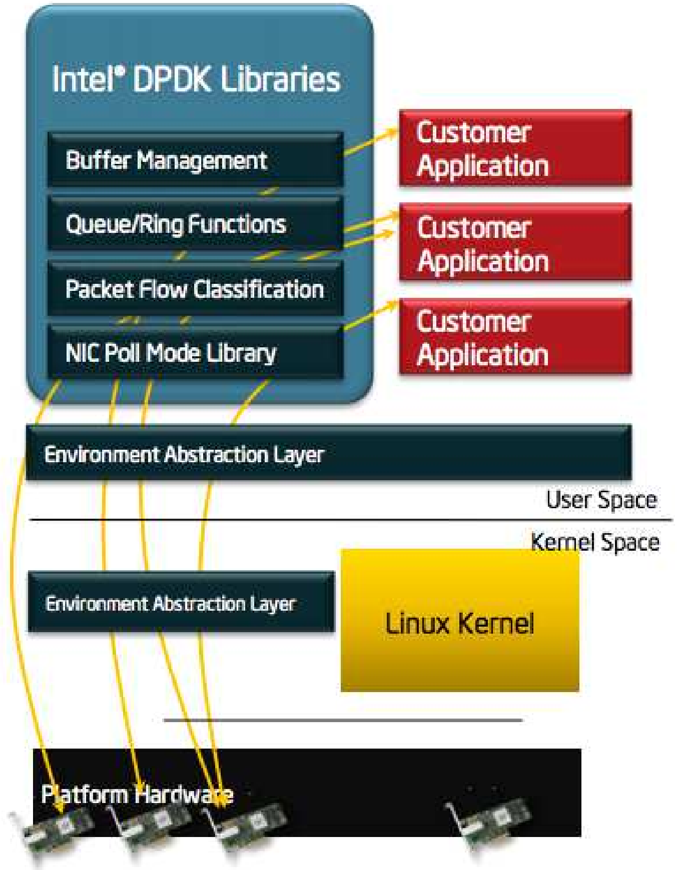
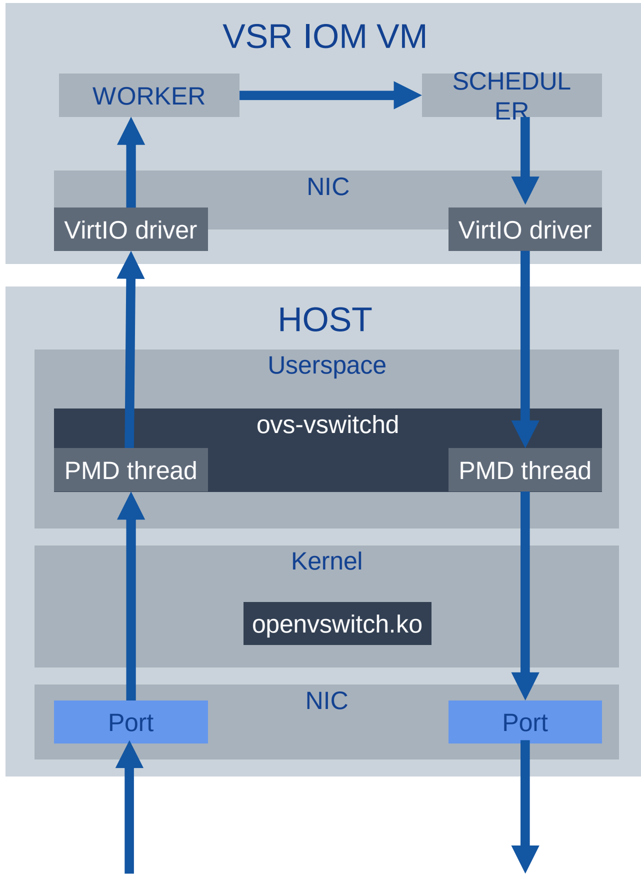
Virtualised I/O: OVS-DPDK

- DPDK is an **open-source toolkit** for **fast packet processing**.
- When OVS is **compiled to use DPDK libraries** and DPDK NIC drivers, the result is a **high-performance vSwitch**, which is referred to as OVS-DPDK (in this document).
- OVS-DPDK is considerably faster (7x to 10x) than native OVS due to the following reasons:
  - The OVS-DPDK fast path moves from the openvswitch.ko kernel module to a **user-space implementation** (the dpif-netdev component of the ovsvswitchd daemon).
  - OVS-DPDK communicates with virtual machine vNIC ports (that use a VirtIO driver) using **user-space vHost drivers** (vhostuser).
  - **Poll-Mode-Driver** (PMD) threads of the user space ovs-vswitchd process send and receive packets over the OVS switch ports.



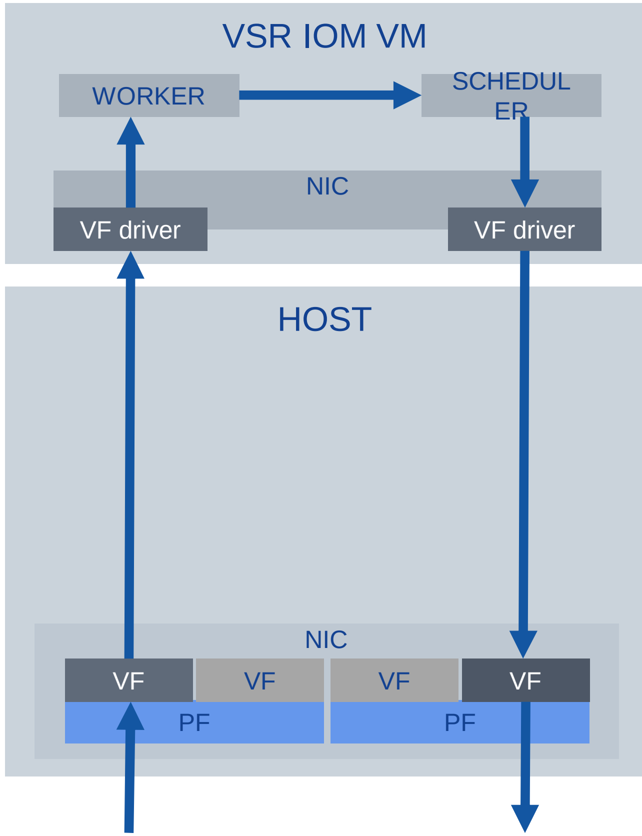
Virtualised I/O: DPDK accelerated OVS

- vSwitch with DPDK acceleration:
  - A software implementation of an L2/L3 switch runs in the host
  - Guests send and receive packets via the vSwitch
  - **Datapath is implemented entirely in user-space**
- A guest vNIC port is logically connected (by the hypervisor) to a port of the vSwitch
  - The guest attaches a VirtIO driver to the vNIC port
  - Host implements the other side of the driver in user-space (vhost-user)
- Throughput performance is significantly higher than native vSwitch model due to use of poll-mode drivers (PMD), more advanced CPU instructions, huge pages, etc.
  - But still lower than pass-through models due to **packet copying** between guest and host memory locations
- Advantages of the native vSwitch model are retained:
  - Live migration/vMotion
  - SDN control by openflow rules
  - NVO3 encapsulations (VxLAN, GRE, etc.)
  - Open Virtual Network (OVN) support



Virtualised I/O: SR-IOV

- Single Root I/O Virtualization
- PCI-SIG standard that allows **one PCIe device** (Physical Function/PF) to appear as **multiple lightweight PCIe devices** (Virtual Functions/VFs)
- vNIC in **guest uses VF driver specific** to the physical NIC type
- Direct I/O path between NIC and VM
  - **Limited hypervisor involvement**
  - VLAN/MAC transparency to be considered on NIC driver side
  - **Zero copy** receive and transmit due to DMA remapping in NIC (guest physical address -> host physical address)
  - **Near-native throughput**



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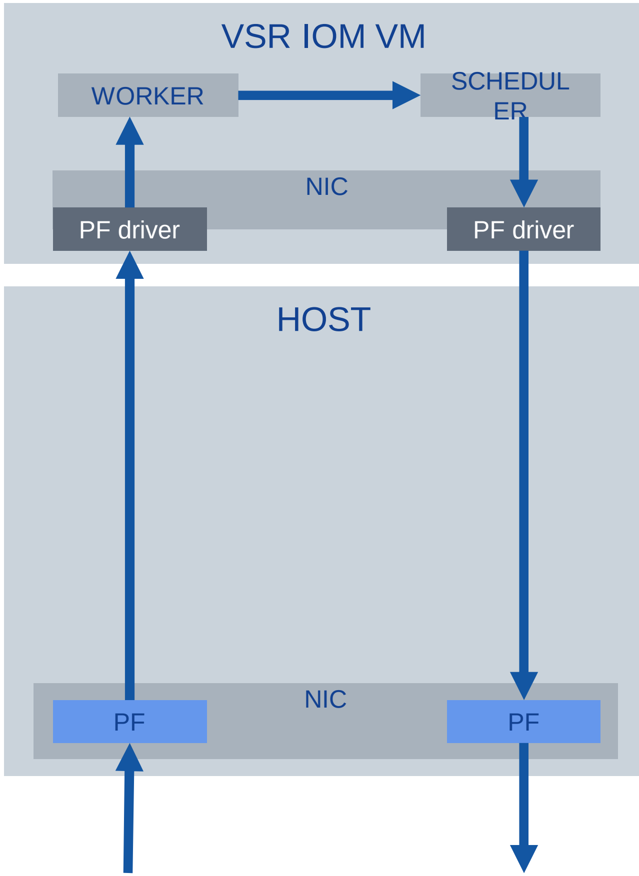
Virtualised I/O: PCI Passthrough

- Allows a **physical PCI device** from the host to be assigned **directly** to a guest
  - Guest controls the port using its own equivalent of the **bare-metal NIC driver**
  - The device is automatically **detached from** the **host OS** drivers when the guest is started and re-attached when the guest shuts down (managed mode)

- Direct I/O path between NIC and VM
  - **No hypervisor involvement**
  - All frames sent through untouched – fully up to the VM to handle
  - **Zero copy receive and transmit** due to DMA remapping in NIC (guest physical address -> host physical address)
  - **Near-native throughput**

- **No sharing of physical NIC** ports by different VMs



Hardware vs. Software Routers

Applicability

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Software routers: some very basic rules for applicability

- Great for control-plane intense tasks
  - The control plane of a hardware router is also just some piece of software running on a CPU
  - Running protocols and keeping tables is a nice job for a CPU, and hardly hardware-assisted anyway
- Single line-card designs, reasonably low port count
- Examples:
  - BGP route reflector – very little data plane required
  - CG-NAT appliance – mostly mapping table management, and some header rewriting
  - BNG, subscriber management – keeping state tables, QoS to be emulated
  - L2TP tunnel termination – mainly header management plus some state keeping
  - Large-scale IPsec gateway – encryption can be done in software reasonably well
  - DPI – hardware chipsets usually only look at packet headers anyway
  - Router simulator for lab use (if it actually behaves like real hardware does…)

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Software routers: some very basic rules for applicability

- Limited throughput and packet processing activated
  - Good scenario: Enterprise router - low number of 10G interfaces, full BGP table, a bit of peering, otherwise standard routing, little to no QoS, maybe some VPNs in addition
  - Questionable: higher (>4) number of physical 40G/100G interfaces
  - Unrealistic: trying to build a router/switch with many really high bandwidth ports in software
- Do you need guaranteed performance ?
  - For a hardware router, you can get somewhat guaranteed performance values from your vendor
  - Performance you can actually achieve with a software router depends a lot on your specific hard- and software configuration – little to no vendor guarantees for performance possible upfront
  - You will only know how well your actual hardware performs with all your actually configured features once you really try it out on exactly THIS system
  - Any change in server hardware or router configuration WILL affect performance again
- Way out of this: buy a fixed combination of server and routing software as applicance

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Software routers: some very basic rules for applicability (cont‘d)

- Is your network fully automated already - is compute power a „consumable resource“ ?
  - Software routers can be instantly deployed and destroyed „on-demand“
  - No special hardware to be bought
  - No delivery times from your supplier
  - Use your existing automation platform also for routing, like you do for plain compute-VMs
  - Your datacenter is also your backbone room in this case

- No chance to get to this level of flexibility with regular hardware routers - software routers are WAY more flexible for this scenario
- Cover the possible limited throughput of software routers by more instances in parallel
- „Deploy as you grow“ model - „from pets to cattle“
- If you really need a very big box in one place, you can still add a hardware router there

Software routers: free software or commercial products ?

- Do you need every bit of performance squeezed out ?
  - If so, does your free implementation „pull all the available registers“ ?
  - Or is it simply already „good enough“ for what you have in mind ?
- Do you feel comfortable with the user interface of your routing software ?
- Do you need SLA-based support ?
  - Do you have SLAs towards your own customers that you need to keep ?
  - Does „the community“ always (!) react quickly enough for you ?
  - If not, can you fix really everything just by yourself quickly enough ?
  - Is the time you spend on this also „free“ ?
  - What other things of your regular job can‘t you do while you fix routing software bugs ?
  - Does your company have someone else with the same skills next to you, just in case…?
- Is your software router for lab use only ?

Q&A

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