Network Interface Cards

ECE/CS598HPN

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Challenges of deploying RDMA in DCs

- Need for a lossless network
  - Congestion control to mitigate PFC issues (DCQCN, Timely, ZTR).
  - Better loss recovery in the NIC (IRN, SIGCOMM'18)
  - Large enough buffers + congestion control (eRPC, NSDI'19)
- Limited NIC cache:
  - Use bigger pages for memory translation (FaRM, NSDI'14).
  - Optimizing number of QPs (FaRM, NSDI'14; FASST, OSDI'16).
- Limited resource sharing and isolation
  - Kernel re-direction (LITE, SOSP'17)
- Supporting RDMA for VMs (para-virtual RDMA)
  - Commercial solution from VMWare requiring NIC support.
- Limited flexibility (tied to increased heterogeneity)
  - FPGA-based implementation / firmware patches.

Wednesday's reading

- Empowering Azure Storage with RDMA (NSDI'23)
- Primary usecase: intra-*region* storage.
- What are the additional challenges that arise?

Is RDMA the right choice for datacenters?

What will a clean slate approach look like?

Network Interface Card (NIC)

- Physical layer processing
- Some link layer processing
- Direct Memory Access (DMA) for copying data.
- Mechanism to trigger interrupts.

Modern NICs do much more than this

NIC Features: Protocol Offload

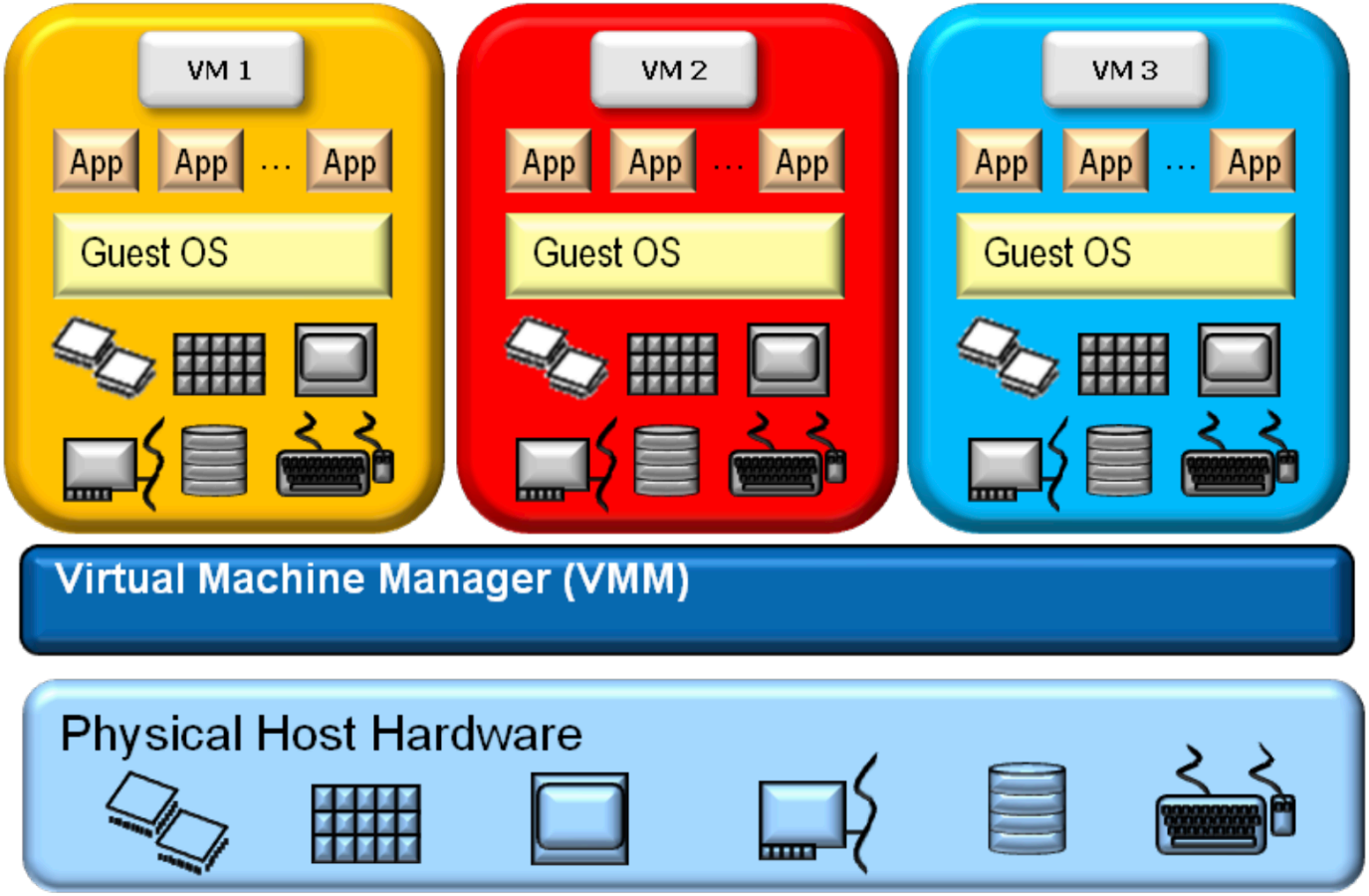
- TCP Segmentation offload
  - Split a large outgoing packet into MTU-sized packets and assign appropriate headers.
- Checksum Offload
  - TCP / UDP / IPv4 checksum computation.
- Large Receive Offload
  - Combine multiple MTU-sized packets for the same connection into a single large packet.

NIC Features: Packet Steering

- Receive Side Scaling
  - Load balance incoming packets across different queues.
  - Hash of packet header fields mapped to queue index.
  - Can pick which queue corresponds to which index.

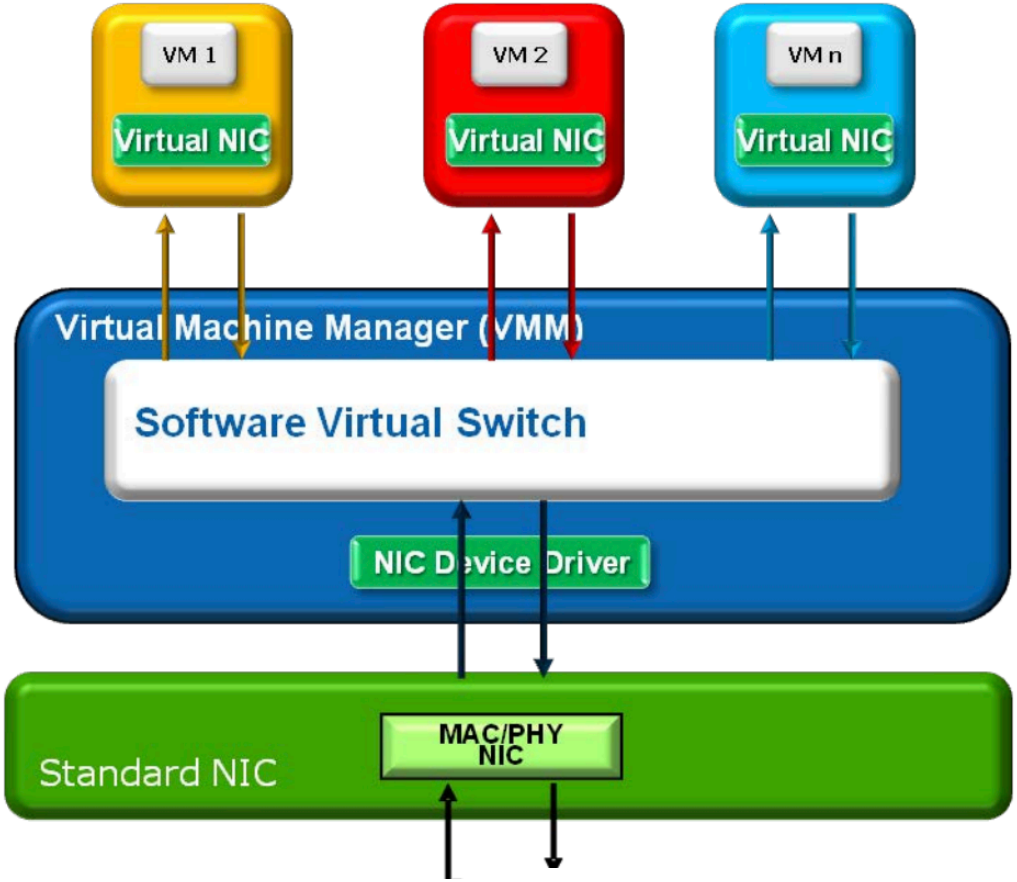
- Flow Director
  - Maintain explicit mapping between packet header fields and queue.
  - Other actions including dropping and incrementing counters.

NIC Features: Virtualization

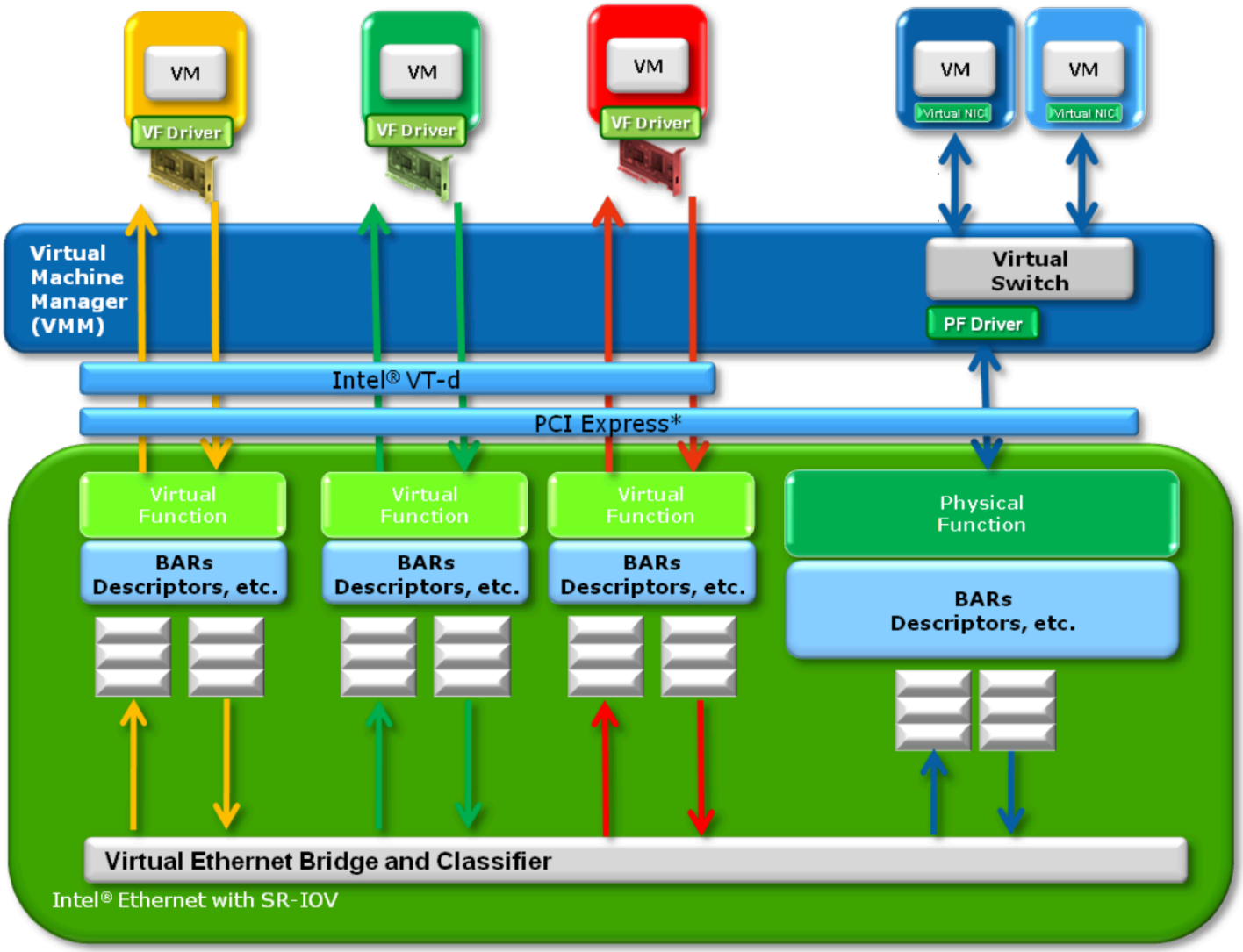


Source: Intel White Paper on VMDq, March 2008

NIC Features: Virtualization

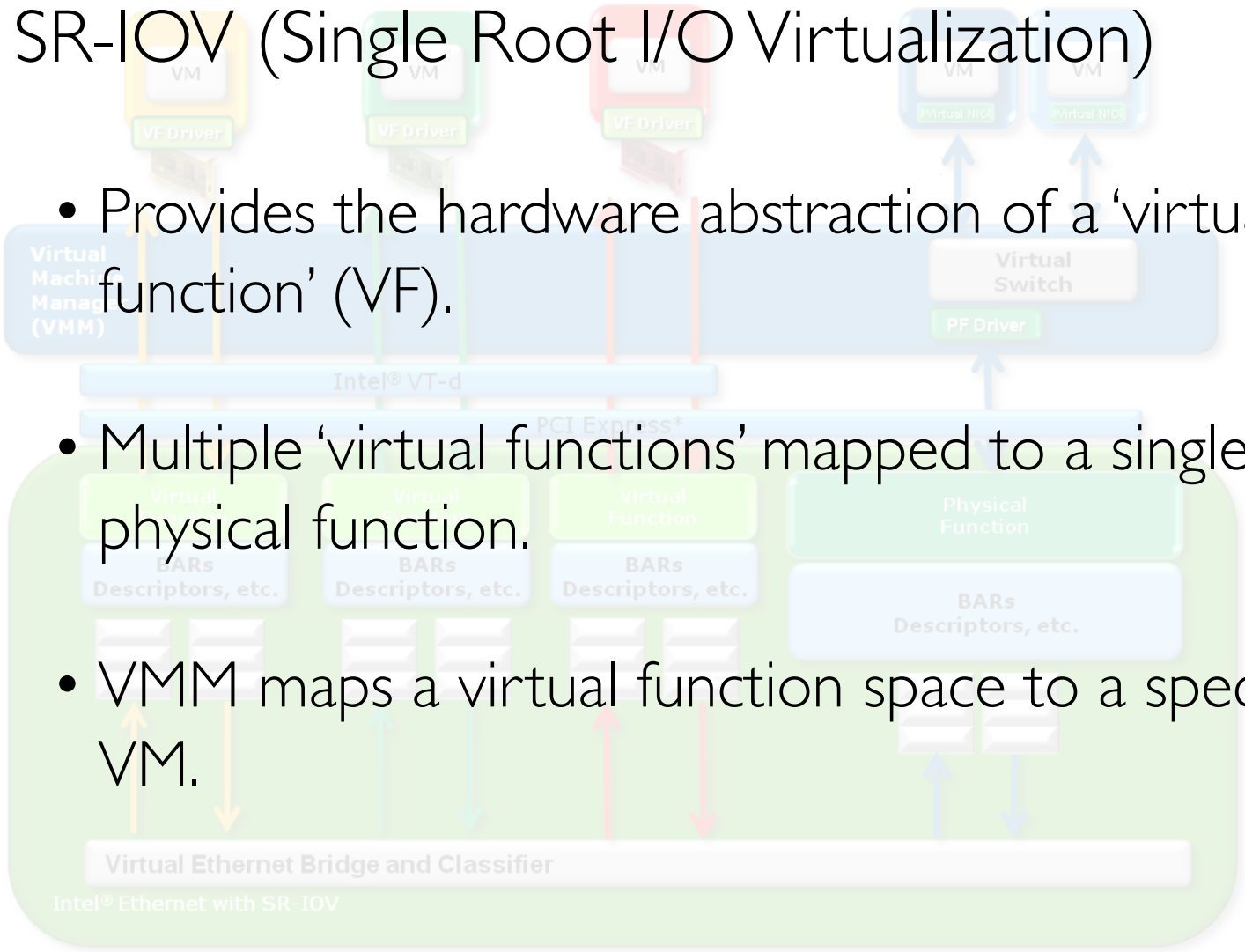


NIC Features: Virtualization



NIC Features: Virtualization

- SR-IOV (Single Root I/O Virtualization)
  - Provides the hardware abstraction of a 'virtual function' (VF).
  - Multiple 'virtual functions' mapped to a single physical function.
  - VMM maps a virtual function space to a specific VM.

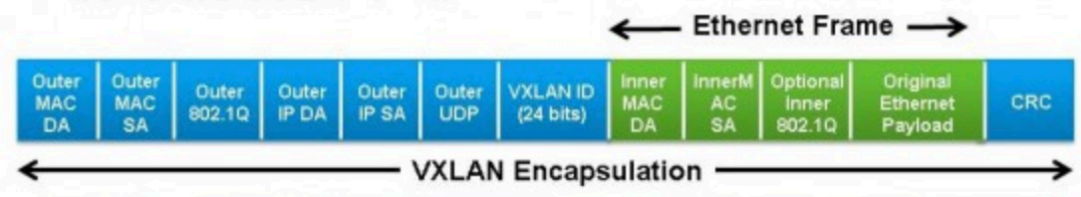


NIC Features: Virtualization

- SR-IOV (Single Root I/O Virtualization)
  - Share a single physical port across multiple VMs.
- VMDq (Virtual Machine Device Queues)
  - Sort packets across VM specific queues based on MAC address and VLAN tags.
  - Round-robin across VM queues.
- VT-d (Virtualization technology for directed I/O)
  - DMA support for VMs, manage interrupts for VMs, protection and isolation across VMs for I/O operations.

NIC Features: Tunneling Support

- Examples:
  - VXLAN:



  - NVGRE:

- Offload encapsulation/decapsulation.
- Ability to parse tunneled information.

Limitations

- Lack of flexibility and fine-grained control.
  - E.g. TSO offload can be useless without VXLAN support.
  - Even minor fixes can take years.
- Resource constraints.
  - Limited memory (packet buffers, flow table size, etc).
  - E.g. Flow Director allows only 8K flow entries.

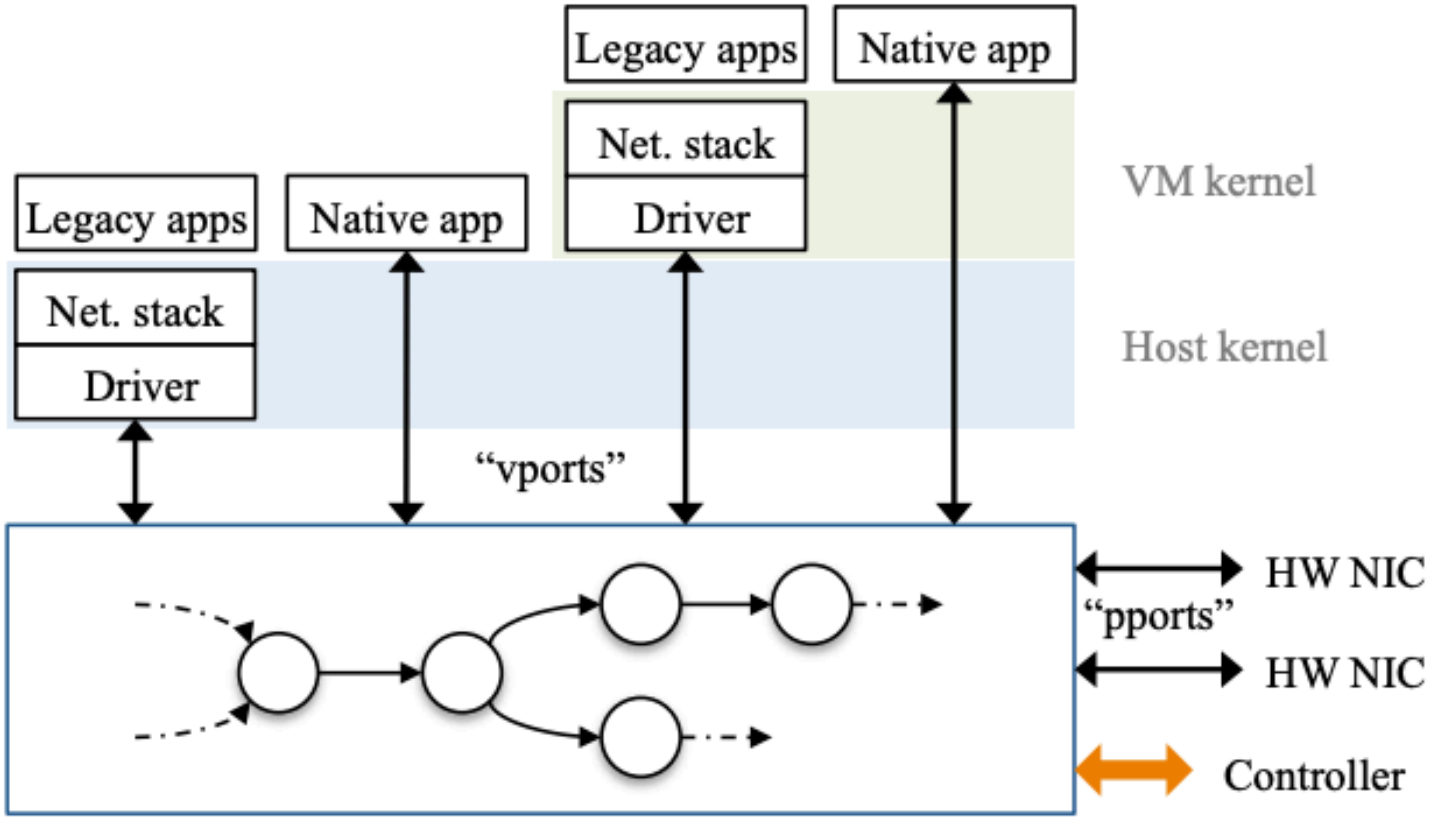
SoftNIC: A Software NIC to Augment Hardware

Sangjin Han, Keon Jang, Aurojit Panda,
Shoumik Palkar, Dongsu Han, Sylvia Ratnasamy

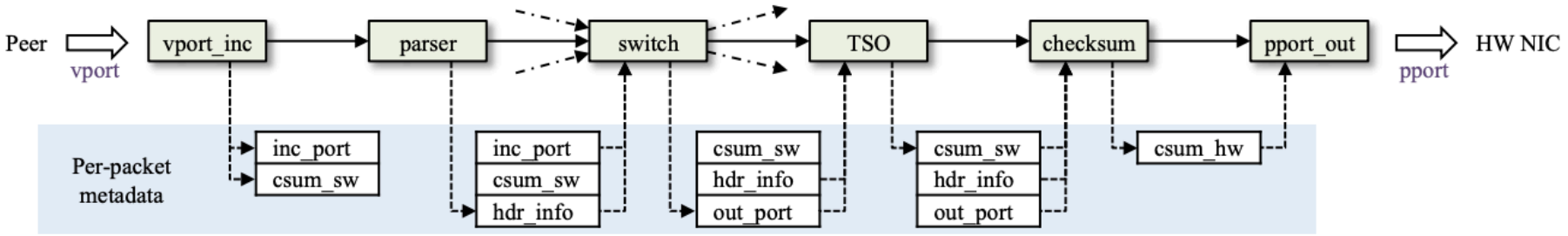
SoftNIC Design Goals

- Programmability and extensibility
- Application performance isolation
- Backwards Compatibility

Architecture

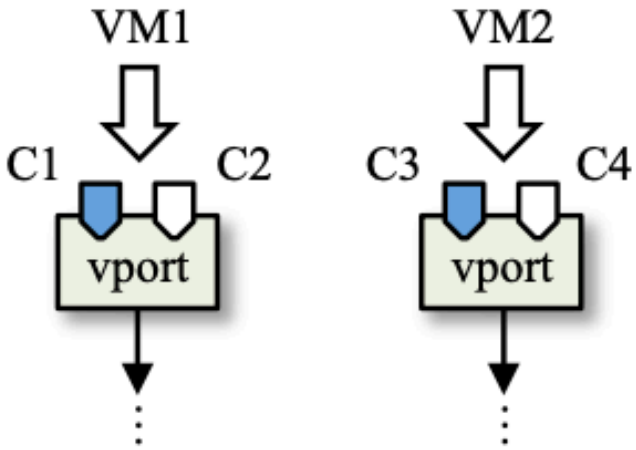


Packet Processing Example

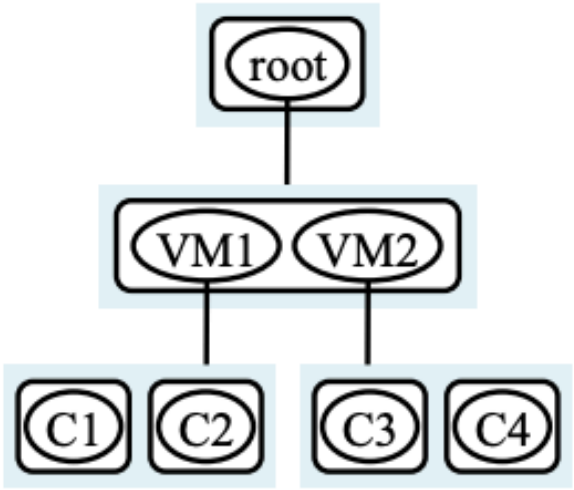


Resource Scheduling

- Allocate both processor and bandwidth resources.



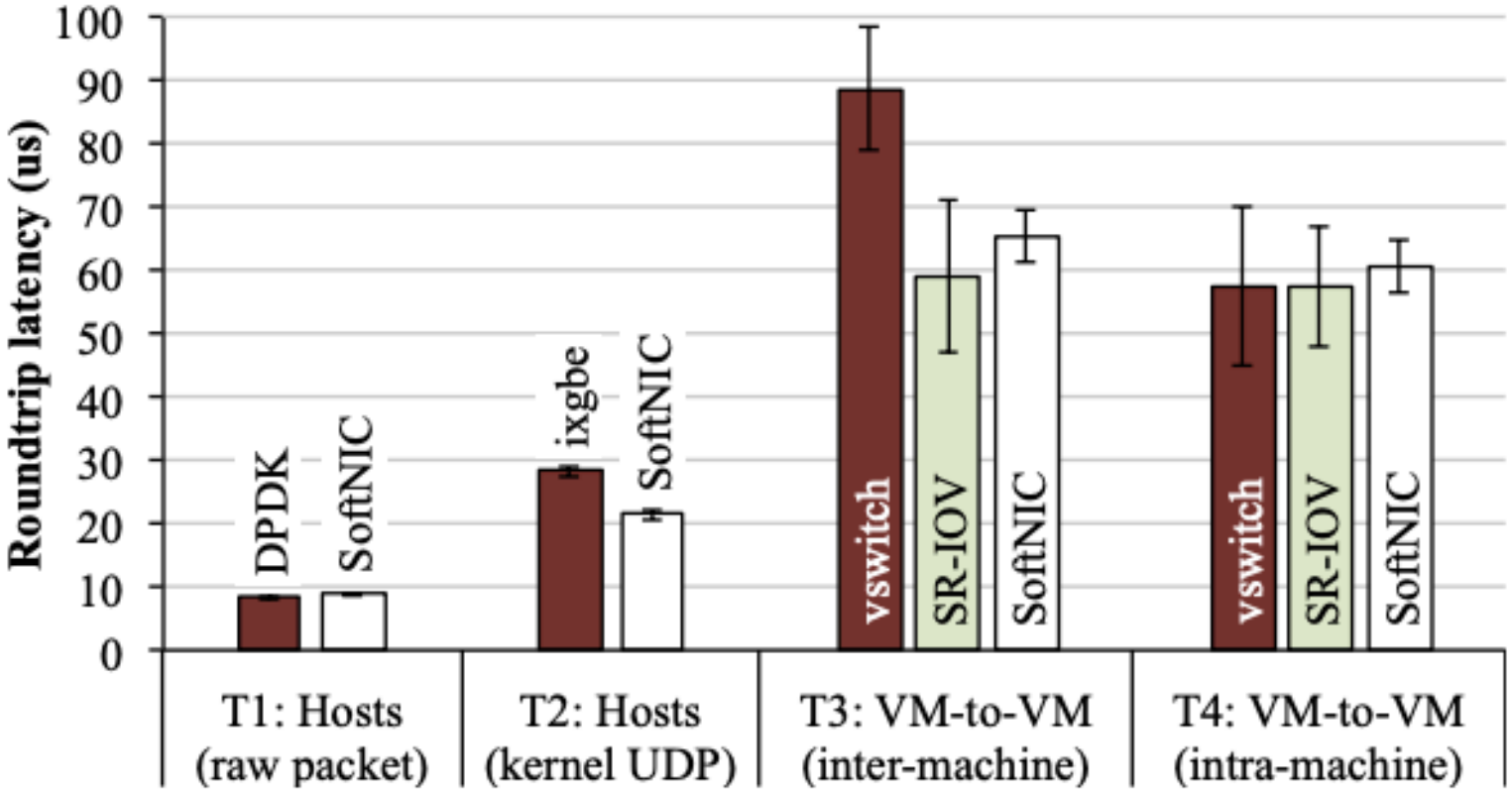
C1, C3: high priority, 1 Gbps
C2, C4: low priority, no limit
Per VM: 5 Gbps limit



Implementation

- Over DPDK.
- Dedicate a small number of cores to SoftNIC.
  - Multi-core scaling achieved by associating each SoftNIC core with different set of queues.
  - Requires peers to ensure packets from same flow go to the same queue.
- Supports different packet I/O interfaces at vports for user-space / kernel-bypass applications and kernel.
  - Implement a kernel driver, requiring no modification to kernel.
- Polling to check for packets from vport and pport.
- Batching to amortize software processing overheads.

Evaluation


Roundtrip latency (us)
100
90
80
70
60
50
40
30
20
10
0
DPDK
SoftNIC
ixgbe
SoftNIC
vswitch
SR-IOV
SoftNIC
vswitch
SR-IOV
SoftNIC
T1: Hosts (raw packet)
T2: Hosts (kernel UDP)
T3: VM-to-VM (inter-machine)
T4: VM-to-VM (intra-machine)

Case Studies

- If NICS do not understand tunneling format, cannot support TSO for "inner" TCP frames.

- SoftNIC can be used to augment the TSO/LRO feature in these cases.

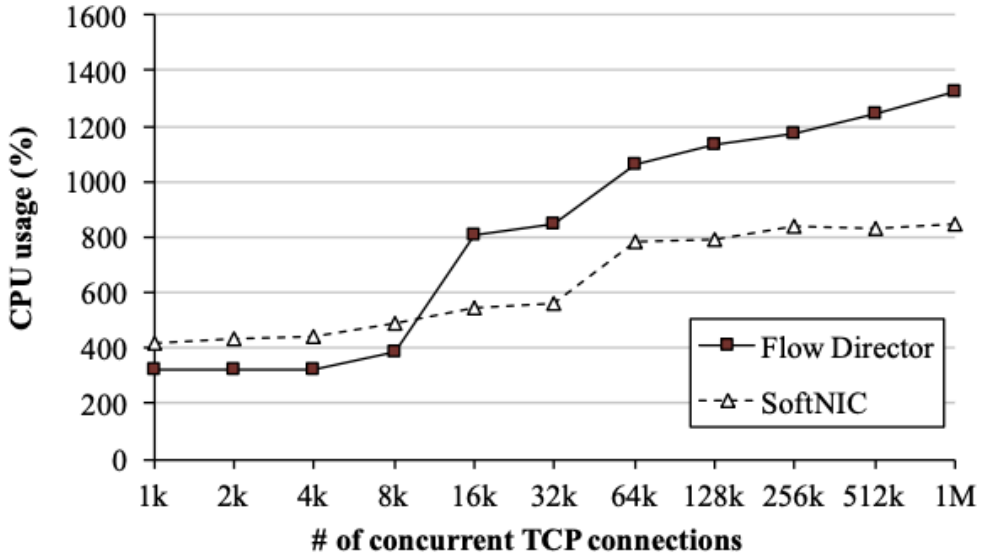
Case Studies

- NIC supports a limited number of "rate-limiters" – few hundreds.
  - There may be thousands of flows.
- SoftNIC can be used to implement a scalable rate limiter.

Case Studies

- Flow Director directs packets with specific header fields to specific queues.
  - Can only support 8K entries.

- SoftNIC can support almost unlimited flow entries using system memory.



Case Studies

- Scaling legacy applications: send packets to different cores based on hash of packet header fields.
- RSS (NIC feature) is too limiting.
- SoftNIC can be used to provide such scaling.

Your thoughts?

- What did you like about the paper?
- What are its limitations?
- Other ways of achieving flexible NIC offload?

Next few classes

- Host SDN and network virtualization in multi-tenant datacenters.
- Two case-studies:
  - Google (SNAP)
  - Microsoft (AccelNet)
- Other forms of programmable NICs
  - FPGA-based NICs (AccelNet)
  - NICs with general-purpose compute (FlexTOE)
  - Custom NIC-CPU co-design (NanoPU)

Student Presentation on Nov 17th

- Student presentations on Friday, Nov 17th
  - Present a relevant paper of your choice
    - A paper that is related to the topics we covered, but not part of your reading list (can select a paper from the "optional" list).
    - 6 minute presentation with 1-2mins for Q/A.
      - What problem is the paper trying to solve?
      - How does it solve it at a high-level / what's the key idea?
      - Key result.
    - Watch out for an email with a sign-up sheet.
      - Select a slot and a paper of your choice on a first-come-first serve basis.

Other logistics

- No class on Wed, Nov 29.
- Second progress report due next Friday.

Thank you for your feedback!

- Many of you want harder assignments ☺
- Student presentations
- Broader variety of topics – more papers per class?
- Sometimes discussions tend to drag…
- More background before diving into details.