Accelerating VM networking through XDP

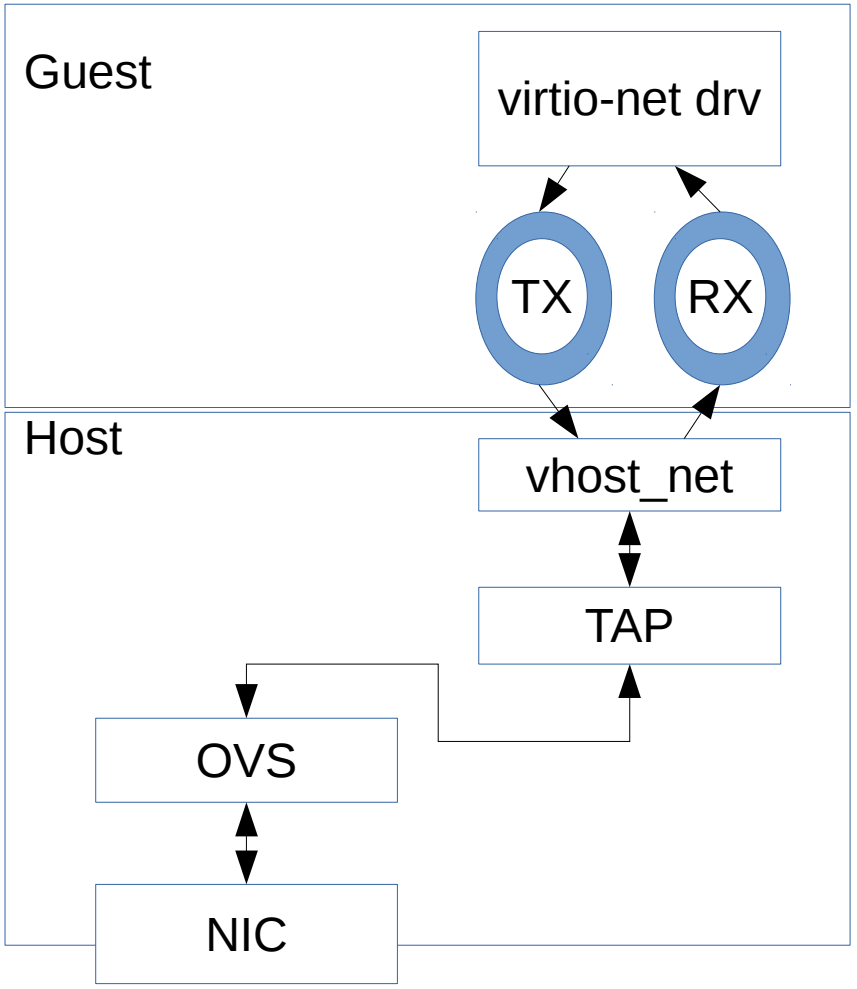
Jason Wang
Red Hat

Agenda

- Kernel VS userspace
- Introduction to XDP
- XDP for VM
- Use cases
- Benchmark and TODO
- Q&A

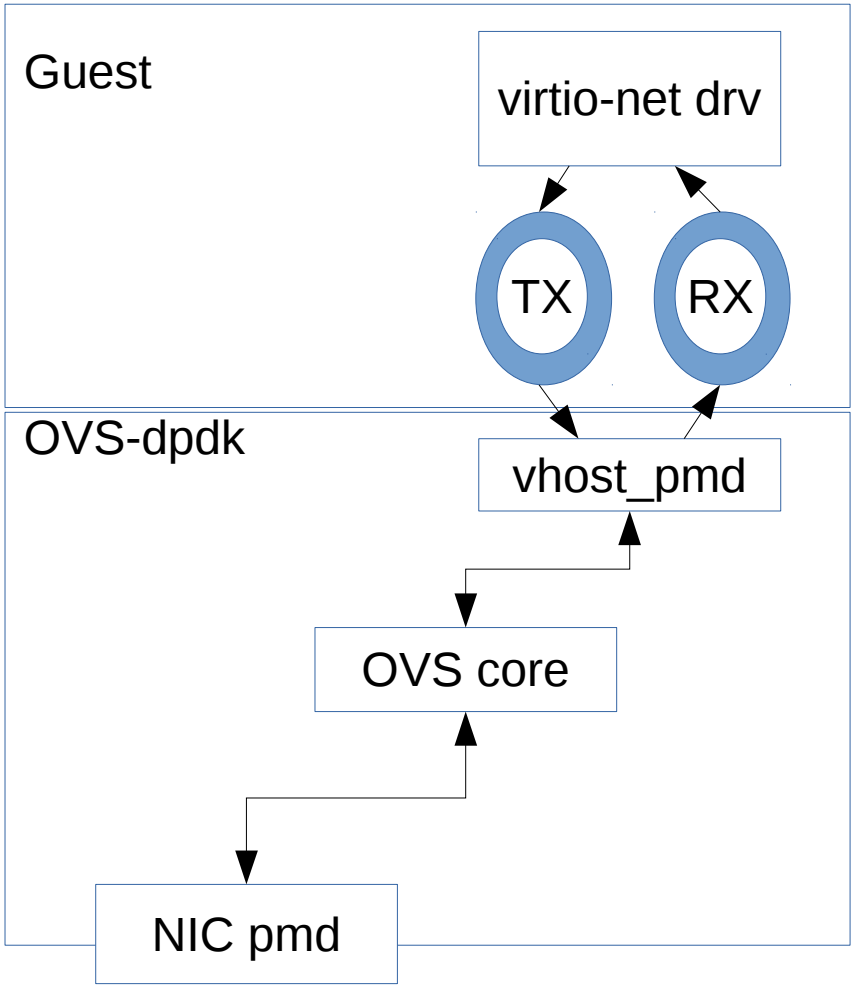
Kernel Networking datapath

- **TAP**
  - A driver to transmit to or receive from userspace
  - Backend for vhost_net
- **Vhost**
  - Virtio protocol to co-operate with guest driver
- **OVS**
  - Forwarding packets between interfaces

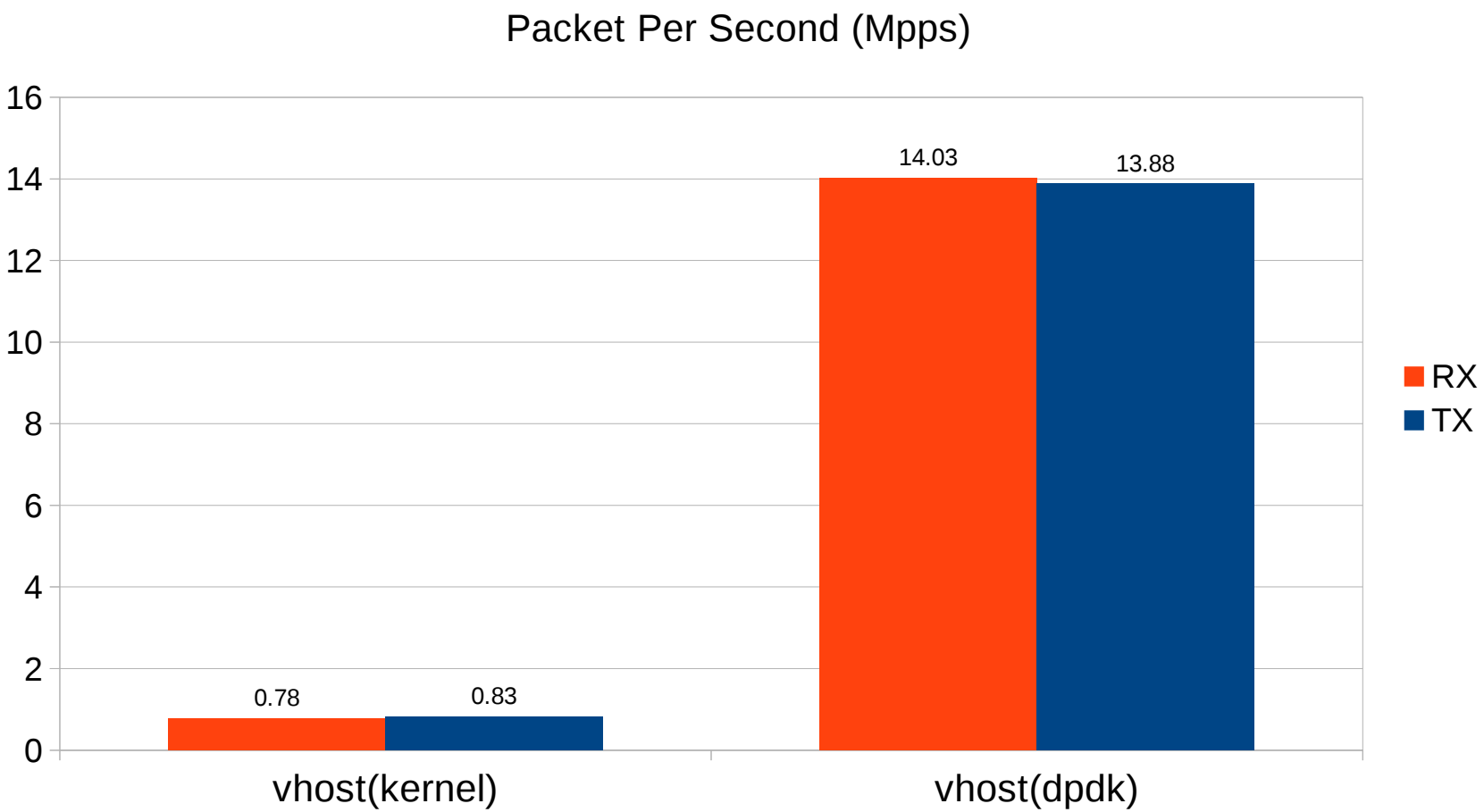


Userspace Networking datapath

- **vhost-user**
  - For implementing vhost dataplane in another userspace process
- **OVS-Dpdk**
  - Userspace OVS
  - Datapath were accelerated through dpdk
    - Polling mode driver
    - VFIO
    - Vhost-user slave



Because we(kernel) are slow



Why? Difference in datapath

	dpdk	kernel
Meta-data	rte_mbuf, head of packet	heavyweight, skb, extra allocation
Memory model	memory pool for both TX and RX	vendor specific (RX), protocol specific (TX)
DMA	statically mapped	dynamically mapped
Batching (forwarding)	aggressive	almost no
Busy polling	Polling Mode Driver	NAPI (polling + event)
VM datapath in host	vhost pmd	TAP + vhost_net
vhost	bulking, prefetching, busy polling	no bulking, no prefetching, event based (or limited busy polling)

Question:

A fast and lightweight data path for kernel?

Answer:

XDP = eBPF + early packet processing

eBPF

- *Generic, efficient, secure in-kernel (Linux) virtual machine. Programs are injected and attached in the kernel, event-based.*
- **extend BPF**
  - Evolution from classical BPF, assembly-like, interpreter
  - Effective: more registers and instructions, larger stack
  - Read or write access to context (packets for net)
  - LLVM backend
  - safety: in kernel verifier
  - JIT(Just in time)
  - Bpf() syscall for managing program

eBPF features

- **Maps: key-value entries (hash, array, …) shared between eBPF program and with the user space**
- **Tail calls: “long jump” form one program into another, context is preserved**
- **Helpers: for each type of eBPF program, a set of white-list of kernel functions that could be called:**
  - Get time
  - Debug information printing
  - Lookup or update maps
  - Shrink or grow packets
  - XDP is a type of eBPF program

A fast path in kenrel stack - XDP

- **Short for eXpressed Data Path (4.8+)**
- **Allow run eBPF program at lowest point in the software stack**
- **Use cases:**
  - Early dropping - DDOS
  - Load balancing
  - Monitoring
  - Fast forwarding (networking device, CPU, userspace - AF_XDP)
- **Designed for**
  - High performance, fast path in the kernel stack
    - Multiqueue for lockess TX, Simple memory layout, NAPI loop, Batching
  - Programmability, new function without modifications for kernel
  - Not a kernel bypass, work with kernel networking stack
  - No need for specialized stack

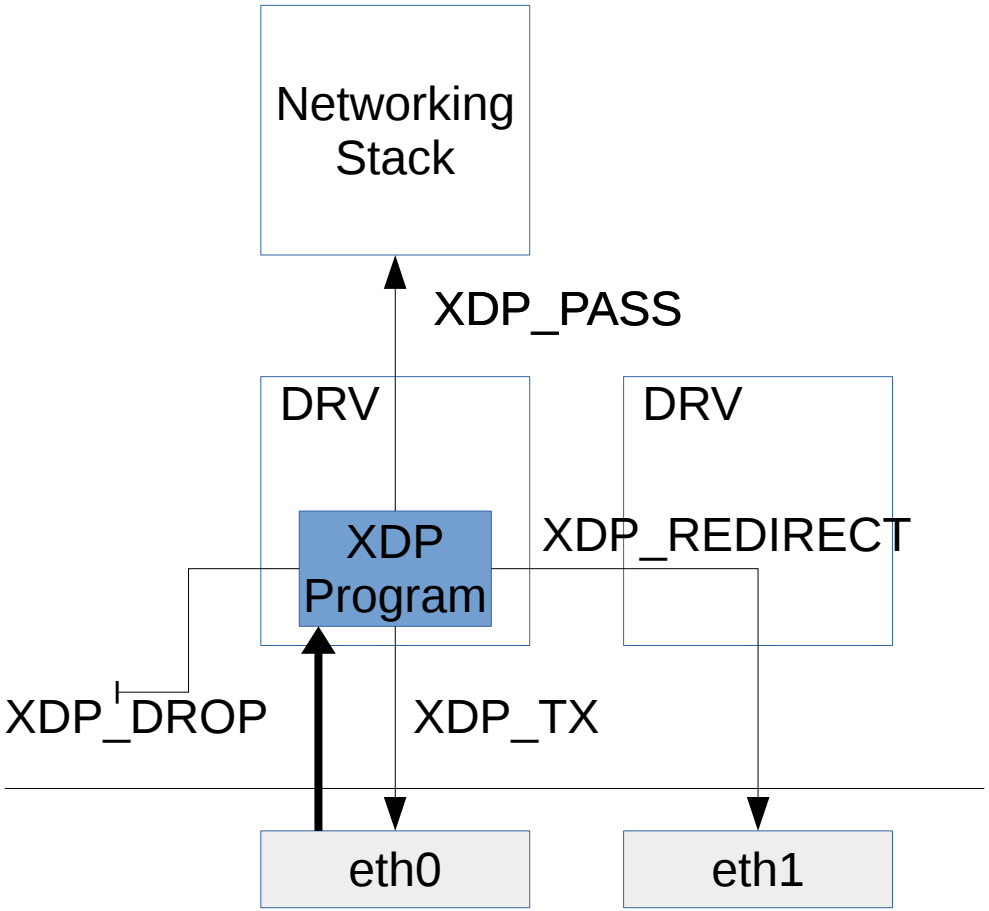
XDP context

- **Simple**
  - Driver need prepare the XDP context and call XDP program
  - Allocated on the stack usually, no pressure for the memory allocator
  - Stored at the head of a packet
  - Packet address, metadata, and receive queue information
  - Linear, no frag, frag_list,

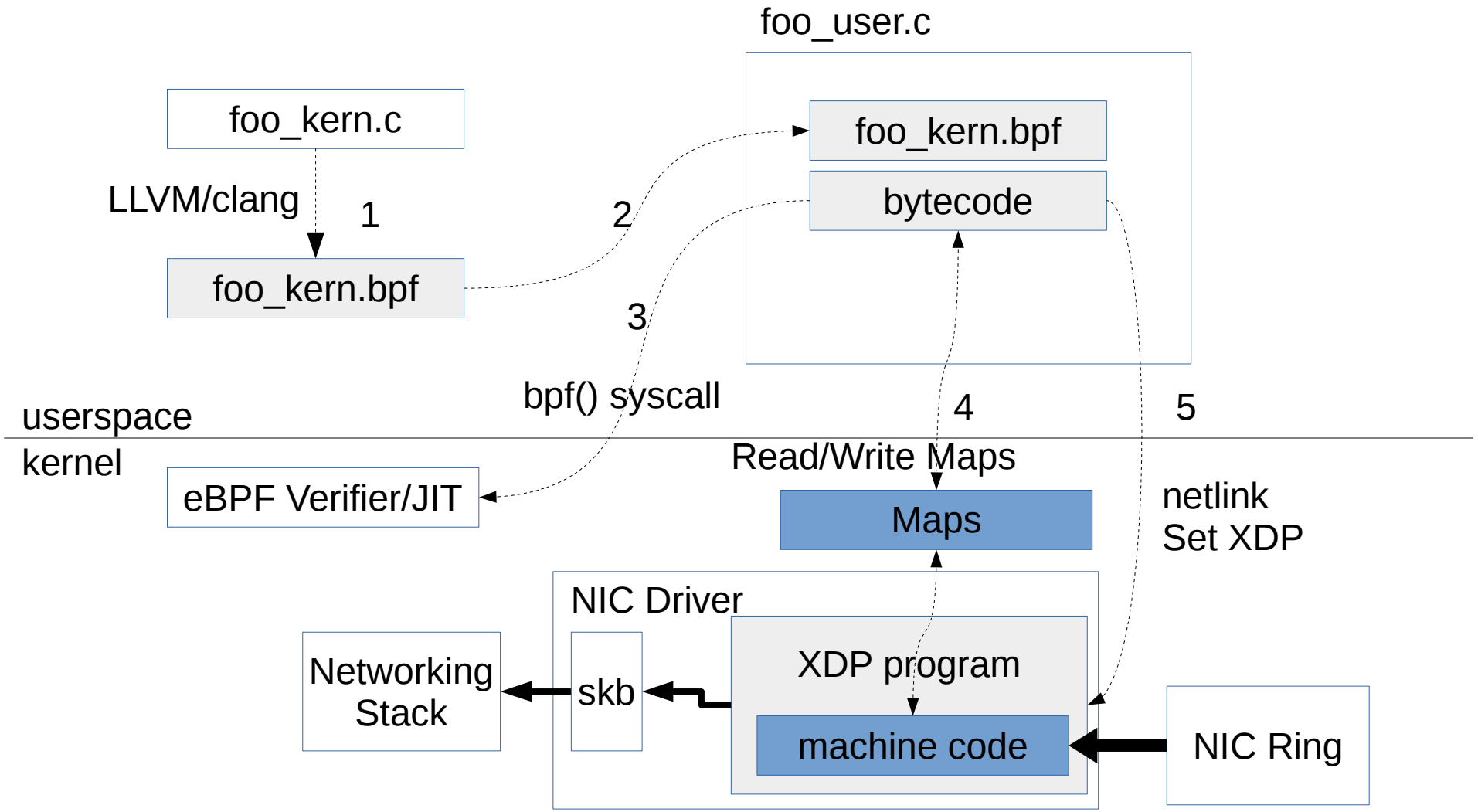
```
struct xdp_buff {
        void *data;
        void *data_end;
        void *data_meta;
        void *data_hard_start;
        struct xdp_rxq_info *rxq;
};
```

XDP Actions

- **Driver behave depends on XDP program return value**
  - XDP_DROP: drop packet immediately
  - XDP_TX: transmit the packet back to the interface
  - XDP_PASS: build skb and pass the packet to network stack
  - **XDP_REDIRECT**: redirect packets
    - Bulking in forwarding path



XDP = eBPF program run inside driver

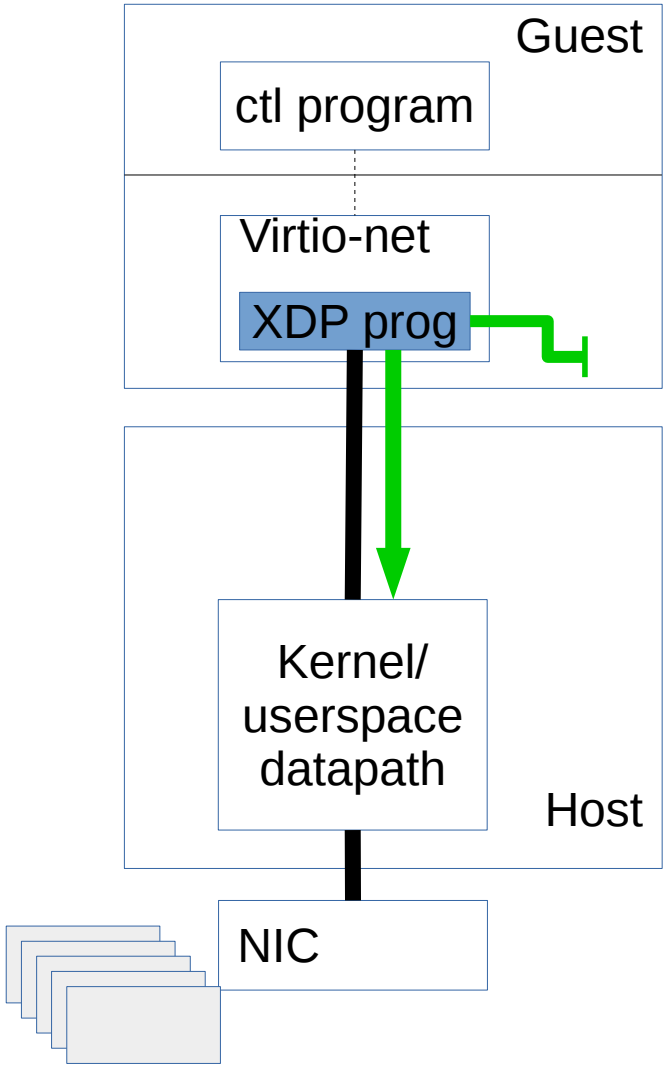


XDP support

- **eBPF**
  - Interpreter, JIT, Verifier, helpers
- **Networking device driver support**
  - Native mode, driver can work on XDP buff
    - Native XDP support before building skb
    - Simple memory model (e.g one page per packet)
    - ndos for redirection, can transmit XDP buffs, bulking
    - Best performance
- **Networking core support**
  - Attach XDP program to a network device
  - XDP generic
    - skb level
    - Prototype developing
    - Deal with e.g SG or GSO packets

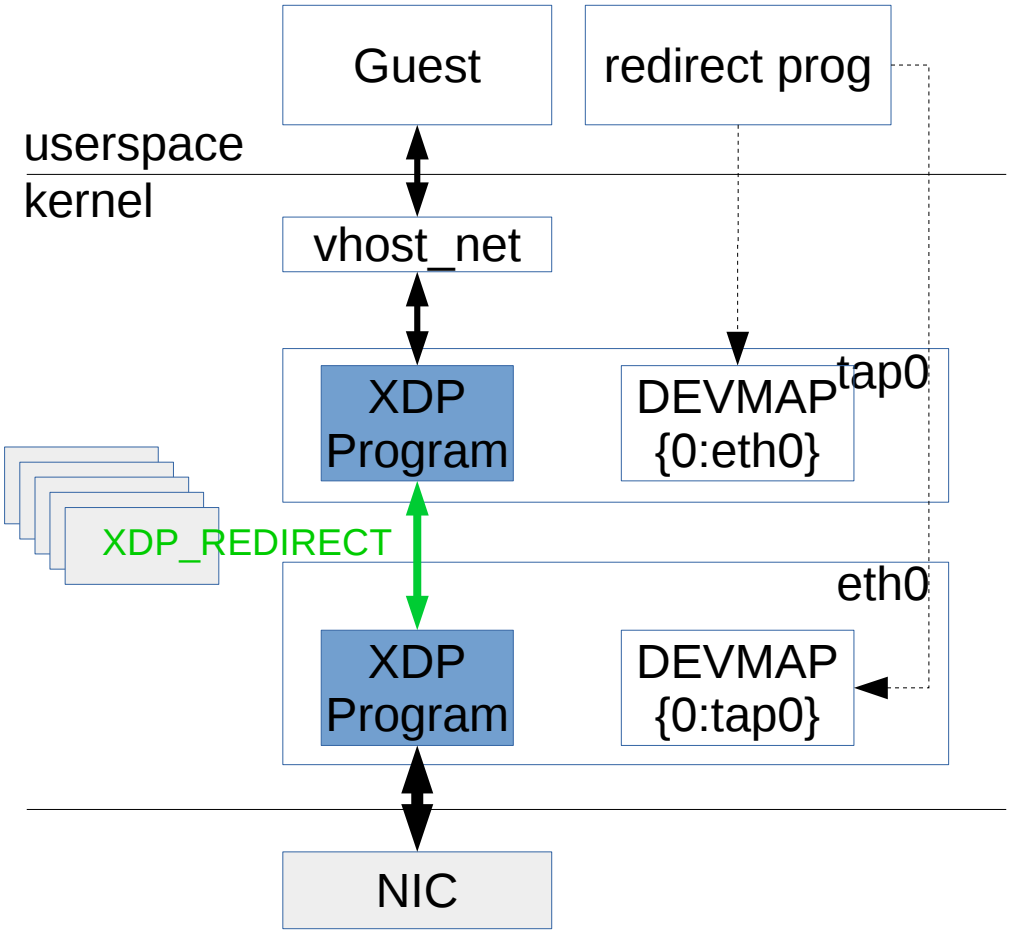
Accelerating method I: accelerate guest networking

- **XDP support in virtio-net (4.10)**
- **Works for**
  - Kernel datapath on host
  - Userspace datapath on host
- **Usecase:**
  - Typical usage for XDP:
    - DDOS, LB, AF_XDP, ...
  - Developing XDP features
  - Accelerate nested VM (+vhost_net)



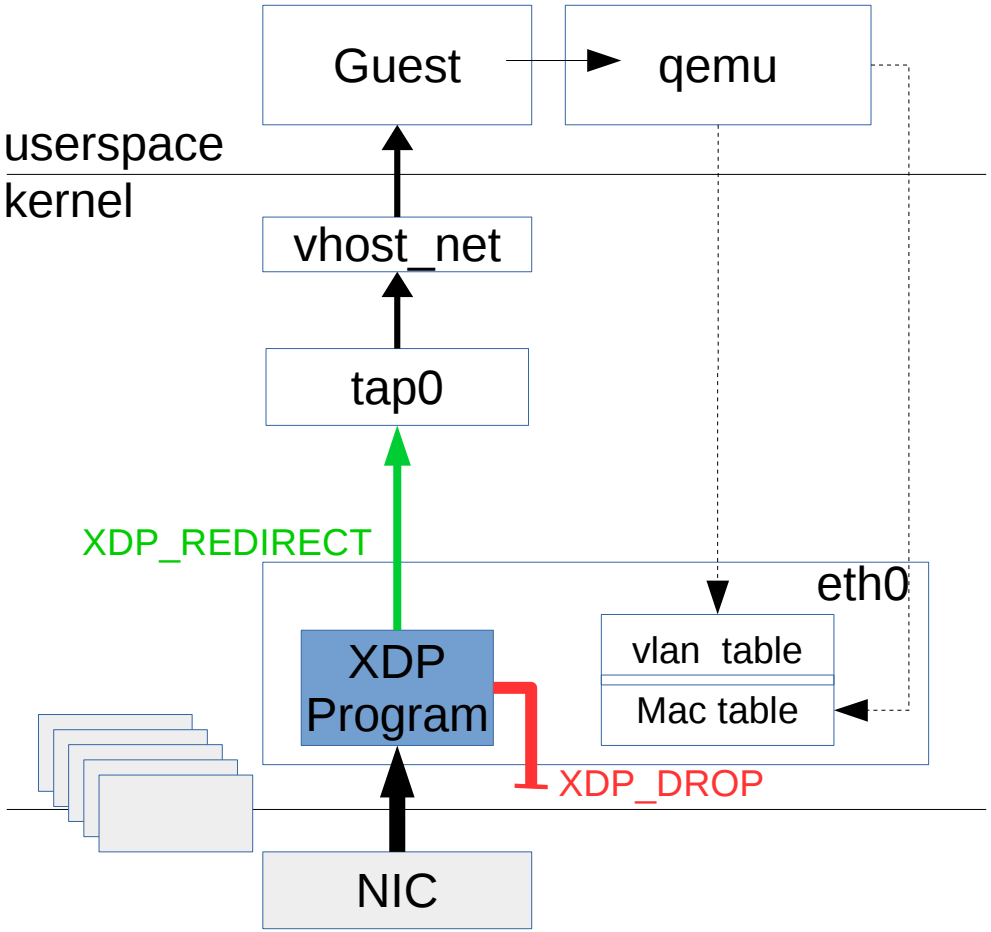
Accelerating method II: Accelerate host VM datapath

- **XDP support in TAP (4.14)**
- **A userspace prog**
  - setup DEVMAP, record the destination interface (batching through flush)
  - bpf_redirect() for destination interface
  - return XDP_REDIRECT
- **Usecases:**
  - Host networking stack bypassing
  - VM2VM communication



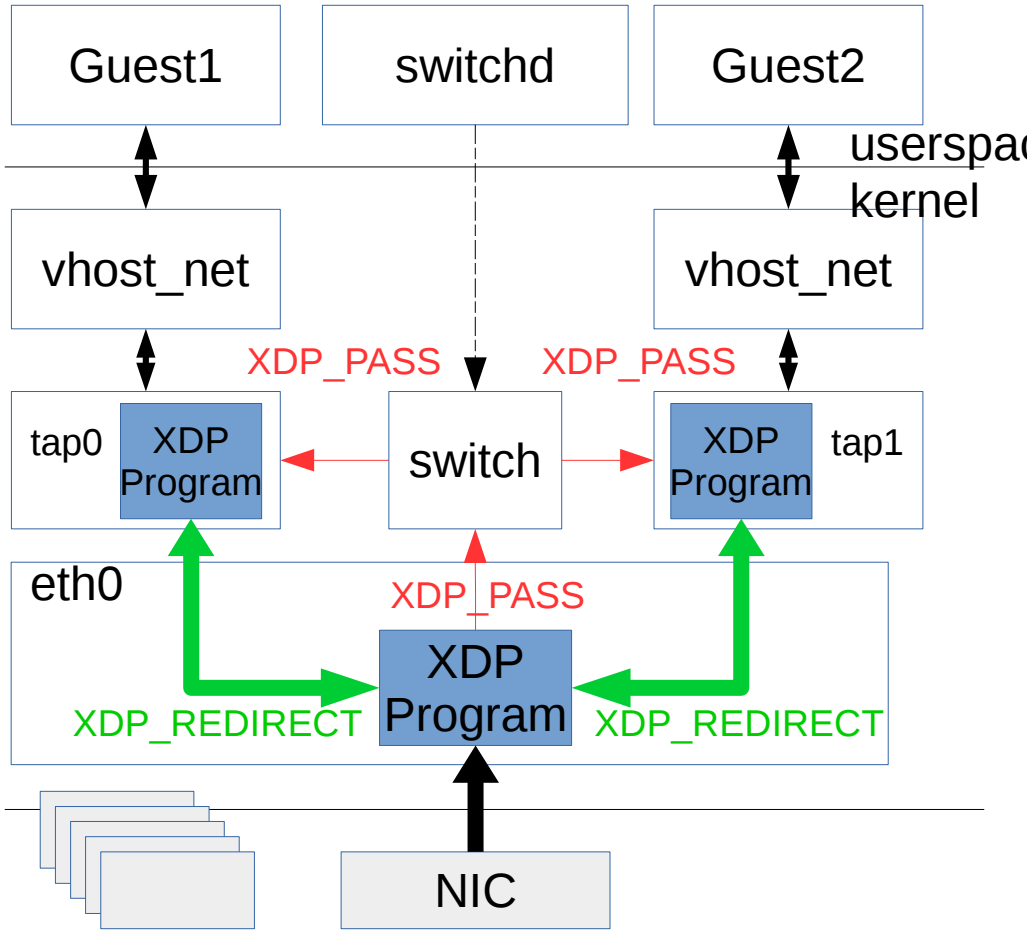
XDP accelerated Receive filter (WIP)

- **Qemu/Libvirt**
  - intercept receive filter request guest through control vq
  - Setup maps for vlan/mac table
  - Attach XDP program to physical interface
- **XDP program**
  - query vlan/mac table for each packet
  - drop packets early if not permitted
  - otherwise redirect them to tap0



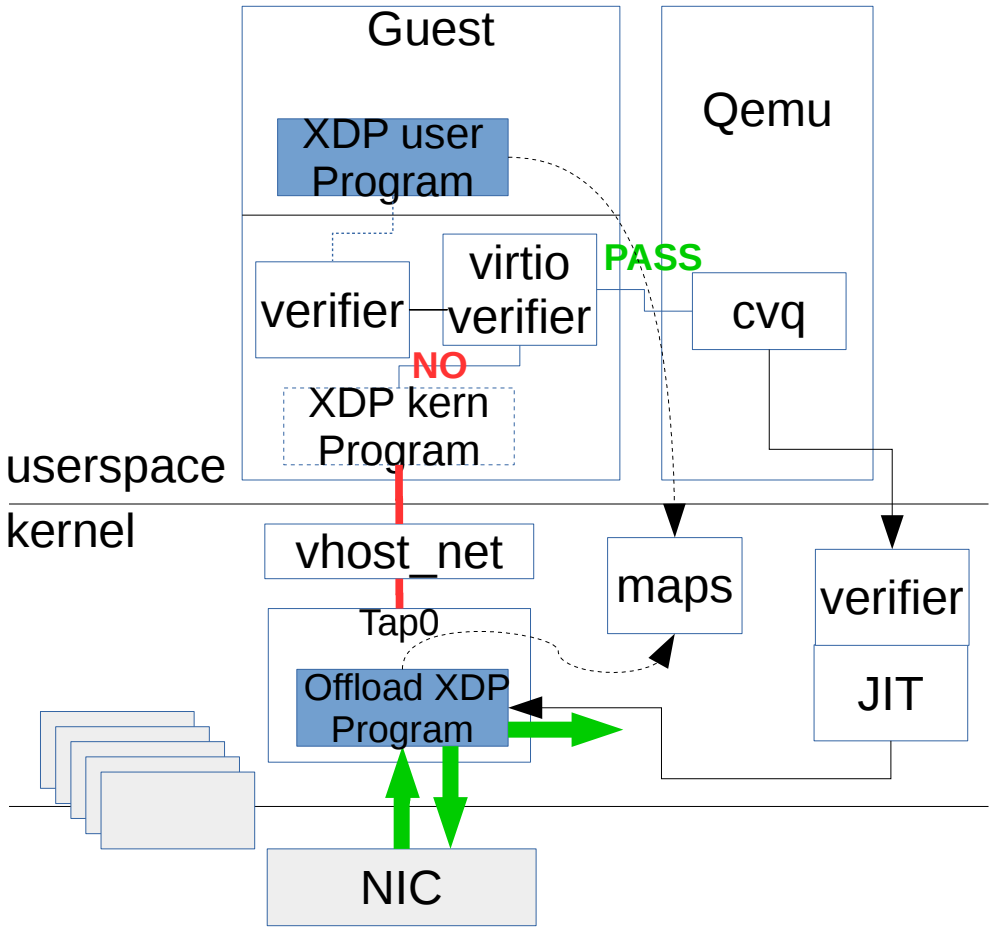
XDP accelerated switch (WIP)

- **switchd**
  - build forwarding table through eBPF maps
  - attach XDP to each interfaces
- **XDP program**
  - Mac table via map
  - for packets with destination in the table, redirect it directly through XDP (fast path)
  - for packets with unknown destination, return XDP_PASS and pass it back to normal kernel path for switchd to process (slow path)



Acceleration Method III: XDP offload to host (WIP)

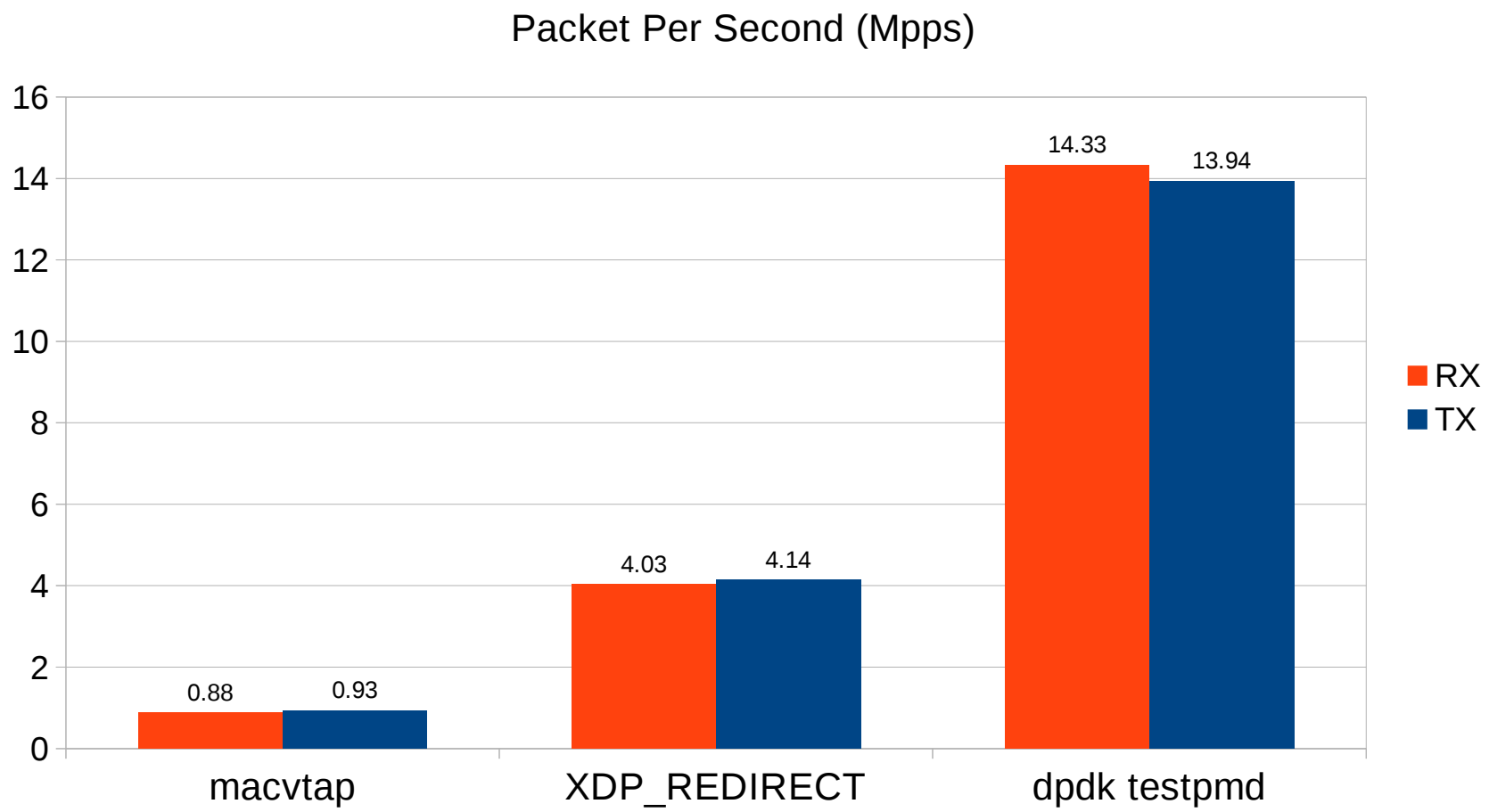
- **Offload XDP to host**
  - Almost “self-contained”
  - Lower and faster
    - Datapath run inside host
    - No virt overhead
  - With XDP offload framework
  - Dedicated verifier
    - Classification:
      - Good: Filtering, dropping, XDP_TX
      - BAD: XDP_REDIRECT, debug print
      - Hard to support all from startup
    - Run inside guest if it can’t be offloaded
  - Verified again in host, JIT in host
  - MAPs in host, way to access it from guest userspace



How XDP help for VM datapath

	dpdk	Kernel + XDP
Meta-data	rte_mbuf, head of packet	lightweight, XDP_buff, head of packet
Memory model	memory pool for both TX and RX	vendor specific or generic XDP page pool, frame return API
DMA	statically mapped	dynamically mapped
Batching (forwarding)	aggressive	batching via devmap (XDP_REDIRECT)
Busy polling	Polling Mode Driver	NAPI (polling + event)
VM datapath in host	vhost pmd	TAP + vhost_net, vhost_net can see XDP buff directly (RX)
vhost	bulking, prefetching, busy polling	Batch dequeuing XDP buffs from TAP, no prefetching, event based (or limited busy polling)

Here we are


Packet Per Second (Mpps)
16
14
12
10
8
6
4
2
0
0.88
0.93
4.03
4.14
14.33
13.94
macvtap
XDP_REDIRECT
dpdk testpmd
RX
TX

Future work

- **WIP**
  - XDP accelerated vswitch
  - Virtio-net XDP offload
- **Performance optimization**
  - Send and receive XDP_buff to vhost_net directly
  - Better bulking in TAP/vhost_net
    - (XDP_REDIRECT can give +10Mpps on host between physical ports)
  - Better inter driver co-operation (inter driver page recycling)
  - AF_XDP instead of TAP?
- **More driver support for XDP/XDP_REDIRECT**
  - supported by i40e, ixgbe, tuntap, virtio-net, mlx5(partial)
  - **please add XDP_REDIRECT support for your driver! (VF as well)**

Summary

- **Performance of kernel datapath for VM is improve(ing)!**
  - XDP
    - Fast kernel datapath
    - Userspace defined policy
  - More coming soon
- **Patches are welcomed!**

Q&A

Thanks!

APPENDIX samples/bpf/xdp*

xdp1	Early packet dropping(XDP_DROP)
xdp2	Rewrite(macswap) + forwarding(XDP_TX)
xdp_tx_iptunnel	Tunneling(header adjustment) + forwarding(XDP_TX)
xdp_redirect	Simple redirection (XDP_REDIRECT)
xdp_redirect_map	Batching (DEVMAP) + redirection (XDP_REDIRECT)
xdp_fwd_kern	ipv4+ipv6 forwarding (XDP_REDIRECT)
...