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Efficient and Flexible Virtual Machine Networking through eBPF

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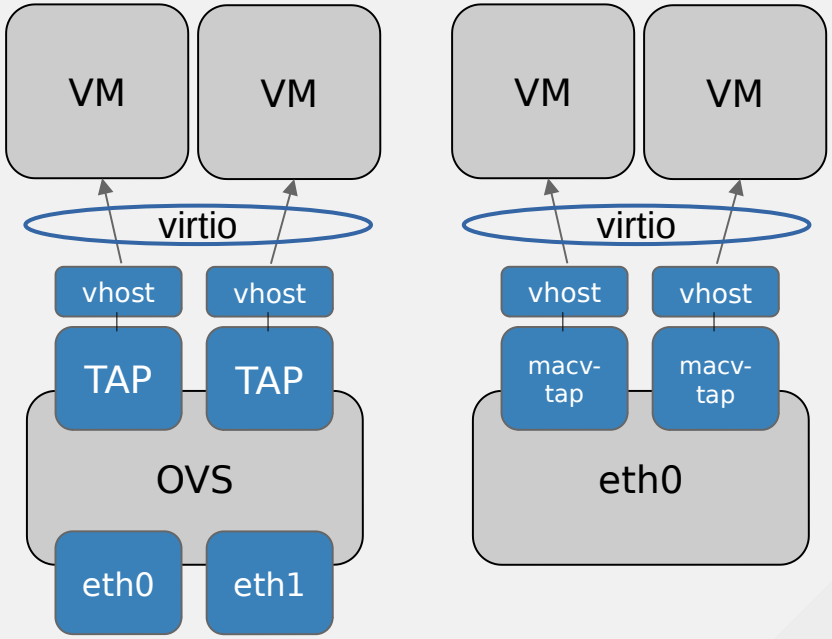
Outline

- Review
- Problems
- Introduction to eBPF/XDP
- Simple usage of XDP
- Advanced Features: advantages and limitations
- Status
- Q&A

Overview of virtual machine networking

- Virtio: IPC between host and guest
- Vhost: virtio dataplane in kernel
- TAP: network driver for userspace, works with OVS/bridge for complex cases
- Macvtap: stacked device on top of lower NIC, for simple use cases



Issues

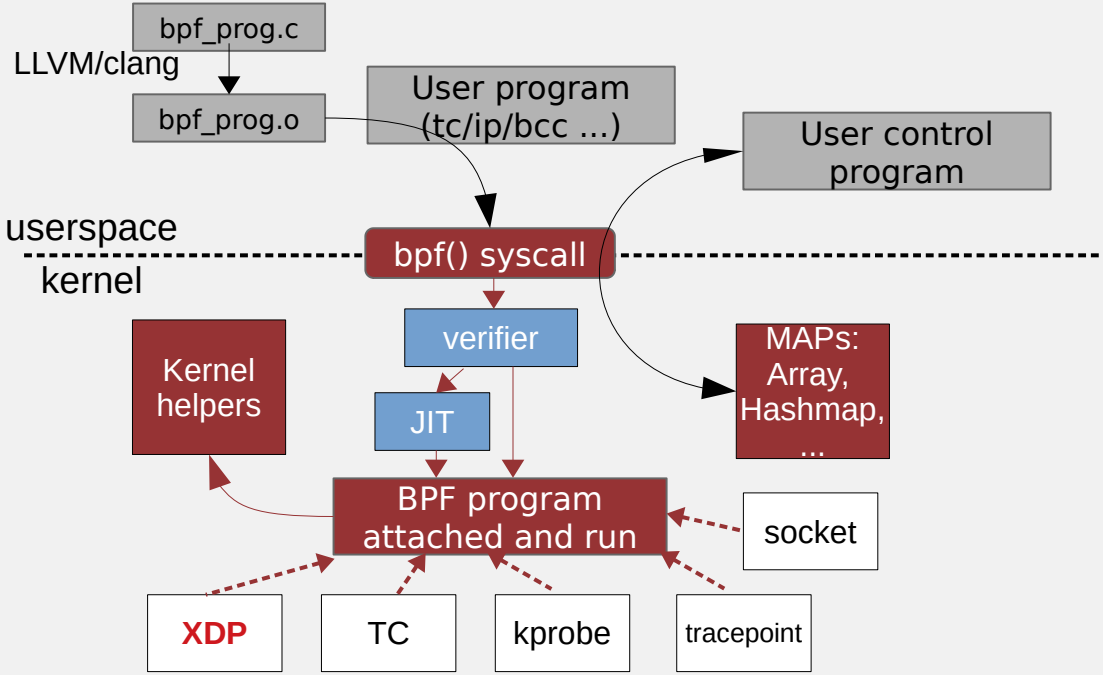
- Efficiency:
  - Slower than userspace datapath or VF
  - Only get 10% of userspace if measured by PPS
  - No fundamental barrier but why?
- Flexibility:
  - New features were added slowly
    - Developing kernel module is hard
    - Need new kernel/qemu/host to get new feature
  - Mew features just new new firmware (virtual)

eBPF introduction

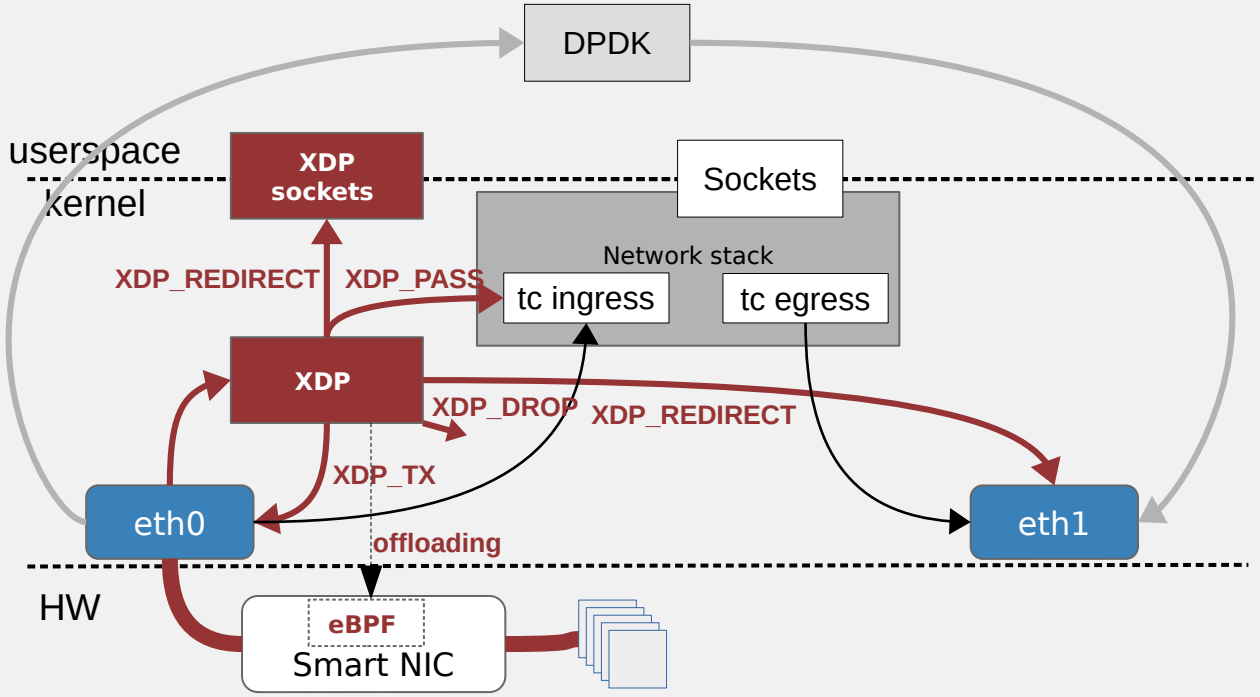
- *Generic, efficient, secure in-kernel (Linux) virtual machine. Programs are injected and attached in the kernel, event-based.*
- extend BPF
  - Evolution from classical BPF, assembly-like, interpreter
  - Effective: more registers and instructions, larger stack
  - Read or write access to context (packets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

```
0: (79) r1 = *(u64 *)(r1 +8)
1: (7b) *(u64 *)(r10 -8) = r1
2: (b7) r1 = 1
3: (7b) *(u64 *)(r10 -16) = r1
4: (18) r1 =
0xffff8801a6098a00
6: (bf) r2 = r10
7: (07) r2 += -8
8: (85) call
bpf_map_lookup_elem#1
9: (15) if r0 == 0x0 goto
pc+3
```

eBPF introduction (cont)



XDP – eXpressed DataPath

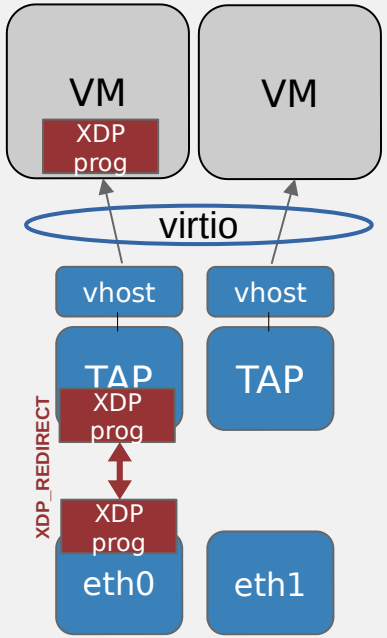


XDP – Why it was efficient and flexible?

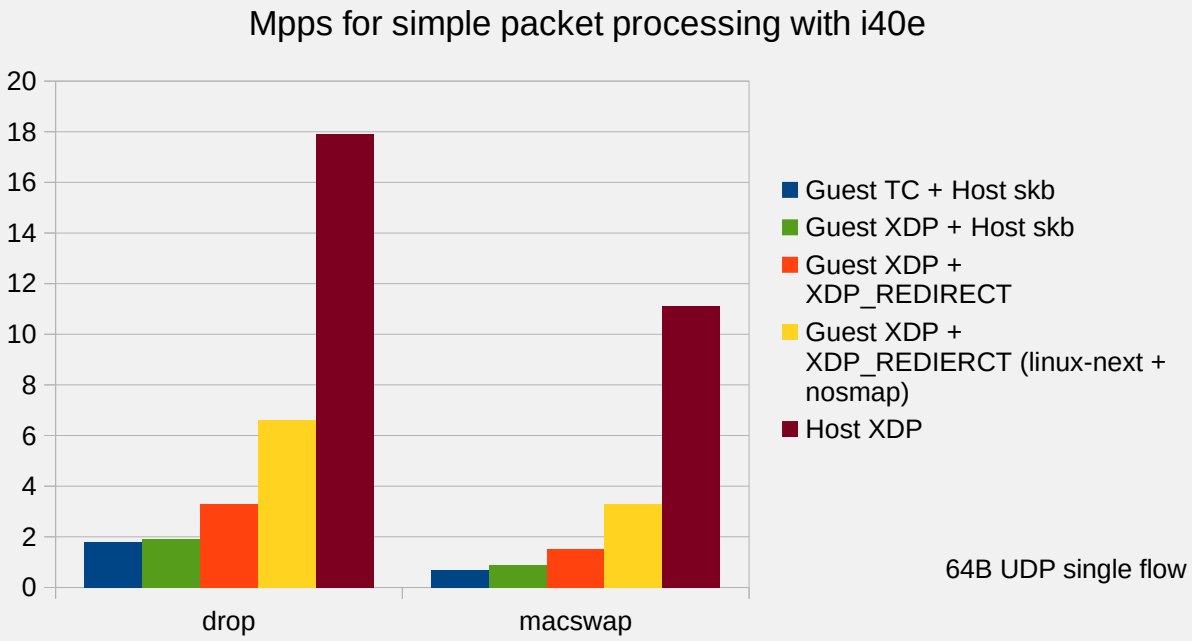
- Efficiency:
  - Earliest point: before networking stack
  - Lightweight metadata
  - Driver specific optimization
    - Simple assumption: e.g page per frame
    - Page recycling: either vendor specific or through page pool
    - Batching: devmap
  - Offloading
- Flexible:
  - Co-operate with exist kernel networking stack
    - Management, configuration, debugging, visibility, mature protocol stack
  - Separation policy (either in userspace or well defined exist in kernel) from mechanism (datapath)
  - Generic mode fallback

How does XDP can help

- Virtio-net XDP support accelerates guest datapath
- TAP XDP support processes packets early
- Redirect XDP frames between TAP and another XDP capable NIC to accelerate host datapath



Performance



Advanced Features

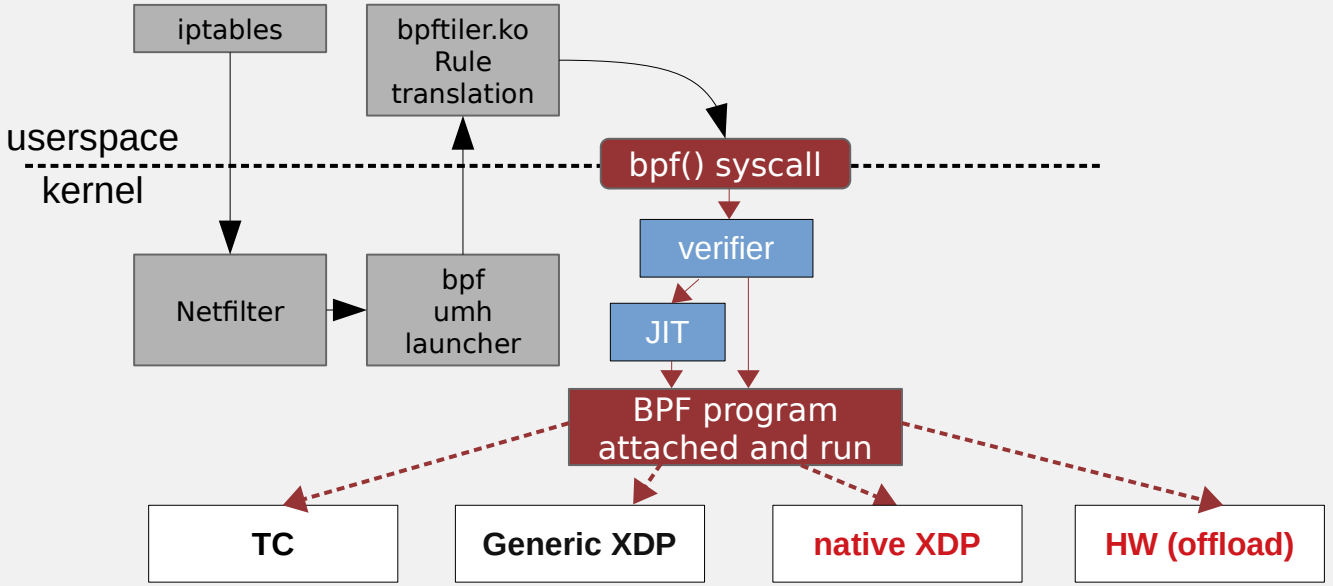
- bpfilter
- XDP offload
- XDP for stacked device
- OVS XDP datapath
- AF_XDP for VM
- eBPF and vhost

bpfilter

- eBPF based backend for iptables
- translate rules of iptables to eBPF and attach to XDP (native, generic or offload)
- bpfilter.ko (to reduce the attack surface)
  - ELF file running in userspace
  - Based on user mode helpers (UMH)
  - Shipped and built from kernel tree, work with modprobe,modinfo
  - Special thread
- Only skeleton merged, main logic is RFC

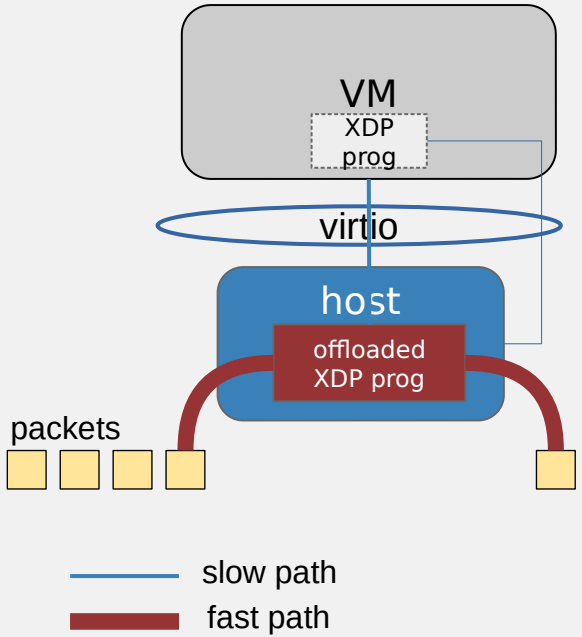
bpfilter internals

JIT on major archs, offload,
verifier, transparent to admin,
Write rules in C, ...

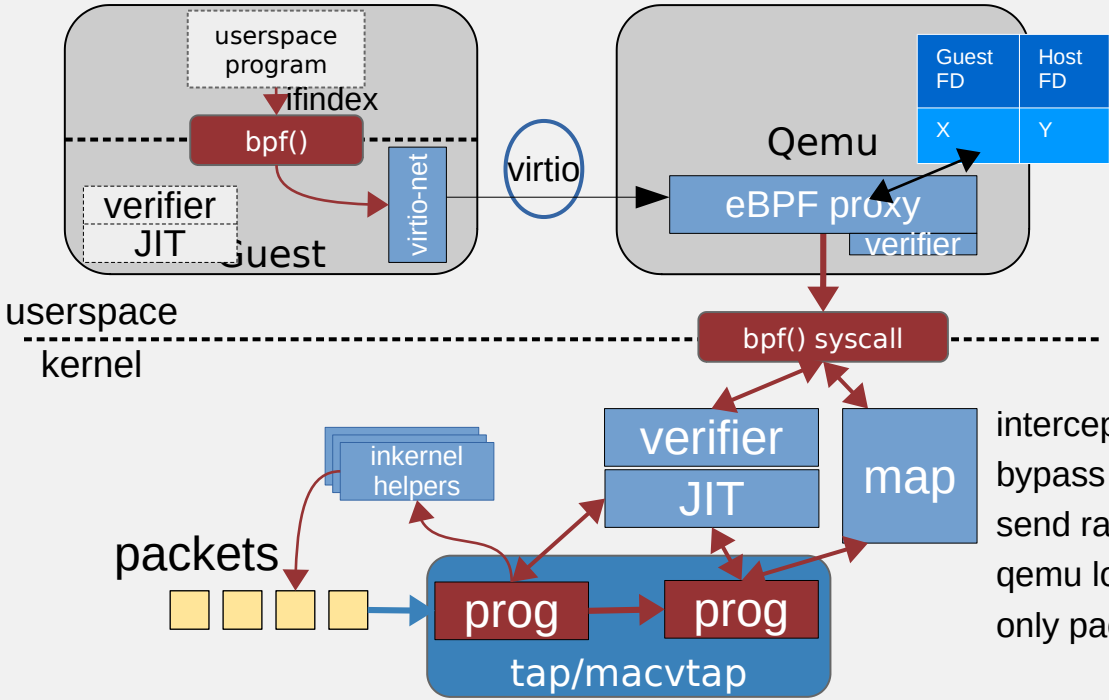


Offload XDP to host?

- No virtualization overhead
- No virtio overhead
- Packet does not need to enter guest if it could be handled by eBPF as fast path ! No datacopy in this path.
- XDP_PASS as a fallback to slowpath for the packets can not be dealt with eBPF/XDP
- Further offload to hardware (macvtap)

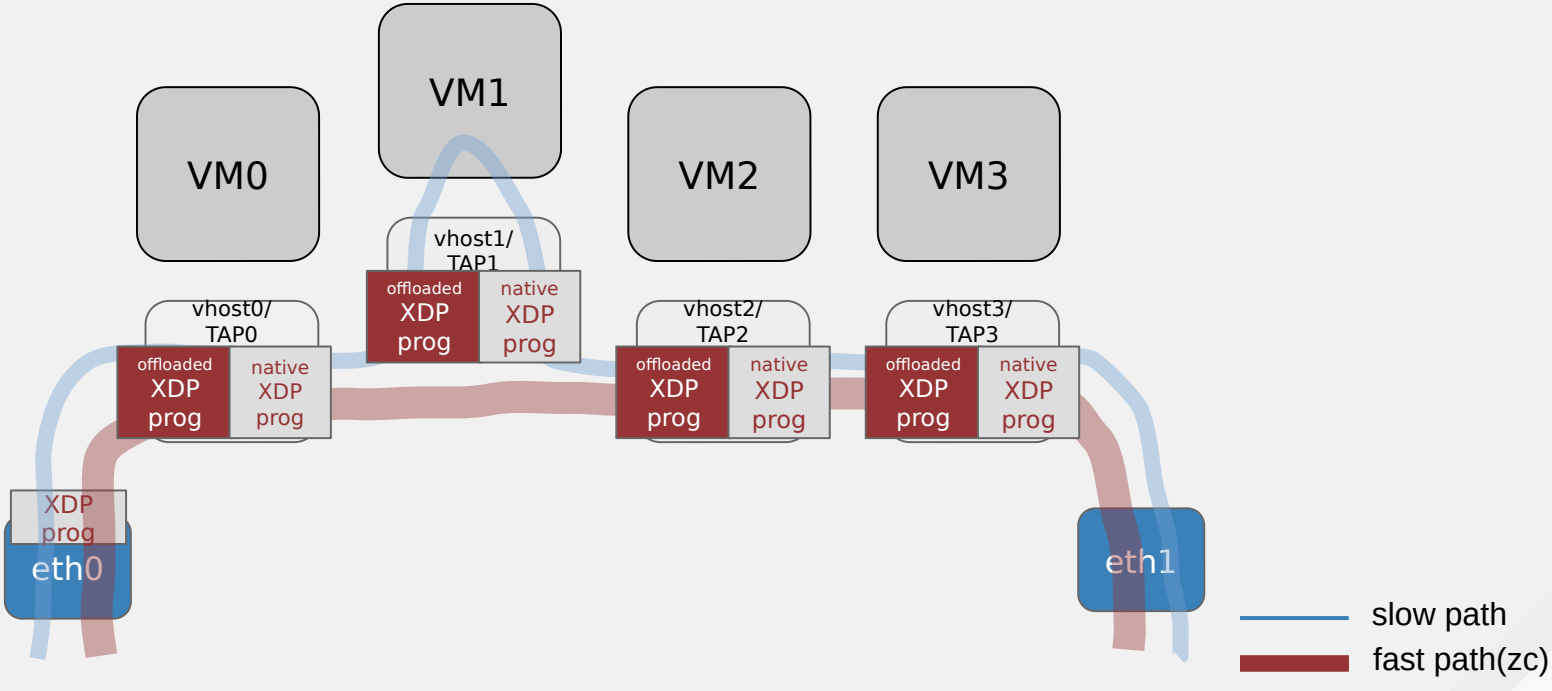


eBPF transport through virtio

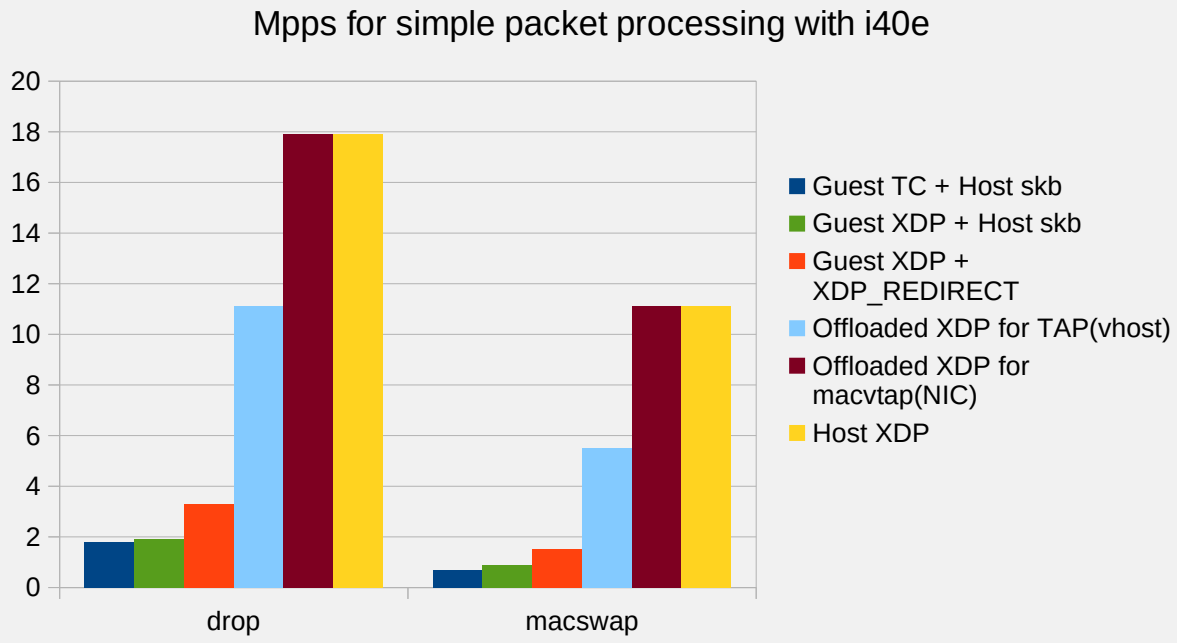


intercept bpf() through offload ops
bypass guest JIT/verifier
send raw bytecode to Qemu
qemu loads it on host as a proxy
only packet manipulation helpers

Service chaining

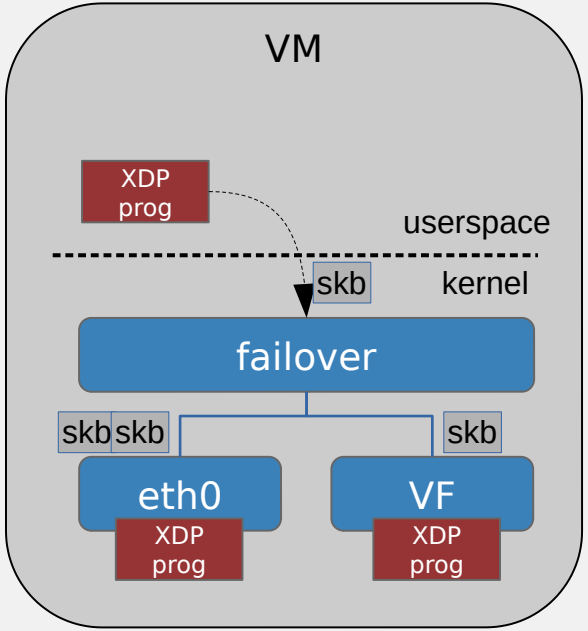


POC performance

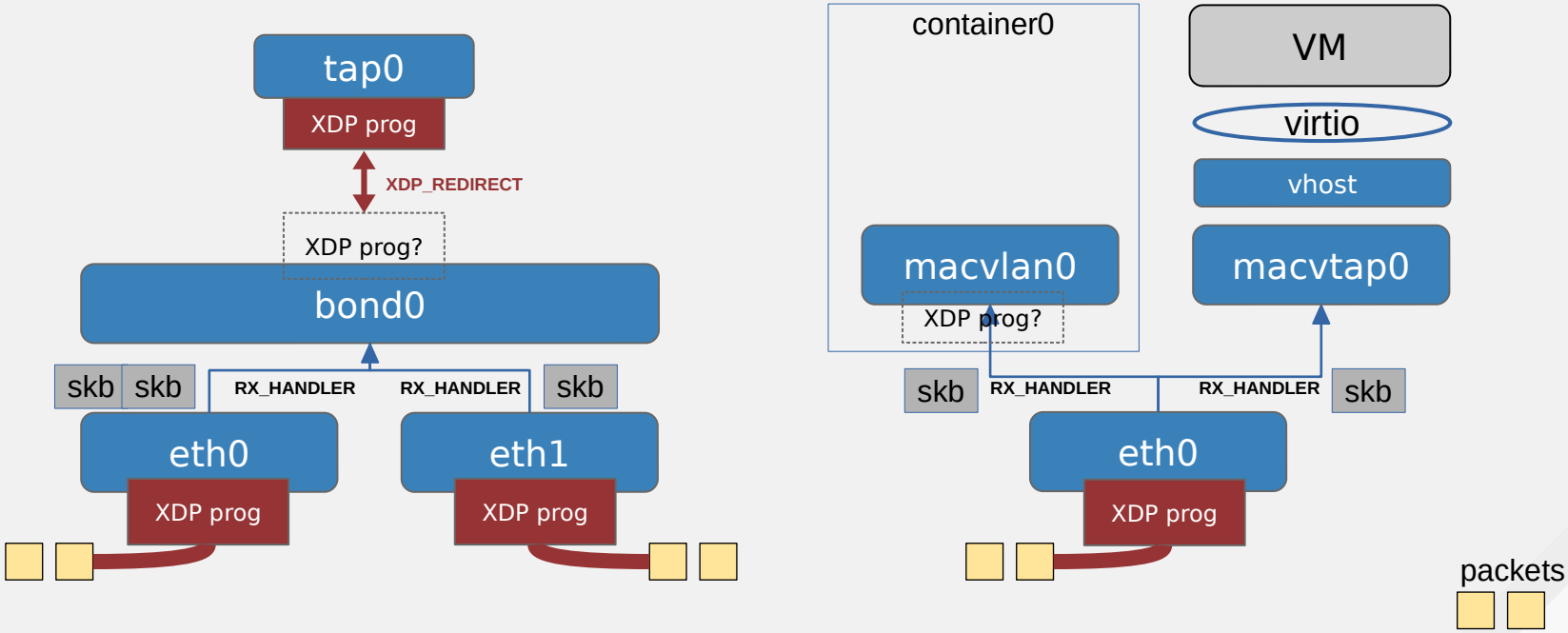


XDP for stacked device

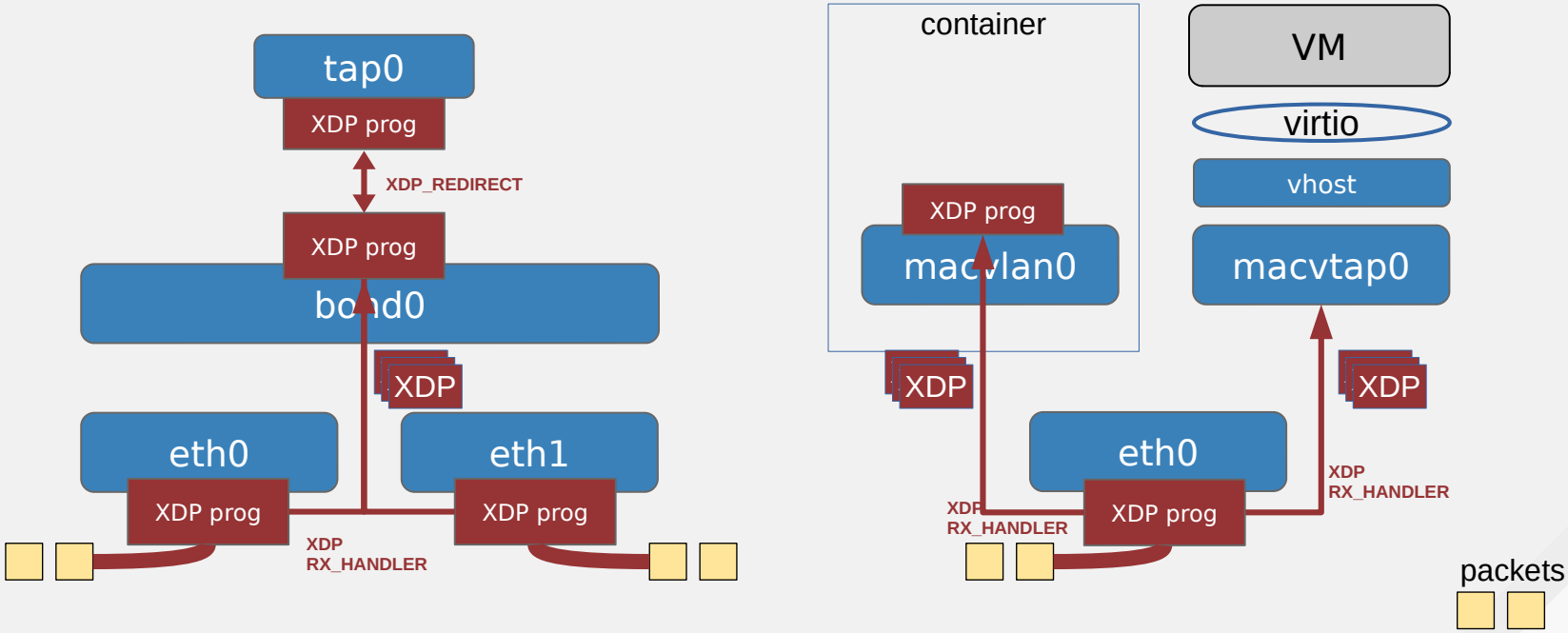
- Stacked device
  - The virtual device that is based on the function of lower device: bond, team, macvlan, bridge, OVS, failover, etc
  - Implemented through skb based rx handler
- Problem:
  - native XDP can not run on such device (but XDP generic)
  - But production environment use them heavily
  - Userspace topology logic?



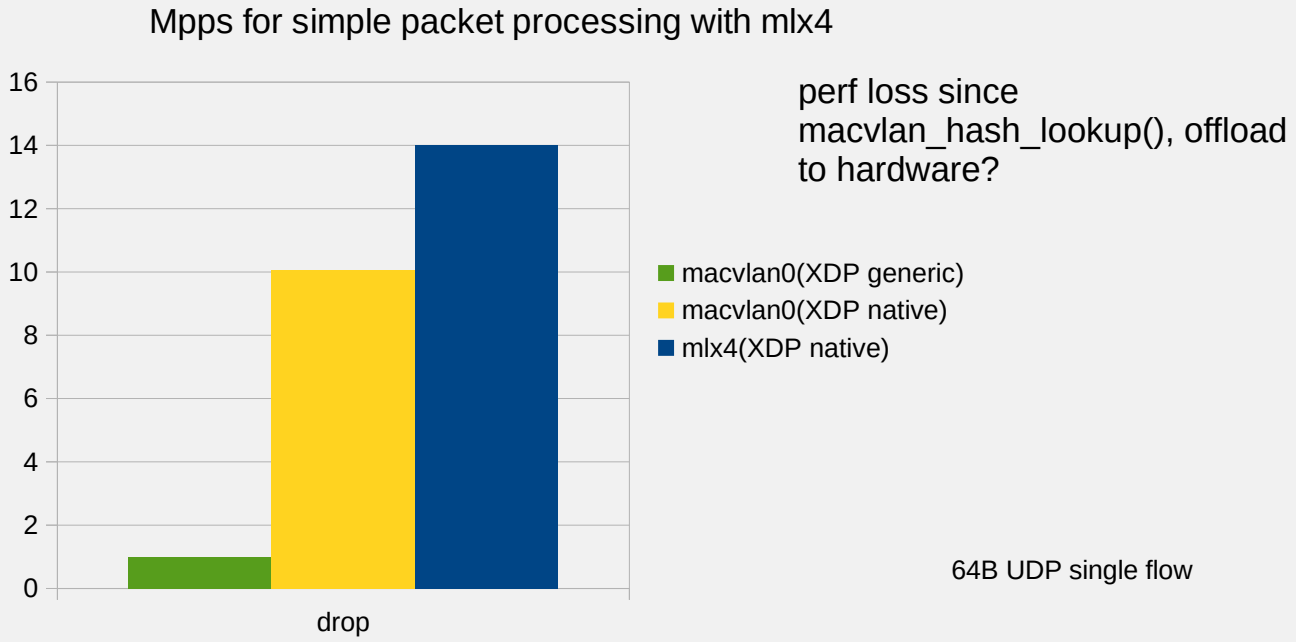
XDP for stacked device (example)



XDP rx handler



POC Performance

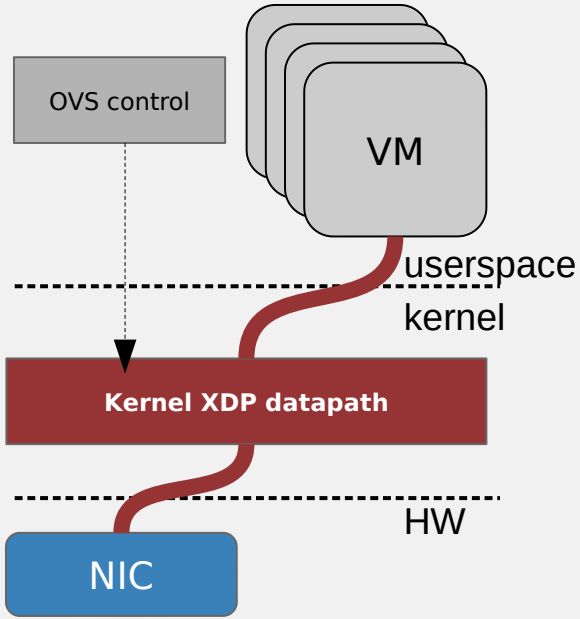


perf loss since macvlan_hash_lookup(), offload to hardware?

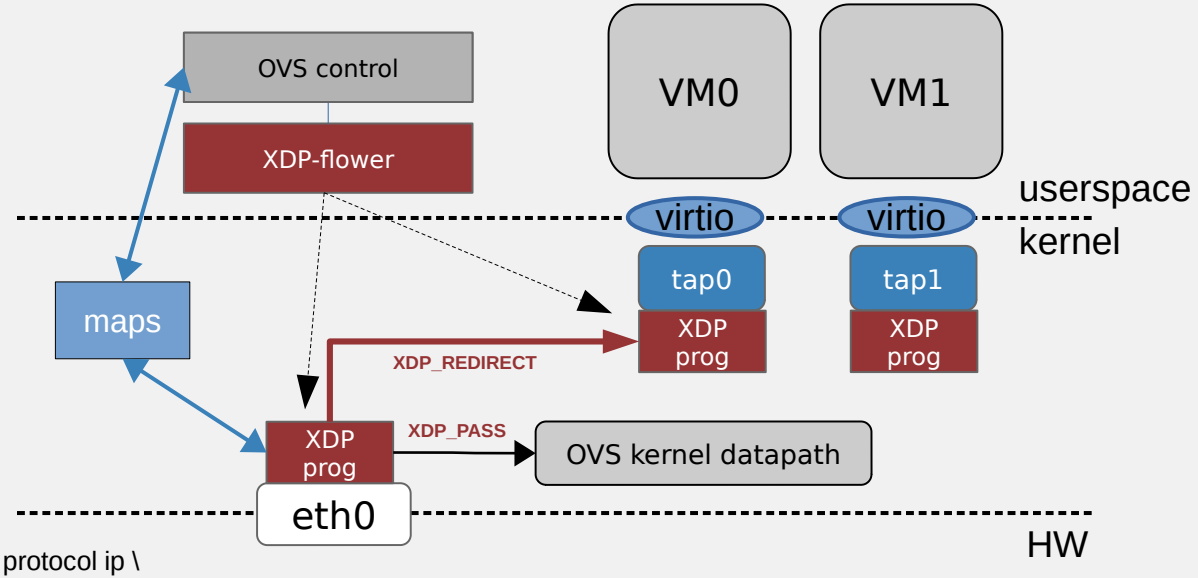
64B UDP single flow

OVS XDP datapath

- Inspired by OVS TC flower datapath:
- Implement TC flower logic through XDP: tc-xdp ?
- OVS control load appropriate XDP program to the interface, or update the action through maps
- Native XDP for acceleration
- XDP generic for fallback
- Can do things that is not easy for hardware offload: e.g conntrack
- Limitation: match/action chaining



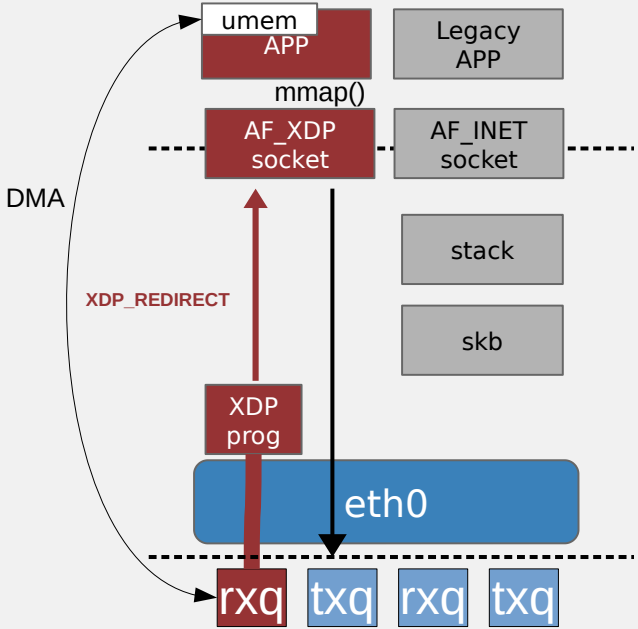
OVS XDP datapath



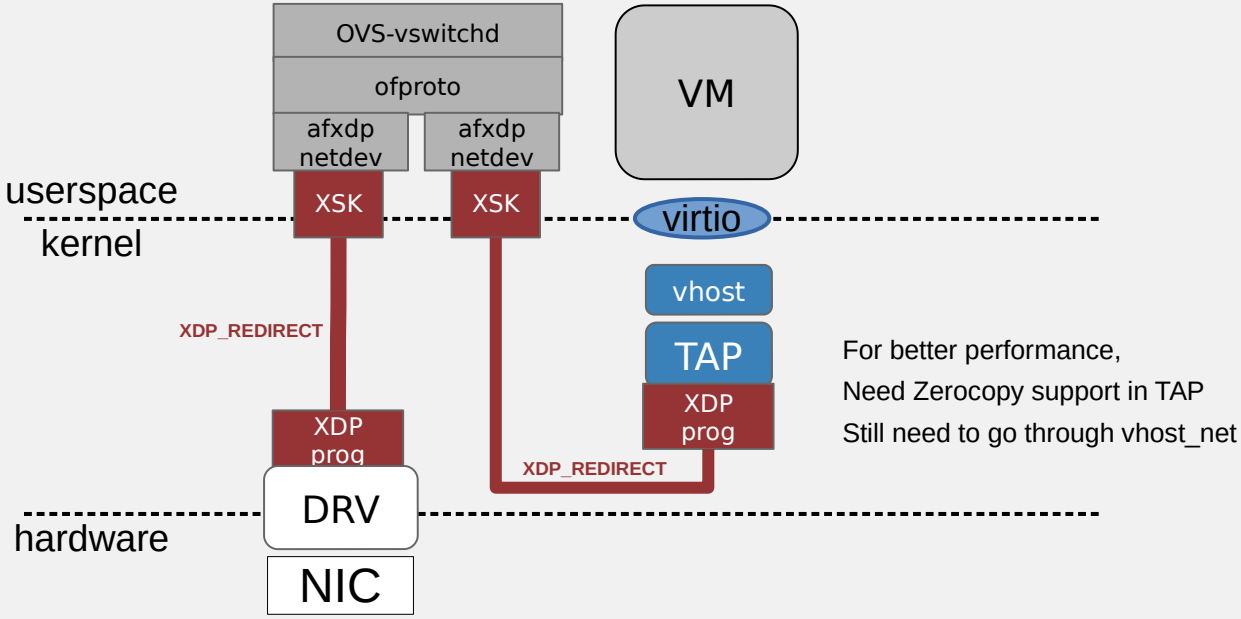

```
# xdp-flower add dev eth0 protocol ip \
   skip_generic dst_mac e4:11:22:11:4a:51 src_mac e4:11:22:11:4a:50 \
   action mirred egress redirect dev tap0
```

AF_XDP (XSK)

- Evolved from AF_PACKET but based on XDP, up to (20x ?) compares to AF_PACKET
- Optimized ring layout
  - ideas come from virtio 1.1
  - unify?
- Redirect XDP frames to socket directly
- Socket were bound to specific queue
- Two modes:
  - Zerocopy (driver/vendor support)
  - Generic
- Limitation: umem, zc (PIN), packet size limitation, non zerocopy perf is very poor, metadata is too simple



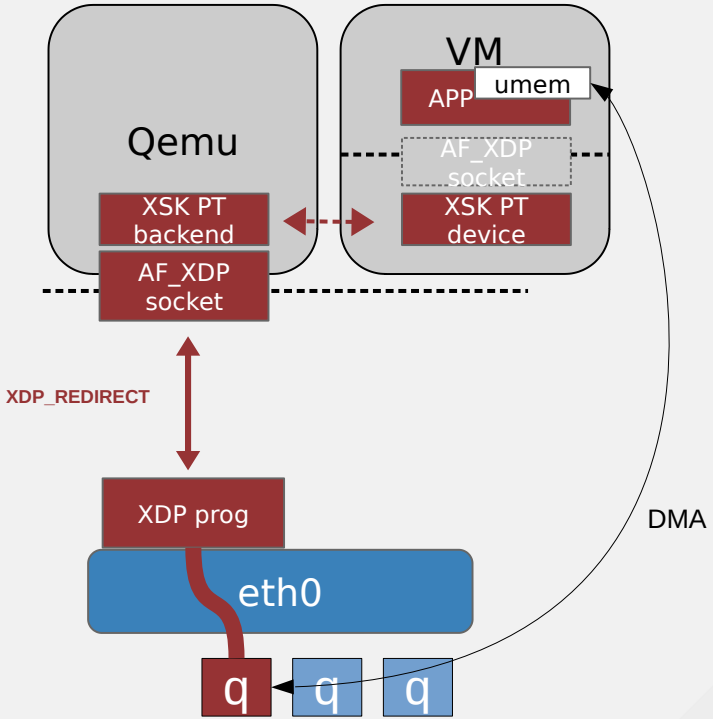
OVS AF_XDP datapath



For better performance,
Need Zerocopy support in TAP
Still need to go through vhost_net

AF_XDP passthrough

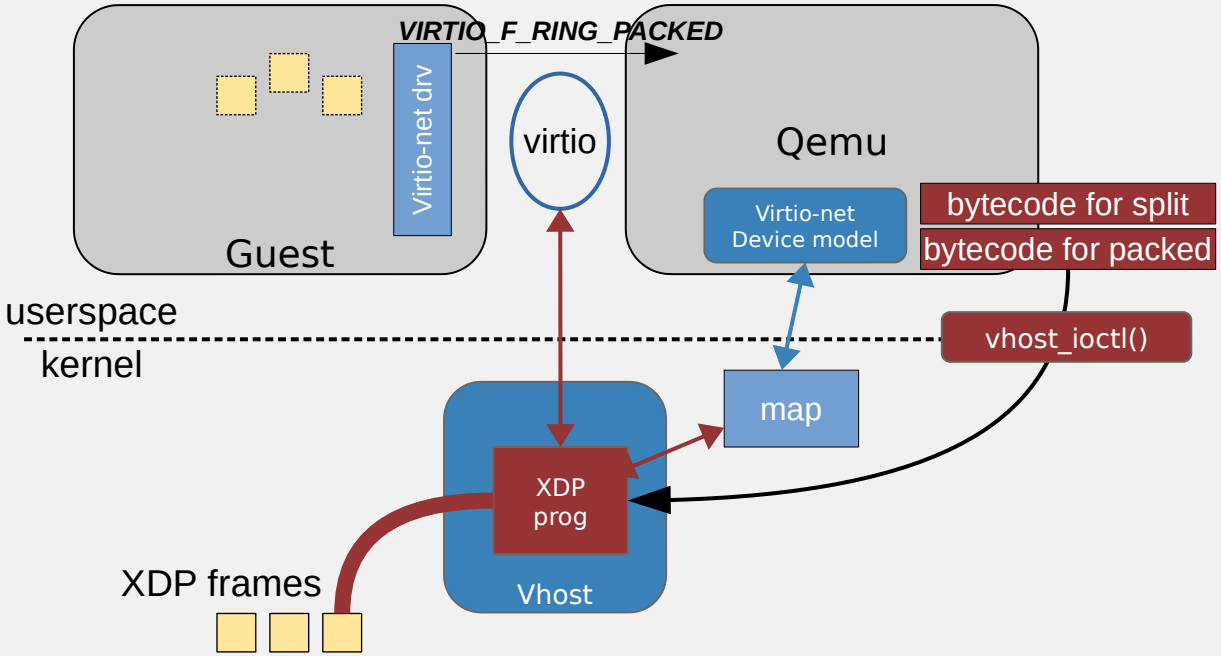
- A new kind of network device in guest – XSK PT(passthrough) device
  - When bind to XSK, backend can setup AF_XDP socket on host
  - Guest can drive AF_XDP ring on host
  - Inspired by netmap passthrough
- Guest APP still uses AF_XDP ring layout and API
- Host AF_XDP speed were preserved
- XSK PT device were only used for:
  - Configuration
  - Control: start/stop
  - Synchronization: kick/interrupt



eBPF based vhost datapath

- Problem to solve:
  - deal with different ring layout is painful
  - bug fixes need restart datapath
  - POC for new ring layout
- How about decouple the ring layout specific code out of kernel through eBPF
  - Descriptor translation and manipulation being done through eBPF program
  - New ring layout was simply implemented by attaching eBPF program, no new code in kernel
- Challenges:
  - eBPF performance
  - Batching

eBPF based vhost datapath



Status

- bpfilter: only skeleton
- Virtio-net XDP offload: POC
- XDP for stacked device: generic path, native path RFC
- OVS XDP datapath: WIP
- OVS AF_XDP datapath: RFC
- AF_XDP (zerocopy) for TAP: RFC
- AF_XDP passthrough: planning
- eBPF base vhost datapath: planning
- Libvirt support: planning

Reference

- bpfilter: https://lwn.net/Articles/747504/
- virtio-net XDP offload: https://www.netdevconf.org/0x13/session.html?xdp-offload-with-virtio-net
- XDP for stacked device: https://lwn.net/Articles/762464/
- AF_XDP: Documentation/networking/af_xdp.rst
- OVS AF_XDP: https://mail.openvswitch.org/pipermail/ovs-dev/2019-April/358373.html
- Netmap passthrough: https://conferences.sigcomm.org/sigcomm/2017/files/tutorial-netmap/02-virtualization.pdf

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