Low-Latency, Deterministic Networking with Standard Linux using XDP Sockets

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$ whoami

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Linux kernel networking hacker @ Intel
AF_XDP and RISC-V BPF JIT maintainer
XDP sockets?
The big picture

- Network hardware
- Linux kernel
- BPF maps
- XDP
- Network stack
- Device driver
- Queueing and forwarding
- TC BPF
- TCP/UDP
- AF_INET
- AF_PACKET
- Applications
- VMs and containers
- Userspace
- Control plane
- AF_XDP
- Virtual devices
- Build sk_buff
- Drop
- IP layer
- BPF maps

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Good ol’ sockets

/* Cooked INET sockets */
fd = socket(PF_INET, SOCK_DGRAM, 0);
bind(fd, addr);
for (;;)
    receive_packet(fd, buff);
    send_packet(fd, buff);

/* Raw XDP sockets */
fd = socket(PF_XDP, SOCK_RAW, 0);
/* mmap/posix_memalign/malloc */
pktbuffs = alloc_buffs();
setsockopt(fd, SOL_XDP,
    XDP_MEM_REG, pktbuffs);
setsockopt(fd, SOL_XDP,
    XDP_{RX,TX,FILL,COMPLETE}_RING,
    ring_size);
/* map kernel rings */
{rx,tx,f,c}_ring = mmap(..., fd, ...);
bind(fd, {"eth0", qid});
for (;;)
    read_process_send_packets(fd);
Descriptors

```
$ grep -A 5 Rx/Tx\ descriptor include/uapi/linux/if_xdp.h
/* Rx/Tx descriptor */
struct xdp_desc {
    __u64 addr;
    __u32 len;
    __u32 options;
};
```
Rings, rings, and more rings

- **Rx**
  - *struct xdp_desc*
  - 4 entries
  - *consumer (user)*
  - *producer (kernel)*

- **Tx**
  - *struct xdp_desc*
  - *consumer (kernel)*
  - *producer (user)*

- **Fill**
  - u64
  - *consumer (kernel)*
  - *producer (user)*

- **Completion**
  - u64
  - *consumer (user)*
  - *producer (kernel)*
 Syscalls
Pitfalls

Warning
Risk of Falling
Docs and Samples

Docs: Documentation/networking/af_xdp.rst
Samples: samples/bpf/xdpsock_user.c
libbpf: tools/lib/bpf/*
Softirqs, NAPI, and SPSC rings
XDP modes

[Image of a rabbit and a turtle]
AF_XDP zero-copy driver support

/* from include/linux/netdevice.h */
enum bpf_netdev_command {
    ...
    XDP_SETUP_XSK_UMEM,
};
struct netdev_bpf {
    enum bpf_netdev_command command;
    union {
        ...
        /* XDP_SETUP_XSK_UMEM */
        struct {
            struct xdp_umem *umem;
            u16 queue_id;
        } xsk;
    }
};
...
int (*ndo_bpf)(struct net_device *dev, struct netdev_bpf *bpf);
int (*ndo_xdp_xmit)(struct net_device *dev, int n, struct xdp_frame **xdp,
    u32 flags);
int (*ndo_xsk_wakeup)(struct net_device *dev, u32 queue_id, u32 flags);
net/xdp/* kernel/bpf/xskmap.c
drivers/net/ethernet/intel/i40e/*
drivers/net/ethernet/intel/ice/*
drivers/net/ethernet/intel/ixgbe/*
drivers/net/ethernet/mellanox/mlx5/*
...soon Broadcom
Test setup

Linux pre-5.5 (bpf-next) non-preemptive ‘mitigations=on’
Intel Xeon Gold 6154 CPU @ 3.00GHz (Skylake)
Intel XL710 40GbE (i40e) NIC

1 Rx HW queue, 1 Tx HW queue
 “two cores”: kernel and userland processing on different cores
 “one core”: kernel and userland processing on same core
IXIA packet load generator
Latency is end-to-end, measured at load generator
AF_PACKETv3 vs AF_XDP, throughput, two cores

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AF_PACKETv3 vs AF_XDP, throughput, one core

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AF_PACKETv3 vs AF_XDP, e2e latency, normal

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