The eXpress Data Path

Fast Programmable Packet Processing in the Operating System Kernel

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Outline

- Challenges with high-speed packet processing
- XDP design
- Performance evaluation
- Example applications
- Conclusion

High-Speed Packet Processing is Hard

- Millions of packets per second
  - 10 Gbps: 14.8Mpps / 67.5 ns per packet
  - 100 Gbps: 148Mpps / 6.75 ns per packet

Operating system stacks are too slow to keep up

Previous solutions

- Kernel bypass - move hardware to userspace
  - High performance, but hard to integrate with the system
- Fast-path frame-to-userspace solutions (Netmap etc)
  - Kernel in control, but lower performance
- Custom in-kernel modules (e.g., Open vSwitch)
  - Avoids context switching, but is a maintenance burden

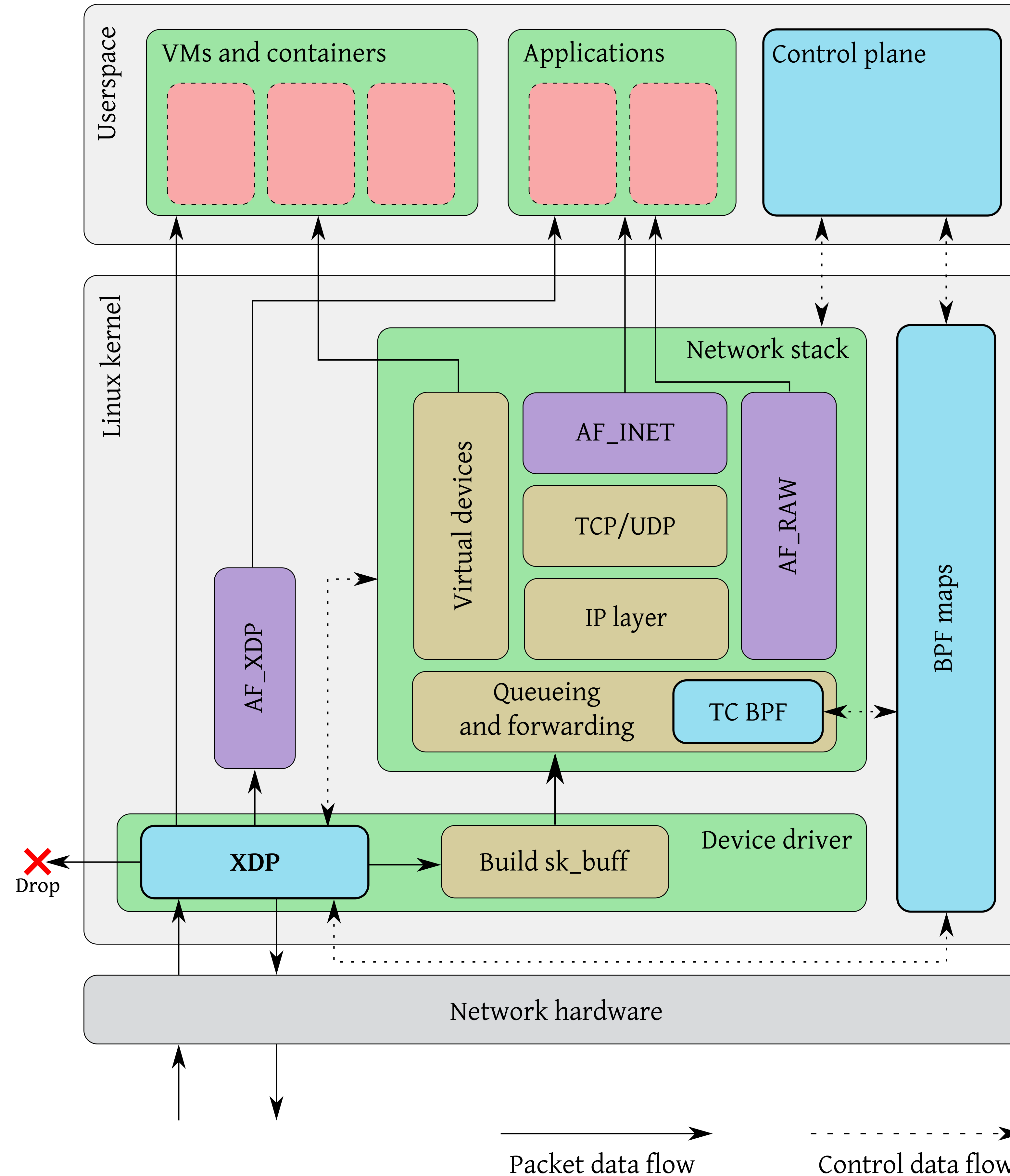
XDP: Move processing into the kernel instead

XDP: Benefits

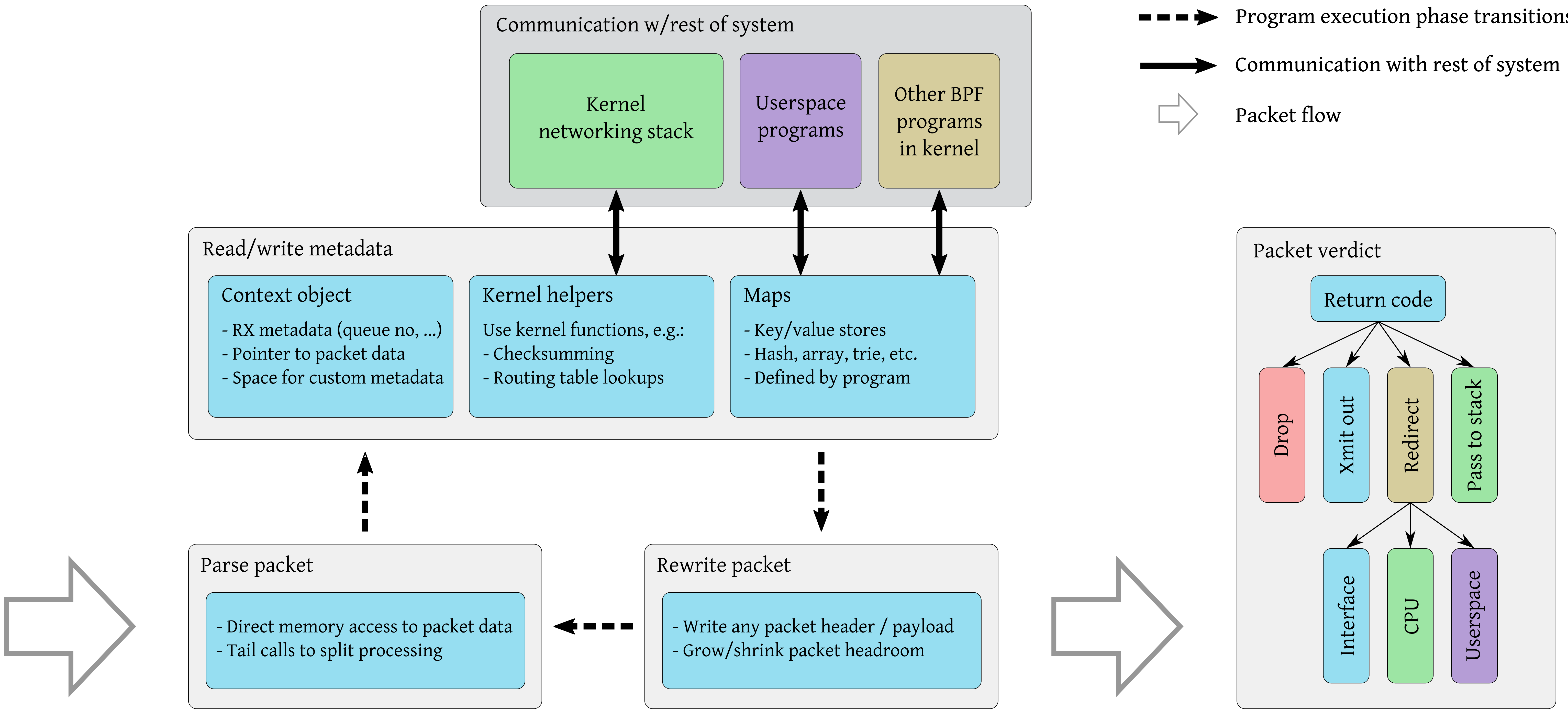
- Integrated with the kernel; driver retains control of hardware
- Can selectively use kernel stack features
- Stable API
- No packet re-injection needed
- Transparent to the host
- Dynamically re-programmable
- Doesn’t need a full CPU core

XDP: Overall design

- The XDP driver hook
- The eBPF virtual machine
- BPF maps
- The eBPF verifier



XDP program flow



Example XDP program

```c
/* map used to count packets; key is IP protocol,
   value is pkt count */
struct bpf_map_def SEC("maps") rxcnt = {
        .type = BPF_MAP_TYPE_PERCPU_ARRAY,
        .key_size = sizeof(u32),
        .value_size = sizeof(long),
        .max_entries = 256,
};

/* swaps MAC addresses using direct packet data access */
static void swap_src_dst_mac(void *data)
{
        unsigned short *p = data;
        unsigned short dst[3];
        dst[0] = p[0];
        dst[1] = p[1];
        dst[2] = p[2];
        p[0]   = p[3];
        p[1]   = p[4];
        p[2]   = p[5];
        p[3]   = dst[0];
        p[4]   = dst[1];
        p[5]   = dst[2];
}

static int parse_ipv4(void *data, u64 nh_off, void *data_end)
{
        struct iphdr *iph = data + nh_off;
        if (iph + 1 > data_end)
                return 0;
        return iph->protocol;
}
```

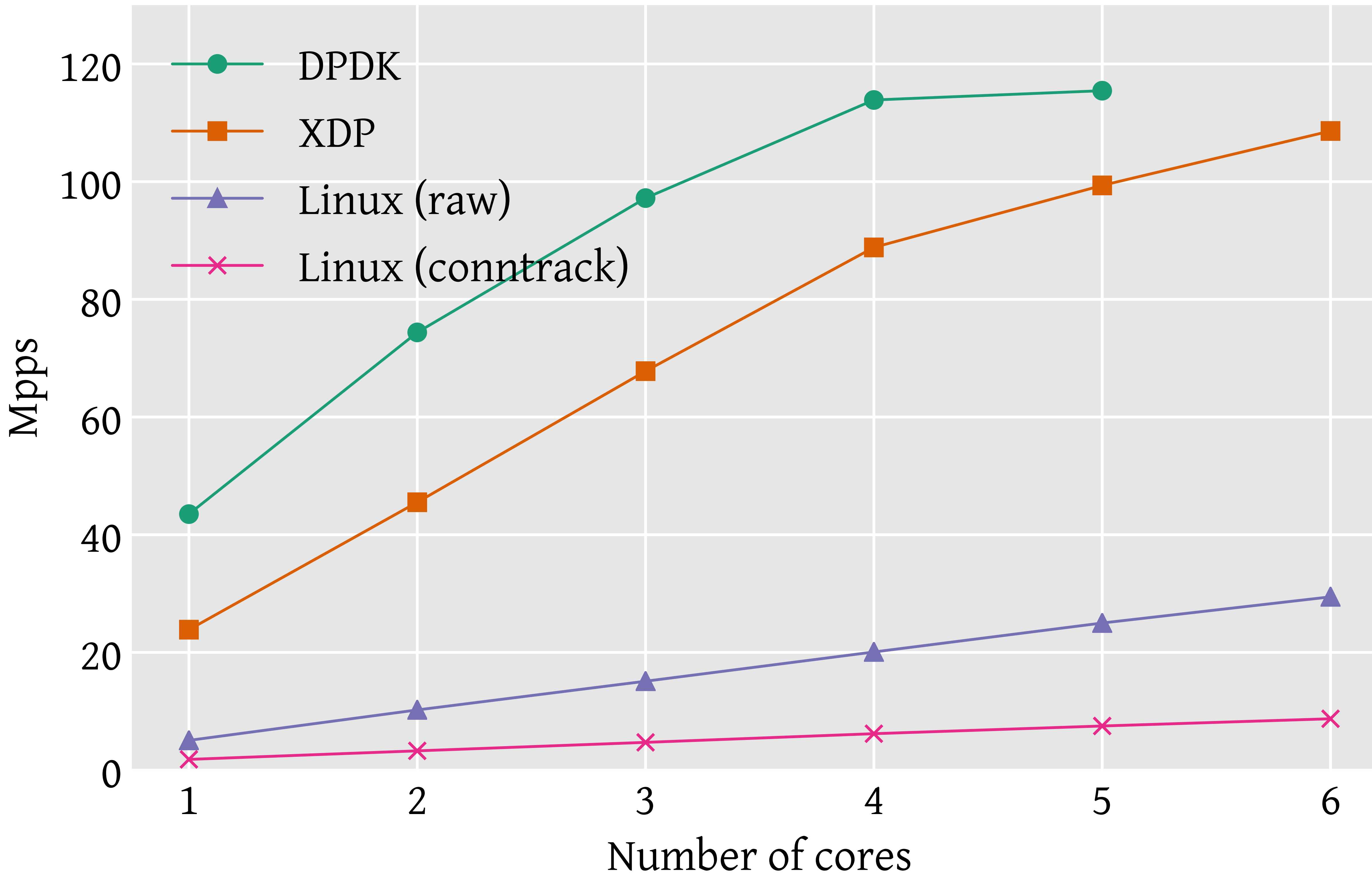
```c
SEC("xdp1") /* marks main eBPF program entry point */
int xdp_prog1(struct xdp_md *ctx)
{
        void *data_end = (void *)(long)ctx->data_end;
        void *data = (void *)(long)ctx->data;
        struct ethhdr *eth = data; int rc = XDP_DROP;
        long *value; u16 h_proto; u64 nh_off; u32 ipproto;

        nh_off = sizeof(*eth);
        if (data + nh_off > data_end)
                return rc;

        h_proto = eth->h_proto;

        /* check VLAN tag; could be repeated to support double-tagged VLAN */
        if (h_proto == htons(ETH_P_8021Q) || h_proto == htons(ETH_P_8021AD)) {
                struct vlan_hdr *vhdr;

                vhdr = data + nh_off;
                nh_off += sizeof(struct vlan_hdr);
                if (data + nh_off > data_end)
                        return rc;
                h_proto = vhdr->h_vlan_encapsulated_proto;
        }

        if (h_proto == htons(ETH_P_IP))
                ipproto = parse_ipv4(data, nh_off, data_end);
        else if (h_proto == htons(ETH_P_IPV6))
                ipproto = parse_ipv6(data, nh_off, data_end);
        else
                ipproto = 0;

        /* lookup map element for ip protocol, used for packet counter */
        value = bpf_map_lookup_elem(&rxcnt, &ipproto);
        if (value)
                *value += 1;

        /* swap MAC addrs for UDP packets, transmit out this interface */
        if (ipproto == IPPROTO_UDP) {
                swap_src_dst_mac(data);
                rc = XDP_TX;
        }
        return rc;
}
```

Performance benchmarks

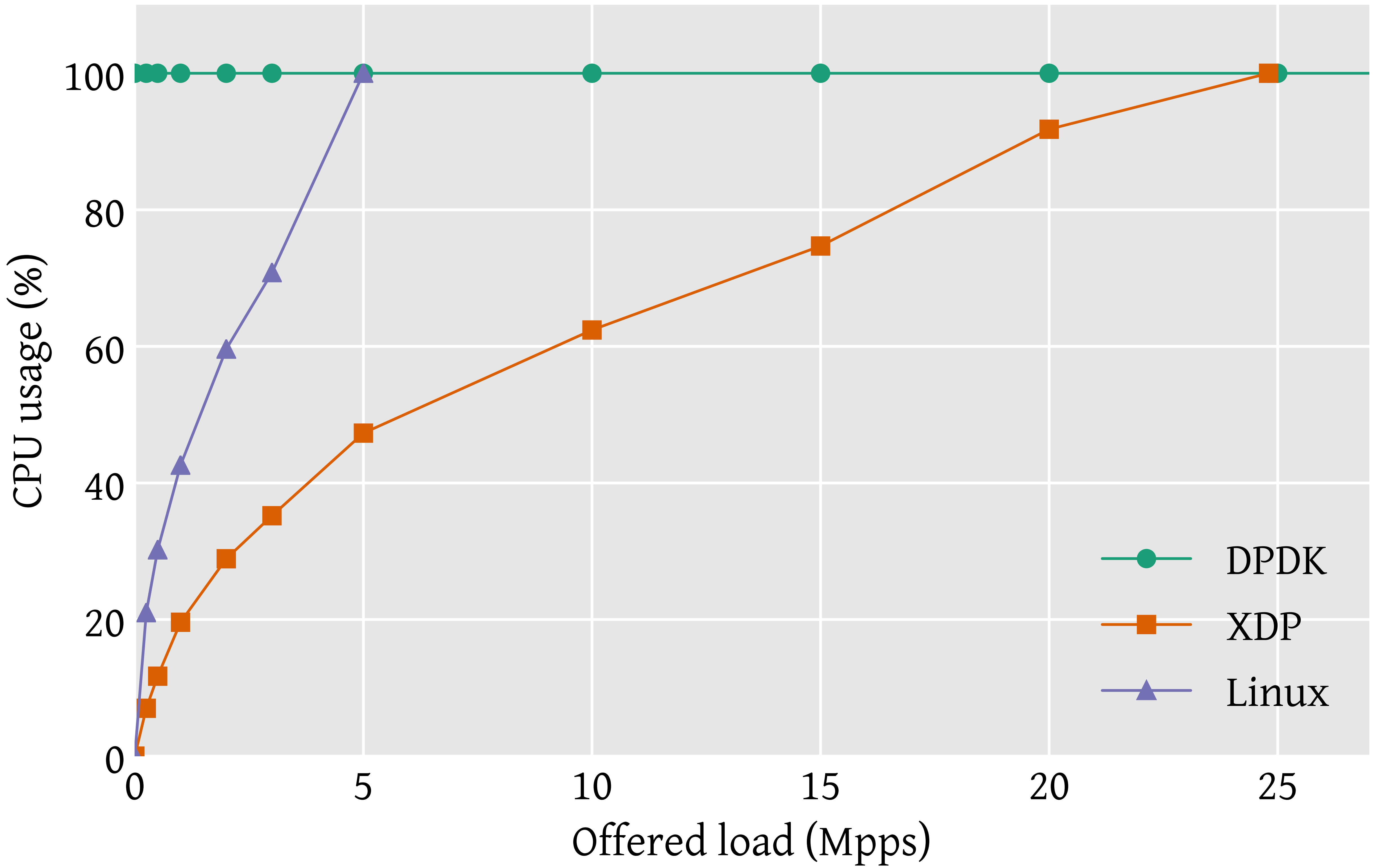
- Benchmark against DPDK
  - Establishes baseline performance
  - Simple tests
    - Packet drop performance
    - CPU usage
    - Packet forwarding performance

All tests are with 64 byte packets - measuring Packets Per Second (PPS).

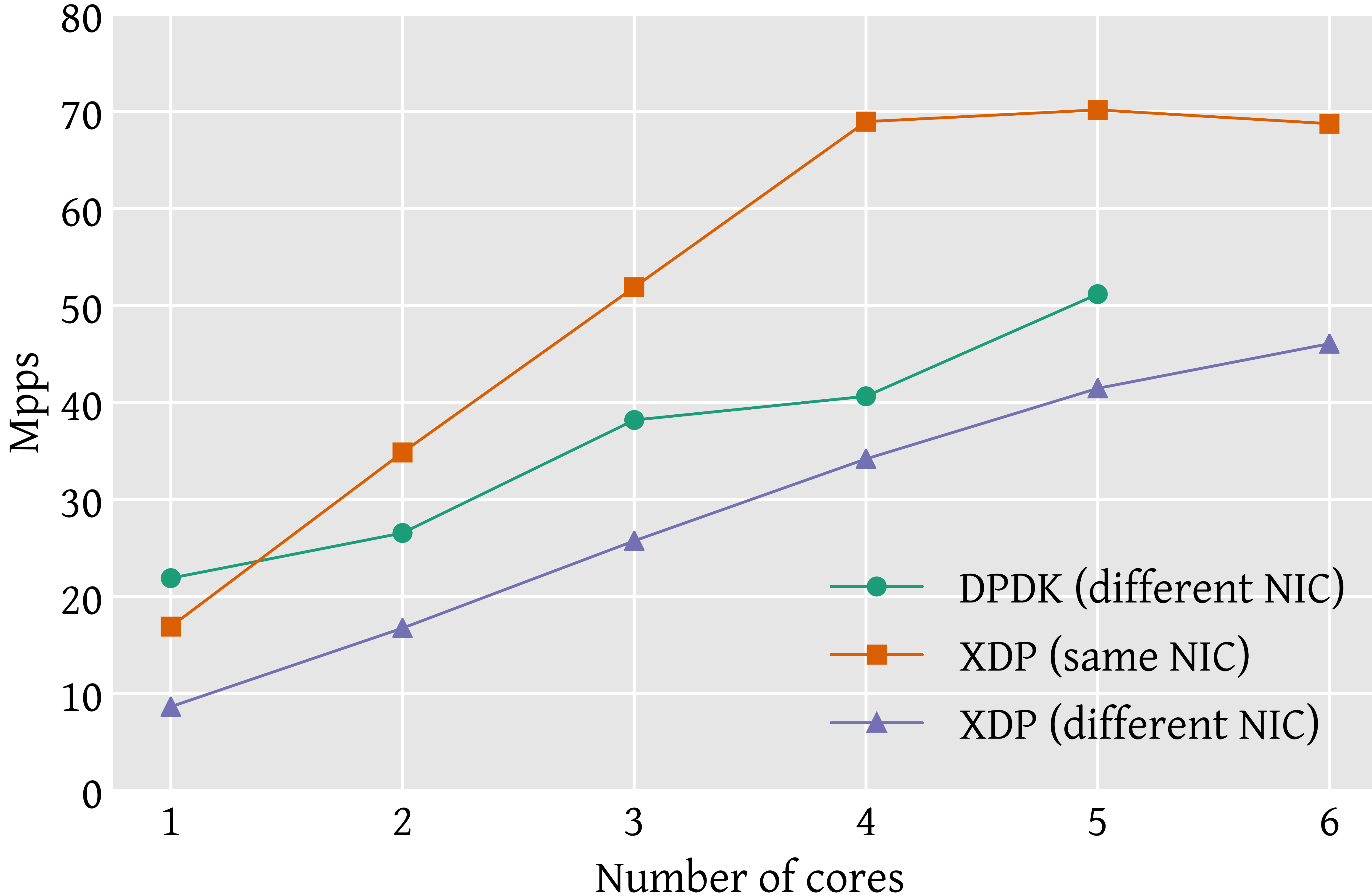
Packet drop performance



CPU usage in drop test



Packet forwarding throughput



Packet forwarding latency

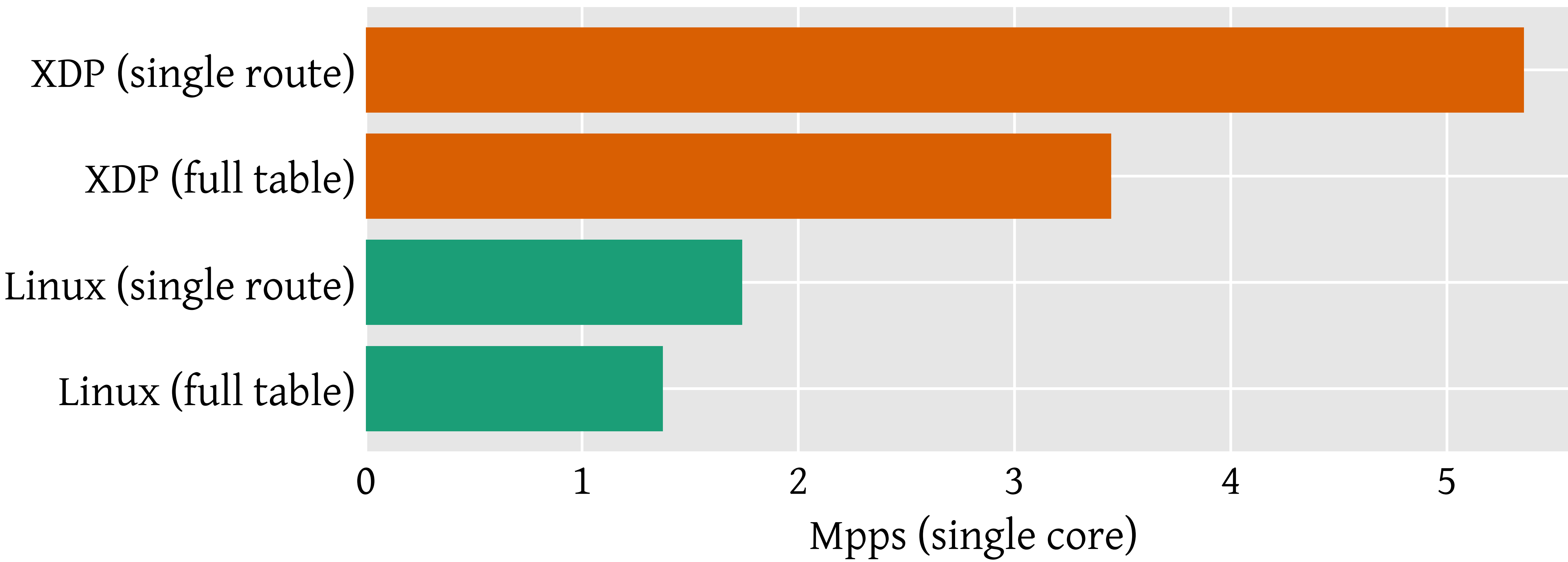
	Average		Maximum		$< 10\mu s$	
	100 pps	1 Mpps	100 pps	1 Mpps	100 pps	1 Mpps
XDP	$82\mu s$	$7\mu s$	$272\mu s$	$202\mu s$	0%	98.1%
DPDK	$2\mu s$	$3\mu s$	$161\mu s$	$189\mu s$	99.5%	99.0%

Application proof-of-concept

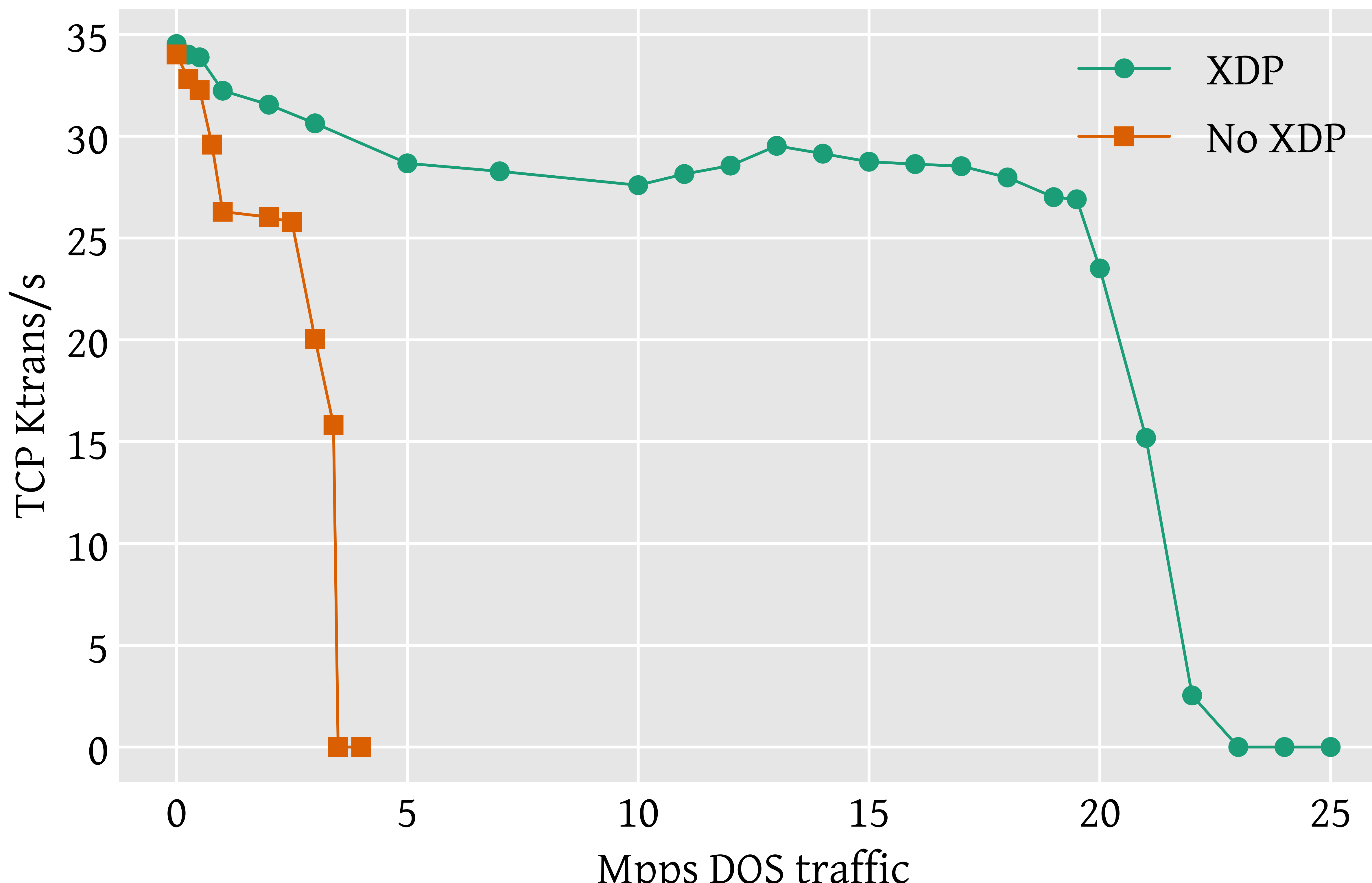
- Shows feasibility of three applications:
  - Software router
  - DDoS protection system
  - Layer-4 load balancer

Not a benchmark against state-of-the-art implementations

Software routing performance



DDoS protection



Load balancer performance

CPU Cores	1	2	3	4	5	6
XDP (Katran)	5.2	10.1	14.6	19.5	23.4	29.3
Linux (IPVS)	1.2	2.4	3.7	4.8	6.0	7.3

Based on the Katran load balancer (open sourced by Facebook).

Summary

XDP:

- Integrates programmable packet processing into the kernel
- Combines speed with flexibility
- Is supported by the Linux kernel community
- Is already used in high-profile production use cases

See https://github.com/tohojo/xdp-paper for details

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