이해력

XDP For the Rest of Us

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Motivation for this talk

- Follow Up on NetDev 2.1 tutorial/talk
  - Less time, focus on updates and new tools from XDP ecosystem
- Still motivated to:
  - Demystify XDP and eBPF
  - Help you understand and consume this new technology

What will you learn?

What do *you* get out of this presentation

What will you learn?

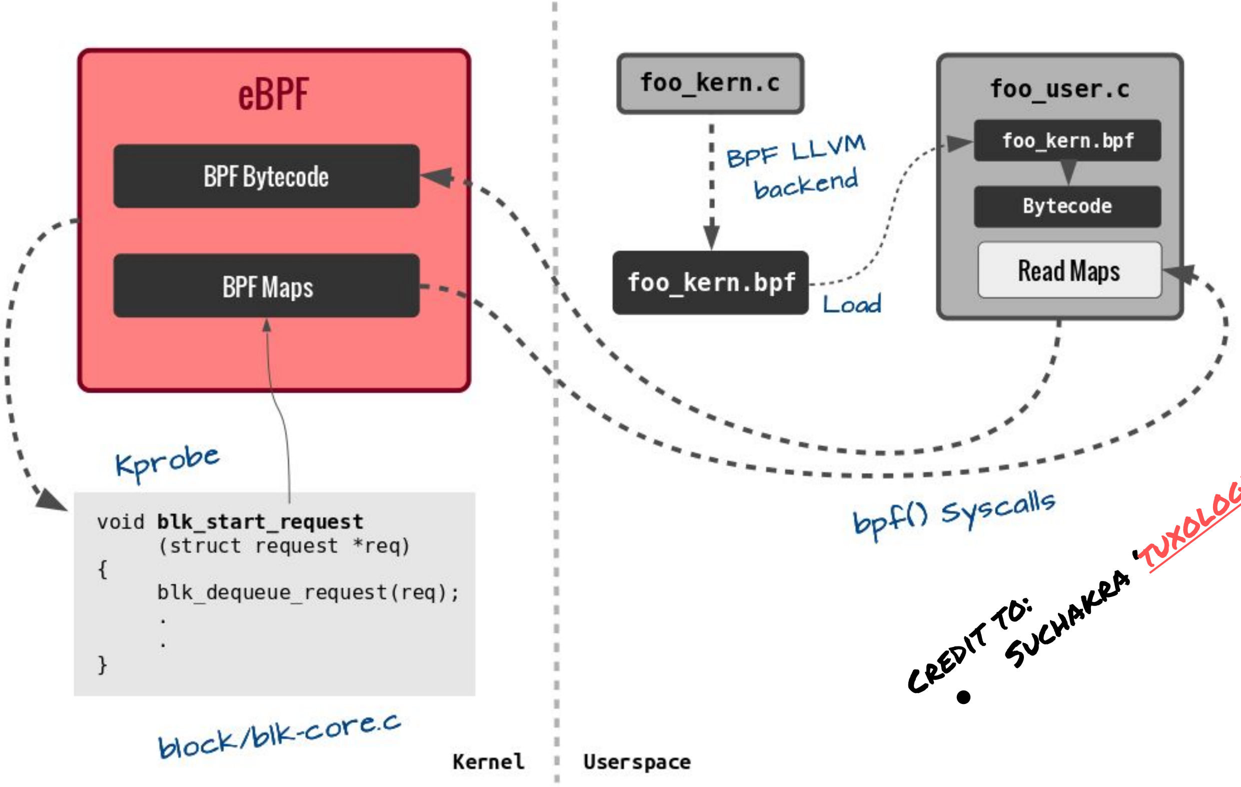
- Bring you up-to-date with the XDP ecosystem
  - highlight subset of recent changes
- We want you in the driver's seat
  - fast, user-programmable networking
- Teach you about some new tools
- Spark new ideas for XDP+BPF use-cases
  - Going beyond DDoS and (bouncing) Load-Balancer use-cases

What will you NOT learn!

- Getting Started with eBPF and XDP
    - Is covered in Netdev 2.1 talk, like:
        - Compiler toolchain LLVM / clang
        - Compiling `kernel/samples/bpf`
            - Source file split `foo_kern.c` + `foo_user.c`
            - ELF-object containing map-definitions,
                - How handled by BPF loader code
                - Invoking appropriate BPF-syscalls

Want to understand drawing?

- Watch Netdev 2.1 talk on YouTube ;-)



```
void blk_start_request
     (struct request *req)
{
     blk_dequeue_request(req);
     .
     .
}
```

CREDIT TO:
- SUCHAKRA 'TUXOLOGY' SHARMA

The XDP technology

A new era with user-programmable networking

Framing: The XDP technology

- XDP a new, lower layer in Linux network stack
  - Programmable hook in drivers can run before allocating full SKB
  - New building block for Linux kernel networking
- Operate at same "layer" as bypass solutions (like DPDK)
  - Operate at same speeds as bypass solutions (low number of CPU instructions per packet)
  - Raw-data access to (Ethernet) frame (before SKB exists)
  - An in-kernel fast-path (XDP core in Linux kernel v4.8)
- The XDP programming language is eBPF
  - eBPF is bigger than XDP, complete compiler toolchain
  - XDP just one-hook using/invoking eBPF
- Real power comes from using more bpf-hooks combined
  - From userspace: Controlling XDP/BPF via maps

XDP + eBPF = User programmable networking

- XDP and eBPF really good combination
  - New era in user programmable networking
- Kernel side: responsible for moving packet fast
- BPF side: maximum flexibility and opt-in
  - User-programmable protocols and policies
  - Administrators can quickly implement something
    - No need to upgrade kernel
  - Only run program code needed for use-case
    - No accumulative feature bloat
- In-kernel solution
  - Maintained by the Linux kernel community
  - New XDP program deployed via atomic swap operation

XDP interface: the basics

- What can XDP do?
  - Can read and modify packet contents
  - Can push and pull headers
- XDP interface: BPF program returns an action-code
  - XDP_**DROP** – very fast drop by recycling (DDoS mitigation)
  - XDP_**PASS** – pass possibly modified packet to network stack
  - XDP_**TX** – Transmit packet back out same interface with or without packet modification
  - XDP_**ABORTED** – also drop, but indicate error condition (catch via tracepoint)
  - XDP_**REDIRECT** – Transmit out other NIC or steer via maps
- All BPF programs interact via
  - Helper function that can lookup or modify kernel state
  - Shared maps that userspace and other bpf-programs can use to track state

Designed to cooperate with network stack

- How to handle new protocol/encapsulation
  - That the kernel doesn't know yet?
  - Without upgrading the running kernel!
- On RX:
  - XDP can adjust packet headers to something kernel understand
    - E.g. steer into VLAN devices
  - XDP can add metadata to data buffer than can be used by other eBPF programs
- On TX:
  - BPF can add back (encapsulation) headers
    - BPF hooks in Traffic Control or Socket filter
    - Restore packet-data based on shared BPF-map, VLAN device or SKB marking

The XDP ecosystem

Where should you start?!?

XDP ecosystem

- Mailing lists:
  - XDP newbies join: xdp-newbies@vger.kernel.org
  - Kernel devel-side: netdev@vger.kernel.org
  - BPF devel-side: iovisor-dev@lists.iovisor.org
- Sample code available:
  - Kernel git-tree: samples/bpf/
  - Github: prototype-kernel under samples/bpf/
  - IOvisor BCC project (if you prefer Python)
- Documentation:
  - prototype-kernel.readthedocs.io - plan integrate into kernel.org/doc
  - Cilium: “BPF and XDP Reference Guide”

Recent changes of interest

Since last NetDev 2.1

- Only covering constrained subset

Recent changes: BPF introspection

- Visibility into running BPF programs
  - Kernel v4.13: BPF ID's for loaded progs and maps
  - can be accessed and dumped from userspace
- `bpftool`
  - Part of Kernel tree: tools/bpf/bpftool/
  - Allows inspection and simple modification of BPF objects
  - Easy to list all programs currently loaded
- `xdp_monitor`
  - Part of kernel tree: samples/bpf
  - BPF prog monitoring XDP via tracepoints
  - Helps debugging XDP

THANKS TO:

- MARTIN KAFAI LAU (FACEBOOK)
- JAKUB KICINSKI (NETRONOME)

Is an XDP program loaded?

```
# 2: enp1s0f0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500  xdp qdisc mq [...]
      link/ether 00:0a:f7:8d:ab:60 brd ff:ff:ff:ff:ff:ff
      prog/xdp id  4
```

bpftool

```
# bpftool
Usage: bpftool [OPTIONS] OBJECT { COMMAND | help }
       bpftool batch file FILE
       bpftool version

       OBJECT := { prog | map }
       OPTIONS := { {-j|--json} [{-p|--pretty}] }
```

# bpftool

```
# bpftool map help
Usage: bpftool map show   [MAP]
       bpftool map dump    MAP
       bpftool map update  MAP  key BYTES value VALUE [UPDATE_FLAGS]
       bpftool map lookup  MAP  key BYTES
       bpftool map getnext MAP [key BYTES]
       bpftool map delete  MAP  key BYTES
       bpftool map pin     MAP  FILE
       bpftool map help

       MAP := { id MAP_ID | pinned FILE }
       PROGRAM := { id PROG_ID | pinned FILE | tag PROG_TAG }
       VALUE := { BYTES | MAP | PROGRAM }
       UPDATE_FLAGS := { any | exist | noexist }
       OPTIONS := { {-j|--json} [{-p|--pretty}] }
```

bpftool

```
# bpftool program help
Usage: bpftool prog show [PROG]
       bpftool prog dump xlated PROG [{ file FILE | opcodes }]
       bpftool prog dump jited  PROG [{ file FILE | opcodes }]
       bpftool prog pin   PROG FILE
       bpftool prog help

       PROG := { id PROG_ID | pinned FILE | tag PROG_TAG }
       OPTIONS := { {-j|--json} [{-p|--pretty}] }
```

Running xdp_ddos01_blacklist

```
# xdp_ddos01_blacklist --dev enp1s0f0
Documentation:
 XDP: DDoS protection via IPv4 blacklist

This program loads the XDP eBPF program into the kernel.
Use the cmdline tool for add/removing source IPs to the blacklist
and read statistics.

 - Attached to device:enp1s0f0 (ifindex:2)
 - Export bpf-map:blacklist                      to   file:/sys/fs/bpf/ddos_blacklist
 - Export bpf-map:verdict_cnt                    to   file:/sys/fs/bpf/ddos_blacklist_stat_verdict
 - Export bpf-map:port_blacklist                 to   file:/sys/fs/bpf/ddos_port_blacklist
 - Export bpf-map:port_blacklist_drop_count_tcp  to   file:/sys/fs/bpf/ddos_port_blacklist_count_tcp
 - Export bpf-map:port_blacklist_drop_count_udp  to   file:/sys/fs/bpf/ddos_port_blacklist_count_udp
blacklist_modify() IP:198.18.50.3 key:0x33212C6
blacklist_port_modify() dport:80 key:0x50
```

bpftool inspecting xdp_ddos01_blacklist

```
# bpftool prog show
4: xdp  tag 575d0fd6aa6dde66
        loaded_at Oct 25/15:04  uid 0
        xlated 864B  jited 566B  memlock 4096B  map_ids 5,6,7,8,9
# bpftool map show
5: percpu_hash  flags 0x1
        key 4B  value 8B  max_entries 100000  memlock 14897152B
6: percpu_array  flags 0x0
        key 4B  value 8B  max_entries 4  memlock 4096B
7: percpu_array  flags 0x0
        key 4B  value 4B  max_entries 65536  memlock 4722688B
8: percpu_array  flags 0x0
        key 4B  value 8B  max_entries 65536  memlock 4722688B
9: percpu_array  flags 0x0
        key 4B  value 8B  max_entries 65536  memlock 4722688B
```

`bpftool` inspecting eBPF maps

```
# bpftool map dump id 5
Key:
c6 12 32 03
value (CPU 00): 00 00 00 00 00 00 00 00
value (CPU 01): 00 00 00 00 00 00 00 00
value (CPU 02): 00 00 00 00 00 00 00 00
value (CPU 03): 00 00 00 00 00 00 00 00
value (CPU 04): 00 00 00 00 00 00 00 00
value (CPU 05): 00 00 00 00 00 00 00 00
value (CPU 06): 00 00 00 00 00 00 00 00
value (CPU 07): 00 00 00 00 00 00 00 00
Found 1 element
# printf "%d.%d.%d.%d\n" 0xc6 0x12 0x32 0x03
198.18.50.3
```

bpftool now with JSON output

```
# bpftool map --json dump id 5
[{"key":["0xc6","0x12","0x32","0x03"],"values":[{"cpu":0,"value":["0x00","0x00","0x00","0
x00","0x00","0x00","0x00","0x00"]},{"cpu":1,"value":["0x00","0x00","0x00","0x00","0x00","
0x00","0x00","0x00"]},{"cpu":2,"value":["0x00","0x00","0x00","0x00","0x00","0x00","0x00",
"0x00"]},{"cpu":3,"value":["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"]},{"cp
u":4,"value":["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"]},{"cpu":5,"value":
["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"]},{"cpu":6,"value":["0x00","0x00
","0x00","0x00","0x00","0x00","0x00","0x00"]},{"cpu":7,"value":["0x00","0x00","0x00","0x0
0","0x00","0x00","0x00","0x00"]}]}]
```

Thanks to:

- Quentin Monnet (Netronome)

bpftool now with JSON output (cont)

```
# bpftool map --json --pretty dump id 5
[{

        "key": ["0xc6","0x12","0x32","0x03"
        ],
        "values": [{
                "cpu": 0,
                "value": ["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"
                ]
            },{
                "cpu": 1,
                "value": ["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"
                ]
            },{
                "cpu": 2,
                "value": ["0x00","0x00","0x00","0x00","0x00","0x00","0x00","0x00"
[...]
```

Load another XDP program on another interface

```
# bpftool prog show
4: xdp  tag 575d0fd6aa6dde66
        loaded_at Oct 25/15:04  uid 0
        xlated 864B  jited 566B  memlock 4096B  map_ids 5,6,7,8,9
8: xdp  tag 0381911915bc8d7f
        loaded_at Oct 25/23:07  uid 0
        xlated 496B  jited 339B  memlock 4096B  map_ids 14
# bpftool map show id 14
14: percpu_array  name rxcnt  flags 0x0
     key 4B  value 8B  max_entries 256  memlock 20480B
```

`xdp_monitor` as a debugging tool

```
# ./xdp_monitor --stats
ACTION          result      pps         pps-human-readable measure-period
XDP_REDIRECT    Success     31533       31,533             2.000119
XDP_REDIRECT    Error       0           0                  2.000121
XDP_ABORTED     Exception   13274271    13,274,271         2.000121
```

Above results from XDP_REDIRECT+ cpumap:

- Misconfig resulted in all UDP (pktgen) traffic drop via XDP_ABORTED
  Cmd: `# xdp_redirect_cpu --dev ixgbe1 --prog 3 --cpu 2`
- TCP request-response traffic flowing to another CPU (31Kpps)
  Cmd: `# netperf -H 172.16.0.2 -t TCP_RR`

xdp_redirect_cpu + cpumap output

Program running while xdp_monitor was inspecting system

```
# ./xdp_redirect_cpu --dev ixgbe1  --prog 3 --cpu 2

Running XDP/eBPF prog_num:3
XDP-cpumap      CPU:to  pps            drop-pps    extra-info
XDP-RX          0       13,273,868     0           13,273,868  cpu-dest/err
XDP-RX          4       31,530         0           0          cpu-dest/err
XDP-RX          total   13,305,399     0
cpumap-enqueue    4:2   31,530         0           1.00       bulk-average
cpumap-enqueue  sum:2   31,530         0           1.00       bulk-average
cpumap_kthread  2       31,530         0           31,530     sched
cpumap_kthread  total   31,530         0           31,530     sched-sum
redirect_err    total   0              0
xdp_exception   total   0              13,273,869
```

Great tools, but “patches accepted”

- `bpftool`
  - Decode/pretty-print more values stored in maps
  - Inspect BPF progs before loaded (compare `tag` to running programs)
  - Accumulate results in percpu maps (examples use them as counters)
- `xdp_monitor`
  - Use as a framework/example for more application development
  - JSON output
  - --oneshot support to gather current stats rather than running interactively

Recent changes: XDP metadata for BPF

- XDP metadata: generic and flexible
  - Communication channel between XDP-hook and TC-hooks
  - XDP dynamic reserve **part of packet headroom**
    - Max 32-Bytes avail, BPF prog choose meaning
  - Later BPF hooks (e.g. TC) load prog that knows meaning
    - Can access, extract and populate SKB members,
    - e.g. `skb->mark`
- Provide way for XDP to cooperate with network stack
  - By saving info in `xdp_buff->data_meta` area

Recent changes: `XDP_REDIRECT`

- New XDP return code `XDP_REDIRECT`
  - Innovative part: Redirect using maps (use `bpf_redirect_map()`)
- Redirect via maps:
  - Introduces RX bulking, via flush operation after napi_poll
  - Dynamic adaptive bulking
    - Method of adding bulking without introducing additional latency
    - Bulk only frames available in driver NAPI poll loop
- New map types for redirect
  - devmap - `BPF_MAP_TYPE_DEVMAP`
    - Bulk effect via delaying HW tail/doorbell (like xmit_more)
  - cpumap - `BPF_MAP_TYPE_CPUMAP`
    - Bulk 8 frame to remote CPU, amortize cross CPU cost
    - Provide CPU separation at XDP “layer”

Use-cases

Even new use-cases you did not realize were possible…

Well known use-cases

- DDoS protection
- Load-balancing router (Facebook use-case)
- Forwarding between containers (Cilium use-case)
- Rapid prototyping of protocol extensions

Fix NIC and existing kernel limitations

- Handling protocols currently unknown to kernel
  - Kernel upgrade not always easy or possible
    - As described earlier XDP+BPF can help
    - BUT even harder to upgrade hardware NIC
  - NIC hardware cannot parse protocol
    - Only safe option for hardware is delivery to single RX-queue
    - Single core cannot scale to handle all traffic
- XDP_REDIRECT via cpumap helps
  - Allow redistributing load on CPUs
  - Benchmarks (ixgbe) shows it scales to 11 Mpps per RX CPU

Enable XDP offload of routing stack

- Functions like IPv4 forward could be handled by XDP
    - See proposal for XDP sample (xdp_router_ipv4) implementing IPv4 forward
- Use normal Linux tools to change Routing and Neighbor tables
    - Maintain BPF shadow maps of routing and ARP table
    - Subscribe to changes via rtnetlink updates
- Use XDP_REDIRECT to rewrite packets and forward between known destinations

The End

Are we out of time yet?

XDP Summary

- In-kernel fast-path solution
- Programmable networking inside the network stack!
- Lower maintenance and deployment cost as it is part of the Linux Kernel
- Does not take over NIC hardware and isolate it from the network stack

Thanks to

- XDP + BPF combined effort of many people
  - Alexei Starovoitov
  - Daniel Borkmann
  - Brenden Blanco
  - Tom Herbert
  - John Fastabend
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