Evaluation of tail call costs in eBPF

Clément Joly, François Serman

Agenda

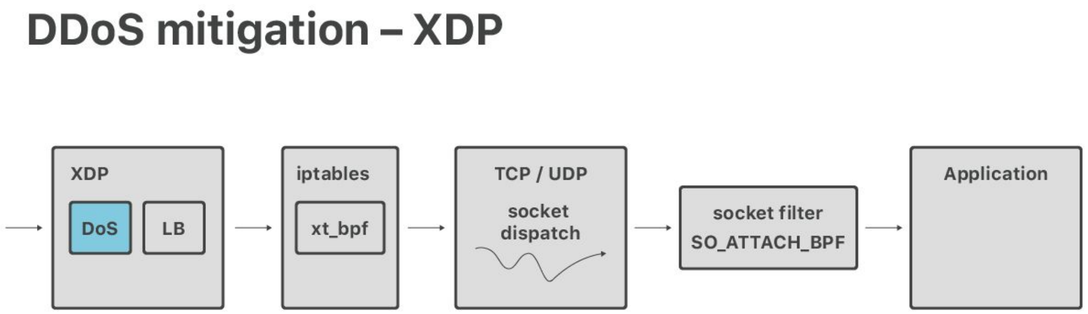
- Problem
- Benchmark 1
- Benchmark 2
- Future

CLOUDFLARE

Problem

Cloudflare

- DDoS mitigation on all machines, in our 200+ PoPs
- L4Drop: XDP / eBPF
  - Set of rules (Rulesets)
  - Tail calls



CLOUDFLARE

https://blog.cloudflare.com/cloudflare-architecture-and-how-bpf-eats-the-world/

Tail calls

C code

```
tail_call((void *)ctxt, &MAP, 0);
```

CLOUDFLARE

Improved tail calls (Daniel Borkmann)

- Avoid the retpoline overhead
  - Direct jump with static map
- Apply to L4Drop
- V5.4 vs v5.5

CLOUDFLARE

https://lwn.net/ml/netdev/cover.1574452833.git.daniel@iogearbox.net/

Tail calls

C code

```
tail_call((void *)ctxt, &MAP, 0);
```

eBPF assembly

```
0: (b7) r3 = 0
1: (18) r2 = map[id:526]
3: (85) call bpf_tail_call#12
4: (b7) r0 = 1
```

CLOUDFLARE

From https://cilium.io/blog/2020/02/18/cilium-17/

x86-64 eBPF JITed: Before

```
19:   xor  %edx,%edx                   |_ index (r3 = 0)
1b:   movabs $0xffff88d95cc82600,%rsi  |_ map (r2 = map[id:526])
25:   mov  %edx,%edx                   |  index >= array->map.max_entries
check
27:   cmp  %edx,0x24(%rsi)             |
2a:   jbe  0x0000000000000066          |_
2c:   mov  -0x224(%rbp),%eax           |  tail call limit check
32:   cmp  $0x20,%eax                  |
35:   ja   0x0000000000000066          |
37:   add  $0x1,%eax                   |
3a:   mov  %eax,-0x224(%rbp)           |_
40:   mov  0xd0(%rsi,%rdx,8),%rax      |_ prog = array->ptrs[index]
```

```
48:   test   %rax,%rax                 |  prog == NULL check
4b:   je  0x0000000000000066           |_
4d:   mov  0x30(%rax),%rax             |  goto *(prog->bpf_func +
prologue_size)
51:   add  $0x19,%rax                  |
55:   callq  0x0000000000000061        |  retpoline for indirect jump
5a:   pause                            |
5c:   lfence                           |
5f:   jmp  0x000000000000005a          |
61:   mov  %rax,(%rsp)                 |
65:   retq                             |_
```

CLOUDFLARE

From https://cilium.io/blog/2020/02/18/cilium-17/

x86-64 eBPF JITed: After (Daniel Borkmann)

```
19:    xor   %edx,%edx                  |_ index (r3 = 0)
1b:    movabs $0xffff9d8afd74c000,%rsi |_ map (r2 = map[id:526])
25:    mov   -0x224(%rbp),%eax          |  tail call limit check
2b:    cmp   $0x20,%eax                 |
2e:    ja    0x000000000000003e         |
30:    add   $0x1,%eax                  |
33:    mov   %eax,-0x224(%rbp)          |_
39:    jmpq   0xffffffffffd1785         |_ [direct] goto *(prog->bpf_func + prologue_size)
3e:    mov   $0x1,%eax                  (next instruction, r0 = 1)
```


From https://cilium.io/blog/2020/02/18/cilium-17/

Measuring

- No existing, well-known solution specific enough

Benchmark 1

BPF_PROG_TEST_RUN

- One packet
- One XDP program
- Multiple runs
  - Returns average time

https://lwn.net/Articles/718784/

Benchmark 1

- Advantage: stable, one program
- Drawback: not production-like

CLOUDFLARE

Machine: 9th generation

Machine name	CPU	Number of core (logical)	Frequency (GHz)	Maximum frequency (GHz)	RAM (GB)
testM8	Intel(R) Xeon(R) Platinum 6162	**96**	1.90	**3.50**	188

CLOUDFLARE

https://blog.cloudflare.com/a-tour-inside-cloudflares-g9-servers/

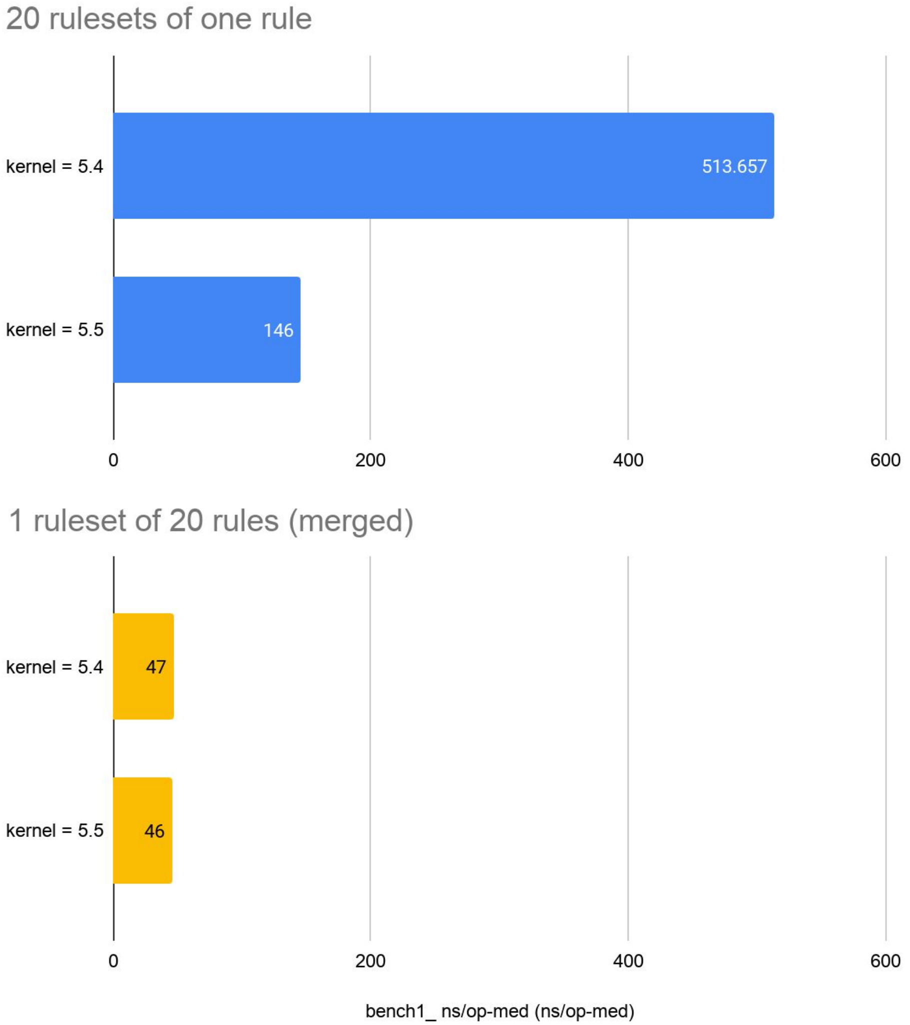
Measuring tail call CPU time cost

- Single tail call
  - Difficult to get the diff
- 20 rulesets of one rule
  - With tail calls
  - Merged
- Same number of instructions
  - Difference -> cost of tail calls

CLOUDFLARE

Benchmark 1

- Average cost per tail call
  - 25 -> 5 ns



CLOUDFLARE

Benchmark 2

2 network namespaces

- Deploy L4Drop + load balancer & sampler
  - Kernel probes & eBPF
- Simulate traffic
  - `ip netns exec m1 iperf3 -c <ip_srv> -N -J`

KProbes

- Entry time, exit time
  - Stored in a map
- Bias due to code around
- Here, on `veth_poll`

Sample data

```
@less_16: count 1933452, average 1742, total 3369543330

@more_16: count 965732, average 61751, total 59635349493

@ns:
[512, 1K)              1 |                                                    |
[1K, 2K)         1512012 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@|
[2K, 4K)          410325 |@@@@@@@@@@@@@@                                      |
[4K, 8K)            9240 |                                                    |
[8K, 16K)           1890 |                                                    |
[16K, 32K)           668 |                                                    |
[32K, 64K)        569424 |@@@@@@@@@@@@@@@@@@@                                 |
[64K, 128K)       394983 |@@@@@@@@@@@@@                                       |
[128K, 256K)         499 |                                                    |
[256K, 512K)          78 |                                                    |
[512K, 1M)            64 |                                                    |


@stats: count 2899184, average 21731, total 63004892823
```

Sample data

< 16000ns

> 16000ns

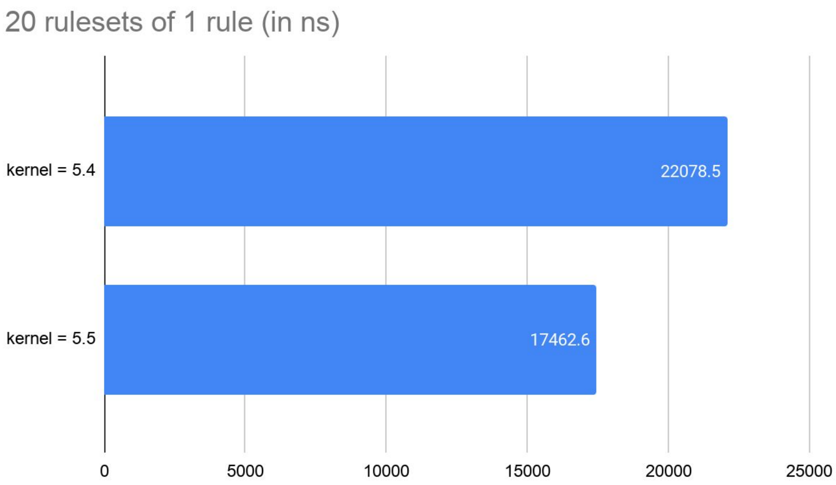
```
@less_16: count 1933452, average 1742, total 3369543330

@more_16: count 965732, average 61751, total 59635349493

@ns:
[512, 1K)              1 |                                                    |
[1K, 2K)         1512012 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@|
[2K, 4K)          410325 |@@@@@@@@@@@@@@                                      |
[4K, 8K)            9240 |                                                    |
[8K, 16K)           1890 |                                                    |
[16K, 32K)           668 |                                                    |
[32K, 64K)        569424 |@@@@@@@@@@@@@@@@@@@                                 |
[64K, 128K)       394983 |@@@@@@@@@@@@@                                       |
[128K, 256K)         499 |                                                    |
[256K, 512K)          78 |                                                    |
[512K, 1M)            64 |                                                    |


@stats: count 2899184, average 21731, total 63004892823
```

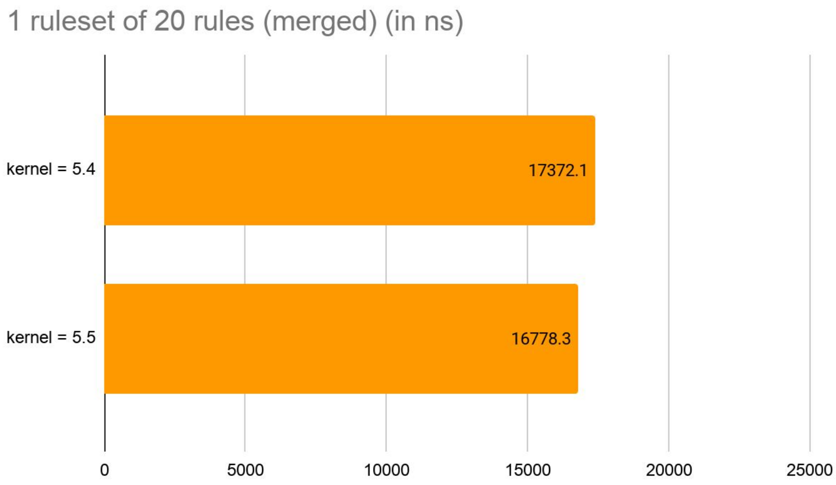
Benchmark 2

- Benefit: production-like conditions
- Drawback: complexity, less precision
    - Surrounding code

Benchmark 2 (CPU)

- Roughly 20 % gain
  - Due to code in the kprobed function
- Graphs on global average



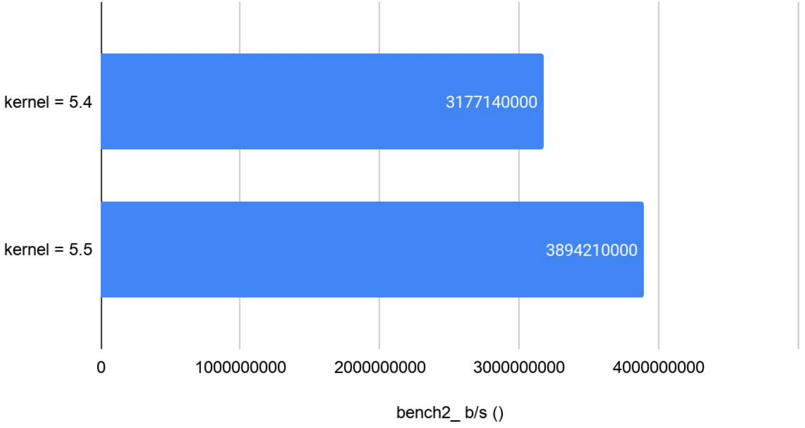


CLOUDFLARE

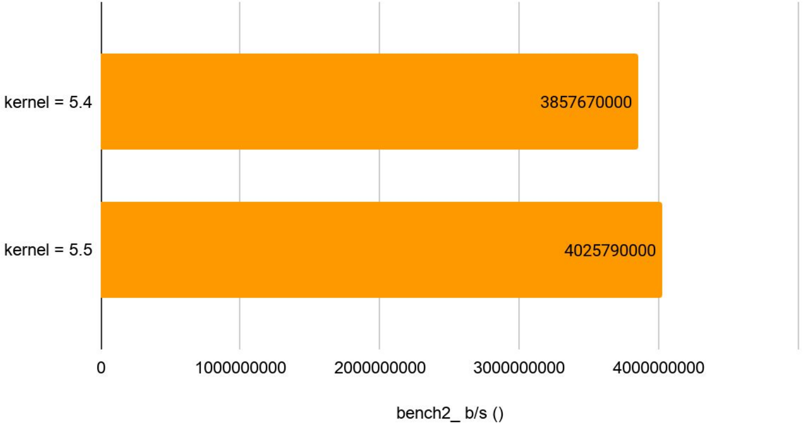
Benchmark 2 (throughput)

- Slower eBPF program → lower throughput
- 17-23 % gain
- Less reliable

20 rulesets of one rule



1 ruleset of 20 rules (merged, no tail call)



CLOUDFLARE

Future

Drawbacks

- Clusters of values with KProbes
- Overhead with IPerf between namespaces
  - Not always precise enough
- More direct measurements for specific instructions (tail calls for instance)?

Perf

- Difficult to isolate various eBPF programs
  - Not isolated either in the second benchmark
- Not used at first
  - Record: not enough to distinguish
  - Trace: too much overhead

Bpftool prog profile

Bpf stats enabled

`run_time_ns / run_cnt`

```
bash-5.0# sysctl -w kernel.bpf_stats_enabled=1
kernel.bpf_stats_enabled = 1
bash-5.0# bpftool prog show id 1

1: xdp  tag 3b185187f1855c4c  gpl run_time_ns 20881 run_cnt 148
        loaded_at 2020-08-17T22:01:04+0200  uid 0
        xlated 16B  jited 35B  memlock 4096B
bash-5.0#
```

Conclusion

Thanks