Performance Implications of Packet Filtering with Linux eBPF

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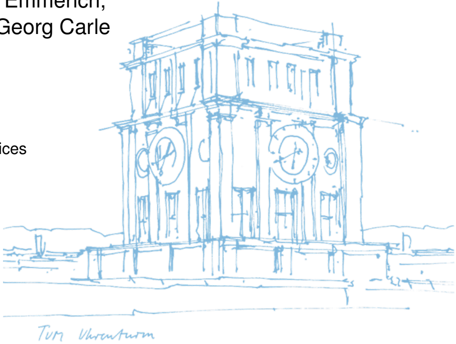


History of Extended Berkeley Packet Filter (eBPF)

Recent Hot Topic

- 1992: BPF developed for UNIX
  - Packet filtering, e.g. *tcpdump*
- 2014: eBPF introduced into Linux Kernel
  - Network monitoring
  - Network traffic manipulation
  - Non-networking purposes
    - Tracing
    - Security auditing
    - ...
- Since then:
  - Continuous (performance) improvements [1]
  - “super powers have finally come to Linux” [2]
  - Offloading support, e.g. Netronome SmartNIC [3]
  - At Host Dataplane Acceleration Tutorial @ SIGCOMM 2018 [4]

[1] A thorough introduction to eBPF, `https://lwn.net/Articles/740157/`
[2] Brendan Gregg, BPF: Tracing and More, `https://www.youtube.com/watch?v=JRFNIKUROPE`
[3] NetroNews, August 2018, `http://hosted.verticalresponse.com/183413/a79f667b58/1413119999/c60e793082/`
[4] ACM SIGCOMM 2018 Morning Tutorial on Host Dataplane Acceleration (HDA), `https://conferences.sigcomm.org/sigcomm/2018/tutorial-hda.html`

Outline

Extended Berkeley Packet Filter (eBPF)

What is it?

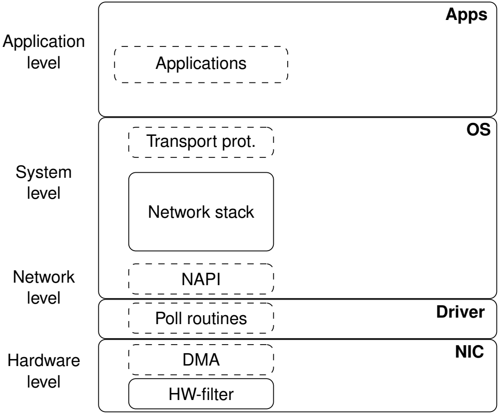
- User space program
- Run in virtual machine in kernel space (“sandboxed”)
- Dynamically interpreted (default) or compiled just-in-time (JIT)

Limitations

- Static verification
  - No backward jumps (loops)
  - Maximum of 4096 instructions
  - ➔ Cannot compromise/block kernel
- Data access: key-value stores (maps)
  - Memory region set up before program is loaded
  - Key size, value type, max. number of entries predetermined
  - ➔ Secure data access between user space and kernel space

Study: Packet Filtering

Layers of Packet Filters



- Hardware offloading and filtering
- Dedicated platforms based on FPGAs or SmartNICs

→ High-performance, ideal for coarse filtering (DoS)

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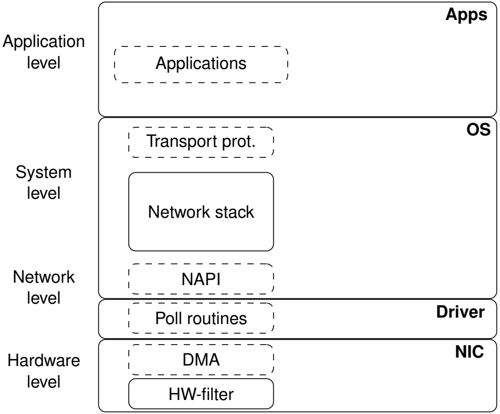

- Before network stack processing

→ Dropping packets with low overhead in software

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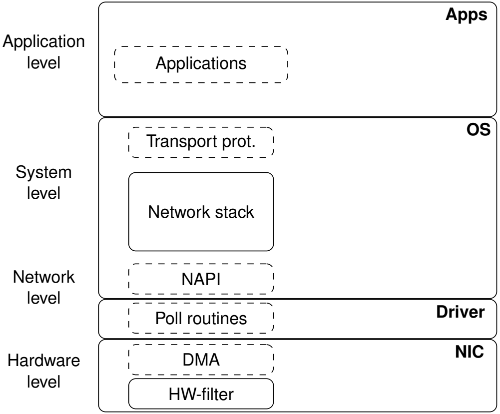

- Hooks into packet processing of network stack
- e.g. iptables or nftables
- → Requires root access, system-specific knowledge

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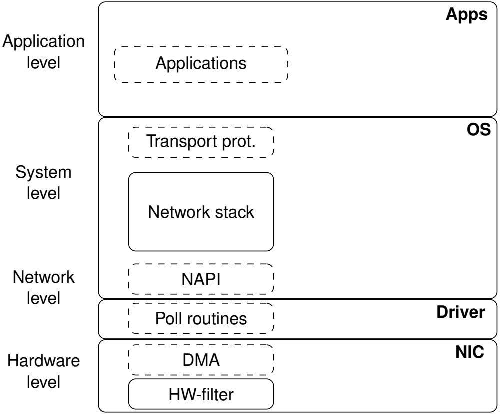

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- → Application “knows best”, high penalty for dropping packets

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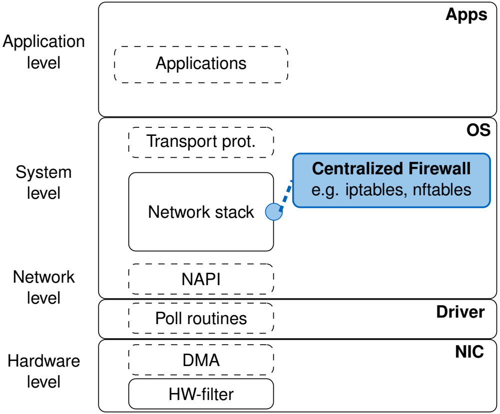
Use Case: Packet Filtering

Common Scenario – State of the Art



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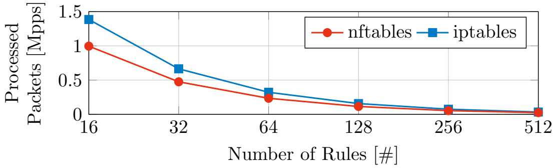
Performance Baseline



Maximum packet rate

Use Case: Packet Filtering

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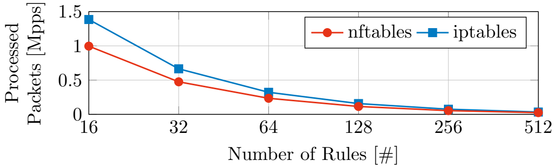

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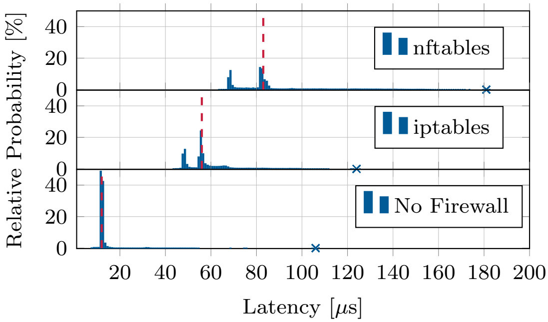

Latency distribution at 0.03 Mpps

Use Case: Packet Filtering

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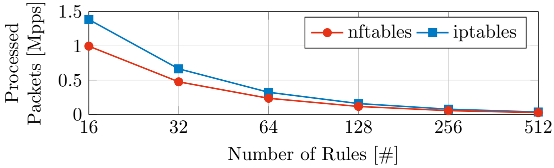

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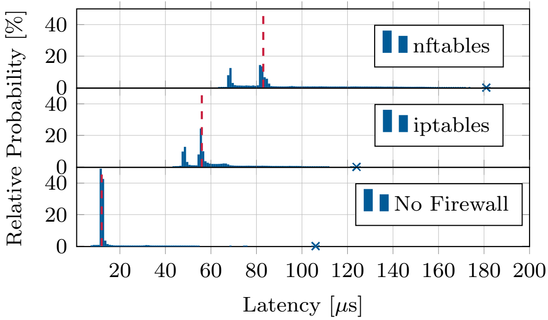


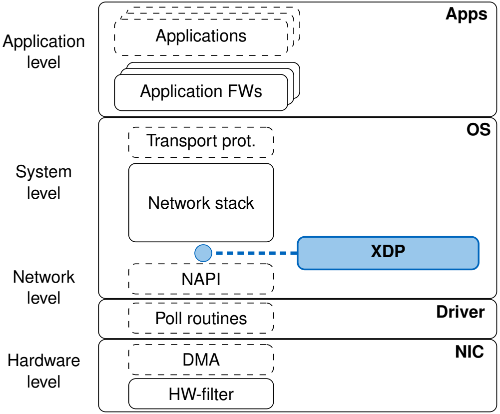
Latency distribution at 0.03 Mpps

Performance sufficient for today's applications?

Limitations: Centralized, complex ruleset, requiring root access

Use Case: Packet Filtering (using Commodity Hardware)

Possibilities with eBPF



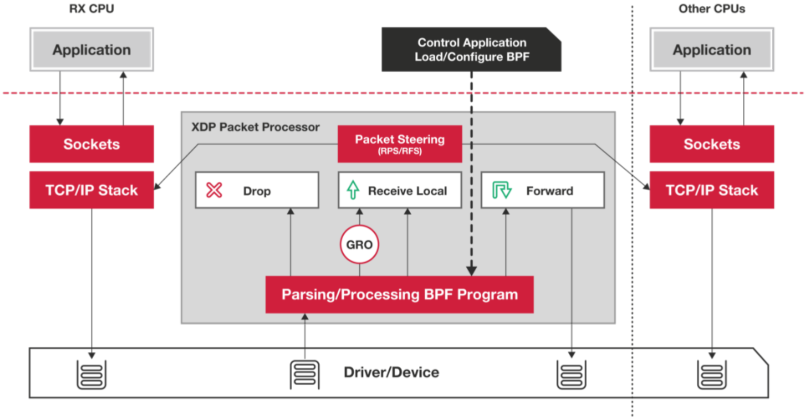
eXpress Data Path

- First line of defense
- Coarse but efficient filtering

→ Protection against DoS attacks

Case Study I: eXpress Data Path (XDP)

Overview



Source: https://www.iovisor.org/technology/xdp

Case Study I: eXpress Data Path (XDP)

Measurement Setup

- XDP program:
  - Drop if port is blacklisted
  - Otherwise, forward to outgoing interface
  - ➔ Excludes network stack
- Load generator:
  - MoonGen [7]
  - Generates *n* UDP flows
- Just-in-time compiler enabled
- Traffic pinned to single core
- Hyper-threading and Turbo Boost disabled

[7] `https://github.com/emmericp/MoonGen`

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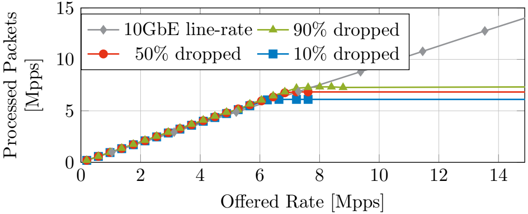
Performance Baseline



Packet filtering performance

- Drop everything: 10 Mpps
- Drop x-Percent: 6.4 Mpps to 7.2 Mpps

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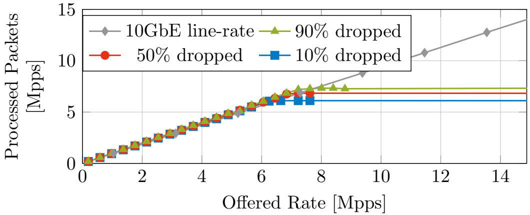

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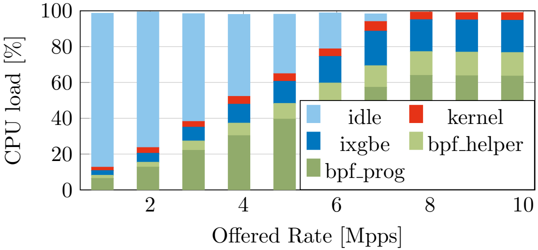

Whitebox measurement – Profiling

- Drop everything: 10 Mpps
- Drop x-Percent: 6.4 Mpps to 7.2 Mpps
- Kernel < 5% CPU time

→ 5 to 10 times performance increase compared to in-kernel filtering

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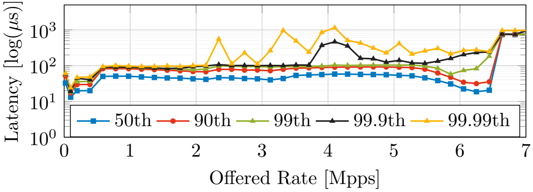
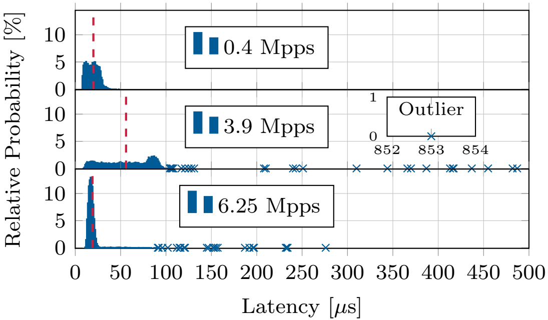
Latency



Latency percentiles (90 % passing traffic)



Selected histrograms

Comparison

- iptables: 55μs (median), 110μs (99.99th %ile)
- nftables: 82μs (median), 154μs (99.99th %ile)

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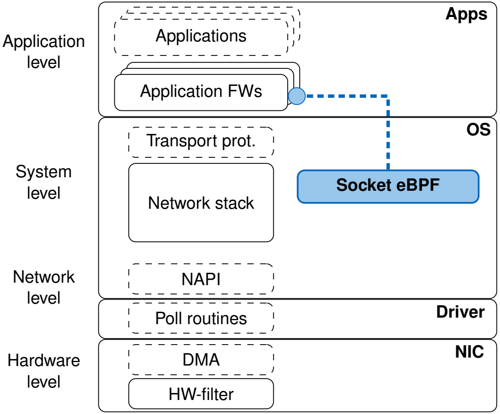

Application Firewall

- Socket attached filtering
- Application (developer) can extract desired traffic

→ Fine-grained and flexible filtering

Case Study II: Socket Attached Filtering

Application Firewall

Steps

- Write filter in C
- Add eBPF virtual machine to socket
- Run filter in virtual machine

➔ Drop or forward to application

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Technical Implementation

- BPF Compiler Collection
- systemd socket activation
- ➔ Added command-line interface and wrapper functions [8]
- ➔ E.g. port-knocking simple to implement

[8] `https://github.com/AlexanderKurtz/alfwrapper`

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What have we gained?

- Application developer knows best
- Rule-set shipped with application
- Independent of system administrator
- Small rule-set per application/socket
- Not interfering with rule-set of another socket
- ➔ Optimized for application
- ➔ Reduced complexity, less error-prone

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Case Study II: Socket Attached Filtering

Measurement Setup

Differences

- Application interested in throughput
- (Stateful) applications more difficult to benchmark

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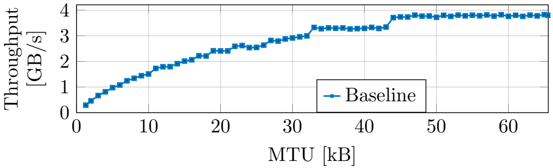


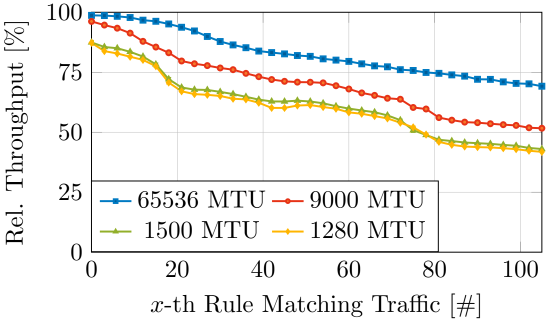
Baseline transmission speeds

Case Study II: Socket Attached Filtering

Performance

Interface filtering

- Simple operation
- Whitelisting: Matching rule at *x*-th position



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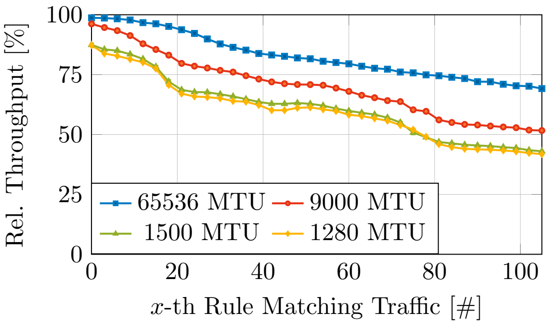
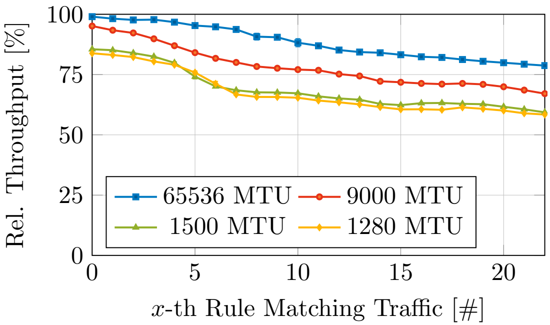


Subnet filtering

- Complex operation
- Limits number of rules

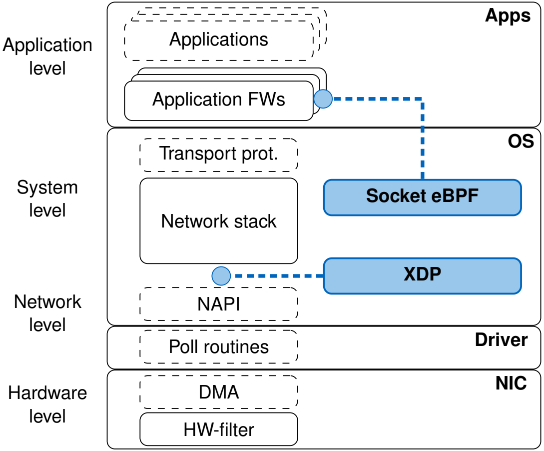


Conclusion

eBPF allows to break up traditional packet filtering

- Adds flexibility
- High-performance
- But: limitations

→ Many applications can benefit from eBPF



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Future developments

- Improvements for eBPF just-in-time compiler
- Hardware accelerators and offloading capabilities
- P4 programming language