TruSDEd: Composable, Efficient, Secure XDP Service Function Chaining on Single Board Computers

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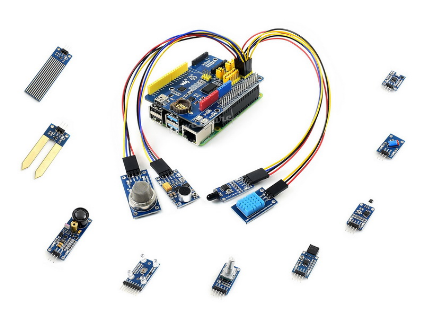
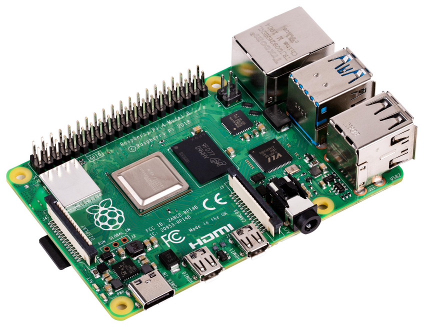
Securing Sensor & IoT Networks

- Security – ingress/egress packet processing by *network functions*.
  - IP layer – Firewalls, DPI, ACLs...
  - Middleboxes a bad fit.
  - Needs to be reconfigurable – attacks and security context evolve.
- Ideally in-situ.
  - Dynamic/retrofitted.
  - But limited space + power in the field.
  - Physically vulnerable!



Fast, cheap, and secure IoT Defence – pick 3?



- Single-board compute like RPis are small, capable, affordable! Cheap!
    - See also: NUCs, Jetsons.
- Sensor networks have low data rates; a good fit.
- Project goals:
    - Fast! Low-latency, quickly reconfigurable.
    - Secure! *Device*-level authentication.

Research Objectives

- Fast reconfiguration:
  - State, Program Code, Composition
- Attestation and authentication:
  - Right programs on right machine, requested by trusted server.
- 'Acceptably' low-latency packet-processing, without pushing CPU/power draw too high?
  - I.e., as low as we can get without polling.
- Easy development and composition.
  - One Rust program per NF $\implies$ compiled for stack.
  - Simple, dynamic chain format.

Limits of existing solutions

- 'Best' low latency processing (DPDK) is expensive – CPU and power.
    - …IFF you have HW support (NUCs)
- SotA in *secure* processing needs server-only capabilities like *trusted execution environments* (TEEs).
- No powerful hardware offloads or acceleration.
    - FPGA hats/daughterboards 'off-path'
- Devices physically vulnerable, no ECC memory.
- …So, how to reconcile with cheap & portable SBCs?

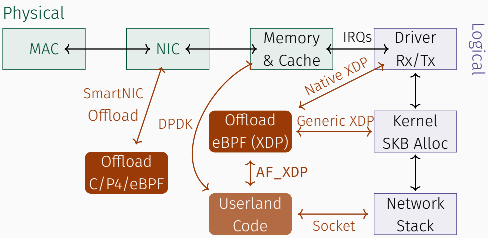
What tools do we *consistently* have?

- SBCs often linux-based
  - Easy(/ier) to target and write for.
  - Advantage: We also get kernel network stack advancements.
- Can run commodity software with no issues, reasonable target archs like Aarch64, x86_64, ...
- Includes, principally, eBPF tooling!

eBPF: What and Why?

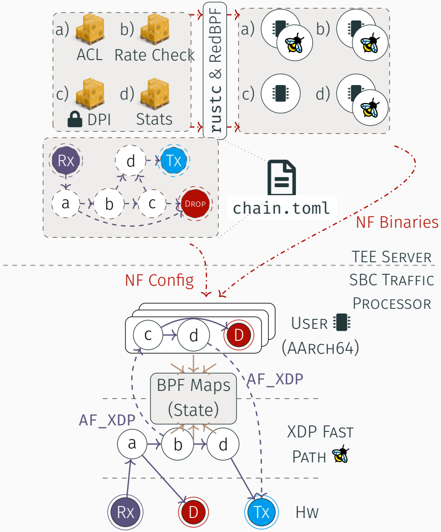
- Simple register machine VM (user-written) code, derived from BPF.
- Modern use – Kernel hooks, perf instrumentation, debugging
- JIT compiled
- Kernel-verified
    - Bounds-checked pointer accesses
    - Program size limited, no unbounded loops
    - Syscalls (*eBPF helpers*) exposed based on hook point

Network stack improvements: XDP



- eBPF hook attached to packet ingress
- Variations on hook $\in$ {Offload, Driver, Generic}
  - Perf degrades gracefully according to driver support
- Hook can modify & inspect packets before forwarding to Linux stack, sending straight to (another) NIC, or drop.
- Since 2019: **AF_XDP** stack bypass!

Design: Bird's eye view



- Two-tier approach—XDP & User.
- Composable NFs – graph structure.
- Critical or high performance NFs go into XDP:
  - Early results – low latency for most packets.
- Rare 'slow-path' still kernel bypass:
  - Expensive & proprietary code.
  - Only for candidate attack traffic.
- Reconfigurable, dynamic.

How does this differ from other frameworks?

In Security? SafeBricks[1], AuditBox[2] or similar.

- ...No SGX support in devices of interest.

In eBPF/XDP space? Polycube[3]!

- Built around datacentres – we often have just one HW queue for a NIC.

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[1] Poddar *et al.*, 'SafeBricks: Shielding Network Functions in the Cloud'.
[2] Liu *et al.*, 'Don't Yank My Chain: Auditable NF Service Chaining'.
[3] Miano *et al.*, 'A Framework for eBPF-Based Network Functions in an Era of Microservices'.

Concrete design differences

- **Problem:** Mismatch of HW queues to physical cores:
  - Soln: load balance or place high-latency NFs in userland.
  - ...also, don't pass packets back to k-space.
- **Problem:** XDP hooks only on ingress (*for now*):
  - Soln: load balance or place high-latency NFs in userland?
  - Write an individual NF *once*, compile for both envs, and replicate NFs as needed.

Skeleton details

- Consistent NF API for both XDP/userland.
- Rust compiler should be able to enforce…
  - `#![forbid(unsafe_code)]` (or similar cargo tooling) on NF module crates,
  - all NF branches specified.
- All compilation on external server.
  - SBC too constrained.
  - If compile-server is TEE-equipped, can attest compiler/code etc. following SotA!

```rust
#![no_std]
pub enum Action {
    Left,
    Right,
    Up,
    Down,
}

pub fn packet(bytes: impl Packet) -> Action {
    let addr_lsb_idx = 14 +
    match pkt.slice_from(12, 2) {
        Some(&[0x08, 0x00]) => 19, //v4
        Some(&[0x86, 0xDD]) => 39, //v6
        _ => {return Action::Left},
    };

    match pkt.slice_from(addr_lsb_idx, 1)
        .map(|v| v[0] % 2) {
            Some(0) => Action::Left,
            Some(1) => Action::Right,
            Some(2) => Action::Up,
            Some(3) => Action::Down,
            _ => unreachable!(),
    }
}
```

`mod.rs`: Load balance on dest addr

A quick code walkthrough...

< In lieu of a demo... >

How do we upcall to userland?

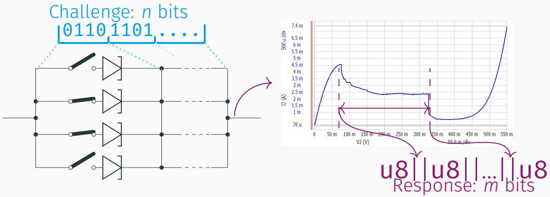
- **Problem:** Can send packet over `AF_XDP`, but *no context on what the next (callee) NF is.*
  - Polycube's solution inadequate: one discrete userland component per *cube*.
- Soln: Adjust headroom of packets, write in ID and action of caller.
- ...might be a **`memcpy`**, but ideally only paid on packets who need it.

Control plane: PUF-based authentication

- How to attest the above code and config is correct?
  - TLS w/ pre-shared certs works well.
  - But corruption, unplanned expiry possible on field devices.
- *Physical Unclonable Functions* (PUFs) – input-based device signatures, CRPs.
- Authenticate keys in the wild without root certs.
  - Two-way: Client $\leftrightarrow$ Server!
  - Soln: RusTLS modification to declare challenge via X.509 extension, mix response bits into signature algo input [Zero-knowledge].
- Strong attestation of identities to physical devices.

Control plane: PUF-based authentication (II)

- RTD-based array designs – quantum property.
- Behaviour in purple region (NDR region) physical device-dependent
  - Perturbations from 'ideal' behaviour can't be replicated
  - N° peaks and perturbations depend on active devices.
- Challenge bits control used transistors in circuit
  - $\sim$ Exp amount in n, Large Resp.



...What's next?

- Currently measuring on RPi and NUC:
  - Power, CPU use, ...
  - Latency (distribution), Throughput
  - Showing usefulness in relocating 'expensive' NFs.
- Working out the details on paper for control plane reconfiguration:
  - eBPF ProgMaps, etc. allow atomic replacement.
  - Still need to codify details on chain & map building to prevent inconsistencies.

Takeaways:

Cheap NFs: SBCs for packet processing.

Low-latency and fast: XDP path for majority of traffic, early & cheap anomaly checks.

Secure: PUFs for device, server, and function chain attestation.

Ongoing work: complex NFs, power + latency measures, better characterising PUF behaviour.

Questions?

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