Can we exploit buggy P4 programs?

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Funding from
Cornet H2020

Bugs and undefined behaviors

Undefined behaviors have unpredictable, unreliable effects

What *really happens* depends on the platform

Bugs and exploits in the world of C

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int vuln_func(const  char *user_input) {
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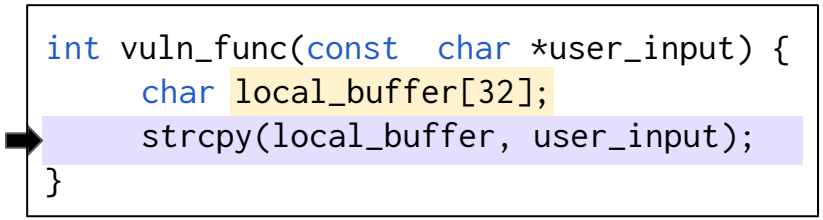

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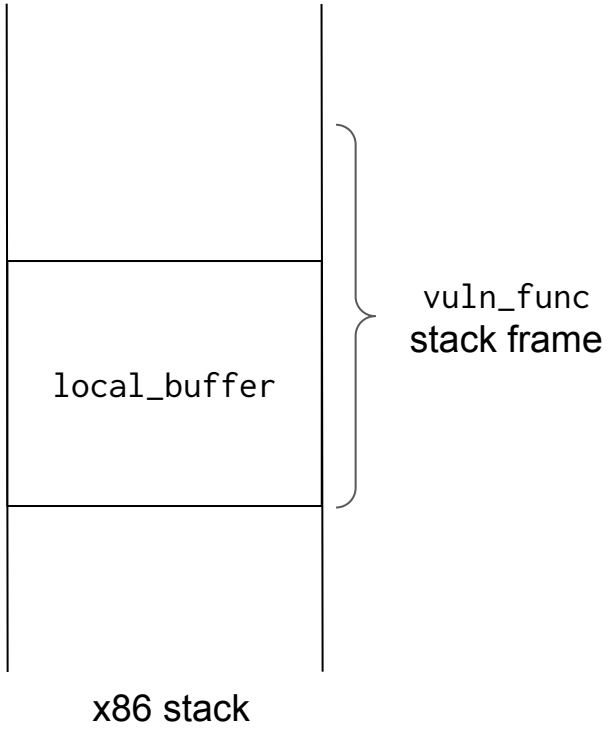

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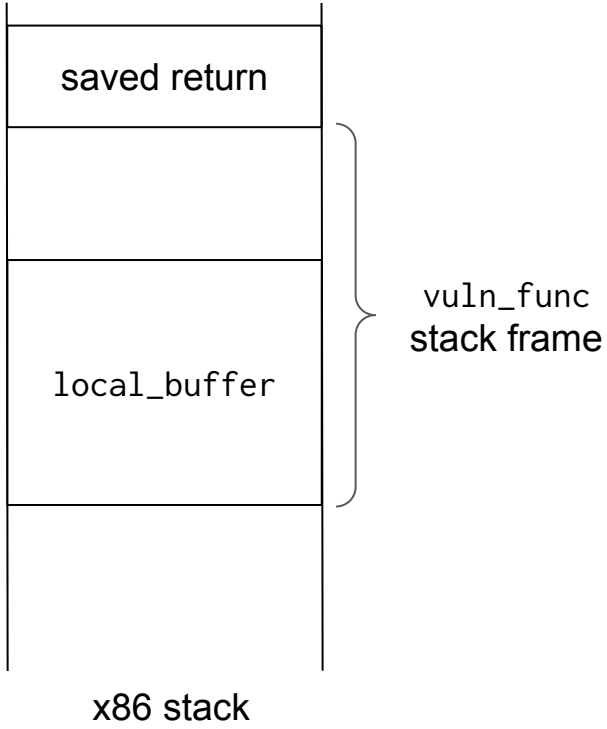

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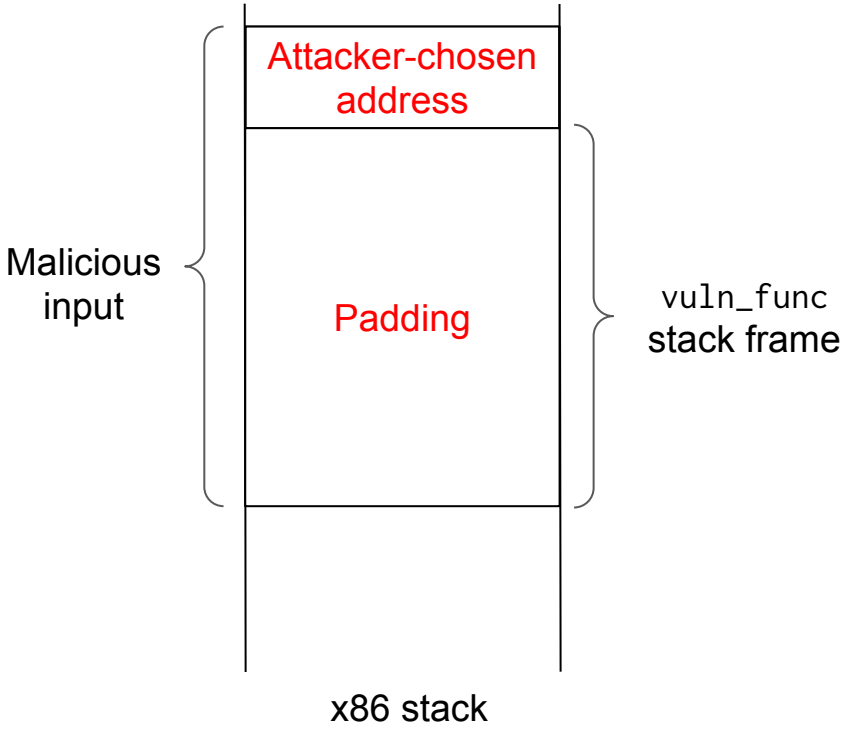


What about the P4 world?

Our Work

Document actual manifestations of undefined behaviors on:

- BMv2 simple_switch
- P4-NetFPGA
- Barefoot Tofino

Examples of exploits on P4 programs

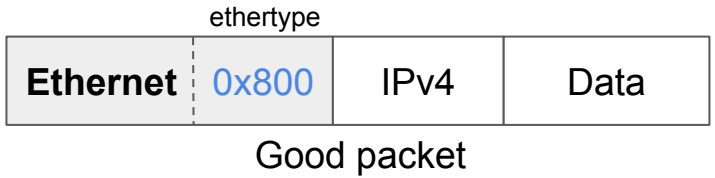
P4 headers

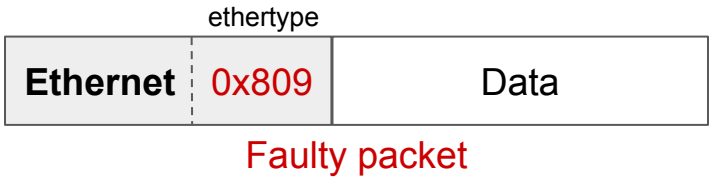
```
header ethernet_t {
     bit<48> dst;
     bit<48> src;
     bit<16> type;
}
```

```
struct headers {
     ethernet_t ethernet;
     ipv4_t ipv4;
     ipv6_t ipv6;
}
```

```
state parse_ethernet {
     packet.extract(hdr.ethernet);
     transition select(hdr.ethernet.type) {
          0x0800: parse_ipv4;
          0x86DD: parse_ipv6;
     }
}
```

Reads from invalid headers



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apply {
    if (!hdr.ipv4.isValid())
        hdr.ethernet.ether_type = hdr.ipv4.checksum;
        send_back();
}
```

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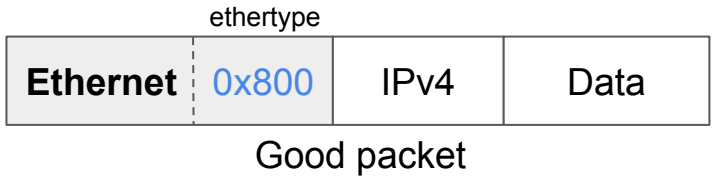

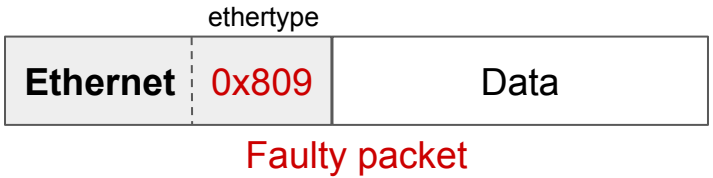


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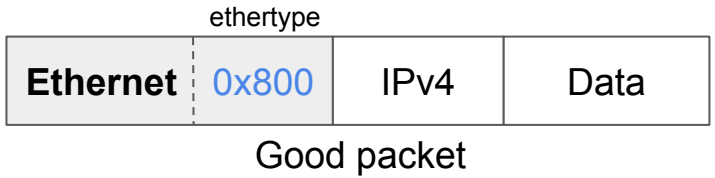

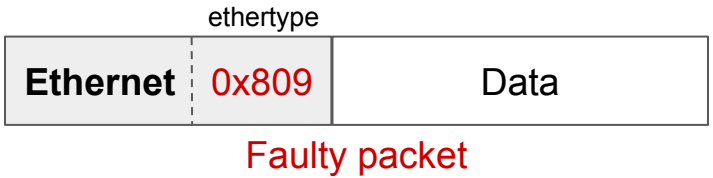


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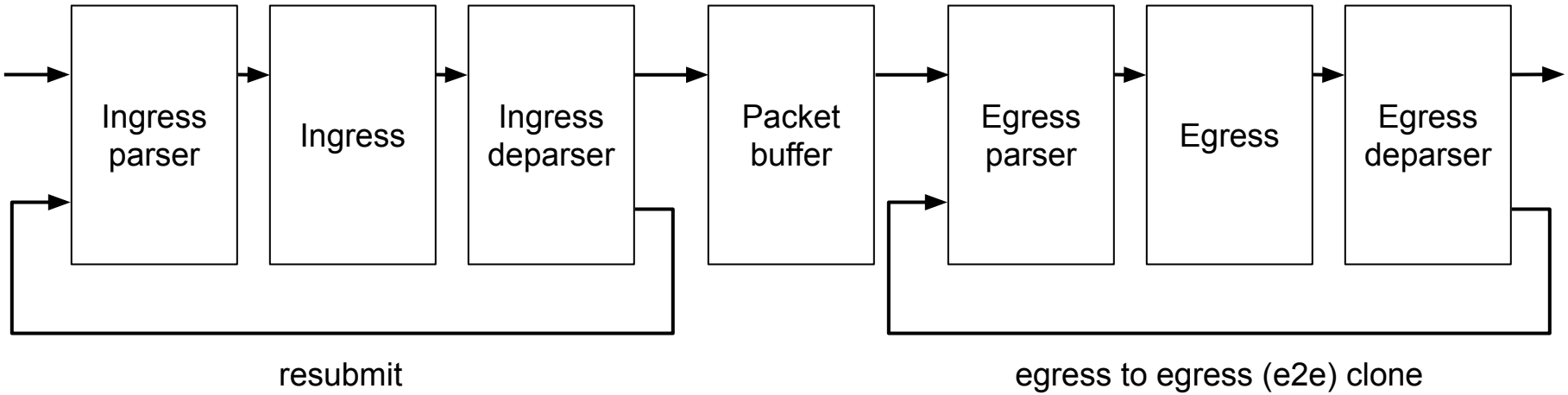
Reads from invalid headers

	Value of ethertype for output packet
simple_switch	*IPv4 checksum of previous good packet*
P4-NetFPGA	Zero
Tofino	Zero

Infinite loops



Infinite loops

	resubmit	e2e clone
simple_switch	Incoming packets dropped	Flood egress port with clones
Tofino	Can only resubmit once	Flood egress port with clones
P4NetFPGA	N/A	N/A

Resurrecting dropped packets

Dropping means changing metadata:

```
meta.drop = 1;
```

OR

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meta.output_port = DROP_PORT;
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apply(acl);    // mark as dropped => egress_spec = 511
apply(lpm);    // hit               => egress_spec = 2
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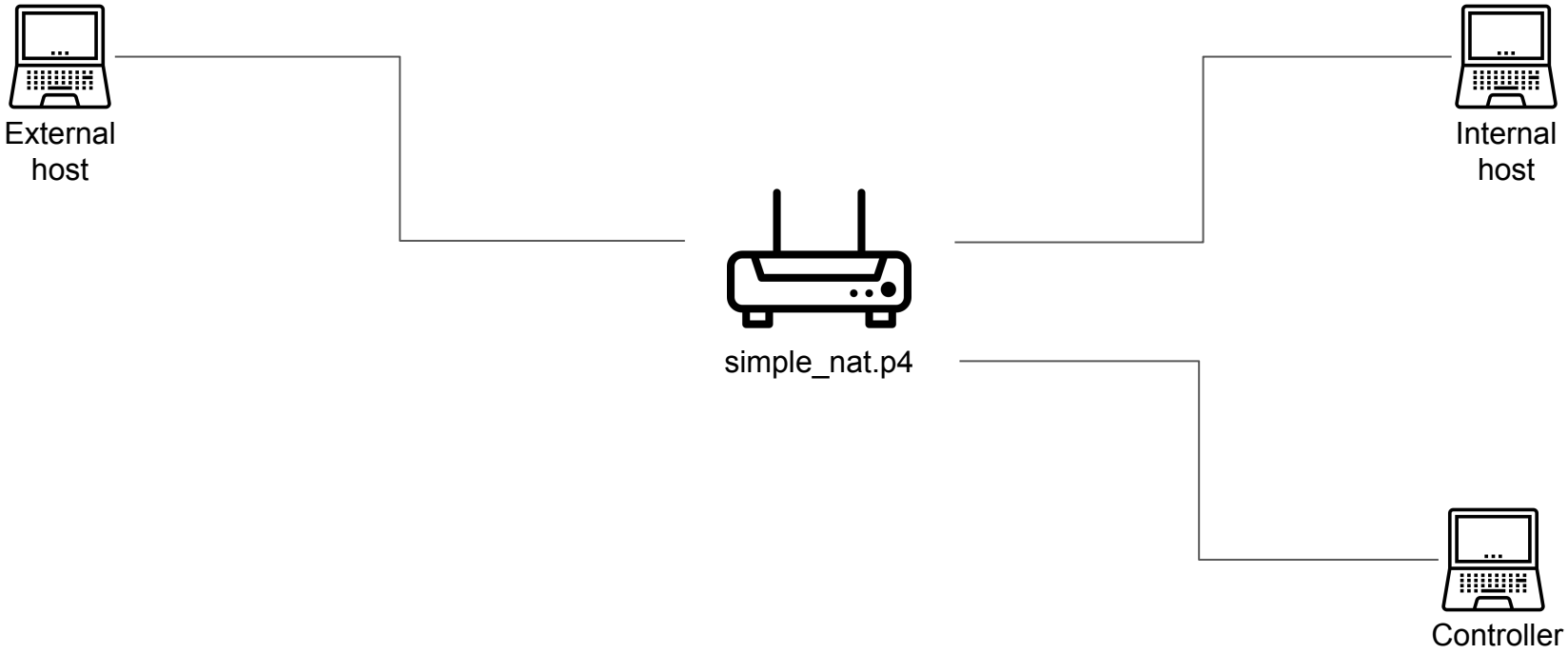
Resurrecting dropped packets

	Drop method
v1model	Set output port to a special value
SimpleSumeSwitch	Set output port to a special value
PSA	Set metadata boolean

Simple NAT setup



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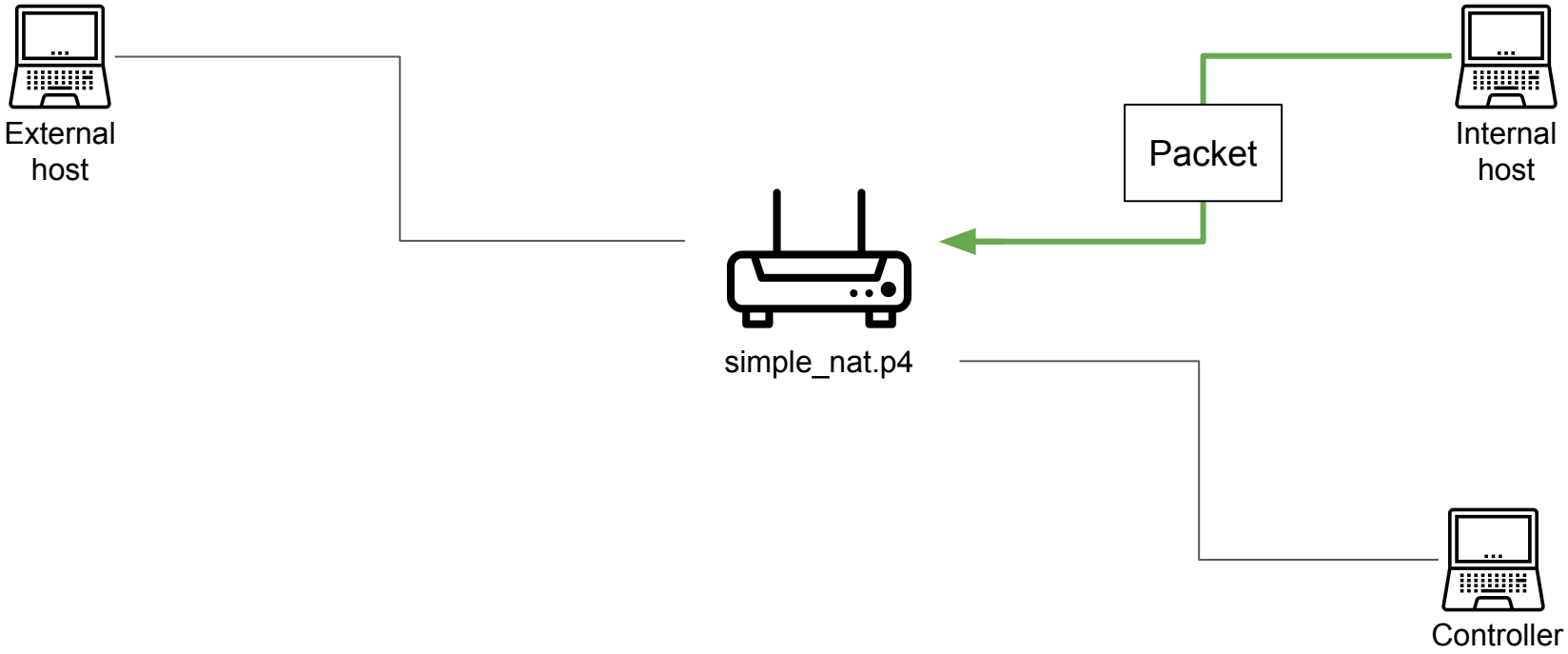

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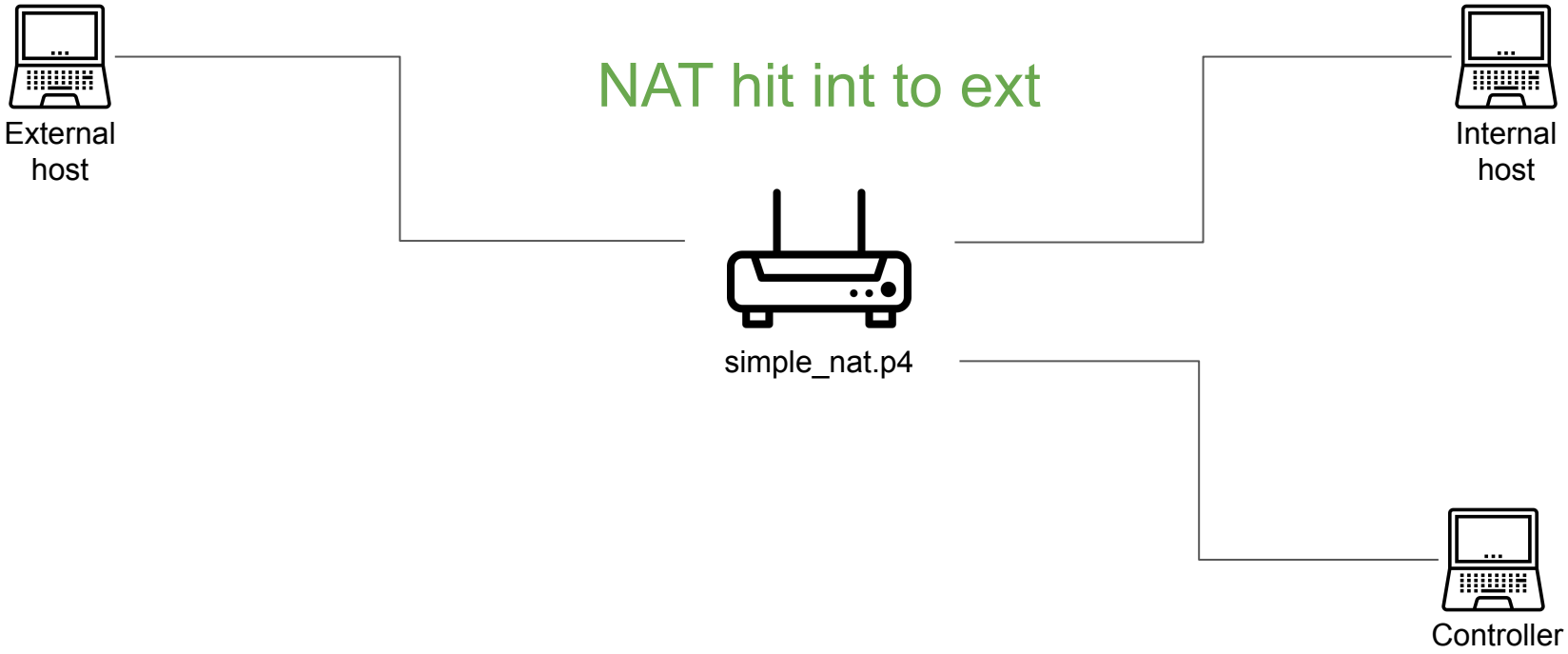

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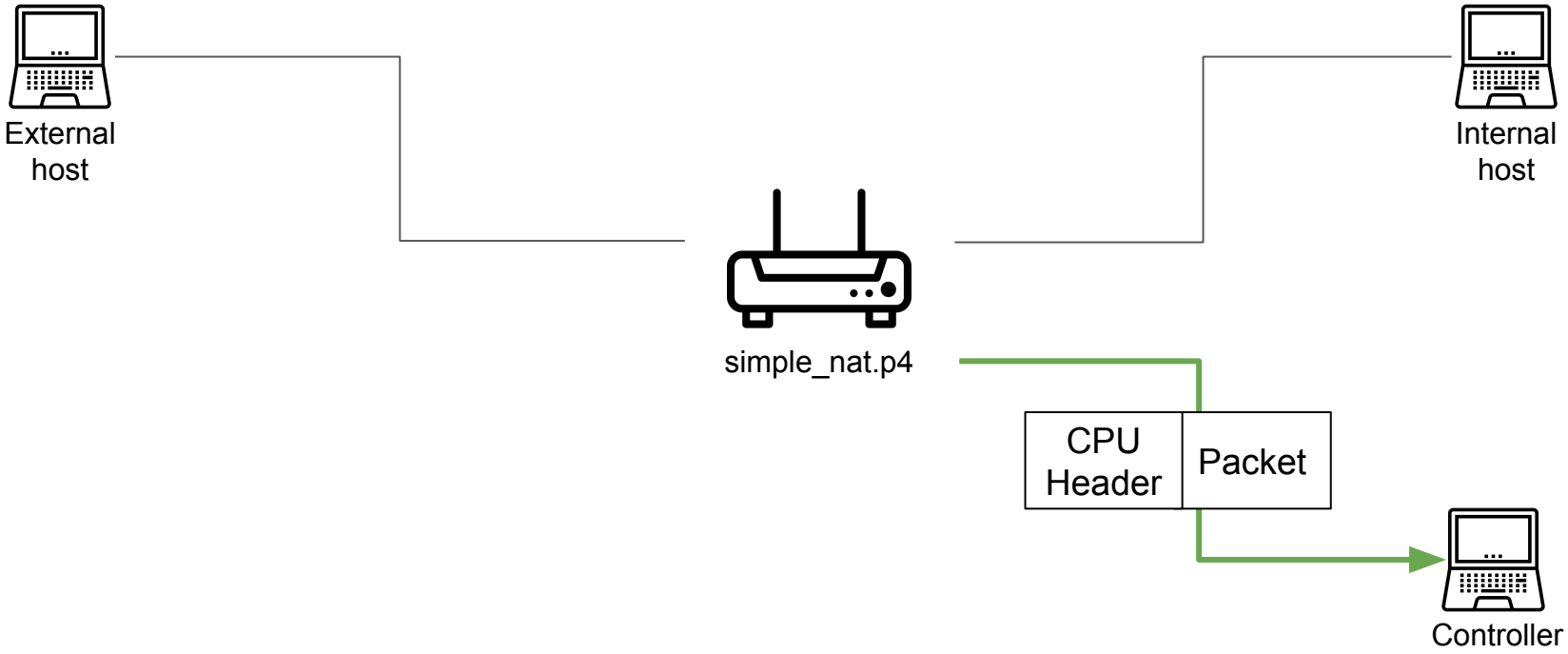

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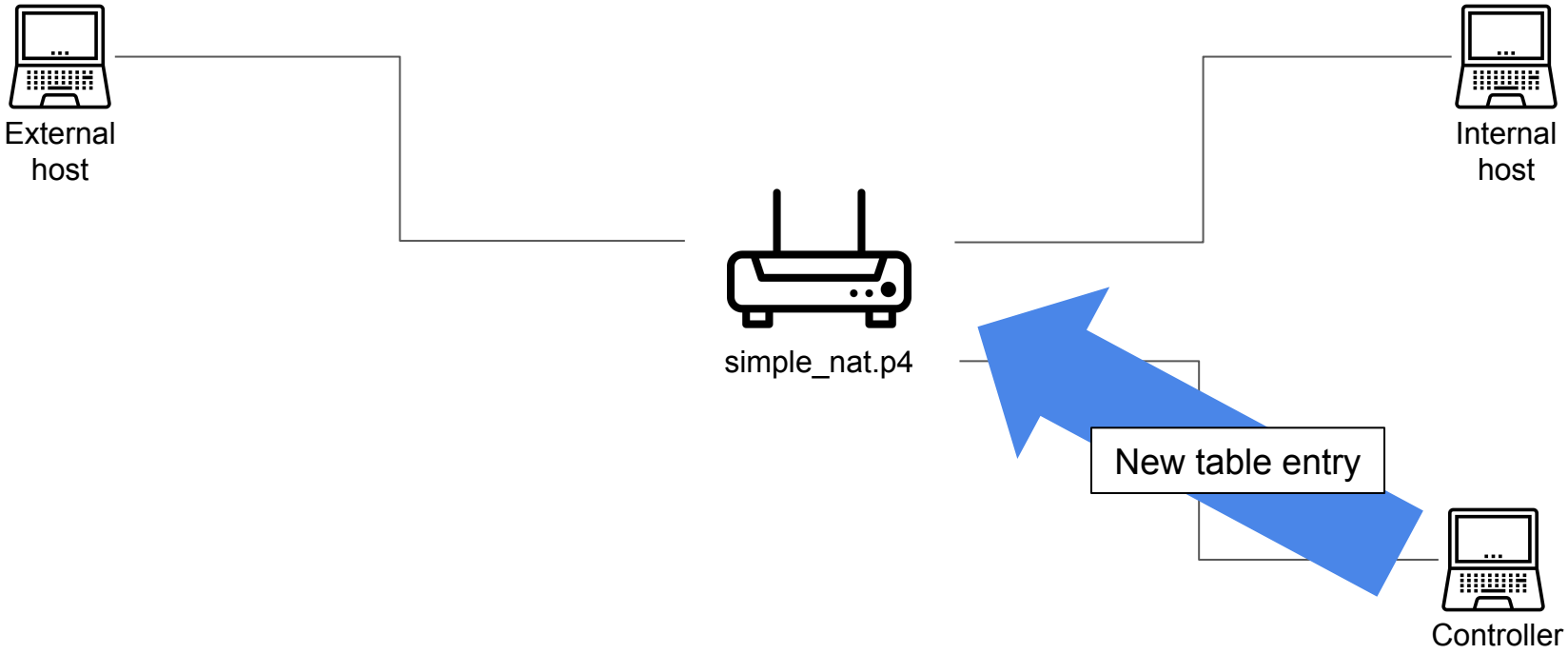

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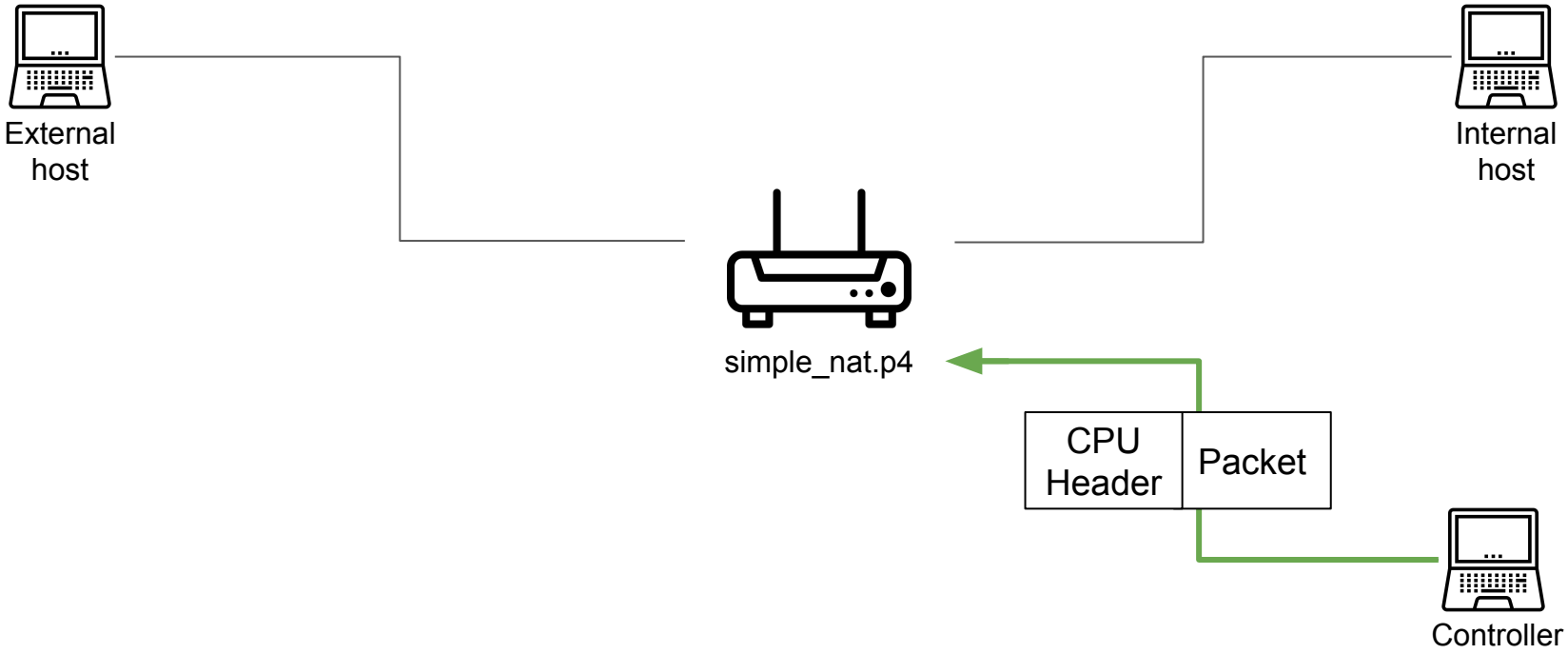

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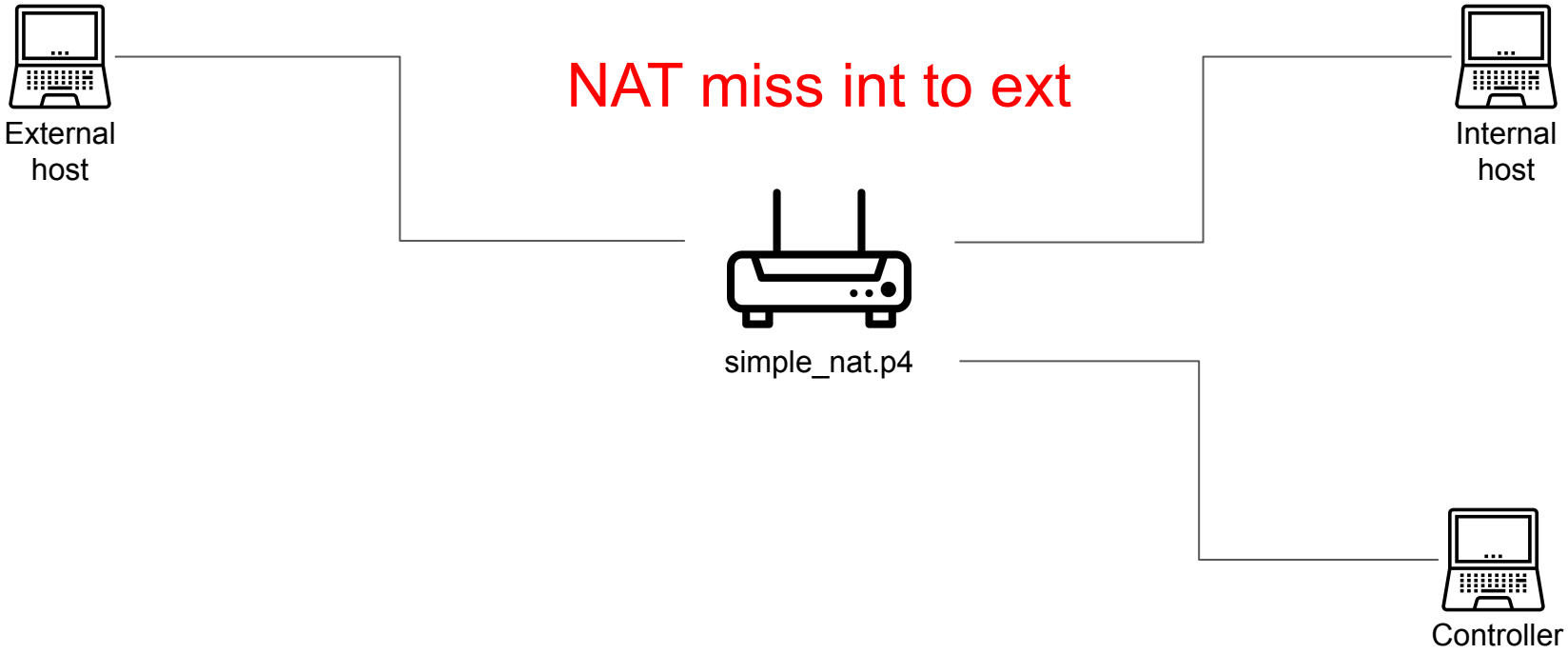

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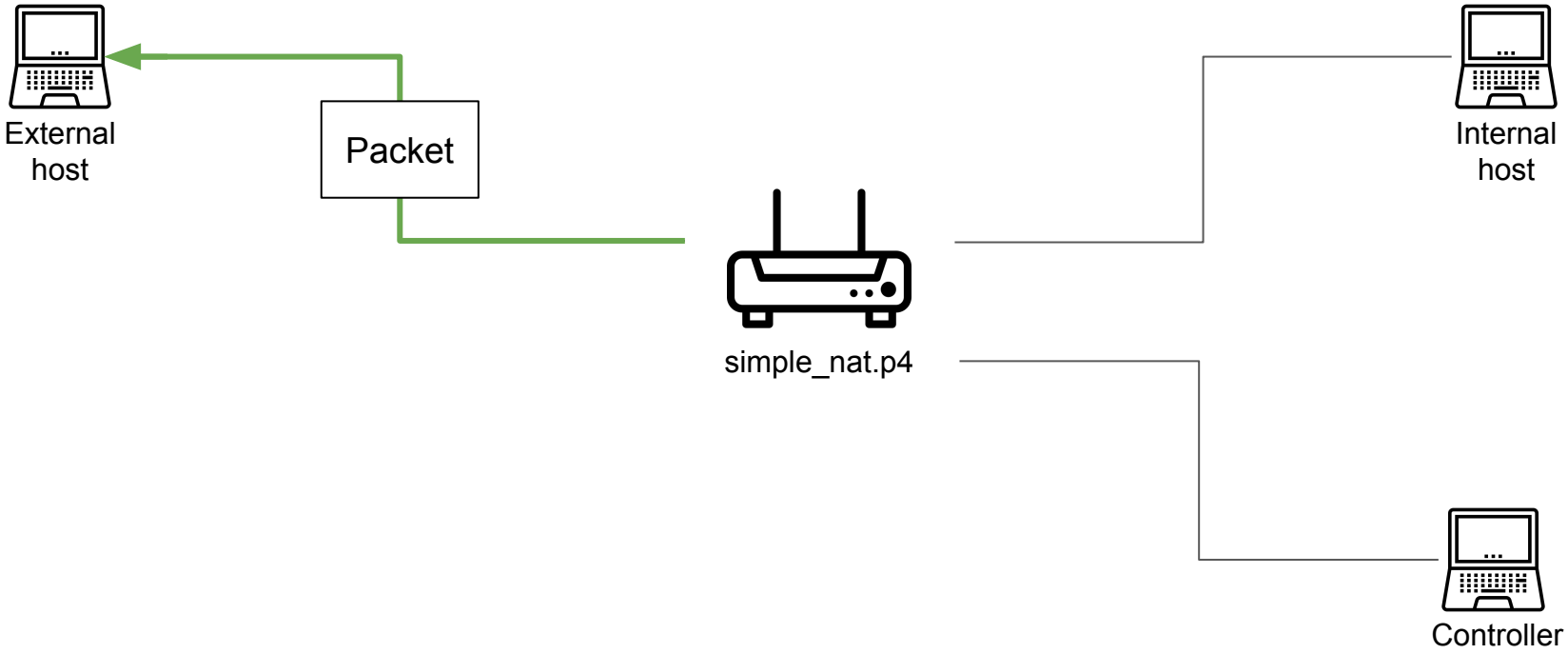
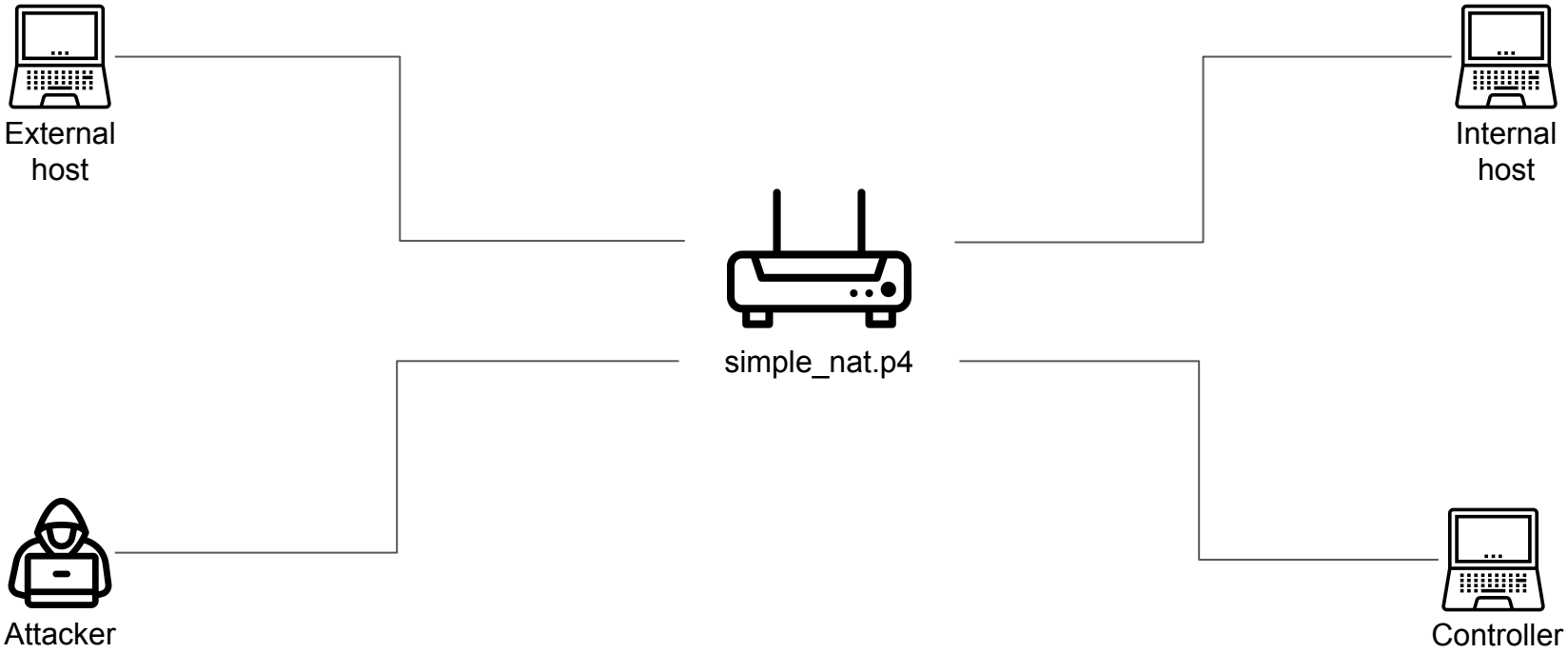


Simple NAT setup

Attacker model



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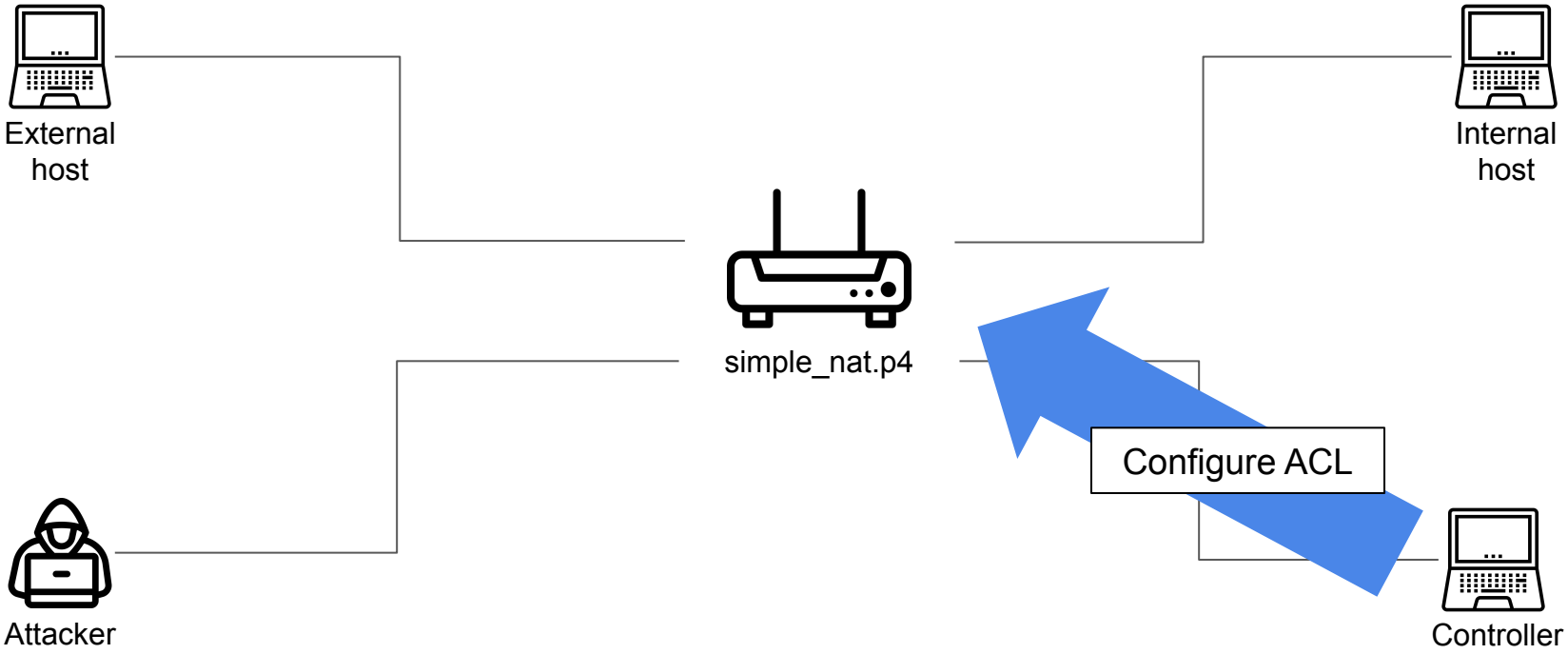

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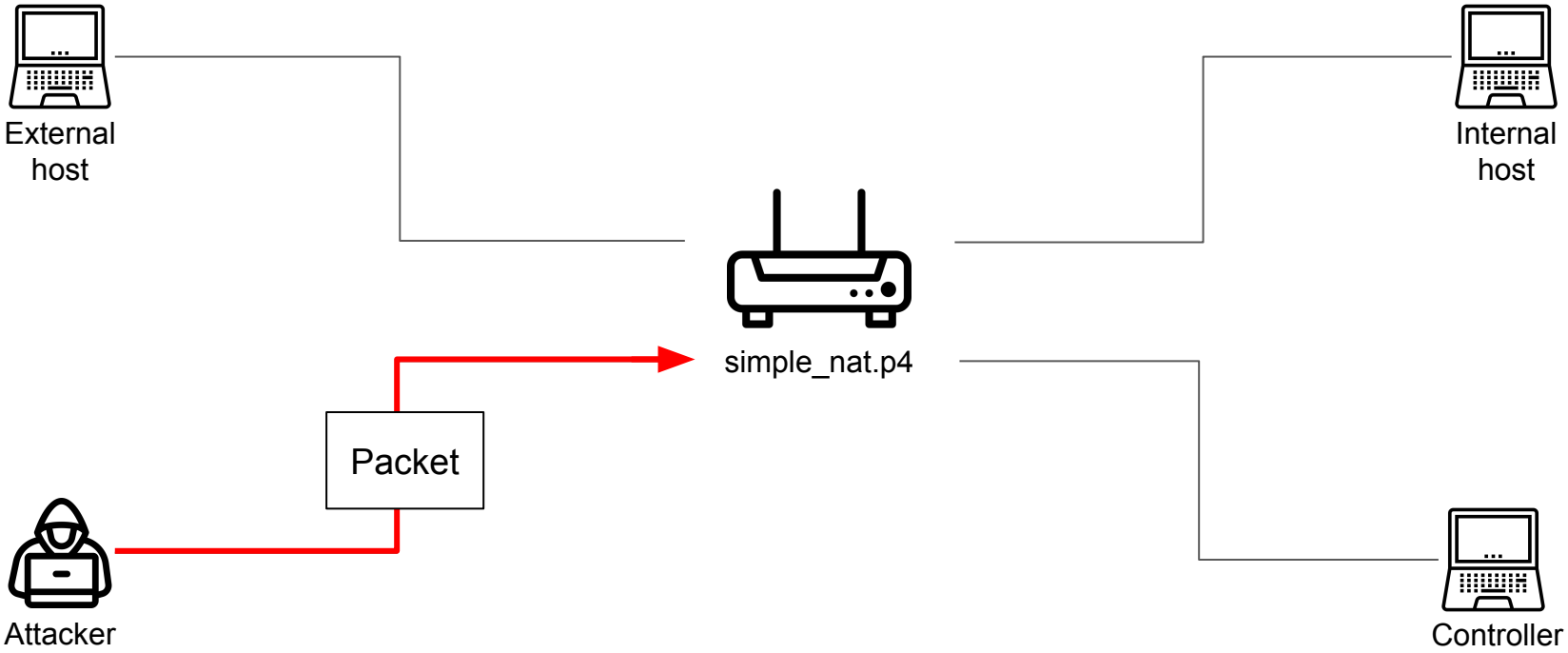

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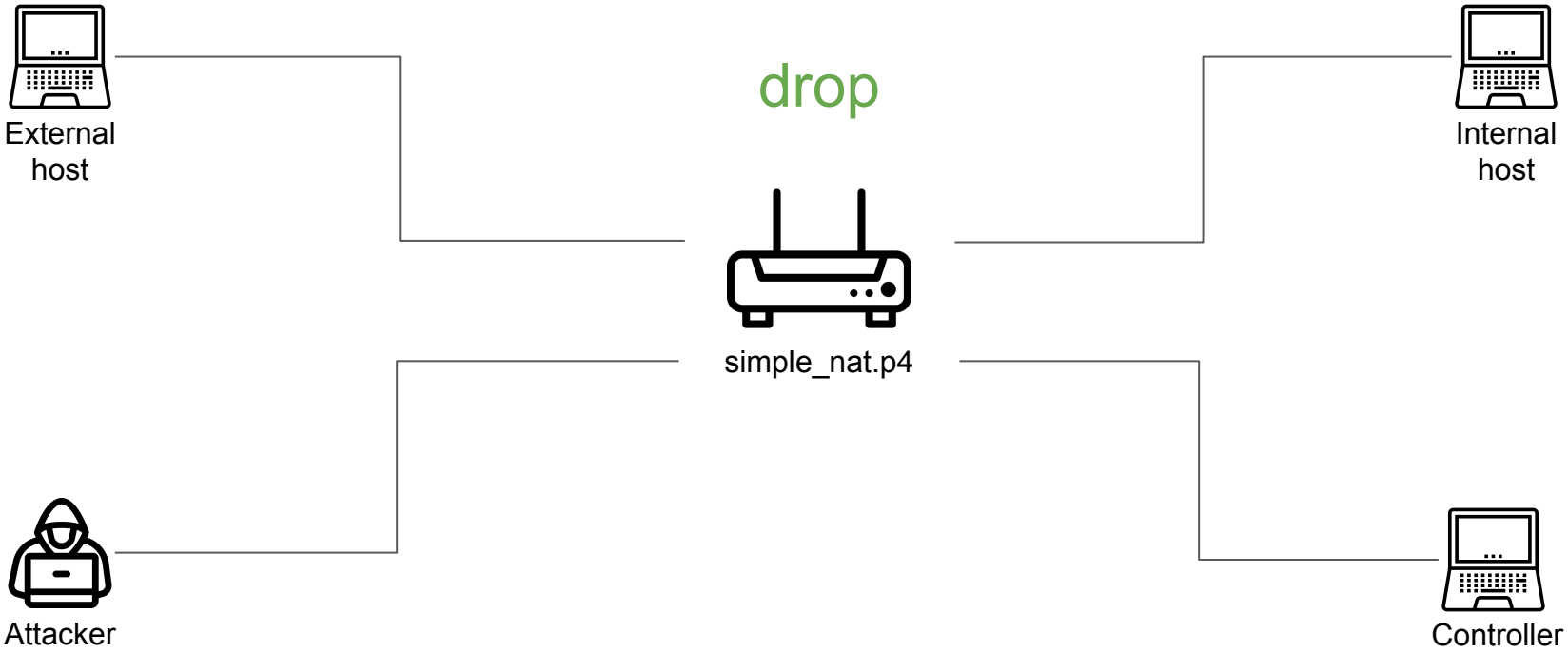
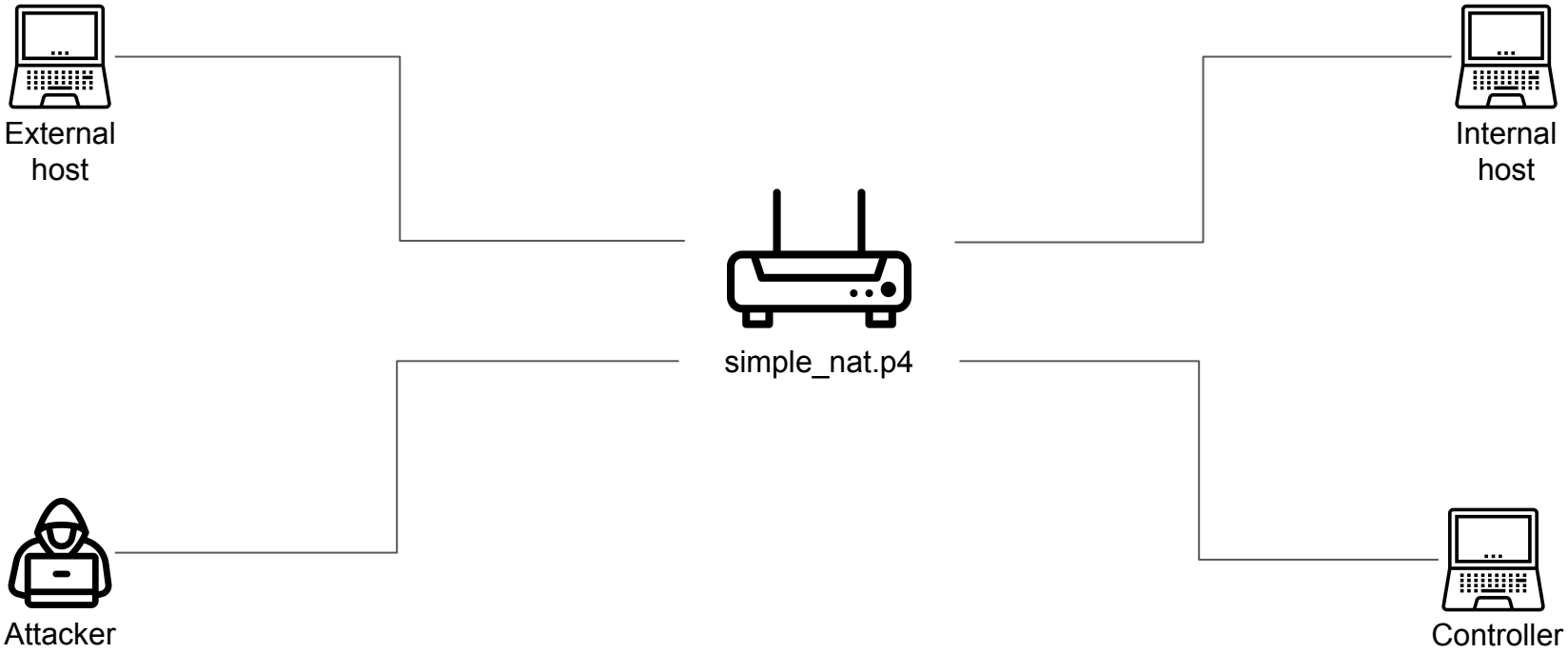


CPU header spoofing



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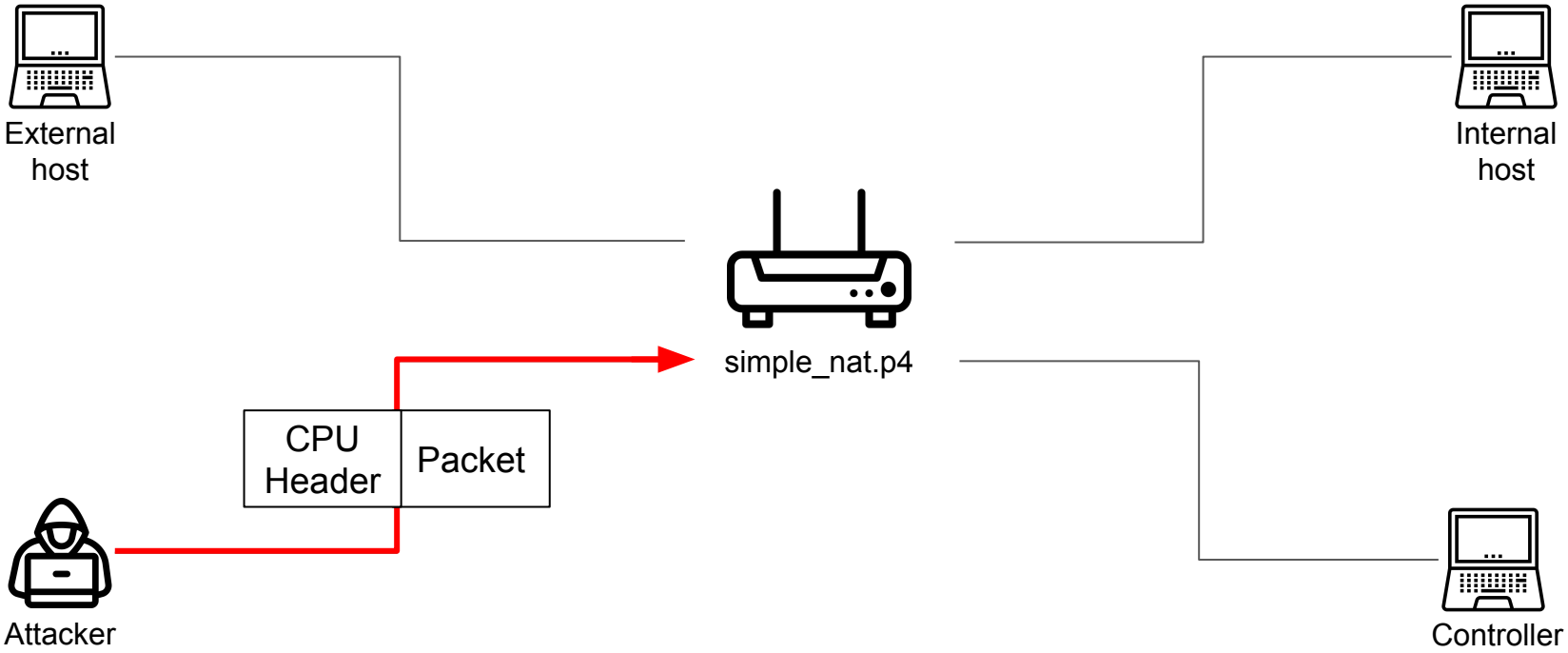

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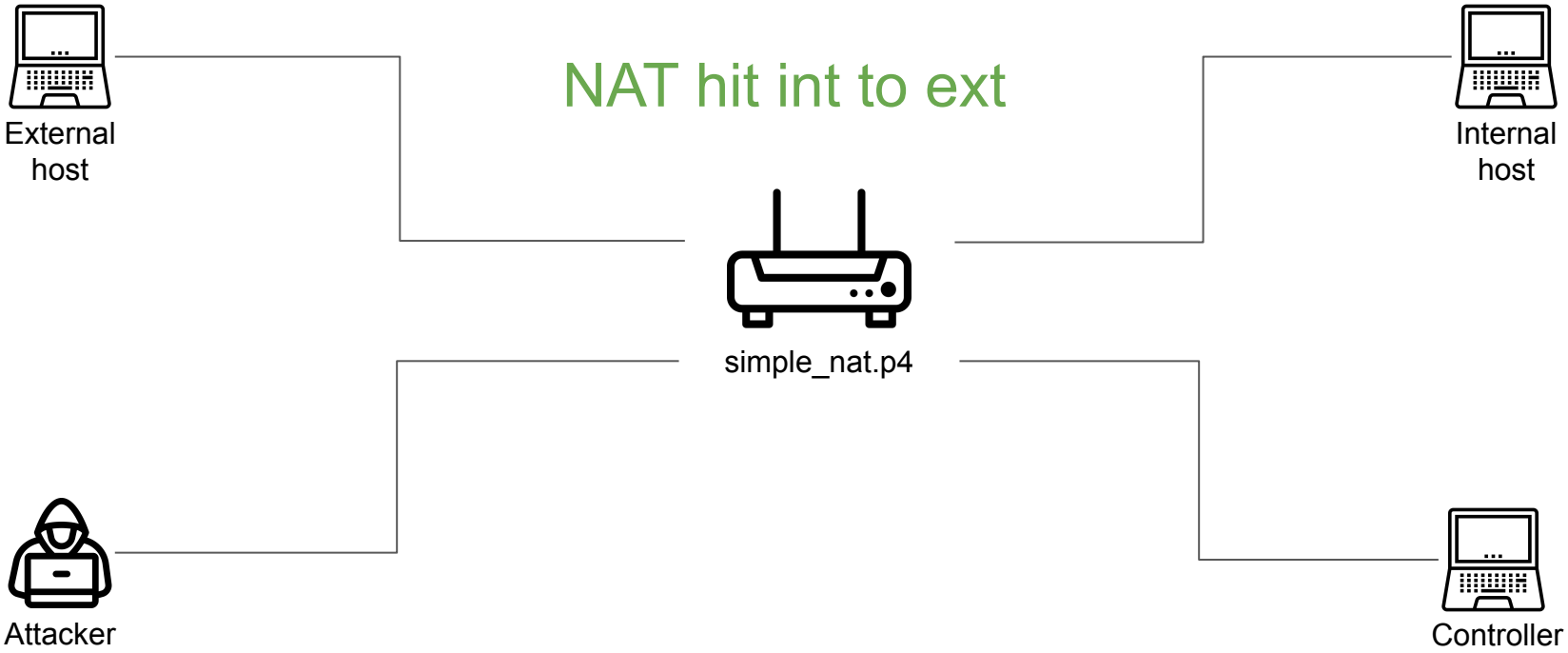

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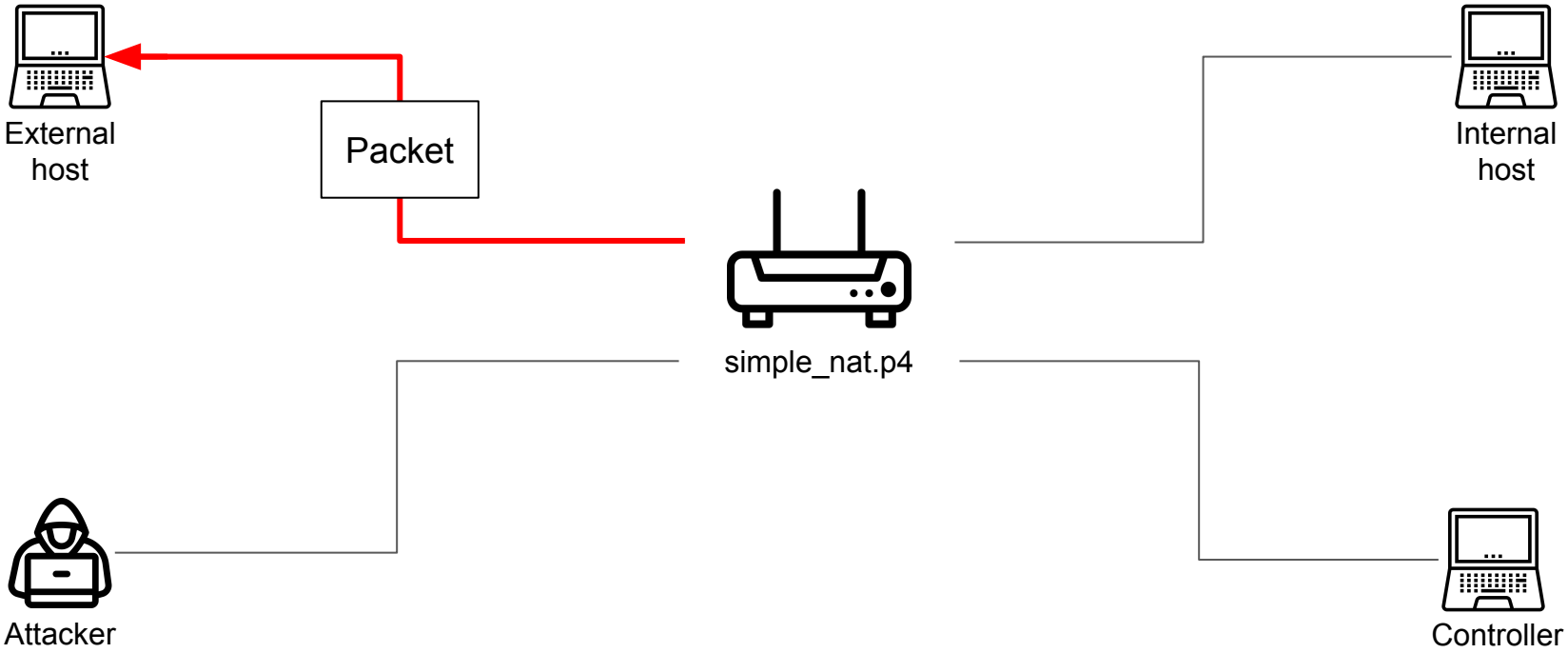

CPU header spoofing

Bypassing ACLs with revived packets

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apply(if_info);
apply(nat);
if (meta.do_forward == 1 && ipv4.ttl > 0) {
    apply(ipv4_lpm);
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          set_if_info;
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Packet from attacker is forwarded

What can and cannot be done exploit-wise?

Impossible attacks

- immutable code => no code injection
- no instruction pointer => no code reuse
- no dynamic memory > no use-after-free

Possible attacks

- data leakage
- Denial-of-Service
- spoofing

Summary

Assess exploitability of buggy P4 programs

Document undefined behaviors on real targets

Provide examples of exploits

Ongoing work:

- Explore weaker attackers
- Provide more exploits on real P4 programs
- Automate bug discovery and exploit generation