Preacher: Network Policy Checker for Adversarial Environments

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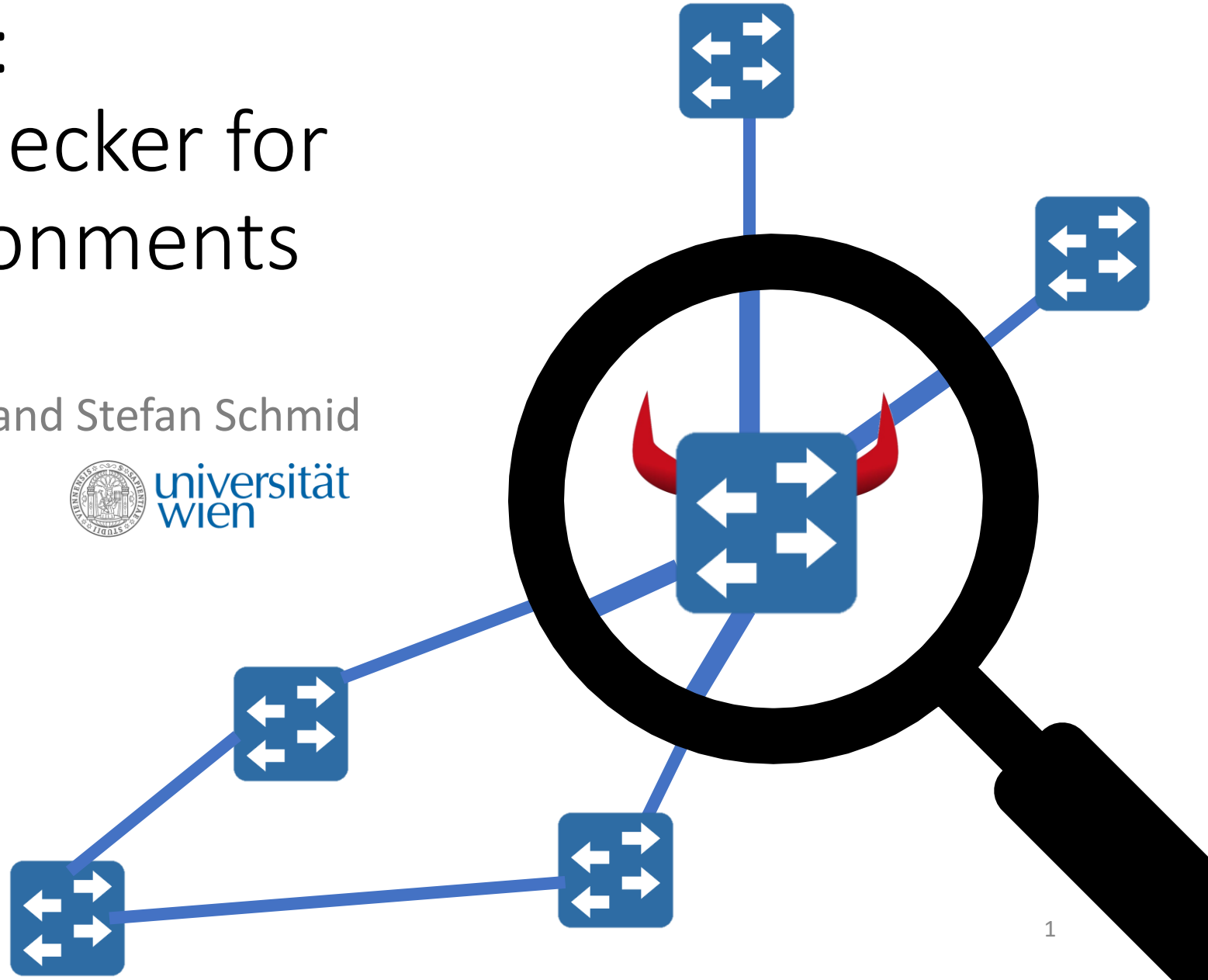

Backdoors and exploits

- Network devices are very effective attack vectors
  - Provide access to internal networks
  - Transparent to many security measures
  - Hard to detect
- Mostly used by state actors
  - Exploiting 0-day vulnerabilities
  - Compromising supply chains

[ovs-announce] CVE-2016-2074: MPLS buffer overflow vulnerabilities in Open vSwitch

Ben Pfaff blp at ovn.org
Mon Mar 28 17:10:13 PDT 2016

- Next message: [ovs-announce] Open vSwitch 2.4.1 and 2.3.3 Available
- **Messages sorted by:** [date] [thread] [subject] [author]

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Description
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Multiple versions of Open vSwitch are vulnerable to remote buffer
overflow attacks, in which crafted MPLS packets could overflow the
buffer reserved for MPLS labels in an OVS internal data structure.
The MPLS packets that trigger the vulnerability and the potential for
exploitation vary depending on version:

    - Open vSwitch 2.1.x and earlier are not vulnerable.
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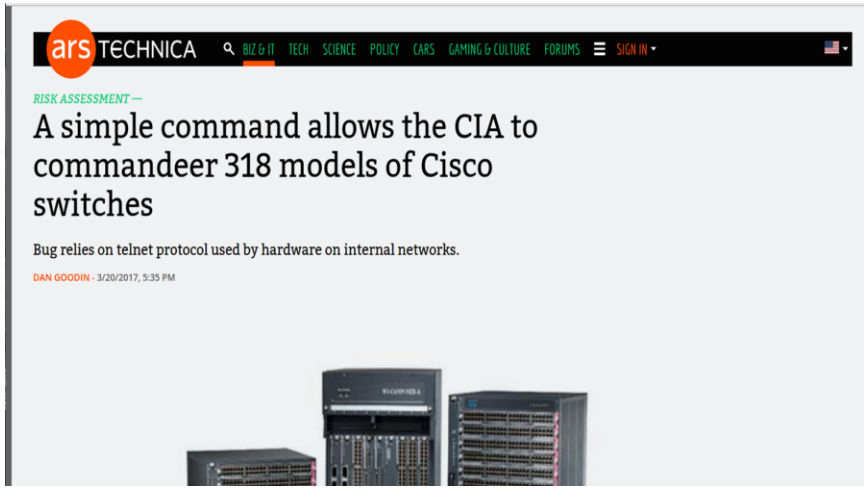
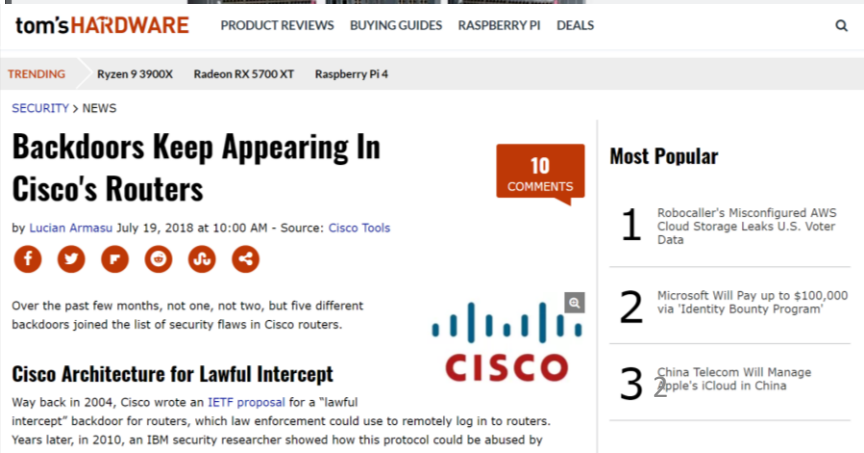


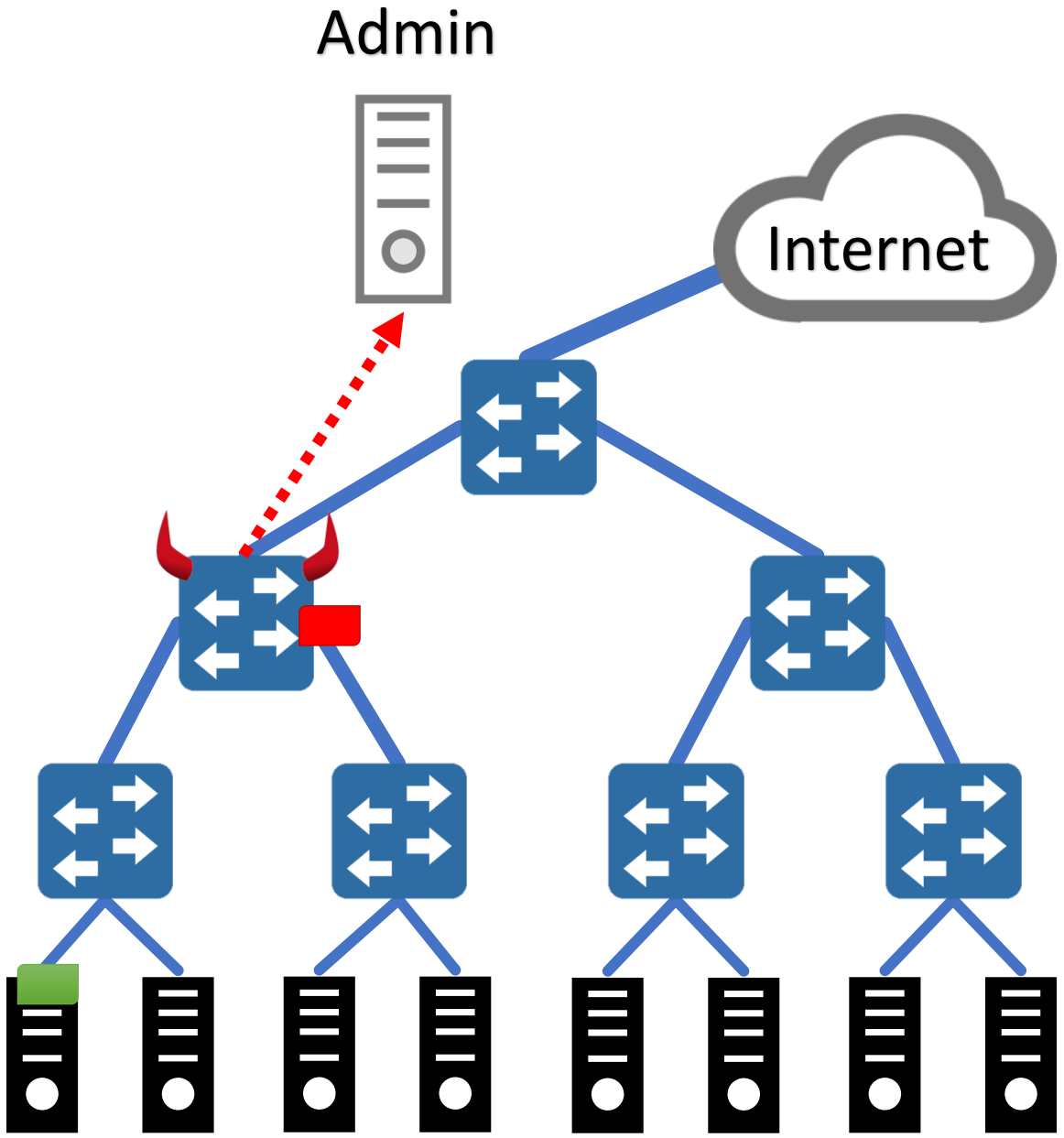


Attack model

- A compromised network device can run arbitrary malicious code.
  - Modify traffic
    - To attack network hosts (including DoS)
  - Report false configuration and state
    - To evade detection

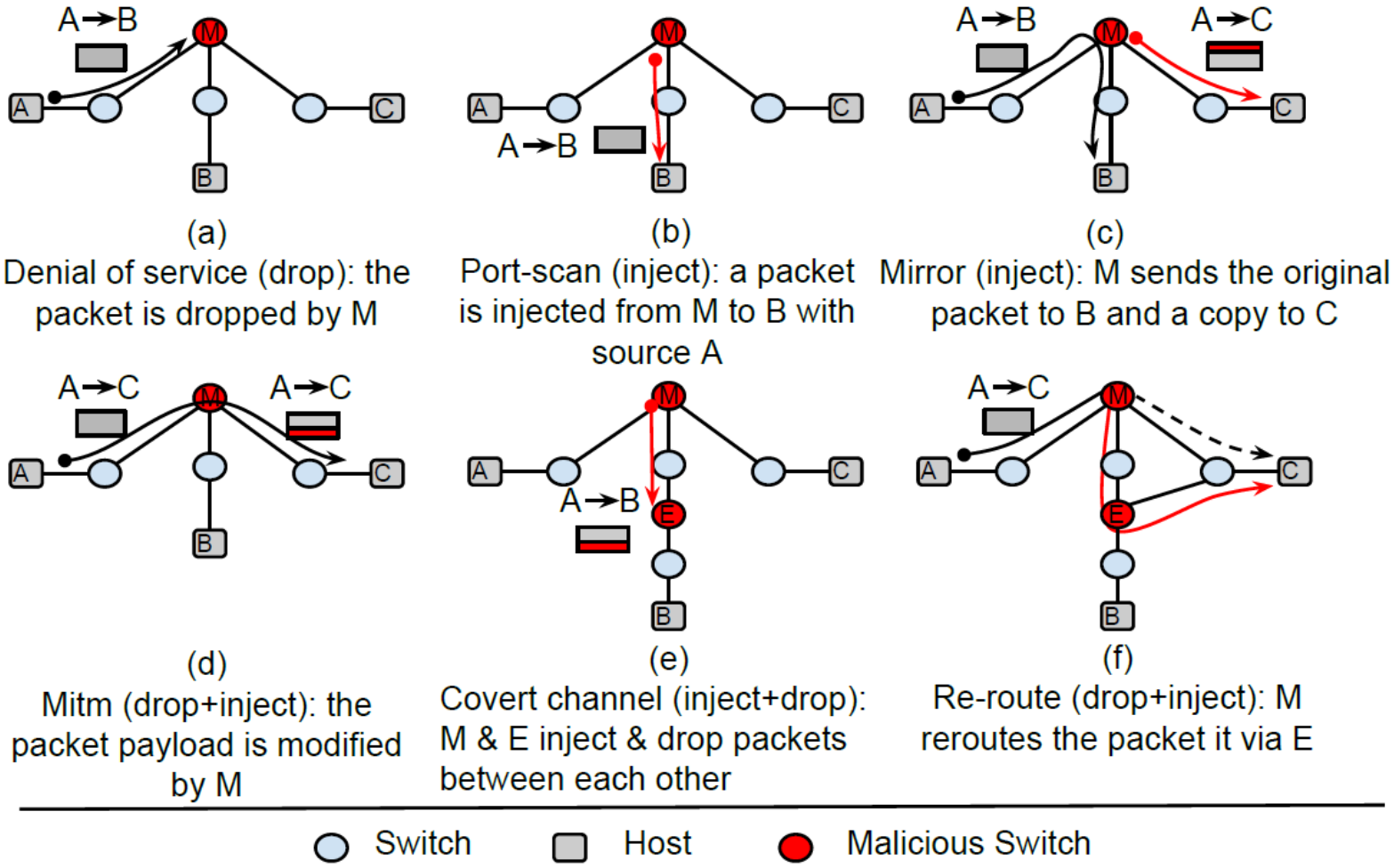
- Two attack building blocks:

1) **Drop:** An adversary prevents a packet from being sent (from one or more ports).
2) **Injection:** An adversary fabricates and sends a new packet or resends a packet sent earlier. This also includes sending a packet from an unintended port.



Attack model (cont.)

- Attack examples:
  a) Denial of service
  b) Port-scan
  c) Mirroring
  d) MitM
  e) Covert channel
  f) Re-route

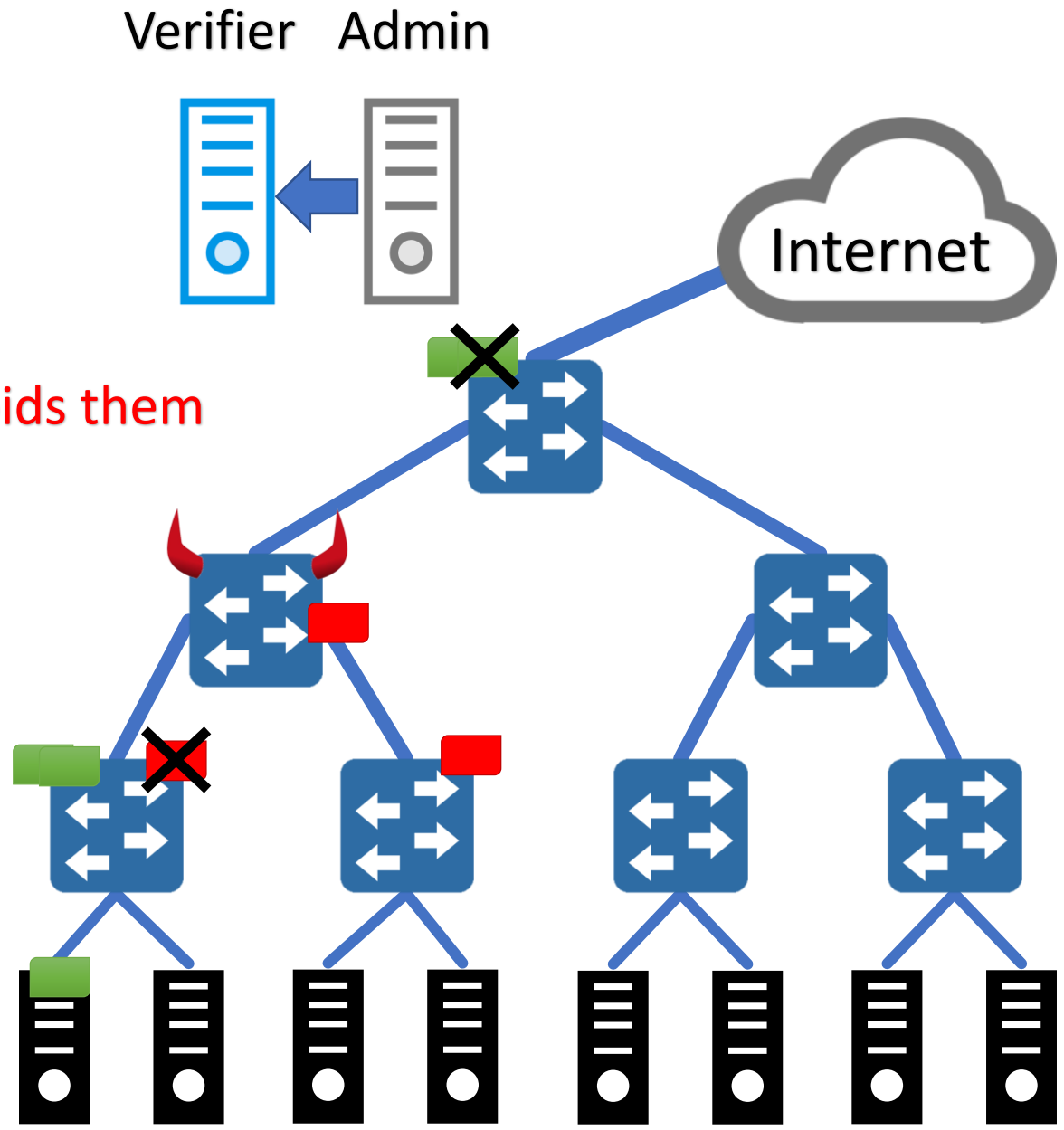


Naïve solution:

Trajectory Sampling (TS)

- Sample packets
  - Global set of hash values - Attacker avoids them
- Send samples to verifier
  - Attacker corrupt them on the way
- Compare trajectories to policy

- Good for traffic monitoring, but not suited adversarial settings

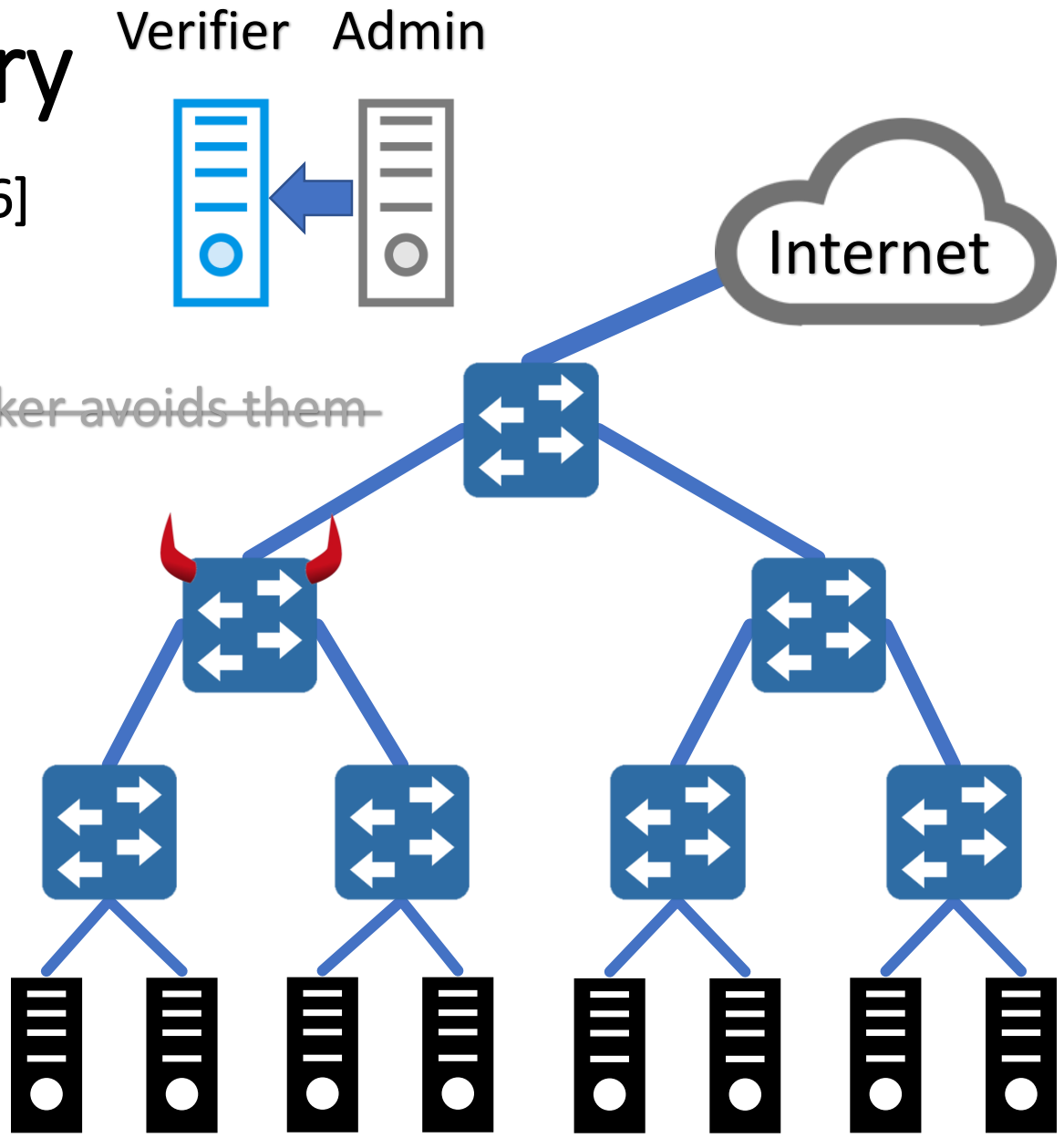


Split Assignment Trajectory Sampling (SATS) [Lee&Kim DSN06]

- Sample packets
  - Independent sets of hash values ~~– Attacker avoids them~~
- Send samples to verifier
  - Switch should use encryption
- Compare trajectories to policy

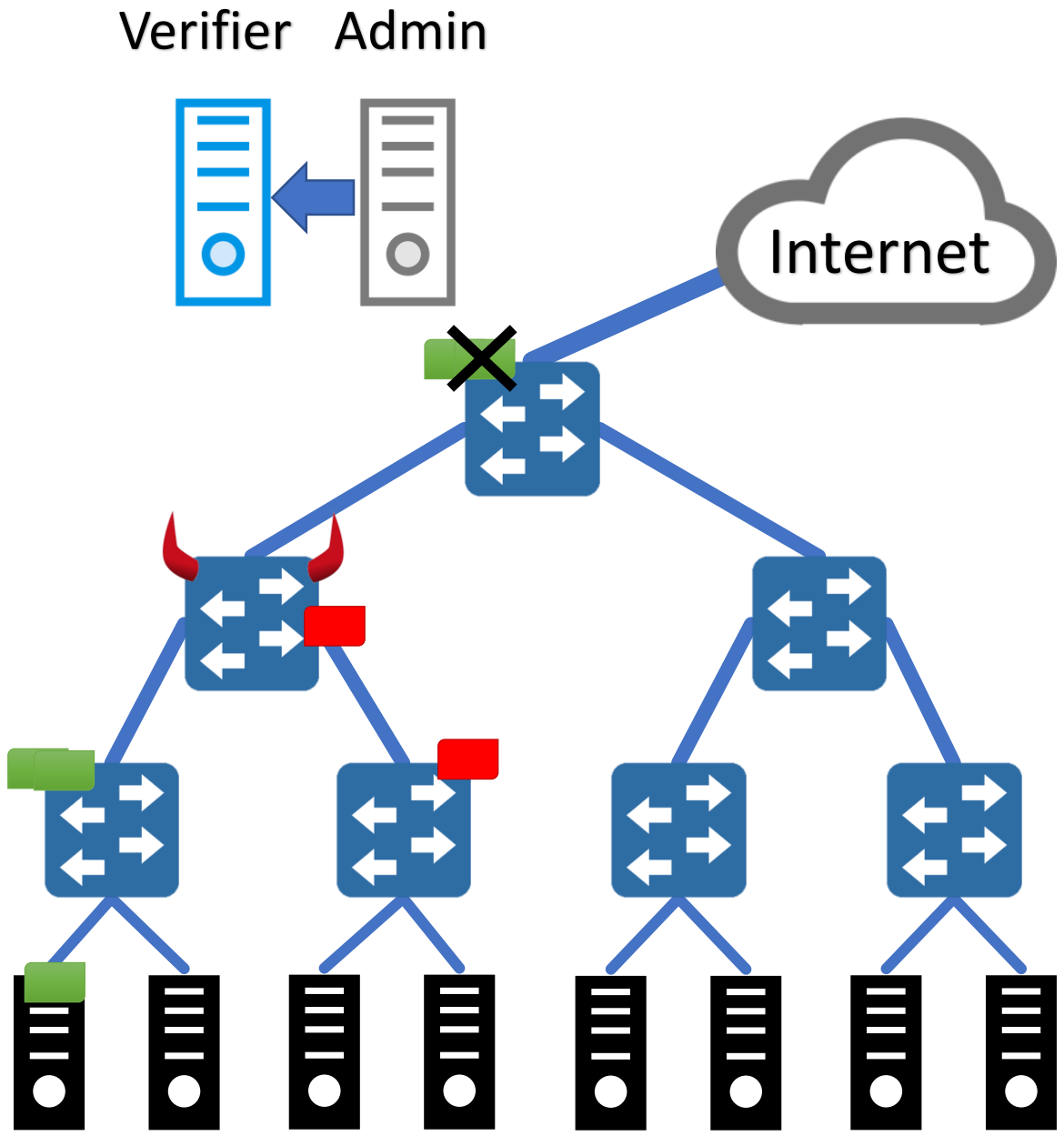
- Designed for adversarial settings

- But…



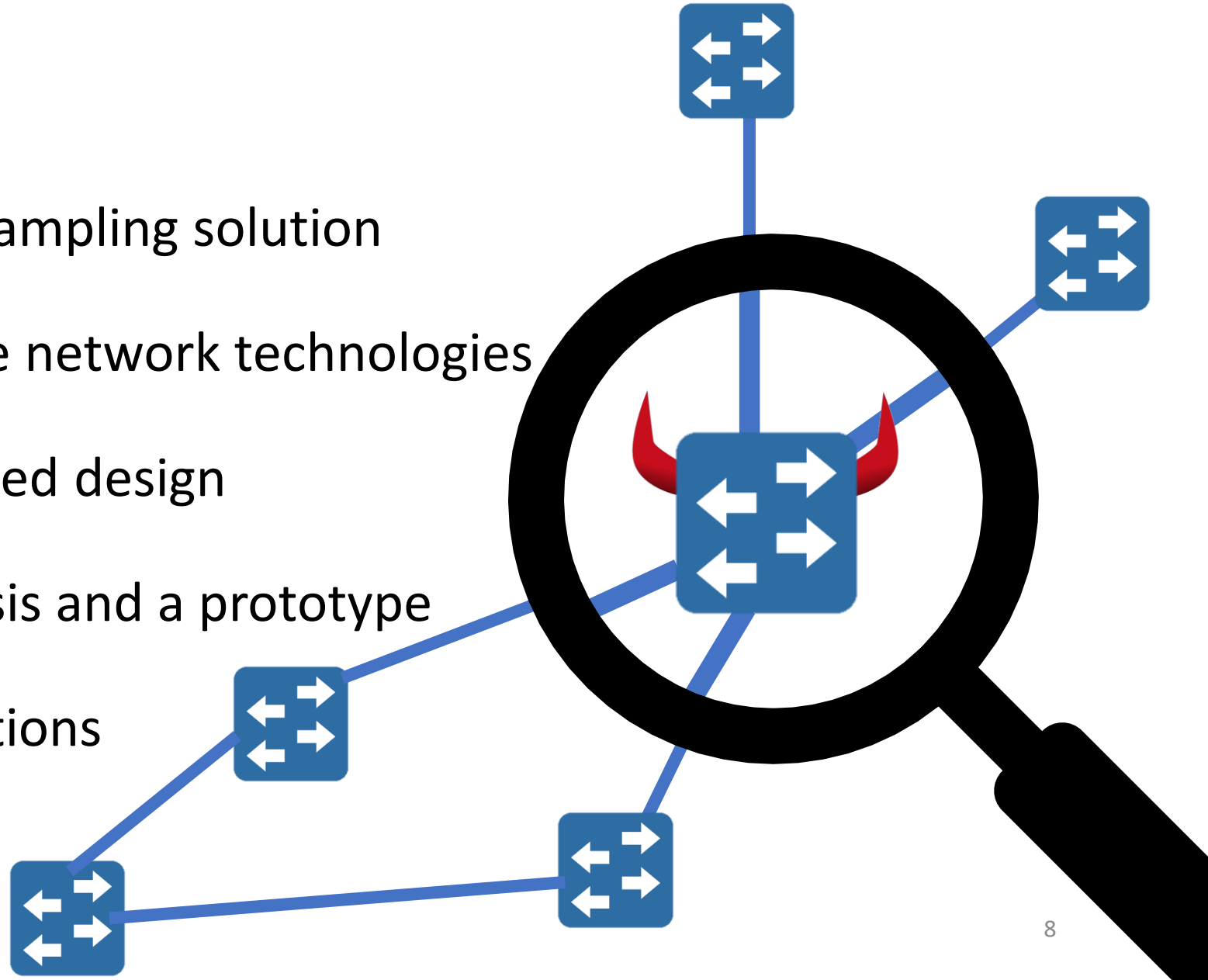
SATS Limitations

- Sample packets
  - Security guarantees?
  - Fixed-hash-crafted injection!
  - Switch compatibility
- Control plane security
  - Messages (samples and assignments)
  - Endpoints (verifier etc.)
- Compare trajectories to policy
  - Obtain policy (network compatibility)?
  - Scalability?



Preacher

- An improved trajectory sampling solution
- Harnesses programmable network technologies
- Uses robust and distributed design
- Includes a security analysis and a prototype
- Addresses all SATS limitations



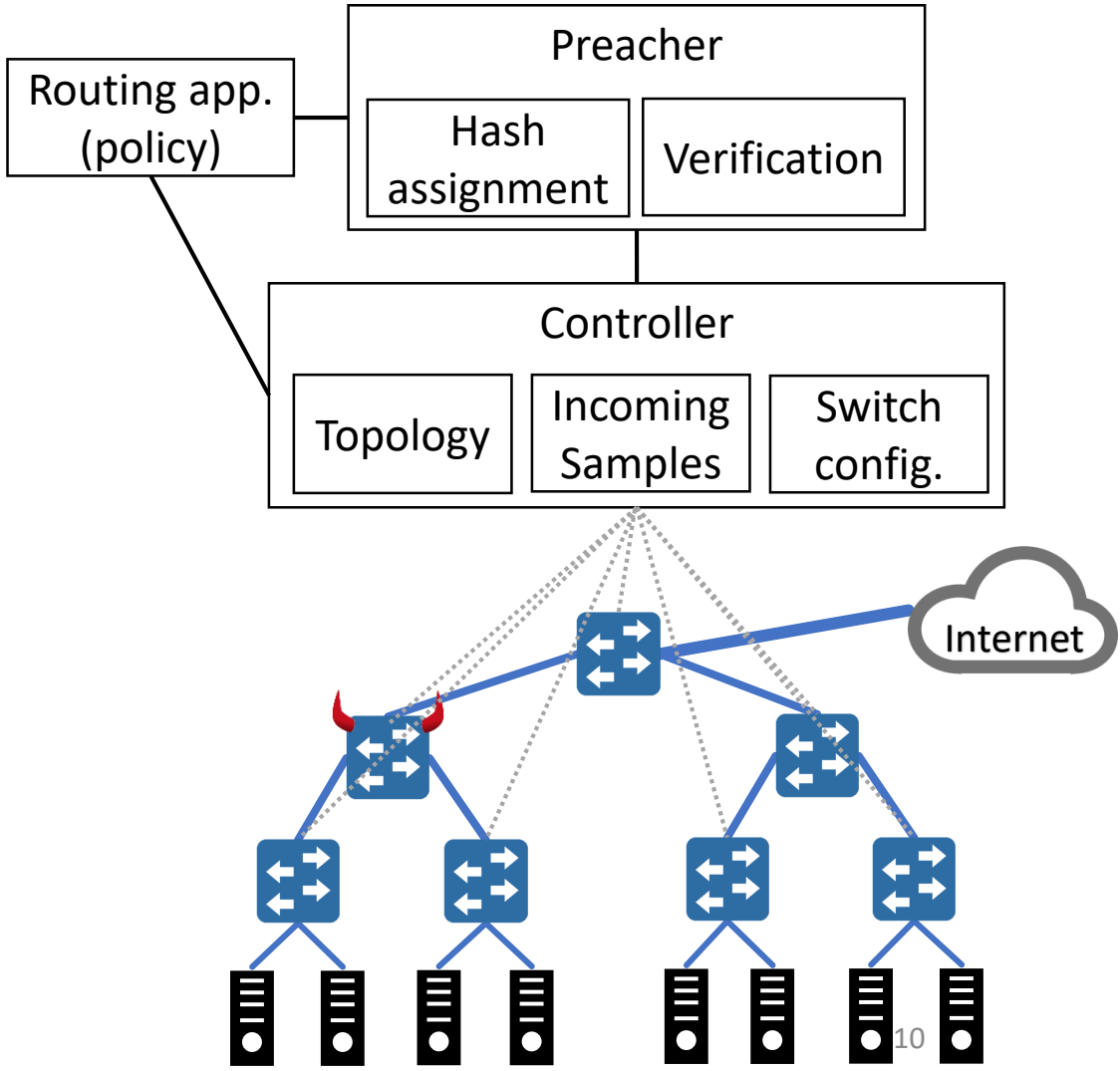
Contributions

- Sample packets
  - Security guarantees
  - Fixed-hash-crafted injection
  - Switch compatibility
- Control plane security
  - Messages (samples and assignments)
  - Endpoints (verifier etc.)
- Compare trajectories to policy
  - Obtain policy (network compatibility)
  - Scalability

✓ Analysis + evaluations
✓ Dynamic assignment
✓ SDN switch
✓ OpenFlow encryption
✓ Distributed design
✓ SDN controller
✓ Parallel design

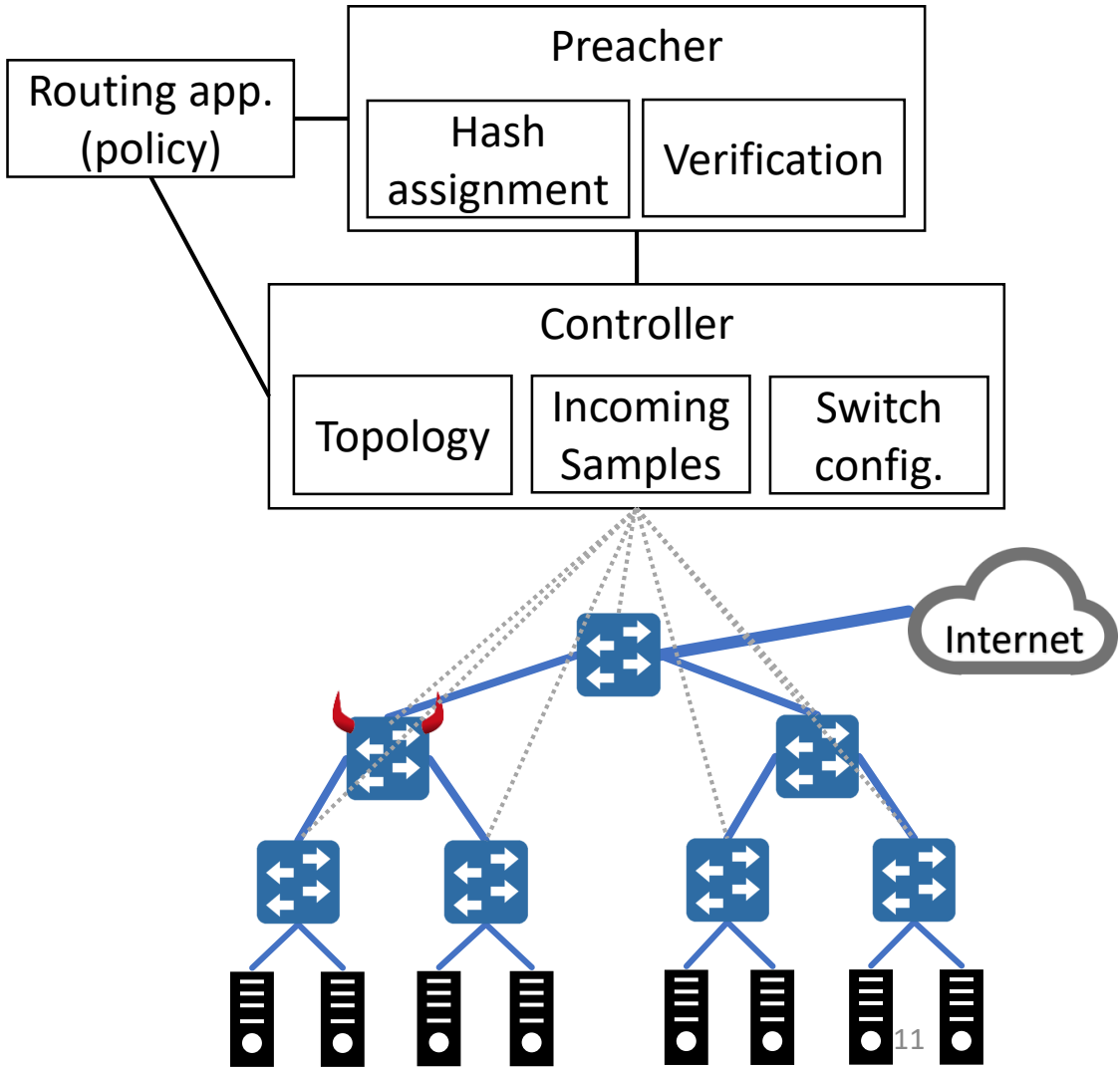
Preacher Scheme

- Cooperates with controller and routing apps
  - Sends hash assignments (switch configuration)
  - Receives samples (e.g., PacketIns)
  - Obtains a policy
- Verifies samples
  - For each sample computes other expected samples (using the policy)
  - Detects inconsistencies (with timeouts)



Preacher Scheme – Distributed and Parallel

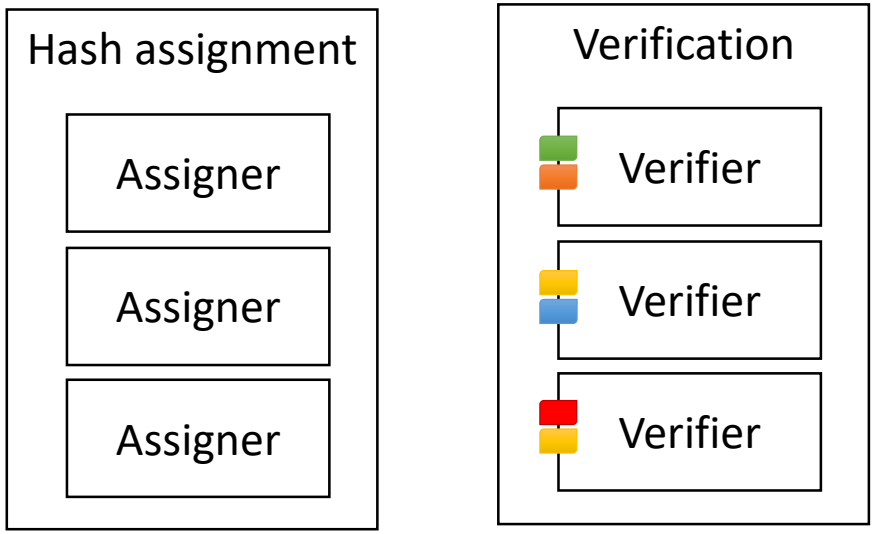
Use redundancy to improve security and fault tolerance!

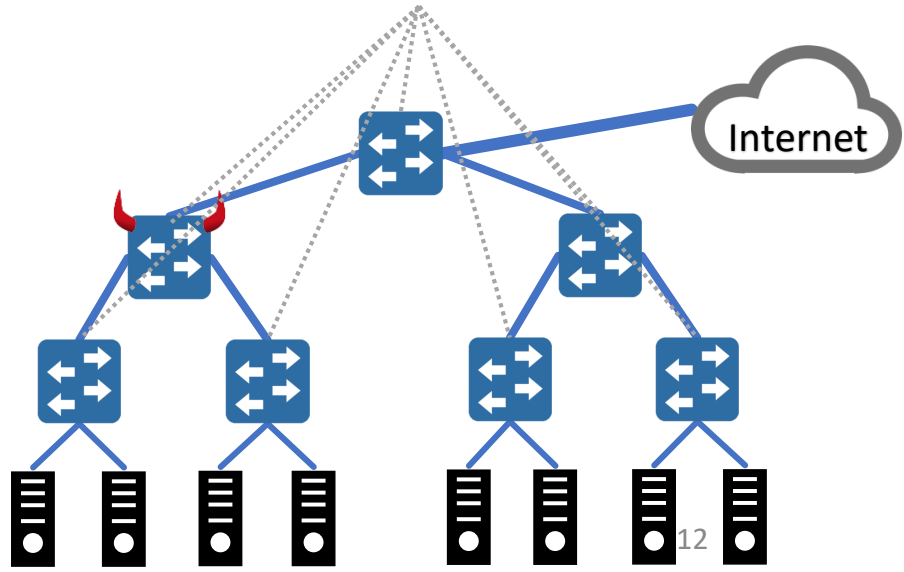


Preacher Scheme – Distributed and Parallel

Use redundancy to improve security and fault tolerance!

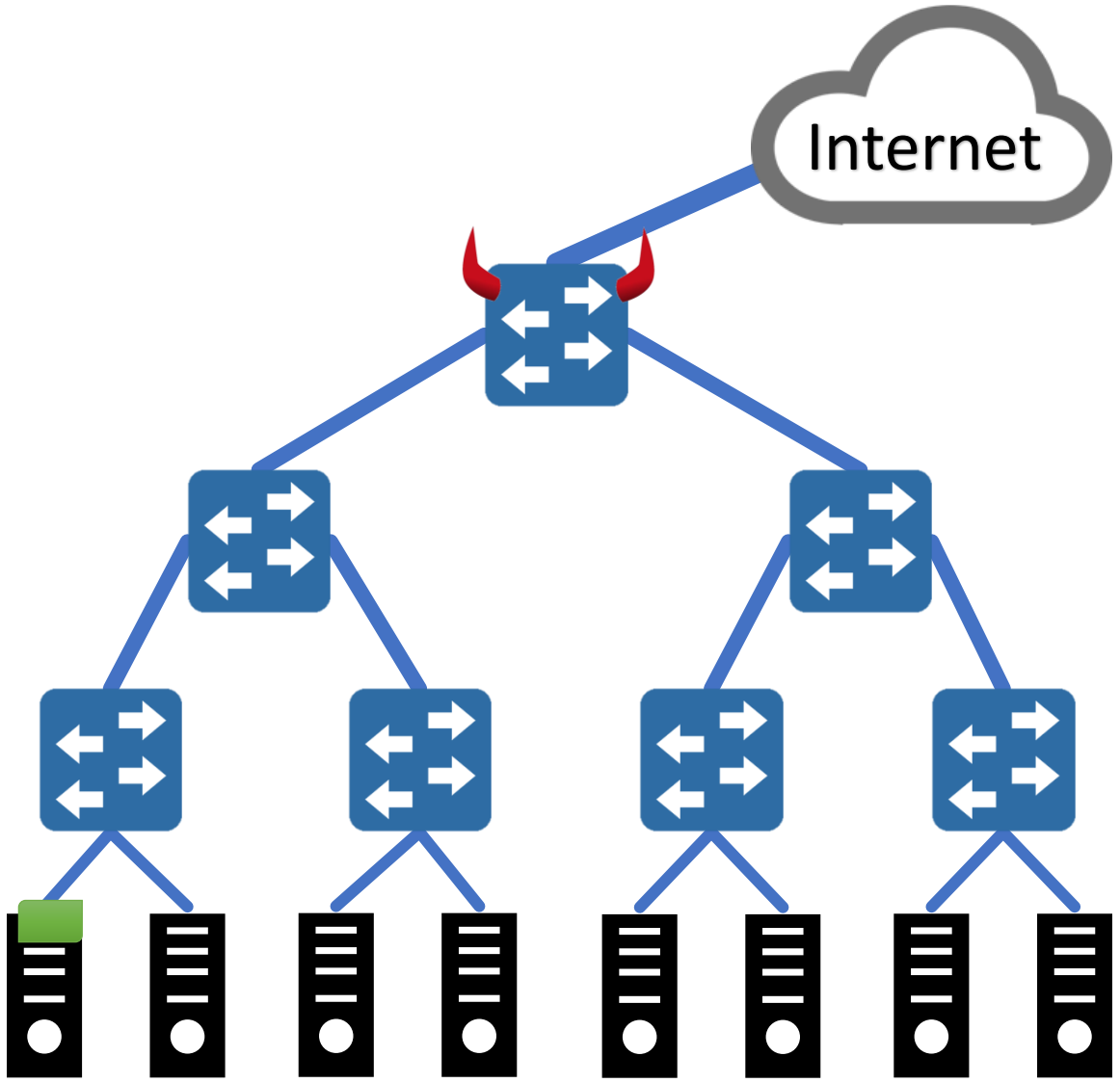
- Hash Assignment
  - Each assigner configures a subset of switches (or pairs)
  - Compromise or malfunction of one assigner is not fatal
- Verification
  - Each verifier is responsible for a subset of hashes, and receives a subset of the samples.
  - Better performance and security (depending on subset overlaps)



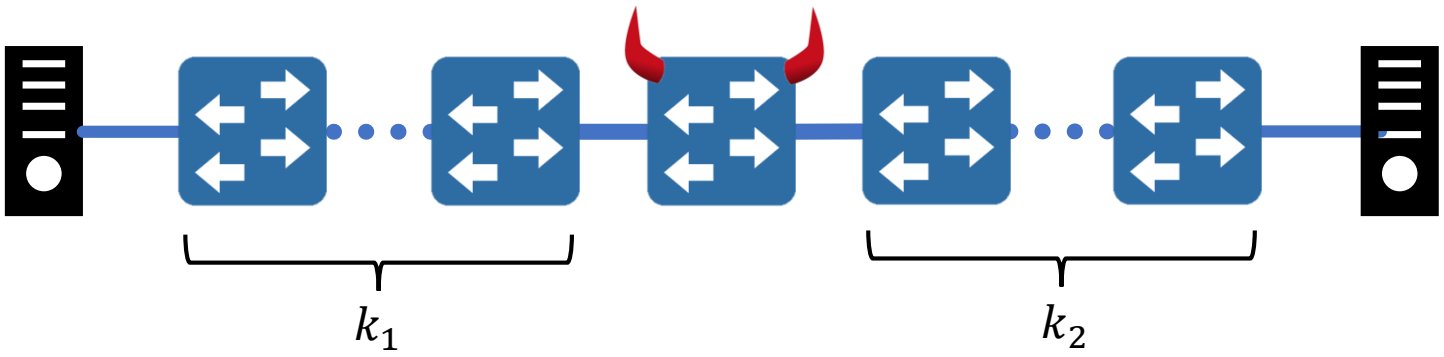


Security Analysis

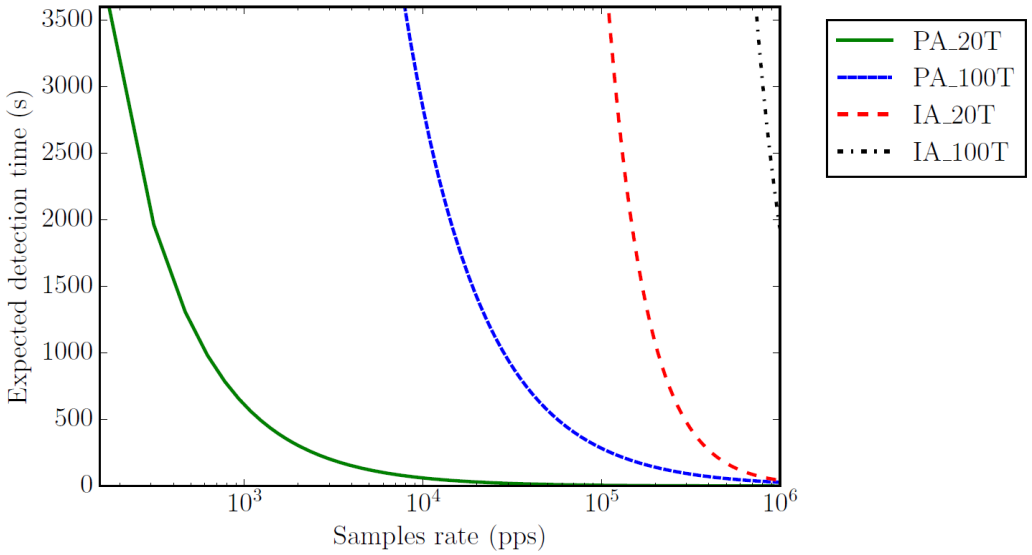
- An attack occurs along a directed path
  - Where the packet should have traversed
- Detection requirement
  - Attacked packet hash is assigned before and after attack
  - Same for drop and inject
- Hash assignments
  - Each switch is assigned with p of hash space. p is very small ($p \ll \frac{1}{n}$).
  - Independent vs. pairs assignment



Security Analysis

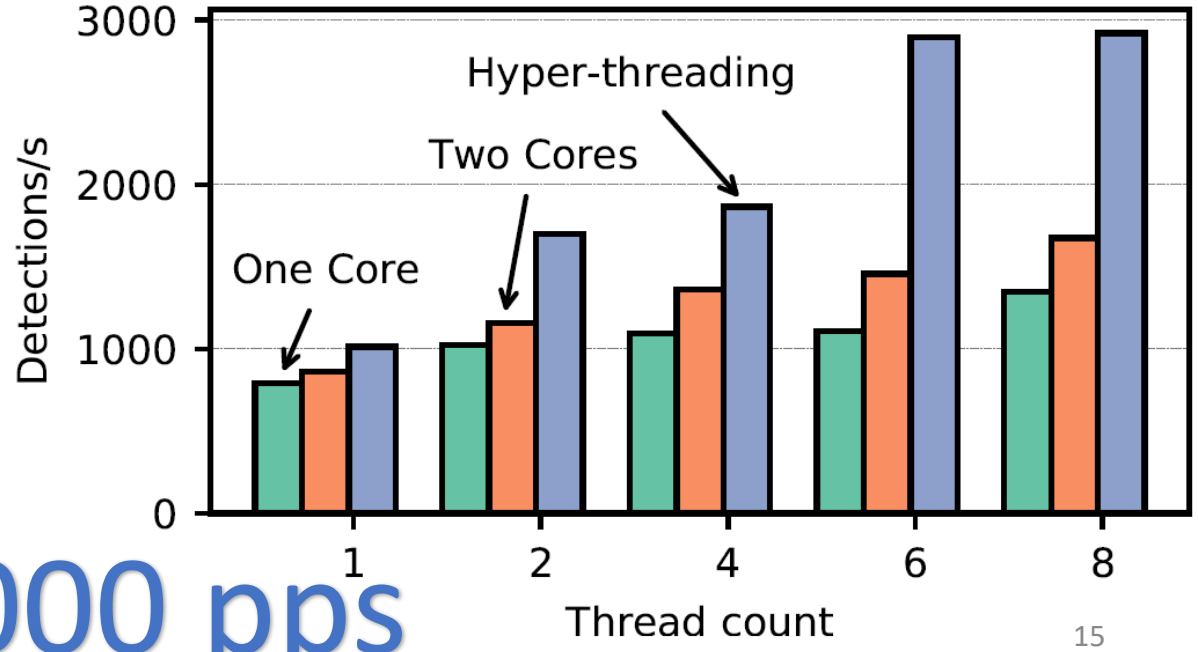


- Detection probability
  - For independent assignment:
    $$P_{ia} = \left(1-(1-p)^{k_1}\right)\cdot\left(1-(1-p)^{k_2}\right) \approx p^2 k_1 k_2$$
  - For pairs assignment:
    $$P_{pa} > 1-\left(1-\frac{p}{n-1}\right)^{k_1 k_2} \approx \frac{p k_1 k_2}{n-1}$$
- We assume *#packets-till-detection* follows geometric distribution.
- We use common packet rates to get *expected detection time*.
- We use common data center link capacities to derive expected total *samples' rate (pps)*.



Evaluation

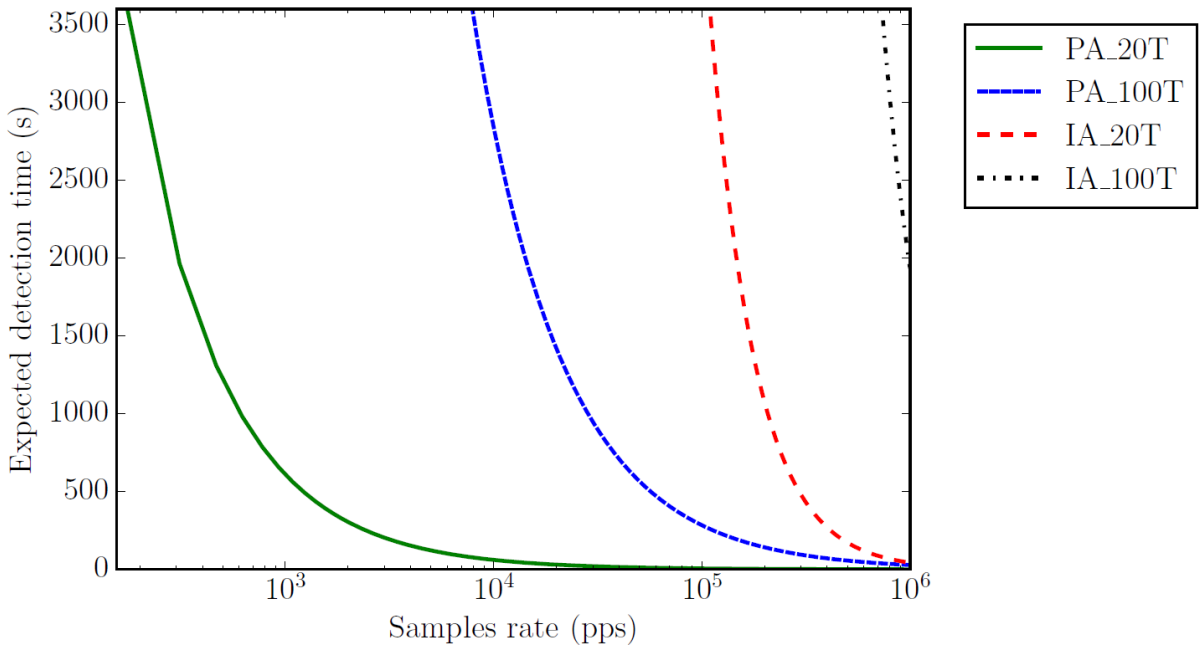
- Prototype based on ONOS-1.4 with OpenFlow 1.3 as controller.
  - Used services: Flow objective, Flow rule, Device, Packet-in
- Clos topology with k=4
  - Open vSwitch (OvS) for switches
- Experiments goals:
  - Verifying analysis
  - Evaluating overheads
    - Switch
    - Controller
  - Evaluating throughput



1 core ≈ 1000 pps

Detection Time vs. Resources

- With pairs-assignment
  - Attacks in small network can easily be detected within minutes
  - In big networks ~10 servers (~100 cores) are needed.
- With simple independent assignment
  - Even in small networks it is very hard to detect.
  - In big networks it is infeasible.



Future work

- Implementation with more programmable network devices
  - hardware switches, P4 switches and smart NICs
- Experimenting at SDN datacenters

Summary

- Preacher harnesses programmable network technologies
- Uses distributed design to ensure robustness and security
- Provides provable security
- Open source prototype is available at:

  www.github.com/securedataplane/preacher