Automatic Test Packet Generation

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CS@Stanford Network Outage

Tue, Oct 2, 2012 at 7:54 PM:

"Between 18:20-19:00 tonight we experienced a complete network outage in the building when a loop was accidentally created by CSD-CF staff. We're investigating the exact circumstances to understand why this caused a problem, since automatic protections are supposed to be in place to prevent loops from disabling the network."

Outages in the Wild

On April 26, 2010, NetSuite suffered a service outage that rendered its cloud-based applications inaccessible to customers worldwide for **30 minutes**… NetSuite blamed a **network issue** for the downtime.

Hosting.com's New Jersey data center was taken down on June 1, 2010, igniting a cloud **outage and connectivity loss for nearly two hours**… Hosting.com said the connectivity loss was due to a **software bug in a Cisco switch** that caused the switch to fail.

The Planet was rocked by a pair of network outages that knocked it **off line for about 90 minutes** on May 2, 2010. The outages caused disruptions for **another 90 minutes** the following morning.... Investigation found that the outage was **caused by a fault in a router** in one of the company's data centers.

Network troubleshooting a problem?

- Survey of NANOG mailing list (June 2012)
  - Data set: 61 responders: 23 medium size networks (<10K hosts), 12 large networks (< 100K hosts)
  - Frequency: 35% generate >100 tickets per month
  - Downtime: 25% take over an hour to resolve. (estimated $60K-110K/hour [1])
  - Current tools: Ping, Traceroute, SNMP
  - 70% asked for better tools, automatic tests

[1] http://www.evolven.com/blog/downtime-outages-and-failures-understanding-their-true-costs.html

The Battle

Hardware
Buffers, fiber cuts, broken interfaces, mis-labeled cables, flaky links

Software
firmware bugs, crashed module

vs

`ping, traceroute, SNMP, tcpdump`

+

wisdom and intuition

Automatic Test Packet Generation

Goal: automatically generate test packets to test the network state, and pinpoint faults before being noticed by application.

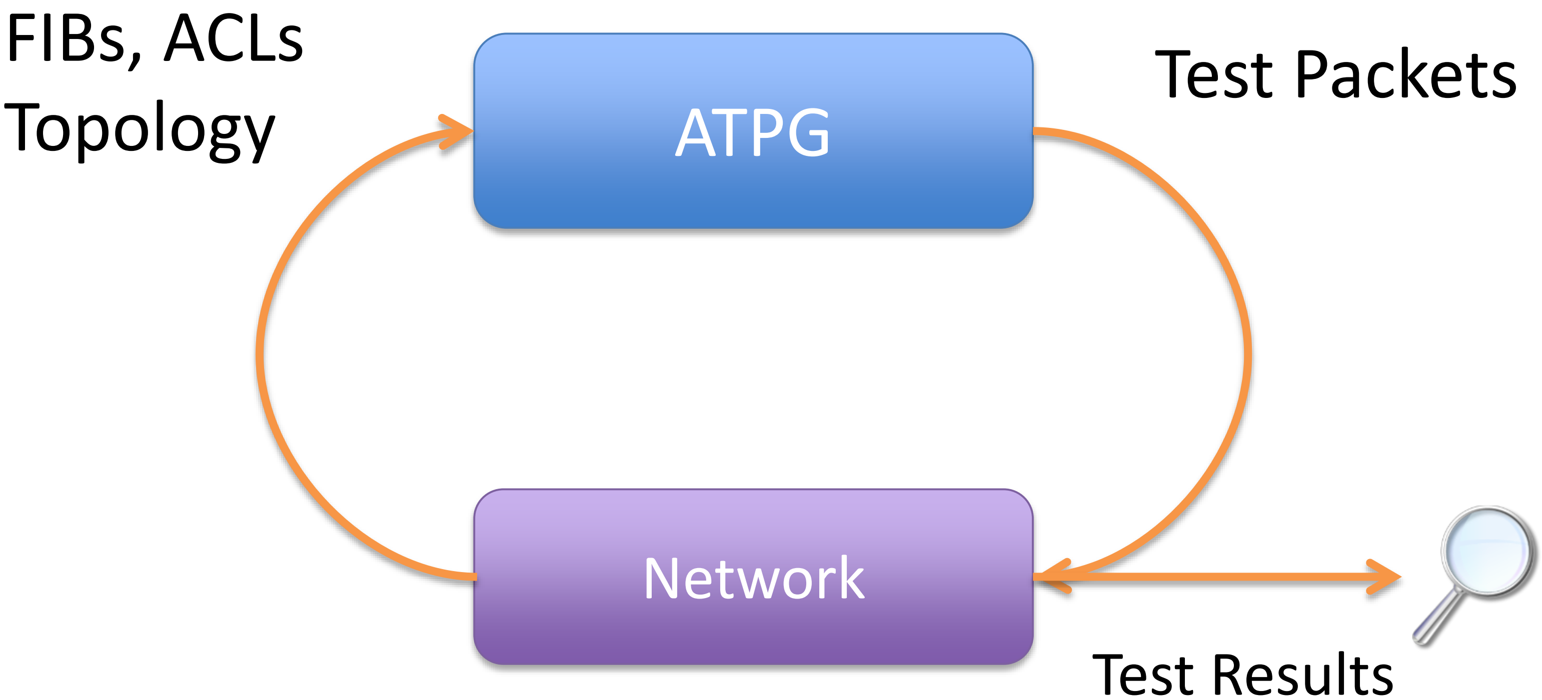
Augment human wisdom and intuition.

Reduce the downtime.

Save money.

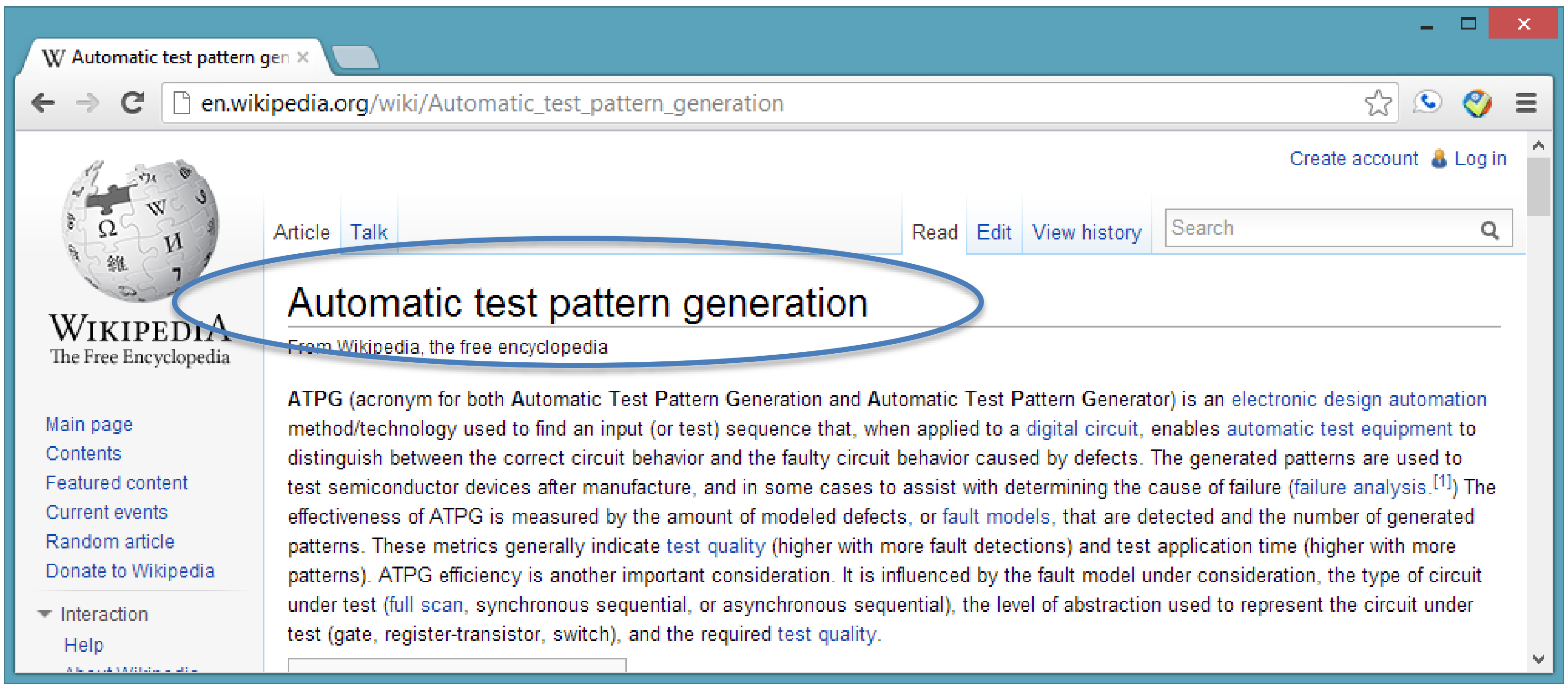
Non-Goal: ATPG cannot explain why forwarding state is in error.

ATPG Workflow



Systematic Testing

- Comparison: chip design
  - Testing is a billion dollar market
  - ATPG = Automatic Test Pattern Generation

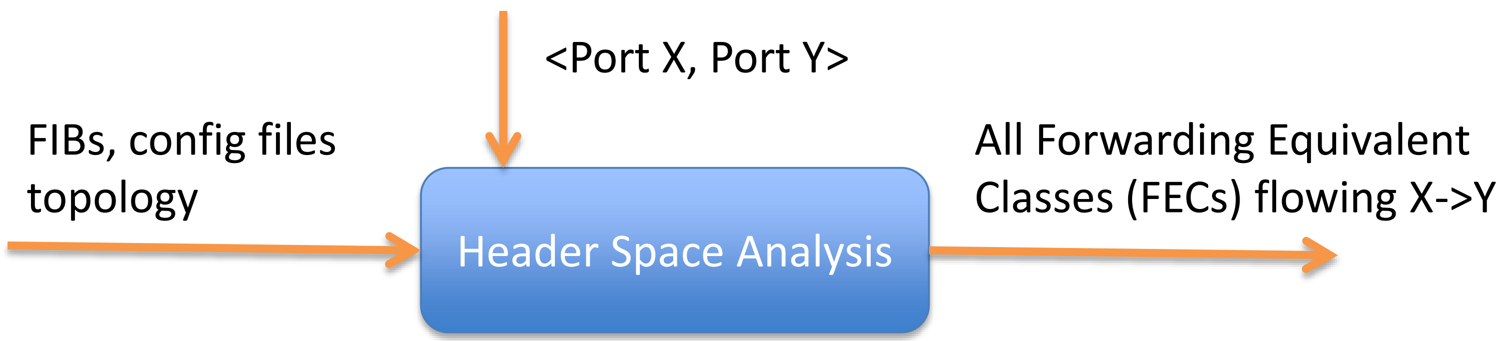


Roadmap

- Reachability Analysis
- Test packet generation and selection
- Fault localization
- Implementation and Evaluation

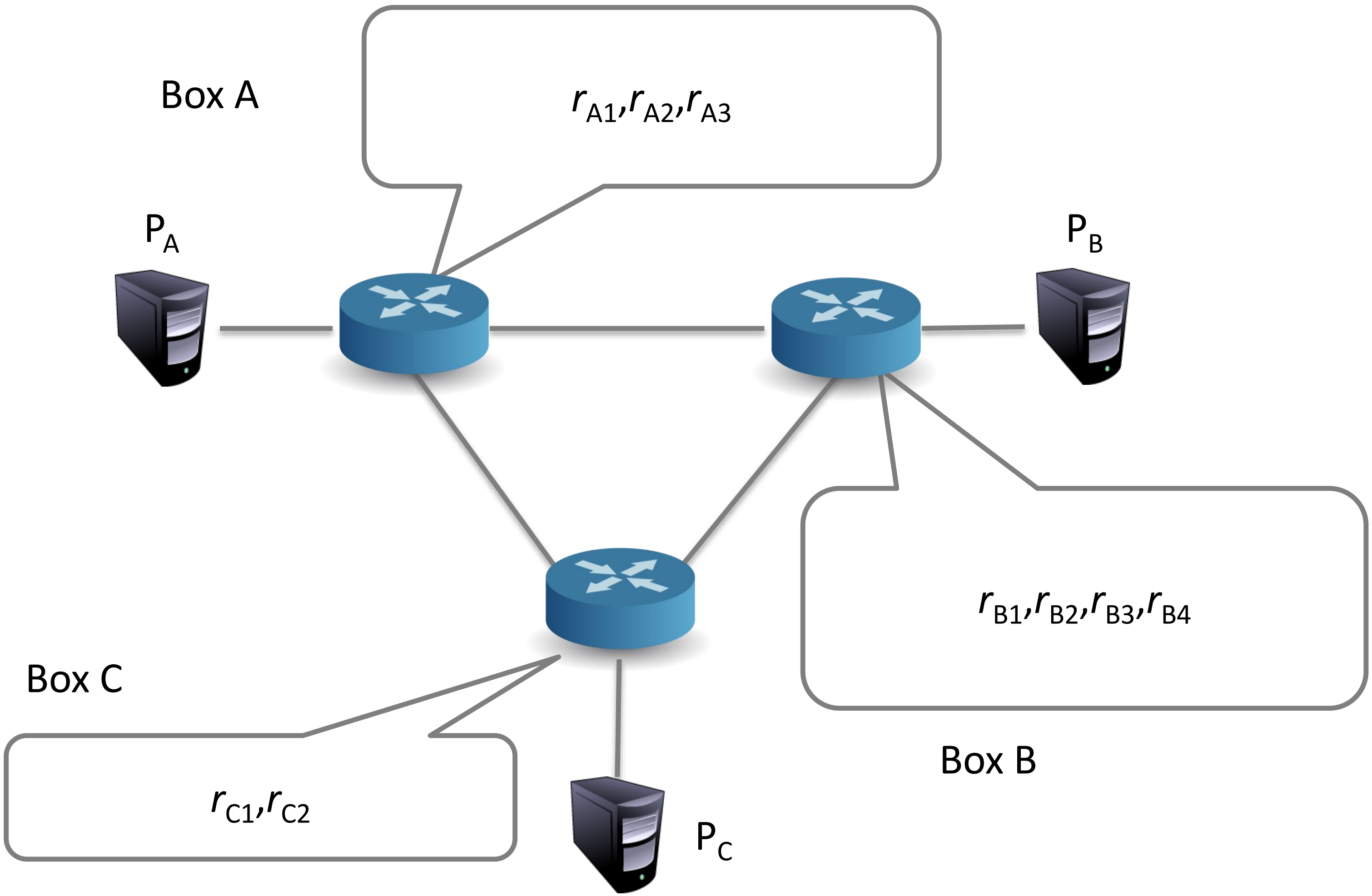
Reachability Analysis

- Header Space Analysis (NSDI 2012)

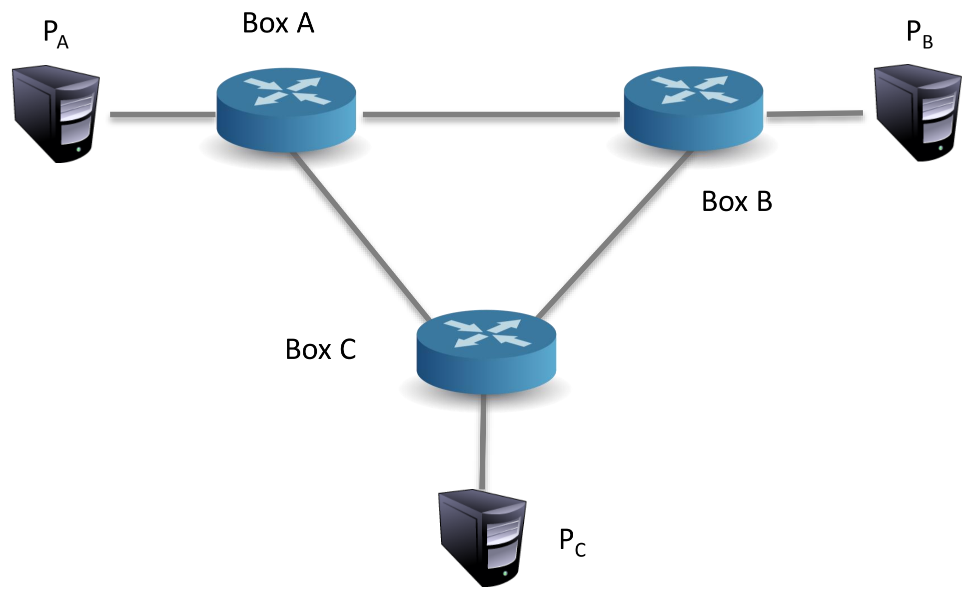


- All-pairs reachability: Compute all classes of packets that can flow between every pair of ports.

Example



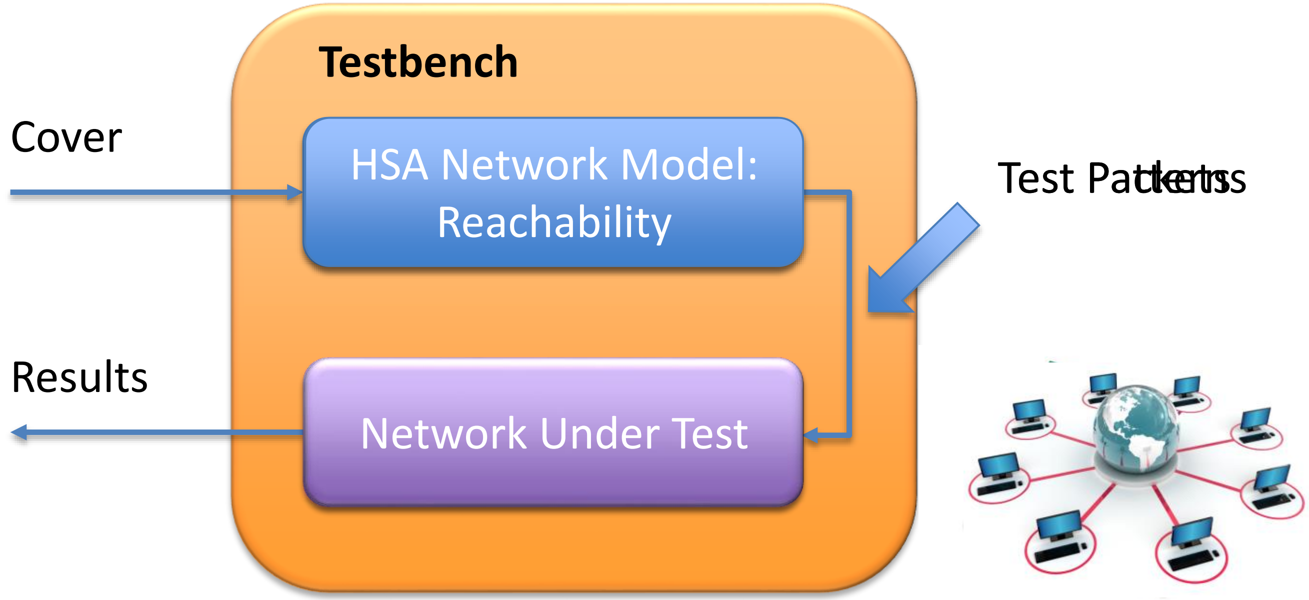
All-pairs reachability



	Header	Ingress Port	Egress Port	Rule History
p_1	`dst_ip=10.0/16, tcp=80`	P_A	P_B	r_{A1}, r_{B3}, r_{B4}, link AB
p_2	`dst_ip=10.1/16`	P_A	P_C	r_{A2}, r_{C2}, link AC
p_3	`dst_ip=10.2/16`	P_B	P_A	r_{B2}, r_{A3}, link AB
p_4	`dst_ip=10.1/16`	P_B	P_C	r_{B2}, r_{C2}, link BC
p_5	`dst_ip=10.2/16`	P_C	P_A	r_{C1}, r_{A3}, link BC
(p_6)	`dst_ip=10.2/16, tcp=80`	P_C	P_B	r_{C1}, r_{B3}, r_{B4}, link BC

New Viewpoint: Testing and coverage

- HSA represents networks as chips/programs
- Standard testing finds inputs that cover every gate/flipflop (HW) or branch/function (SW)



New Viewpoint: Testing and coverage

- In networks, packets are inputs, different covers
  - Links: packets that traverse every link
  - Queues: packets that traverse every queue
  - Rules: packets that test each router rule
- Mission impossible?
  - testing all rules 10 times per second needs < 1% of link overhead (Stanford/Internet2)

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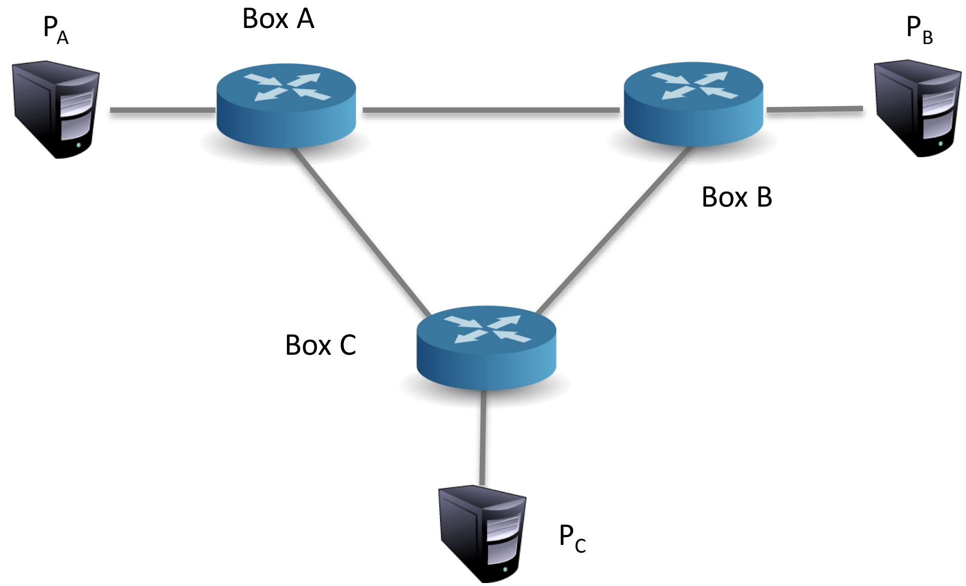
All-pairs reachability and covers



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p_5	`dst_ip=10.2/16`	P_C	P_A	r_{C1}, r_{A3}, link BC

Test Packet Selection

- Packets in all-pairs reachability table are more than necessary
- Goal: select a minimum subset of packets whose histories cover the whole rule set

A Min-Set-Cover problem

Min-Set-Cover

Packets

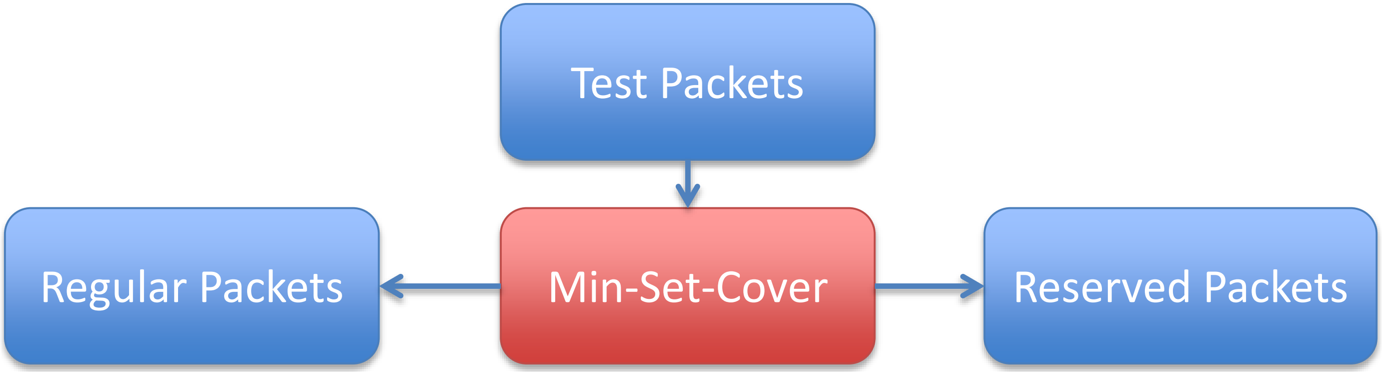
	R1	R2	R3	R4	R5	R6
A	✓					
B		✓			✓	✓
C				✓		
D	✓				✓	
E			✓			✓
F					✓	
G	✓	✓	✓			

Packets

	R1	R2	R3	R4	R5	R6
B		✓			✓	✓
C				✓		
G	✓	✓	✓			

Test Packets Selection

- Min-Set-Cover
  - Optimization is NP-Hard
  - Polynomial approximation (O(N^2))



- Exercise all rules
- Sent out periodically

- “Redundant”
- Will be used in fault localization

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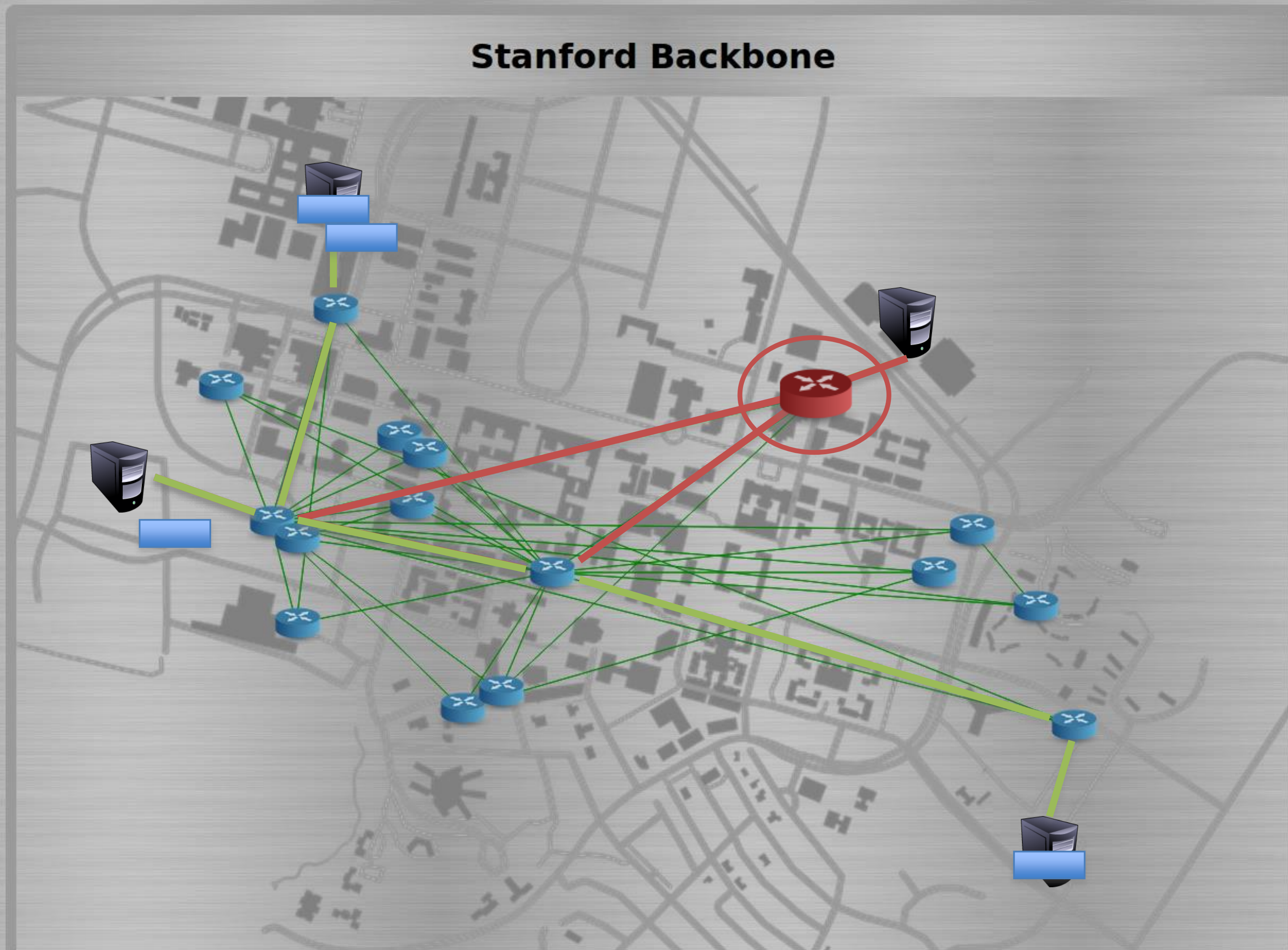
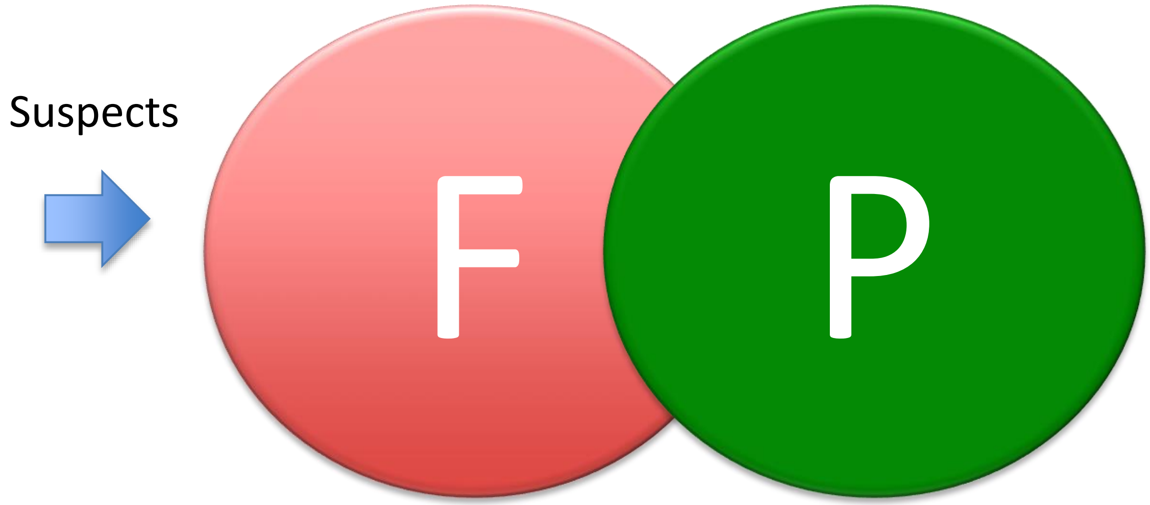
- Evaluation: offline (Stanford/Internet2), emulated network, experimental deployment

Fault Localization



Fault Localization

- Network Tomography? → Minimum Hitting Set
- In ATPG: we can choose packets!
- Step 1: Use results from regular test packets
  - F (potentially broken rules) = Union from all failing packets
  - P (known good rules) = Union from all passing packets
  - Suspect Set = F – P



Fault Localization

- Step 2: Use reserved test packets
  - Pick packets that test only one rule in the suspect set, and send them out for testing
  - Passed: eliminate
  - Failed: label it as “broken”
- Step 3: (Brute force…) Continue with test packets that test two or more rules in the suspect set, until the set is small enough

Roadmap

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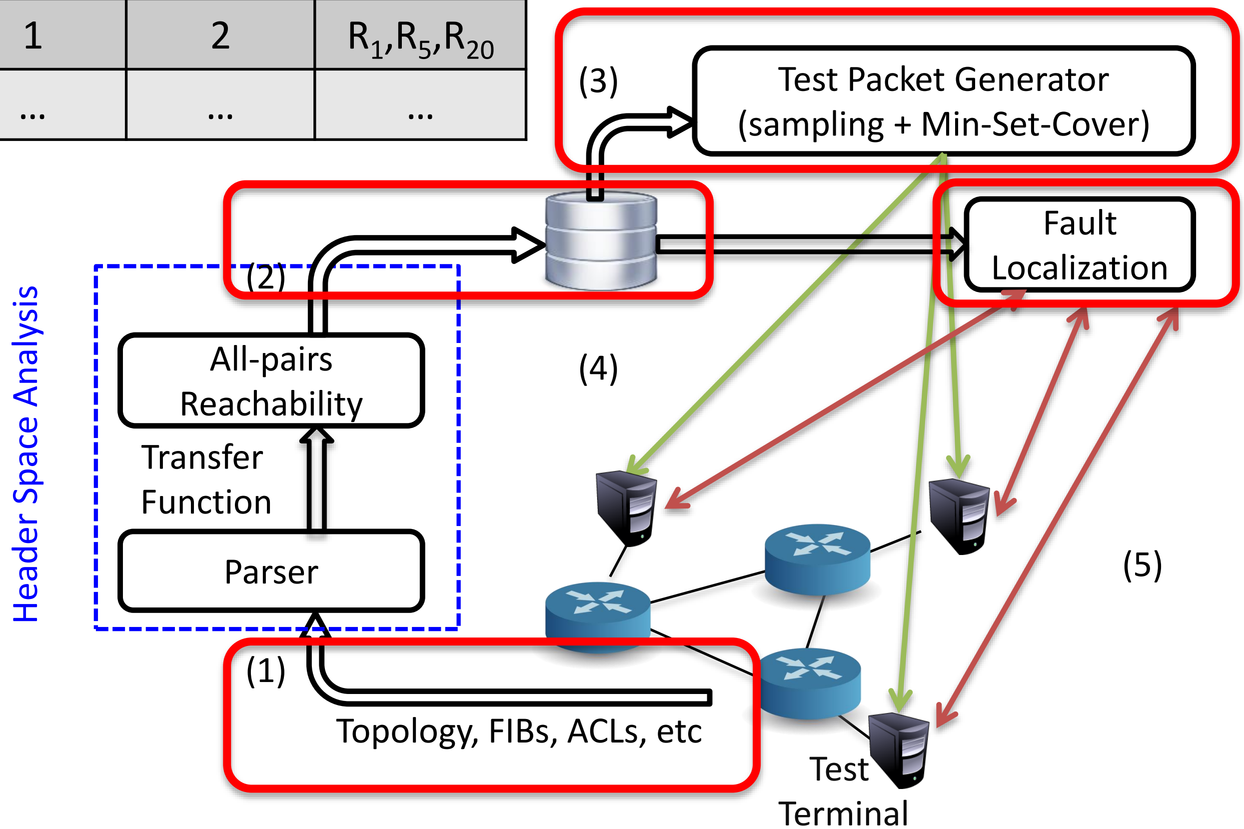
Putting them all together

All-pairs Reachability Table

Header	In Port	Out Port	Rules
10xx…	1	2	R_1,R_5,R_{20}
…	…	…	…



Implementation

- Cisco/Juniper Parsers
  - Translate router configuration files and forwarding tables (FIB) into Header space representation
- Test Packet Generation/Selection
  - Hassel: A python header space library
  - Min-Set-Cover
  - Python's `multiprocess` module to parallelize
- SDN can simplify the design

Datasets

- Stanford and Internet2
  - Public datasets
- Stanford University backbone
  - ~10,000 HW forwarding entries (compressed from 757,000 FIB rules), 1,500 ACLs
  - 16 Cisco routers
- Internet2
  - 100,000 IPv4 forwarding entries
  - 9 Juniper routers

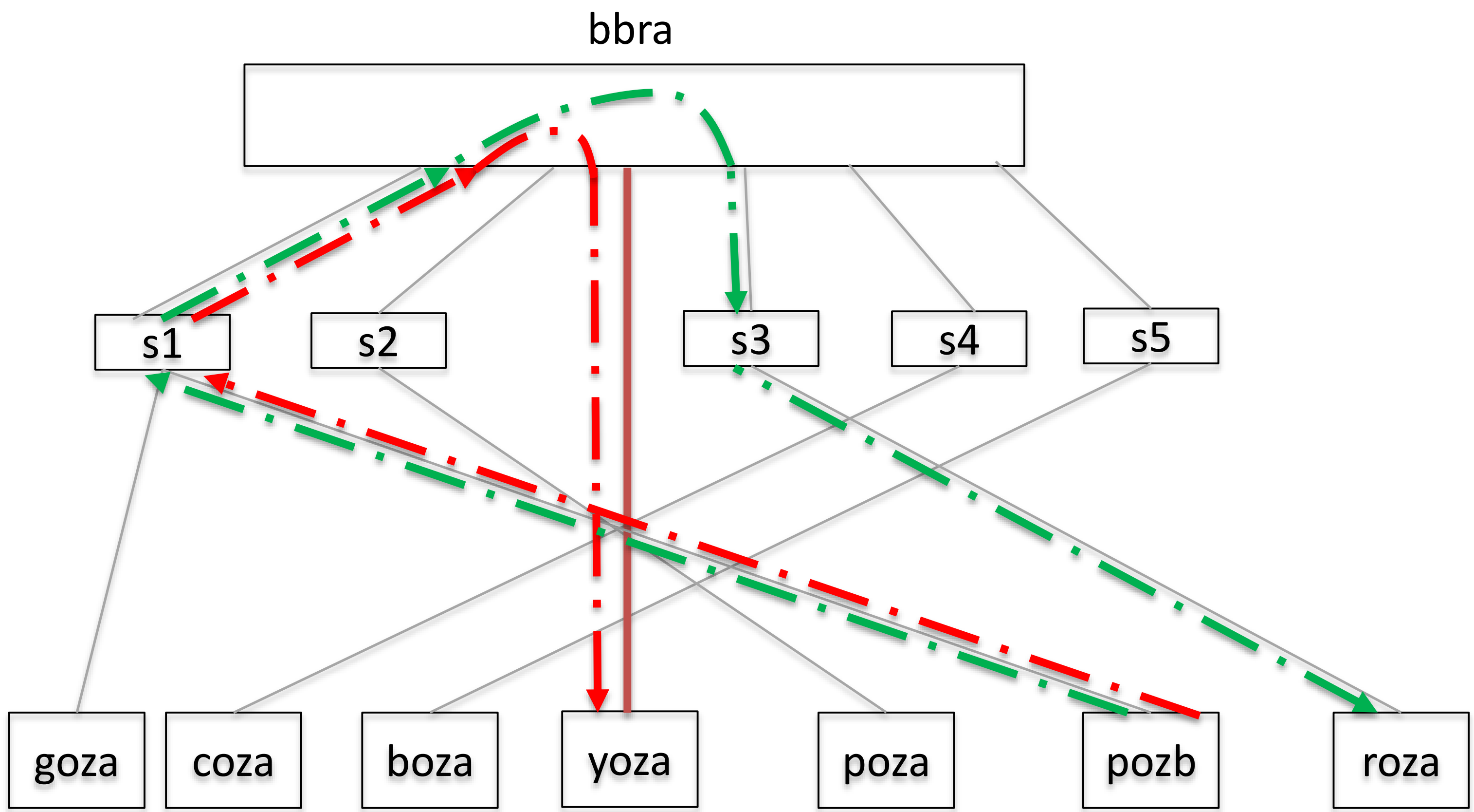
Test Packet Generation

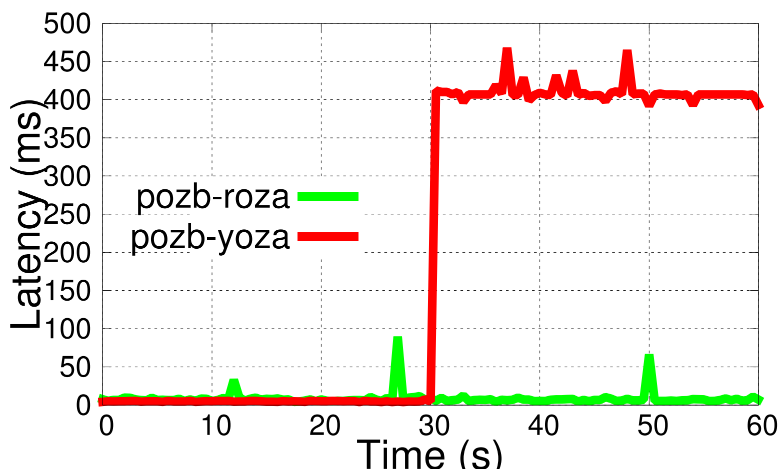
	Stanford	Internet2
Computation Time	~1hour	~40min
Regular Packets	3,871	35,462
Packets/Port (Avg)	12.99	102.8
Min-Set-Cover Reduction	160x	85x
Ruleset structure	✓	✓

<1% Link Utilization
when testing 10 times per second!

Using ATPG for Performance Testing

- Beyond functional problems, ATPG can also be used for detecting and localizing performance problems
- Intuition: generalize results of a test from success/failure to performance (e.g. latency)
- To evaluate used emulated Stanford Network in Mininet-HiFi
  - Open vSwitch as routers
  - Same topology, translated into OpenFlow rules
- Users can inject performance errors


bbra
s1
s2
s3
s4
s5
goza
coza
boza
yoza
poza
pozb
roza


500
450
400
350
300
250
200
150
100
50
0
Latency (ms)
0
10
20
30
40
50
60
Time (s)
pozb-roza
pozb-yoza

Does it work?

- Production Deployment
  - 3 buildings on Stanford campus
  - 30+ Ethernet switches
    - Link cover only (instead of rule cover)
  - 51 test terminals

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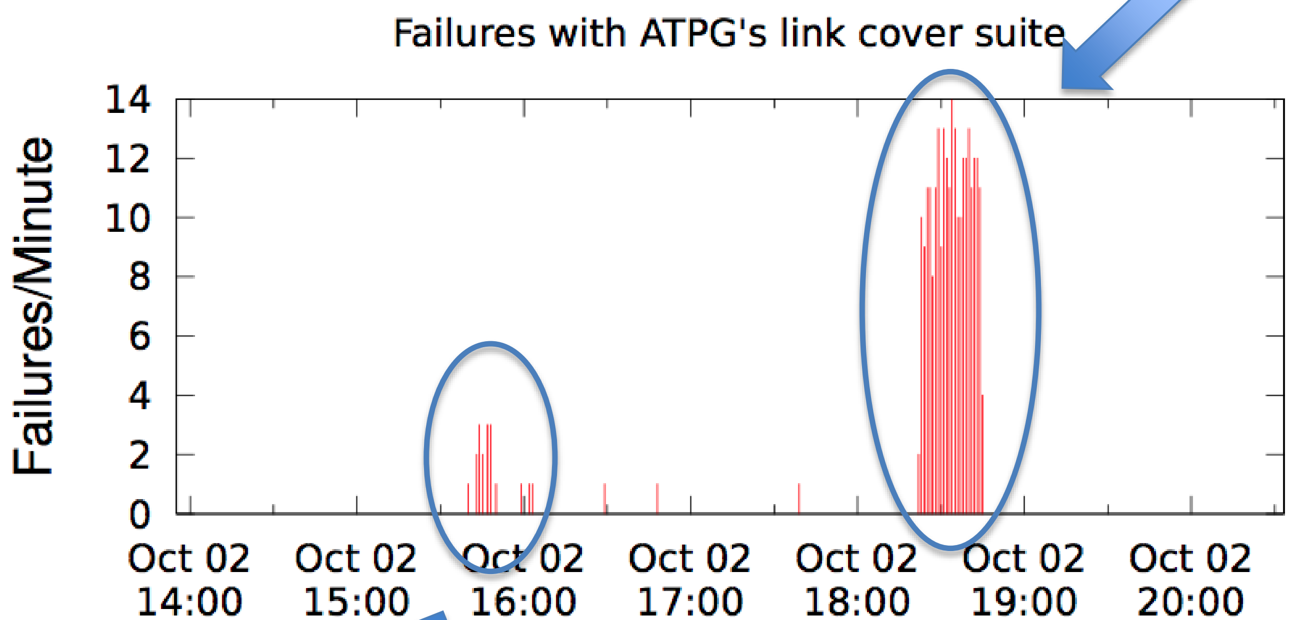
The problem in the email

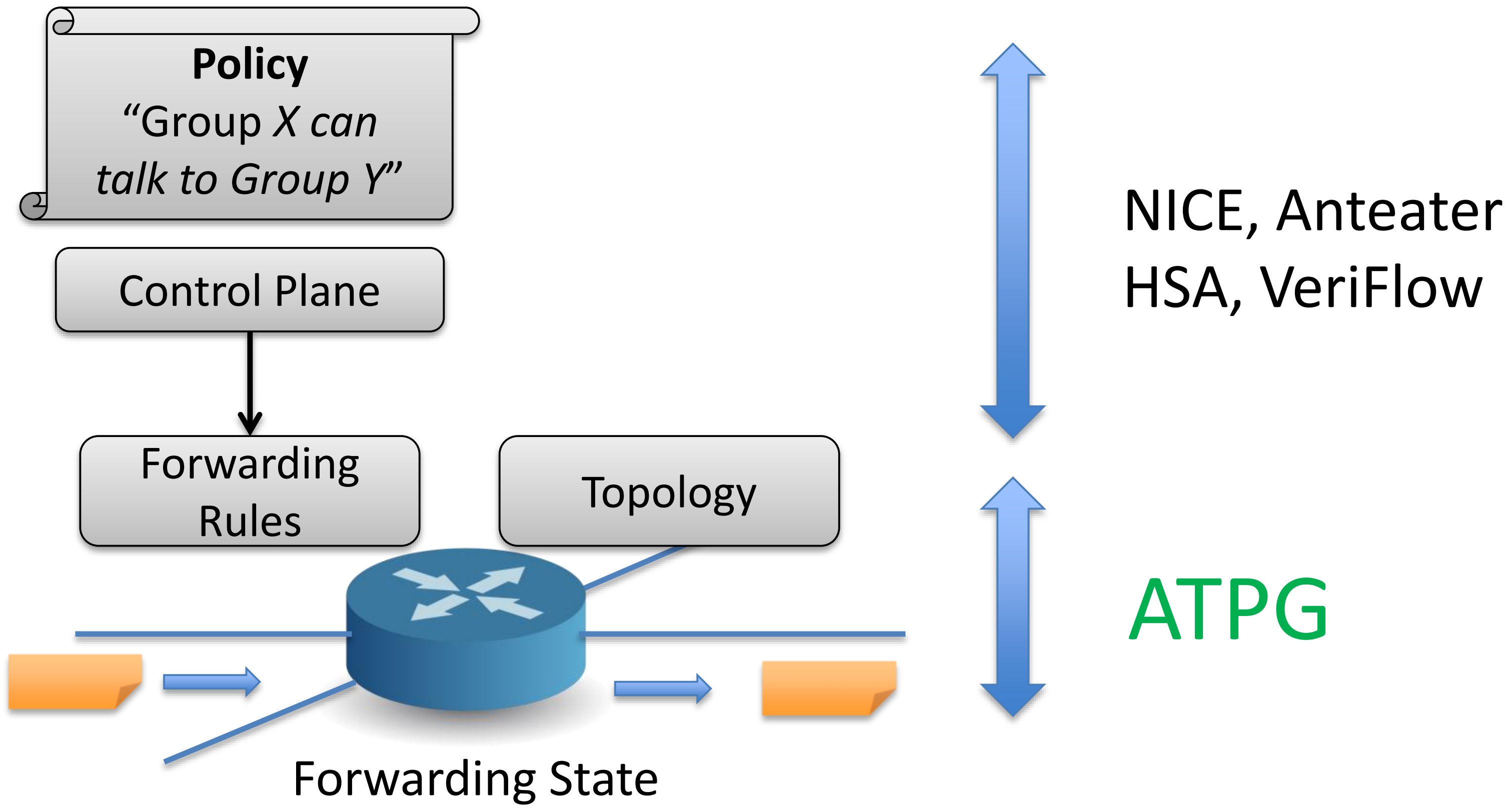


Unreported problem

ATPG Limitations

- Dynamic/Non-deterministic boxes
  - e.g. NAT
- “Invisible” rules
  - e.g. backup rules
- Transient network states
- Ambiguous states (work in progress)
  - e.g. ECMP

Related work



Forwarding Rule != Forwarding State
Topology on File != Actual Topology

Takeaways

- ATPG tests the forwarding state by generating minimal link, queue, rule covers automatically
- Brings lens of testing and coverage to networks
- For Stanford/Internet2, testing 10 times per second needs <1% of link overhead
- Works in real networks.

Merci!

http://eastzone.github.com/atpg/