iSPY: Detecting IP Prefix Hijacking on My Own

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1. Introduction – *What's Prefix Hijacking?*

- A special form of DoS Attack - *corrupting Internet routing tables*
  - Bad BGP announcement - Forwarding tables get polluted with bogus route
  - *Malicious AS can send & receive traffic using addresses it does not own*
  - Used for carrying out malicious activities
- Serious threat and *hard to eliminate*
  - Lack of authoritative info. on prefix ownership

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Critical Requirements

- Prefix Hijack Detection System should satisfy all requirements
  1. Real-time
  2. Accurate
  3. Light-weight
  4. Easy to deploy
  5. Incentive to deploy
  6. Robust in Victim Notification

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Existing Detection mechanisms

- Infrastructure-based detection
  1. *Control-plane-based only*
     - Easily deployable, yet needs live BGP feeds & fairly inaccurate
  2. *Control plane + Data plane* (joint analysis)
     - Real-time, yet needs live BGP feeds and has vantage point limitation
  3. *Data plane only*
     - Easily deployable, yet has vantage point limitation

  – None of them satisfy all critical requirements

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2. BGP Prefix Hijacking (3 main types)

1. Regular prefix hijacking
   – Attacker originates route to an existing IP prefix of the victim network *(Partial pollution)*
2. Subprefix hijacking
   – Steals subnet of existing prefix by announcing route for it *(Most networks get polluted)*
3. Interception based hijacking

iSPY addresses the regular prefix hijacking

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3. Key Observations

- Significant percentage of ASes get polluted
- Probes from prefix-owner are unreachable to many ASes
- *Unique Unreachability Signature of Hijacking*
  - *Can distinguish it from other disruptive routing events* such as link failure and congestion

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3.1 Prefix Owner's View of Reachability

- Capture it as a set of paths called *vPath* (victim's path)
  - Set of AS-level *forward paths* from prefix owner to a specific AS on the Internet
  - traceroute replies will not reach the victim network *(indirectly capture reachability)*
- Networks with multiple prefixes
  - vPath to these prefixes may differ
  - Select any prefix and regard the path to it as path to destination AS

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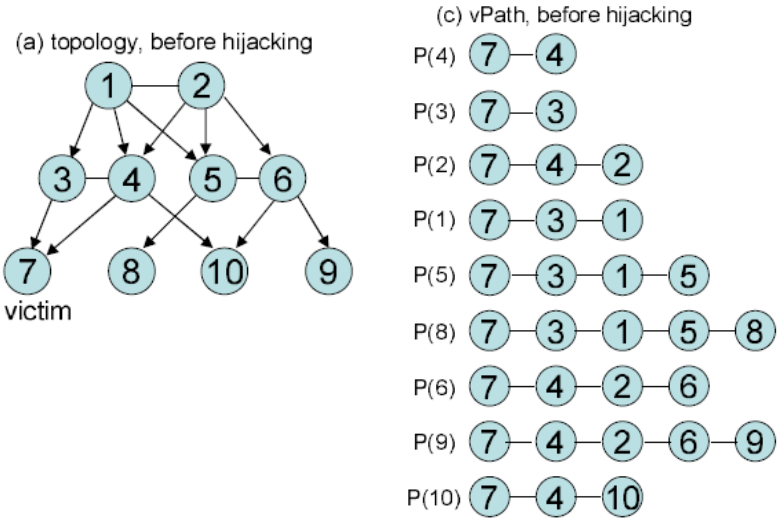
AS Topology Example



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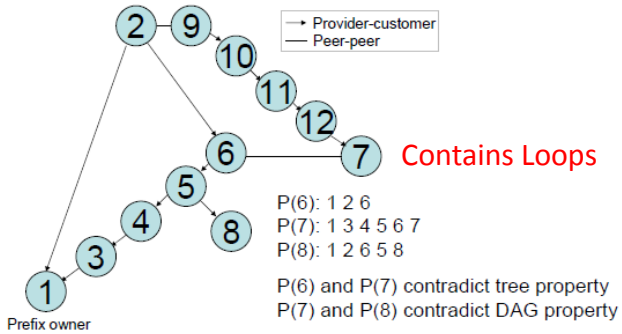
AS Topology Example (cont'd)

- Cannot compress vPath to *trees* or *Directed acyclic graphs*
  - Due to policy-based routing in the Internet



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Prefix Owner's View of Reachability (cont'd)

- Case of Potential Route Asymmetry
  - *Destination AS can be reachable* even if *certain ASes* along the forward path to it *are polluted*
  - [a,b,**c**,**d**,e] : polluted c & d returns "*", finally reach e
  - [a, b, **#**, e] : AS-level path may contain # (*uncertain part of AS path*)
- Monitoring Reachability to Transit ASes Only
  - Cost of obtaining paths to many ASes is high
  - All attacks are still covered because *hijack from a stub AS has to pollute its provider transit AS(es)*

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3.2 Hijack Detection Problem

- Potential Hijack Detection
  - Take periodic snapshots of vPath
  - Compare new snapshot($\mathbf{T_{new}}$) with old snapshot($\mathbf{T_{old}}$) to check for unreachability
  - Possible hijacking when $\mathbf{T_{old}}$ has full reachability and $\mathbf{T_{new}}$ has partial reachability
- Problem
  - Partial reachability ($\mathbf{T_{new}}$) could be *due to other routing anomalies*
  - Need to *analyze the unique characteristics of the gap* between $\mathbf{T_{new}}$ and $\mathbf{T_{old}}$

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Four Cases - Definition of cuts

Old Path P(d) = {s, u_1, u_2, ... , u_n, d}
New Path P'(d) = {s, v_1, v_2, ... , v_n, d}

1. P(d) remains complete - no cut
2. P(d) becomes partial in T_{new}
   - ui: Last AS in P(d) for which traceroute obatined a reply
   - (u_i, u_i+1) is a cut
3. P(d) changes to P'(d) in T_{new}, and P'(d) is complete - no cut

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Four Cases - Definition of cuts (Cont'd)

4. P(d) changes to P'(d) in Tnew, and P'(d) is partial
   - v_i: Last AS in P'(d) for which traceroute obtained a reply
   - (v_i, v_i+1) is a cut – if v_i appears in P(d)
   - (v_i, *) is a cut – if v_i does not appear in P(d)

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Four Cases - Definition of cuts (Cont'd)

- Denote set of distinct cuts as Ω
- Definition of cuts can handle the cases of uncertain subpaths "#"

Table 2: Examples of cuts under the cut definition.

Cut		Current path $P'(d)$		
		abcd	ab#d	ab#
Previous path $P(d)$	abcd	no cut	no cut	bc
	ab#d	no cut	no cut	b#

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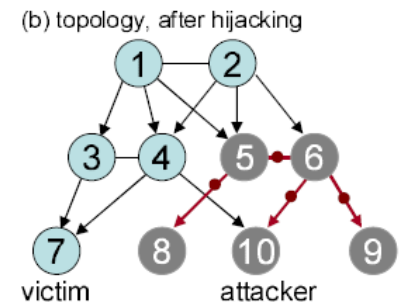
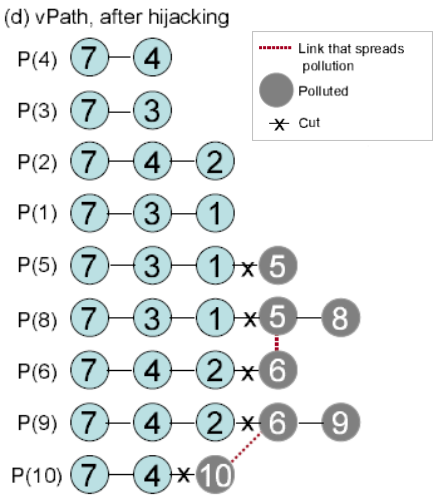
Cuts in vPath – Example



Ω={(1,5), (2,6), (4,10)}
Create 3 cuts



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3.3 Unreachability Signature of Hijacking

- Size of Ω
  - *Almost Always Large* during ongoing prefix hijack, typically small otherwise
- Rationale
  - Internet topology is *not a tree*
  - *Many peering & multi-homed links*
    - Pollution spreads far and victim network sees many cuts
  - Conventional disruptive Routing Events *(Link failure, congestion)*
    - small cuts, mostly near victim AS

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3.4 Simulation Validation

- Methodology
  - *Simulate 2,450 hijacking instances*
  - Algorithm on data from RouteViews from *100 vantage points*
  - AS relationship obtained by running *Gao's algorithm*
  - ASes classified into 5: *tier-1, tier-2 transit, tier-2 stub, tier-3+ transit, tier-3+ stub, based on type and number of providers*

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Simulation Validation (Cont'd)

- Procedure
  - Compute the forward path P(d) – old vPath
  - Simulate false origin prefix hijacking
  - Compute the forward path P'(d) - new vPath
    - Simulate uncertain non-trailing subpath (#) by aborting traceroute after a *fixed number(abort-after)* of consecutive unreachable hops
  - Calculate the cuts Ω using P(d) and P'(d)
- Limitation
  - Detection delay (due to snapshot durations / start time of hijack and probing rounds)

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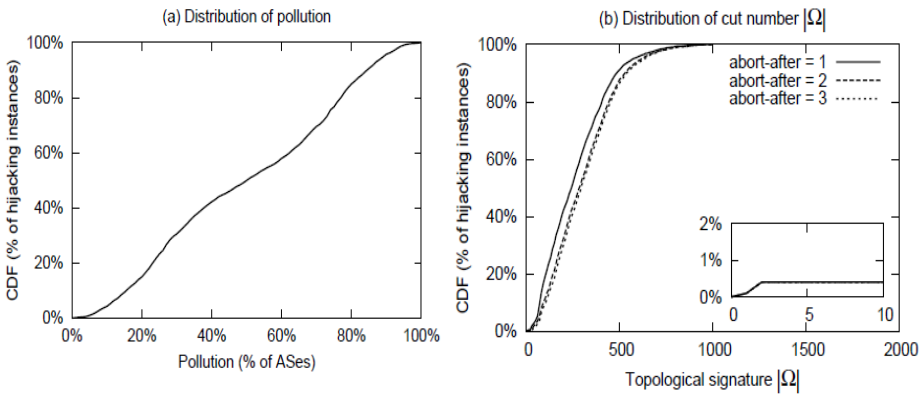
Simulation Results



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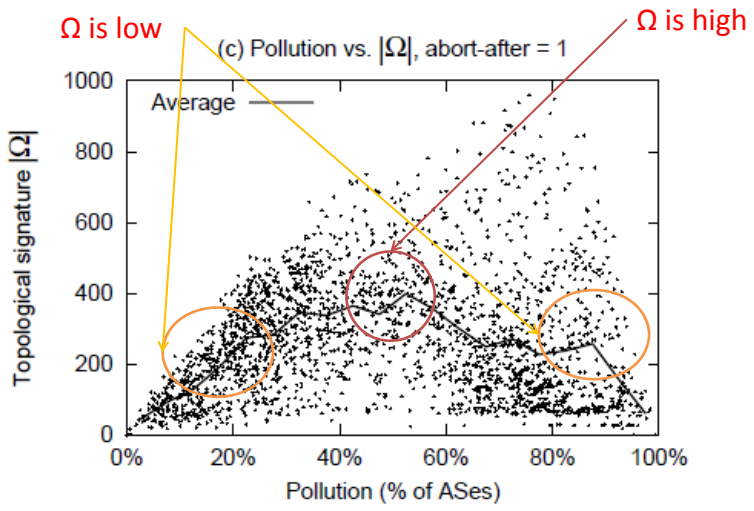
Simulation Results (Cont'd)



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Simulation Results (Cont'd)

- When Ω is small, Ω varies little under different traceroute configuration (abort-after)

Table 3: The percentage of small $|\Omega|$ instances.

Victim category	Total instances	Small $\|\Omega\|$ instances		
		$\|\Omega\| \leq 5$	$\|\Omega\| \leq 10$	$\|\Omega\| \leq 20$
Tier-1	490	3 (0.61%)	3 (0.61%)	4 (0.82%)
Tier-2 transit	490	1 (0.20%)	1 (0.20%)	1 (0.20%)
Tier-2 stub	490	4 (0.82%)	4 (0.82%)	5 (1.02%)
Tier-3+ transit	490	3 (0.61%)	3 (0.61%)	4 (0.82%)
Tier-3+ stub	490	0 (0.00%)	0 (0.00%)	0 (0.00%)
Any	2450	11 (0.45%)	11 (0.45%)	14 (0.57%)

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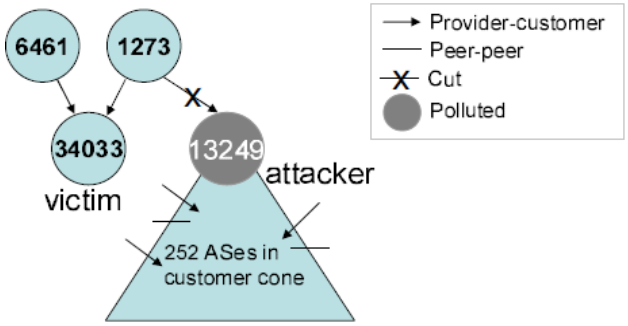
An example hijacking instance with small |Ω|

- AS 13249 hijacks AS 34033
  - Pollution is restricted to the attackers' customer cone
  - Only 144 ASes are polluted
- The inverse case also has a small # of cuts



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Analyzing Hijacking Instances with Small cuts

- Two Key Rare Conditions for a small cuts
  1. None of attacker's provider(s) is polluted
     - Not likely for randomly picked victim & attacker pairs
     - To satisfy, the victim must also be same provider's customer
  2. Attacker's customers rely heavily on attacker's transit service
     - Not likely unless the customer cone is small

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3.5 Detecting Known Hijacking Events

Table 4: Cuts in historical hijacking events.

Victim prefix	Victim prefix owner		Attacker	Pollu. (%)	$\|\Omega\|$
64.233.161.0/24	Google	15169	Cogent	31.6	492
63.165.71.0/24	Folksamerica	26913	ConEd.	65.7	458
64.132.55.0/24	OverseasMedia	33477	ConEd.	33.1	176
65.115.240.0/24	ViewTrade	23004	ConEd.	49.4	369
65.209.93.0/24	LavaTrading	35967	ConEd.	16.4	221
66.194.137.0/24	MacKayShields	31860	ConEd.	32.3	261
66.207.32.0/20	ADI	23011	ConEd.	83.0	594
69.64.209.0/24	TheStreet.Com	14732	ConEd.	78.0	658
160.79.45.0/24	RhodesASN	33313	ConEd.	27.5	380
192.251.16.0/24	T&TForex	20179	ConEd.	14.7	170
198.15.10.0/24	TigerFund	5703	ConEd.	86.0	707
204.13.72.0/24	FTENNY	33584	ConEd.	34.6	205
216.223.46.0/24	SDSNY	12265	ConEd.	77.6	606

- All highjacks: $\Omega > 170$
  - though the pollution varies from 14.7% to 86%

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4. Design – Probing Module Components

1. Probing only transit Ases
   - Reduce the probing cost (23,191 ASes → 3,742 ASes)
2. Live IPs
   - Collect probing candidate IPs from several sources
3. Resolving IP-level paths to AS-level paths
   - Generate *IP-to-AS mapping* using BGP routing tables
   - *Collapse consecutive hops mapped to the same AS*
   - Unresolved hops collapsed to symbol '#'
4. Increasing the efficiency & Robustness of Traceroute
   - Modify *Paris-traceroute* to perform IP-to-AS translation on the fly

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Evaluation – No Prefix Hijacking

Table 5: Efficiency of iSPY's probing module.

		Five sample sources (by location)					Overall (108 sources)		
		UK	Pitts,US	LA,US	Norway	Japan	min	max	median
①	Avg hops per traceroute	16.6	13.5	17.2	16.7	16.1	10.7	19.9	15.5
②	Probing traffic per round (MB)	1.7	1.4	1.8	1.7	1.7	1.1	2.1	1.6
③	Time per traceroute (sec)	11.3	10.9	11.7	11.0	11.4	9.6	19.5	11.4
④	Probing time per round (min)	17	17	19	17	17	15	29	18
⑤	Bandwidth (KB/s)	1.7	1.4	1.6	1.7	1.6	0.8	2.2	1.5

- 108 PlanetLab nodes (each node probes the 3470 transit Ases)

① determine the efficiency of the whole probing round

② traceroute + ICMP ping + TCP ping

③ 9.6s ~ 19.5s

④ Short turn around time: iSPY can obtain the up-to-date vPath

⑤ Low bandwidth - Light-weight

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Evaluation - Coverage

	Transit ASes	
	Number	Percent
Traceroute stat		
Probed	3470	100.0%
Reached	3170	91.4%
AS-path completely resolved	2663	76.7%
AS-path incompletely resolved	807	23.3%
Has at least 1 unmapped IP hop	155	4.5%
Has at least 1 unmapped * hop	680	19.6%
Complementary ping stat		
Probed	300	8.6%
Reached	261	7.5%
Complementary TCP stat		
Probed	39	1.1%
Reached	37	1.1%
Traceroute + ping + TCP stat		
Reached	3468	99.9%
AS-path completely resolved	2663	76.7%

- 99% ASes are reached
- 76.7% AS-path completely resolved
  - Due to unmapped hops (*s)

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Evaluation – Coverage (Cont'd)

Table 7: Coverage of probing on 108 PlanetLab nodes.

	Five sample sources (by location)					Overall (108 sources)		
	UK	Pitts,US	LA,US	Norway	Japan	min	max	median
ASes reached by probing (%)	99.9	100.0	99.9	100.0	100.0	95.6	100.0	99.9
ASes having complete path (%)	79.7	74.5	80.7	82.4	82.4	69.7	85.9	81.0

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5. Prefix-Owner-Centric Hijack Detection

- Handling Uncertain Subpaths
  - *Calculate the lower bound* of |Ω| (*all uncertain cuts sharing the same starting node are the same)*
  - *Calculate the upper bound* of |Ω| (*each uncertain cut is a different cut)*
  - *Use the lower & upper bound to aid decision making*
- Continuous Decision Making
  - *Continuously stream new vPath data into the decision making module*
  - Can detect hijacking well before all cuts in a complete round of probing are witnessed.

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6.1 PlanetLab Experiment

- Evaluate the detection false positive ratio
- Detection Accuracy
  - 0.17% alarm (all false positive)
  - Ω did not last for more than one round & No Multiple Origin AS announcement
- Choice of Detection Threshold
  - 10 cuts

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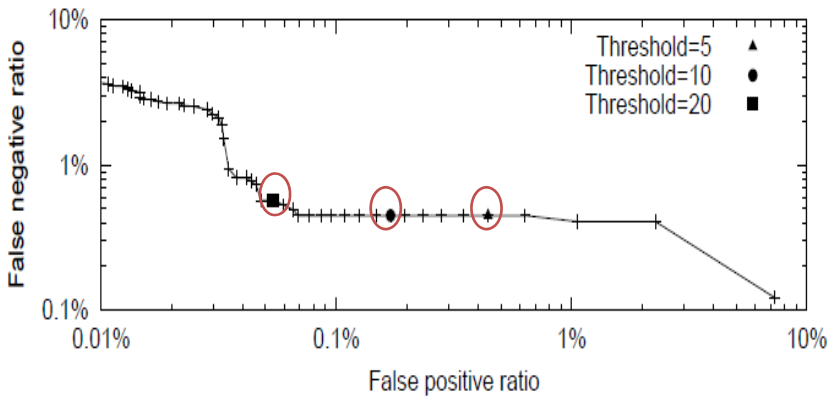
PlanetLab Experiment (Cont'd)



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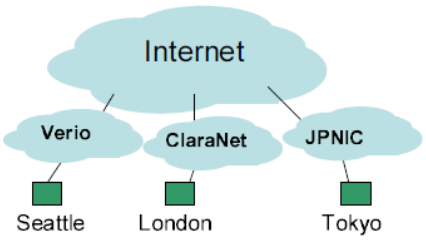
6.2 Hijacking Experimen



- Experiment Setup
  - 3 hosts
  - Launched 15 attacks on their own prefix
  - Allow to inject an anycast prefix from 3 hosts
- Experiment Step
  1. The victim injects the target prefix
  2. Two hours later, the attacker also injects
  3. The attacker withdraws prefix after 2 more hours

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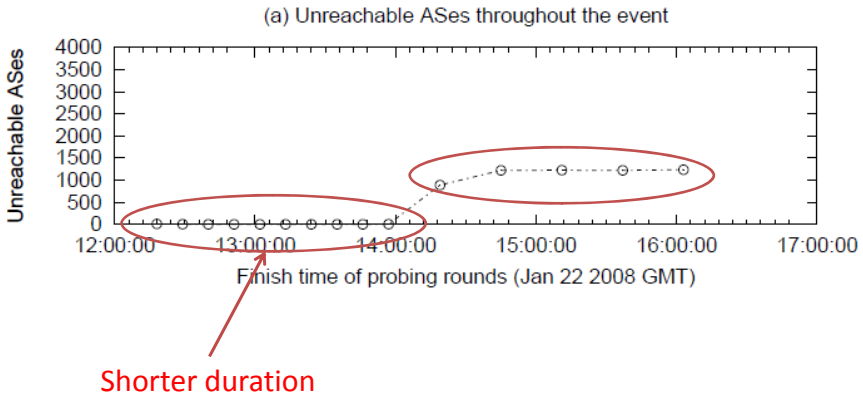
of unreachable ASes & cuts



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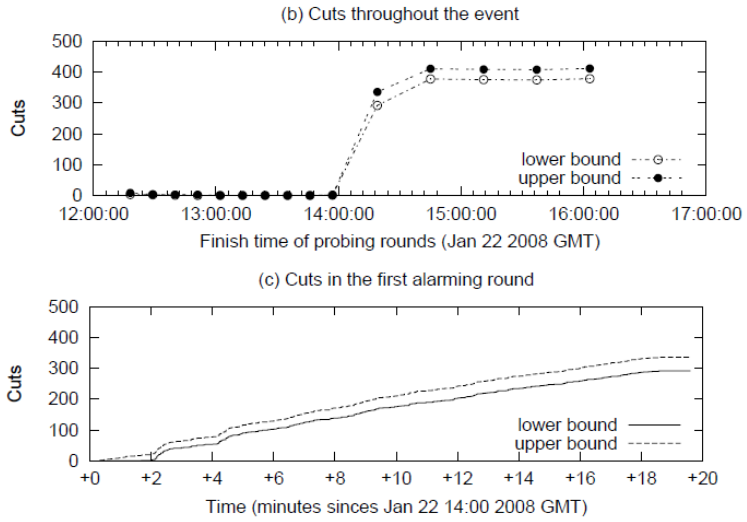
of unreachable ASes & cuts (Cont'd)



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Statics of the 15 hijacking events / Detection Performance

Event #	Scenario					iSPY Performance			
	Victim	Attacker	Hijack start time (GMT)	Pollution (%)	Cuts ([LB, UB])	Detected?	1st alarming round start time (min)	Detection latency (min)	Pollu. at alarm (%)
1	Seattle	London	Jan 22 14:00	35.6	[376, 409]	yes	-2.1	2.1	0.4
2	"	"	Jan 23 20:00	36.0	[383, 415]	yes	-4.0	2.1	0.4
3	"	"	Jan 25 02:00	36.0	[384, 417]	yes	-7.0	2.1	0.3
4	"	"	Jan 26 08:00	36.4	[382, 417]	yes	-4.7	2.7	0.4
5	"	"	Jan 27 14:00	36.1	[376, 409]	yes	-8.3	2.3	0.4
6	"	"	Jan 28 20:00	36.3	[379, 413]	yes	-2.6	2.7	0.5
7	Seattle	Tokyo	Jan 22 20:00	31.4	[205, 231]	yes	-2.7	2.7	0.5
8	"	"	Jan 24 02:00	31.0	[201, 226]	yes	-4.5	2.1	0.3
9	"	"	June 04 02:00	34.4	[219, 246]	yes	0.2	3.1	1.0
10	London	Seattle	Jan 27 02:00	51.3	[331, 376]	yes	-2.9	1.4	0.3
11	"	"	Jan 28 02:00	51.1	[328, 372]	yes	-2.7	1.4	0.4
12	Tokyo	Seattle	June 02 02:00	51.0	[788, 839]	yes	-0.4	3.1	0.4
13	"	"	June 02 06:00	52.3	[805, 855]	yes	-10.9	1.8	0.4
14	"	"	June 03 08:00	51.4	[785, 833]	yes	-5.5	2.3	0.4
15	"	"	June 03 14:00	51.2	[793, 841]	yes	-6.2	2.4	0.3

Large number of cuts

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Discussion

- Counter Measures by attackers against iSPY
  - Probe Modification
    - Need to manipulate replies to all traceroute probes
  - Pollution shaping
    - Difficult to shape a small-cut pollution
    - Hard to calculate ASes to add to the initial bogus route
- Future work
  - Detection accuracy improvement selecting personalized thresholds by each network
  - Identifying the attacker in real-time

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Conclusion

- Highly effective prefix-owner-based IP prefix hijacking detection system (iSPY)
  1. Highly accurate
  2. Almost real time detection (1.4 ~ 3.1 minutes)
  3. Lightweight
  4. Easy to deploy for prefix owner
  5. Strong Incentive to deploy
  6. Robust in victim notification (Hijack detection decision made locally)

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