Neutralizing BGP Hijacking within a Minute

(funded by RIPE NCC RIPE NETWORK COORDINATION CENTRE Community Projects 2017)

Vasileios Kotronis

(Joint work with: Pavlos Sermpezis, Petros Gigis, Dimitris Mavrommatis, Xenofontas Dimitropoulos, Alberto Dainotti, Alistair King, Lefteris Manassakis)

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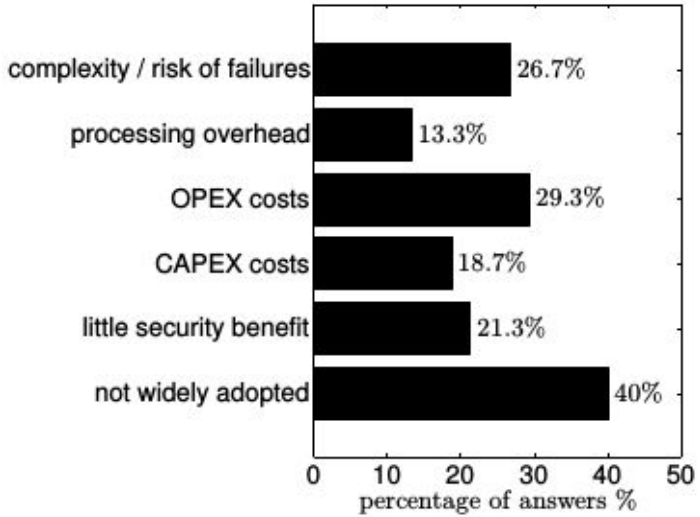
How do people deal with hijacks today?→ **RPKI**

- X **< 10%** of prefixes covered by ROAs [1]
- X Why? → limited adoption & costs/complexity [2]
- X Does not protect the network against all attack types



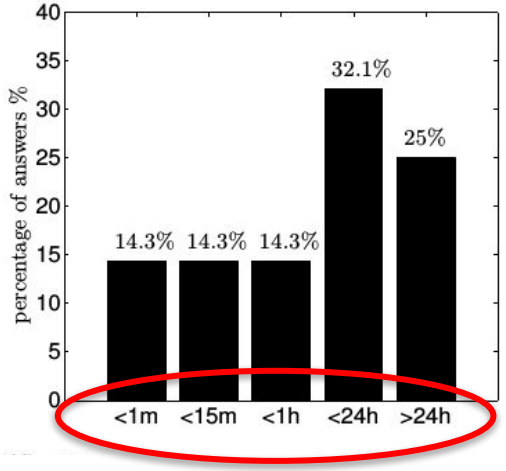
Reasons for not using RPKI [2]

[1] NIST. RPKI Monitor https://rpki-monitor.antd.nist.gov/.July 2018

[2] P. Sermpezis, et. al., "A survey among Network Operators on BGP Prefix Hijacking", in ACM SIGCOMM CCR, Jan 2018.

How do people deal with hijacks today? → **3rd parties**

- X **Comprehensiveness**: detect only simple attacks
- X **Accuracy**: lots of false positives (FP) & false negatives (FN)
- X **Speed**: manual verification & then manual mitigation
- X **Privacy**: need to share private info, routing policies, etc.



How much time an operational network was affected by a hijack [1]

[1] P. Sermpezis, et. al., "*A survey among Network Operators on BGP Prefix Hijacking*", in ACM SIGCOMM CCR, Jan 2018.

Our solution: ARTEMIS

- Operated in-house: no third parties
- Real-time Detection
- Automatic Mitigation

✓ **Comprehensive**: covers *all* hijack types
✓ **Accurate**: *0% FP*, *0% FN* for basic types;
low tunable FP-FN trade-off for remaining types
✓ **Fast**: neutralizes (detect & mitigate) attacks in < *1 minute*
✓ **Privacy preserving**: no sensitive info shared
✓ **Flexible**: configurable mitigation per-prefix + per-hijack type

[1] ARTEMIS website www.inspire.edu.gr/artemis/
[2] P. Sermpezis et al., "ARTEMIS: Neutralizing BGP Hijacking within a Minute", under revision ACM/IEEE ToN, arXiv 1801.01085.
[3] G. Chaviaras et al., "ARTEMIS: Real-Time Detection and Automatic Mitigation for BGP Prefix Hijacking", ACM SIGCOMM'16 demo.

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BGPSTREAM

BGP Monitors:
- RIPE RIS
- BGPStream
  -- Live
  -- Historical
- Local (exaBGP)

Runs as a container/VM in the NOC

ARTEMIS

MONITORING → DETECTION → MITIGATION

Operator Configuration File

AS1234

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BGP STREAM

BGP Monitors:
- RIPE RIS
- BGPStream
  -- Live
  -- Historical
- Local (exaBGP)

"Monitor X saw a BGP update for 10.0.0.0/23 originated by AS4."

"Origin sub-prefix HIJACK by AS4 vs. 10.0.0.0/23."

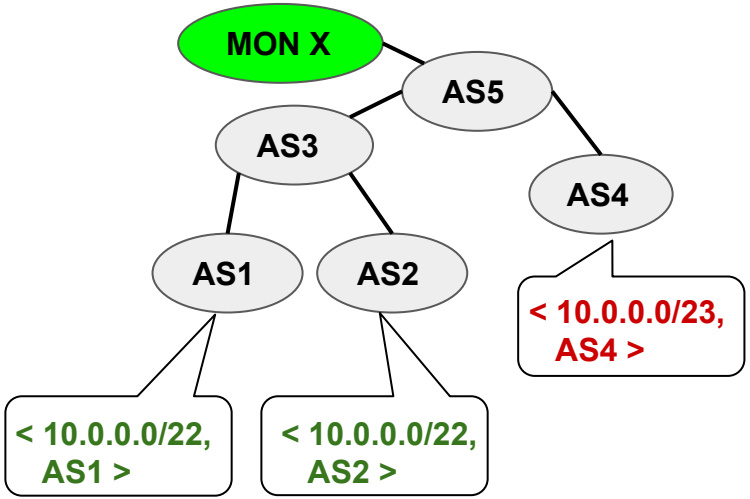
ARTEMIS

MONITORING → DETECTION → MITIGATION

React to hijack!

Operator Configuration File

"I own 10.0.0.0/22 and announce it from AS1 and AS2; both have AS3 as upstream."



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BGP Monitors:
- RIPE RIS
- BGPStream
  -- Live
  -- Historical
- Local (exaBGP)

"2 monitors saw in last 5 minutes < 10.0.0.0/22, AS1, AS2, AS4, … >"

"Link AS2-AS4 not seen in last 10 months for any prefix or direction. Path manipulation exact -prefix HIJACK by AS4 vs. 10.0.0.0/22."

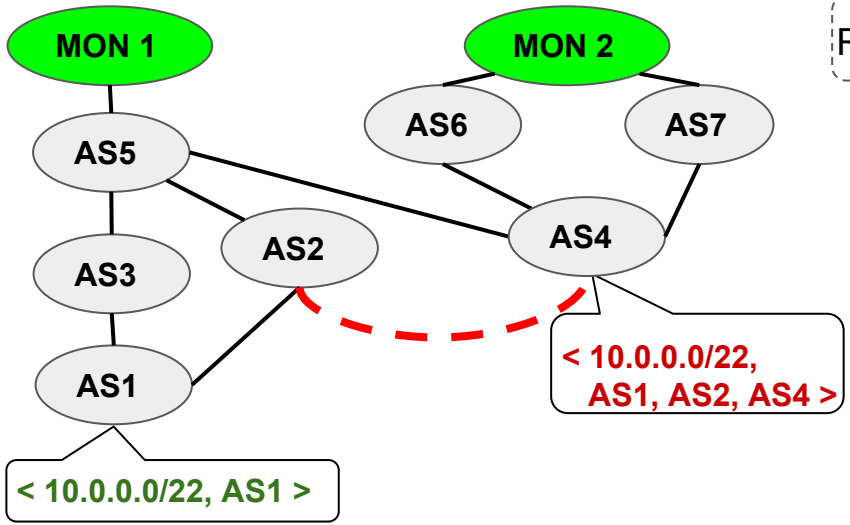
ARTEMIS

MONITORING → DETECTION → MITIGATION

React to hijack!

Operator Configuration File

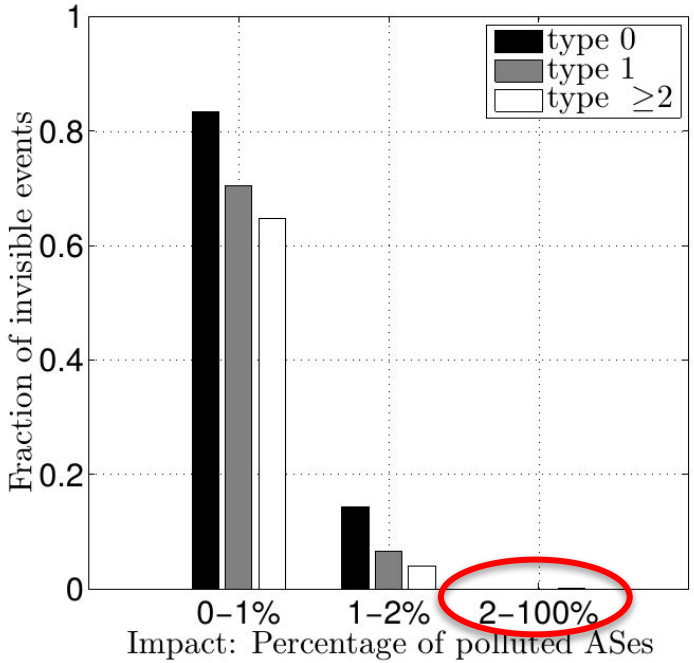
"I own 10.0.0.0/22 and announce it from AS1 with AS2 and AS3 as upstreams."



ARTEMIS: visibility of *all* impactful hijacks

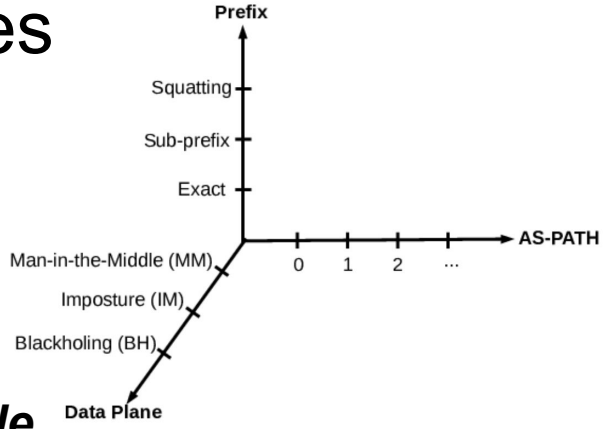
- Public BGP monitor infrastructure
  - RIPE RIS, RouteViews, BGPmon
  - ~500 vantage points worldwide (BGP routers)

Simulation results on the AS-level graph [1]



[1] P. Sermpezis et al., "*ARTEMIS: Neutralizing BGP Hijacking within a Minute*", under revision IEEE/ACM ToN, arXiv 1801.01085.

ARTEMIS: detection of *all* hijack types



- Hijack types taxonomy - 3 dimensions:
  1. Affected prefixes:
     prefix or ***sub-prefix*** or ***squatting***
  2. Data-plane:
     blackholing or ***imposture*** or ***man-in-the-middle***
  3. AS-path manipulation: ***Type-0*** or ***Type-1*** or … or ***Type-N***
     - Legit announcement: <my_prefix, **MY_AS**>
     - Type-0 hijack: <my_prefix, **BAD_AS**, …>
     - Type-1 hijack: <my_prefix, **MY_AS**, **BAD_AS**, …>
     - Type-2 hijack: <my_prefix, **MY_AS**, MY_PEER, **BAD_AS**, …>
     - …
     - Type-N hijack: <my_prefix, **MY_AS**, ..., **BAD_AS**, …>
     - Type-U hijack: <my_prefix, unaltered_path>

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ARTEMIS: detection of *all* hijack types

TABLE 1: Comparison of BGP prefix hijacking detection systems/services w.r.t. ability to detect different classes of attacks.

Class of Hijacking Attack			Control-plane System/Service			Data-plane System/Service		Hybrid System/Service		
Affected prefix	AS-PATH (Type)	Data plane	ARTEMIS	Cyclops (2008) [21]	PHAS (2006) [36]	iSpy (2008) [68]	Zheng *et al.* (2007) [70]	HEAP (2016) [57]	Argus (2012) [60]	Hu *et al.* (2007) [32]
Sub	U	*	✓	×	×	×	×	×	×	×
Sub	0/1	BH	✓	×	✓	×	×	✓	✓	✓
Sub	0/1	IM	✓	×	✓	×	×	✓	×	✓
Sub	0/1	MM	✓	×	✓	×	×	×	×	×
Sub	≥ 2	BH	✓	×	×	×	×	✓	✓	✓
Sub	≥ 2	IM	✓	×	×	×	×	✓	×	✓
Sub	≥ 2	MM	✓	×	×	×	×	×	×	×
Exact	0/1	BH	✓	✓	✓	✓	×	×	✓	✓
Exact	0/1	IM	✓	✓	✓	×	✓	×	×	✓
Exact	0/1	MM	✓	✓	✓	×	✓	×	×	×
Exact	≥ 2	BH	✓	×	×	✓	×	×	✓	✓
Exact	≥ 2	IM	✓	×	×	×	✓	×	×	✓
Exact	≥ 2	MM	✓	×	×	×	✓	×	×	×

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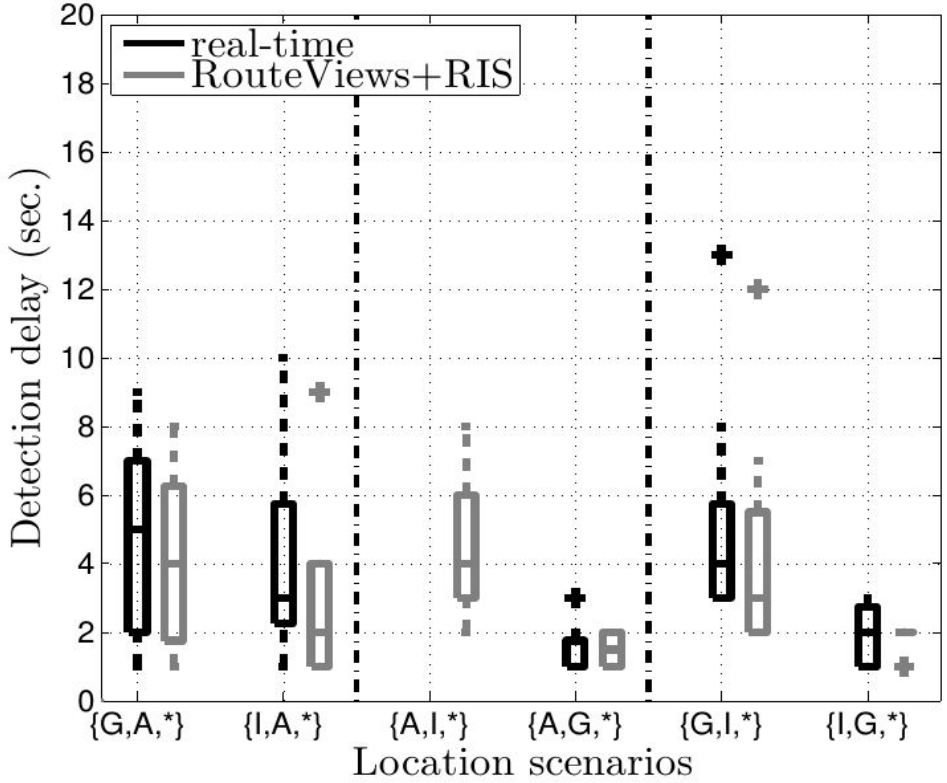
ARTEMIS: *accurate* detection

Hijacking Attack			ARTEMIS Detection				
Prefix	AS-PATH (Type)	Data Plane	False Positives (FP)	False Negatives (FN)	Detection Rule	Needed Local Information	Detection Approach
Sub-prefix	*	*	None	None	Config. vs BGP updates	Pfx.	Sec. 5.2
Squatting	*	*	None	None	Config. vs BGP updates	Pfx.	Sec. 5.2
Exact	0/1	*	None	None	Config. vs BGP updates	Pfx. + ASN (+ neighbor ASN)	Sec. 5.3
Exact	≥ 2	*	< 0.3/day for $> 73\%$ of ASes	None	Past Data vs BGP updates (bidirectional link)	Pfx.+ Past AS links	Sec. 5.4 *Stage 1*
Exact	≥ 2	*	None for 63% of ASes ($T_{s2} = 5min$, $th_{s2} > 1$ monitors)	$< 4\%$	BGP updates (waiting interval, bidirectional link)	Pfx.	Sec. 5.4 *Stage 2*

ARTEMIS: real-time monitoring, detection in *5 sec.*!

Real experiments in the Internet [1] (PEERING testbed)



[1] P. Sermpezis et al., "*ARTEMIS: Neutralizing BGP Hijacking within a Minute*", under revision IEEE/ACM ToN, arXiv 1801.01085.

ARTEMIS: mitigation methods

- DIY: react by **de-aggregating** if you can
- Otherwise (e.g., /24 prefixes) **get help** from other ASes

  → *announcement (MOAS) and tunneling from siblings or helper AS(es)*

TABLE 7: Mean percentage of polluted ASes, when outsourcing BGP announcements to organizations providing DDoS protection services; these organizations can provide highly effective outsourced mitigation of BGP hijacking.

	without outsourcing	top ISPs	AK	CF	VE	IN	NE
Type0	50.0%	12.4%	2.4%	4.8%	5.0%	7.3%	11.0%
Type1	28.6%	8.2%	0.3%	0.8%	0.9%	2.3%	3.3%
Type2	16.9%	6.2%	0.2%	0.4%	0.4%	1.3%	1.1%
Type3	11.6%	4.5%	0.1%	0.4%	0.3%	1.1%	0.5%

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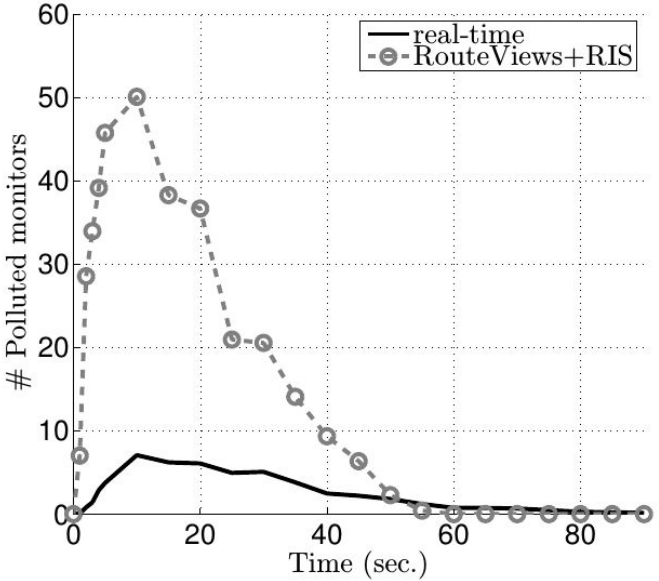
ARTEMIS: automated & flexible mitigation

- Automated: triggered immediately upon detection
- Flexible: configure per prefix / hijack type / impact / etc.

detection + mitigation:

NOW	ARTEMIS
hours/days →	**1 min.**



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The ARTEMIS tool: status

- Development funded by RIPE NCC Community Projects 2017
  - Tool presented at RIPE76 Routing WG (17 May 2018)
- Alpha (containerized) version soon available
- Modules:
  - GUI (web application)
  - Configuration (list of prefixes, ASNs, rules, etc.)
  - Monitoring: log BGP updates for all owned (sub-)prefixes
  - Detection
    - Working
    - Under development
  - Mitigation
    - Under development: automated mitigation

Affected prefix	AS-PATH (Type)	Data plane	ARTEMIS
Sub	U	*	✓
Sub	0/1	BH	✓
Sub	0/1	IM	✓
Sub	0/1	MM	✓
Sub	≥ 2	BH	✓
Sub	≥ 2	IM	✓
Sub	≥ 2	MM	✓
Exact	0/1	BH	✓
Exact	0/1	IM	✓
Exact	0/1	MM	✓
Exact	≥ 2	BH	✓
Exact	≥ 2	IM	✓
Exact	≥ 2	MM	✓

ARTEMIS configuration file

- Configure manually, react automatically
  - Define prefix, ASN, monitor groups
  - Declare ARTEMIS rules:

```
[group1]
prefixes:       my_prefixes
origin_asns:    my_asn, moas_asn
neighbors:      peer_65003,upstream_65002
mitigation:     manual
```

  - (Optionally) define mitigation parameters
- Future work: automated configuration
  - Extract from local routers
  - Extract from IRR (e.g., RADB, RPKI DBs)
  - Collect from RIPE RIS / RouteViews datasets

```
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
#                    ARTEMIS Config File                            #
# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #


#   #   #   #   #   #   #   #   #   #   #   #   #   #   #   #   #
# - - - - - # Start of Prefix Definition Groups # - - - - - #

[prefixes_group]

my_prefixes: X.Y.Z.W/N, ...
...: ...

# - - - - - # End of Prefix Definition Groups # - - - - - - #
# - - - - - # Start of Monitor Definition Groups # - -- - - #

[monitors_group]

riperis: rrc15, ...
exabgp: (<IP1> : <PORT_1>), ...
bgpstreamhist: <path_to_dir_with_hist_csv_files>
bgpstreamlive: routeviews, ris
...: ...

# - - - - - # End of Monitor Definition Groups #  - - - - - #
# - - - - - # Start of ASN  Definition Groups # - - - - - - #

[asns_group]

my_asn: 65001
my_upstream_asn: 65002
moas_asn: 65005
moas_upstream_asn: 65003
...: ...

# - - - - - # End of Monitor Definition Groups #  - - - - - #
# - - - - - # Start of Rule Declaration Groups  # - - - - - #

[group1]
prefixes: my_prefixes
origin_asns: my_asn, moas_asn
neighbors: my_upstream_asn, moas_upstream_asn
mitigation: manual

# - - - - - # End of Rule Declaration Groups  # - - - - - - #
```

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ARTEMIS UI: Monitor Logs

DISCLAIMER: The data used on this slide for hijacks are under verification, and are used to demonstrate how the UI looks.

ID	Prefix	Origin AS	Peer AS	AS Path	Service	Type	Timestamp	↑Hijack ID	Handled
54	139.91.0.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.jinx	A	6/7/18, 3:43 PM	3	Yes
56	139.91.0.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.linx	A	6/7/18, 3:43 PM	3	Yes
58	139.91.0.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.napafrica	A	6/7/18, 3:43 PM	3	Yes
43	139.91.128.0/17	8522	37497	37497 2914 8522	RIPEris rrc19	A	6/7/18, 3:43 PM	2	Yes
55	139.91.128.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.jinx	A	6/7/18, 3:43 PM	2	Yes
57	139.91.128.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.linx	A	6/7/18, 3:43 PM	2	Yes
59	139.91.128.0/17	8522	37497	37497 2914 8522	bgpstream|routeviews|route-views.napafrica	A	6/7/18, 3:43 PM	2	Yes

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ARTEMIS UI: Hijack Logs

DISCLAIMER: The data used on this slide for hijacks are under verification, and are used to demonstrate how the UI looks.

↑ID	Type	Prefix	Hijack AS	CNum Peers Seen	CNum ASNs Infected	Time Started	Time Last Updated	Time Ended	Mit Pending	Mit Started	Mitigate	Resolved
7	1	139.91.128.0/17	174	1	1	6/26/18, 3:28 PM	6/26/18, 3:28 PM		False		Mitigate	Resolved
6	1	139.91.0.0/17	174	1	1	6/26/18, 3:28 PM	6/26/18, 3:28 PM		False		Mitigate	Resolved
5	1	139.91.128.0/17	1299	1	1	6/19/18, 2:43 PM	6/19/18, 2:43 PM		False		Mitigate	Resolved
4	1	139.91.0.0/17	1299	1	1	6/19/18, 2:43 PM	6/19/18, 2:43 PM		False		Mitigate	Resolved
3	1	139.91.0.0/17	2914	1	1	6/7/18, 3:43 PM	6/26/18, 7:30 PM		False		Mitigate	Resolved
2	1	139.91.128.0/17	2914	1	1	6/7/18, 3:43 PM	6/26/18, 7:30 PM		False		Mitigate	Resolved

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What's next?

- Testing ARTEMIS as a tool in an operational environment
- Improved UI
- Automated configuration
- Advanced detection + mitigation
- Using data-plane measurements for
  - automated verification of hijack events
  - detection of events with limited regional impact
- Cooperation with CAIDA on Internet Observatory
  - centralized service for detection of BGP hijacks and anomalies (including MitM)

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What do we need from you?

- Feedback:
  - Answer our questionnaire at: http://inspire.edu.gr/artemis/qa
  - Try current test version at: http://inspire.edu.gr/artemis/demo (credentials: test / ripe76_artemis)
  - Advice on integrating ARTEMIS in operational environments
- Collaboration for testing ARTEMIS (e.g., configuration)
- Contact us:
  - Come and talk to us during GRNOG7 (*Vassilis, Lefteris*)
  - Mail us at: *{vkotronis, sermpezis, leftman, fontas}@ics.forth.gr, {alberto, alistair}@caida.org*
  - Visit the ARTEMIS website http://www.inspire.edu.gr/artemis/

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Thank you! Questions?

www.inspire.edu.gr/artemis

- ***Questionnaire:*** *http://inspire.edu.gr/artemis/qa*
- ***Toy version for testing:*** *http://inspire.edu.gr/artemis/demo/* (creds: test/ripe76_artemis)
- ***ARTEMIS: Neutralizing BGP Hijacking within a Minute*** under revision in ACM/IEEE ToN, *https://arxiv.org/abs/1801.01085*
- ***A Survey among Network Operators on BGP Prefix Hijacking*** in ACM SIGCOMM CCR, Jan' 18, *https://arxiv.org/abs/1801.02918*
- ***ARTEMIS: Real-Time Detection and Automatic Mitigation for BGP Prefix Hijacking (demo)*** in ACM SIGCOMM 2016, *https://arxiv.org/abs/1702.05349*

funded by: RIPE NCC RIPE NETWORK COORDINATION CENTRE, NSF, erc European Research Council Established by the European Commission **EU338402**

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BACKUP

BGP prefix hijacking is a critical threat

→ to your **organization** & **customers** & **peers**

BACKUP

- **Outages** in the Internet cause losses of millions of $$$
- **Interception** of bitcoins, credit card transactions, passwords, ...
- **Bad reputation** for hijacked networks: security, service reliability

...only in 2017: ***5,304*** hijacks, with ***3,106*** organizations as victims [1]

[1] “14,000 Incidents: A 2017 Routing Security Year in Review”, www.internetsociety.org

Threat Model → the hijacker:

- controls a single AS and its edge routers
- has full control of the control plane and data plane within its own AS
- can arbitrarily manipulate the:
  - BGP messages that it sends to its neighboring ASes (control plane)
  - traffic that crosses its network (data plane)
- has otherwise no control over BGP messages and traffic exchanged between two other ASes.

BACKUP

→ Extensions (future work): multiple ASes controlled by a single hijacker

Type-N, N≥2, hijacks: Stage 1

BACKUP

- Triggered upon a BGP update (for a monitored prefix) whose AS-PATH contains a N-hop AS-link (N ≥ 2) that is not included in the previously verified AS-links list
- Legitimate if this link has been observed in the opposite direction in the AS-links list from monitors and local BGP routers
  (10 months history) (and there appears consistently at least 1 AS on the left of the link*)
- Example with fake link directly attached to hijacker:

<my_prefix, **MY_AS**, MY_PEER, **BAD_AS**, …> attack announcement

<any_prefix, ..., **BAD_AS**, MY_PEER, …, **BAD_AS**, ...> pre-attack fails (discard loops)

<any_prefix, ..., **BAD_AS**, MY_PEER, …, **2nd_BAD_AS**, ...> pre-attack succeeds
(beyond adopted threat model)

- * Works also when hijacker is hiding behind a legitimate upstream provider!

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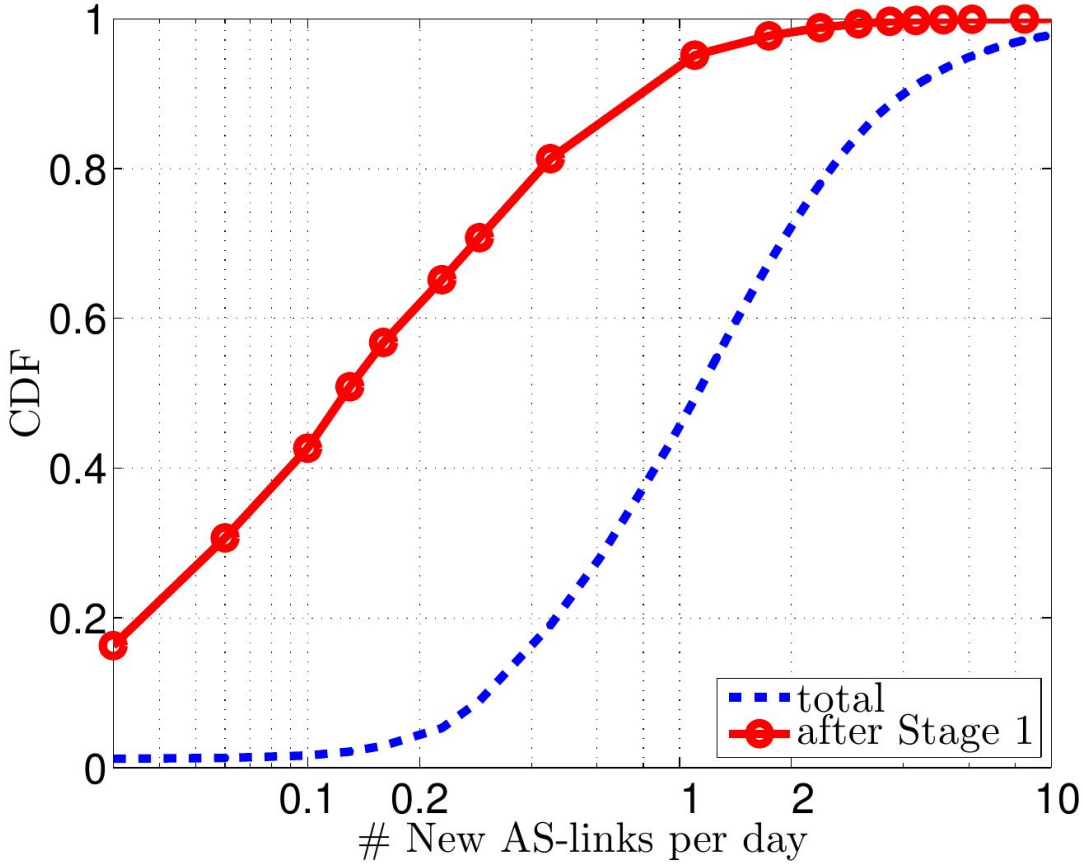
Type-N, N≥2, hijacks: Stage 1

BACKUP



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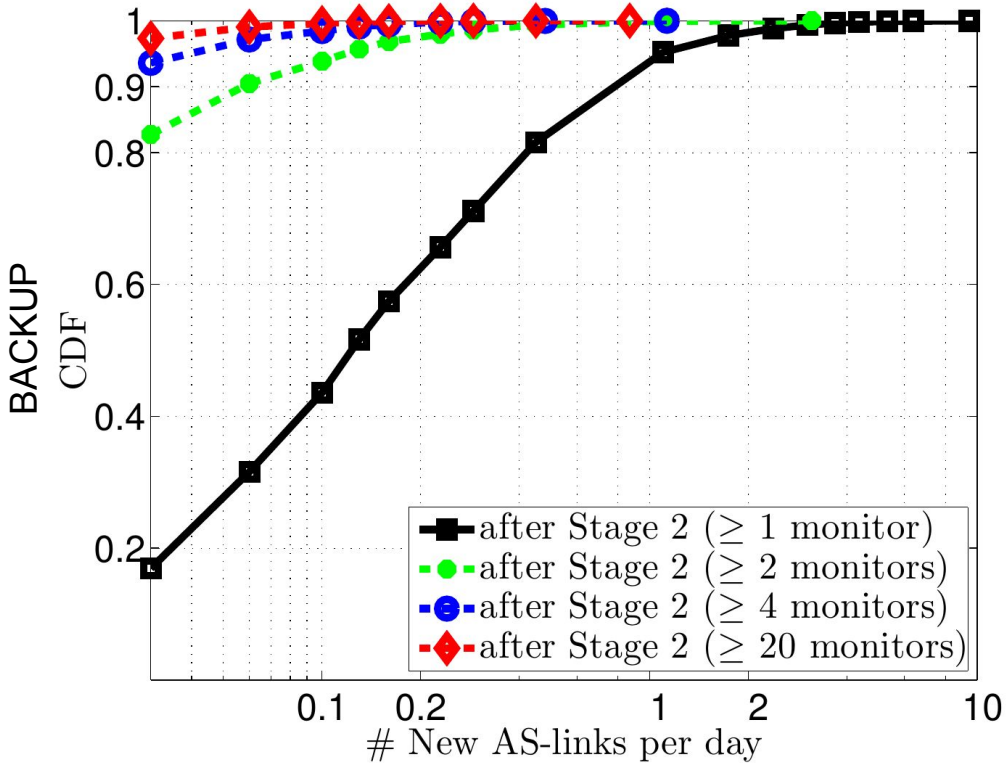
Type-N, N≥2, hijacks: Stage 2 w/ FN of small impact



- **Stage 2**
  - Wait 5 minutes
  - Recheck tables on monitors + local routers
  - Optional: decisions based on observable impact (e.g., number of monitors involved)

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Note: What we do not cover as hijacks →route leaks

- Not actual hijacks in the classic threat model
  - All links involved in the announced paths are valid!
- Fall in the context of “policy violations”, e.g.,
  - What if Google decided to be a Tier-1 global transit network for one hour?
  - What if your friendly IXP peer decided to act as your upstream?
- Detecting them requires detailed knowledge of in-path policies
  - These are not publicly available
  - Existing datasets → would yield high numbers of FP
  - 30% of observed routes are not consistent with available routing policy data [1]
  - **Ongoing work! (beyond “good filtering”)**

BACKUP

[1] Ruwaifa Anwar et al. Investigating interdomain routing policies in the wild. In Proc. ACM IMC, 2015.