

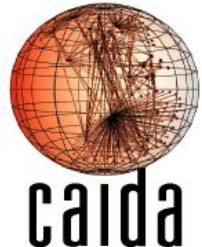
# ARTEMIS: Neutralizing BGP Hijacking within a Minute

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

Foundation for Research and Technology - Hellas (FORTH), Greece  
&

Center for Applied Internet Data Analysis (CAIDA) UCSD, US

*RIPE76, Marseille, France, 14-18 May, 2018*



# Hijacks: Human Errors

## Today's BGP leak in Brazil

Posted by Andree Toonk - October 21, 2017 - News and Updates - No Comments

Earlier today several people noticed network reachability problems.

Twitter, Google and others. The root cause turned out to be another BGP mishap.

mtu	src_ip	dst_ip	src_port	dst_port	loss%	drop	rcv	set	last	best	avg	nrst	stdDev	gmean	jttt	javg	jmax	
mtu	4rwct0	172.217.16.106																
client	3017-10-21T13:26:59+0200																	
dst	linux-blcr																	
1.	A57???	10.235.224.157			0.0%	0	10	10	71.9	37.6	56.7	71.9	9.3	56.0	15.8	5.1	16.2	72.4
2.	A562292	217.112.143.217			0.0%	0	10	10	58.6	47.0	54.8	65.2	6.2	54.5	1.3	7.1	16.7	53.2
3.	A57???	bix.ho.net (193.188.107.175)			0.0%	0	10	10	45.8	45.1	55.9	69.3	7.4	55.4	16.2	7.7	16.2	62.6
4.	A56939	100ge11-1.core1.viettel.net (184.105.213.249)			10.0%	1	9	10	68.0	44.7	54.6	73.4	8.8	54.0	9.7	8.2	28.6	57.5
5.	A56939	100ge13-1.core1.par2.he.net (184.105.65.5)			0.0%	0	10	10	120.0	62.6	86.8	120.0	21.7	84.4	52.5	23.3	52.5	193.0
6.	A56939	100ge19-2.core1.asahi.he.net (184.105.213.173)			0.0%	0	10	10	166.6	144.0	152.1	161.4	6.2	152.0	16.6	6.1	16.6	52.6
7.	A56939	100ge8-2.core1.asahi.he.net (184.105.213.69)			0.0%	0	10	10	157.5	148.1	164.4	185.9	12.5	164.0	11.1	14.1	37.8	100.2
8.	A56939	100ge4-1.core1.mtai.he.net (184.105.213.26)			0.0%	0	10	10	174.5	160.1	172.2	181.7	7.5	172.1	0.7	8.1	21.5	59.1
9.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
10.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
11.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
12.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
13.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
14.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
15.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
16.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
17.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
19.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
20.	A57???	???			100.0%	10	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
21.	A552328	200.16.78.209			80.0%	8	2	10	495.2	496.2	498.3	500.3	2.9	498.2	4.1	2.1	4.1	4.1
22.	A57???	45.6.52.32			85.9%	8	1	9	530.5	530.5	530.5	530.5	0.0	530.5	0.0	0.0	0.0	0.0
23.	A57???	???			100.0%	4	0	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	



Fusl

@OhNoltsFusl

VANTAGEPOINT  
IN: RESEARCH

24分前より  
33分前より

情報種別

故障情報

ステータス

復旧日時

2017年08月25日12時22分頃

Large BGP Leak by Google Disrupts Internet in Japan

2017年08月25日12時45分

通信不安定は復旧しております。  
安定が継続しておりましたが、通信の安定化を

Aug 28, 2017 // Doug Madory

# Hijacks: Malicious Attacks

ANDY GREENBERG SECURITY 08.07.14 01:00 PM

**ars TECHNICA**

BIZ & IT TECH SCIENCE POLICY CARS GAMING & CULTURE

**BIZ & IT**

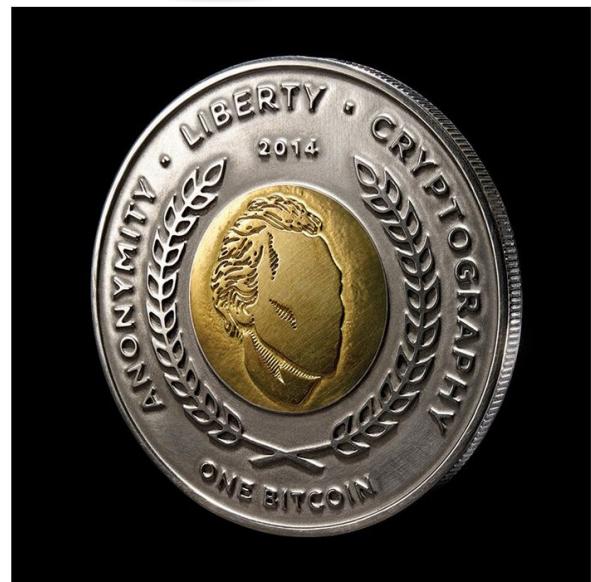
**“Suspicious” event routes traffic for big-name sites through Russia**

Google, Facebook, Apple, and Microsoft all affected by “intentional” BGP mishap.

DAN GOODIN - 12/14/2017, 12:43 AM

ANDY GREENBERG SECURITY 08.07.14 01:00 PM

HACKER REDIRECTS TRAFFIC  
FROM 49 INTERNET PROVIDERS  
TO STEAL BITCOINS



# BGP prefix hijacking is a critical threat

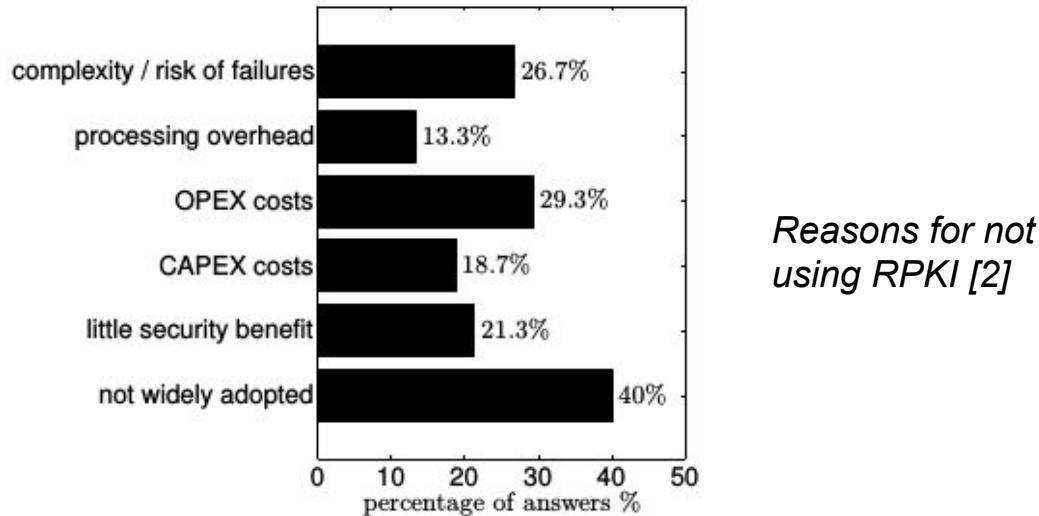
→ to your **organization & customers & peers**

- **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]

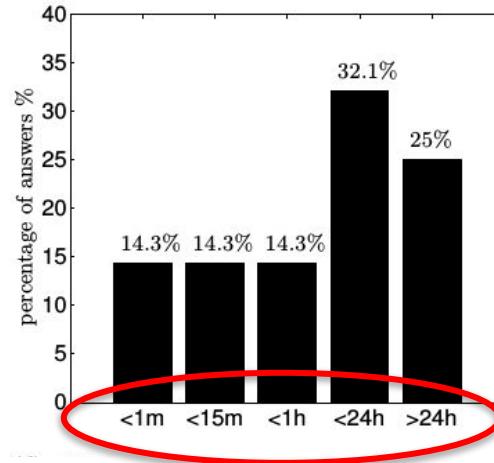
# How do people deal with this today? → RPKI

- ✗ Only 8% of prefixes covered by ROAs [1]
- ✗ Why? → limited adoption & costs/complexity [2]
- ✗ Does not protect the network against all attack types



# How do people deal with this today? → Third parties

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



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

# 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/](http://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.



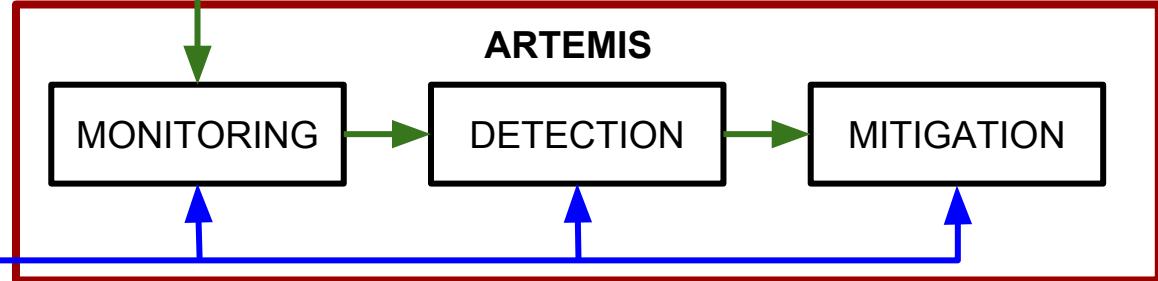
## BGP Monitors:

- RIPE RIS
- BGPStream
  - Live
  - Historical
- Local (exaBGP)

Runs as a VM in the NOC or in the cloud



Operator  
Configuration  
File



AS1234

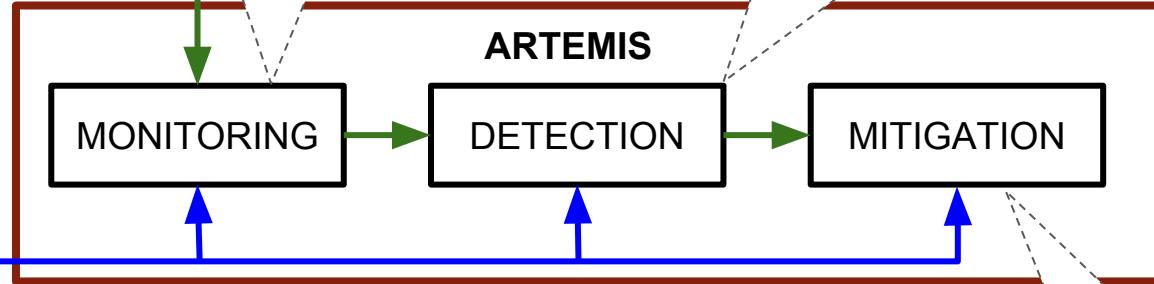


## BGP Monitors:

- RIPE RIS
- BGPStream
  - Live
  - Historical
- Local (exaBGP)

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

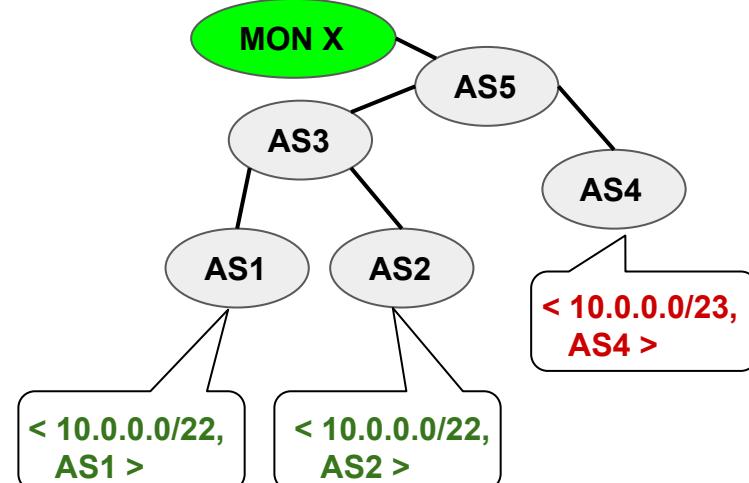
“Origin sub-prefix HIJACK by AS4 against 10.0.0.0/23.”



Operator Configuration File



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



React to hijack!

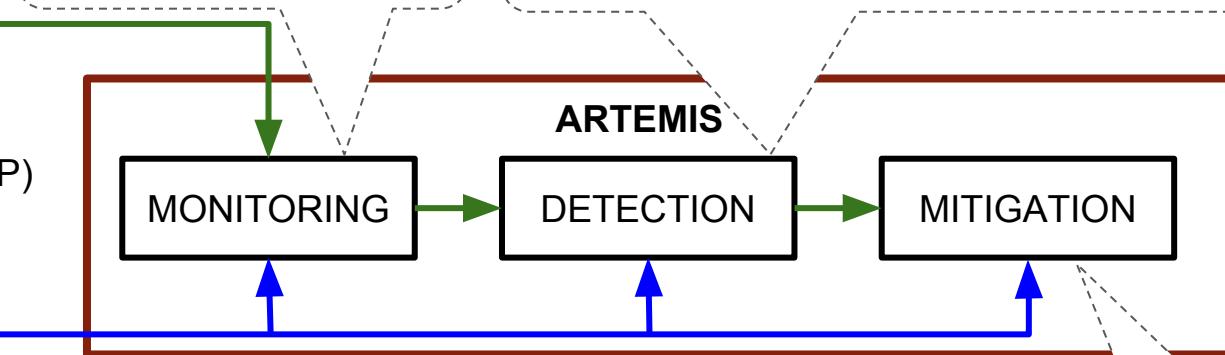


## BGP Monitors:

- RIPE RIS
- BGPStream
  - Live
  - Historical
- Local (exaBGP)

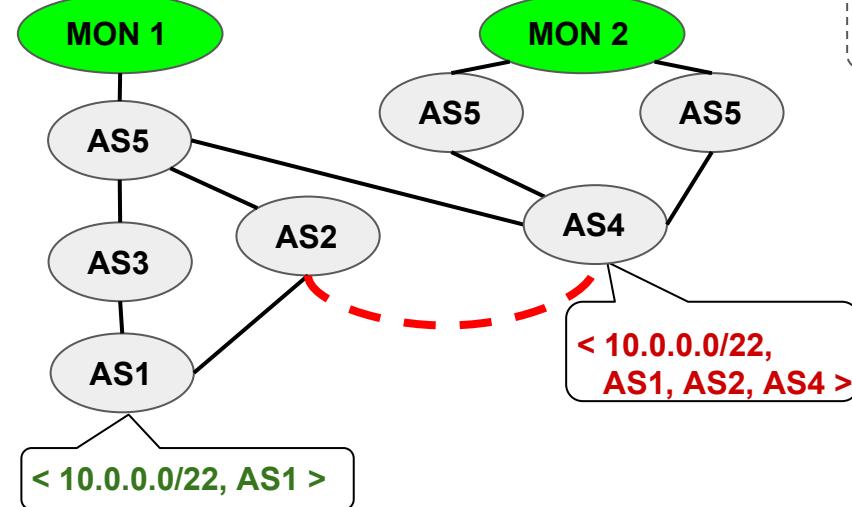
“2 monitors saw in last 5 minutes < 10.0.0.0/22, AS1, AS2, AS4, ... >”

“Link AS2-AS4 not seen in last 10 months for any prefix, in any direction. Path manipulation HIJACK by AS4 against 10.0.0.0/22.”



Operator Configuration File

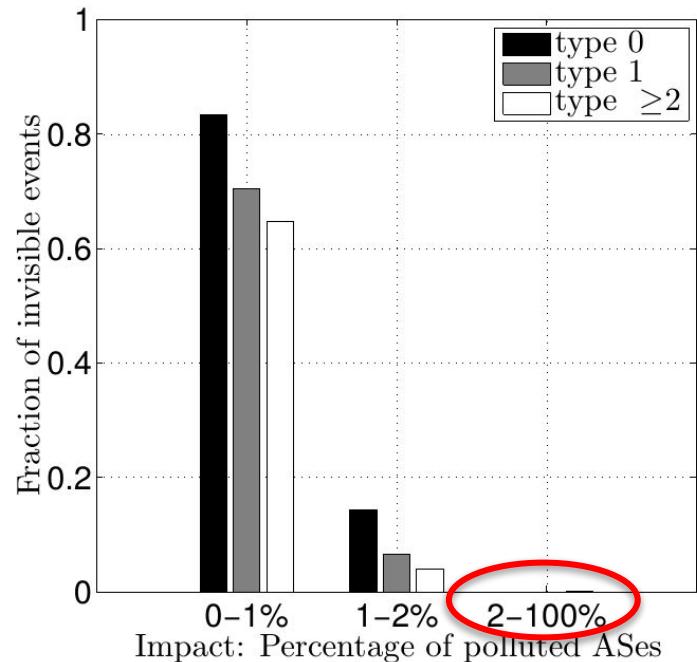
“I own 10.0.0.0/22 and announce it from AS1 with AS2 and AS3 as upstreams.”



# ARTEMIS: Visibility of *all* impactful hijacks

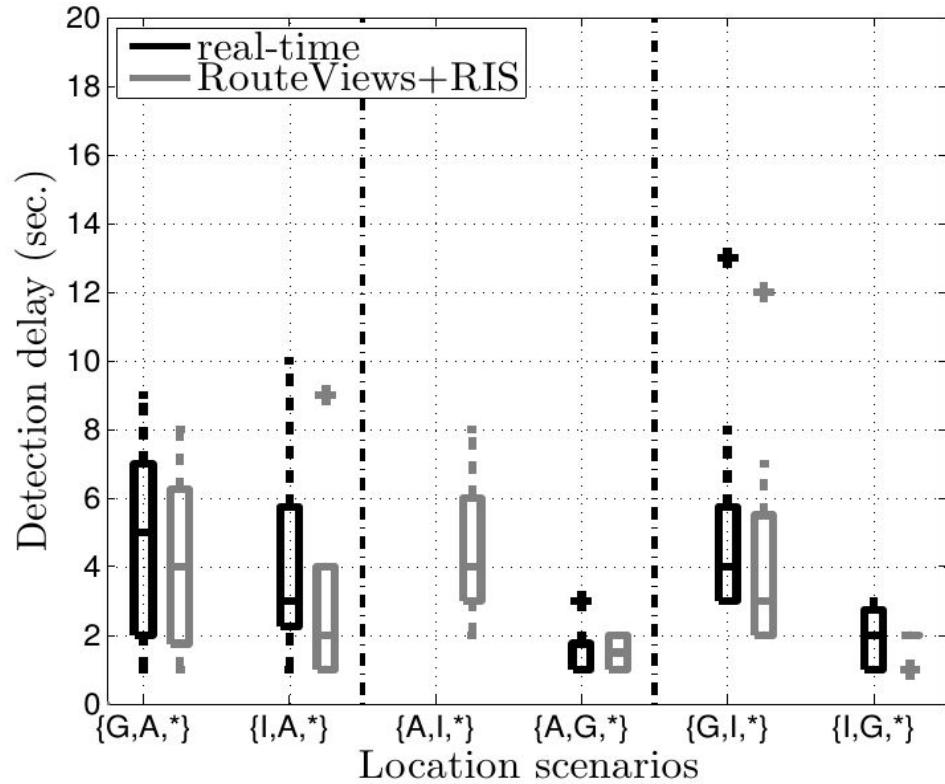
- Public BGP monitor infrastructure
  - RIPE RIS, RouteViews, BGPmon
  - ~500 vantage points worldwide (BGP routers)

Simulation results on  
the AS-level graph [1]



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

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

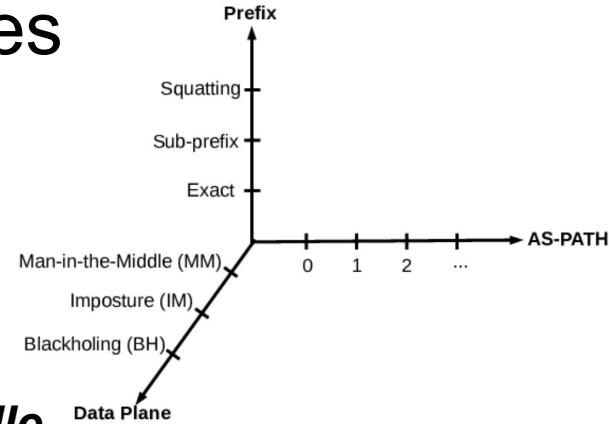


[1] P. Sermpezis et al., “[ARTEMIS: Neutralizing BGP Hijacking within a Minute](#)”, under revision IEEE/ACM ToN, arXiv 1801.01085. 12

# ARTEMIS: detection of all hijack types

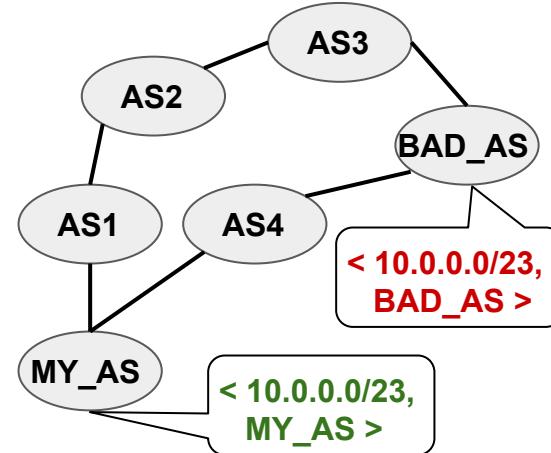
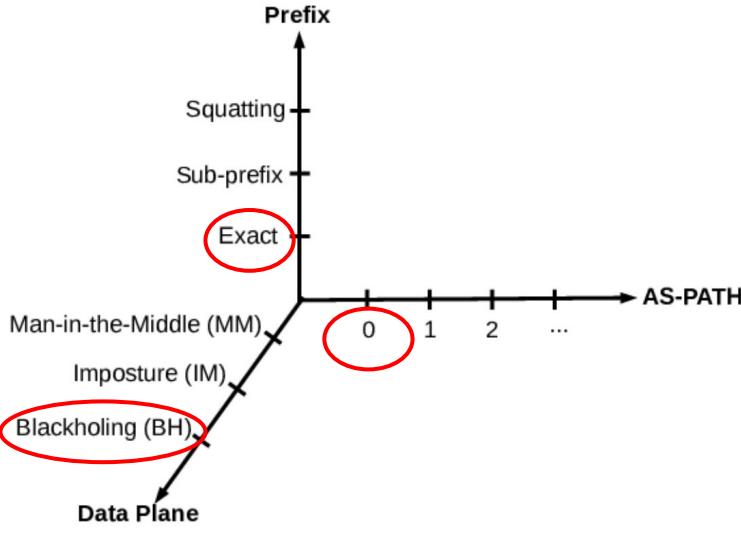
- Hijack types taxonomy - 3 dimensions:
  1. Affected prefixes:  
**prefix** or **sub-prefix** or **squatting**
  2. Data-plane:  
**blackholing** or **imposture** or **man-in-the-middle**
  3. AS-path manipulation: **Type-0** or **Type-1** or ... or **Type-N**

- 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>



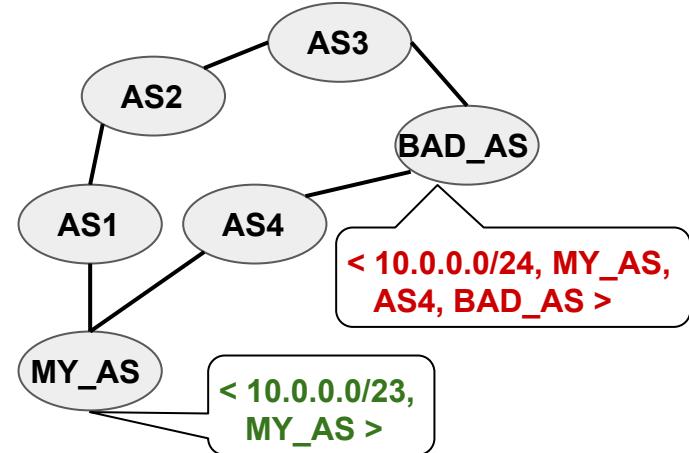
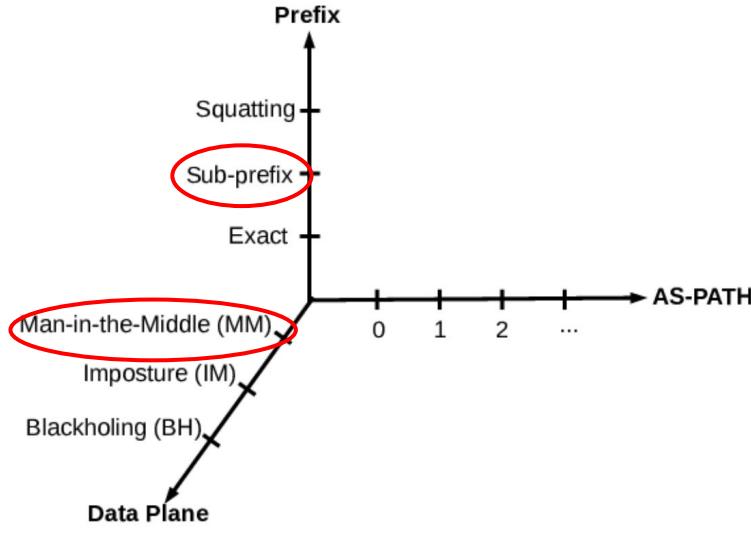
# ARTEMIS: detection of all hijack types

- Taxonomy - Example 1: prefix + Type-0 + blackholing



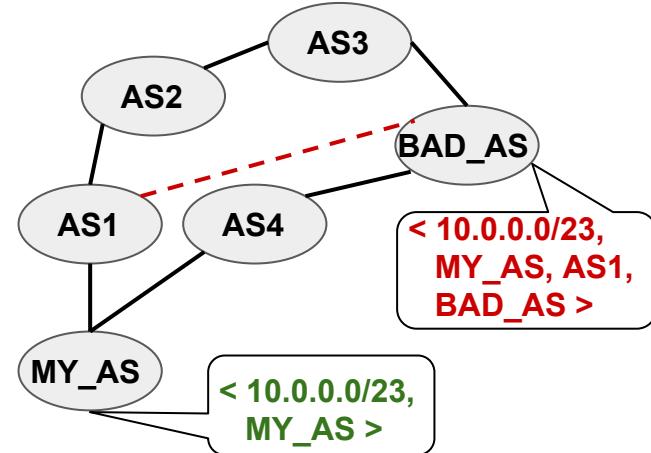
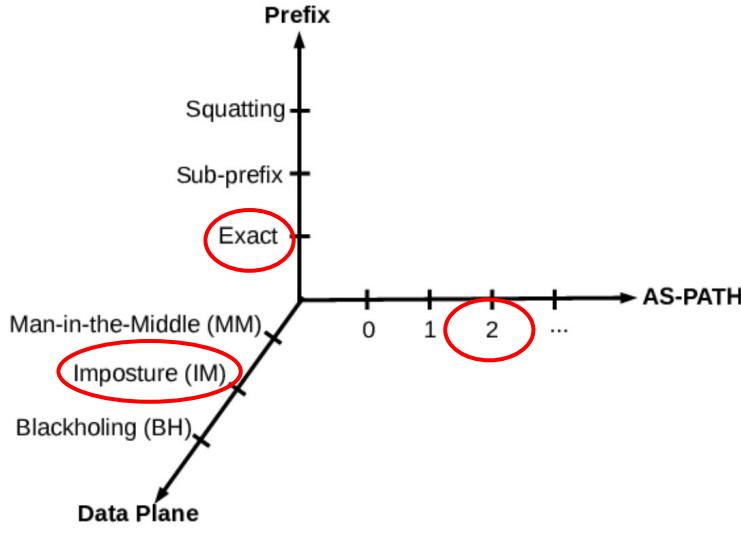
# ARTEMIS: detection of all hijack types

- Taxonomy - Example 2: **sub-prefix + Type-U + man-in-the-middle**



# ARTEMIS: detection of all hijack types

- Taxonomy - Example 3: **prefix + Type-2 + imposture**



# 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 <i>et al.</i> (2007) [70]	HEAP (2016) [57]	Argus (2012) [60]	Hu <i>et al.</i> (2007) [32]
Sub	U	*	✓	✗	✗	✗	✗	✗	✗	✗
Sub	0/1	BH	✓	✗	✓	✗	✗	✓	✓	✓
Sub	0/1	IM	✓	✗	✓	✗	✗	✓	✗	✓
Sub	0/1	MM	✓	✗	✓	✗	✗	✗	✗	✗
Sub	$\geq 2$	BH	✓	✗	✗	✗	✗	✓	✓	✓
Sub	$\geq 2$	IM	✓	✗	✗	✗	✗	✓	✗	✓
Sub	$\geq 2$	MM	✓	✗	✗	✗	✗	✗	✗	✗
Exact	0/1	BH	✓	✓	✓	✓	✗	✗	✓	✓
Exact	0/1	IM	✓	✓	✓	✗	✓	✗	✗	✓
Exact	0/1	MM	✓	✓	✓	✗	✓	✗	✗	✗
Exact	$\geq 2$	BH	✓	✗	✗	✓	✗	✗	✓	✓
Exact	$\geq 2$	IM	✓	✗	✗	✗	✓	✗	✗	✓
Exact	$\geq 2$	MM	✓	✗	✗	✗	✓	✗	✗	✗

# ARTEMIS: accurate detection

Hijacking Attack			ARTEMIS Detection				
Prefix	AS-PATH	Data Plane	False Positives (FP)	False Negatives (FN)	Detection Rule	Needed Local Information	Detection Approach
	(Type)	Plane					
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	$\geq 2$	*	< 0.3/day for > 80% of ASes	None	Past Data vs BGP updates (bidirectional link)	Pfx.+ Past AS links	Sec. 5.4 Stage 1
Exact	$\geq 2$	*	None for 89% of ASes $(T_{s2} = 5min,$ $th_{s2} > 1$ monitors)	< 4%	BGP updates (waiting interval, bidirectional link)	Pfx.	Sec. 5.4 Stage 2

# ARTEMIS: mitigation methods

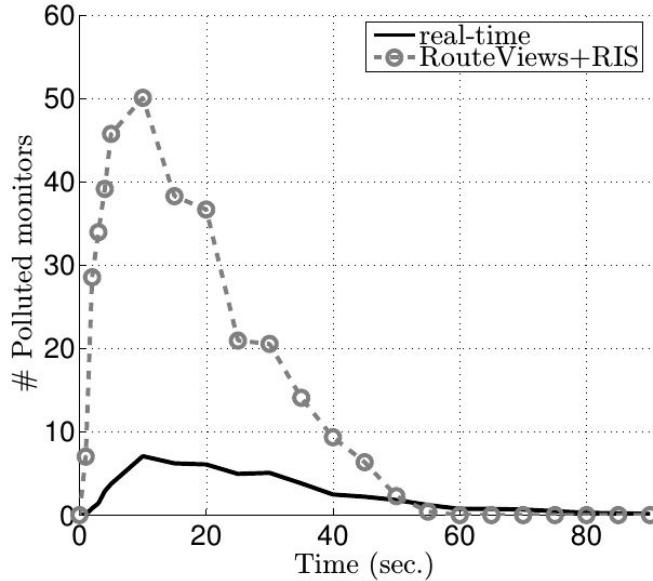
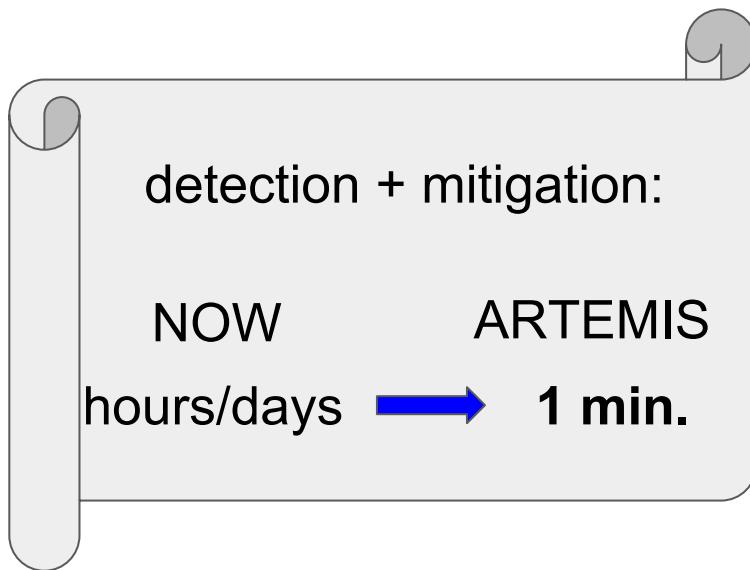
- DIY: react by **de-aggregating** if you can
- Otherwise (e.g., /24 prefixes) **get help** from other ASes  
→ *announcement (MOAS) and tunneling from siblings or helper AS(es)*

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%

# ARTEMIS: automated & flexible mitigation

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



(b) # polluted monitors

# The ARTEMIS tool: status

- Development funded by RIPE NCC Community Projects 2017
- Alpha version soon available
- Modules:
  - Minimal 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	$\geq 2$	BH	✓
Sub	$\geq 2$	IM	✓
Sub	$\geq 2$	MM	✓
Exact	0/1	BH	✓
Exact	0/1	IM	✓
Exact	0/1	MM	✓
Exact	$\geq 2$	BH	✓
Exact	$\geq 2$	IM	✓
Exact	$\geq 2$	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: configuration automation
  - Extract from routers/RR
  - Extract from RADB/RIR

```
# # # # # # # # # # # # # # # # # # # # # # # # # # # # #
#                               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 # - - - - -
```

# ARTEMIS UI

## Monitor Logs

ID	Prefix	Origin AS	Peer AS	AS Path	Service	Type	Timestamp	Hijack ID	Handled
107	139.91.0.0/16	8522	52888	52888 1916 27750 20965 5408 8522	RIPERis rrc15	A	5/7/18, 3:35 PM		Yes
106	139.91.0.0/16	8522	36236	36236 16397 26615 6762 2603 21320 5408 8522	bgpstream routeviews route-views4	A	5/7/18, 2:47 PM		Yes
105	139.91.0.0/16	8522	24482	24482 174 21320 21320 21320 21320 5408 8522	bgpstream routeviews route-views4	A	5/7/18, 2:47 PM		Yes
104	139.91.0.0/16	8522	24482	24482 174 21320 21320 21320 21320 5408 8522	bgpstream routeviews route-views.sg	A	5/7/18, 2:46 PM		Yes
103	139.91.0.0/16	8522	24482	24482 2603 21320 5408 8522	bgpstream routeviews route-views.sg	A	5/7/18, 2:46 PM		Yes

# ARTEMIS UI

## Hijack Logs

DISCLAIMER: The data used on this slide for hijacks are fake/random and serve only to show how the tool 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
6	1	139.91.250.0/24	56910	1	3	5/7/18, 2:33 PM	5/7/18, 2:33 PM	5/7/18, 5:26 PM	False	5/7/18, 5:26 PM	<button>Mitigate</button>	<button>Resolved</button>
5	1	139.91.250.0/24	56910	1	2	5/7/18, 2:20 PM	5/7/18, 2:20 PM		False		<button>Mitigate</button>	<button>Resolved</button>
4	1	139.91.250.0/24	56910	1	2	5/7/18, 2:00 PM	5/7/18, 2:00 PM		False		<button>Mitigate</button>	<button>Resolved</button>
3	1	139.91.250.0/24	56910	1	2	5/7/18, 2:00 PM	5/7/18, 2:00 PM		False		<button>Mitigate</button>	<button>Resolved</button>

# What do we need from you?

- Feedback
  - E.g., try current test version at: <http://inspire.edu.gr/artemis/demo/>  
(credentials: test / ripe76\_artemis)
- Design requirements
- Advice on integrating ARTEMIS in operational environments
- Collaboration for testing ARTEMIS (e.g., configuration)
- Contact us at:
  - Come and talk to us during RIPE76 (*Vassilis, Pavlos, Lefteris, George, Fontas*)
  - Mail us at: {*vkotronis, sermpezis, leftman, gnomikos, fontas*}@ics.forth.gr,  
{*alberto, alistair*}@caida.org
  - Visit the ARTEMIS website <http://www.inspire.edu.gr/artemis/>

# Thank you! Questions?

[www.inspire.edu.gr/artemis](http://www.inspire.edu.gr/artemis)

- **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>



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