BGP Hijackers That Evade Public Route Collectors*

Presentation by
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** Based on our recent IEEE Access Journal (Link)*

Outline

- Background
- The Problem
- Lessons Learned
- Real-world Findings
- Suggestions

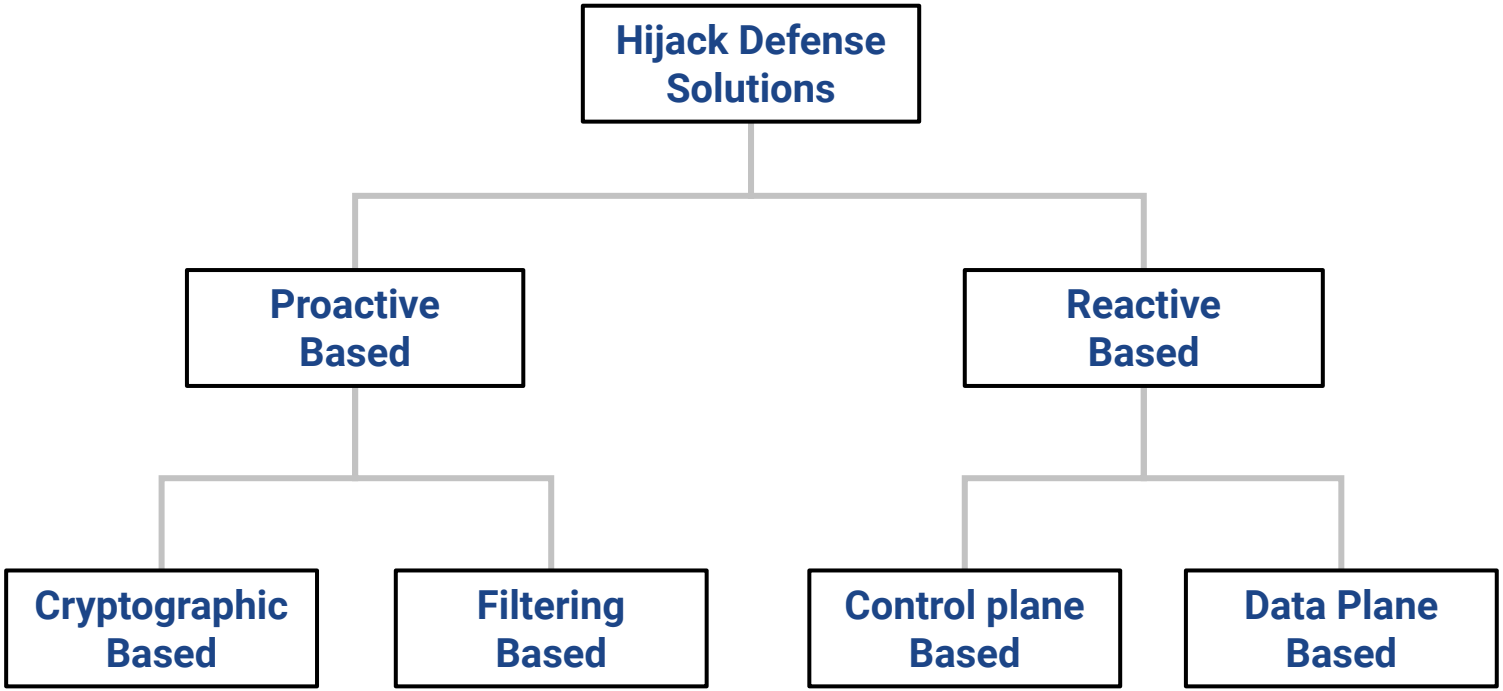
BGP Prefix Hijacking

Documented Suspicious BGP Hijacks:

- Targets 2022: Governmental infrastructure **[1],** Cryptocurrency services **[2],** etc.
- Incidents 2021: 775 suspicious BGP hijacks **[3]**.
- Incidents 2020: 2255 suspicious BGP hijacks **[4]**.
- Incidents 2019: 1727 suspicious BGP hijacks **[4]**.

[1] *Luconi V. Et al."Impact of the first months of war on routing and latency in Ukraine", Computer Networks Journal*
[2] *https://www.kentik.com/blog/bgp-hijacks-targeting-cryptocurrency-services/*
[3] *https://www.manrs.org/2022/02/bgp-security-in-2021/*
[4] *https://www.manrs.org/2021/03/a-regional-look-into-bgp-incidents-in-2020/*

Current Solutions



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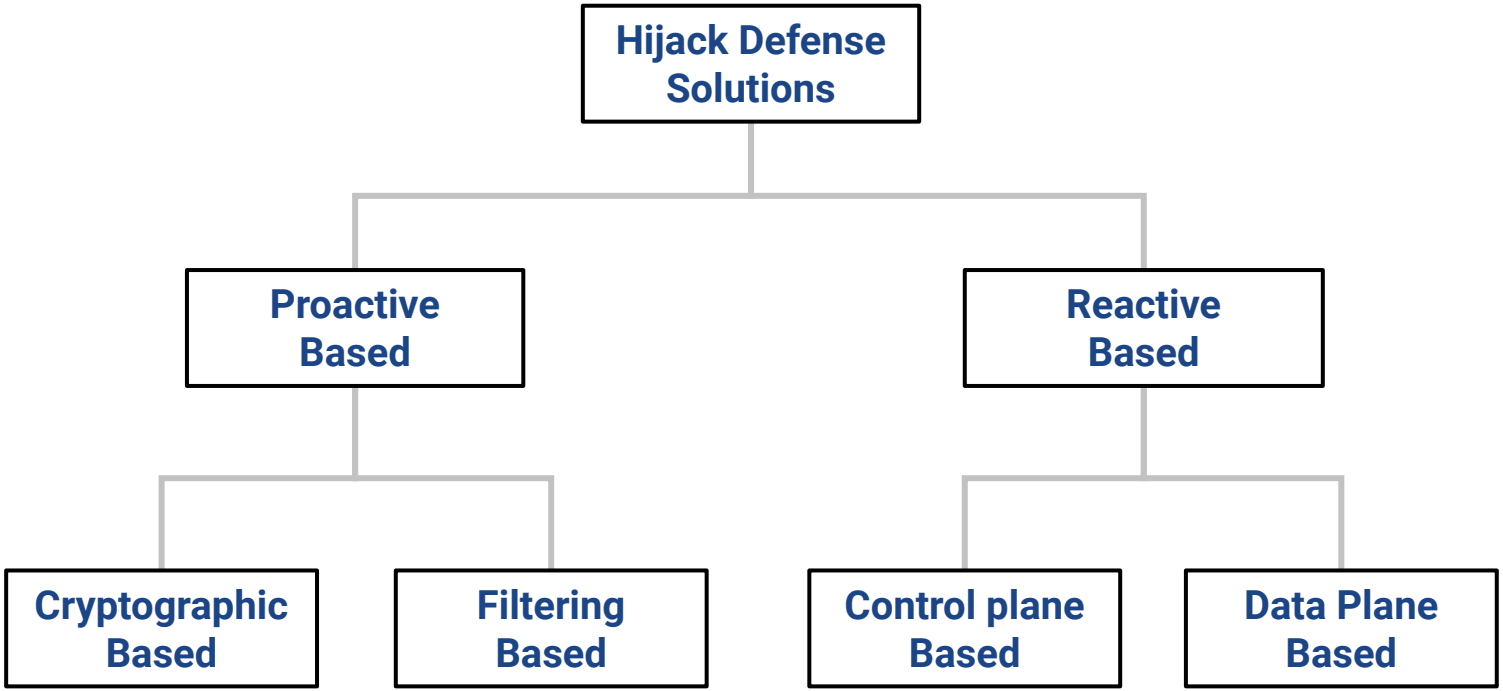
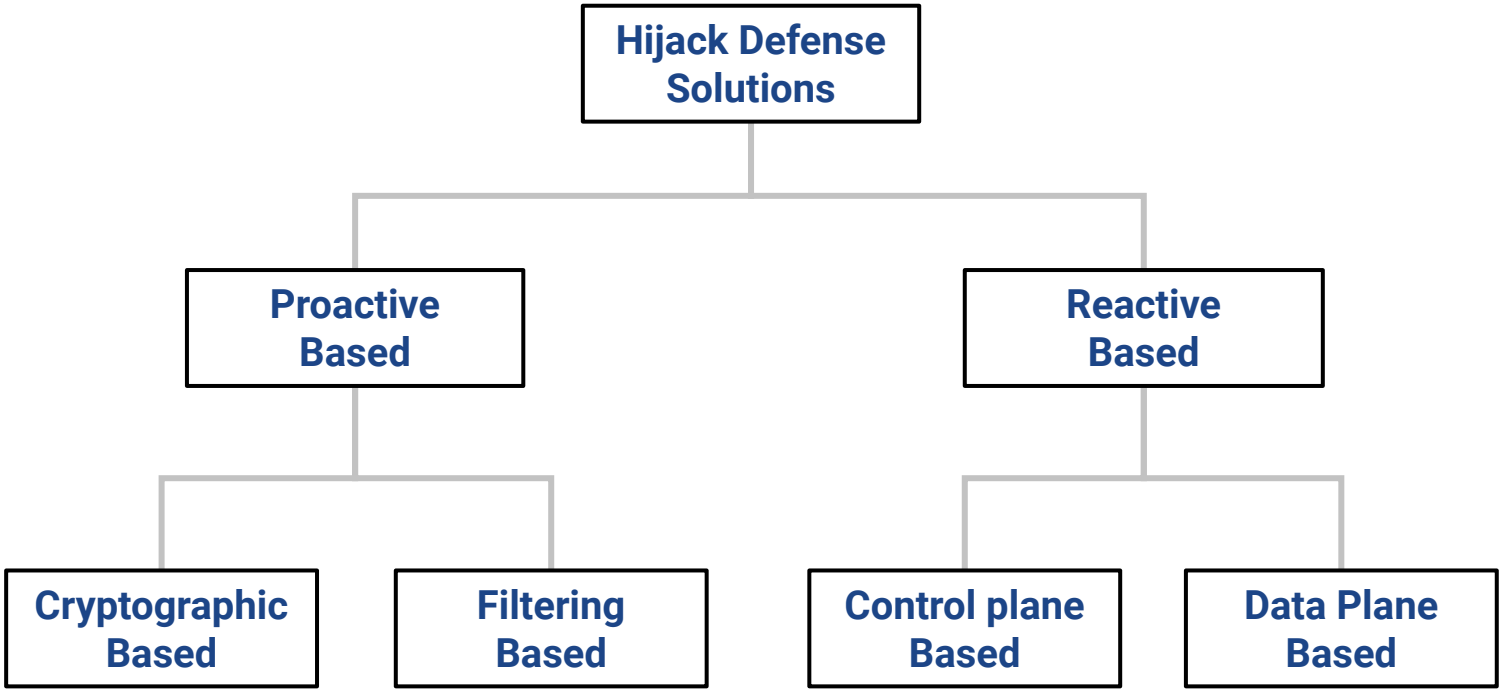


Not Sufficient for all forms of hijacks (currently)

Current Solutions



Current Hijack Solutions

★ Most of current Commercial solutions rely on *Route collectors* & *Looking Glasses*.

Route Collectors (RC):

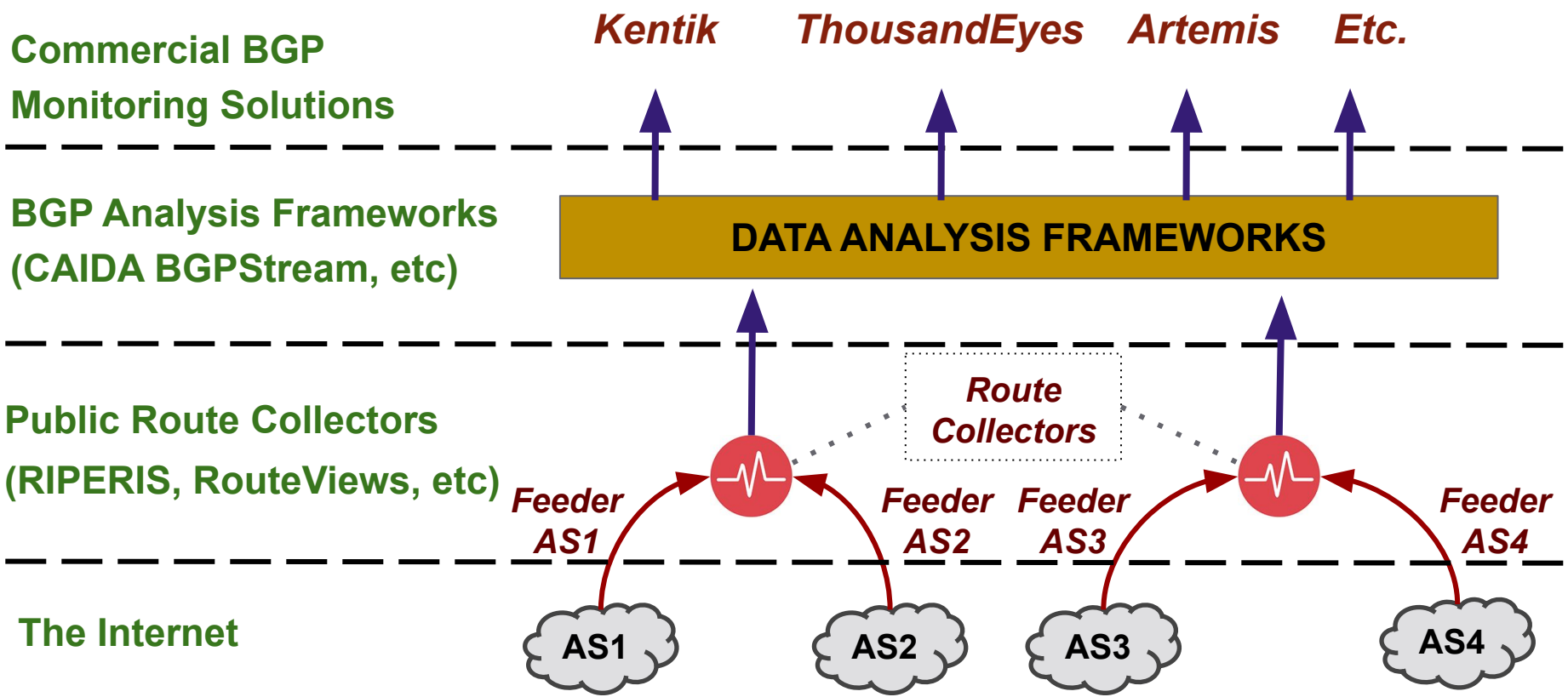
❖ BGP speaking devices that collect & report routes received from their neighbors.

Public Route Collector Infrastructure:

❖ Namely: RIPE-RIS, Routeviews, etc.

❖ Collection of multiple route collectors distributed around the world.

Pipeline: Route Collection by Commercial Solutions



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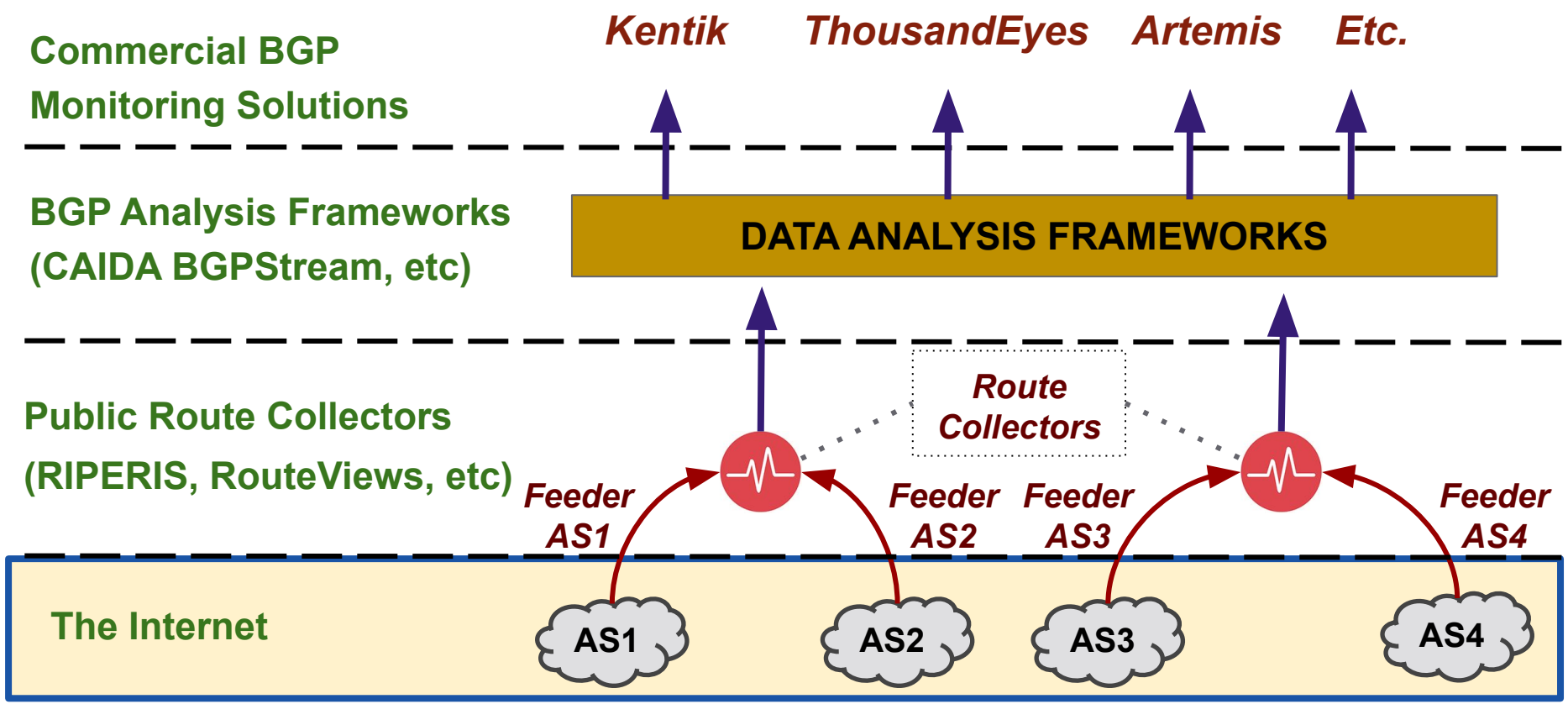

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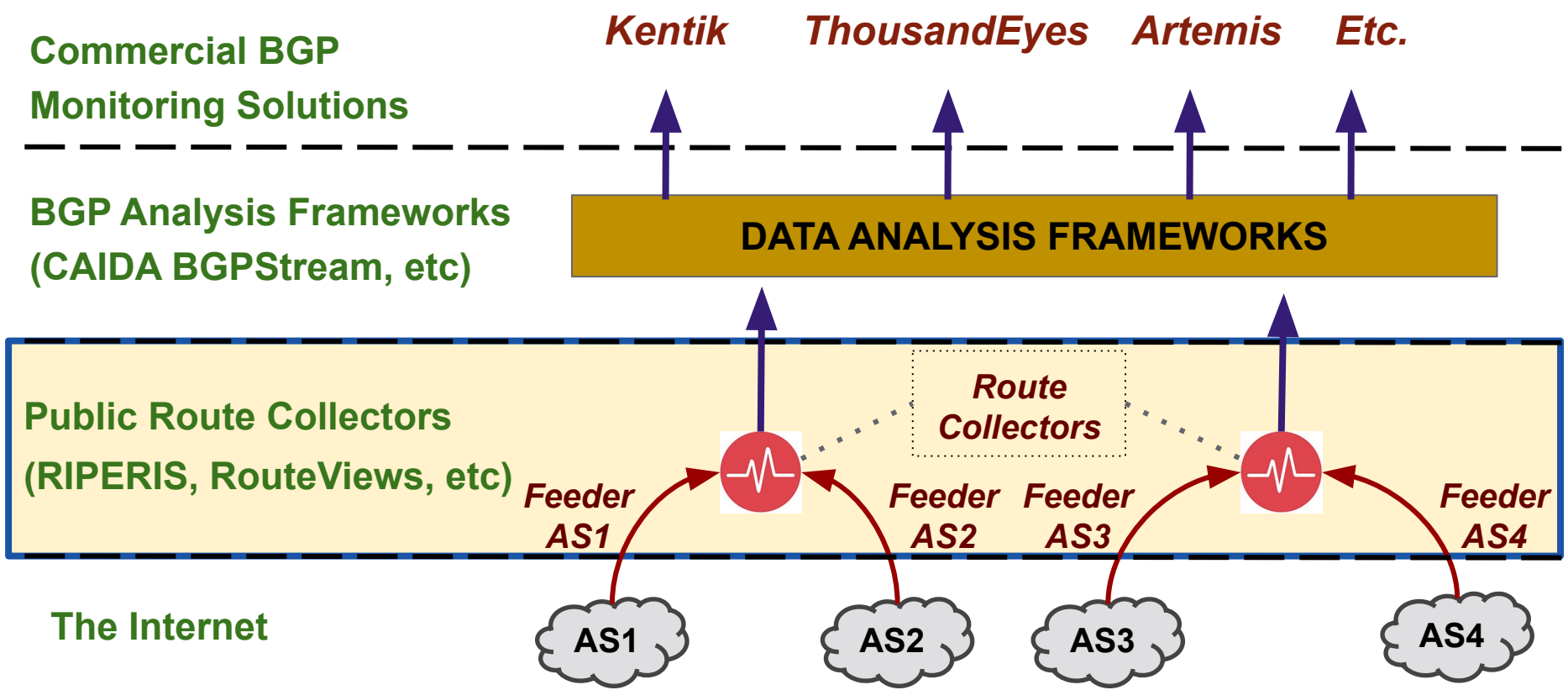

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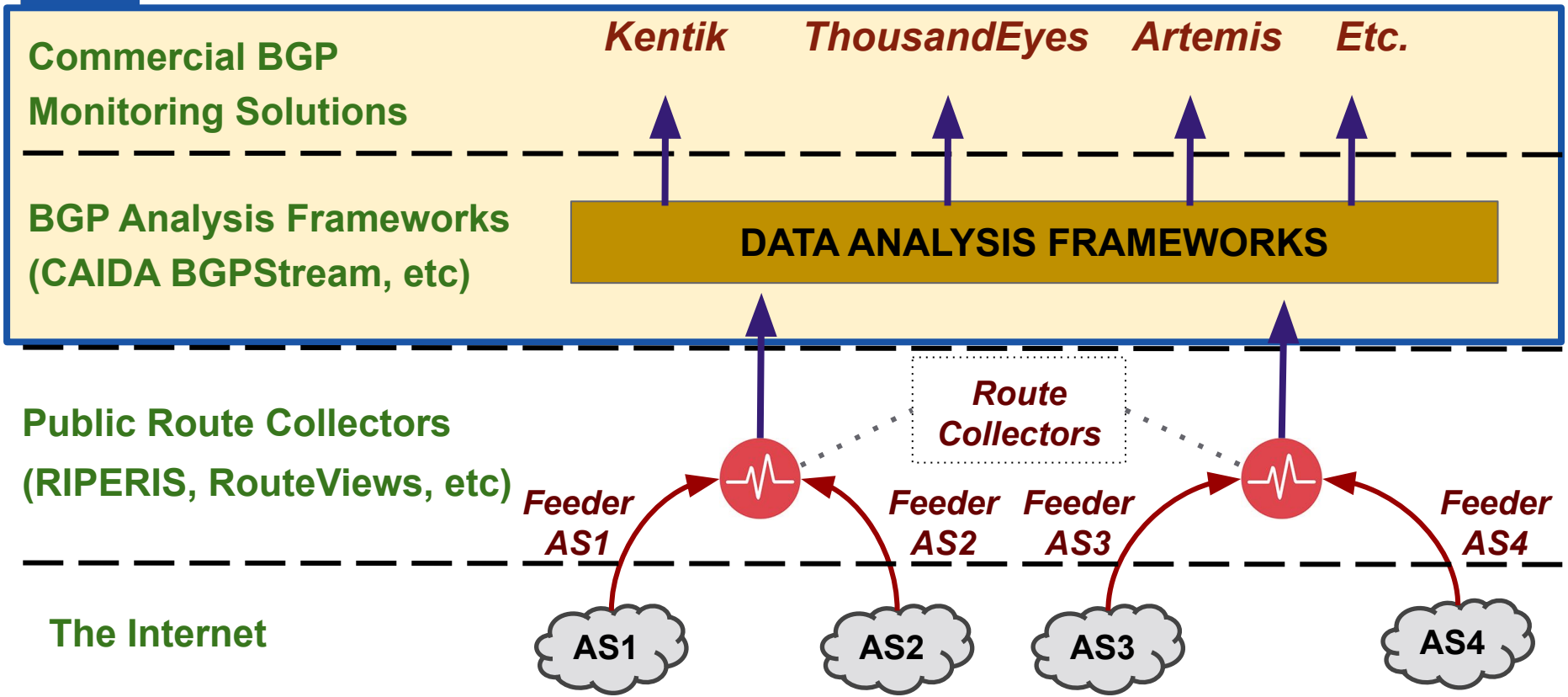
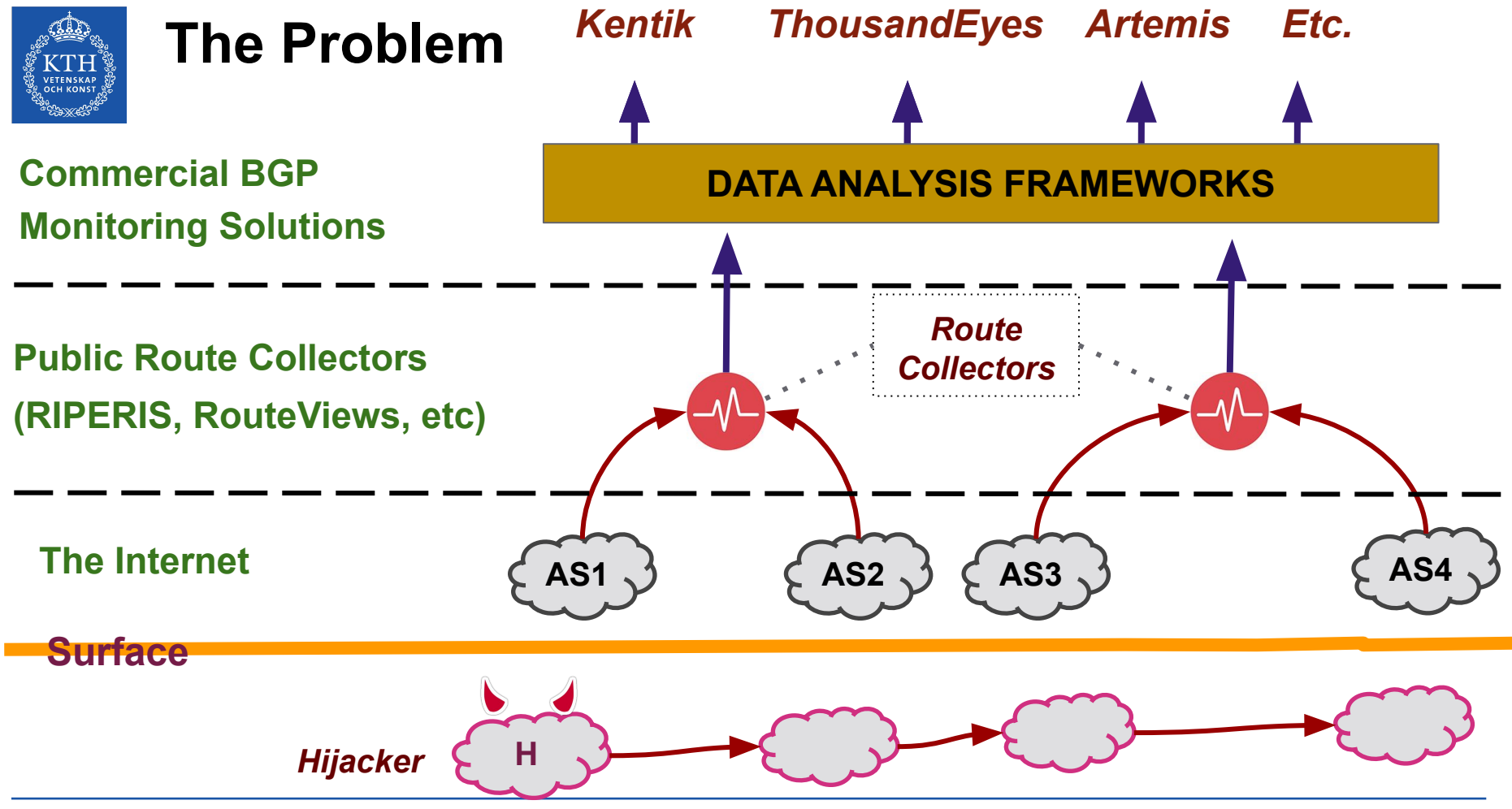
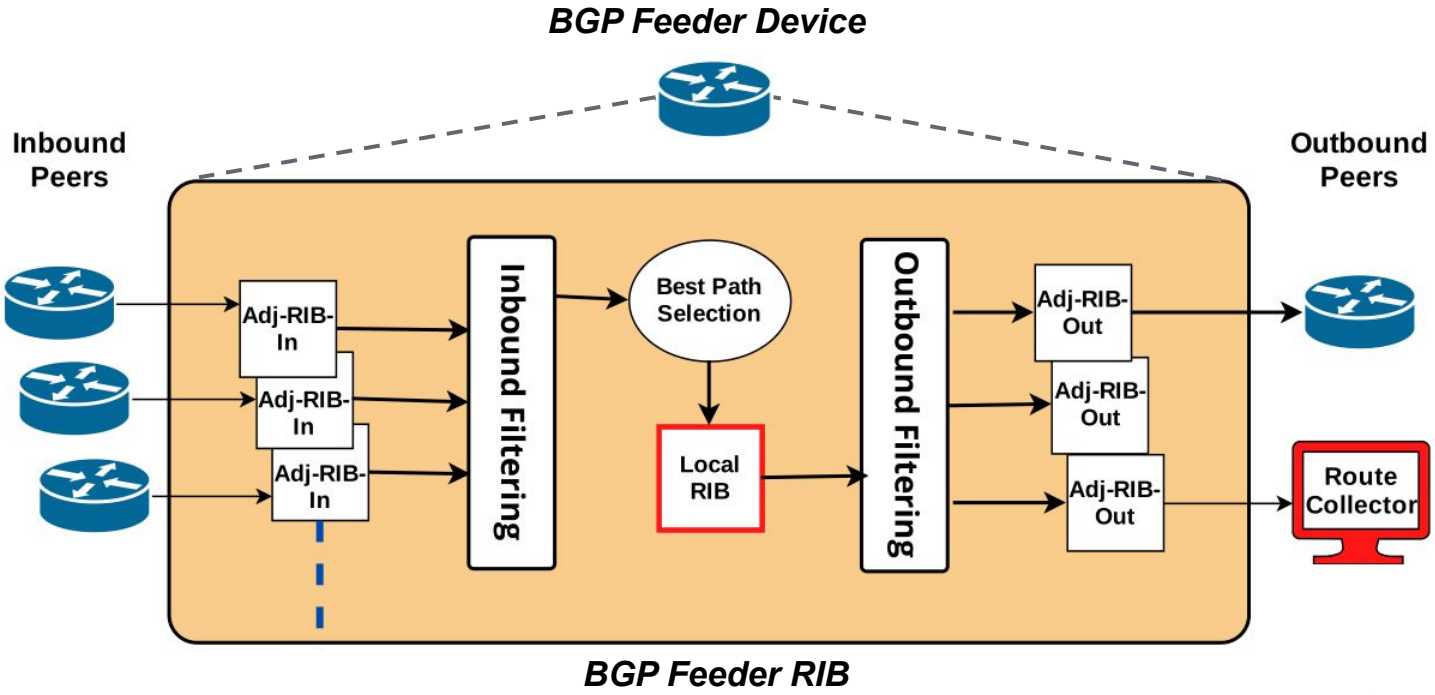


The Problem


Kentik
ThousandEyes
Artemis
Etc.
DATA ANALYSIS FRAMEWORKS
Commercial BGP
Monitoring Solutions
Public Route Collectors
(RIPERIS, RouteViews, etc)
Route
Collectors
The Internet
AS1
AS2
AS3
AS4
Surface
Hijacker
H

The Problem: Example of Stealthy Hijack to RC



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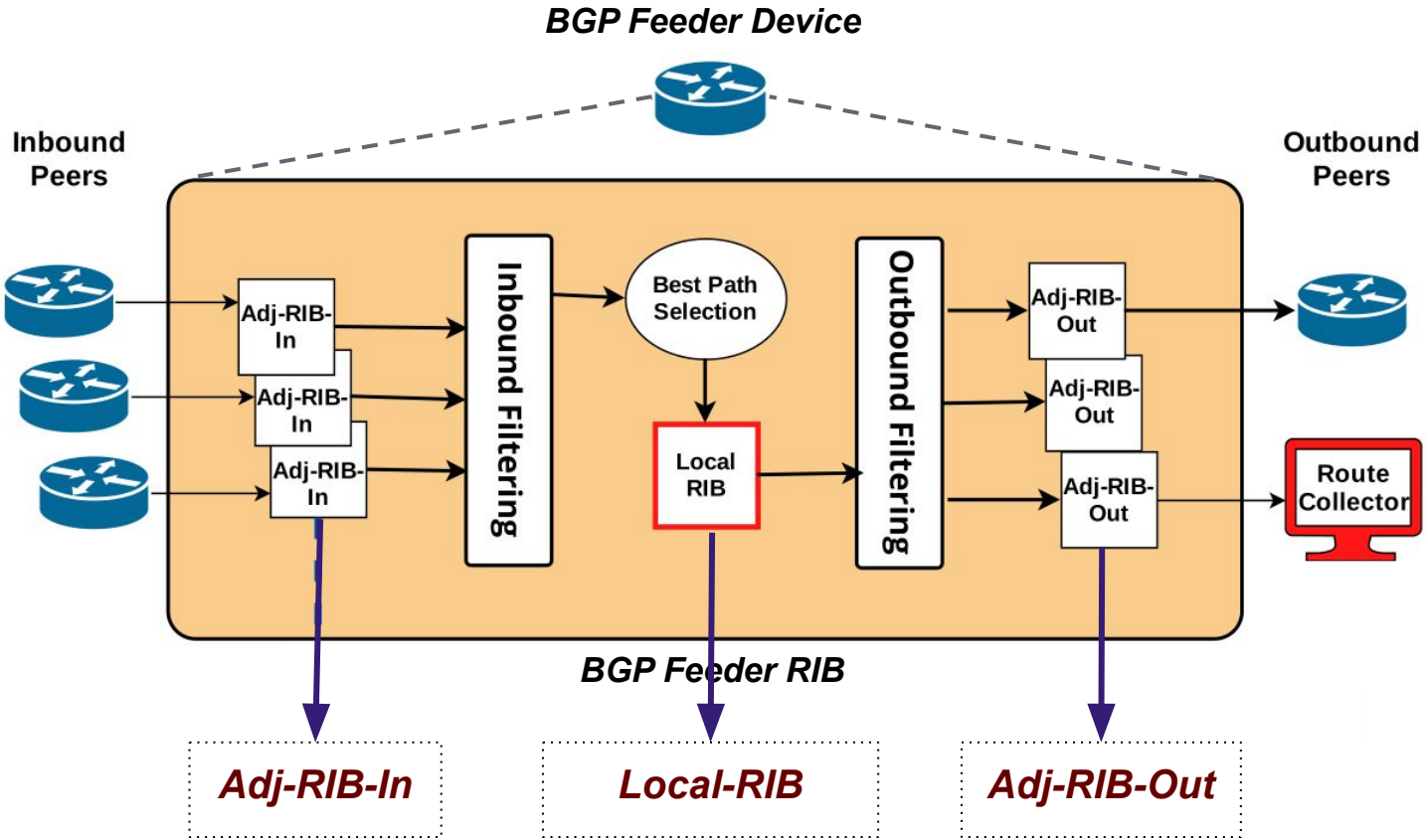

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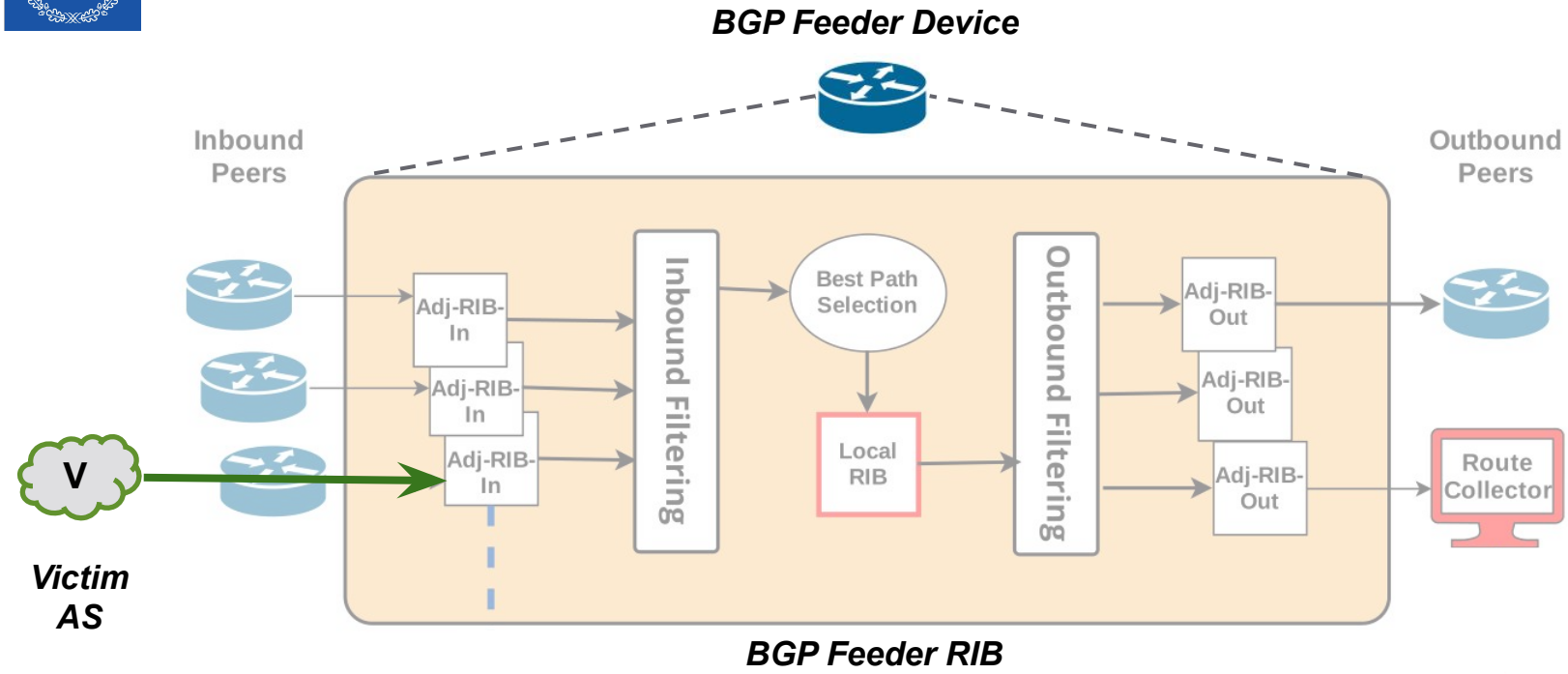

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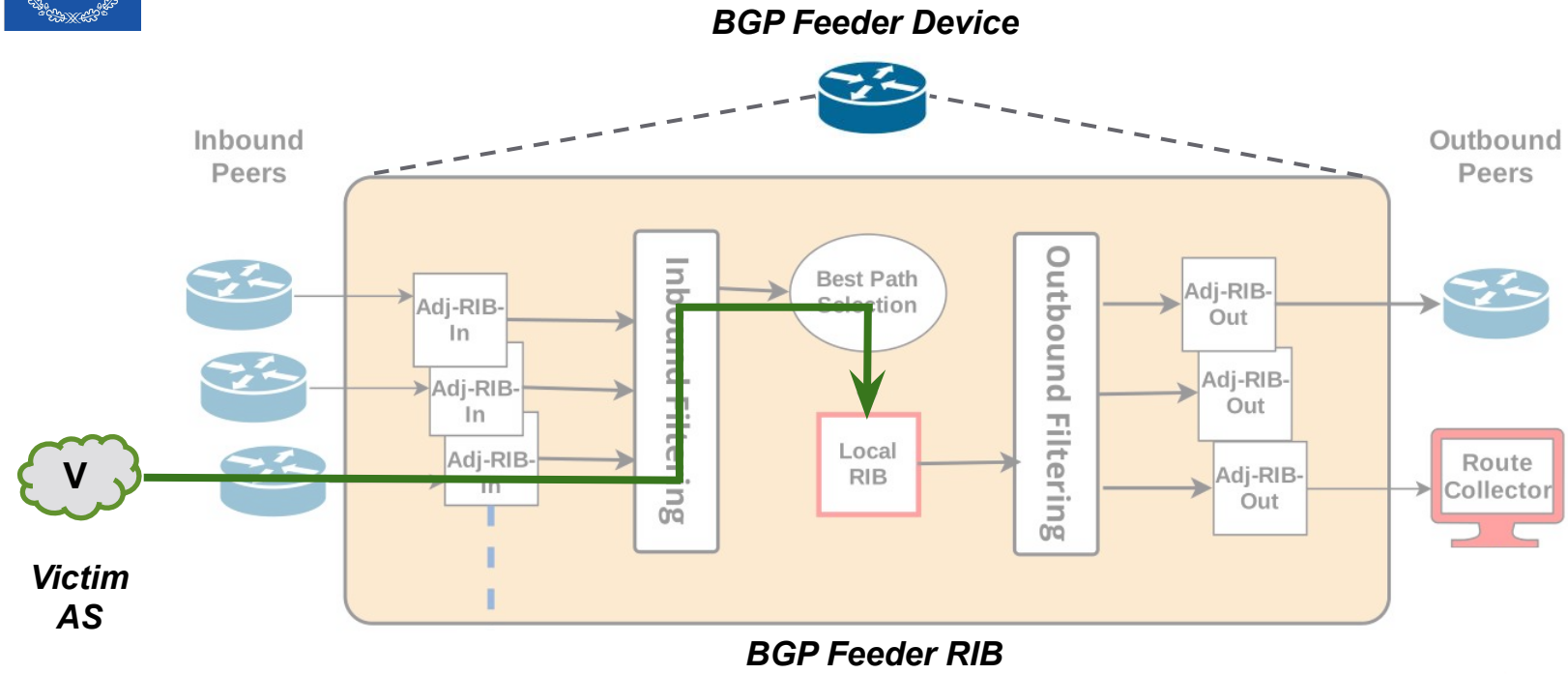

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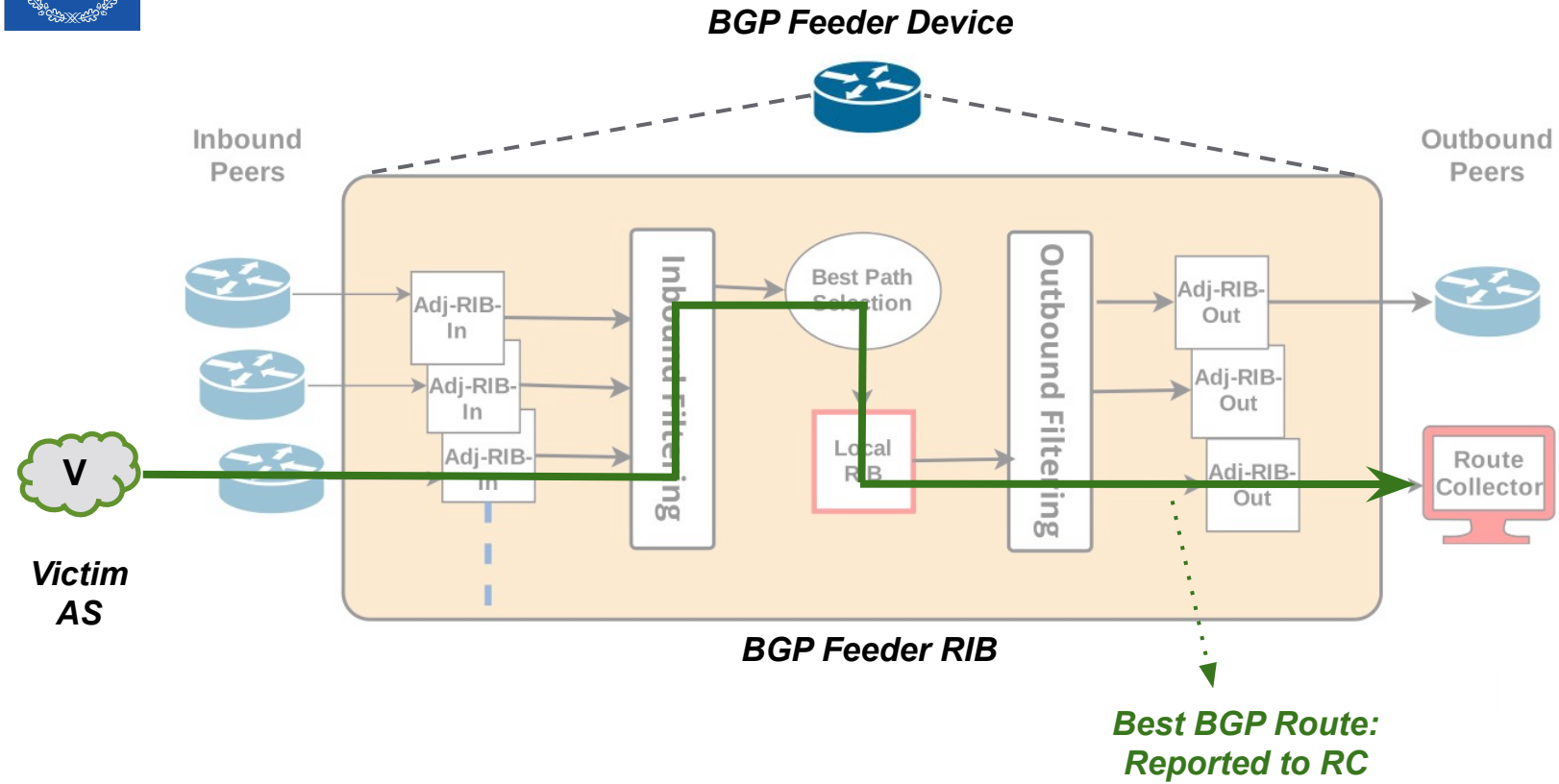

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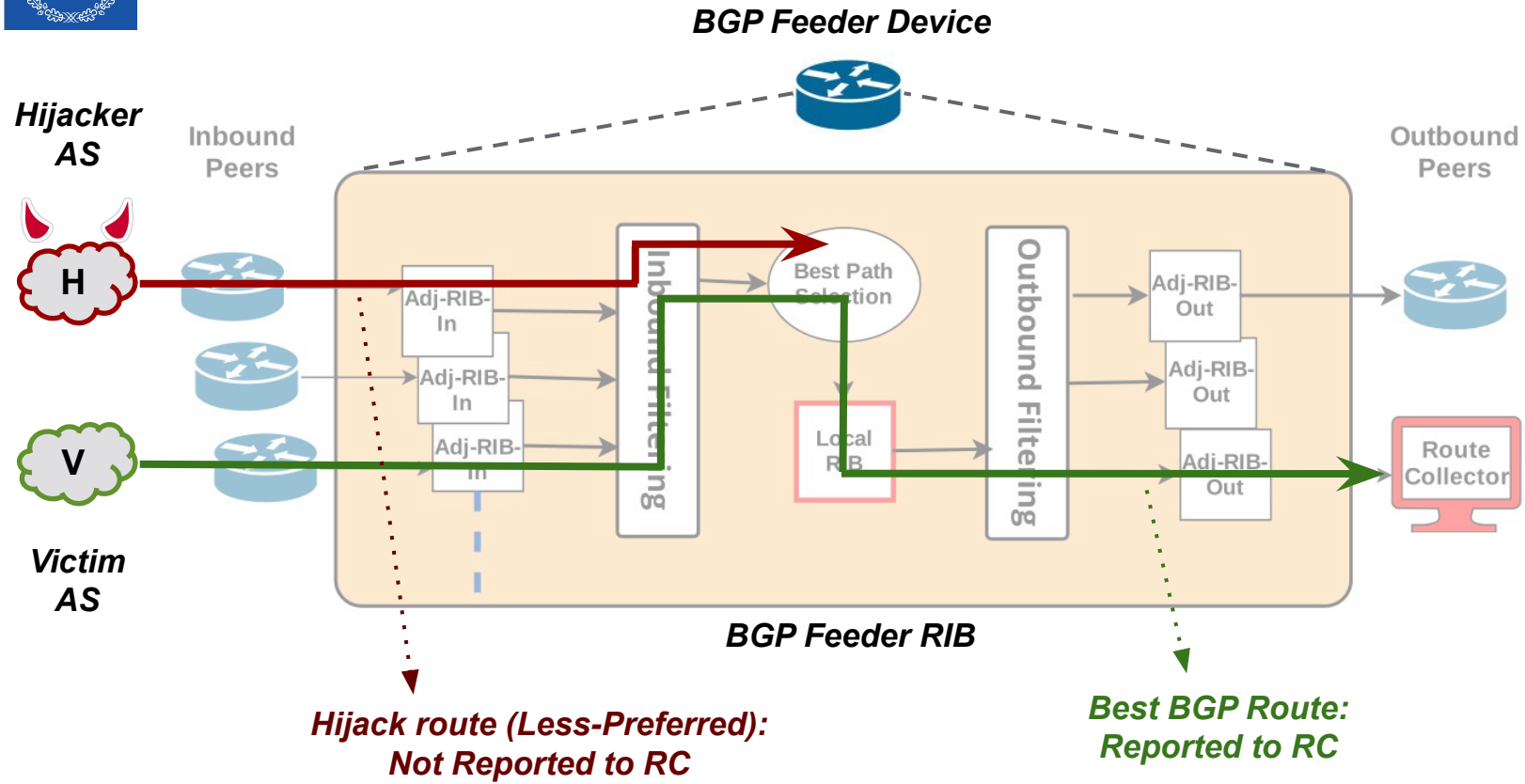
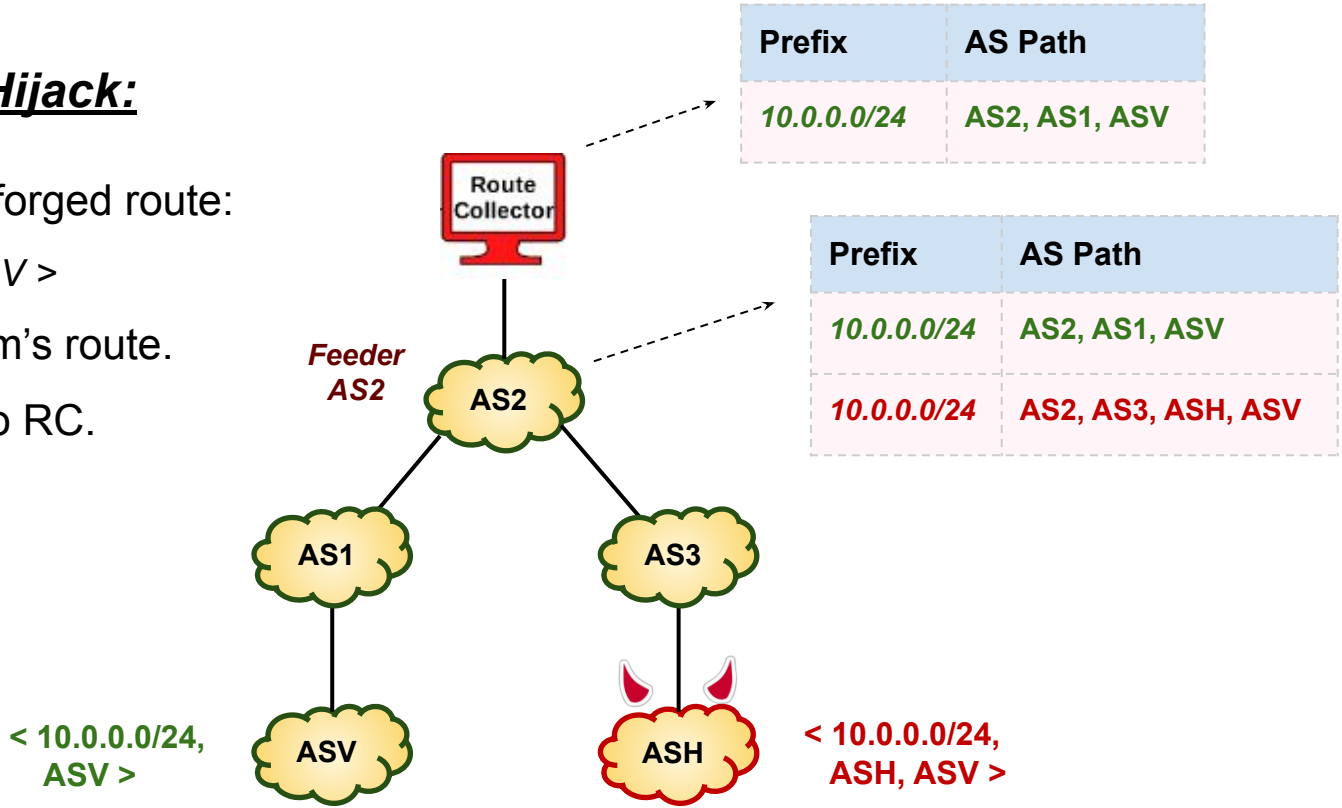


The Problem: Example of Stealthy Hijack to RC

Example of Stealthy Hijack:

- Hijacker announces forged route:

  < 10.0.0.0/24, ASH, ASV >
- AS2 prefers the victim's route.
- Hijack not reported to RC.



Presentation Topic

This Presentation:

- How capable are hijackers to design stealthy hijacks not visible by RCs?

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Our Experiments:

- BGP hijack Simulations.*
- Real-world experiments using the PEERING Testbed.*

* For our full experiment results: See our *journal*.

What we Learned

For a Hijacker to hide from Public RCs:

- Knowledge about which BGP feeders will report the attack matters.
- Knowledge about routing policies of other ASes matters.
- Where the hijack is exported matters.

What we Learned (1/3)

- Knowledge about feeders matters.

➔ Unaffected region feeders: Do **not** observe the hijack.

➔ Affected region feeders: Will observe the hijack.

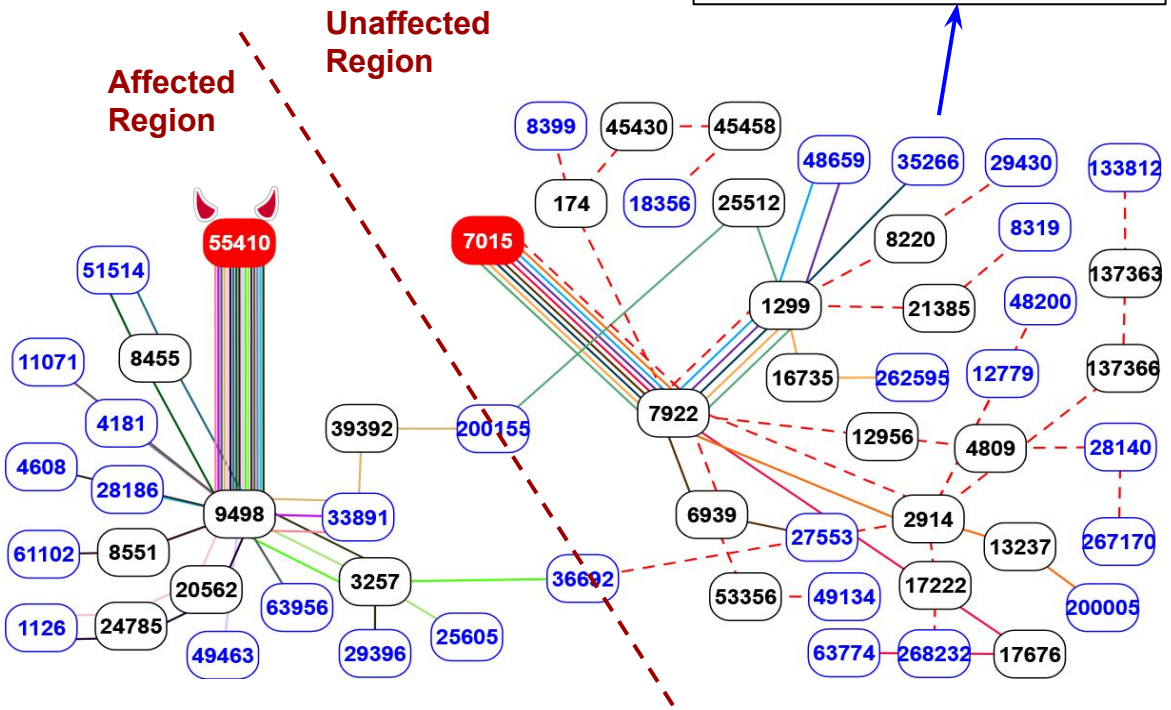

Fig: Vodafone (AS55410) leaking Comcast (AS7015) prefixes (16-04-21)
(Source: Cisco BGPstream monitoring service - visualized using BGPlay)

What we Learned (2/3)

To design not observable hijacks by public RCs:

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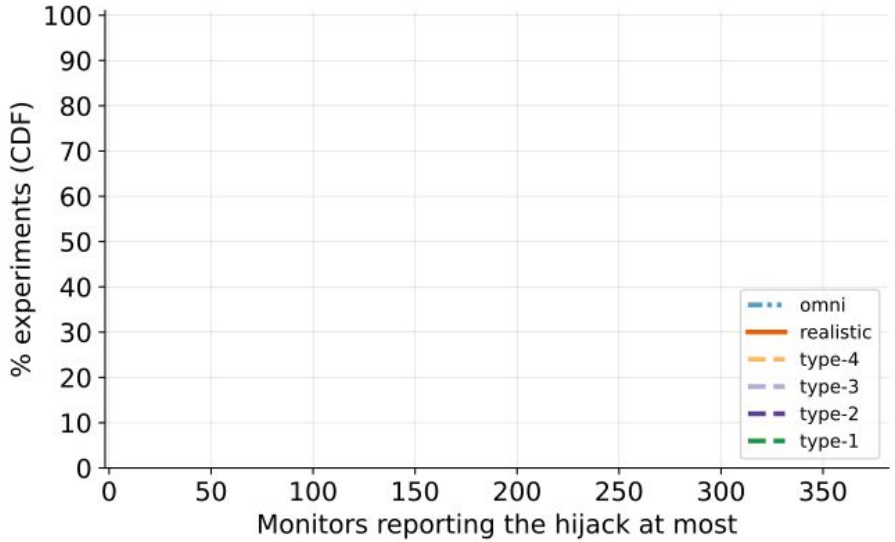
What we Learned (2/3)

To design not observable hijacks by public RCs:

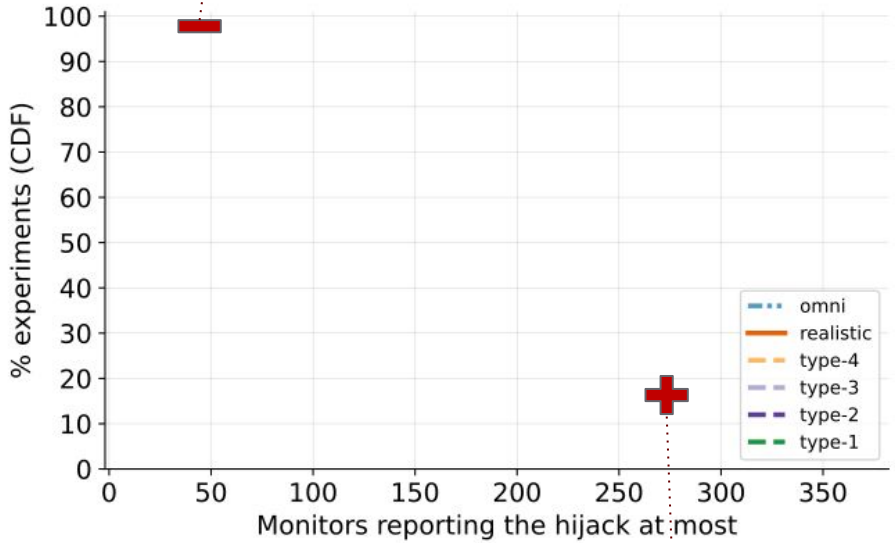
- Knowledge about which BGP feeders will report the attack matters.
- Knowledge about routing policies of other ASes matters.
  - *Baseline hijacker:* Traditional hijacker – does not deliberately avoid RCs.
  - *Realistic hijacker:* Limited knowledge inferred from routes public RCs disclose.
  - *Omniscient hijacker:* Knows routing policies of every AS in the topology.

Knowledge Routing Policies Matters – Visibility



Knowledge Routing Policies Matters – Visibility

Less Visible Hijacks



More Visible Hijacks

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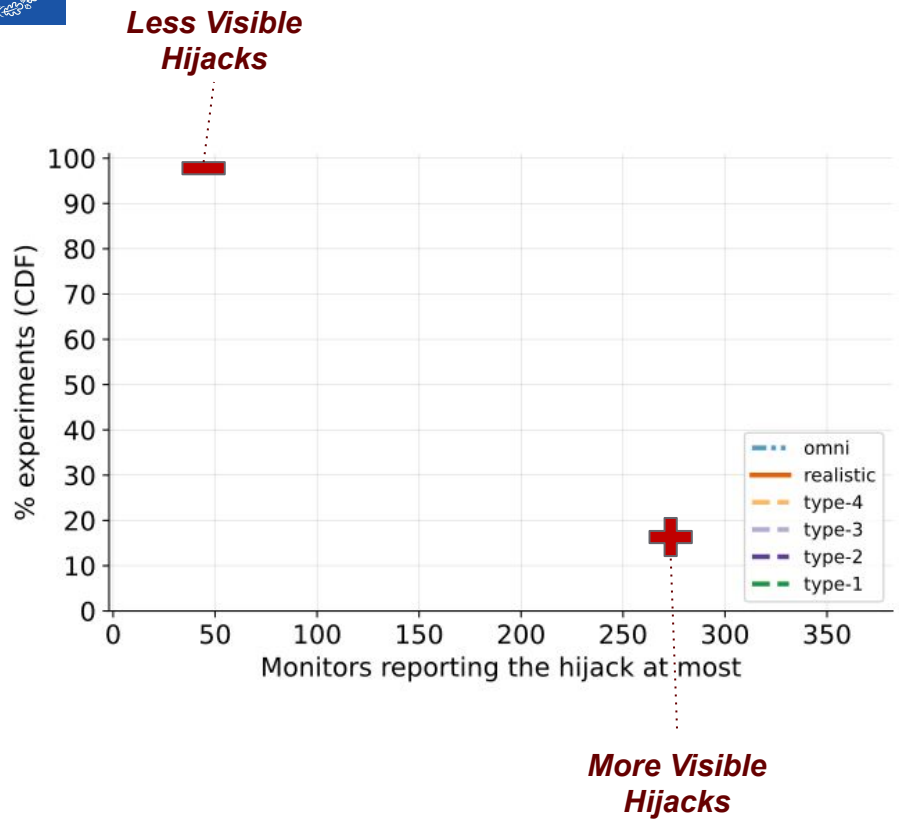

***Baseline Hijackers (shape forged paths)*:**

- **Type-0**: { **ASH** }
- **Type-1**: { **ASH**, **ASV** }
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Higher Type: *Longer* forged paths

** Visibility results based on the AS-level graph*

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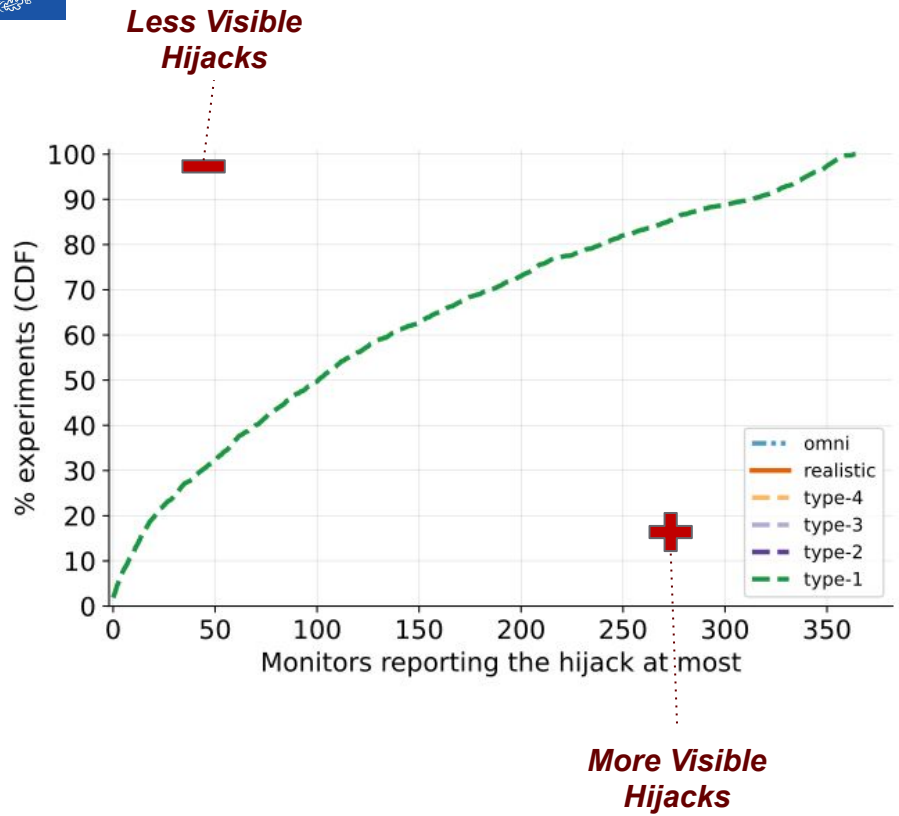

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***Visibility (2K simulations)**:**

- **Type-1: 2% completely stealthy.**
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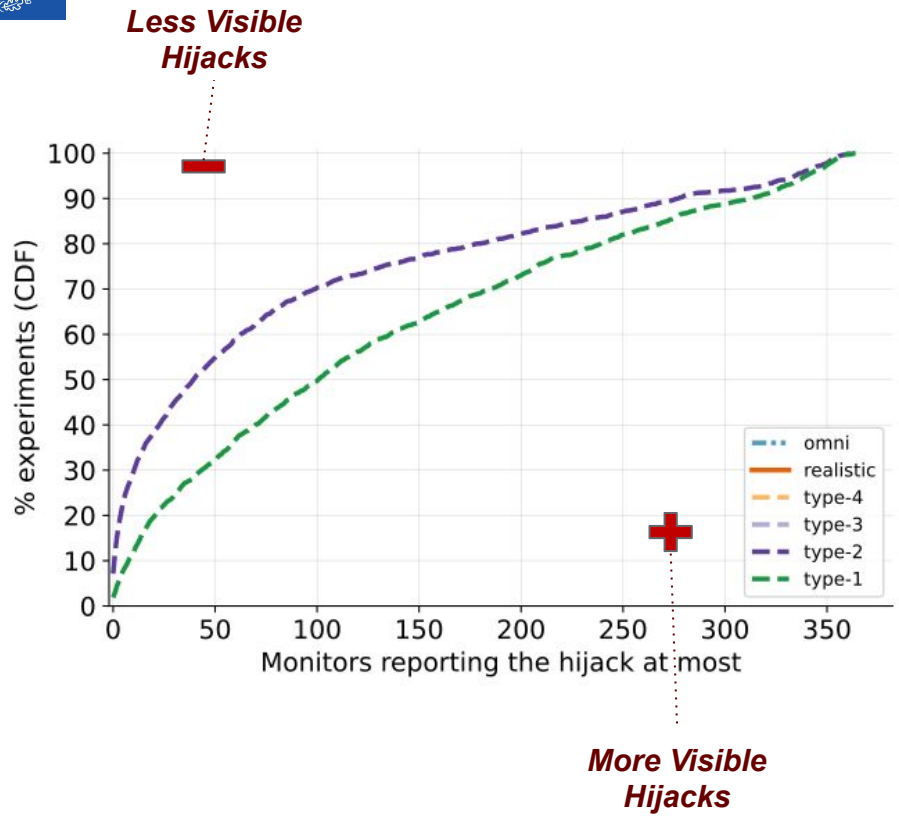

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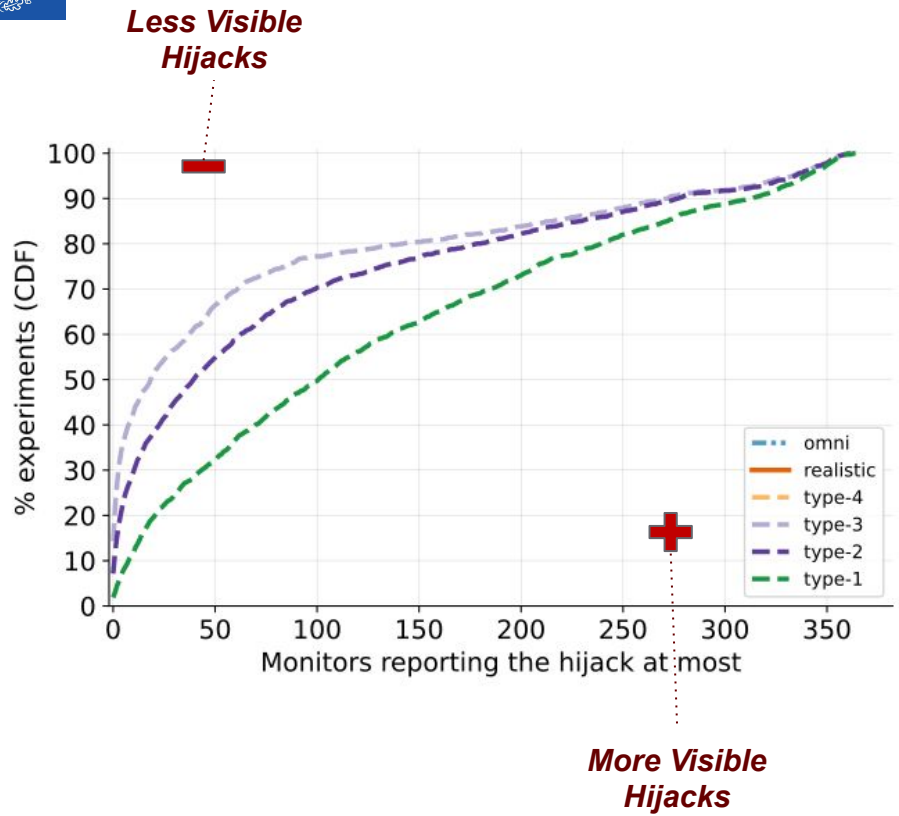

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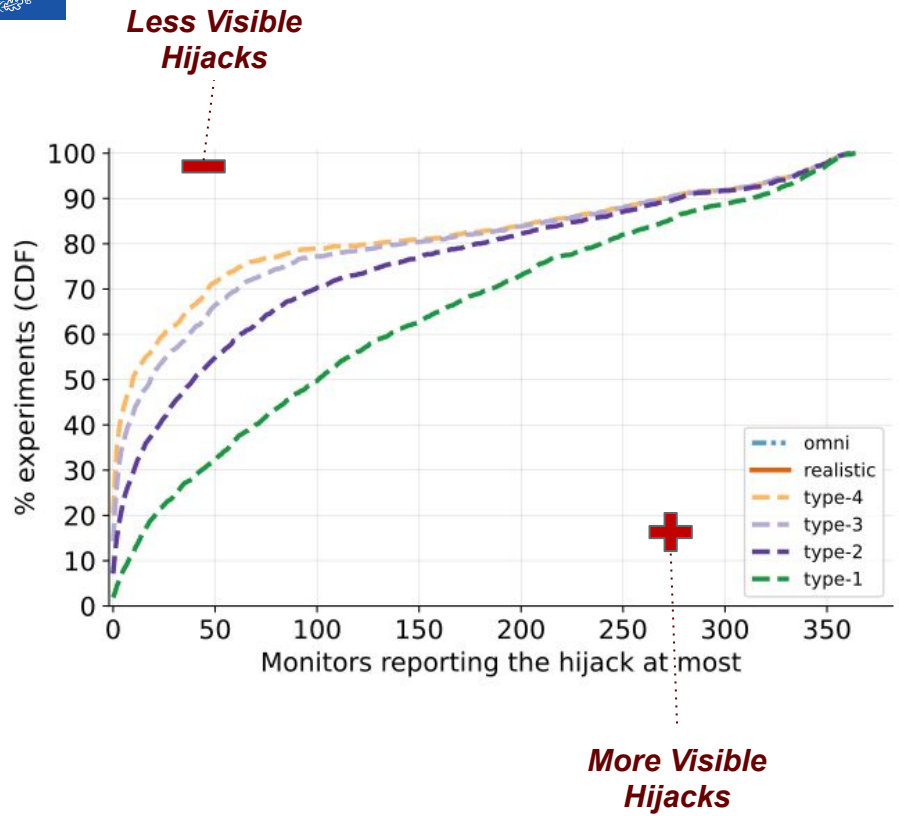

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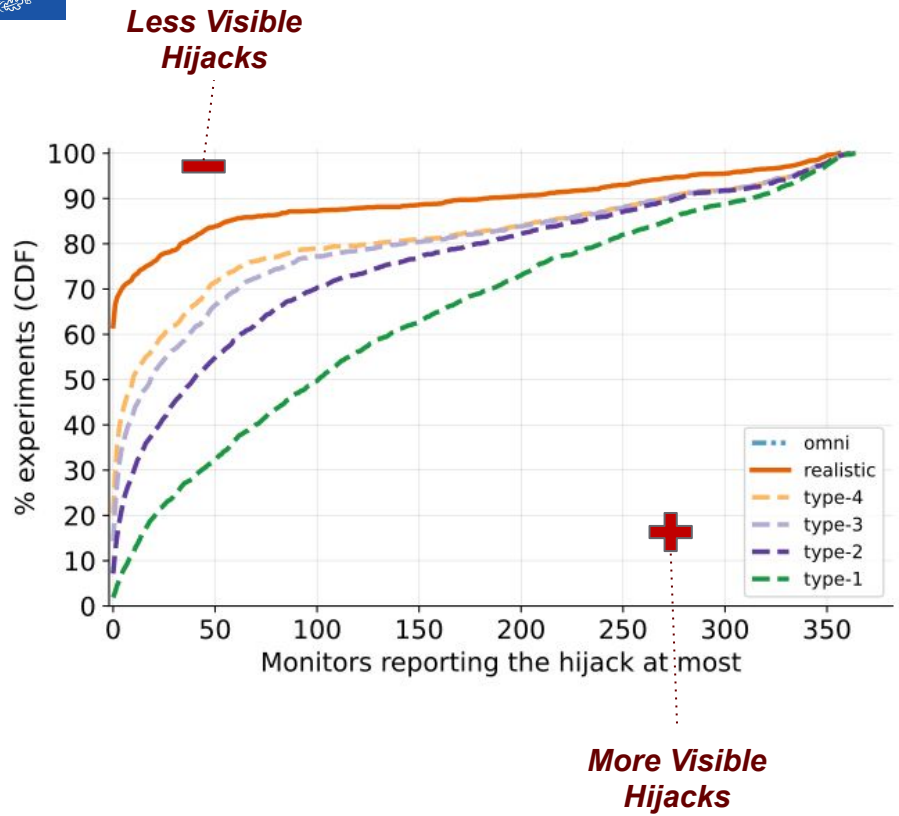

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- **Real: 62% completely stealthy.**

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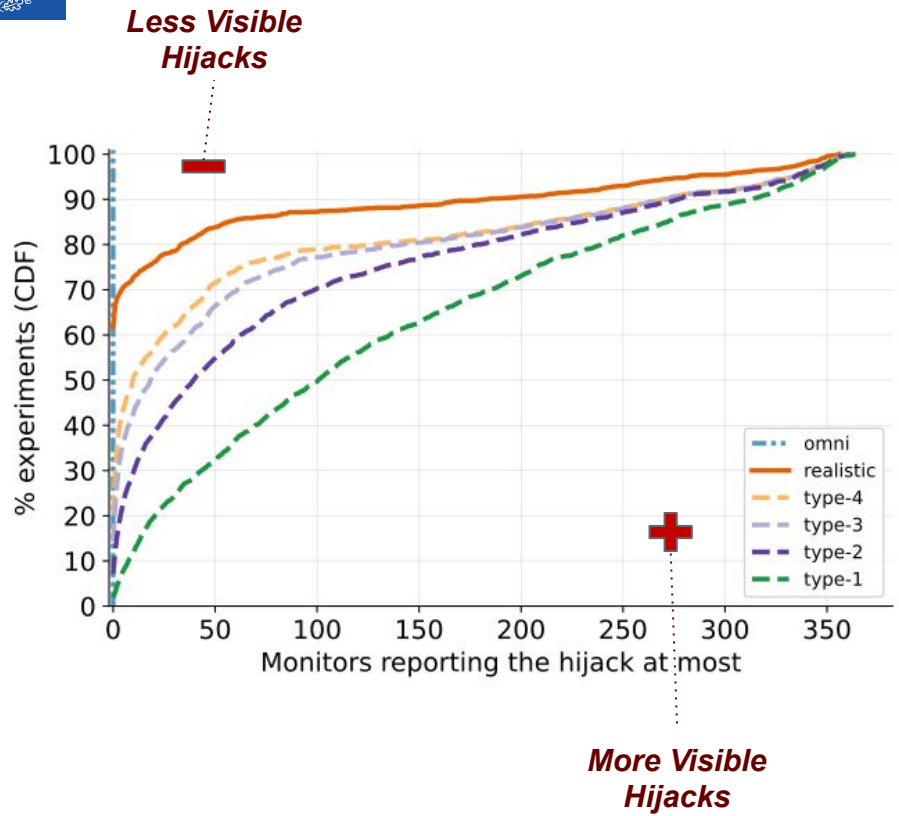

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- **Real: 62% completely stealthy.**
- **Omni: 100% completely stealthy.**

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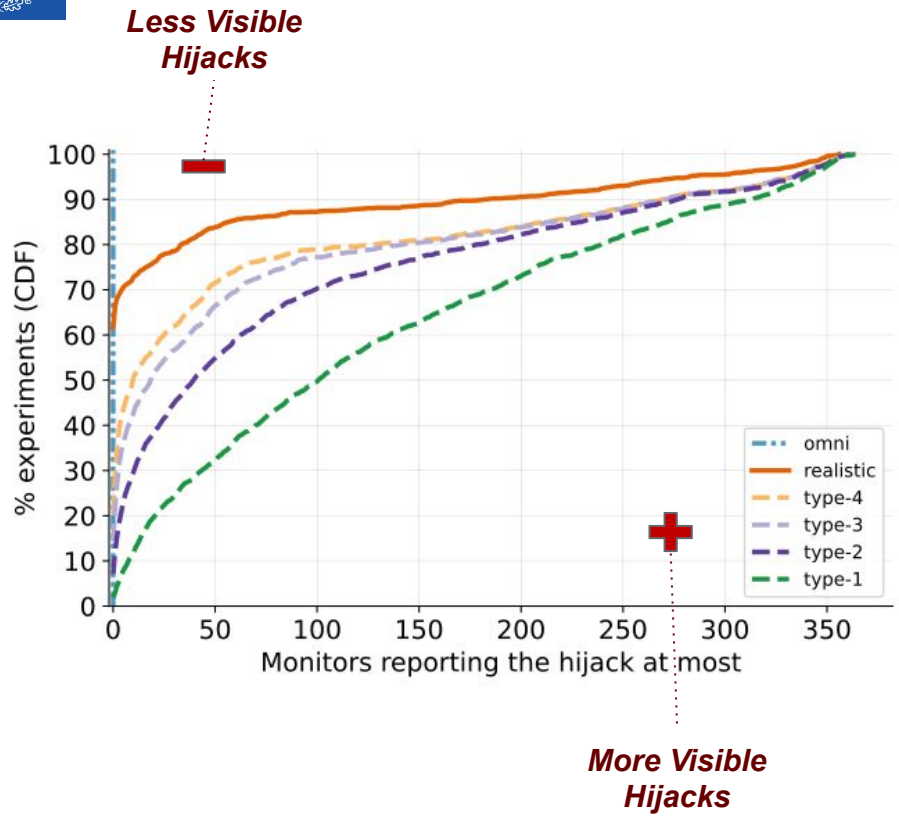

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Higher Type: *Longer* forged paths

***More Findings**:**

- **Potential Impact stealthy attacks.**
- **Future topologies: More IXP links.**
- **Future topologies: More Monitors.**

** Visibility results based on the AS-level graph*

What we Learned (3/3)

- Knowledge about which BGP feeders will report the attack matters.
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	# Visible Simulations	*Customers*	*Peers*	*Transits*
Type-1	1963	0.3%	47%	99%
Type-4	1570	0.0%	24%	99%
Realistic	764	0.0%	3%	99%
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Table: % visible sims based on where the hijack is exported.

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Routes over Peers

- **Easier to influence:**
  Path lengths matter more for such neighbors.

Routes over Transit Providers

- **Harder to influence:**
  Business relations matter more.

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Realistic Hijackers

- **Hijacks easier to hide when exported to Peers.**
- **Harder to hide when exported to transits.**

Omni Hijackers

- **Completely stealthy.**

Real World Evaluation: PEERING Testbed

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Real World Set-up

- ***Testbed:*** PEERING Testbed to emulate BGP hijacks.
- ***Victim:*** Testbed site at *Wisconsin*.
- ***Hijacker:*** Testbed site at *GRNET* and *AMS-IX*.

Experiment Goals

➔ ***Goal:*** Design a stealthy hijack not observable by public RCs.

➔ **(1):** Ability of hijacker to identify all dangerous monitors.

➔ **(2):** Ability of hijacker to circumvent the hijack from reaching RCs.

Binary classification of monitors

❖ ***Safe****:* Will **not** report the attack.

❖ ***Dangerous****:* Will report the attack.

Why Classifying the Monitors Matters

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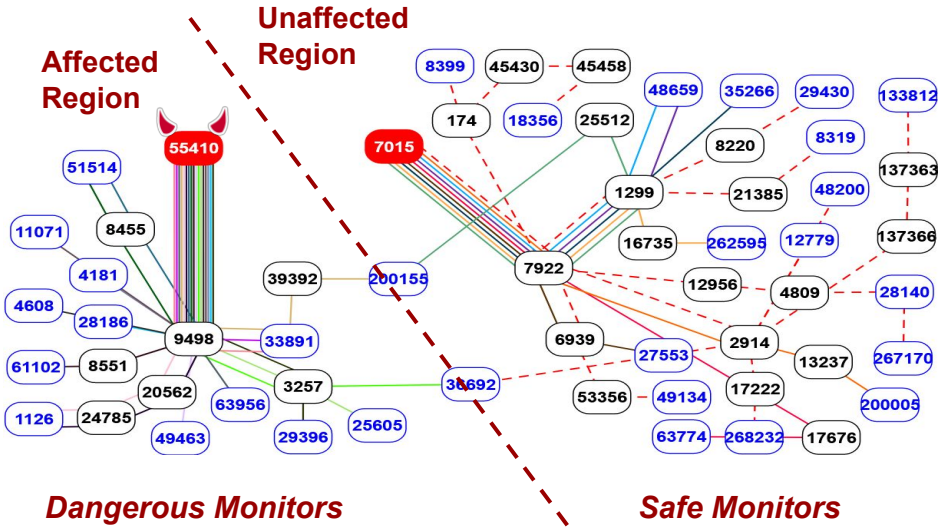

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Binary classification of monitors

- ❖ ***Safe****:* Will **not** report the attack.
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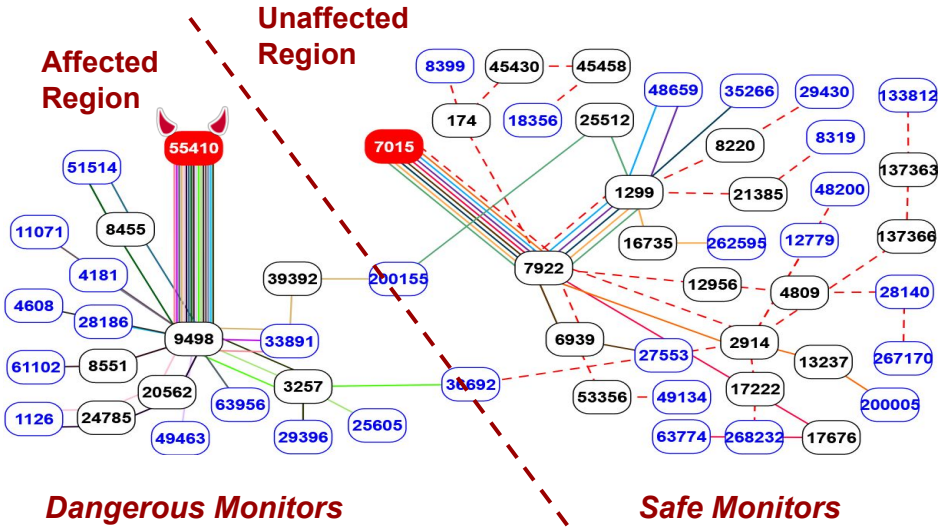
- ❖ A Proximity Classifier (AS-path lengths).
- ❖ A business relationship Classifier (Gao-Rexford).



Findings: Proximity vs Business Classifier

		GRNET Transit ASN 5408	*AMS Transit ASN 8283*	*AMS Transit ASN 12859*	*AMS Peer ASN 9002*	*AMS Peer ASN 6461*	*AMS Peer ASN 52320*
# Total Monitors							
% Monitors Correctly Classified Proximity Classifier	*Accuracy*						
	Dangerous (Safe)						
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% Monitors Correctly Classified Proximity Classifier	*Accuracy*	78%	74%	84%	97%	93%	99%
	Dangerous (Safe)	13% *(99%)*	62% *(93%)*	75% *(91%)*	100% *(97%)*	**10%** *(94%)*	100% *(99%)*
% Monitors Correctly Classified Business Classifier	*Accuracy*						
	Dangerous (Safe)						

Findings: Transit Providers

Proximity Classifier: Average Accuracy = 78%

NOT sufficient to identify all dangerous monitors

(Overestimates Safe Monitors)

Findings: IXP Peers

Proximity Classifier: Average Accuracy = 96%

Possible to identify all dangerous monitors

(But outliers may exist)

Findings: Proximity vs Business Classifier

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% Monitors Correctly Classified Business Classifier	*Accuracy*	90%	92%	89%	*Same*	*Same*	*Same*
	Dangerous (Safe)	95% *(89%)*	96% *(86%)*	97% *(81%)*	*Same*	*Same*	*Same*

Findings: Transit Providers

Business Classifier: Average Accuracy = 90%

Dangerous monitor misclassifications reduced by <= 91%

(At the cost of misclassifying some safe monitors)

Findings: IXP Peers

Practically Unchanged

Suggestions: Dealing with Hijackers that Avoid RCs

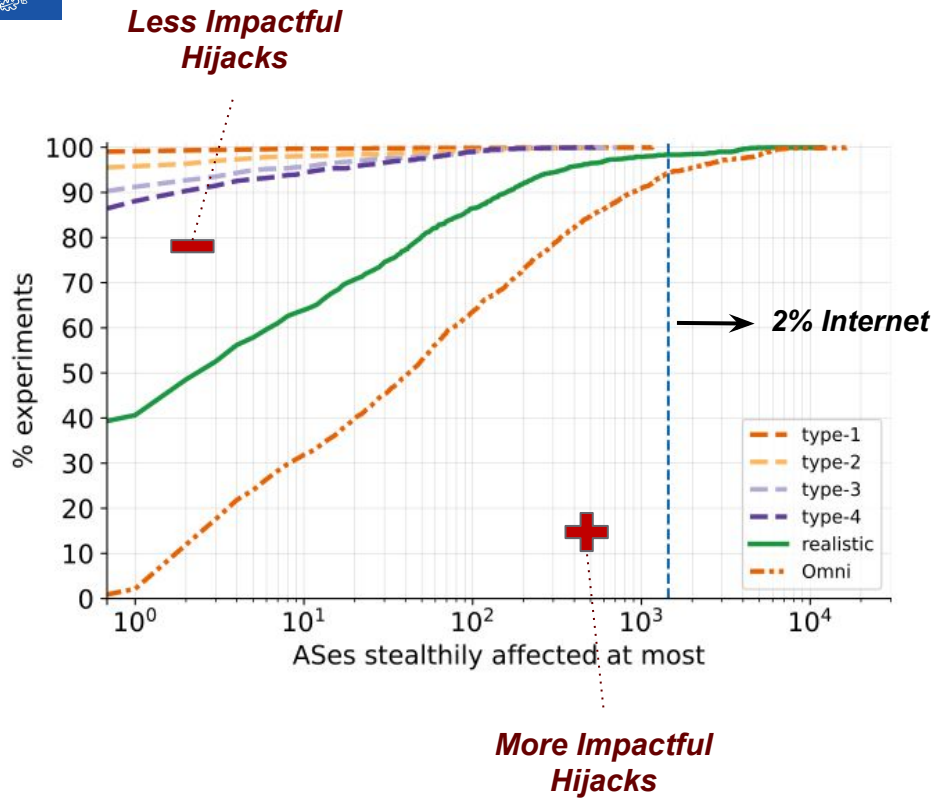
- RQ: How vulnerable are Route Collectors to stealthy attacks?
- Problem: Route collectors may be vulnerable to stealthy attacks if:
  - **(1)** BGP Feeders reports their best routes to RC and
  - **(2)** The Route Collector is public.

- Prevention methods:
  - Better BGP filtering / Following best practices (ASPA helps!).
  - New feeders: feeders in more strategic locations.
  - Smarter feeders: Forwarding suspicious routes to RC (not just the best route).
  - Feeders Forwarding all routes to RCs (BMP).

Questions?

Appendix

Knowledge Routing Policies Matters – Impact



***Baseline Hijackers (forged path shape)*:**

- **Type-0**: { **ASH** }
- **Type-1**: { **ASH**, **ASV** }
- **Type-N**: { **ASH**, **…**, **ASV** }

Baseline Hijackers:

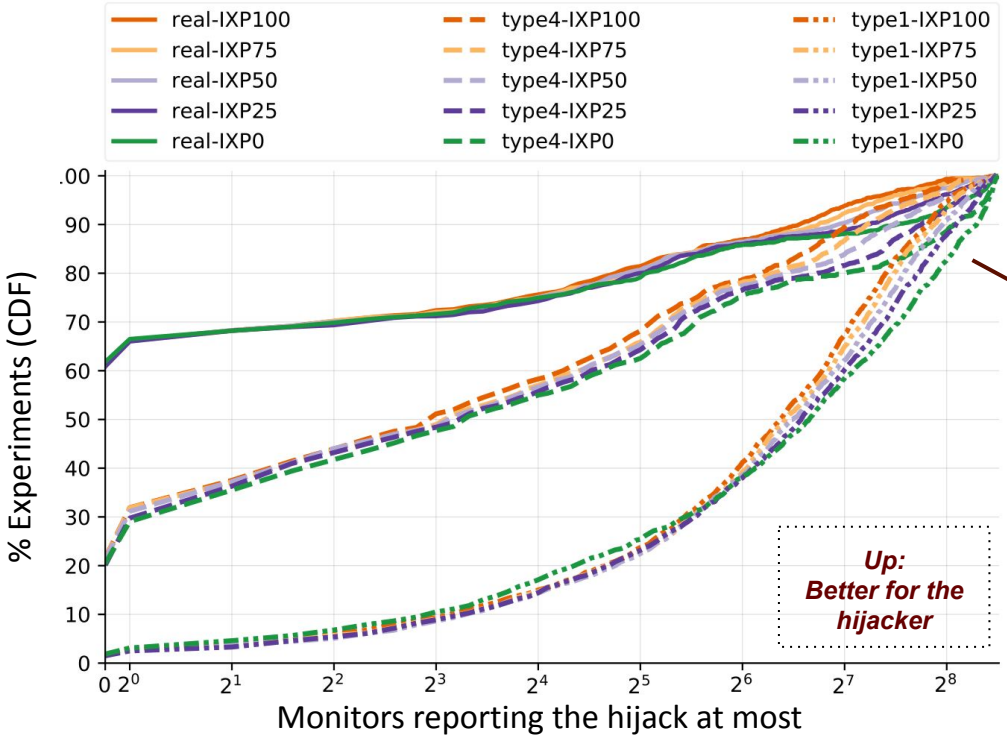
Cannot stealthily intercept > 2% Internet

Realistic & Omni Hijackers:

- **Stealthily intercepts > 2% Internet: 1.65% and 5.65% sims (respectively)**
- **Up to *16.2% & 23.5%* Internet Stealthily intercepted (respectively)**

** Results based on the AS-level graph*

Appendix – Topologies With More IXP Links



Adding more IXP links

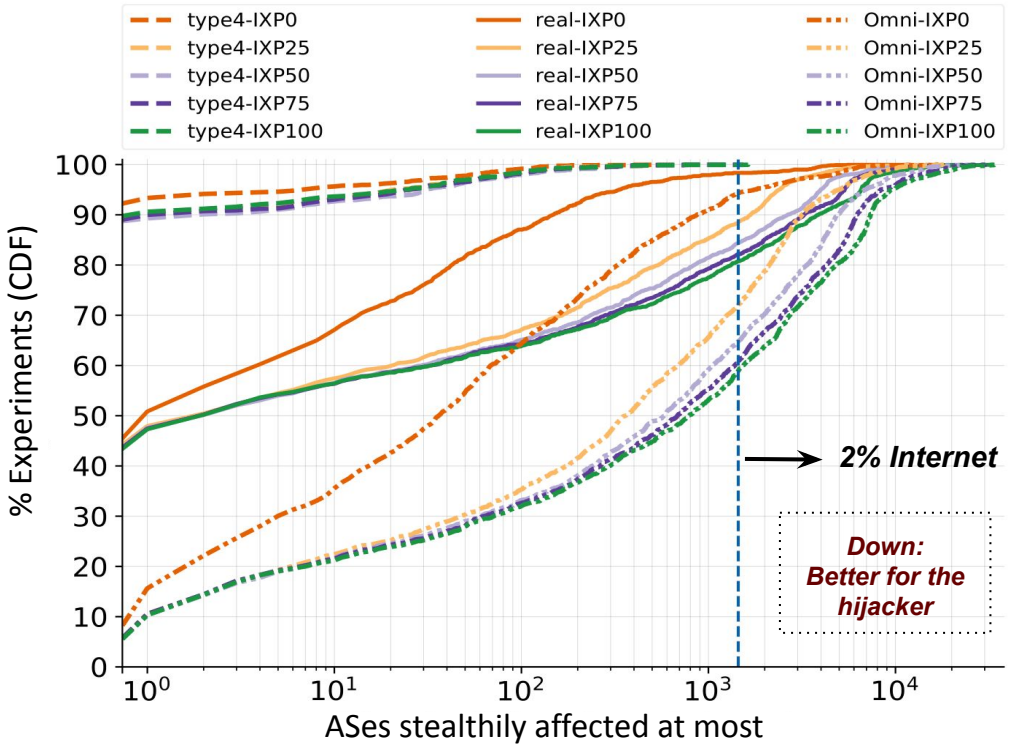
- No impact to success rate
- Visible hijacks: stealthier

90th percentile visibility

- Type-1: 28% less monitors
- Type-4: 50.9% less monitors
- Realistic: 48.3% less monitors
- Omni: Still invisible

** Results based on the AS-level graph*

Appendix – Topologies With More IXP Links



Adding more IXP links

- **Stealthy hijacks more impactful**

Traditional Topology (IXP0)

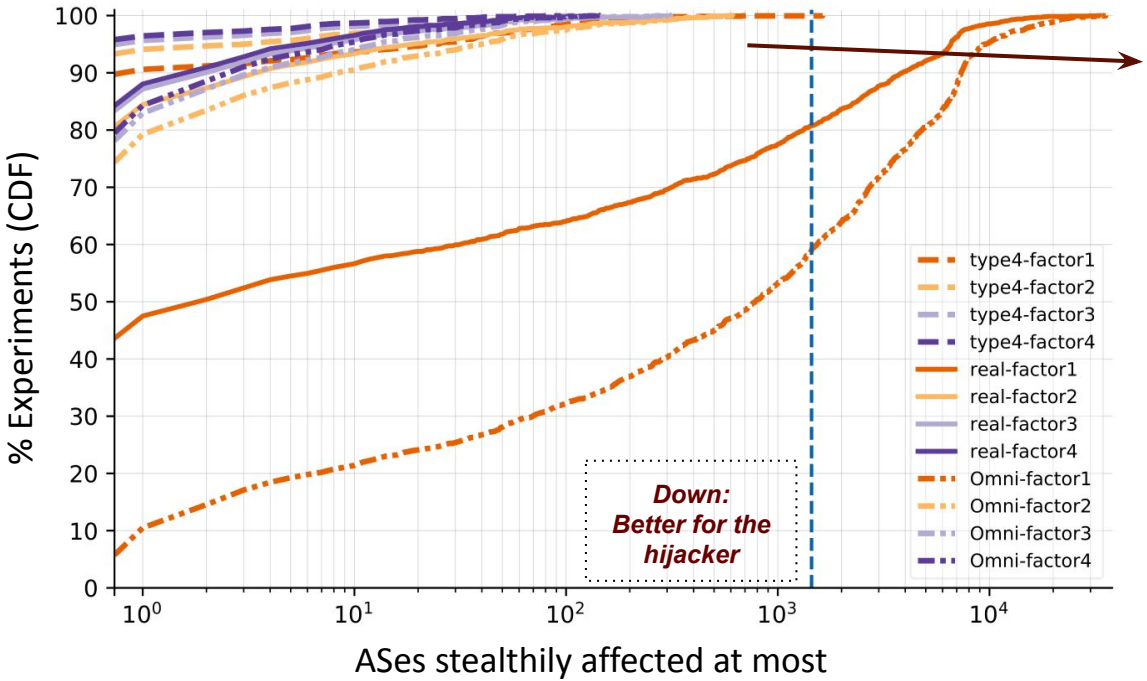
- **Type-1: 0.7% affected ASes**
- **Realistic: 16.2% affected ASes**
- **Omni: 23.5% affected ASes**

Fully IXP Topology (IXP100)

- **Type-1: 2.2% affected ASes**
- **Realistic: 45.5% affected ASes**
- **Omni: 49.0% affected ASes**

** Results based on the AS-level graph*

Appendix – Topologies With More Monitors

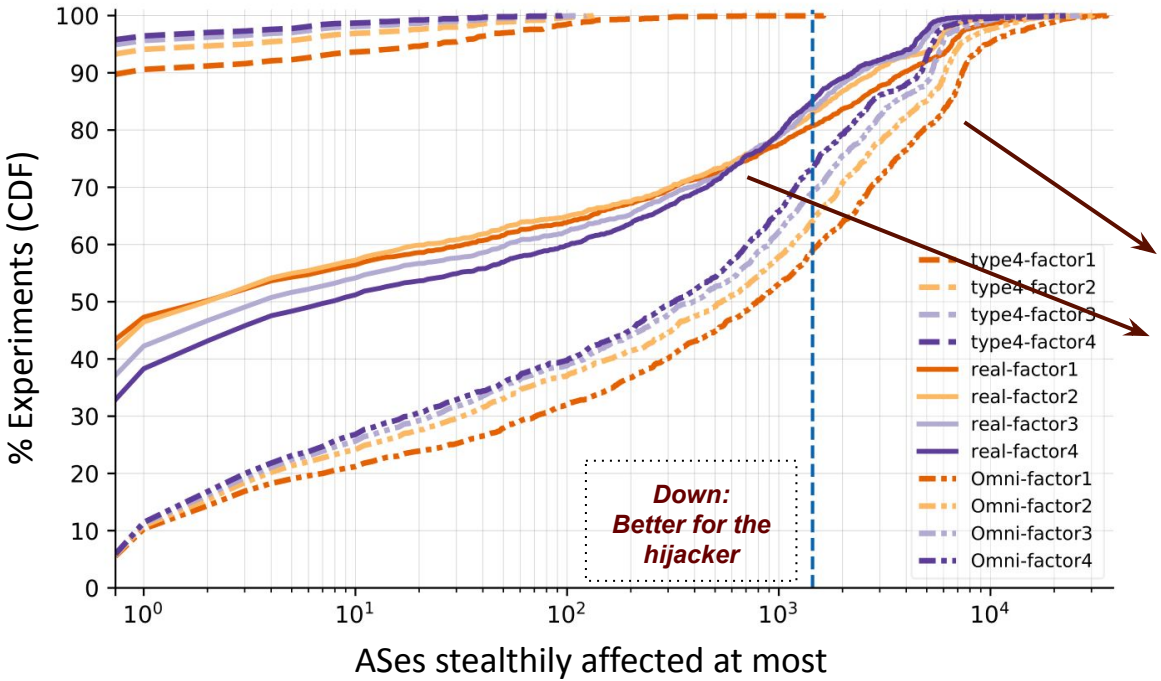


Non-Reactive Hijackers

- **Prevents attacks affecting > 2% Internet**

** Results based on the AS-level graph*

Appendix – Topologies With More Monitors



Non-Reactive Hijackers

- **Prevents attacks affecting > 2% Internet**

Reactive Hijackers

- **Realistic: 28.8% affected ASes down from 45.6%**
- **Omni: 31.8% affected ASes down from 49.0%**
- **Realistic Hijackers may benefit if < 800 ASes affected**

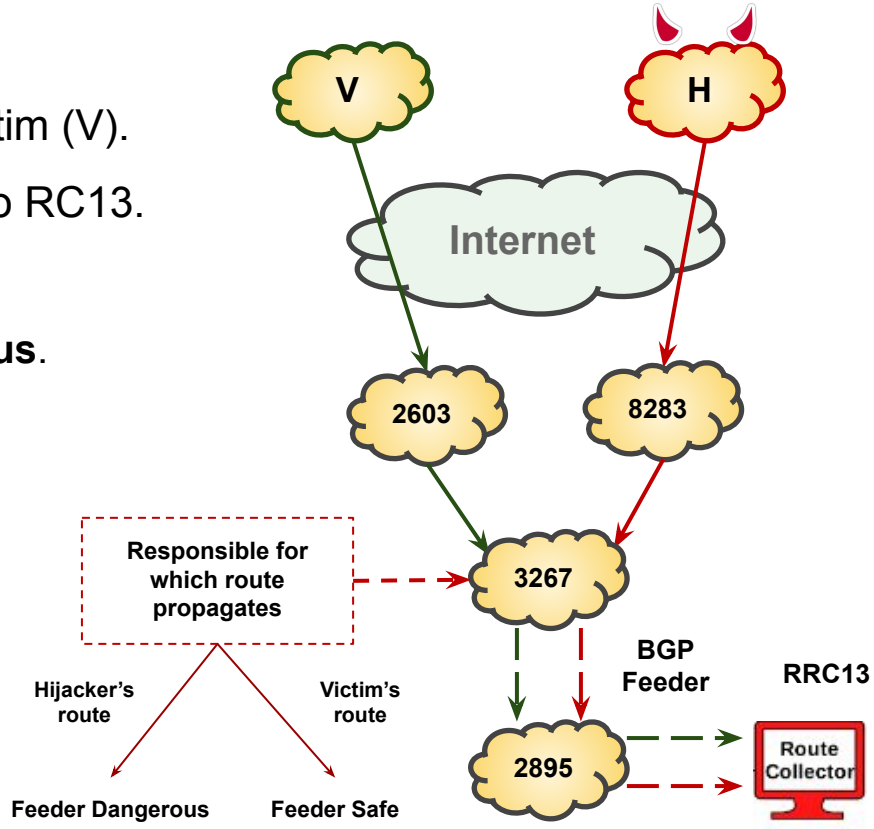
** Results based on the AS-level graph*

Classifying the Feeders: A Real World Example

- ➔ Hijacker (H) announces same prefix as Victim (V).
- ➔ AS3267 chooses which route propagates to RC13.
  - ◆ IF V route propagates: Feeder **safe**.
  - ◆ IF H route propagates: Feeder **dangerous**.

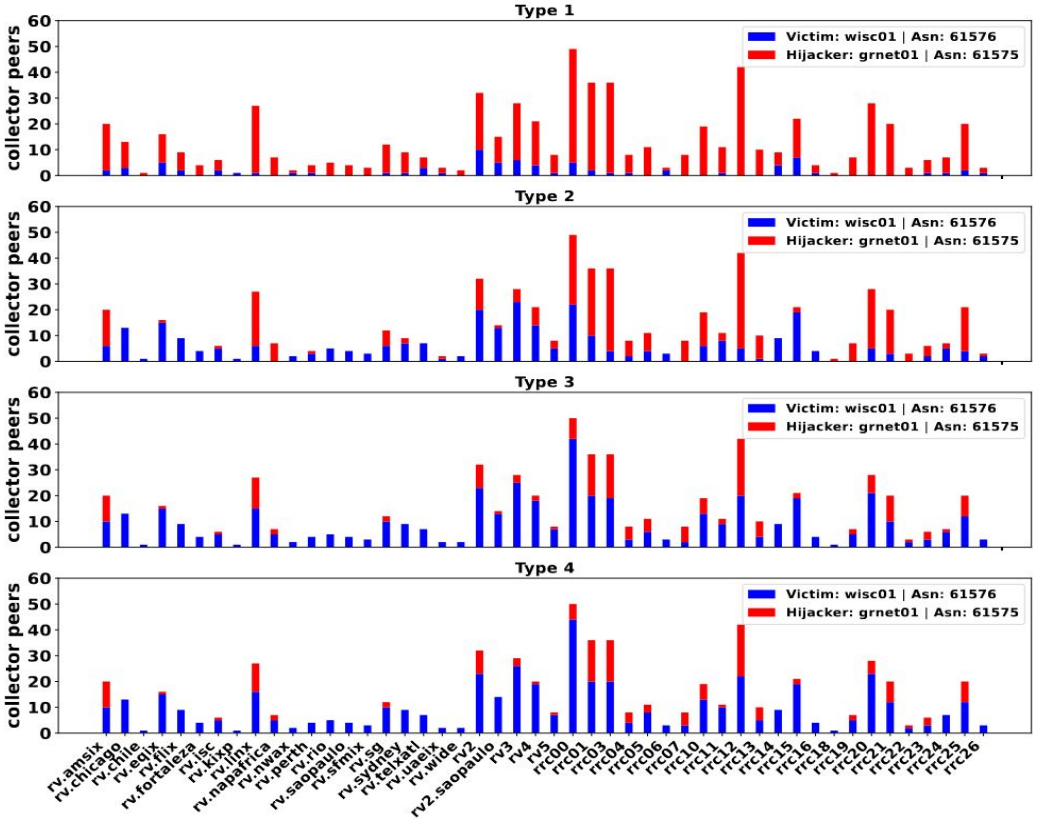
Classifiers Tested:

- ❖ A Proximity Classifier (AS-path lengths).
- ❖ A business relationship Classifier (Gao-Rexford).



Real World: PEERING Testbed

- How the hijack visibility changes (per RC) by announcing less-preferred hijacks.
  - **Type-0**: { **ASH** }
  - **Type-1**: { **ASH**, **ASV** }
  - **Type-N**: { **ASH**, **…**, **ASV** }



Proximity Classifier – Reason for Misclassifications

Proximity Classifier: Reason for Misclassification (FP / FN)	GRnet Transit ASN 5408	AMS Transit ASN 8283	AMS Transit ASN 12859	AMS Peer ASN 9002	AMS Peer ASN 6461	AMS Peer ASN 52320
1. Shortest AS-Path Violation	**FP: 1 FN: 140**	**FP: 2 FN: 158**	**FP: 0 FN: 79**	**FP: 0 FN: 0**	**FP: 1 FN: 8**	**FP: 0 FN: 0**
a) Longer Path preferred	*FP: 0 FN: 139*	*FP: 1 FN: 157*	*FP: 0 FN: 79*	*FP: 0 FN: 0*	*FP: 1 FN: 0*	*FP: 0 FN: 0*
b) Victim Path not observed	*FP: 1 FN: 0*	*FP: 1 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*
c) Hijacker Path not observed	*FP: 0 FN: 1*	*FP: 0 FN: 1*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 8*	*FP: 0 FN: 0*
3. Tie breakers Violations	**FP: 2 FN: 0**	**FP: 15 FN: 0**	**FP: 29 FN: 0**	**FP: 15 FN: 0**	**FP: 33 FN: 0**	**FP: 1 FN: 0**
d) Victim path preferred	*FP: 2 FN: 0*	*FP: 15 FN: 0*	*FP: 29 FN: 0*	*FP: 15 FN: 0*	*FP: 33 FN: 0*	*FP: 1 FN: 0*
Total (FP / FN)	**FP: 3 FN: 140**	**FP: 17 FN: 158**	**FP: 29 FN: 79**	**FP: 15 FN: 0**	**FP: 34 FN: 8**	**FP: 1 FN: 0**

Gao-Rexford Classifier – Reason for Misclassifications

Gao Rexford Classifier Reason for Misclassification (FP / FN)	GRnet Transit ASN 5408	AMS Transit ASN 8283	AMS Transit ASN 12859	AMS Peer ASN 9002	AMS Peer ASN 6461	AMS Peer ASN 52320
1. Gao Rexford Violation	**FP: 52 FN: 0**	**FP: 27 FN: 0**	**FP: 48 FN: 0**	**FP: 3 FN: 0**	**FP: 2 FN: 0**	**FP: 1 FN: 0**
a) customer - provider	*FP:1 FN:0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*
b) customer - peer	*FP: 0 FN: 0*	*FP: 6 FN: 0*	*FP: 20 FN:0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*
c) peer - provider	*FP: 51 FN: 0*	*FP: 21 FN: 0*	*FP: 28 FN:0*	*FP: 3 FN: 0*	*FP: 2 FN: 0*	*FP: 1 FN: 0*
2. Shortest AS-Path Violation	**FP: 1 FN: 8**	**FP: 2 FN: 17**	**FP: 0 FN: 9**	**FP: 0 FN: 0**	**FP: 1 FN: 8**	**FP: 0 FN: 0**
d) Longer Path preferred (Same Gao relation)	*FP:0 FN: 4*	*FP: 0 FN: 13*	*FP: 0 FN: 9*	*FP: 0 FN: 0*	*FP: 1 FN: 0*	*FP: 0 FN: 0*
e) Longer Path preferred (Unknown relation)	*FP: 0 FN: 3*	*FP: 1 FN: 3*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*
f) Victim Path not observed	*FP: 1 FN: 0*	*FP: 1 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 0*
g) Hijacker Path not observed	*FP: 0 FN: 1*	*FP: 0 FN: 1*	*FP: 0 FN: 0*	*FP: 0 FN: 0*	*FP: 0 FN: 8*	*FP: 0 FN: 0*
3. Tie breakers Violations	**FP: 2 FN: 0**	**FP: 8 FN: 0**	**FP: 17 FN: 0**	**FP: 15 FN: 0**	**FP: 33 FN: 0**	**FP: 1 FN: 0**
h) Victim path preferred	*FP: 2 FN: 0*	*FP: 8 FN: 0*	*FP: 17 FN: 0*	*FP: 15 FN: 0*	*FP: 33 FN: 0*	*FP: 1 FN: 0*
Total (FP / FN)	**FP: 55 FN: 8**	**FP: 37 FN: 17**	**FP: 65 FN: 9**	**FP: 18 FN: 0**	**FP: 36 FN: 8**	**FP: 2 FN: 0**

More Results

- For more experiment results: Refer to our *Published Journal*.