Freie Universität Berlin

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Hamburg University of Applied Sciences

USC University of Southern California

Columbia University
in the City of New York

UFMG
Universidade Federal de Minas Gerais

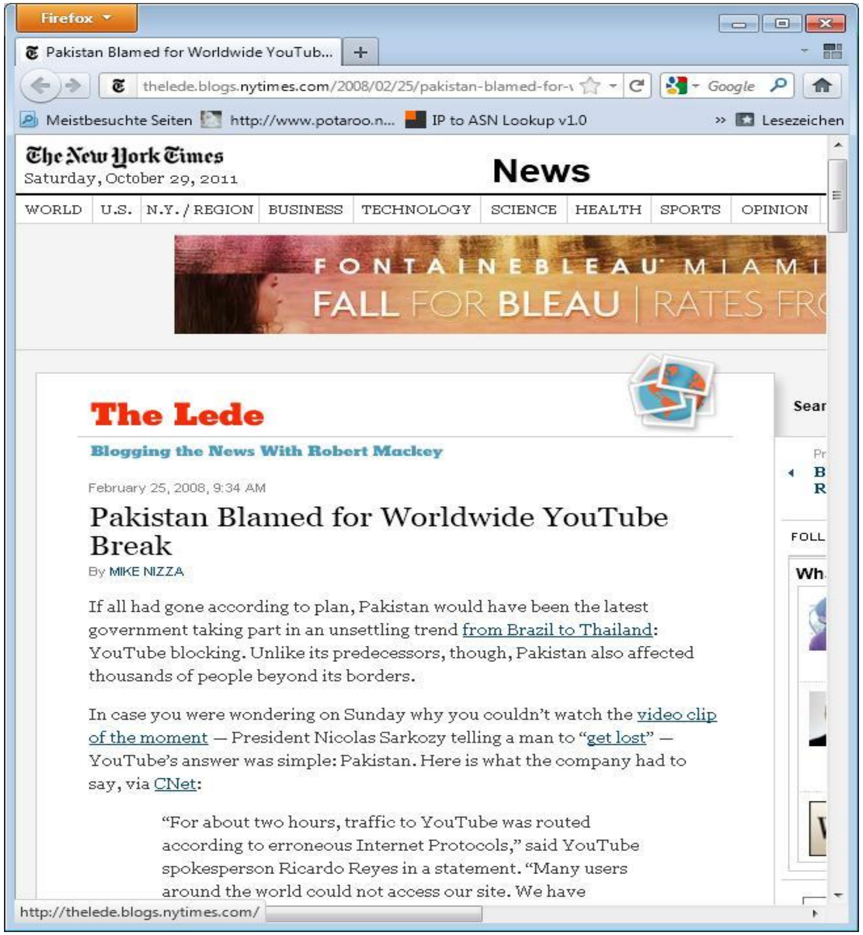
PEERING
The BGP Testbed

Measuring Adoption of RPKI Route Validation and Filtering

Andreas Reuter (andreas.reuter@fu-berlin.de)

Joint work with Randy Bush,
Ethan Katz-Bassett, Italo Cunha,
Thomas C. Schmidt, and Matthias Wählisch

Once upon a time ... someone incorrectly announced an IP prefix.



The New York Times
Saturday, October 29, 2011

News

The Lede

Blogging the News With Robert Mackey

February 25, 2008, 9:34 AM

Pakistan Blamed for Worldwide YouTube Break

By MIKE NIZZA

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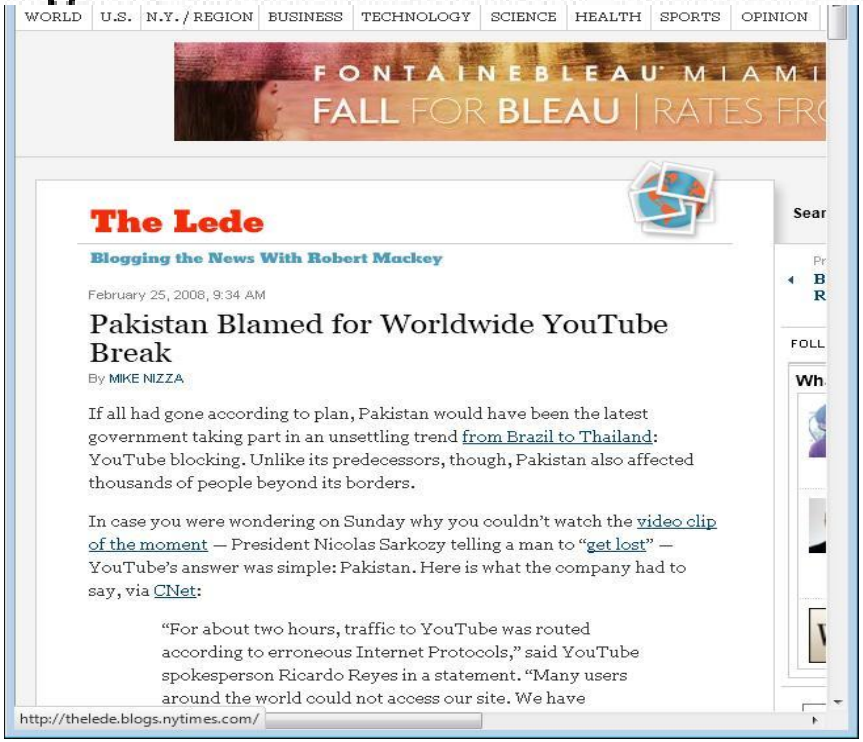

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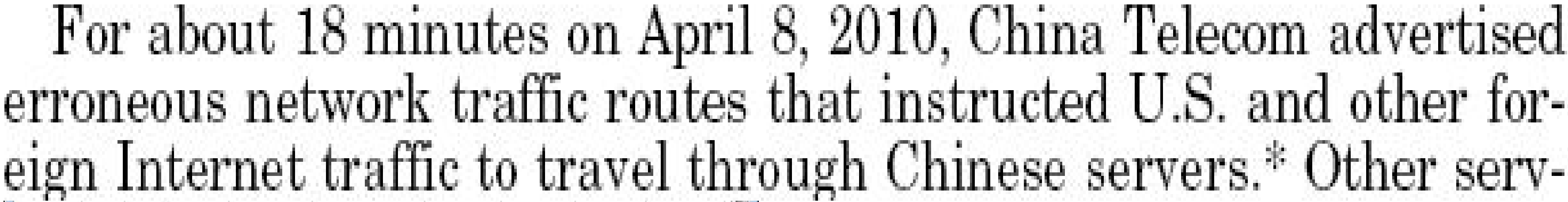

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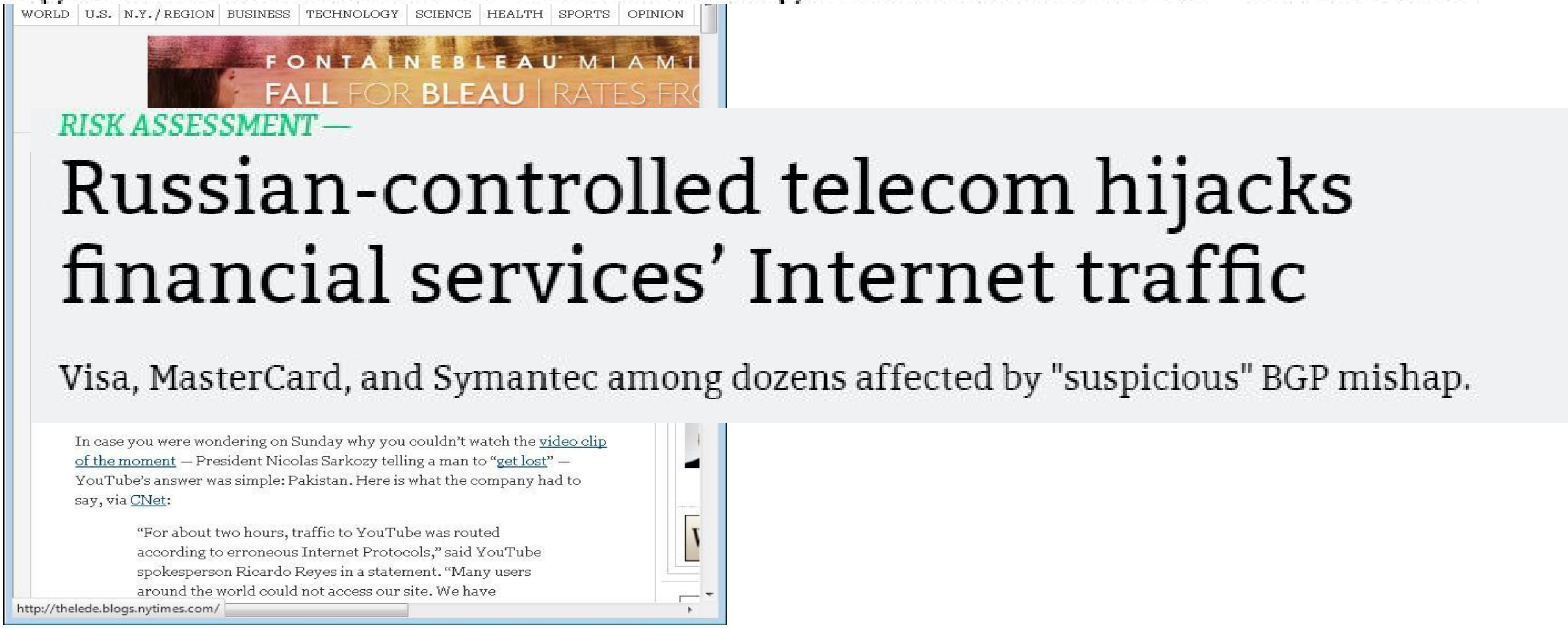

RISK ASSESSMENT —

Russian-controlled telecom hijacks financial services' Internet traffic

Visa, MasterCard, and Symantec among dozens affected by "suspicious" BGP mishap.

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http://thelede.blogs.nytimes.com/

Enter RPKI

Prefix hijacking prevention using Resource Public Key Infrastructure

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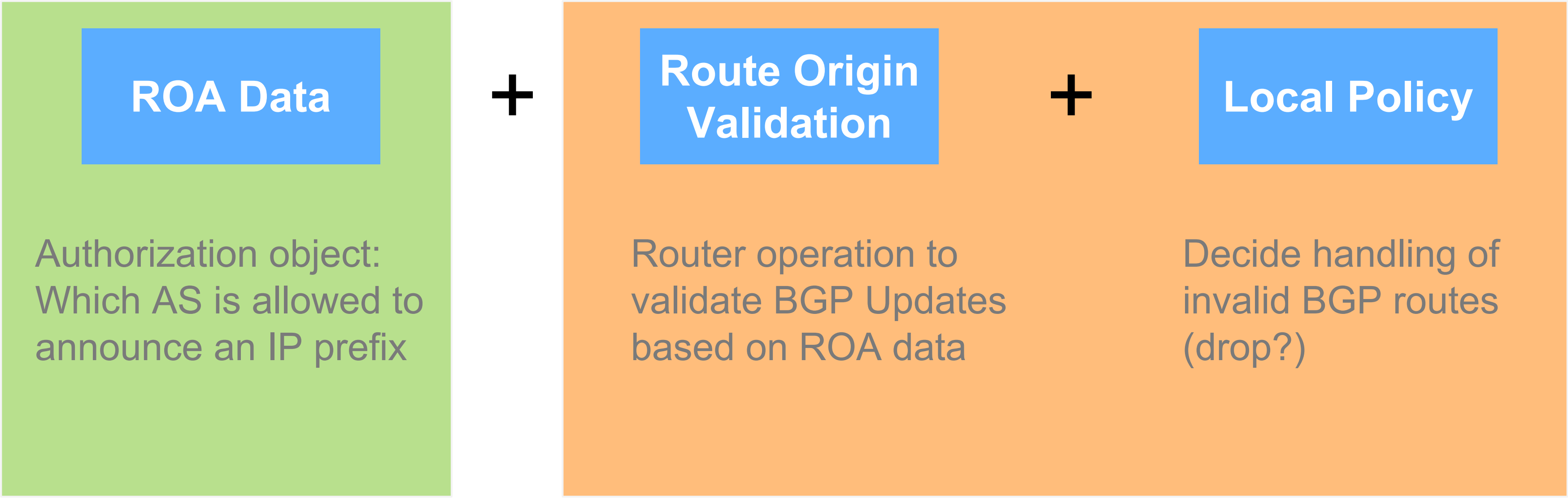
ROA Data

Authorization object: Which AS is allowed to announce an IP prefix

Enter RPKI

Prefix hijacking prevention using Resource Public Key Infrastructure



ROA Data

+

Route Origin Validation

+

Local Policy

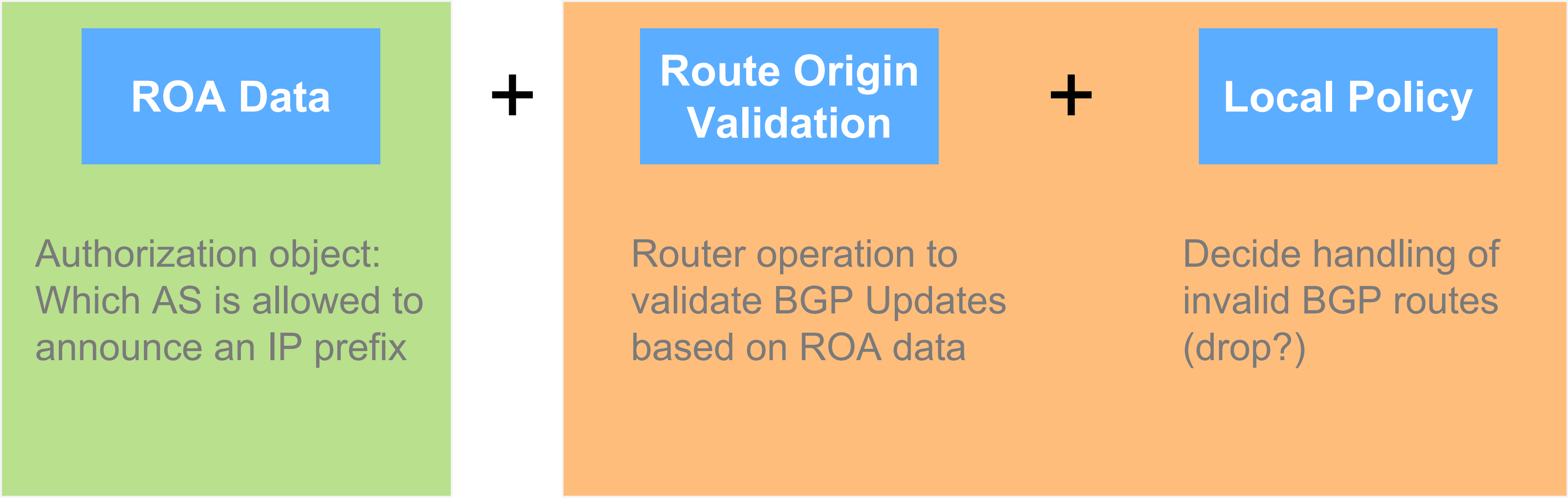
Authorization object: Which AS is allowed to announce an IP prefix

Router operation to validate BGP Updates based on ROA data

Decide handling of invalid BGP routes (drop?)

Enter RPKI

Prefix hijacking prevention using Resource Public Key Infrastructure



ROA Data + **Route Origin Validation** + **Local Policy**

Authorization object: Which AS is allowed to announce an IP prefix

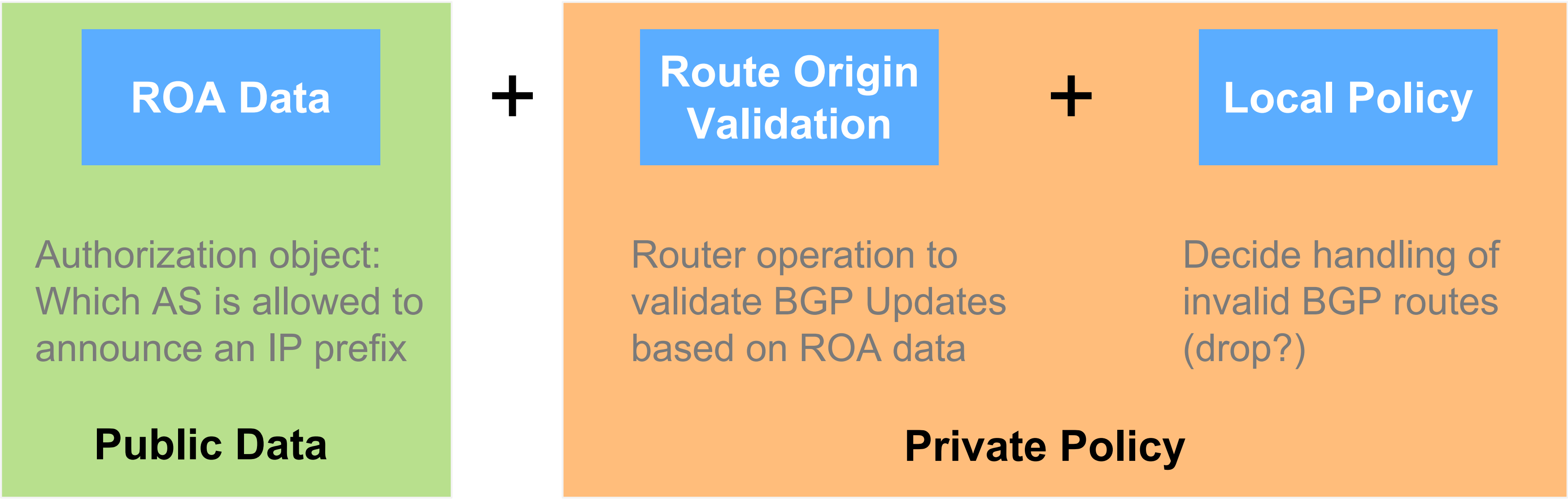
Router operation to validate BGP Updates based on ROA data

Decide handling of invalid BGP routes (drop?)

ROA: 10.20.0.0/16-24 AS100

BGP: 10.20.0.0/16 AS100 ✔ **Accept**
BGP: 10.20.0.0/16 AS666 ✖ **Reject**

Research Problem



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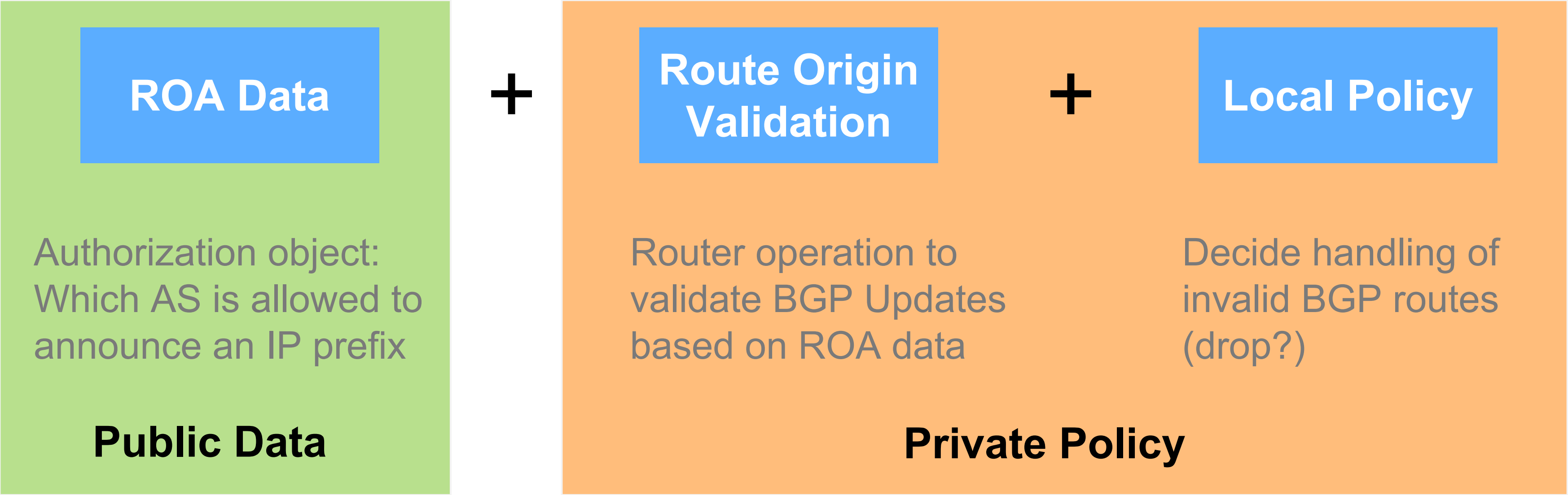
Public Data

Private Policy

Measure the adoption of RPKI-based filter policies.

Research Challenge



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Public Data

Private Policy

Measure the adoption of RPKI-based filter policies.

Challenge: Private policies must be inferred from measurements.

Two principle approaches

Uncontrolled experiments

Analysing existing BGP data and ROAs, trying to infer who is filtering.

➔ **Fast**

➔ **Easy**

Controlled experiments

Actively announcing BGP Updates and dynamically creating ROAs

Analyse resulting BGP data to infer who is filtering.

➔ **Slow**

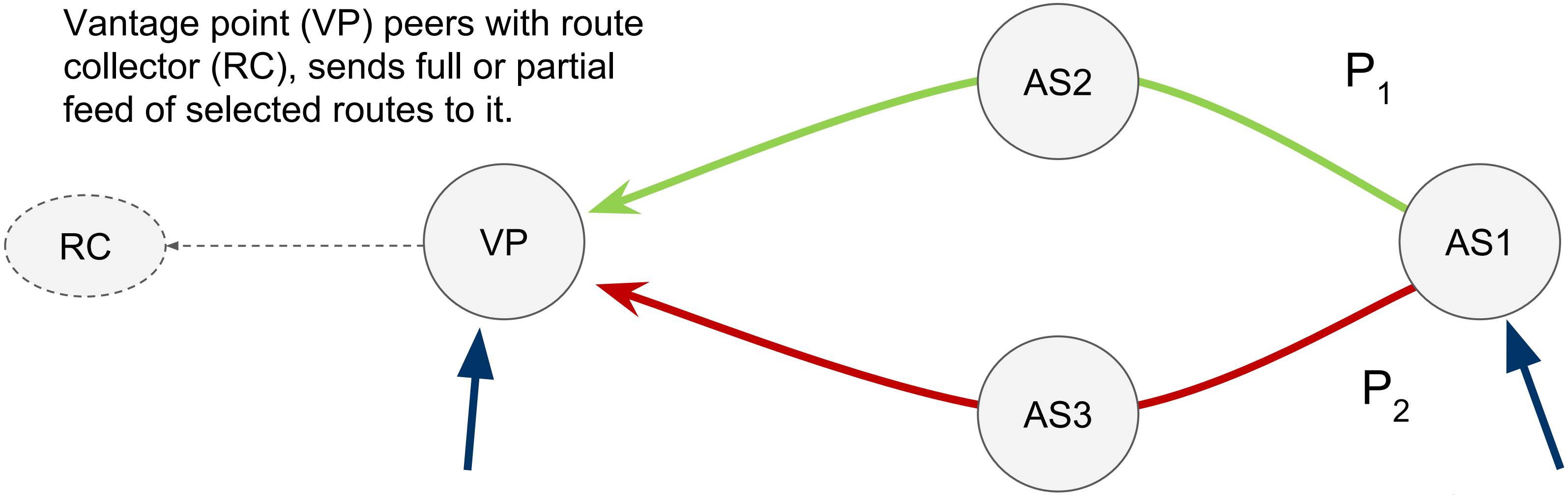
➔ **Needs experimental facilities**

Uncontrolled Experiments: The Basic Idea

➔ **Leverage divergence between AS paths of invalid and non-invalid routes to infer if an AS is filtering**

Uncontrolled Experiments: The Basic Idea

➔ Leverage divergence between AS paths of invalid and non-invalid routes to infer if an AS is filtering



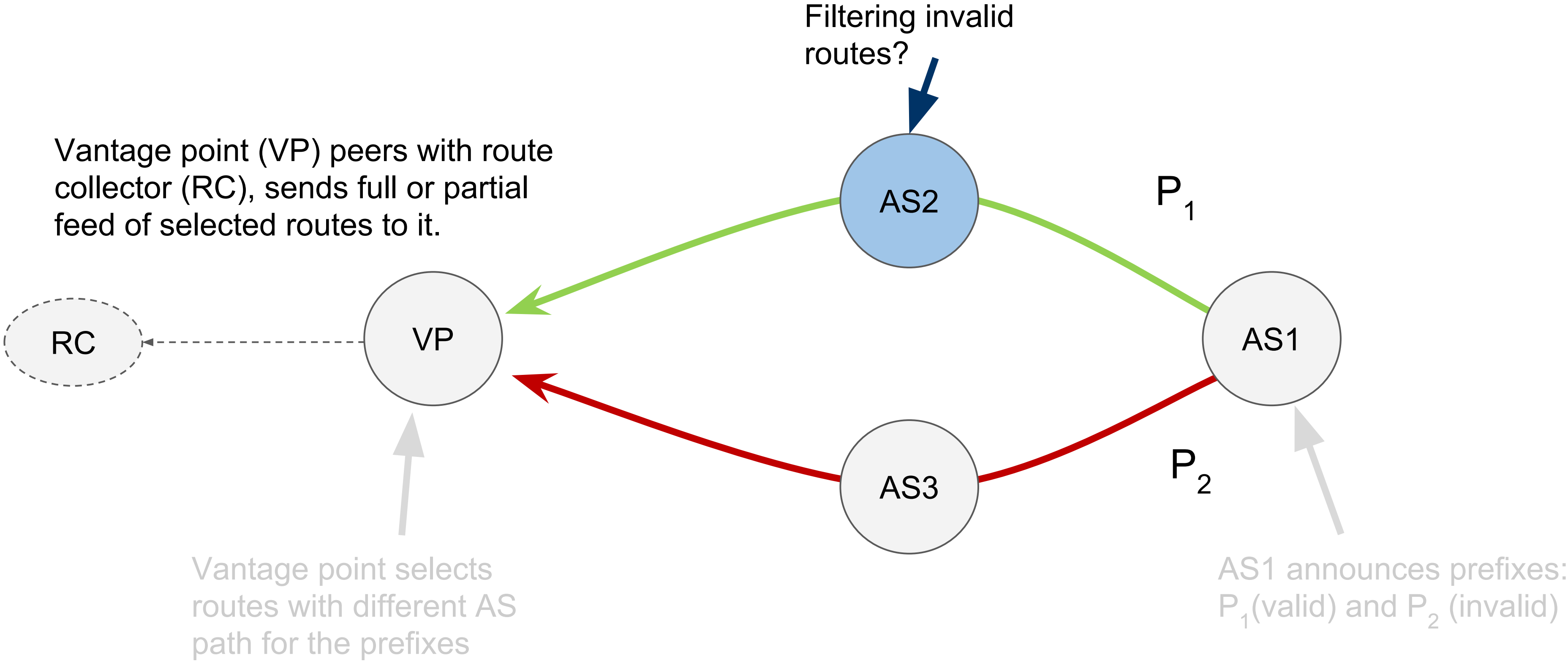
Vantage point (VP) peers with route collector (RC), sends full or partial feed of selected routes to it.

Vantage point selects routes with different AS path for the prefixes

AS1 announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: The Basic Idea

- Leverage divergence between AS paths of invalid and non-invalid routes to infer if an AS is filtering



Filtering invalid routes?

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Uncontrolled Experiments: Problems

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- ➔ Limited Control

Uncontrolled Experiments: Problems

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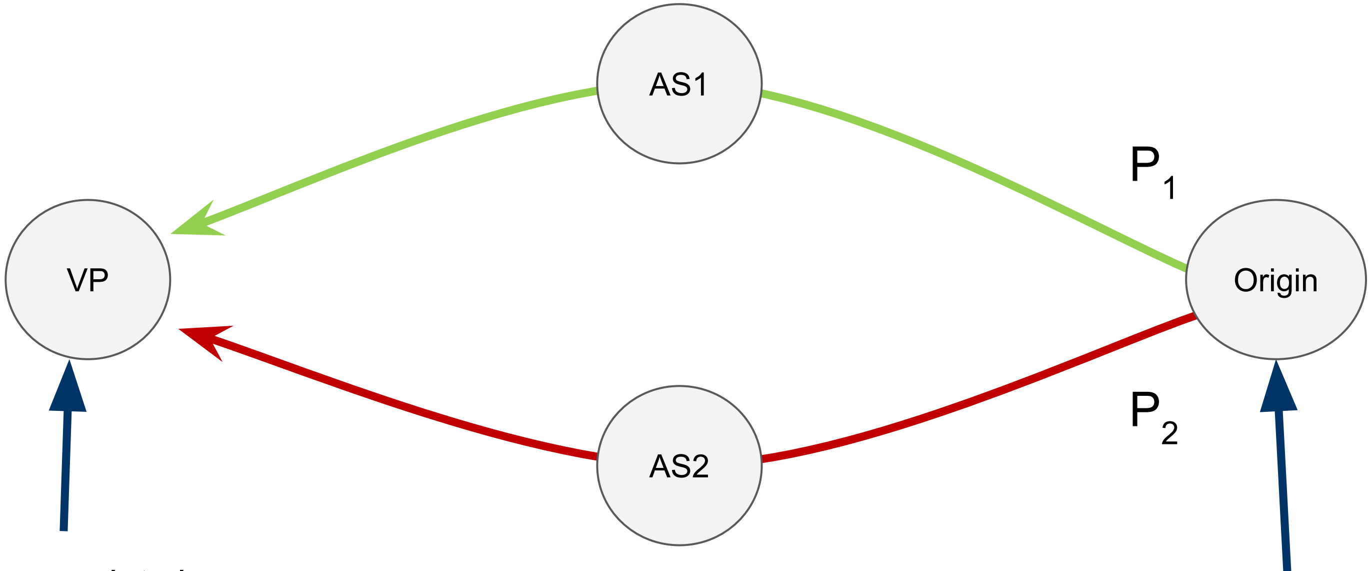
  - Do not know origin AS policy. Traffic engineering might look like RPKI-based filtering.

Uncontrolled Experiments: Limited Control

Origin Policy



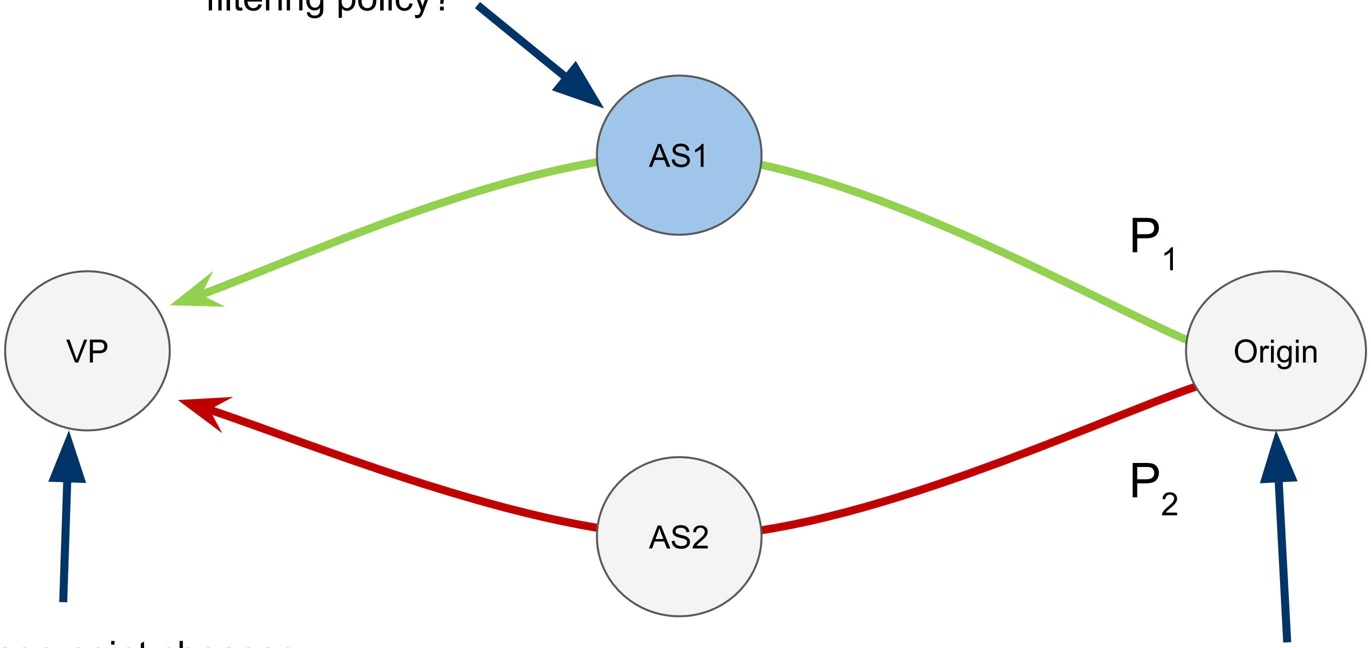
Vantage point chooses routes with different AS path

Origin announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: Limited Control

Origin Policy

Is AS1 using RPKI-based filtering policy?



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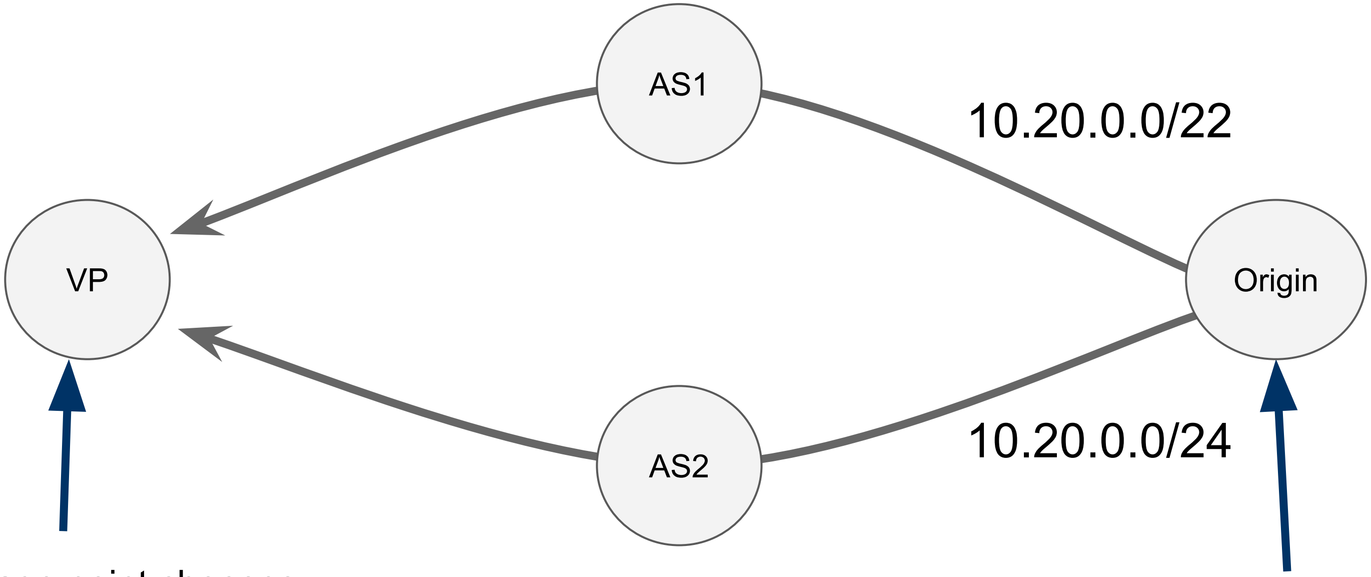


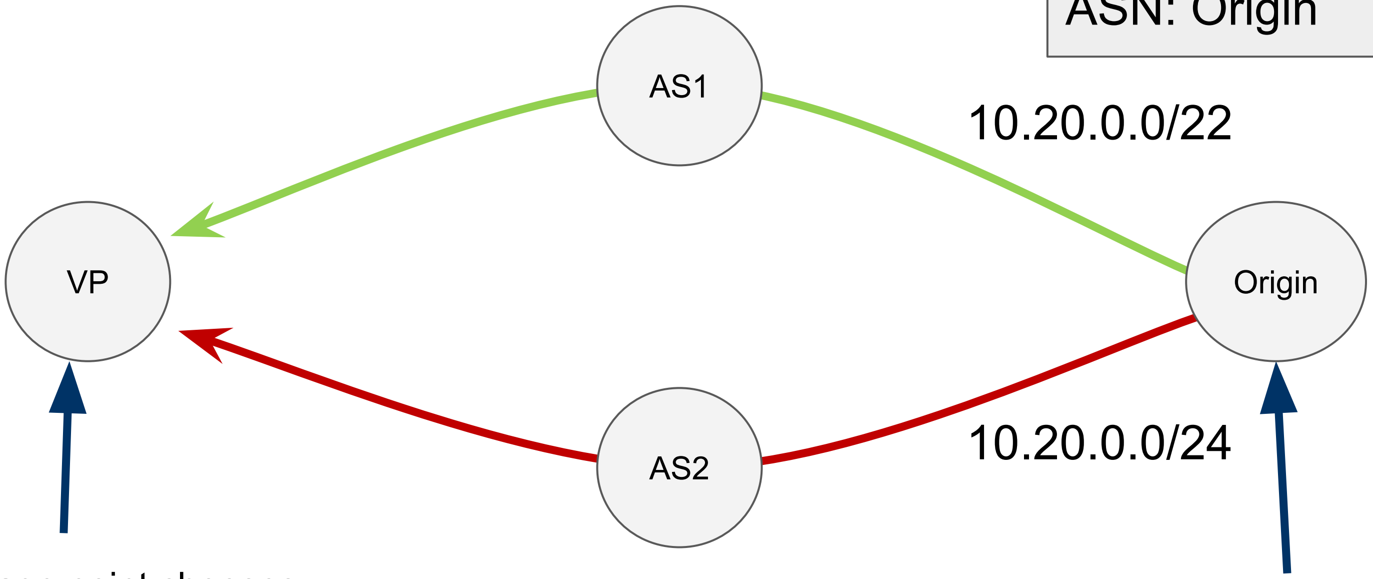
Vantage point chooses routes with different AS path

Origin announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: Limited Control

Origin Policy

ROA:
Prefix:10.20.0.0/22 - 22
ASN: Origin



Vantage point chooses routes with different AS path

Origin announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: Limited Control

Origin Policy

Is AS1 using RPKI-based filtering policy?

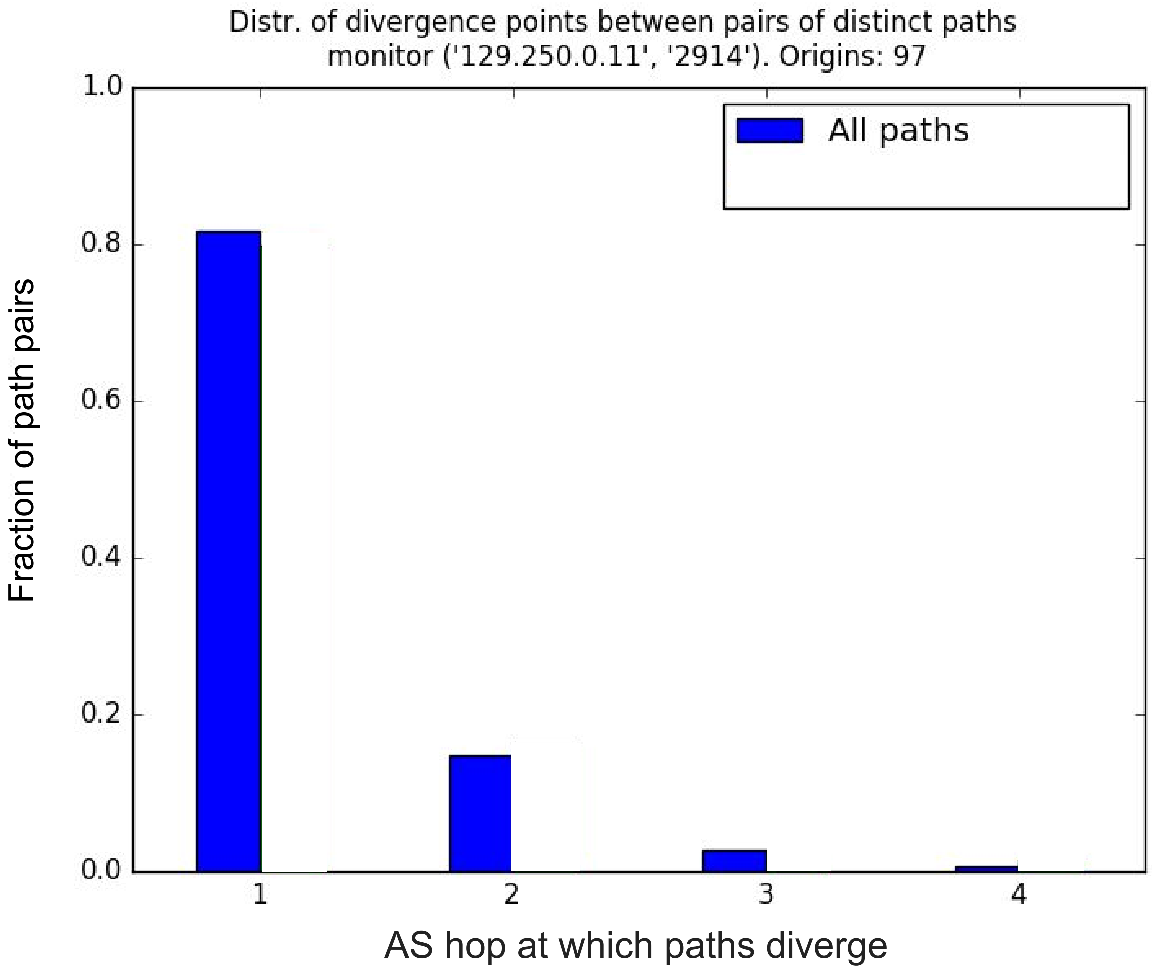
Path divergence at first hop is more likely to be the result of traffic engineering at origin.

Vantage point chooses routes with different AS path

Origin announces prefixes: P$_1$(valid) and P$_2$ (invalid)

Path Divergence

Divergence between AS paths of routes with the same origin



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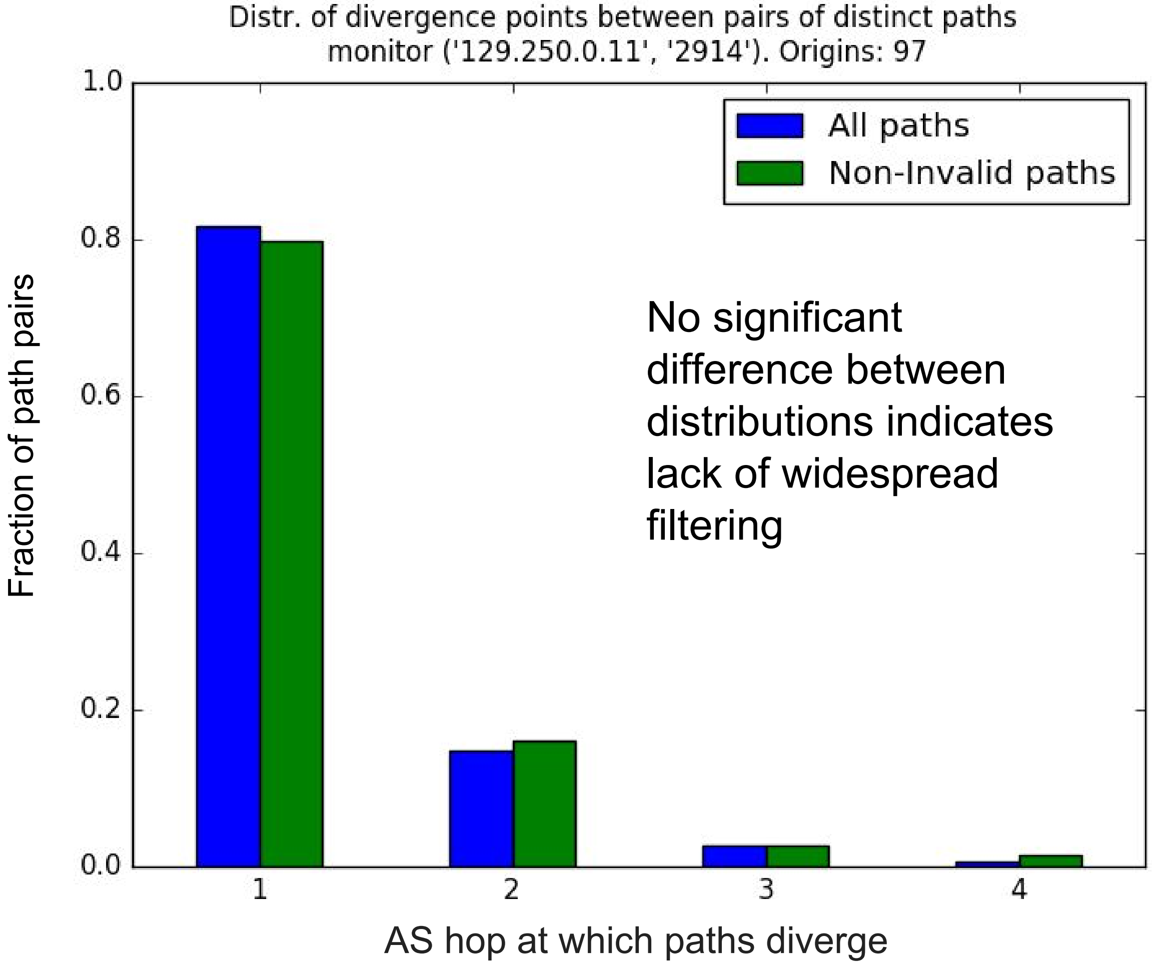


No significant difference between distributions indicates lack of widespread filtering

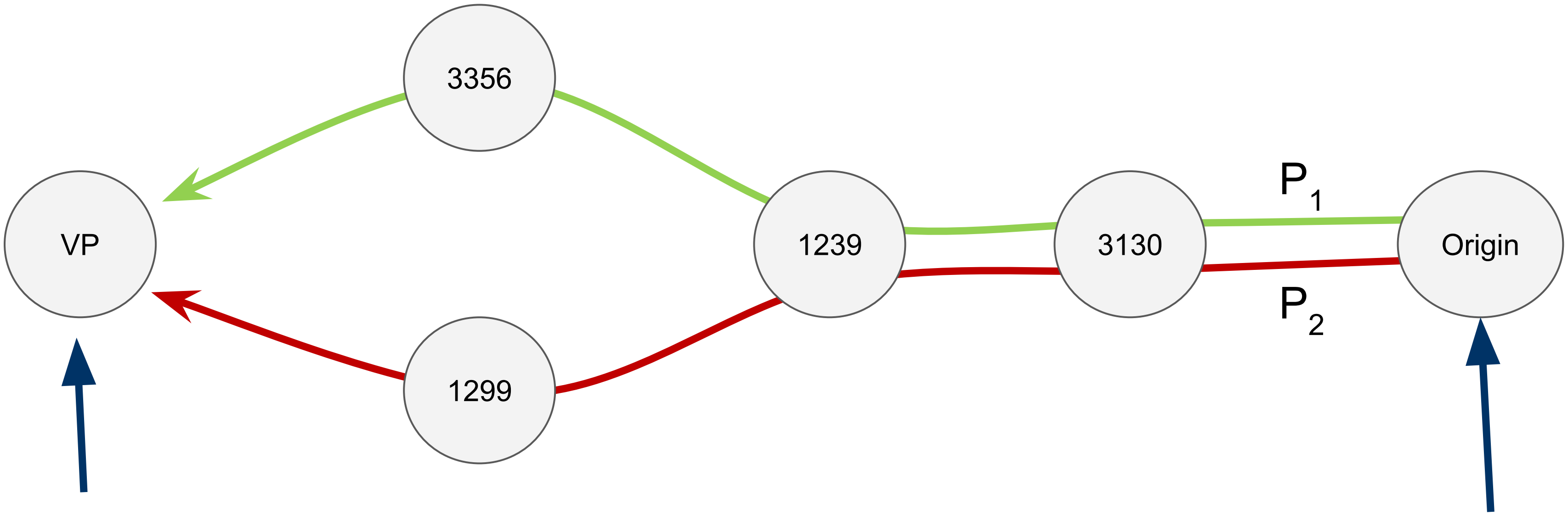
➔ Invalid routes (probably) have different AS paths for non-RPKI reasons

Uncontrolled Experiments: Problems

- ➔ Limited Control
  - ◆ Do not know origin AS policy. Traffic engineering might look like RPKI-based filtering.
  - ◆ Cannot distinguish between filtering based on RPKI vs. filtering based on other attributes

Uncontrolled Experiments: Limited Control

Real World Example



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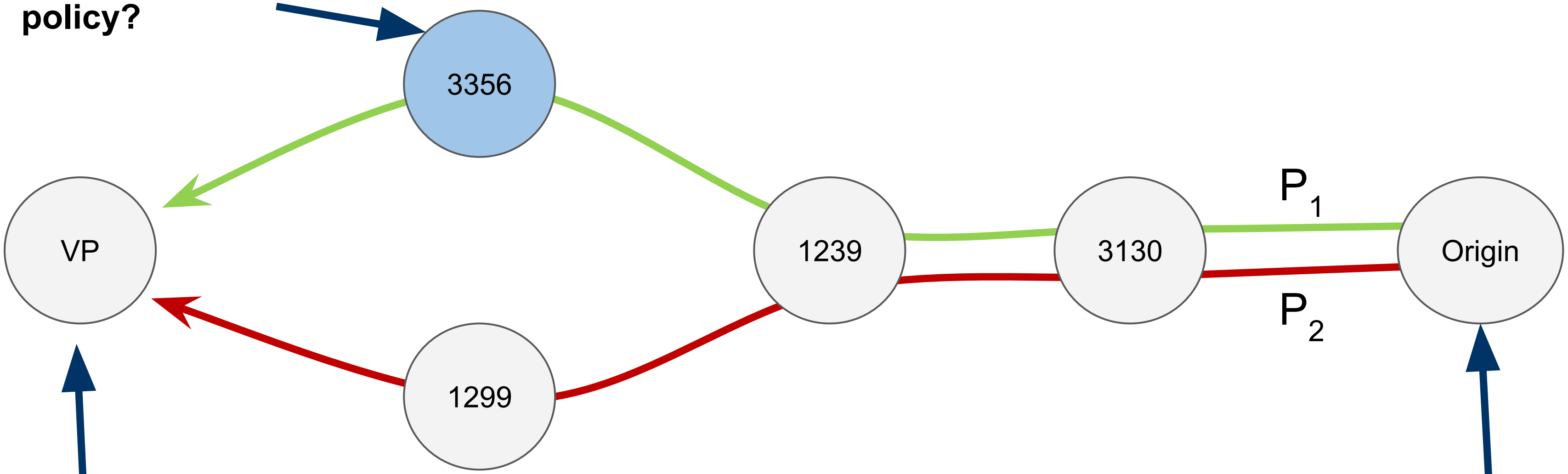
Uncontrolled Experiments: Limited Control

Real World Example

Is AS3356 using RPKI-based filtering policy?



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Uncontrolled Experiments: Limited Control

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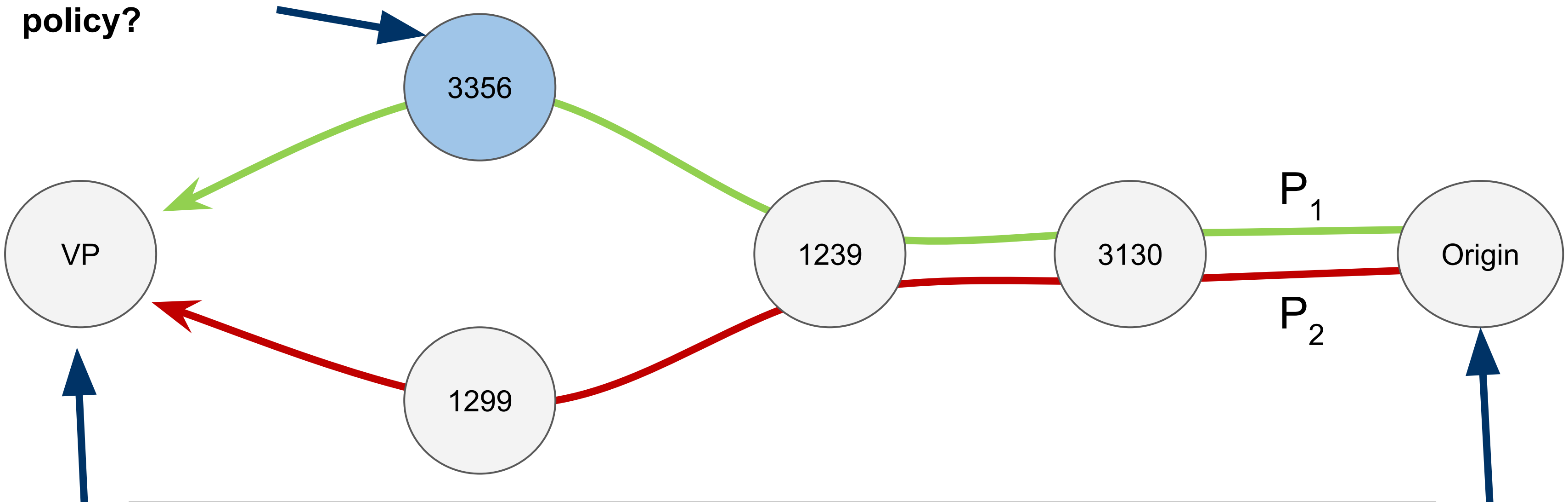

Vantage po
routes with
path

No!

Vantage point is using **route age** as tie breaker.

ounces prefixes:
nd P_2 (invalid)

Uncontrolled Experiments: Problems

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Uncontrolled Experiments: Limited Visibility

➔ Analysing data from different sets of vantage points can yield different classifications

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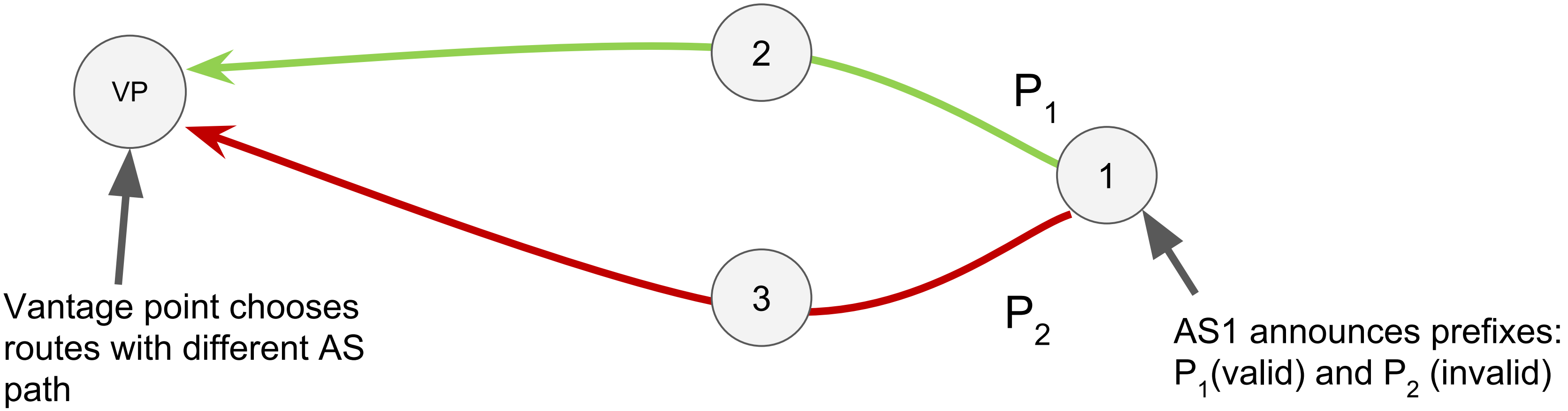

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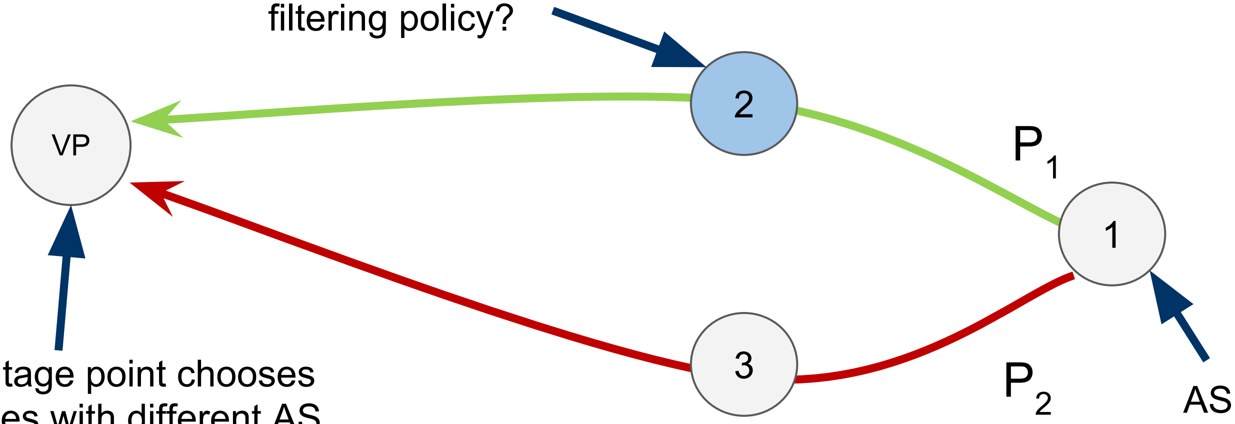

Is AS2 using RPKI-based filtering policy?

Vantage point chooses routes with different AS path

AS1 announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: Limited Visibility

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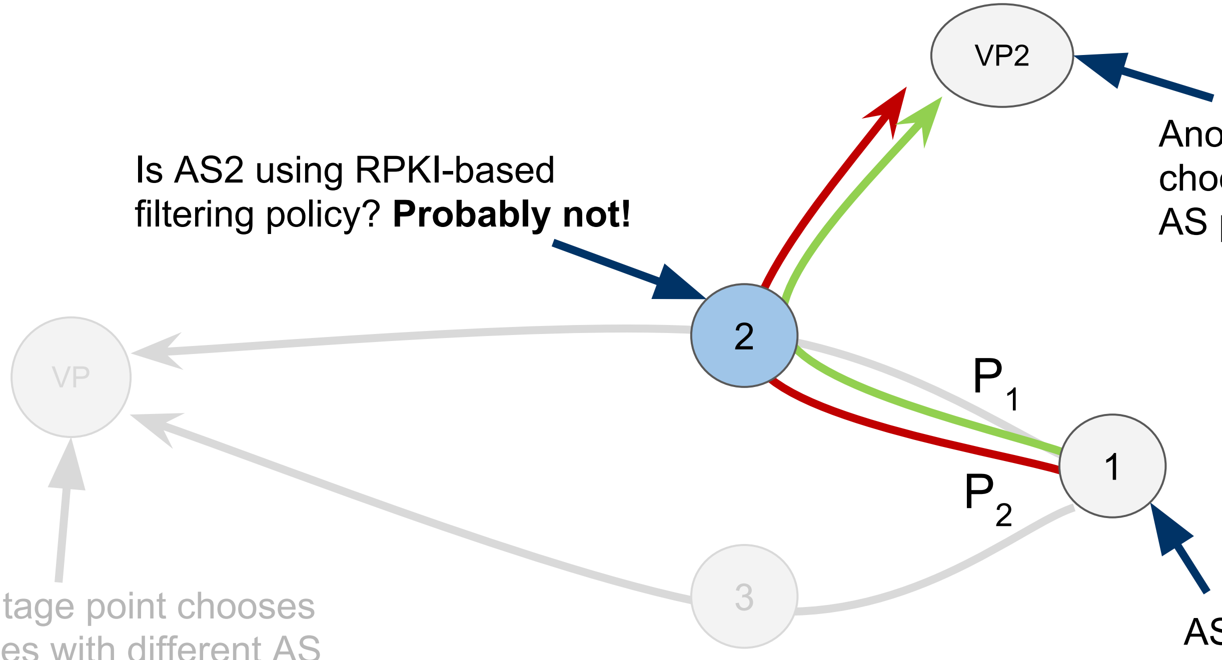

Is AS2 using RPKI-based filtering policy? **Probably not!**

Another vantage point chooses routes with same AS path

Vantage point chooses routes with different AS path

AS1 announces prefixes: P_1(valid) and P_2 (invalid)

Uncontrolled Experiments: Limited Visibility

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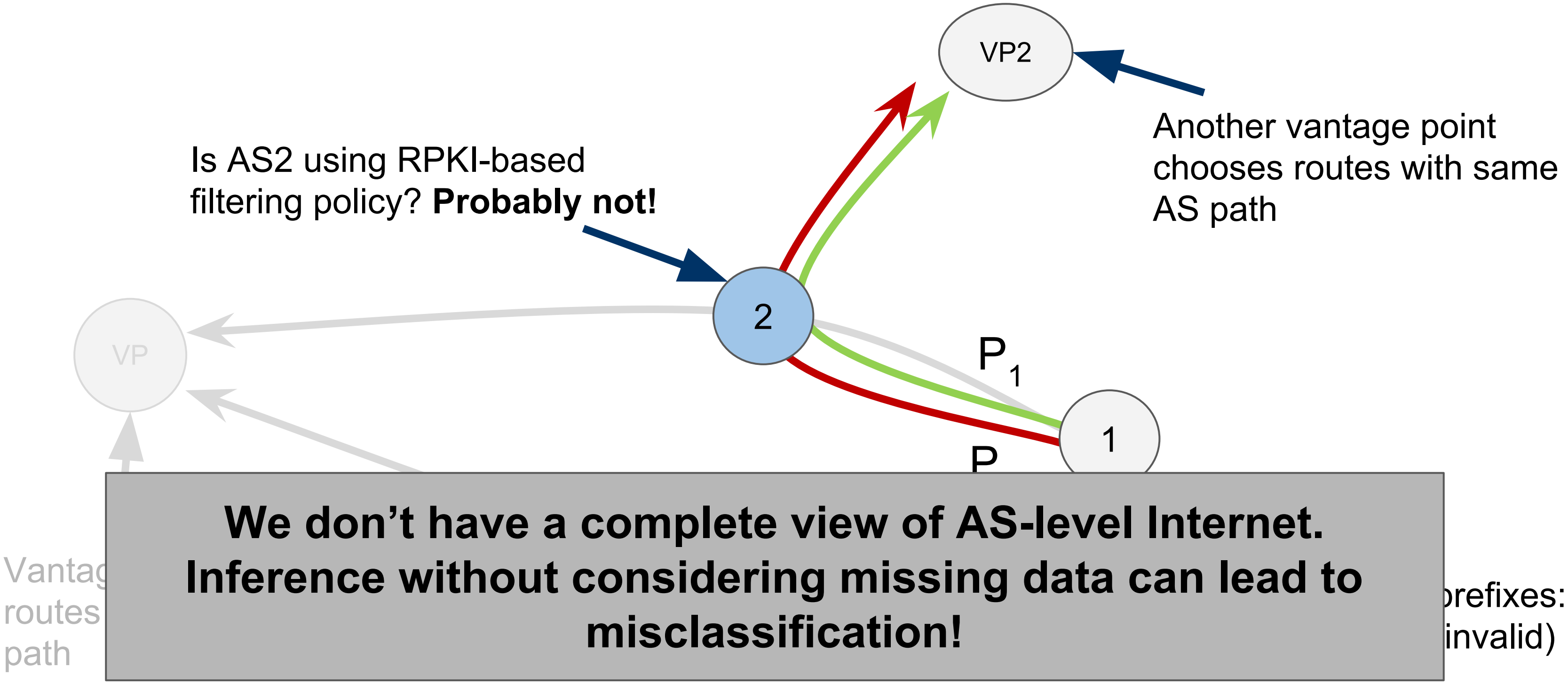

Is AS2 using RPKI-based filtering policy? **Probably not!**

Another vantage point chooses routes with same AS path

We don’t have a complete view of AS-level Internet. Inference without considering missing data can lead to misclassification!

Uncontrolled Experiments: Problems

- Limited Control
  - Do not know origin AS policy. Traffic engineering might look like RPKI-based filtering.
  - Cannot distinguish between filtering based on RPKI vs. filtering based on other attributes
- Limited Visibility can lead to misclassification

Uncontrolled Experiments: Problems

- ➔ Limited Control
  - ◆ Do not know origin AS policy. Traffic engineering might look like RPKI-based filtering.
  - ◆ Cannot distinguish between filtering based on RPKI vs. filtering based on other attributes
- ➔ Limited Visibility can lead to misclassification
- ➔ Not possible to reproduce

Uncontrolled Experiments: Problems

- ➔ Limited Control
  - ◆ D ering

    m
  - ◆ C on

    R
- ➔ Limite
- ➔ Not p

Inferring if a specific AS is using RPKI-based filtering on the basis of uncontrolled experiments is prone to misclassification!

Controlled Experiments

Controlled Experiments

Hand-crafted ROAs *and* BGP Updates

Controlled Experiments: Advantages

Hand-crafted ROAs *and* BGP Updates

- ➔ Limited Control
  - ◆ We know the routing policy of origin AS

Controlled Experiments: Advantages

Hand-crafted ROAs *and* BGP Updates

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- ◆ Can distinguish between RPKI-based filtering vs. filtering based on other attributes by changing ROAs/Updates

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Hand-crafted ROAs *and* BGP Updates

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Hand-crafted ROAs *and* BGP Updates

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  - ◆ We know the routing policy of origin AS
  - ◆ Can distinguish between RPKI-based filtering vs. filtering based on other attributes by changing ROAs/Updates
- ➔ Limited Visibility is less of an issue, we only care about our prefixes
- ➔ Can repeat experiments and target specific AS.

Controlled Experiments: Our Setup

BGP

Announce prefixes P_A (Anchor) and P_E (Experiment)

+ Same RIR DB route object
+ Same length
+ Minimal bit difference
+ Announced at the same time
+ Announced from same origin AS
+ Announced to same peers

RPKI

Issue ROAs for both prefixes

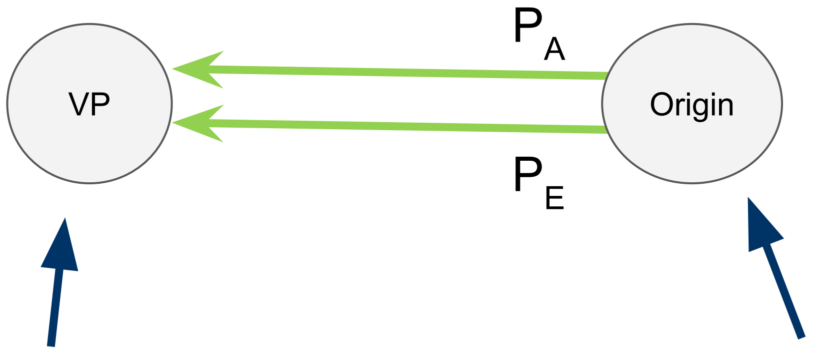
Periodically change ROA for experiment prefix

➔ Flips announcement from VALID to INVALID to VALID once a day

(Yes, we operate a grandchild RPKI CA ;))

Controlled Experiments: Observations

Situation: Origin and vantage point peer directly



Vantage point chooses routes with same AS path

Origin announces prefixes: P_A(valid) and P_E (valid)

Controlled Experiments: Observations

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Vantag point cho
routes with same AS path

Origin announces prefixes:
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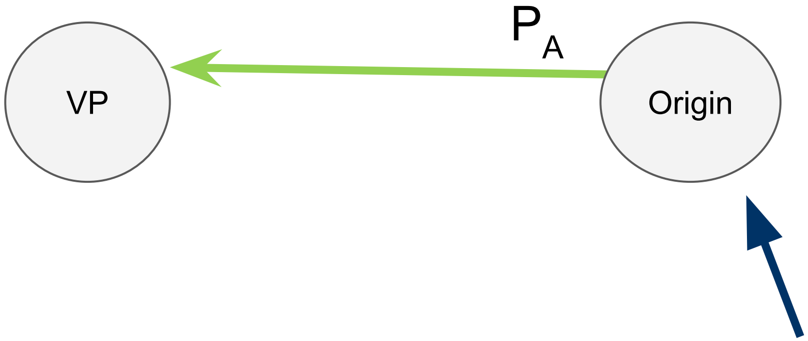
Controlled Experiments: Observations

Situation: Origin and vantage point peer directly

Observation 1: VP has no route for P_E now that it's announcement is invalid



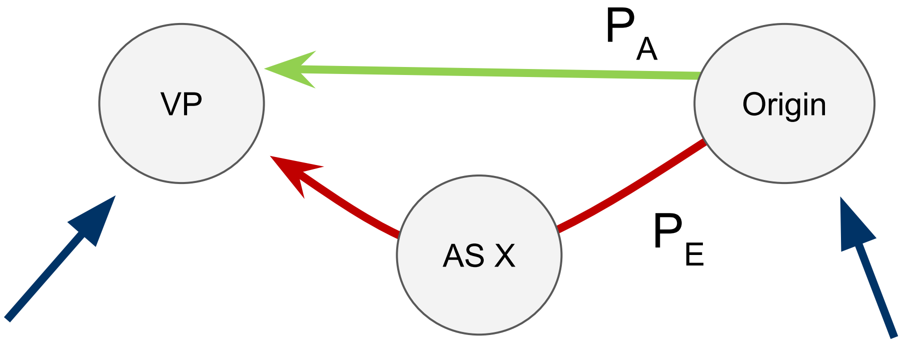
Origin announces prefixes: P_A(valid) and P_E (invalid)

Conclusion: VP is using RPKI-based filtering.

Controlled Experiments: Observations

Situation: Origin and vantage point peer directly

Observation 2: VP has route via AS X for P_E now that it’s announcement is invalid



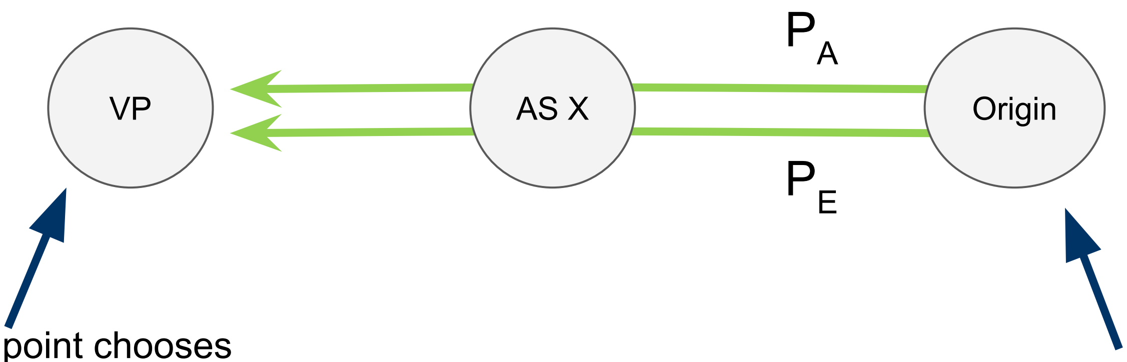
Vantage point chooses routes with different AS path

Origin announces prefixes: P_A(valid) and P_E (invalid)

Conclusion: VP uses RPKI-based filtering **selectively**.

Controlled Experiments: Observations

Situation: Origin and vantage point do not peer directly, other AS on path



Vantage point chooses routes with same AS path

Origin announces prefixes: P_A(valid) and P_E (valid)

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routes with same A path

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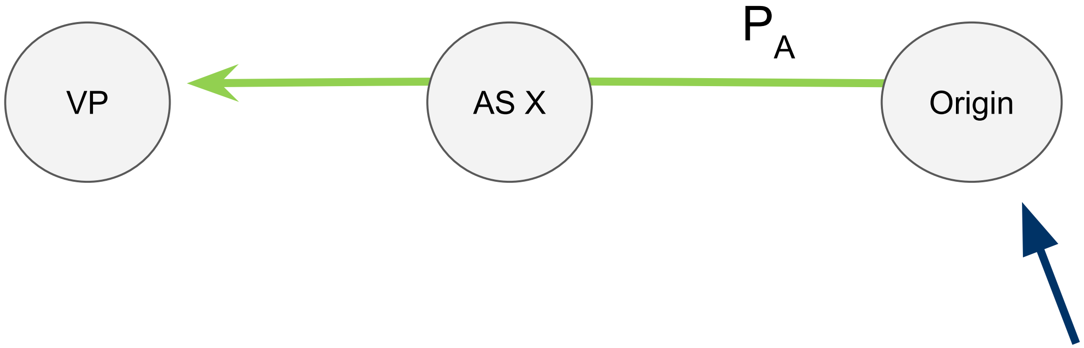


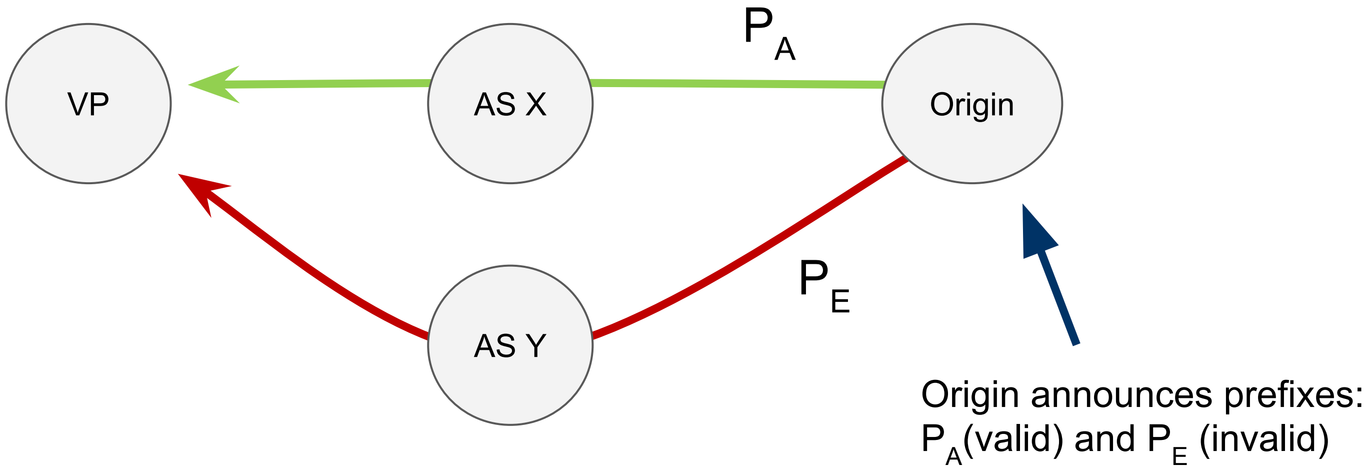
Origin announces prefixes: P_A(valid) and P_E (invalid)

Conclusion: VP or AS X (or both) are using RPKI-based filtering.

Controlled Experiments: Observations

Situation: Origin and vantage point do not peer directly, other AS on path

Observation 2: VP has different route for P_E now that it's announcement is invalid



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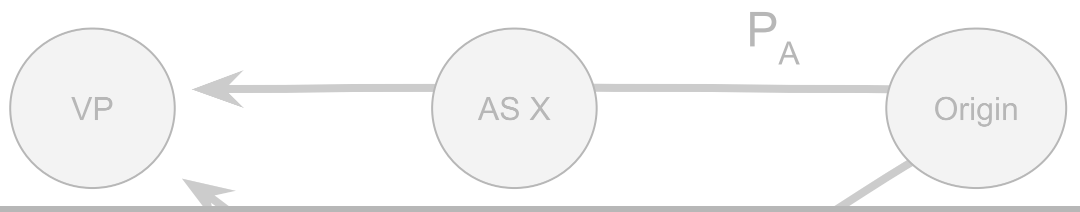

Resolve ambiguity by:

➔ Establishing direct peering with VP

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id)

Controlled Experiments: Observations

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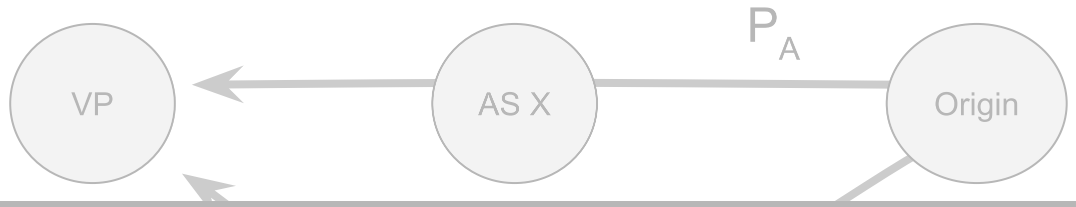


Resolve ambiguity by:

- ➔ Establishing direct peering with VP
- ➔ Checking if AS X has a vantage point

Results

Results

We found at least 3 AS that deployed RPKI-based filtering!

None of them are large providers ...

2 AS filtered all invalid routes

1 AS filtered selectively

Another measurement study found other results.

Results

We found at least 3 AS that deployed RPKI-based filtering!

None

2

Confirmed by
repeated experiments and
talking to operators.

Another

Conclusion

- ➔ There are ASes that do RPKI-based filtering.
  Not many, not the big ones, but at least some (>3).
- ➔ Uncontrolled experiments are unsuited to infer RPKI-based filtering policies
- ➔ Controlled experiments are crucial to measuring adoption of RPKI-based filtering policies

Internet infrastructure requires proper monitoring.

Next Steps

- ➔ We will extend our measurement methodology.
- ➔ We will establish a live monitoring system with public access.

BGP monitoring is based on collaboration!

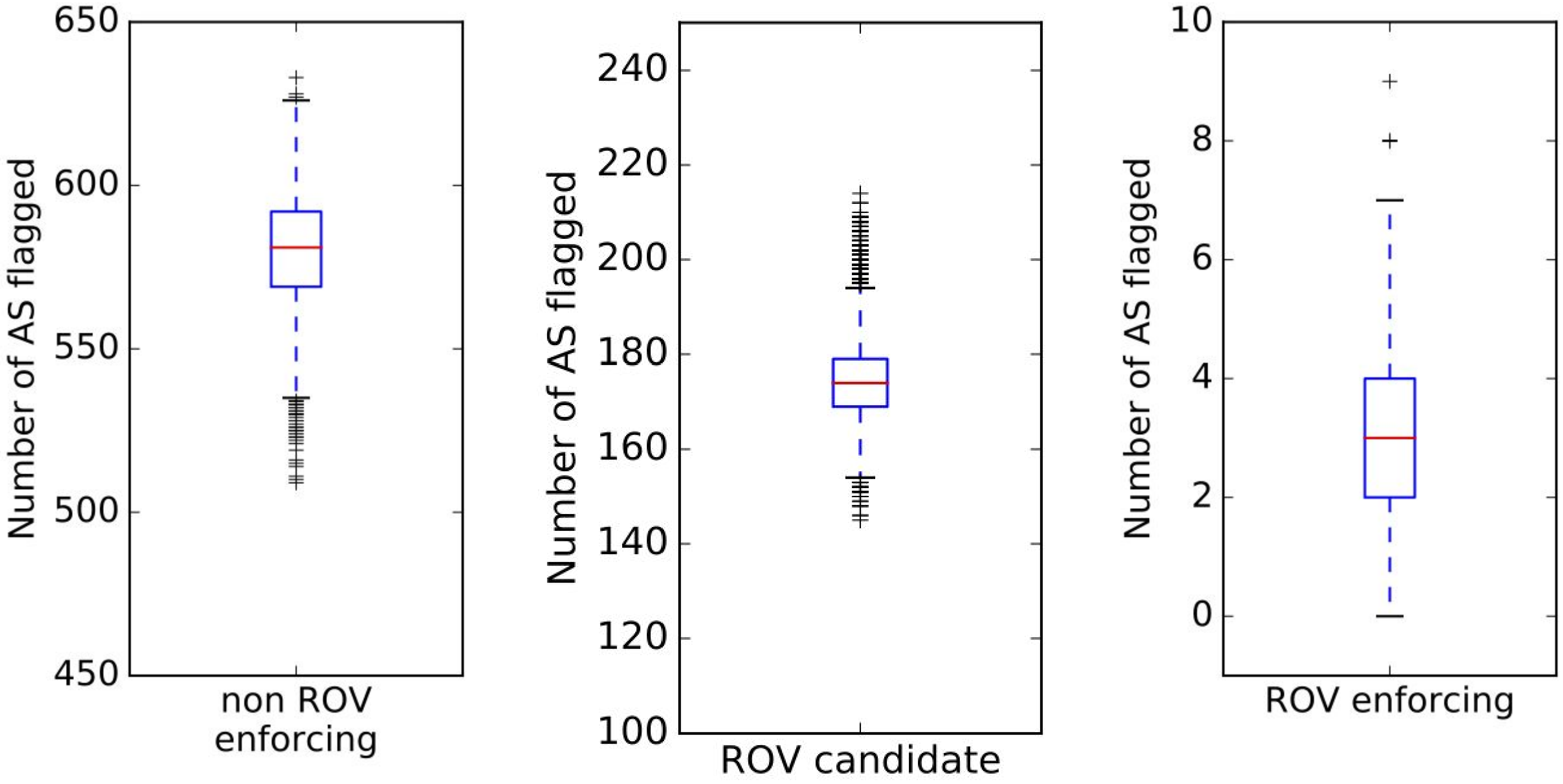
- ➔ Please, establish direct peering with PEERING testbed.
  - ◆ https://peering.usc.edu/peering/
- ➔ Please, peer with public route collectors.

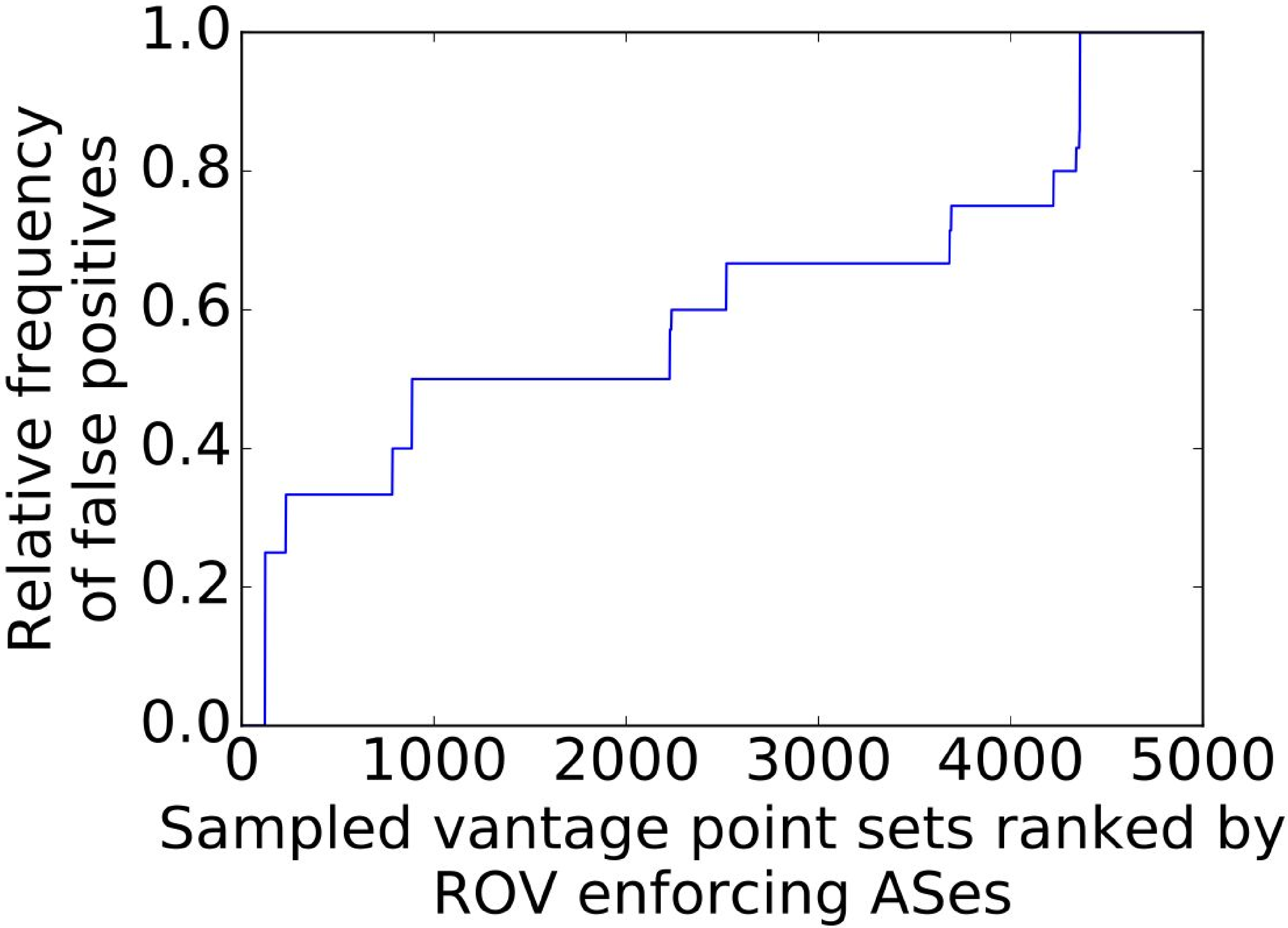
Next Steps

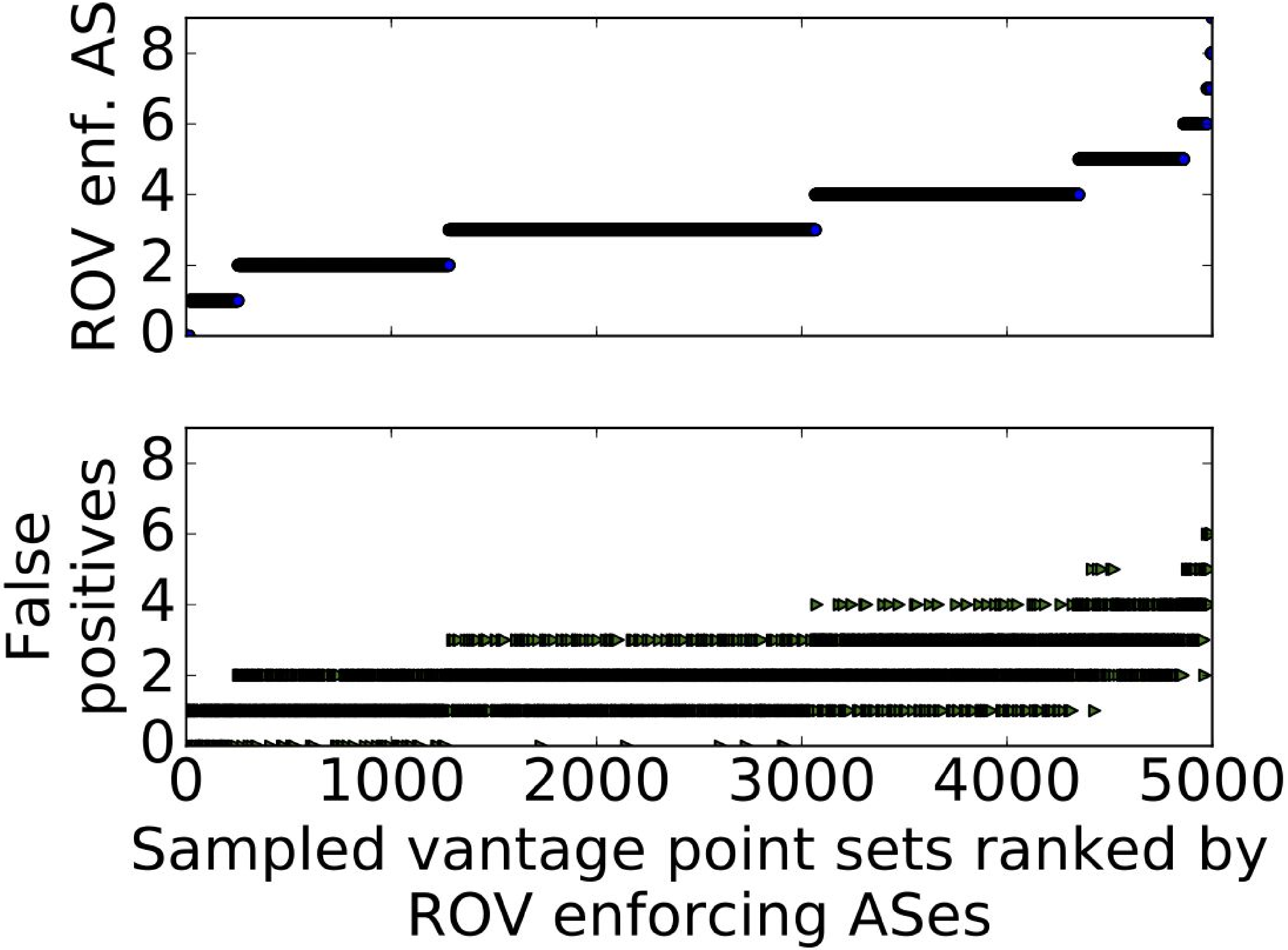
BG

Have you enabled RPKI-based OV on a router today?

Backup

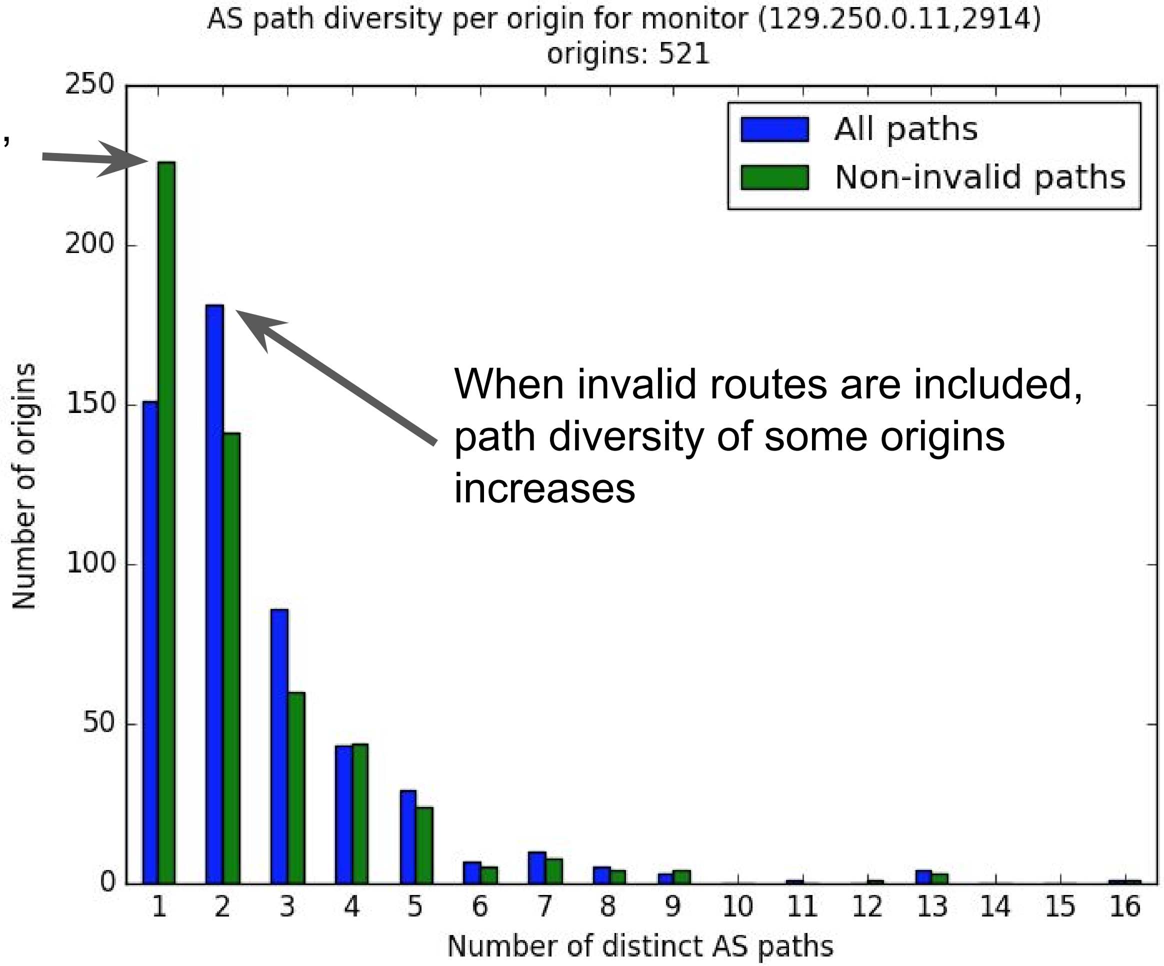

650
600
550
500
450
Number of AS flagged
non ROV enforcing
240
220
200
180
160
140
120
100
Number of AS flagged
ROV candidate
10
8
6
4
2
0
Number of AS flagged
ROV enforcing


1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
5000
Relative frequency of false positives
Sampled vantage point sets ranked by ROV enforcing ASes


ROV enf. AS
0
2
4
6
8
False positives
0
2
4
6
8
0
1000
2000
3000
4000
5000
Sampled vantage point sets ranked by ROV enforcing ASes

Path Diversity

Path Diversity Distribution of a single vantage point



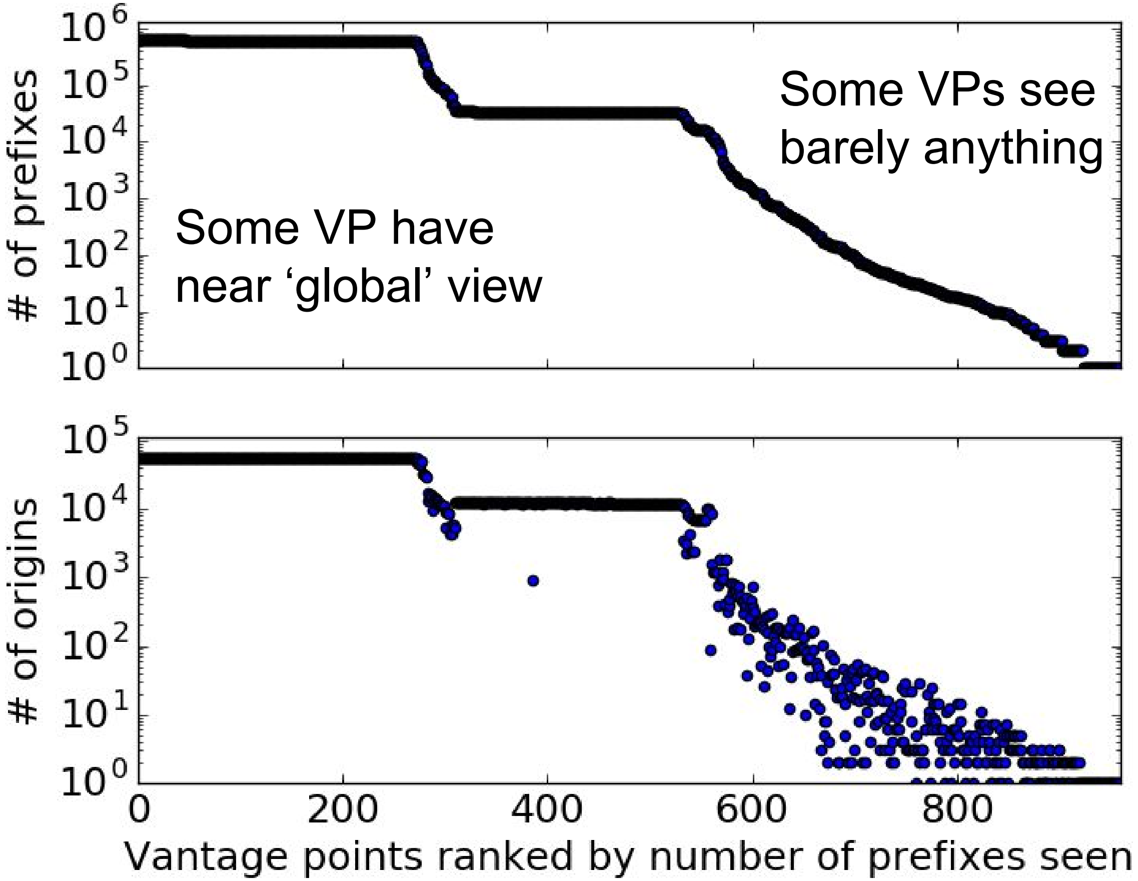
For ~50% of origins, there is exactly one distinct AS path

When invalid routes are included, path diversity of some origins increases

➔ Invalid routes tend to have different AS paths than non-invalid routes

Vantage Point Visibility Matters

Prefixes and their Origins

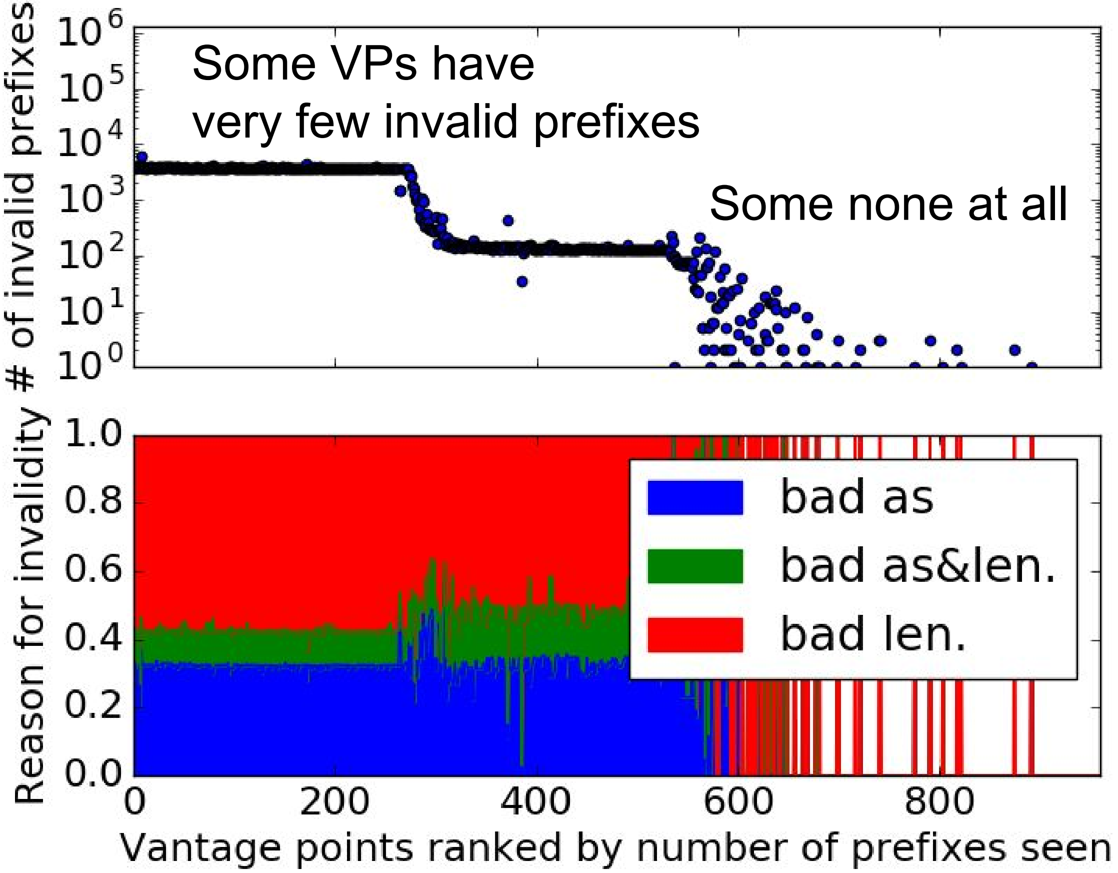


Some VPs see barely anything

Some VP have near ‘global’ view

Vantage Point Visibility Matters

Prefixes of invalid routes and their reasons for invalidity

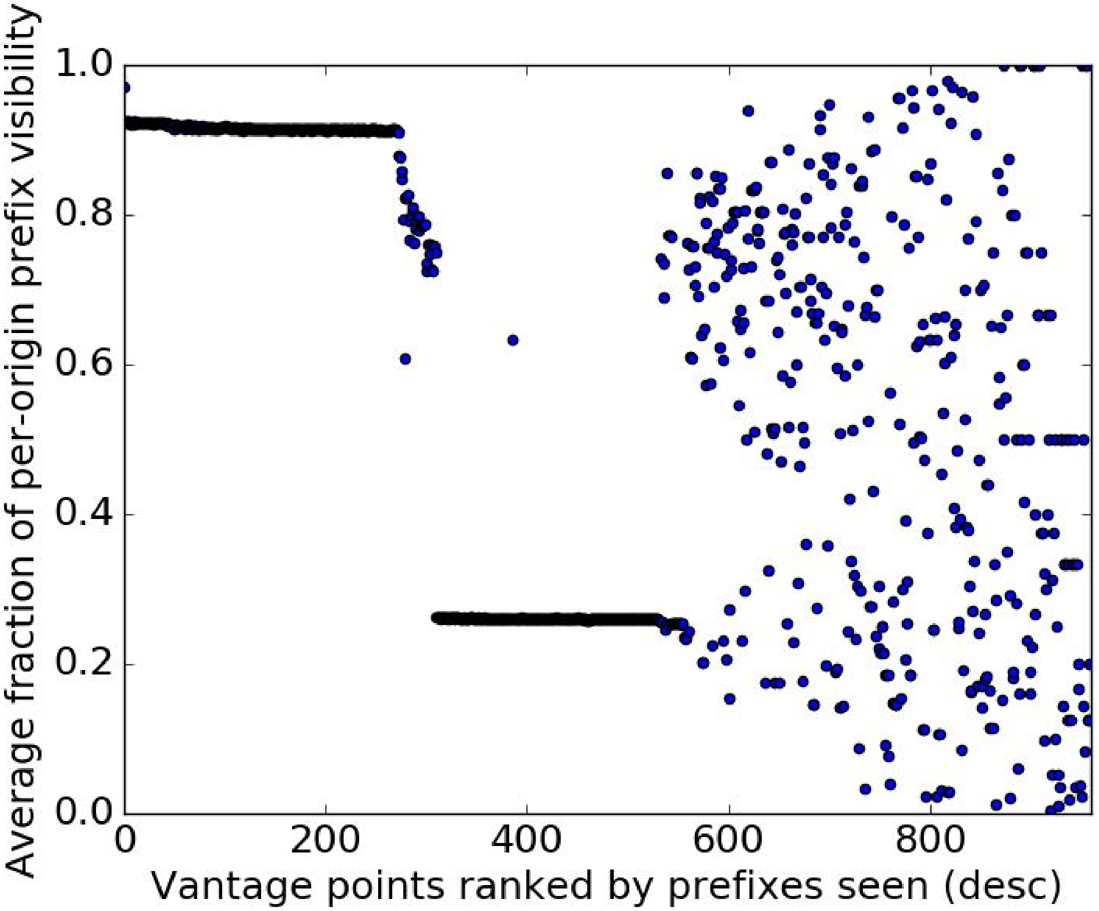


Some VPs have very few invalid prefixes

Some none at all

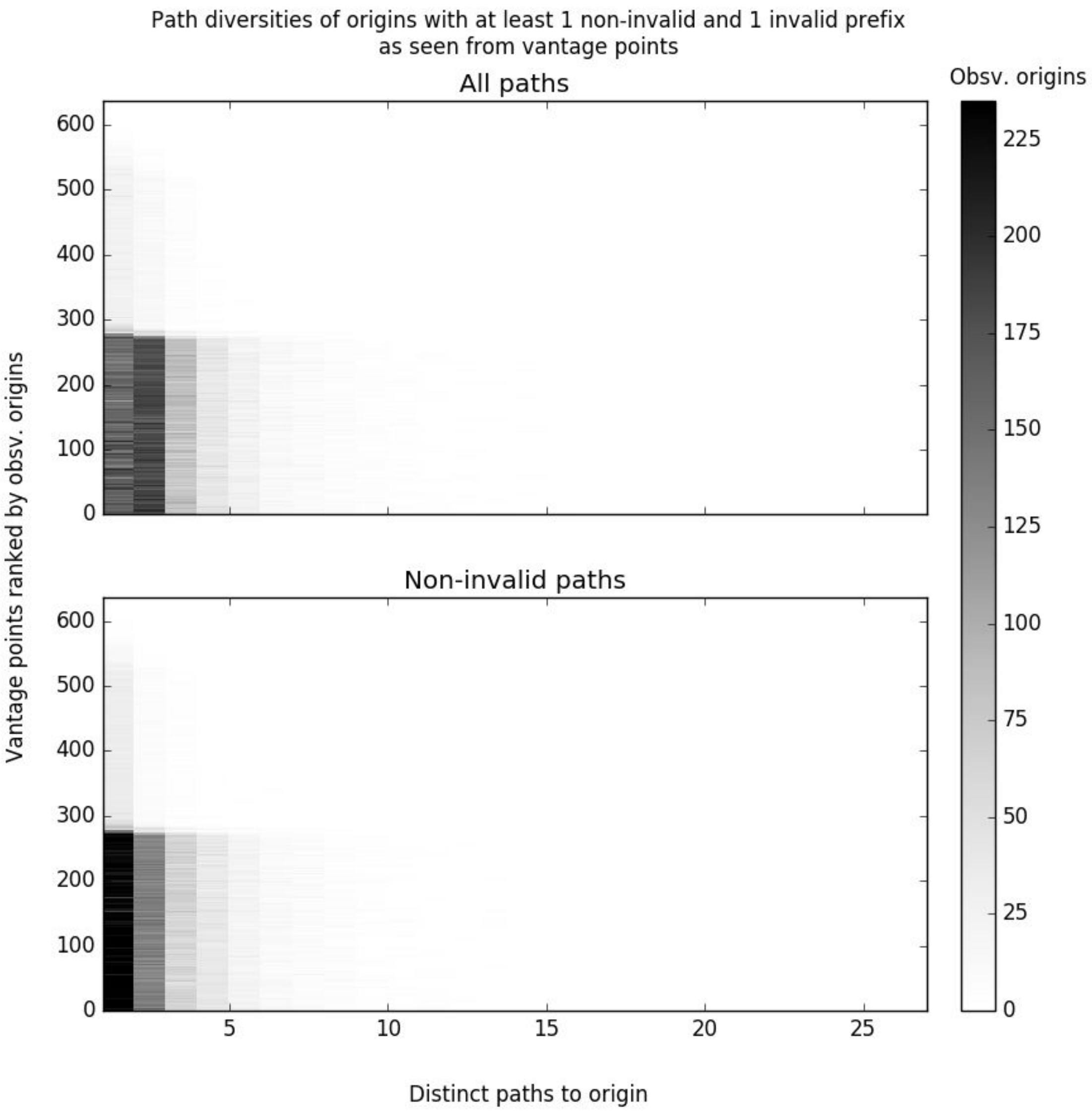
Vantage Point Visibility Matters

Per-Origin Prefix Visibility



➔ Virtually all VPs have some origin AS they only ‘see’ incompletely. Oops!

Invalid Announcements: Path Diversity


Path diversities of origins with at least 1 non-invalid and 1 invalid prefix
as seen from vantage points
All paths
Non-invalid paths
Vantage points ranked by obsv. origins
Distinct paths to origin
Obsv. origins