Hanging by a Thread: A Study of Single-Upstream Networks

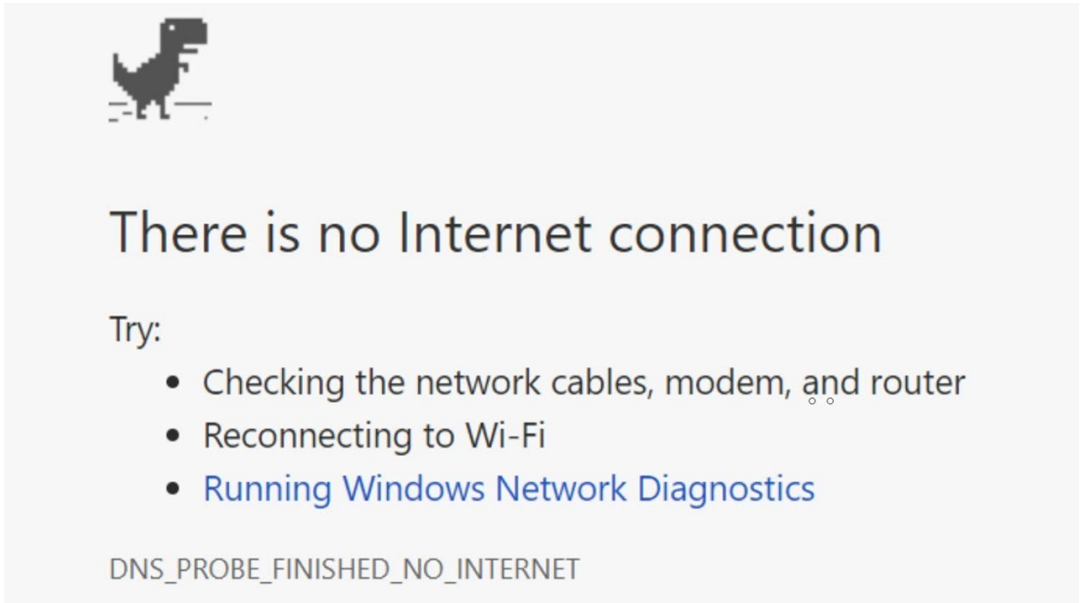
Malte Tashiro (malte@iij.ad.jp)

IIJ Internet Initiative Japan

SOKENDAI

NII 大学共同利用機関法人 情報・システム研究機構 国立情報学研究所 National Institute of Informatics

Why should we care about internet resilience?



Italy's Internet Outage a Perfect Storm

Massimiliano Stucchi
Regional Technical Advisor - Europe, Internet Society

Categories: Resilience

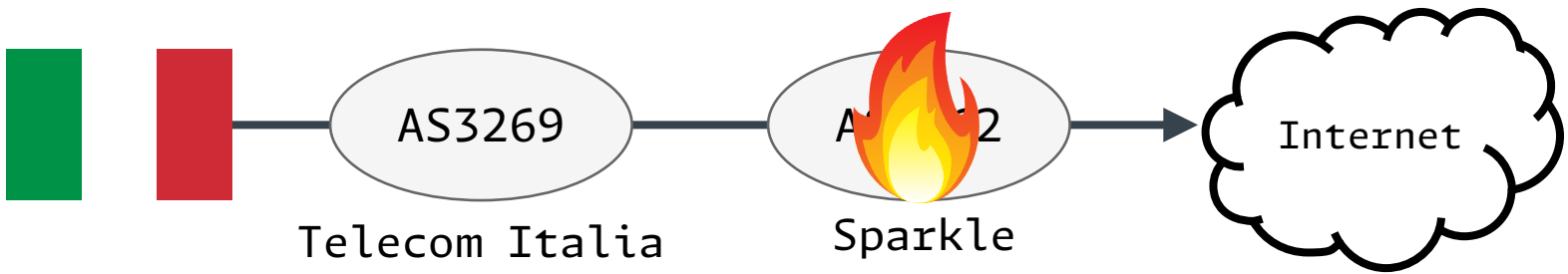
February 8, 2023

https://pulse.internetsociety.org/blog/italys-internet-outage-a-perfect-storm

- Outage at Telecom Italia
- 30% of Italy's users affected
- Lasted five hours

Motivation

- Telecom Italia is connected to the Internet via a single upstream
- Outage was not actually in Telecom Italia, but its upstream
- Dependency on one network increases risk of failure



Research Questions

① Can we reliably infer single-upstream networks?
- Design active measurements for confirmation

② How prevalent are single-upstream networks?
- Quantify number and distribution using BGP
- Verify single-upstream status with measurements

③ Are there differences between IPv4 and IPv6?
- Compare prevalence and measure dual-stack networks

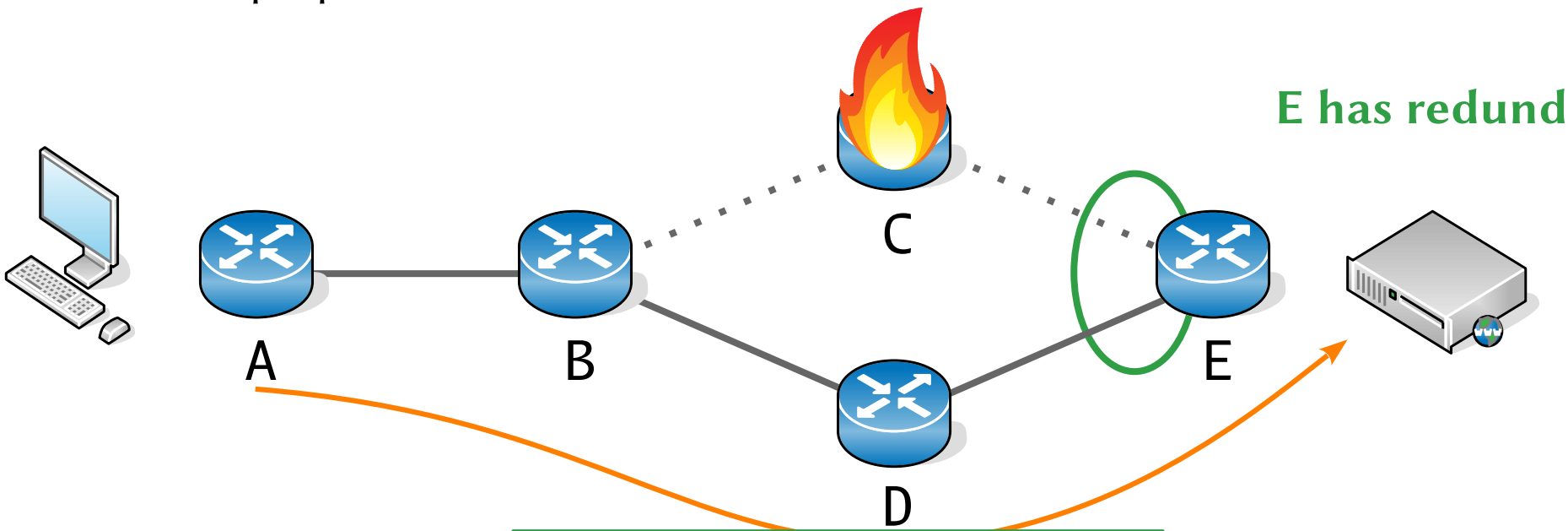
④ What kind of networks rely on a single upstream?
- Identify characteristics if possible

Agenda

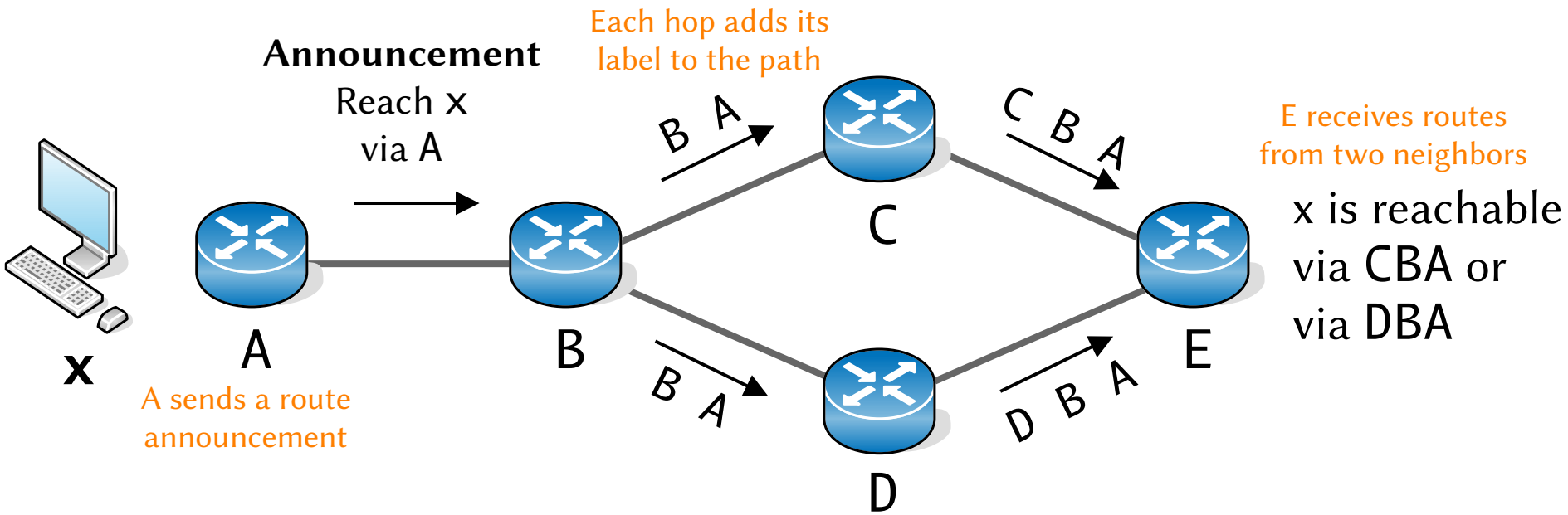
Internet Topology — Basics

The Internet is a network of networks

→ Multiple paths enable fault tolerance

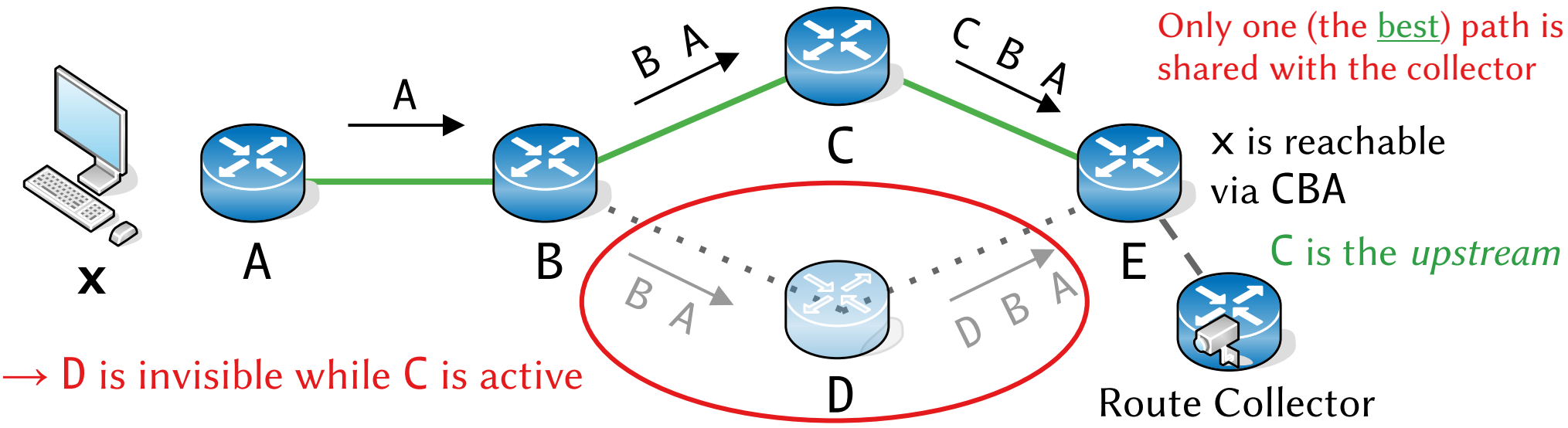


Networks communicate via the Border Gateway Protocol (BGP)



We cannot get this data for the entire Internet

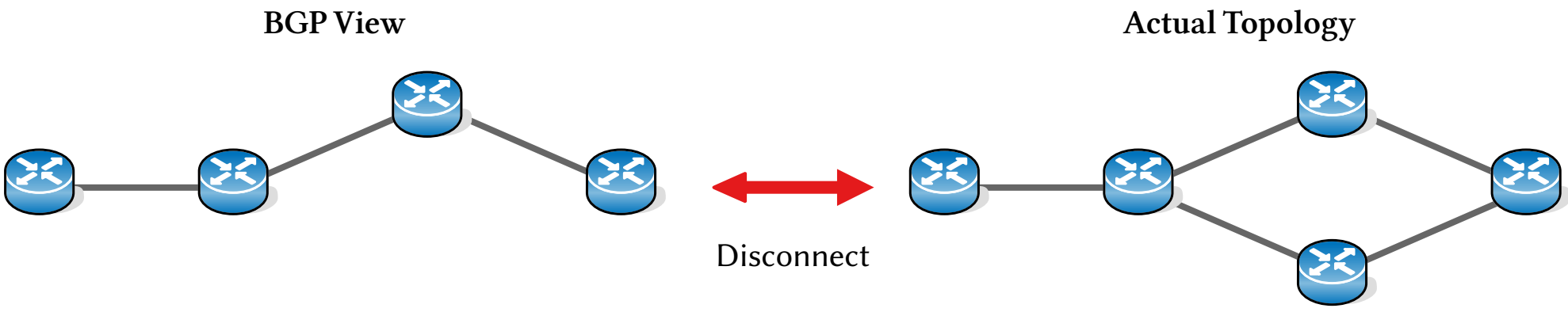
BGP view is based on route collector information



→ D is invisible while C is active

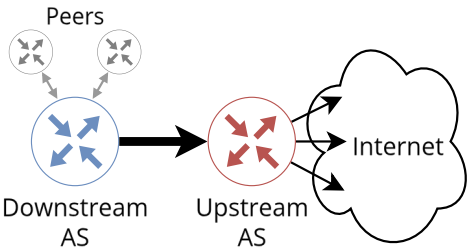
Internet Topology — Challenges

- BGP view is inherently incomplete
- Dependency analysis will include false positives
- Active measurements are required for confirmation

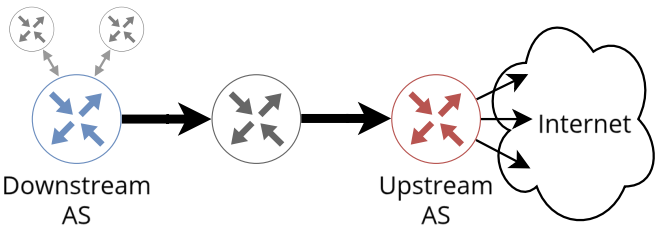


Terminology

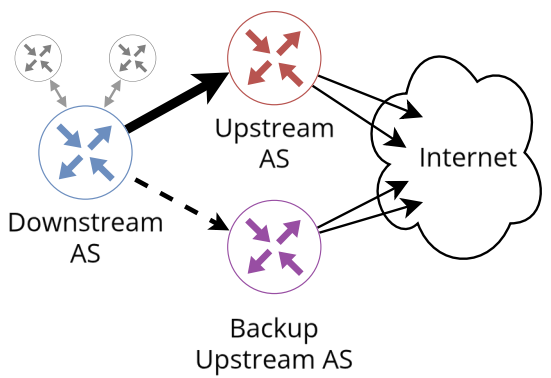
- A *downstream* depends on an *upstream*; they form a *pair*
  - General connectivity to the Internet → Can have peers
- Dependencies can be *direct* or *indirect*
- Links to *backup* upstreams are invisible in the BGP view
  - Active measurements can confirm their existence



Single Upstream
Direct Dependency



Single Upstream
Indirect Dependency



Backup Upstream
Link invisible in BGP view

Related Work

- Existing work [1] analyses resilience based on BGP view
  - Alternate paths are invisible
  - Inferred dependencies include false positives
- BGP Poisoning [2] enables remote path steering
  - Alternate paths can be made visible
  - Enables us to confirm existence of backup upstreams
- **Contribution:** We performed a systematic study and characterization of single-upstream networks for both IPv4 and IPv6.

[1] R. Fontugne et al. “The (Thin) Bridges of AS Connectivity: Measuring Dependency Using AS Hegemony”. Passive and Active Measurement Conference, 2018.
[2] L. Colitti, “Internet Topology Discovery Using Active Probing”. PhD thesis, Università di Roma Tre, 2006.

Agenda

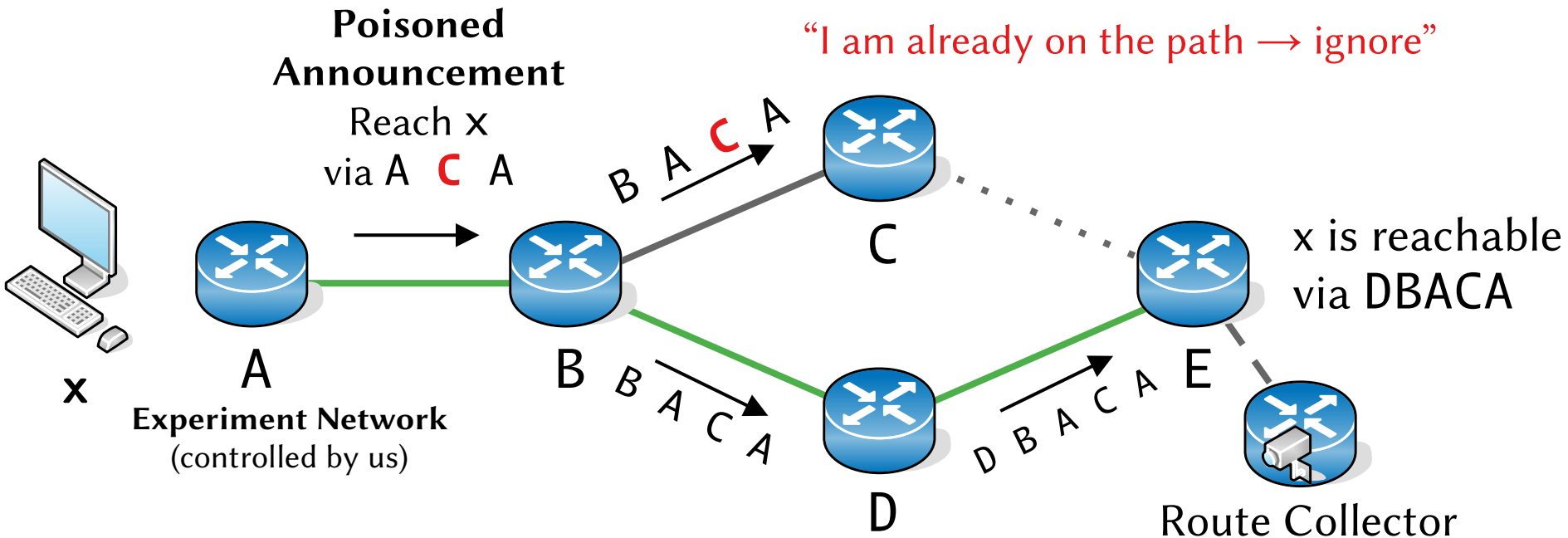
I. Introduction to the Internet Topology
   i. BGP View
   ii. Terminology
   iii. Related Work

II. Methodology
   i. BGP Poisoning
   ii. Measurement Setup

III. Analysis Results

Methodology — BGP Poisoning [2]

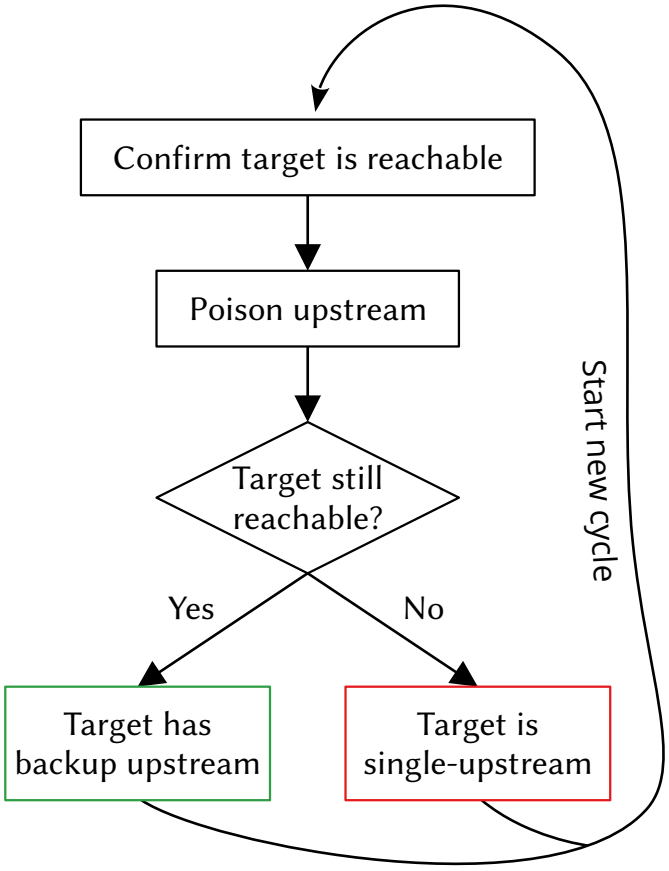
Leverage BGP mechanism (loop prevention) to force a path change

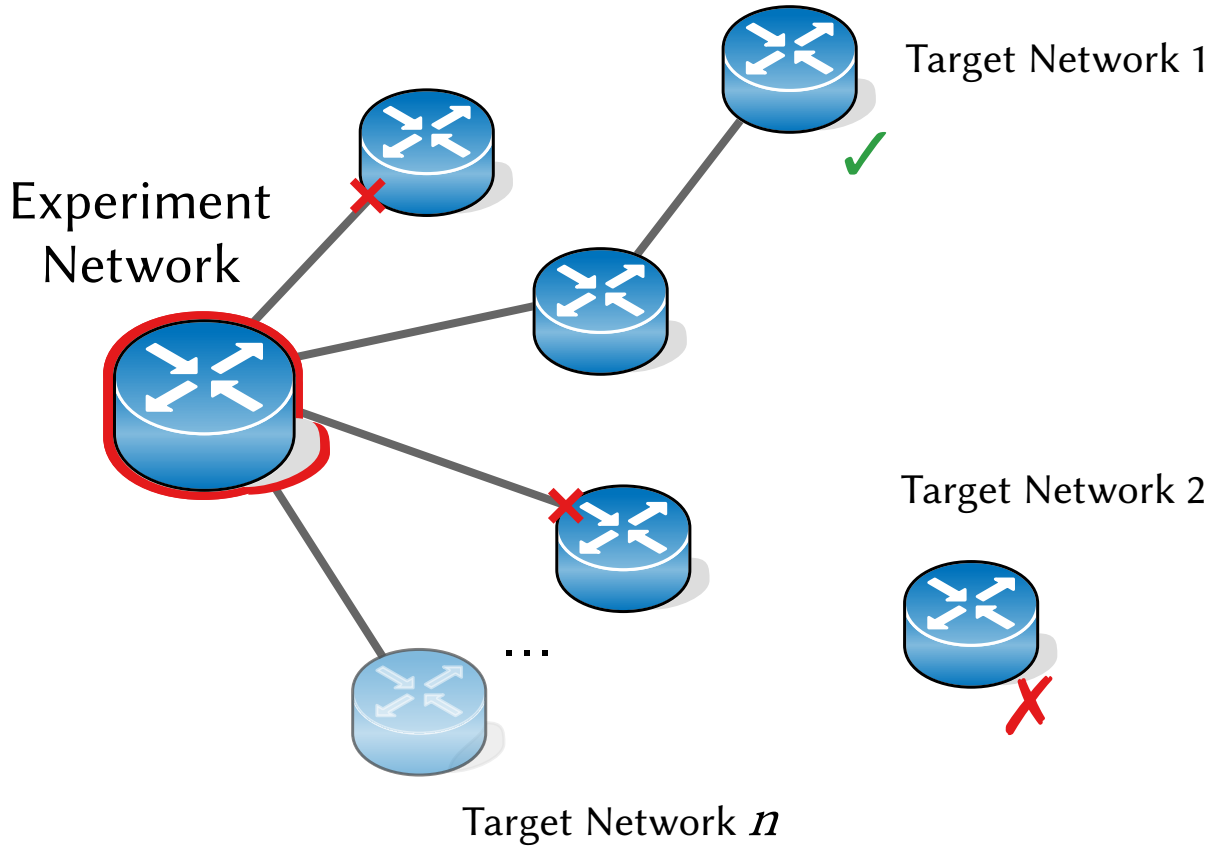


If x is still reachable, E has a backup upstream

[2] L. Colitti, "Internet Topology Discovery Using Active Probing". PhD thesis, Università di Roma Tre, 2006.

Methodology — Measurement Cycle





Agenda

I. Introduction to the Internet Topology
   i. BGP View
   ii. Terminology
   iii. Related Work
II. Methodology
   i. BGP Poisoning
   ii. Measurement Setup
III. Analysis Results

Analysis Result Section Overview

I. BGP View Analysis
   - Overview of potential single-upstream networks in IPv4 and IPv6
   - Centralization of dependencies in large upstreams

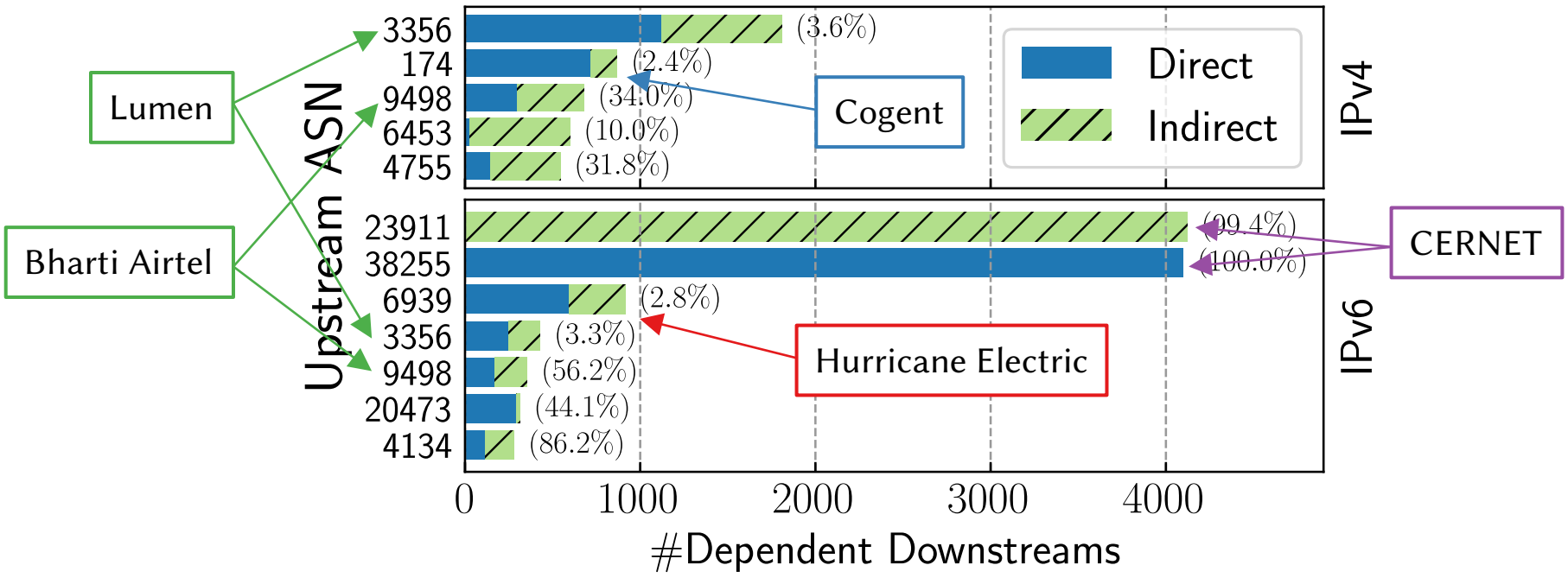
II. Active Measurement Analysis
   - Confirm single-upstream status of a random network sample
   - Characterization by business type and size
   - Dual-stack networks with identical dependencies in IPv4 and IPv6
   - Distribution of large ISP networks
   - Sibling networks as a potential source of dependencies

BGP View — Potential Single-upstream Networks

- Overview of potential single-upstream networks (including false positives)
- Around half of the networks on the Internet rely on a single upstream
  - IPv4: 47% of all networks
  - IPv6: 54% of all networks
- IPv6 is slightly less resilient
- Indirect dependencies are common
  - Need to look beyond direct adjacency

	IPv4	IPv6
Upstreams	7069	3832
Downstreams	36 408	19 058
Pairs	46 795	27 290
Direct	36 010 (77%)	18 935 (69%)
Indirect	10 785 (23%)	8355 (31%)

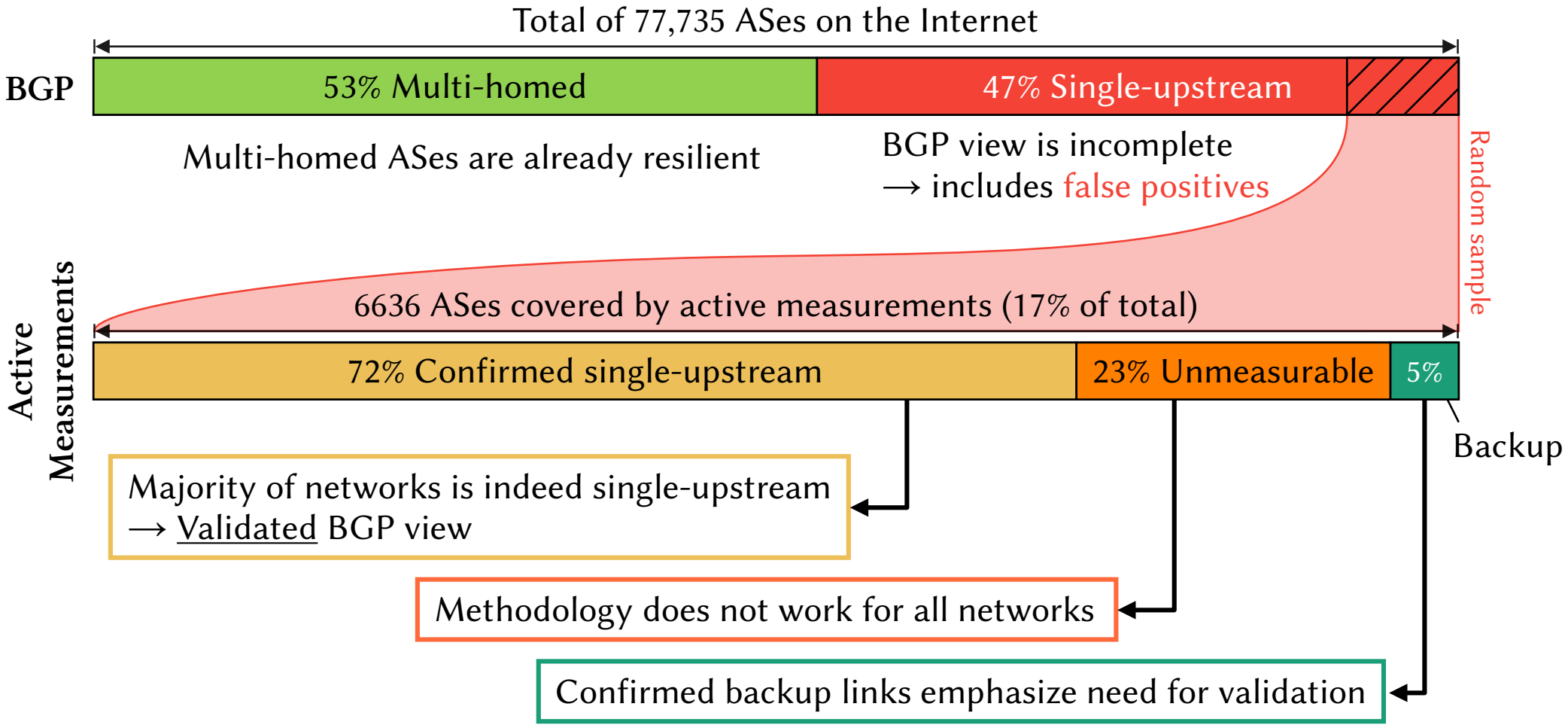
BGP View — Upstream Centralization



- Large networks consolidate many dependencies
- Both direct and indirect
- Some networks central in both protocols

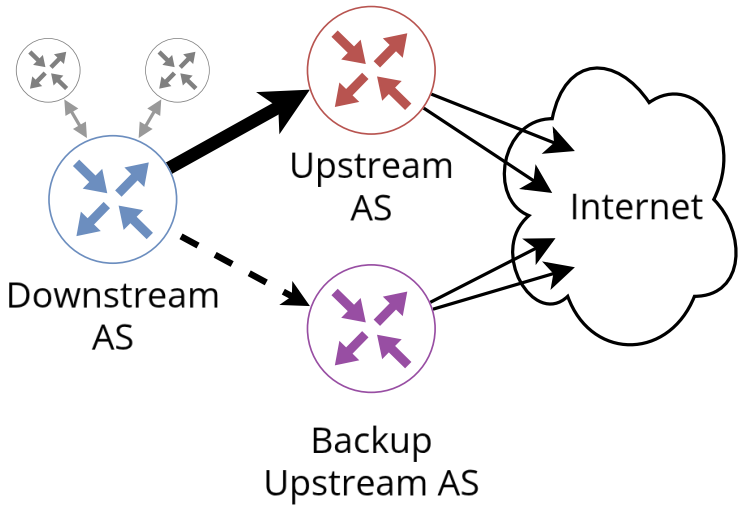
- IPv6 sees outlier in AS23911 / AS38255
  - China Education and Research Network
  - Deaggregated into 4096 IPv6 networks

From BGP to Active Measurements (IPv4)

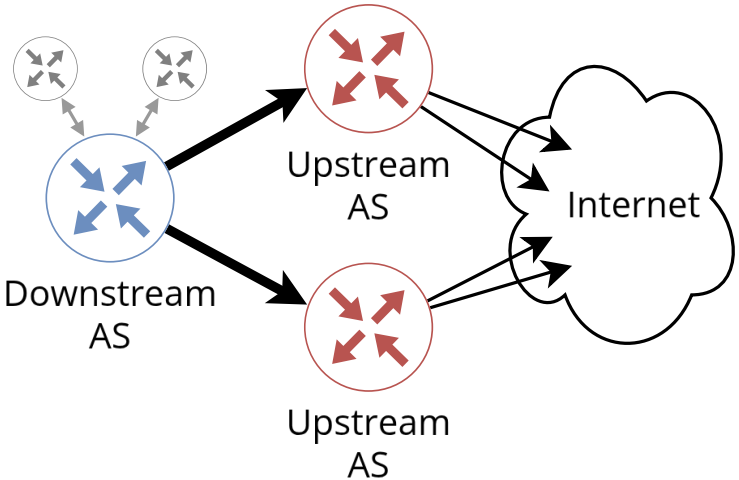


Multi-homed Networks

Backup Upstream

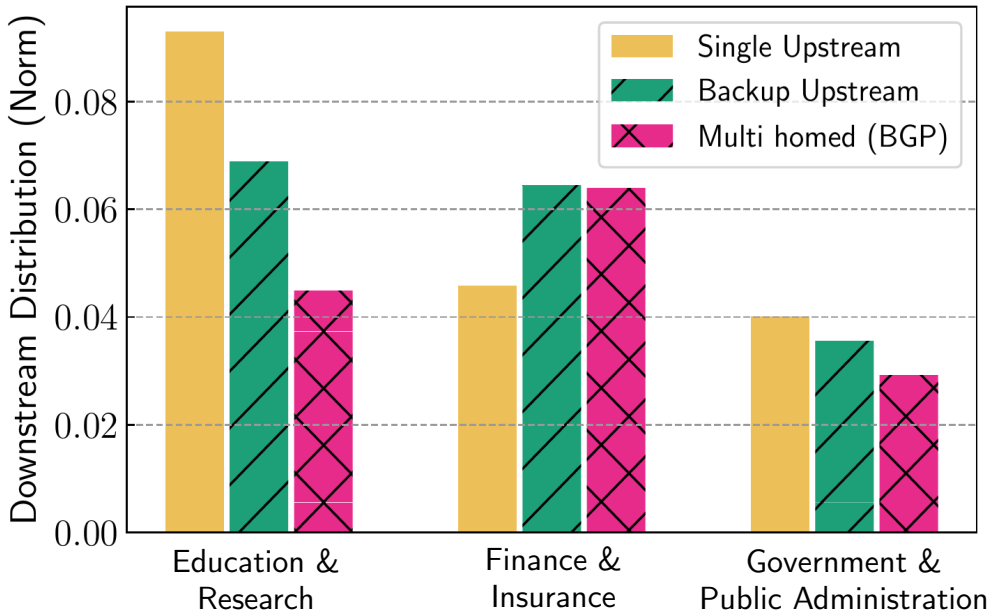


Multi homed



- Multi homed networks are resilient
- Underlying topology is the same
- Difference is visibility in BGP view

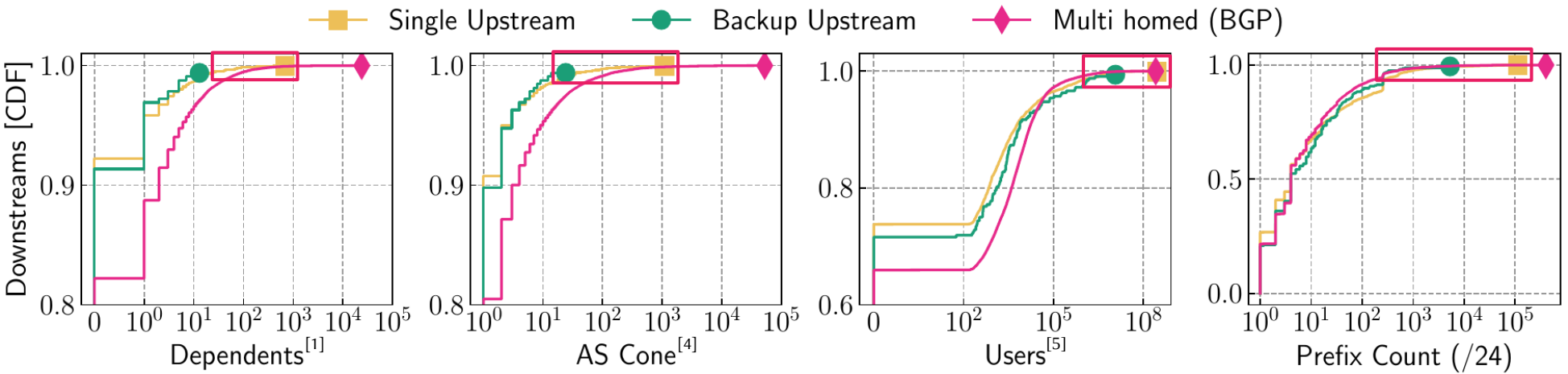
Active Measurements – Network Classification



- ASdb dataset by Ziv et al. [3] assigns business classification to networks
- Three categories (out of 17) with significant differences:
  - "Education & Research" and "Government & Public Administration" networks are more likely single-upstream
  - "Finance & Insurance" networks prefer resiliency

[3] M. Ziv et al. "ASdb: A System for Classifying Owners of Autonomous Systems." IMC'21.

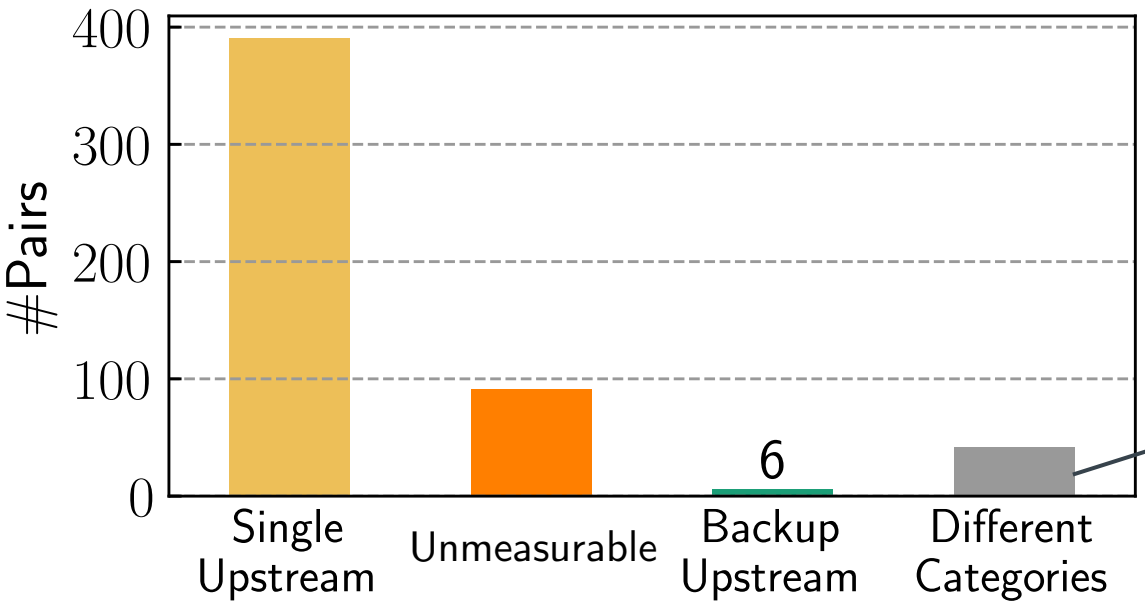
Active Measurements – Network Size

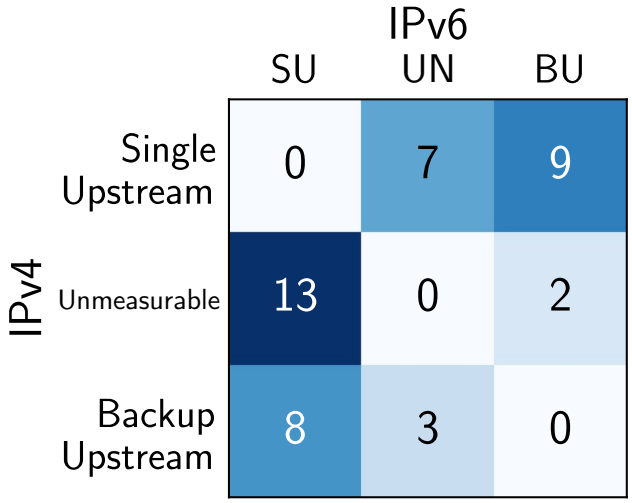


- The largest networks are resilient (Multi homed)
- Networks with invisible backup links are usually small
- There are very large networks relying on a single upstream

[1] R. Fontugne et al. "The (Thin) Bridges of AS Connectivity: Measuring Dependency Using AS Hegemony." PAM'18.
[4] M. Luckie et al. "AS Relationships, Customer Cones, and Validation." IMC'13.
[5] APNIC. "Visible ASNs: Customer Populations (Est.)." https://stats.labs.apnic.net/aspop

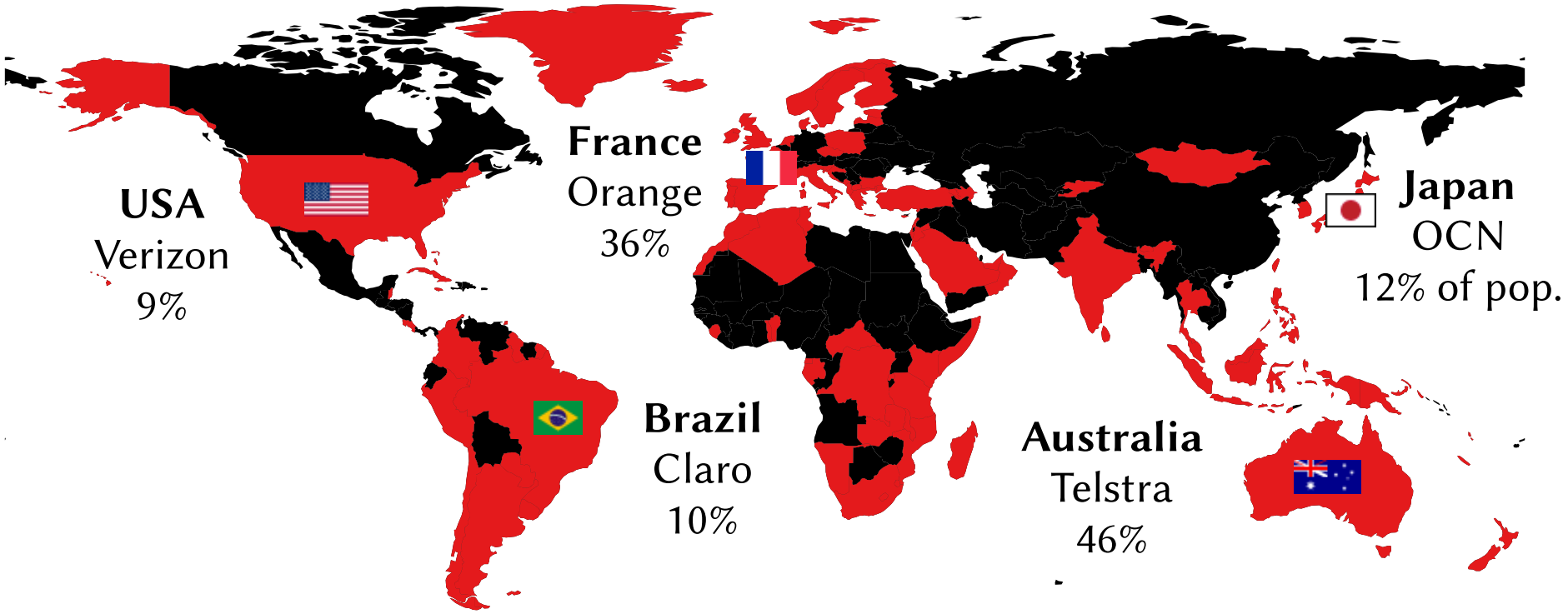
Active Measurements — Dual-stack Networks





- Measured 529 networks with identical upstreams in IPv4 and IPv6
- 92% have the same policy for both protocols
- 42 pairs with different categories
- Redundancy only in one protocol
- Reason unknown

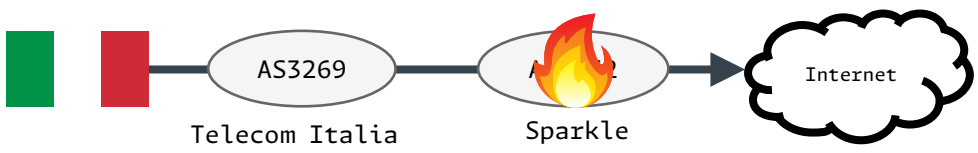
Active Measurements — ISP country distribution



- 197 analyzed ISP networks rely on a single upstream
- 127 countries have at least one ISP without redundancy

Active Measurements — Sibling Networks

- Observed some examples where up- and downstream networks belong to the same company
  - Also called *sibling networks*
- Example: Sparkle is a subsidiary of Telecom Italia
- Inspecting the share of sibling pairs [6] we found that this is not a major source of dependencies
  - Only 7% of all pairs are siblings
  - 22% when focusing on ISPs



[6] C. Selmo et al. "Learning AS-to-Organization Mappings with Borges". Internet Measurement Conference, 2025.

Summary

① Can we reliably infer single-upstream networks?
- Yes, although active measurements are required for more reliable results

② How prevalent are single-upstream networks?
- Account for almost half of the networks in the Internet
- Present all over the world

③ Are there differences between IPv4 and IPv6?
- IPv6 is slightly less resilient in general
- Dual-stack networks apply the same policy

④ What kind of networks rely on a single upstream?
- No clear identifying characteristic
- Some business types have a tendency towards less resilience
- Hidden backup upstreams are usually only present for smaller networks
- Both small and large networks can rely on a single upstream