Stability and Symmetry *of* Internet Routing

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The DIMES project

Background

- The end-to-end (e2e) stability of Internet routing has been studied for over a decade.
  - Paxson's seminal work was the first (1995) to study common route pathologies and symmetries in the Internet
    - Analyzed over 40,000 e2e routes from NIMI 37 vantage points
  - Zhang *et. al* studied the aspects of constancy of Internet paths
    - Analyzed roughly 50 NIMI vantage points
  - Pucha *et. al* studied the causes for observed delay fluctuations and the routing changes that lead to predictable effects on delay
    - Analyzed 60,000 paths from 200 PlanetLab vantage points
    - Intradomain changes are more frequent than Interdomain and there exists stability between delay difference for the path before and after the routing event

Dataset

- Using the DIMES experiments planner in late 2006
  - Selected 104 agents that probed one another for 96-hours, two measurements per minute, using Ping and Traceroute
  - Agents are geographically spread: 78% North America, 11% Europe, 5% Australia and 6% in Asia
- Collected 6,942 source-destination pairs with average of 144 measurements per pair
  - IP-level paths resolved to prefix, AS and geographical regions
  - Paths traversed a large variety of countries and ASes

Types of ASes traversed during the traceroutes

t1	t2	edu	comp	unknown
29%	55%	1%	3%	12%

End-to-End Path Stability

Problem Statement

Measure the **stability** and **symmetry** of end-to-end routing in the modern Internet

The Gap

- Current work use mostly academic networks, possibly contributing bias
  - Academic networks might observe a more stable Internet
- Metrics used for measuring stability ignore the order in which the hops appear in the path
- Comparing paths is not trivial – non responsive hops, different lengths

Innovation

- Quantify the stability of an e2e route using a normalized **edit distance** measure which unlike previous work manages to takes into account the order of elements in each path
  - Detects instabilities in paths that have the same hops with different order

Research Questions

- Routing Stability
  - What is the percentage of appearance of the dominant path(s)?
  - How different are paths in the same source-destination pair?
    - At various level of granularities (IP, AS, Prefix, Geography)
  - Does instability in one level of granularity affects other levels?
- Routing Symmetry
  - Do routes follow the same paths on both directions of the same pair?
  - Does instability holds on both directions of the same pair?
- Delay
  - Can routing instability be correlated to delay instability?
    - Which level of instability affects delay most?
  - Does symmetry exists for delay instability?

Path Analysis

Filtering Pathologies
- Routing loops
- Incorrect replies

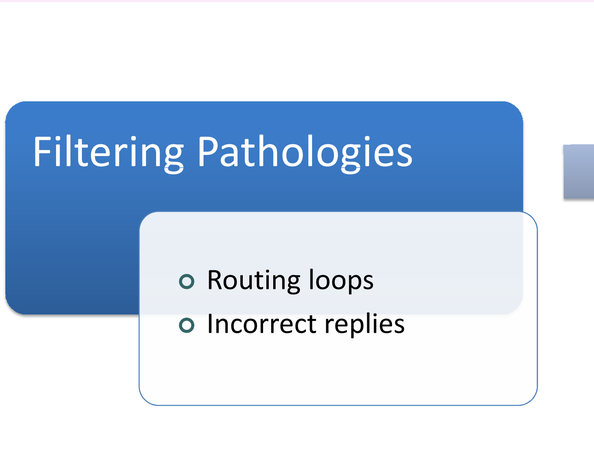
Merging Similar Paths
- Paths that are the same are merged and counted
- Hops that did not reply are used as "wildcards"
  - Match any other hop
  - Contribute higher stability

Finding Dominant Path
- Count the number of appearances of each path
- The path that appear most times is the dominant path
  - Can be more than one

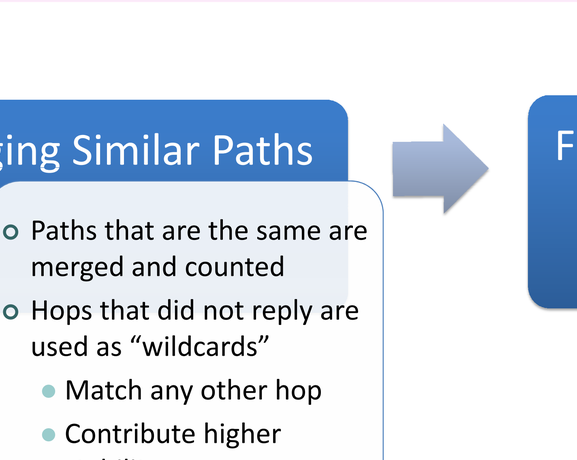
Stability Measure
- Calculate Edit Distance to Dominant
  - Insert, Delete and Modify
- Normalizing each pair with $MAX(\text{Len}(p_1), \text{Len}(p_2))$

Results

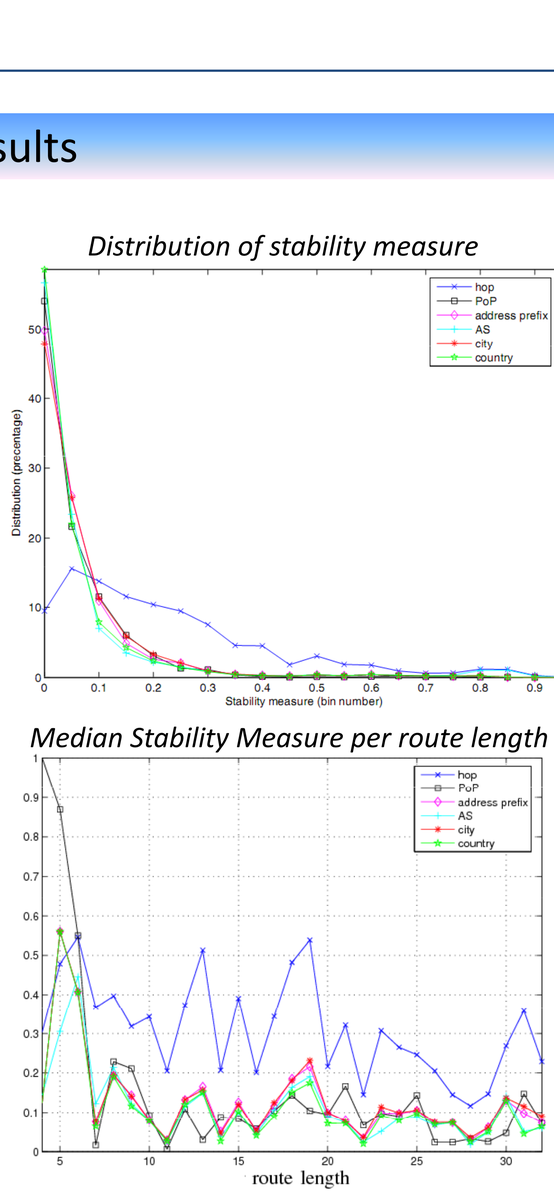
Distribution of stability measure



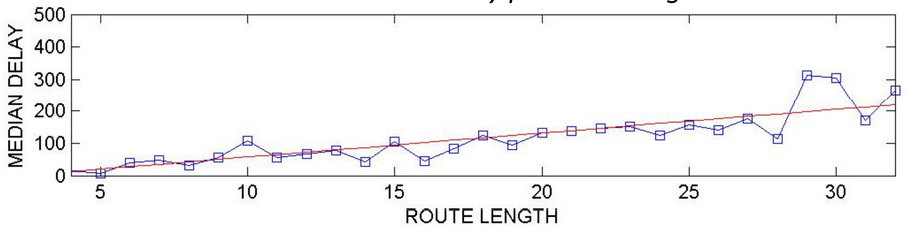
Distribution of opposing pair differential stability measure



Median Stability Measure per route length



End-to-End median delay per route length



Stability Measure for different levels of granularity

IP address	City	AP	AS	Country
0.254	0.025	0.022	0.093	0.011

Resolving Traceroute References

- IP to Prefix and AS
  - RouteViews, IRR and WhoIS
- PoP
  - DIMES and iPlane
- Geography
  - Commercial databases: MaxMind and IPligence

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