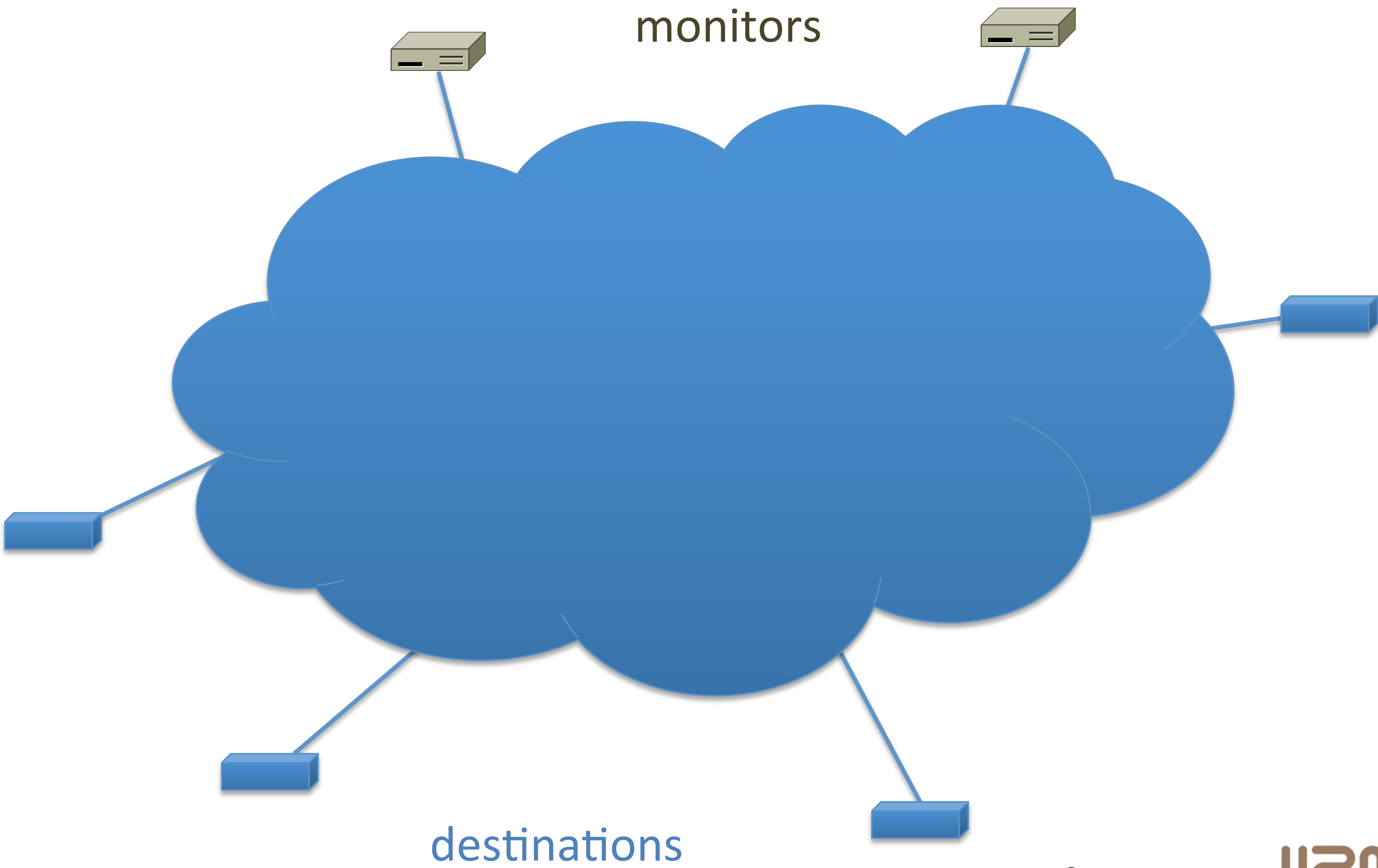
LINCS internal seminar, 26 January 2011

Towards improved measurement systems to capture internet dynamics

Timur Friedman

Distributed network measurement systems



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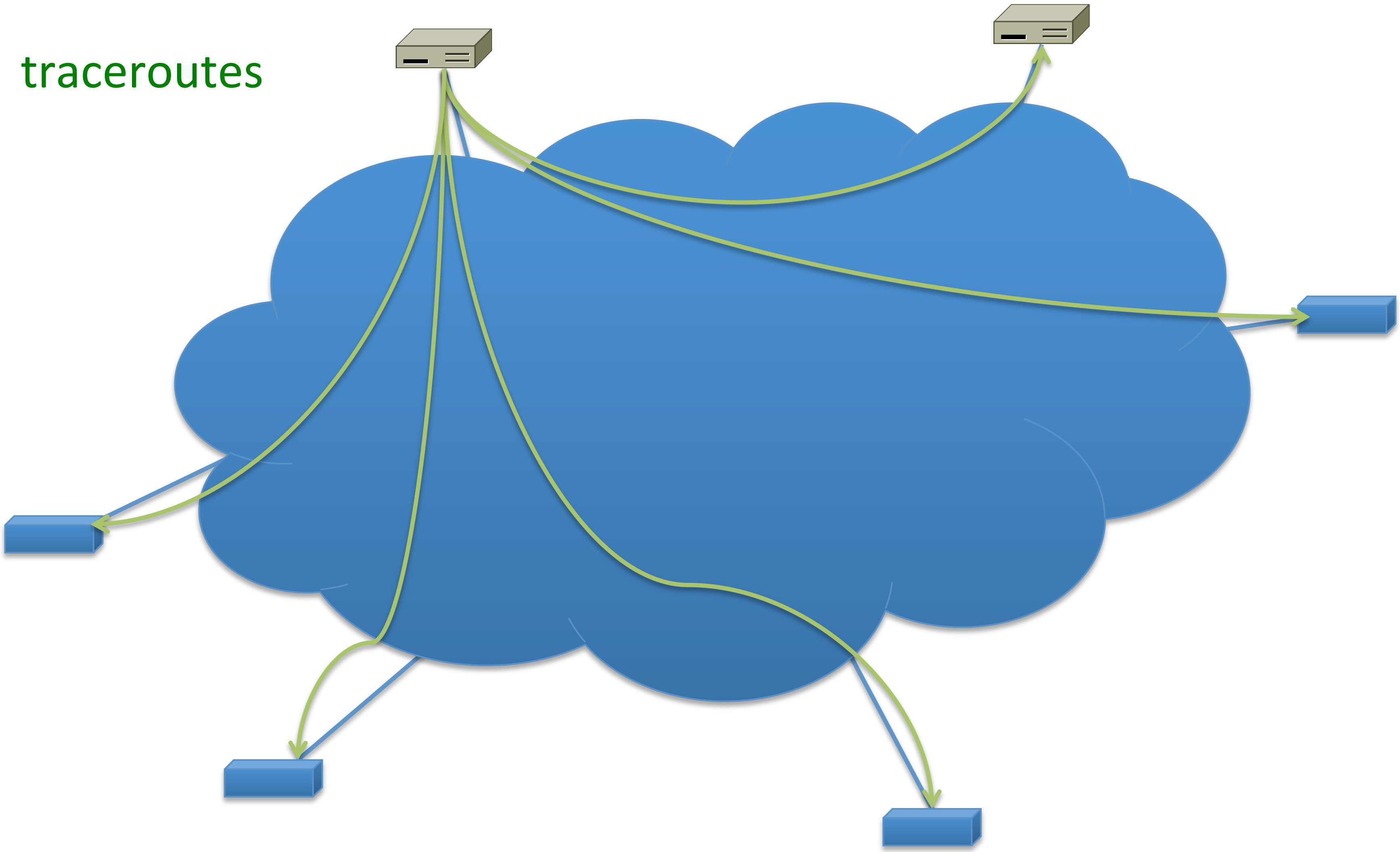
Distributed network measurement systems



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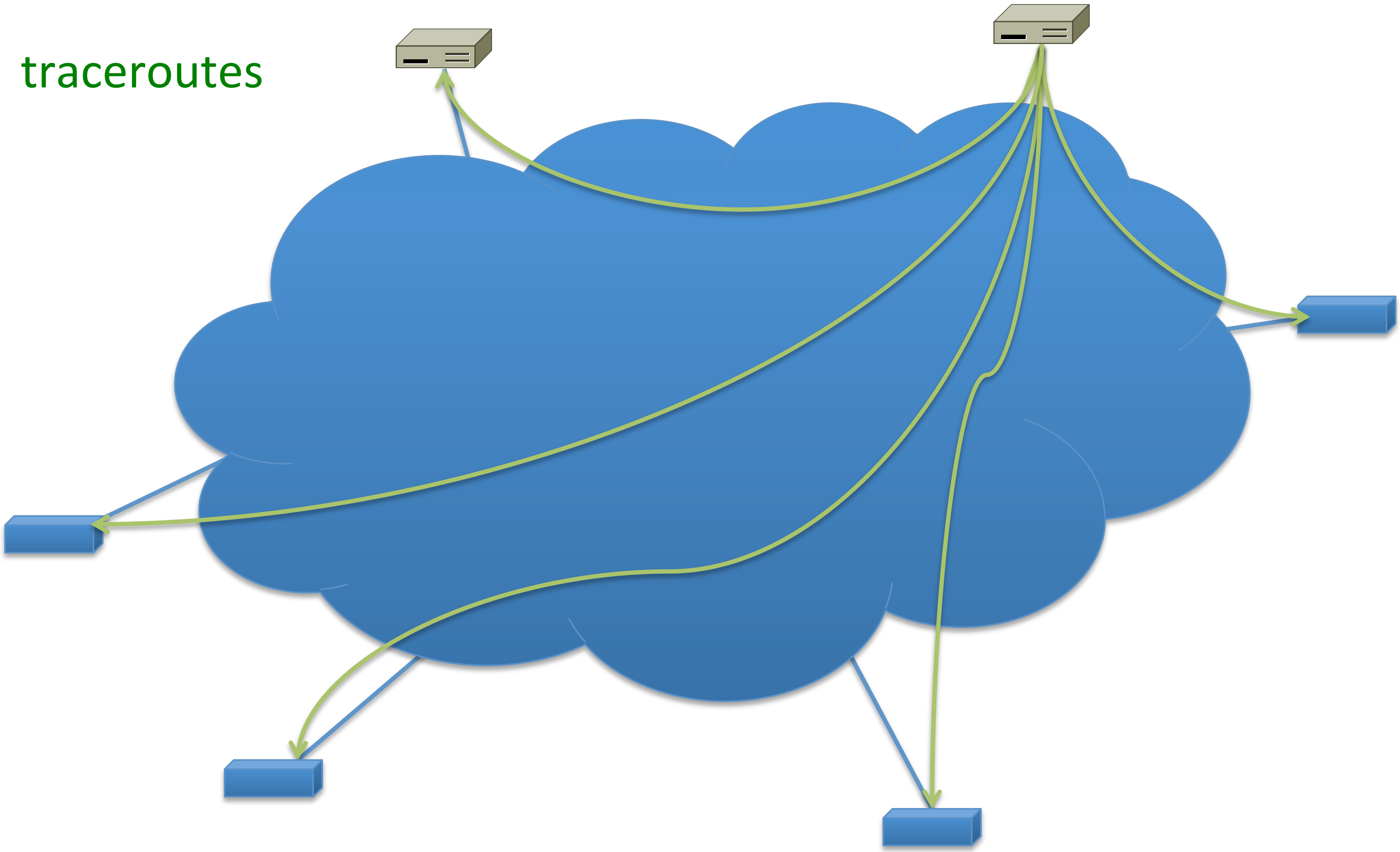
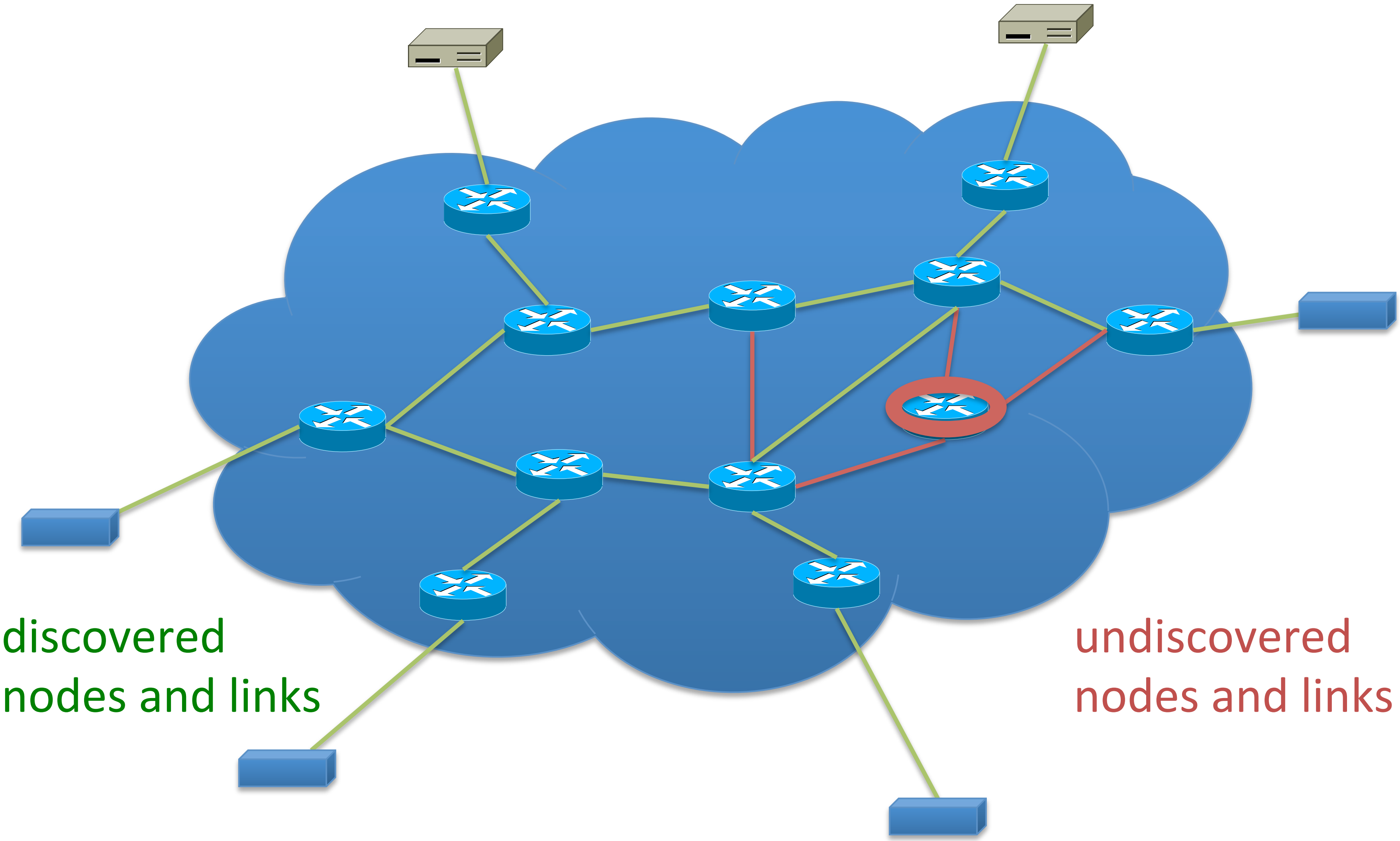


Distributed network measurement systems



discovered
nodes and links

undiscovered
nodes and links

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Principal measurement systems

Project	Institution	Number of monitors	Number of destinations	Measurement frequency
Archipelago (aka Ark, formerly Skitter)	CAIDA center at UC San Diego	45	9.1 million (all /24 prefixes)	2-3 days
EdgeScope (Ono BitTorrent plug-in)	Northwestern University AquaLab	~ 800,000	~ 800,000 (40,000 networks)	unknown
DIMES	Tel Aviv University	~ 1000	~ 10^5	7 days
iPlane	Washington University	~ 300	~150,000	1 day
TTM	RIPE	~ 200	~ 200	6 min

Why measure?

Obtain fundamental understanding

- What is the structure of the internet?
  - Graph properties: small world

Guide protocol design

- Multicast, content distribution, p2p, overlay protocols, etc. depend on assumptions about network structure
- Topology generators for simulators

Guide network planning

- Is the network robust against failure?
- How does it reflect demographics?

Challenges

Completeness

- Are we seeing all of the network?

Accuracy

- Are we getting an accurate picture of what we do see?

Efficiency

- Are we using our probing resources to maximum effect?

Challenge: Completeness

Lakhina et al. sampling bias work

INFOCOM 2003

- Measuring from too few vantage points can in principle introduce biases in the inferred graph properties.

Spring, Mahajan, and Wetherall Rocketfuel work

SIGCOMM 2002

- With enough vantage points and good techniques, we can get full and accurate maps of ISPs.

Shavitt & Weinsberg

INFOCOM 2009

- Broad distribution of vantage points can in actual fact yield good estimates of graph properties.

Challenge: Accuracy

Teixeira et al. path diversity work

IMC 2003

- Rocketfuel topologies suffer from many inaccuracies.

Augustin et al. Paris Traceroute work

IMC 2006

- Classic traceroute was producing inaccurate and incomplete maps. Largely corrected with Paris Traceroute.

Katz-Basset et al. Reverse Traceroute work

NSDI 2010

- Use the IP Record Route option to obtain accurate paths.

Challenge: Efficiency

Govindan & Tangmunarunkit Mercator work

INFOCOM 2000

- When tracing from a single vantage point, trace backwards from the destinations and stop when you encounter familiar nodes.

Donnet et al. Doubletree work

SIGMETRICS 2005

- When tracing from multiple vantage points, trace both backwards and forwards from a medium distance. Communicate between monitors to know when to stop forward tracing.

A new challenge

Capture network dynamics

- Observe network changes over time
  - Long timescale: understand the evolution of the internet
  - Short timescale: detect routing changes, system maintenance, failures, attacks, etc.
- Current timescales:
  - days (Ark, DIMES, iPlane)
  - minutes (TTM) – problem: TTM is just a small mesh

Can we capture graphs at Ark-scale every few minutes?

Our aim: 1000x speedup.

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‘La vérité’

La photographie c’est la vérité. Et le cinéma c’est vingt-quatre fois la vérité par seconde.

- Bruno Forestier, dans *Le Soldat* de Jean-Luc Goddard (1960)

The scope of the challenge

Size of the graph

largest measured graphs today:

15 million nodes, 60 million links

- IPv4 allows for up to 4.3 billion addresses
  (9.1 million /24 prefixes)
- IPv6 allows for up to 3.4×10^{38} addresses

Frequency

speedup in two phases:

- 50x speedup from 2 days to 1 hour
- 20x speedup from 1 hour to 3 minutes

Bandwidth and storage back-of-the-envelope calculations

- one traceroute query: 40 byte probe, 36 byte reply: 76 bytes total
- 120 million probes = 9.12 GB
  - 9.12 GB / 3 minutes = 405 Mbps
- for reference, 3 years of Ark data consumes 3.1 TB

The scope of the challenge

Back-of-the-envelope calculations

Bandwidth

- one traceroute query:
  - 40 byte probe
  - 36 byte reply
  - 76 bytes total
- 120 million probes = 9.12 GB
  - 9.12 GB / 3 minutes = 405 Mbps
- ➢ 405 Mbps for a distributed system is entirely possible

Storage

- 3 years of Ark data consumes 3.1 TB
- ➢ 1000 TB/year would be daunting
  but significant compression should be possible

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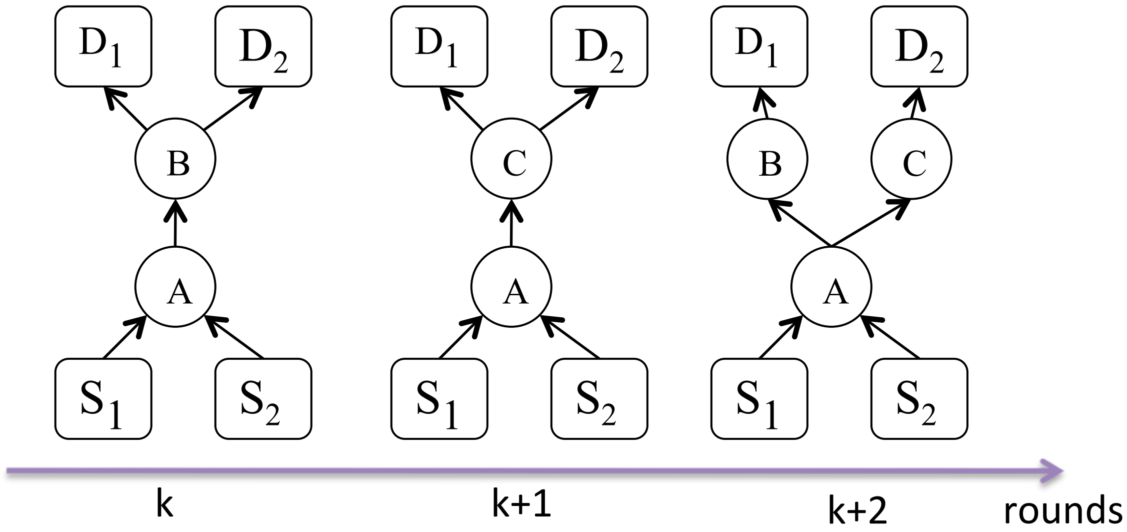
Preliminary work

Research recently begun by Thomas Bourgeau

Initial study:

- How much information is being lost by probing slowly?
- What simple algorithms would allow us to speed up capture?

What we study



- Consecutive rounds of measurements
  $k = 1, 2, 3, \ldots$
- Assemble a graph for each round
  $G_k = (V_k, E_k)$
- Discovered for each round
  nodes V_k and links E_k

Measurement setup

TopHat measurement system on PlanetLab

230 sources

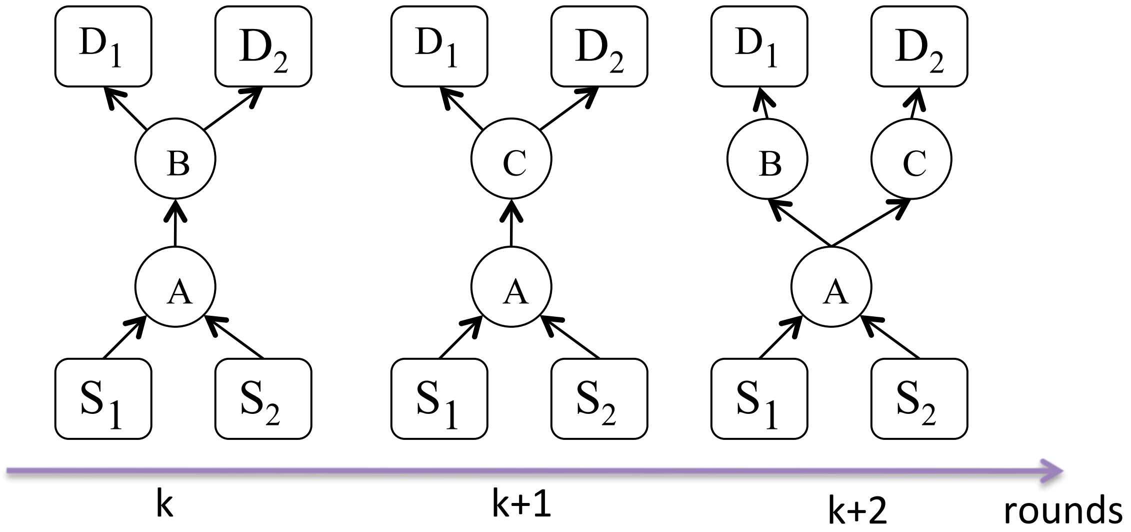
800 destinations

one measurement round per hour

- F_1 (fine grained) time resolution

from 25 May to 25 July 2010

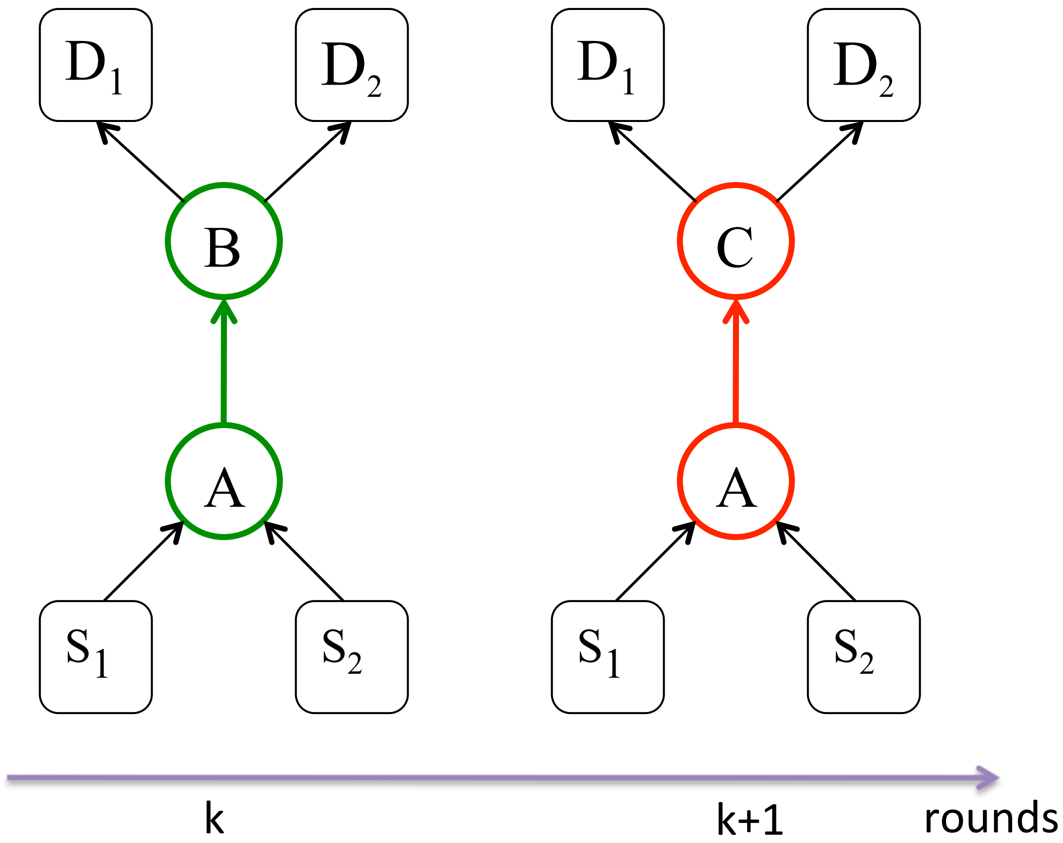
What we study



- Measurement experiments:
  - Each experiment rounds (k) is a full-mesh traceroute probing between a fixed sources-destinations set at a measurement frequency F_n.
- Dynamism observation:
  - Compare consecutive measured traceroute graphs $G_k(V_k,E_k)$

Appearances and disappearances

Event: appearance or disappearance of a node or link between consecutive measurement rounds.



Appearances:

$$A_k = G_{k+1} \setminus G_k$$

Disappearances:

$$D_k = G_k \setminus G_{k+1}$$

Events:

$$T_k = A_k \cup D_k$$

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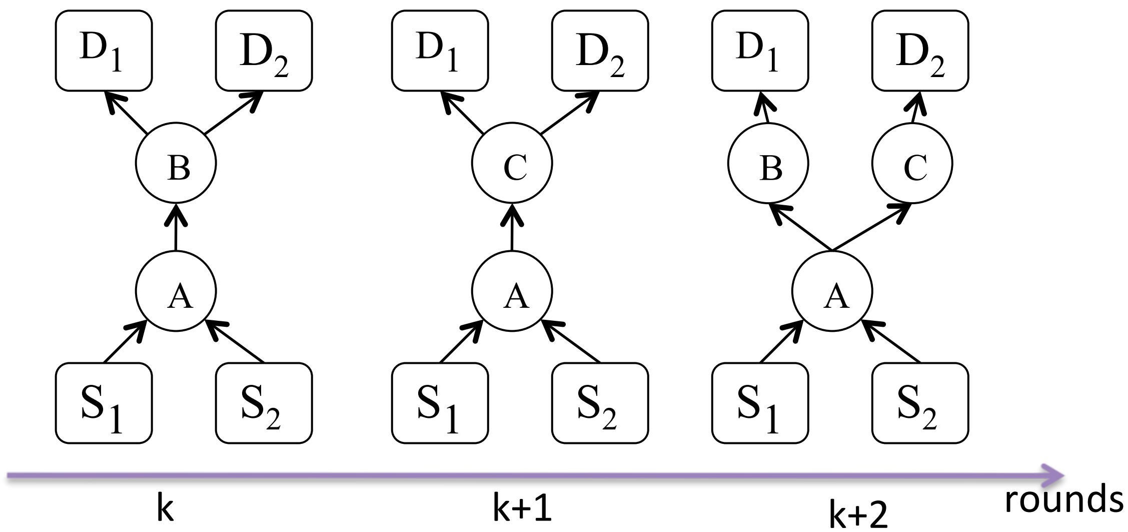
Static states

	k	k+1	k+2
C	**0**	**1**	**1**
B	1	0	1
A	1	1	1

rounds



State variable:

– Presence: $\delta = 1$

– Absence: $\delta = 0$

Static state:

A series of consecutive presences or absences of a node or link

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Simulating lower probing frequencies

<table>
<tr><td>F_1</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>F_3</td><td colspan="3">1</td><td colspan="3">1</td><td colspan="3">0</td><td colspan="3">1</td></tr>
<tr><td>F_6</td><td colspan="6">1</td><td colspan="6">0</td></tr>
</table>

F_1: one round per hour “fine-grained” timescale

F_3: one simulated round every 3 hours

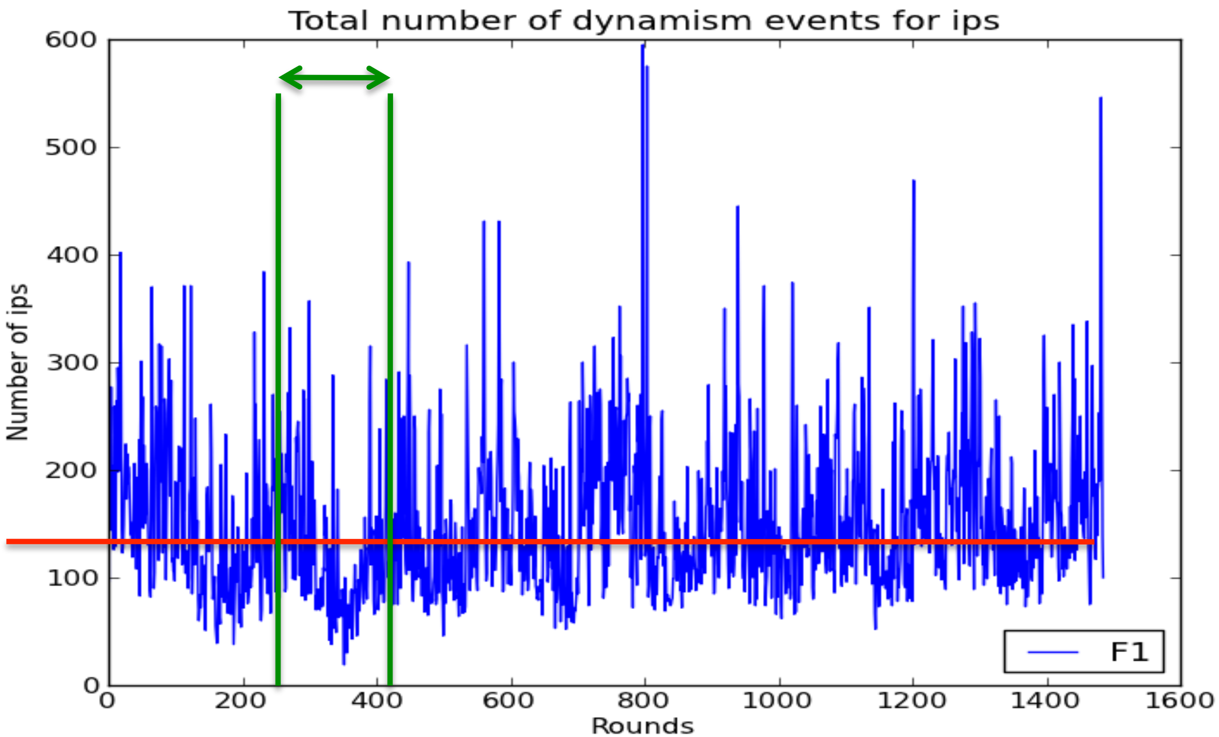
F_6: one simulated round every 6 hours

…

F_{48}: one simulated round every two days

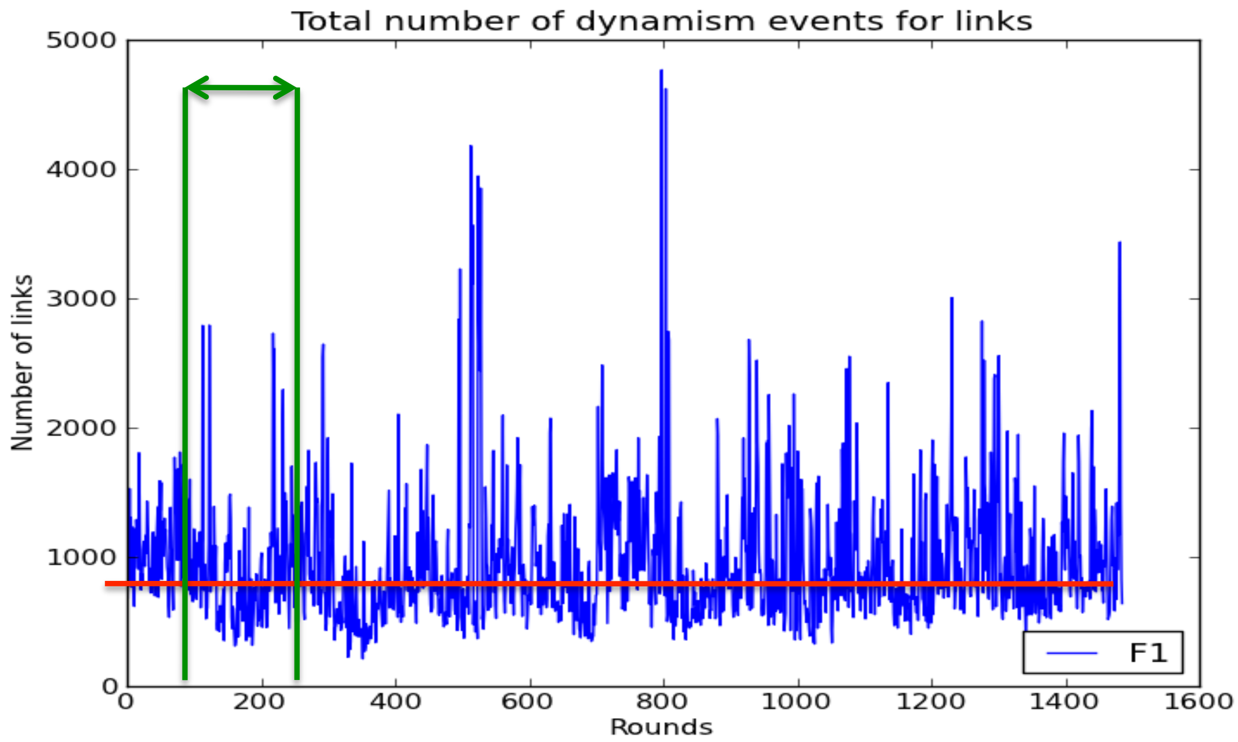
Simulation based upon choosing at random an observation from the prior timescale

Number of node events seen at F_1



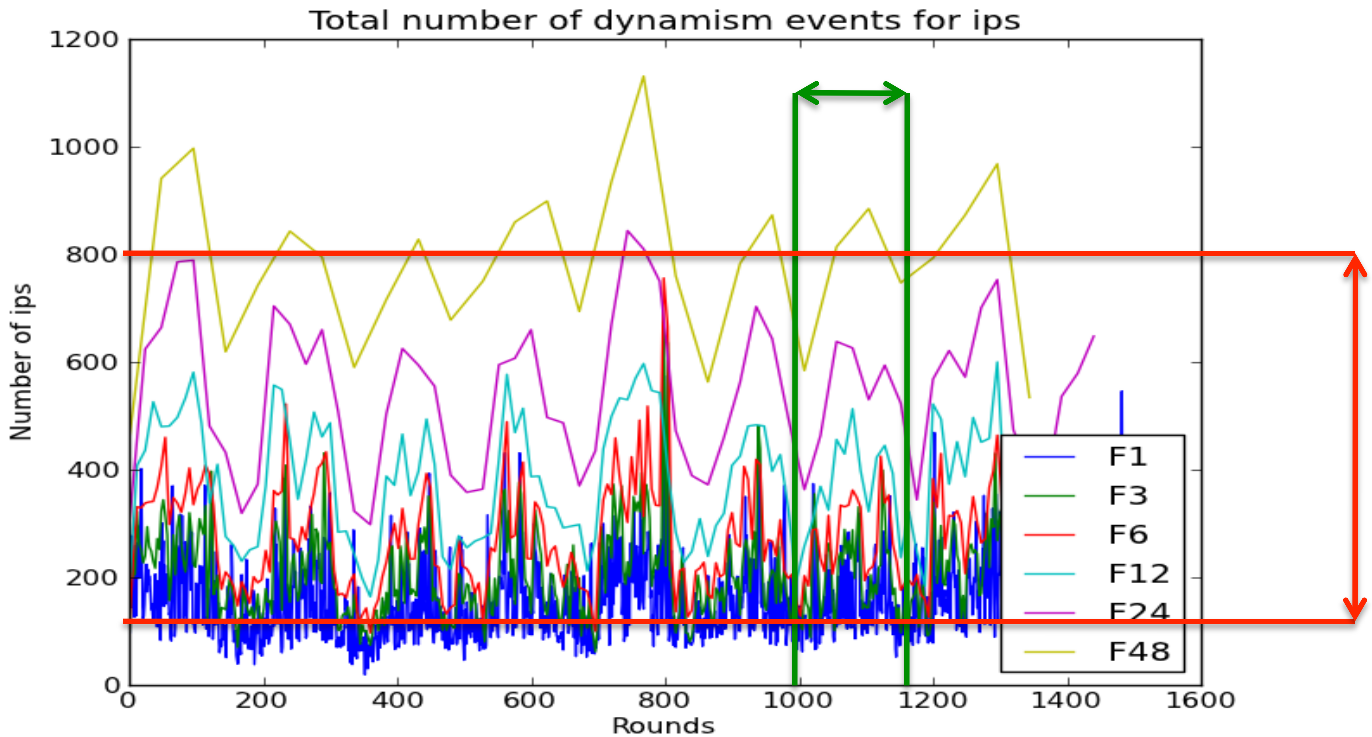
- 14,322 nodes seen in an average round
- 110 node events in an average round (0.8% of all IPs)
- periodic behavior: ~160 rounds (7 days)

Number of link events seen at F_1



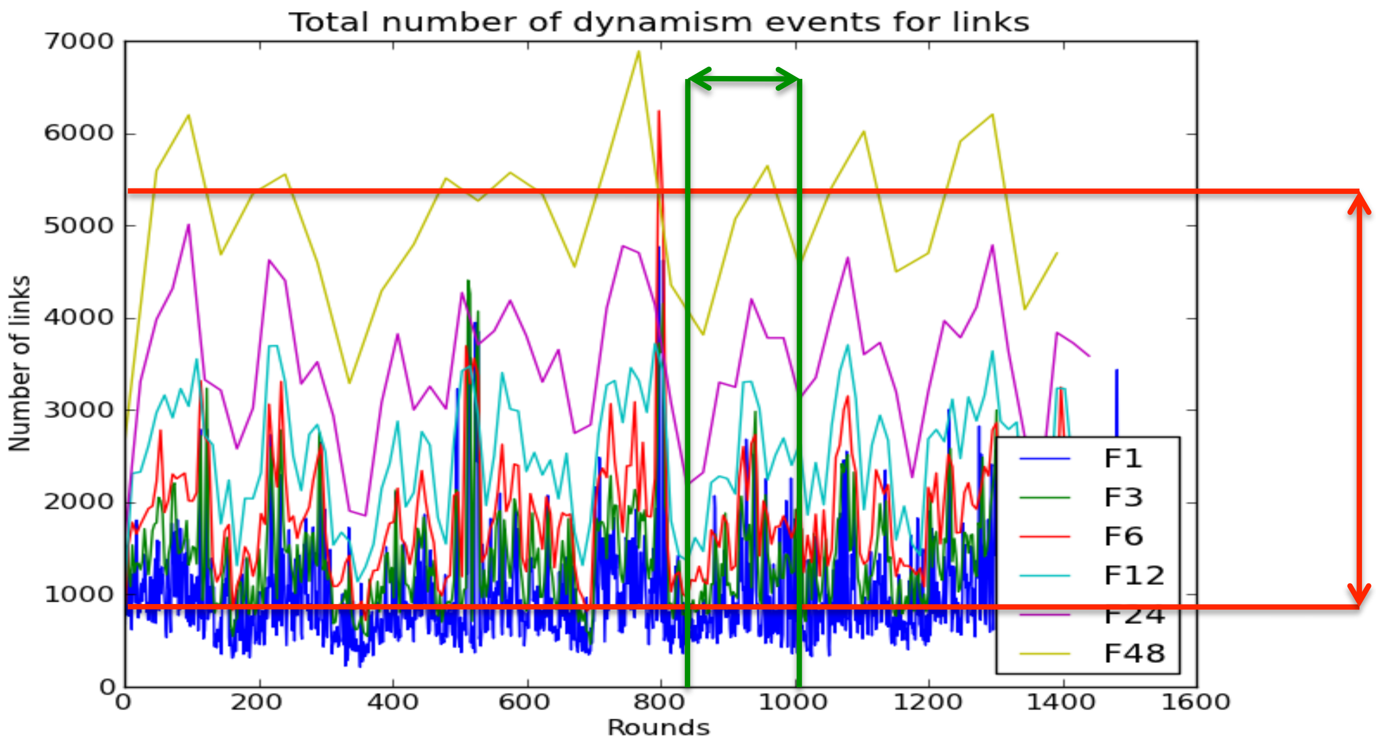
- 40,850 links seen in an average round
- 900 link events in an average round (2.2% of all links)
- Same periodic behavior as for nodes

Number of node events at different scales



- As expected, longer rounds mean more changes per round.
- From ~0.8% of nodes at F_1 to ~ 5.5 % at F_{48}
- Periodic behavior remains.

Number of link events at different scales



- Similar observation as for nodes: more changes per round.
- From ~ 2.2% at F_1 to ~ 12.2 % at F_{48}
- Periodic behavior remains.

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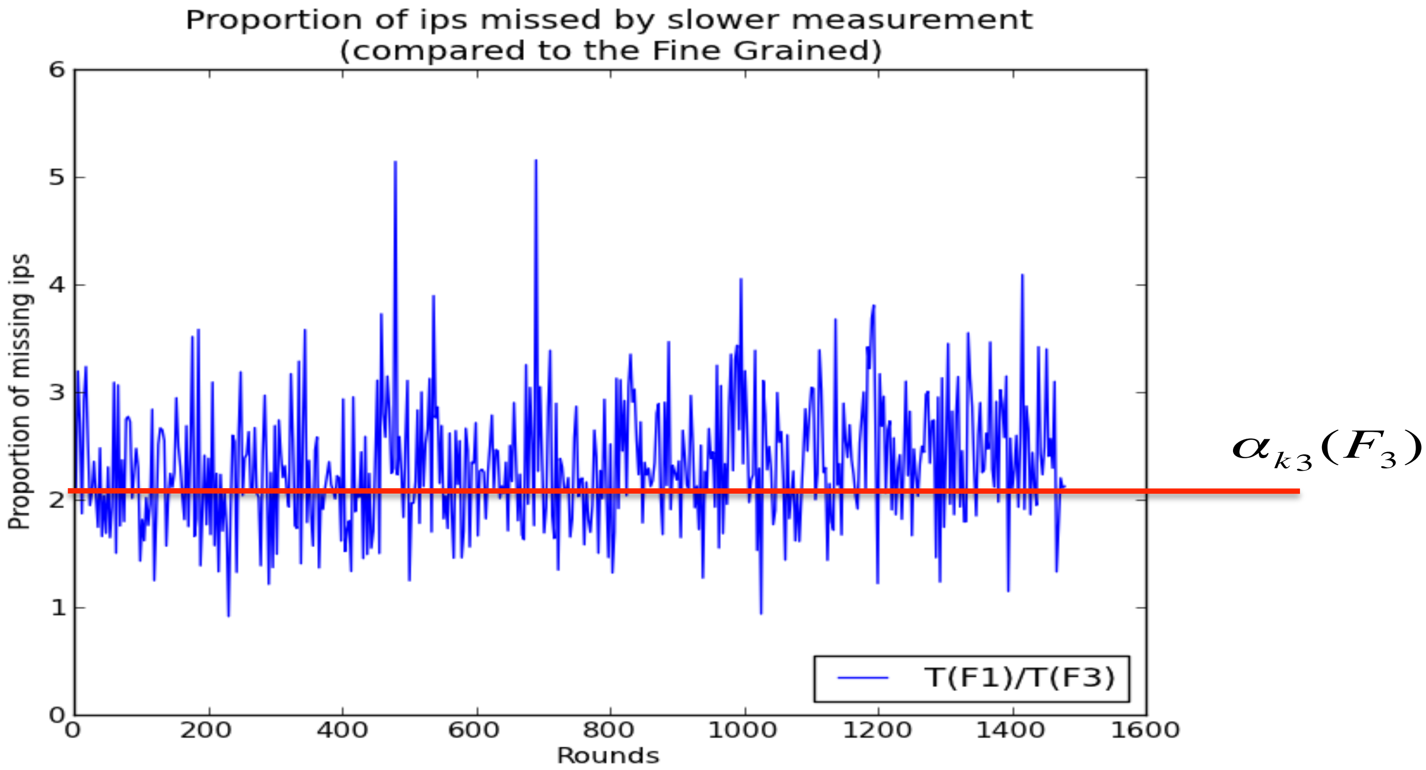
Events missed

- Longer rounds capture more events *per round*, but what do they miss over comparable timescales?
- Proportion of events missed:

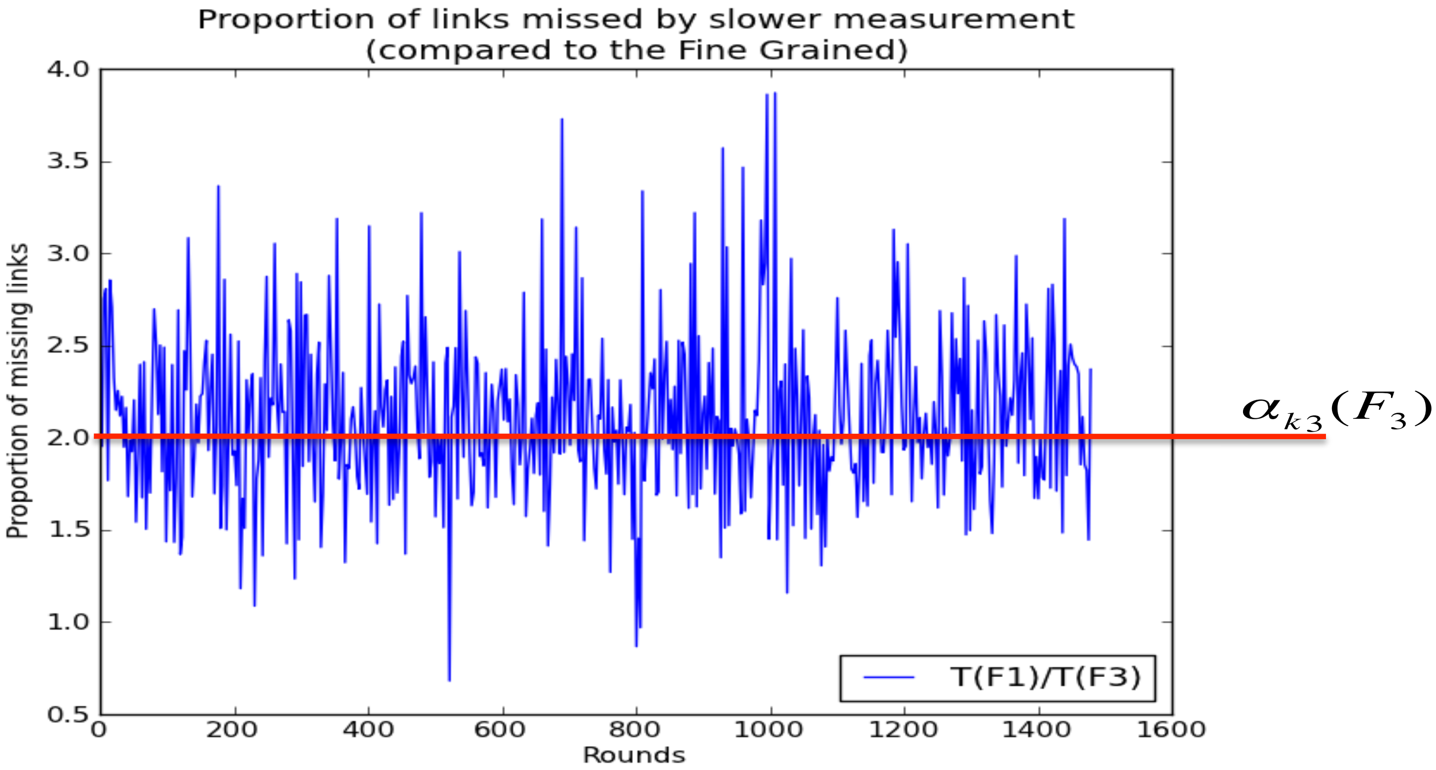
$$\alpha_{k_n}(F_n) = \frac{\left|T_{k_1}(F_1)\right|}{\left|T_{k_n}(F_n)\right|}$$

Proportion of node events missed at F_3



- Half of the node events observed at F_1 are missed when probing 3 times slower.

Proportion of link events missed at F_3



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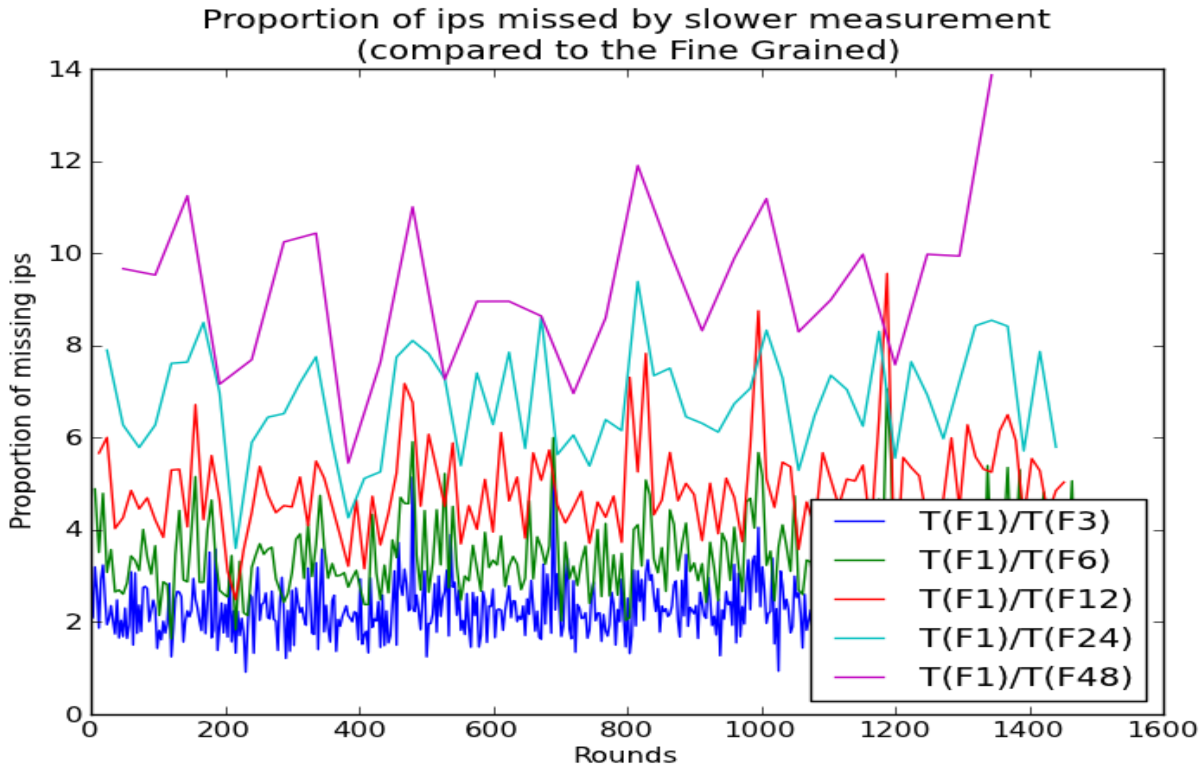
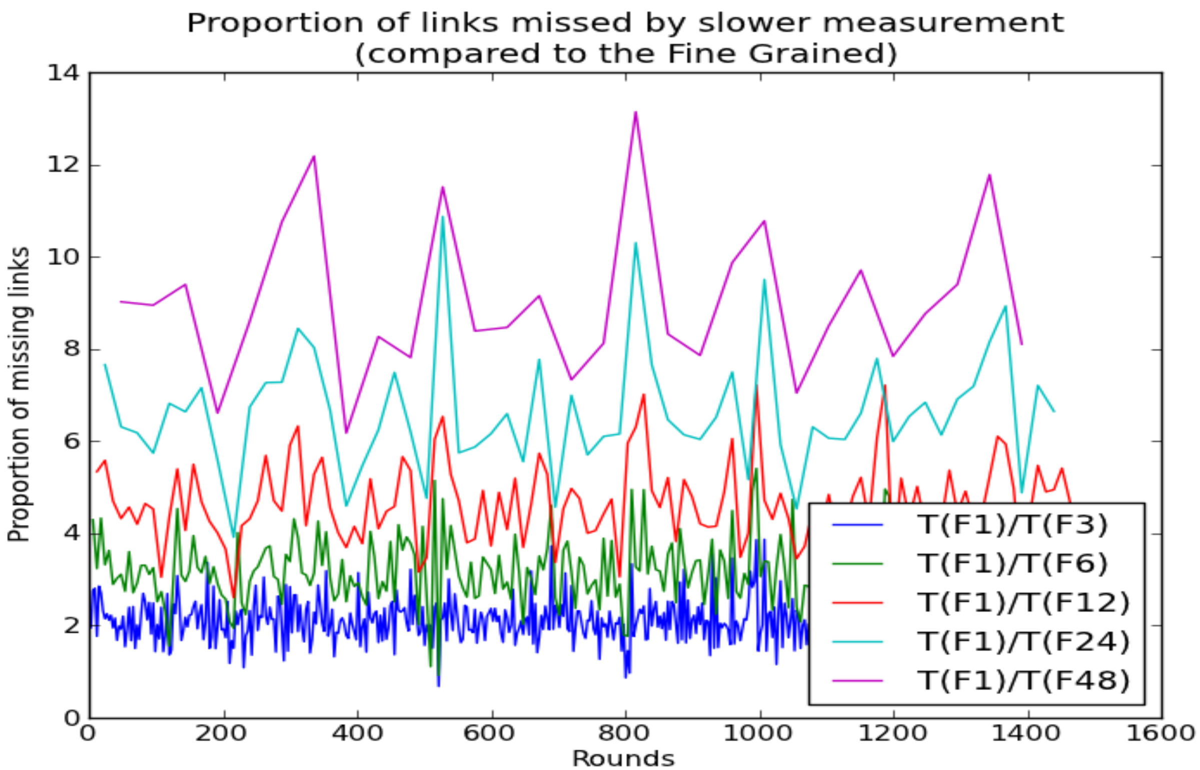
Proportions missed at different scales: nodes



- As we probe more slowly, we miss more and more node events.
  - Probing every 2 days (as does Ark) may reveal 9 times fewer node events compared to probing every hour.

Proportions missed at different scales: links



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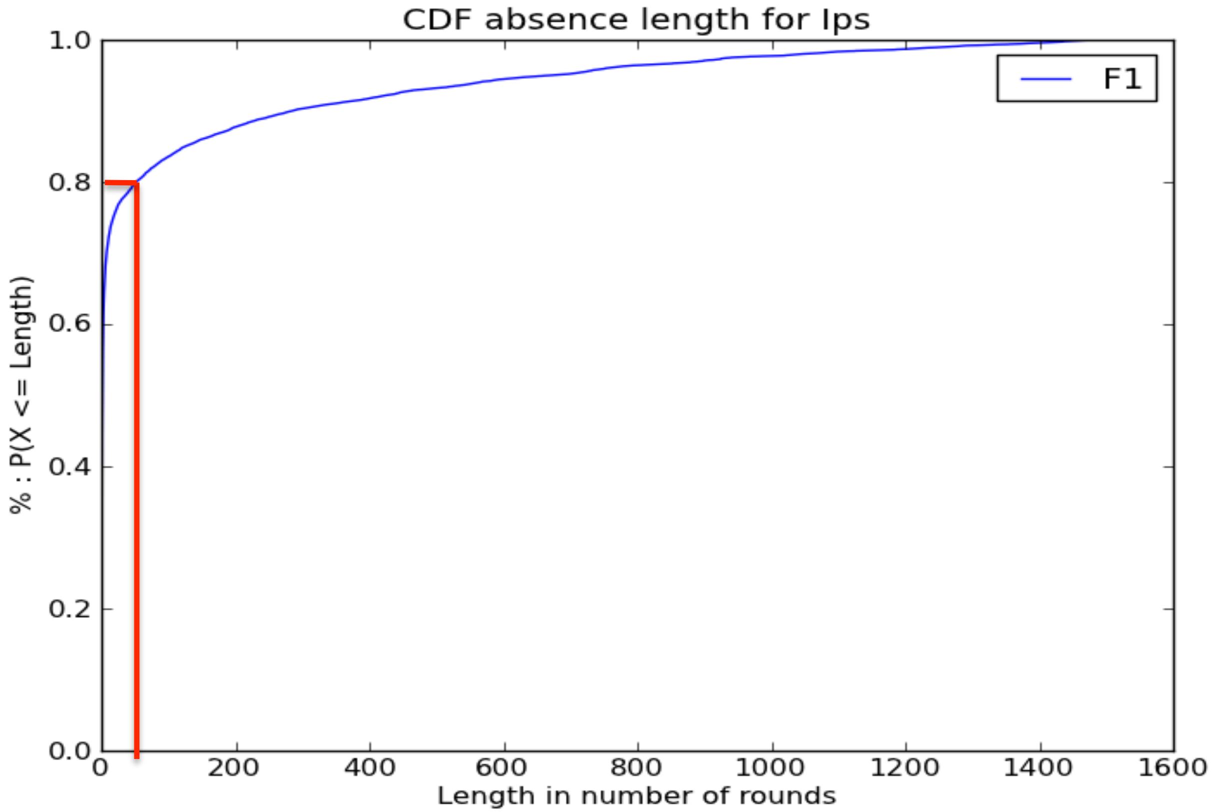
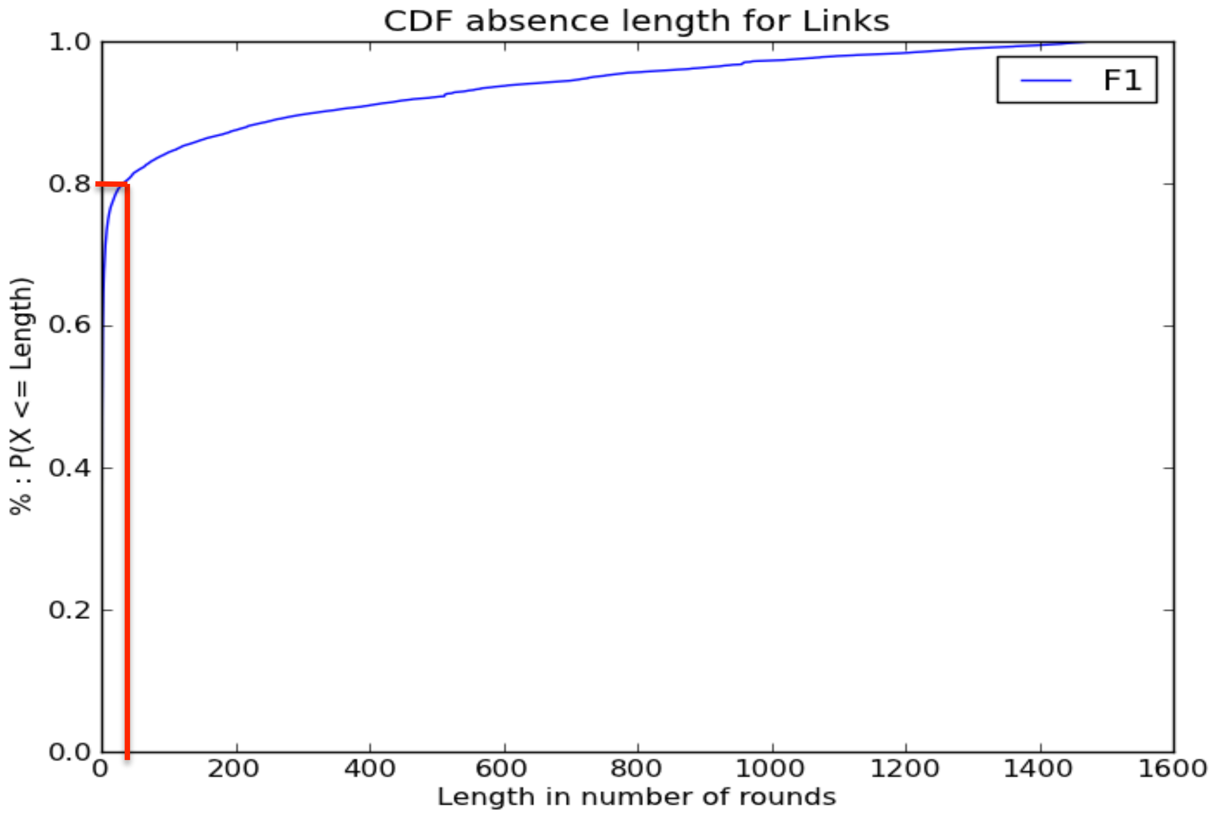
Static states for nodes at F_1



- When an IP is absent, it is typically (80% of the time) absent for a day (20 rounds) or less in our fine-grained measurement.

Static states for links at F_1



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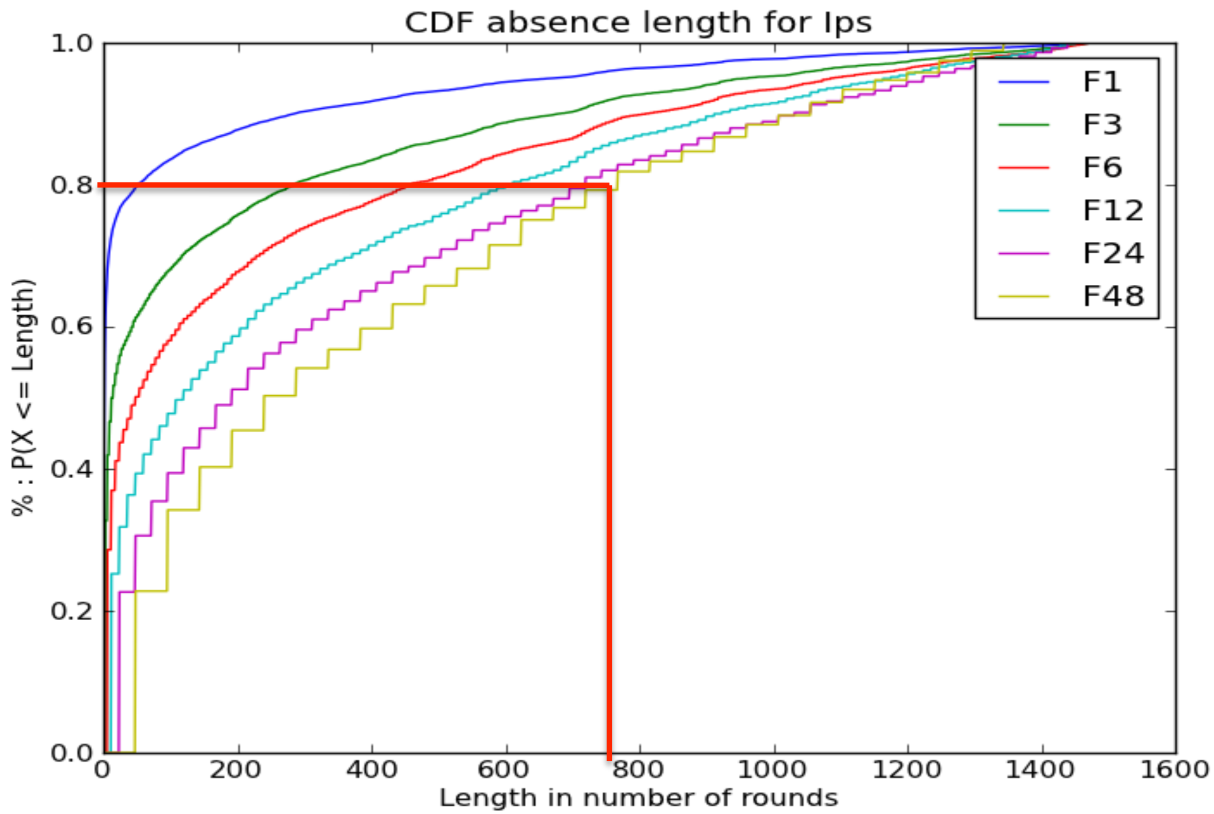
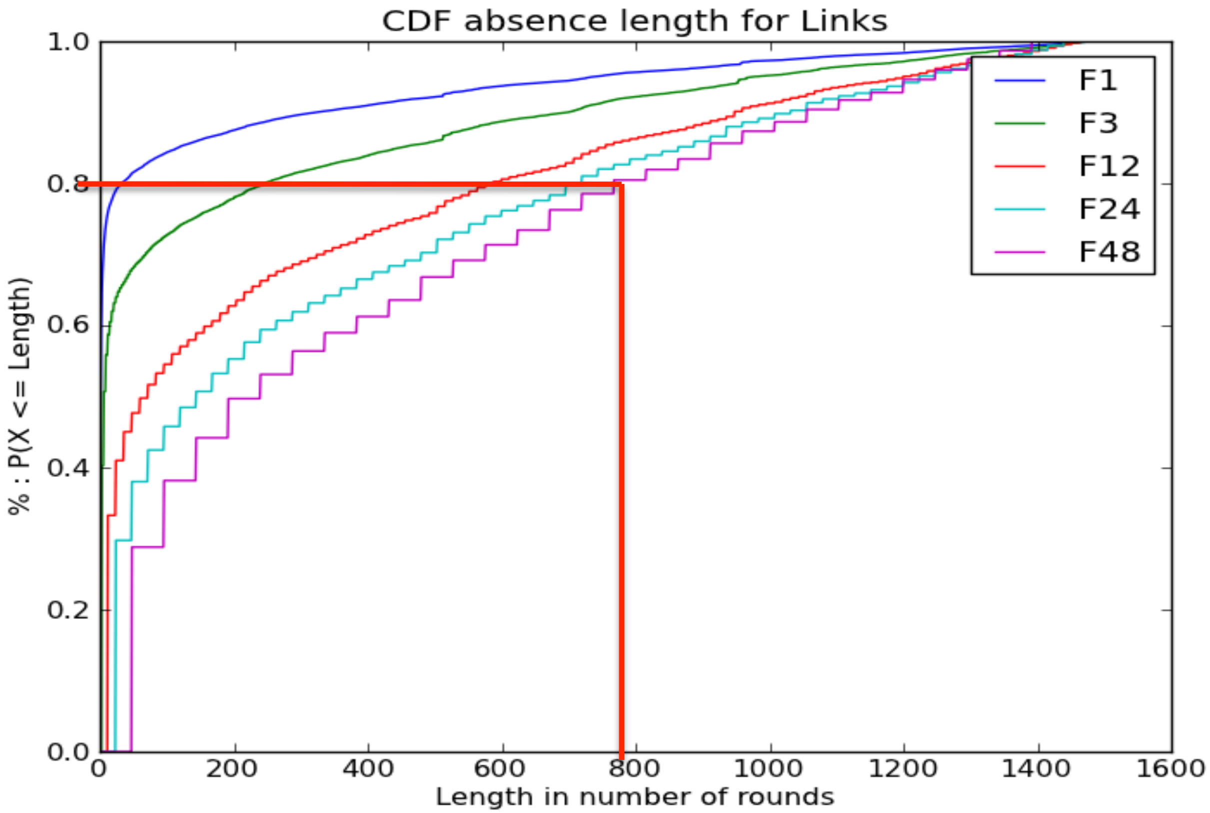


- As we probe more slowly, typical absences for IPs get longer (80% are 30 days or less at F_{48})

Static states at different scales: links



- As we probe more slowly, typical absences for links get longer (80% are 30 days or less at F_{48}).

Summary of results

- Longer intervals between measurements mean more changes from one graph to the next.
  - But: by probing more slowly, we're missing a high proportion of events.

We must probe more frequently if we want to capture this detail

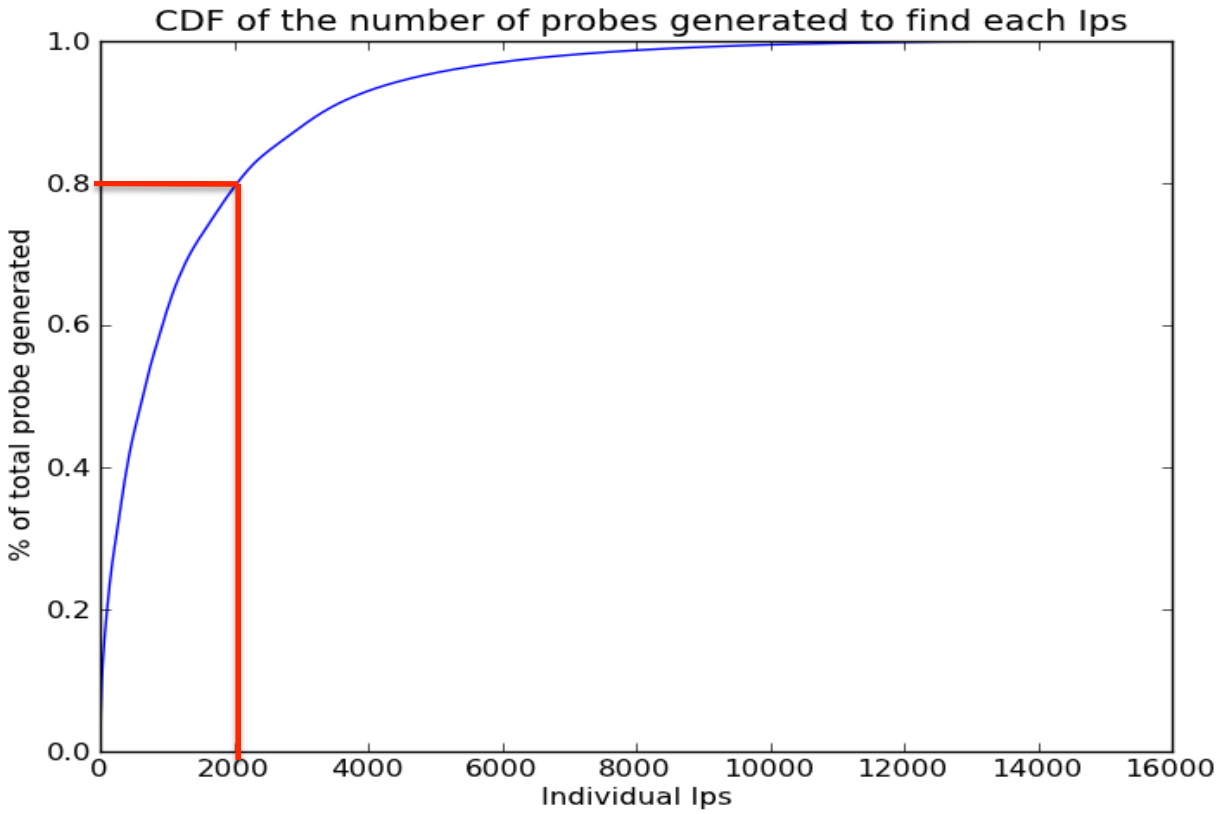
Probing more efficiently

- As we know from Donnet et al.'s Doubletree work, there is considerable probing redundancy
  - We examine redundancy in our data

    node redundancy = number of packets sent to discover a node

    link redundancy = ½ number of packets sent to discover a link
  - Similar results would mean that we have room for greater efficiency without data loss.

Redundancy of measurement probes: nodes



- IPs sorted in decreasing order of redundant discovery
- ~80% of measurement probes only discover ~14% of all IPs in each round

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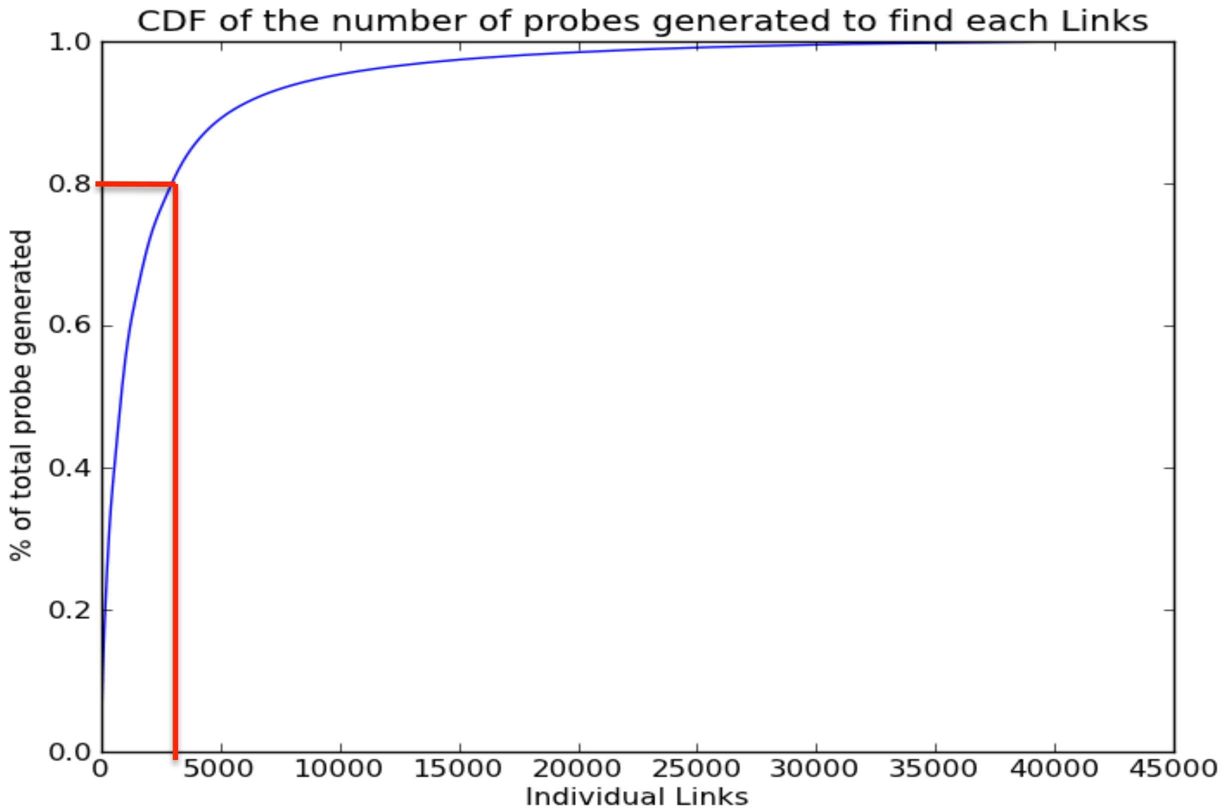
Redundancy of measurement probes: links



- links sorted in decreasing order of redundant discovery
- ~80% of measurement probes only discover ~9% of all links

Next steps

- Develop more efficient probing algorithms:
  - Increase the frequency to catch short timescale events while lowering the load generated on the network.
  - Reduce measurement redundancy while capturing most events.

- Scale up the system:
  - Increase the size of the topology measured (millions of nodes) and increase the frequency (every few minutes).

This work has been supported by:

OneLab

FUTURE INTERNET TESTBEDS

http://onelab.eu/

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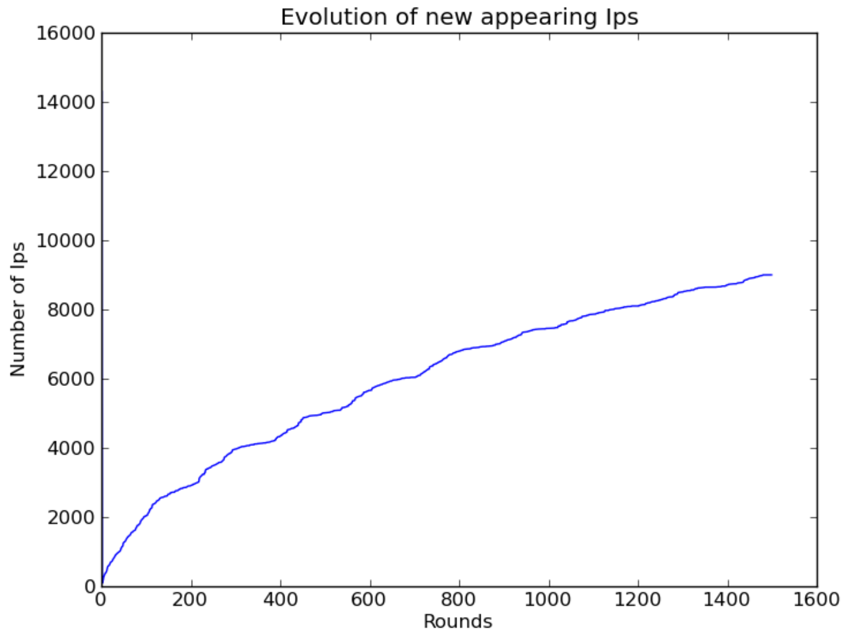
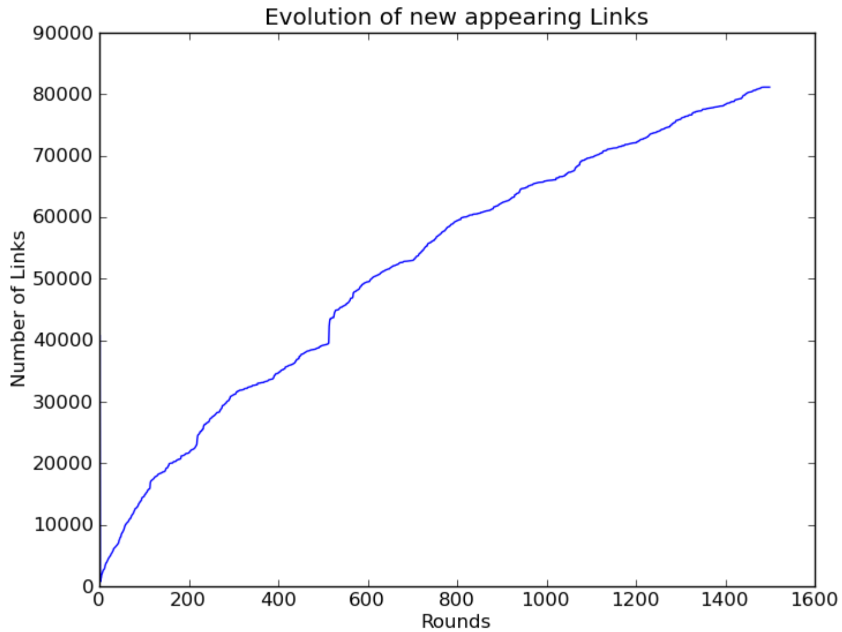
Dynamism events observation





- Over the whole experiment, we observe the birth of new IPs/links (confirming Latapy et al.'s observations).