Selecting new BGP feeders to Address the Incompleteness of the Internet AS-level Graph

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The Internet: a huge set of interconnected networks

Hot research field: Internet mapping
- Different level of abstractions
- We focus on the Internet AS-level topology

Autonomous System (AS) \( \sim \) set of IP networks under the same administrative entity
The Internet

- The Internet: a huge set of interconnected networks
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  - Different level of abstractions
  - We focus on the Internet AS-level topology
- Autonomous System (AS) \(\sim\) set of IP networks under the same administrative entity
Many works analyzed the AS-level topology

Only few works analyzed the data from which is extracted

We analyse the typical data used to map the AS-level topology . . .

. . . and we propose a methodology to address its huge incompleteness

“It is a capital mistake to theorize before you have all the evidence. It biases the judgment.” (sir A.C. Doyle)
Most common data come from the routes that ASes exchange thanks to the Border Gateway Protocol (BGP)

These data are gathered by route-collector projects fed by cooperating ASes (feeders)

Main Route Collector projects
- RouteViews (developed by University of Oregon, USA)
- RIS (developed by RIPE-NCC, Europe)

Total number of route collectors: 23
Total number of BGP feeders: 568
(On February 2012)
Data sources

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What “BGP data” is?

- A Route-collector periodically provides the UPDATE messages received from its feeders.
The AS path field is used to infer the AS-level graph (e.g. \texttt{ASPATH = 3549 137 8978})

- 1 node = 1 AS
- 1 edge = the two ASes are neighbor in \textbf{at least} an AS path

Using data gathered by RouteViews and RIS during \textbf{February 2012}:

- 41,116 nodes
- 144,475 edges
Problem 1) - inter-AS economic relationships

BGP is an economic-driven protocol

- **customer-to-provider (c2p)**: the customer *pays* the provider to receive the Full Routing Table (FRT)

- **peer-to-peer (p2p)**: the two ASes exchange routes towards their respective clients (typically free-of-charge)

We call **high-level contributor** a BGP feeder that treats the route collector as a **client**
Problem 1) - Facts

FRT \approx 2.5 billions of IP addresses

\# of high-level contributors: 120 over 568 feeders (21%)
Problem 2) - Biased View

- About 80% of high-level contributors have a degree > 100, i.e. they are large ISPs (direct checking is possible)
Problem 2) - Example

R has no chance to reveal the p2p link C-D, because the link is below it.

R can reveal the p2p link A-B, because the link is above it.

Thus, the missing links are mostly p2p.
Problem 3) - BGP decision process

- Each AS announces to its neighbors only the best route to reach a given destination (the feeder is not an exception).
- The decision is made by the BGP Decision Process, that from our point of view it is like a filter.

The higher is the distance of an AS from a route collector, the lower is its discoverable connectivity.
A new metric - p2c-distance

- The p2c-distance of an AS X from a route collector R is the minimum number of consecutive p2c links that connect X to R.
- It estimates how well each AS is covered by a given route collector.

<table>
<thead>
<tr>
<th>AS</th>
<th>p2c-distance from R</th>
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<tbody>
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<td>A</td>
<td>1</td>
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<td>B</td>
<td>1</td>
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<tr>
<td>C</td>
<td>-</td>
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<tr>
<td>D</td>
<td>-</td>
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<tr>
<td>E</td>
<td>2</td>
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- Requires the knowledge of inter-AS economic relationships (at least p2c links).
- We exploit the fact that inferred p2c links can be considered reliable (due to the top-tier view).
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p2c-distance of $X$ from a set of route collectors $\mathcal{R}$

\[
\text{p2c-distance} = \min \text{ p2c-distance of } X \text{ from each route collector in } \mathcal{R}
\]

The current set of route collectors cover poorly the AS-level ecosystem.
p2c-distance (cont.)

- p2c-distance of X from a set of route collectors $\mathcal{R}$
  
  $$= \min \text{p2c-distance of X from each route collector in } \mathcal{R}$$

<table>
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<tr>
<th>p2c-distance from rc infrastructure</th>
<th># ASes</th>
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<tr>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>366</td>
</tr>
<tr>
<td>3</td>
<td>275</td>
</tr>
<tr>
<td>3+</td>
<td>40,353</td>
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- The current set of route collectors cover poorly the AS-level ecosystem
How to address the lack of data?

- Simple idea: add new BGP feeders (= deploy new route collectors)
- Questions:
  - How to select these new feeders? Randomly? Graph metric criteria (e.g. degree)?
  - And how many feeders should we add?

Answer: we should select the minimum number of ASes such that the p2c-distance of each AS from the route collector infrastructure is bounded by \( d \) (\( d = 1, 2, \ldots \))
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Minimum Set Cover problem

- This problem can be formulated as a \textit{minimum set-cover (MSC) problem} (NP-complete).

- To reduce its size we focused on the coverage of \textit{not stub} ASes (7,268 over 41,116 ASes).

- Stub ASes are not very interested in establishing p2p connections, e.g. only 7\% of them is member of an IXP.
  - Exception: CDNs
Minimum Set Cover problem

- Select the minimum number of ASes in order to **bound** the p2c-distance of each **not stub AS** from the route collector infrastructure.

- Further reduction
  - reduction by row and column dominance
  - matrix decomposition (the matrix is **very sparse**)

- Then we applied a brute-force phase
So, for example

- Select the minimum number of ASes in order to **bound** the p2c-distance of each **not stub AS** from the route collector infrastructure (e.g. 3)
- Initial set of route collectors = \{∅\}
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The huge number of required feeders is due to the current poor coverage.

Future plains:

- Characterize the ASes in the optimal solution.
- Convince these ASes to participate. How?
  - We believe in the *do ut des* principle.
  - You give us BGP data, we give you (near) real-time inter-domain routing monitor services.
Thank you for your attention!

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Questions?