An Analysis of The Completeness of the Internet AS-level Topology Discovered by Route Collectors

Luca Sani

July 21, 2014
The Internet is the biggest set of interconnected computer networks.

Networks are grouped into **Autonomous Systems (ASes)**.
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**Example of ASes (about 47,000 up to date)**

- **AS 3269** Telecom Italia
- **AS 12145** Colorado State University
- **AS 15169** Google
- **AS 16667** MGM Resorts Intl
- **AS 21115** Nestlé Italia
- **AS 38474** AU Government (Antarctic Division)
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**AS-level of abstraction**

**AS-level**
- No matter about what happens inside each AS
- Inter-AS (inter-domain) routing
- Traffic crosses routes build thanks to the **Border Gateway Protocol** (BGP)
AS-level graph

- 1 node = 1 AS
- 1 edge = 1 or more BGP sessions between two ASes
The Internet AS-level topology

**AS-level graph**
- 1 node = 1 AS
- 1 edge = 1 or more BGP sessions between two ASes

**Main problem**
The (complete) Internet AS-level topology is not known
- ASes are known, not their connections
- No central repository
- No census is possible (ASes cannot be obligated to reveal their connections)
Internet AS-level topology: cui prodest?

- Study potential span of attacks (hijack, spam, natural disaster)
  - how many and which ASes would be affected?
- Positioning of server replicas for CDNs
  - Where should I put my servers in order to serve a certain portion of the Internet?
- Provider selection
The Internet AS-level topology: Common data sources

- Internet Routing Registries (IRR): the major issue is the human-based contribution (stale data, errors, ...)
- Route Collectors: They are the most common source of BGP data to infer an AS-level topology.
Main goal

Analyse the completeness of the AS-level topology that can be inferred from BGP data provided by route collectors
A Route Collector (RC) is a device which collects BGP routing data from co-operating ASes (feeders).

**BGP Route Collectors**

**Route Collector (RC)**

TIME: 02/09/12 08:08:47  
TYPE: BGP4MP/MESSAGE/Update  
FROM: 67.17.82.114 AS3549  
TO: 128.223.51.102 AS6447  
ORIGIN: IGP  
ASPATH: 3549 137 8978  
NEXT_HOP: 67.17.82.114  
MULTI_EXIT_DISC: 14163  
ANNOUNCE: 212.77.0.0/19  

**BGP feeder**

AS 137

AS 3549

AS 8978

212.77.0.0/19
## BGP Route Collector Status (Feb 2014)

<table>
<thead>
<tr>
<th>N. of RC</th>
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<td>N. of feeders</td>
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Total number of feeders: 1142 (over 47,000 ASes)
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We call them **full feeders**
Export Policies/Economic Relationships

- Customer to Provider (c2p)
- Peer to Peer (p2p)

RCs need to be considered as customers by their feeders in order to receive a full routing table.
RCs need to be considered as *customers* by their feeders in order to receive a full routing table
Internet eXchange Points (IXPs)

IXPs are physical facilities which facilitate the establishment of p2p connections.

Up to date there are about 240 IXPs around the world (mostly in Europe).
About 80% of full feeders have a degree higher than 100

The Internet as perceived from large ISPs misses the largest amount of p2p links due to export policies
Export policies consequences

1) Hierarchy:
   - Top: no providers
   - Bottom: no customers
Export policies consequences

1) Hierarchy:
   - Top: no providers
   - Bottom: no customers

2) Usually an AS do not:
   - Transit between a peer and a provider
   - Transit between two peers
A view from the top

Connections that can be discovered

\[(A, C) \ (A, D) \ (A, E) \ (A, F) \ (B, E)\]

RCs connected to large ISPs will fail to retrieve a large amount of p2p-connectivity
A view from the bottom

Connections that can be discovered

(A, B) (A, C) (A, D) (A, E) (A, F) (B, E) (C, D)

RCs need to be connected to ASes part of the lowest part of the Internet hierarchy to discover the missing p2p connectivity
A new metric: p2c distance

p2c distance of AS X from AS Y:
Minimum number of consecutive p2c links that connect X to Y

If the p2c-distance of AS X from a RC is not defined, then the RC cannot discover the p2p connectivity of AS X.
Focusing the target

Thoughts
- Every AS has a finite p2c-distance from a RC: unfeasible and useless (39,000 stubs → 39,000 feeders!)
- The vast majority of missing links are p2p
- Stub ASes are not likely to establish many p2p connections (only 7% are members of at least an IXP)

Goal
- Every non-stub AS has a finite p2c-distance from a RC
- Since they still are about 8400 we do not want to connect to all of them
Select new BGP feeders such that each non-stub AS has a **finite and bounded** p2c distance from the route collector infrastructure.
Goal rephrased

Select new BGP feeders such that each non-stub AS has a **finite and bounded** p2c distance from the route collector infrastructure.

**Minimum Set Cover (MSC) problem**

Minimize \( \left( \sum_{AS_i \in U} x_{AS_i} \right) \)

subject to

\[ \sum_{AS_i : n \in S_{AS_i}^{(d)}} x_{AS_i} \geq 1 \quad \forall n \in \mathcal{N} \]

\[ x_{AS_i} \in \{0, 1\}, \quad \forall AS_i \in U \]
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Covering set

Covering set of AS X: set of non-stub ASes having a finite and bounded p2c distance from AS X
Real World Analysis

Distance parameter

- $d_{p2c} = 1$: to obtain the best quality result without the need to establish a connection with every non-stub ASes
- This means that each non-stub should have at least one p2c distance less than or equal one from a feeder (→ two from a RC).

Economic topologies (Economic Tagging Algorithm)

- Global
- Continental (Geographic Tagging Algorithm)
Real World Analysis

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<th>EU</th>
<th>LA</th>
<th>NA</th>
<th>W</th>
</tr>
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<tbody>
<tr>
<td>ASes</td>
<td>886</td>
<td>7607</td>
<td>19,981</td>
<td>7876</td>
<td>17,449</td>
<td>47,246</td>
</tr>
<tr>
<td>#edges</td>
<td>2222</td>
<td>23,359</td>
<td>121,175</td>
<td>18,834</td>
<td>59,303</td>
<td>202,996</td>
</tr>
<tr>
<td>Non-stub ASes</td>
<td>288</td>
<td>1662</td>
<td>3921</td>
<td>861</td>
<td>2820</td>
<td>8426</td>
</tr>
</tbody>
</table>
The number of feeders required is less than the number of non stubs (e.g. 4344 is about 51% of W non stubs)

However it heavily outnumbers the current number of (full) feeders
Covering sets may overlap

- More than one optimal solution
- All ASes that can be part of at least one optimal solution are in the set of candidates
In which order we should choose selected ASes in order to maximize the covered non stubs?

This could help in choosing firstly the more useful ASes.
Ranking the candidates

- In which order we should choose selected ASes in order to maximize the covered non stubs?
- This could help in choosing firstly the more useful ASes

**Maximum Coverage Problem**

Maximize \( \left( \sum_{AS_j \in N} y_{AS_j} \right) \)

subject to

\[ \sum_{AS_i \in I} x_{AS_i} \leq k \]
\[ \sum_{AS_i \in I \cap AS_j \in S_{AS_i}} x_{AS_i} \geq y_{AS_j}, \quad \forall AS_j \in N \]
\[ y_{AS_j} \in \{0, 1\}, \quad \forall AS_j \in N \]
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\[ y_{AS_j} \in \{0, 1\}, \quad \forall AS_j \in N \]

\[ x_{AS_i} \in \{0, 1\}, \quad \forall AS_i \in U \]

Since we search a ranking, we cannot search for exact solutions

We use a greedy approach
By adding just the same number of current full feeders, the coverage would double
Isolario - The Book of Islands
"where we discuss about all islands of the world, with their ancient and modern names, histories, tales and way of living..."
Benedetto Bordone
(Italian cartographer)

- Isolario is a research project aimed at collecting BGP data from volunteer participants
- In change, Isolario offers **real-time** monitoring services (**do-ut-des**)
Isolario system overview

Users

Web Intelligence

Core

Route Collector 1

Route Collector 2

Route Collector M

Feeder 1

Feeder X

Feeder N

Legend

- BGP flow
- Isolario flow
- HTTPS/WS

BGP UPDATE message

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Services

- Routing table monitoring
- Subnet reachability
- Route flap detection
- Alerting services (Reachability, Prefix Hijack, ...)
- Historic routing data (for troubleshooting, research etc.)
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Current Feeders

1. Registry of ccTLD.it (AS 2597, AS 197440)
2. Toscana Internet Exchange - TIX (AS 6882)
3. Nautilus and Mediterranean IXP - NAMEX (AS 24796)
4. Torino-Piemonte IXP - TOPIX (AS 25309)
6. Panservice (AS 20912)
Conclusions and Future works

Conclusions
- AS-level topology that can be extracted from BGP data provided by RCs is far from being complete
- New feeders are needed
- The typical profile of an ideal feeder is a multi-homed stub AS

Future directions
- Isolario feedback
- Study the impact new data has on Internet AS-level analysis
Thank you for your attention

Any question?

luca.sani@imtlucca.it
www.isolario.it
So, for example...

Select the min number of feeders to have each **not stub AS** with $d_{p2c} = 2$ from the RCs (i.e. $d_{p2c} = 1$ from the feeders)

### Phase a)
Identify covering sets ...

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<td>{B}</td>
</tr>
<tr>
<td>B</td>
<td>{B,D}</td>
</tr>
<tr>
<td>C</td>
<td>{C}</td>
</tr>
<tr>
<td>D</td>
<td>{D}</td>
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\[ P = \{\emptyset\} , \mathcal{D} = \{\emptyset\} \]
So, for example ...

Select the min number of feeders to have each not stub AS with \( d_{p2c} = 2 \) from the RCs (i.e. \( d_{p2c} = 1 \) from the feeders)

**Phase a)**

... and ASes that uniquely cover a non-stub AS

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Select the min number of feeders to have each **not stub AS** with $d_{p2c} = 2$ from the RCs (i.e. $d_{p2c} = 1$ from the feeders)

**Phase b)**
Identify dominated covering sets ...

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$$\mathcal{P} = \{C\}, \mathcal{D} = \{\emptyset\}$$
So, for example ...

Select the min number of feeders to have each not stub AS with \( d_{p2c} = 2 \) from the RCs (i.e. \( d_{p2c} = 1 \) from the feeders).

Phase b)

... record and put them aside

\[
\begin{array}{|c|c|}
\hline
\text{AS} & \text{Not stubs } \in S^{(1)}_{AS_i} \\
\hline
A & \{B\} \\
B & \{B, D\} \\
C & \{C\} \\
D & \{D\} \\
E & \{D, E, G, H\} \\
F & \{E\} \\
G & \{G\} \\
H & \{H\} \\
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\hline
\end{array}
\]

\[\mathcal{P} = \{C\}, \mathcal{D} = \{A, C, D, F, G, H, I\}\]
So, for example...

Select the min number of feeders to have each **not stub AS** with $d_{p2c} = 2$ from the RCs (i.e. $d_{p2c} = 1$ from the feeders)

Repeat previous steps until a solution is found or apply brute force approach (if needed)

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**Phase c)**

Check if dominated covering sets can appear in a solution

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<th>AS</th>
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$\mathcal{D} = \{A, C, D, F, G, H, I\}$, $\mathcal{C} = \{B, C, E\}$
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Candidate feeder details

![Graphs showing the distribution of ASes across regions.](image)

| Region | # of ASes ∈ ℐ (% out of | ℐ| ) |
|--------|--------------------------|
|        | On IXPs                  | Stubs         |
| AF     | 42 (13.63%)              | 138 (44.80%)  |
| AP     | 484 (28.74%)             | 808 (47.98%)  |
| EU     | 2379 (53.41%)            | 2241 (50.31%) |
| LA     | 327 (40.32%)             | 340 (41.92%)  |
| NA     | 528 (16.35%)             | 1591 (49.27%) |
| W      | 3894 (42.47%)            | 4691 (50.92%) |

**Typical candidate feeder**

- Small/Stub multihomed AS
- This is **not** the current typical (full) feeder
Full feeders geographical distribution

Luca Sani