Where the Sidewalk Ends

Extending the Internet AS Graph Using Traceroutes From P2P Users

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Last time we have discussed about the inaccuracy of BGP-based inferred Internet map...

This time we continues... by another measurement: traceroute + BGP
This paper chose a P2P platform — Ono:

1. Internet are always changing, while P2P grows with Internet itself.
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2. P2P traceroutes have significantly more VPs compared to the BGP data.
This paper chose a P2P platform — Ono:

1. Internet are always changing, while P2P grows with Internet itself.

2. P2P traceroutes have significantly more VPs compared to the BGP data.

3. Ono had most number of VPs (2009)

<table>
<thead>
<tr>
<th>Project</th>
<th># unique machines</th>
<th># unique ASes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routeviews/RIPE</td>
<td>790</td>
<td>438</td>
</tr>
<tr>
<td>Skitter</td>
<td>24</td>
<td>≤ 24</td>
</tr>
<tr>
<td>iPlane</td>
<td>192</td>
<td>≤ 192</td>
</tr>
<tr>
<td>DIMES</td>
<td>8,059</td>
<td>200</td>
</tr>
<tr>
<td>Ono</td>
<td>600,000</td>
<td>6,000</td>
</tr>
</tbody>
</table>
Data Collection (Dec, 2007 – Sep, 2008)

1. P2P Traceroutes: our fundamental data.

2. BGP feeds: used to check and obtain the most complete AS links

3. Ground-truth data: to validate the inferred AS links
First part: reducing problematic paths, and convert IP-level paths to AS-level one
Second part: supplement those missing links
Reducing problematic paths, and convert IP-level paths to AS-level one

1. Removing all repeated IPs, which may cause falsely inferred links or routing loops.

2. Eliminating all paths that traverse Internet eXchange Points (IXPs), which can also lead to falsely inferred links.

3. Conversion was simply provided by Team Cymru
Supplement those missing links

4. For links filtered by IXP prefix, the paper could identify those are in the middle of traceroute AS paths that are mapped to multiple ASes.

5. Sibling(X, Y): Check known sibling links from CAIDA.
   
   Examples: Traceroute: [...WXYZ...]; BGP: [...WXZ...] or [...XYZ...]
   Traceroute: [...WXZ...]; BGP: [...XYZ...]

6. Creative heuristics
Heuristics to handle symptoms: Loops

1. rare;
2. some are valid;
3. so the paper conservatively discard these paths.
Heuristics to handle symptoms: Missing hop:

Next, the paper referred BGP data to check the links missed by traceroute data.

Traceroute data:

```
A -> B -> C -> D
```

BGP data:

```
B -> X -> C
```

1. Private peering interface IPs
2. Sibling ASes
3. Unannounced IP
4. Using outgoing interface IPs
Heuristics to handle symptoms:
Substitute hop and extra hop:

1. Unannounced IP
2. IXPs or Sibling ASes
3. Using outgoing interface IPs
Heuristics to handle symptoms: Special case

Traceroute data:

BGP data:

C must exists:
1. If Distance(A, C) = 1, connect A and C directly;
2. If Distance(A, C) != 1, connect B and C.
Validation with ground truth information for 100,000 AS links

<table>
<thead>
<tr>
<th>After heuristics</th>
<th>Remaining false data</th>
</tr>
</thead>
<tbody>
<tr>
<td>beginning</td>
<td>48.80%</td>
</tr>
<tr>
<td>missing hop</td>
<td>10.47%</td>
</tr>
<tr>
<td>extra hop</td>
<td>5.13%</td>
</tr>
<tr>
<td>substitute</td>
<td>0.47%</td>
</tr>
<tr>
<td>distance(B, C) &gt; 2</td>
<td>0</td>
</tr>
</tbody>
</table>
1. Most missing links are customer-provider links
2. Peering links is most invisible
3. Sibling links exist relatively rarely
CDF for each type of links

Tier-5 has few missing links here

Figure 4: The missing provider links.
CDF for each type of links

The tier degree higher, the fewer missing links, except tier 1.

Figure 5: The missing customer links.
CDF for each type of links

Higher tiers have fewer missing links here

Figure 6: The missing peering links.
Exploring missing patterns

Measurement directions: VP at AS, VP to AS, AS to VP

Distance between VP and AS: 0, 1, and more
Exploring missing patterns

Measurement directions: VP at AS, VP to AS, AS to VP

Distance between VP and AS: 0, 1, and more

<table>
<thead>
<tr>
<th>Patterns</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
<th>(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td># of unique links observed</td>
<td>75817</td>
<td>78746</td>
<td>54869</td>
<td>55731</td>
<td>40518</td>
<td>54262</td>
<td>40666</td>
<td>52331</td>
</tr>
<tr>
<td># of peering</td>
<td>19474</td>
<td>16492</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td># of customer-to-provider</td>
<td>5036</td>
<td>4550</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td># of provider-to-customer</td>
<td>49194</td>
<td>55948</td>
<td>52092</td>
<td>53830</td>
<td>39024</td>
<td>51681</td>
<td>39290</td>
<td>50604</td>
</tr>
<tr>
<td># of unique links missed</td>
<td>5185</td>
<td>22535</td>
<td>23094</td>
<td>23909</td>
<td>23889</td>
<td>22676</td>
<td>23691</td>
<td>23884</td>
</tr>
<tr>
<td># of peering</td>
<td>3330</td>
<td>12395</td>
<td>12576</td>
<td>12726</td>
<td>12706</td>
<td>12473</td>
<td>12579</td>
<td>12709</td>
</tr>
<tr>
<td># of customer-to-provider</td>
<td>1521</td>
<td>7220</td>
<td>7973</td>
<td>10563</td>
<td>10410</td>
<td>7484</td>
<td>9722</td>
<td>10274</td>
</tr>
<tr>
<td># of provider-to-customer</td>
<td>1343</td>
<td>6852</td>
<td>7692</td>
<td>10444</td>
<td>10583</td>
<td>7077</td>
<td>9914</td>
<td>10469</td>
</tr>
<tr>
<td>Percentage of missing links</td>
<td>6.83%</td>
<td>28.62%</td>
<td>42.09%</td>
<td>42.90%</td>
<td>58.96%</td>
<td>41.79%</td>
<td>58.26%</td>
<td>45.64%</td>
</tr>
</tbody>
</table>
Main root causes for missing links: Route aggregation

Route aggregation:
that AS X changes packet’s prefix because of route aggression
Main root causes for missing links:
Sub-optimal paths

At suboptimal path; useless!

Sub-optimal paths to VPs:
X is VP but not A, the path X-A-B is too far for link A-B to be found.
Main root causes for missing links: Valley-free policy

Valley-free policy:
After a provider-to-customer link or a peer link, the XA path cannot traverse another customer-to-provider or peering link.
Categorizing the missing links
Categorizing the missing links

1. When missing link is found as valley-containing path
   --> valley-free policy

provider P

A --> B
Categorizing the missing links

1. When missing link is found as valley-containing path
   --> valley-free policy

2. When one AS of missing link is invisible
   --> route aggregation
Categorizing the missing links

1. When missing link is found as valley-containing path
   --> valley-free policy

2. When one AS of missing link is invisible
   --> route aggregation

3. When both ASes of missing link are invisible
   --> sub-optimal path
Quantifying missing links due to each reason

<table>
<thead>
<tr>
<th>Root cause</th>
<th>{\alpha}</th>
<th>{\beta}</th>
<th>{\gamma}</th>
<th>{\delta}</th>
<th>{\alpha, \beta}</th>
<th>{\alpha, \gamma}</th>
<th>{\beta, \gamma}</th>
<th>{\alpha, \beta, \gamma}</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td># of links</td>
<td>330</td>
<td>80</td>
<td>65</td>
<td>216</td>
<td>61</td>
<td>4911</td>
<td>116</td>
<td>17941</td>
<td>194</td>
</tr>
<tr>
<td>Percentage</td>
<td>1.38%</td>
<td>0.33%</td>
<td>0.27%</td>
<td>0.90%</td>
<td>0.26%</td>
<td>20.54%</td>
<td>0.49%</td>
<td>75.02%</td>
<td>0.81%</td>
</tr>
</tbody>
</table>

1. Route aggregation and BGP policies (including valley-policy and sub-optimal paths) are dominant factor

2. Missing links have multiple reasons
Thanks…