Interdomain Routing Policies in the Internet: Inference and Analysis

Massimo Rimondini

Defense of the PhD in Computer Science and Engineering

Mar 16th, 2007
Interdomain Routing

ISP

Autonomous Systems

BGP

LAN

WAN

BGP

Internet
Routing Policies
Directions

- Routing dynamics
- Consistency of commercial relationships
- Interdomain topology discovery
- Oscillation prevention
- Interplay of routing policies
- Traffic engineering
- Interconnection strategies
Interdomain Topology Discovery
State of the Art

- **CAIDA Skitter**
  - B. Huffaker, D. Plummer, D. Moore, kc claffy. Topology Discovery by Active Probing. Proc. SAINT ’02

- **University of Washington Rocketfuel**
BGP Probing: Contributions

- Probing primitives
  - AS-set stuffing
  - Withdrawal observation
- Exploration algorithm
- Experimentation on the IPv4/IPv6 Internet
- Route flap dampening analysis

Publications
- Technical report
- ISCC 2006
- Journal (pending acceptance)
## BGP Probing: Results

<table>
<thead>
<tr>
<th>Method</th>
<th>IPv6 ASes</th>
<th>IPv6 Links</th>
<th>IPv4 ASes</th>
<th>IPv4 Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable state</td>
<td>32</td>
<td>31</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Withdrawal</td>
<td>94 (2.9×)</td>
<td>211 (6.8×)</td>
<td>28 (1.2×)</td>
<td>49 (2.1×)</td>
</tr>
<tr>
<td>Level-by-level</td>
<td>97 (3×)</td>
<td>222 (7.2×)</td>
<td>29 (1.2×)</td>
<td>55 (2.4×)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Induced by W on global (I)</th>
<th>Withdrawal graph (W)</th>
<th>I only</th>
<th>W only</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv6</td>
<td>312</td>
<td>158 (51%)</td>
<td>175</td>
<td>21 (13%)</td>
</tr>
<tr>
<td>IPv6</td>
<td>334</td>
<td>168 (50%)</td>
<td>189</td>
<td>23 (14%)</td>
</tr>
<tr>
<td>IPv6</td>
<td>302</td>
<td>154 (51%)</td>
<td>174</td>
<td>26 (17%)</td>
</tr>
<tr>
<td>IPv4</td>
<td>241</td>
<td>61 (25%)</td>
<td>181</td>
<td>1 (2%)</td>
</tr>
</tbody>
</table>
Internet Routing Registry
- assignment of Internet resources (IP addresses, AS numbers)
- routing policies

Volunteered updates
- inconsistent registrations
- out of date information
aut-num: AS137

import: from AS20965 action pref=100;
from AS1299 action pref=100;
accept ANY

export: to AS1299 announce AS-GARR

changed: noc@garr.it 20000830
source: RIPE
aut-num: ASX5
import: { from ASX2:AS-Z2 accept 100.0.0.0/8;
    } refine {
    from ASX1 ASX2 accept 100.1.0.0/16;
    } except {
    from ASX3 accept 100.1.1.0/24;}
export: to ASX1:PRNG-Y1
    to ASX1:AS-Z1 except ASX9
    announce 100.1.1.0/24
mp-export: to ASX11 at 2001::1 announce 2001::/48
default: to ASX12 action pref=10
default: to ASX13 100.1.1.1 at 100.1.1.2
<table>
<thead>
<tr>
<th>aut-num:</th>
<th>AS24336</th>
</tr>
</thead>
<tbody>
<tr>
<td>as-name:</td>
<td>DIGITALBANK-JP</td>
</tr>
<tr>
<td>descr:</td>
<td>d-b net Backbone</td>
</tr>
<tr>
<td>import:</td>
<td>from AS17685</td>
</tr>
<tr>
<td></td>
<td>accept ANY</td>
</tr>
<tr>
<td>export:</td>
<td>to AS17685</td>
</tr>
<tr>
<td></td>
<td>announce AS24336</td>
</tr>
<tr>
<td>admin-c:</td>
<td>DM210-JP</td>
</tr>
<tr>
<td>tech-c:</td>
<td>DM211-JP</td>
</tr>
<tr>
<td>notify:</td>
<td><a href="mailto:matsuo@po.d-b.ne.jp">matsuo@po.d-b.ne.jp</a></td>
</tr>
<tr>
<td>mnt-by:</td>
<td>MAINT-AS24336</td>
</tr>
<tr>
<td>changed:</td>
<td><a href="mailto:matsuo@po.d-b.ne.jp">matsuo@po.d-b.ne.jp</a></td>
</tr>
<tr>
<td>source:</td>
<td>RADB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>aut-num:</th>
<th>AS24336</th>
</tr>
</thead>
<tbody>
<tr>
<td>as-name:</td>
<td>DIGITALBANK-JP</td>
</tr>
<tr>
<td>descr:</td>
<td>DIGITALBANK, Inc., Regional ISP in Japan</td>
</tr>
<tr>
<td>country:</td>
<td>JP</td>
</tr>
<tr>
<td>import:</td>
<td>from AS17685</td>
</tr>
<tr>
<td></td>
<td>action pref=100; accept ANY</td>
</tr>
<tr>
<td>import:</td>
<td>from AS7682</td>
</tr>
<tr>
<td></td>
<td>action pref=100; accept ANY</td>
</tr>
<tr>
<td>export:</td>
<td>to AS17685</td>
</tr>
<tr>
<td></td>
<td>announce AS24336</td>
</tr>
<tr>
<td>export:</td>
<td>to AS7682</td>
</tr>
<tr>
<td></td>
<td>announce AS24336</td>
</tr>
<tr>
<td>admin-c:</td>
<td>DM210-AP</td>
</tr>
<tr>
<td>tech-c:</td>
<td>DM211-AP</td>
</tr>
<tr>
<td>notify:</td>
<td><a href="mailto:matsuo@po.d-b.ne.jp">matsuo@po.d-b.ne.jp</a></td>
</tr>
<tr>
<td>mnt-routes:</td>
<td>MAINT-JP-DIGITALBANK</td>
</tr>
<tr>
<td>mnt-by:</td>
<td>MAINT-JP-DIGITALBANK</td>
</tr>
<tr>
<td>changed:</td>
<td><a href="mailto:hm-changed@apnic.net">hm-changed@apnic.net</a></td>
</tr>
<tr>
<td>source:</td>
<td>APNIC</td>
</tr>
</tbody>
</table>
IRR Data Extraction: Contribs

A methodology to extract BGP links from the IRR.

A classification of the links into confidence levels.

An online service.

Published papers:
- ACM Sigcomm MineNet 2006
## IRR Data Extraction: Results

<table>
<thead>
<tr>
<th></th>
<th>APNIC</th>
<th>ARIN</th>
<th>RADB</th>
<th>RIPE</th>
<th>VERIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>APNIC</td>
<td>2688</td>
<td>1</td>
<td>423</td>
<td>19</td>
<td>113</td>
</tr>
<tr>
<td>ARIN</td>
<td>1</td>
<td>463</td>
<td>37</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>RADB</td>
<td>423</td>
<td>37</td>
<td>2037</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>RIPE</td>
<td>19</td>
<td>7</td>
<td>50</td>
<td>11238</td>
<td>23</td>
</tr>
<tr>
<td>VERIO</td>
<td>113</td>
<td>14</td>
<td>45</td>
<td>23</td>
<td>310</td>
</tr>
</tbody>
</table>

### This work

- 236663

### RIPE RRCC

- 108521

### [mahadevan06] (RIPE only)

- 56949

### [zhang05] (RIPE)

- 70222

### [siganos04]

- 127498
Inference of Commercial Relationships
State of the Art

Validation

Comparative validation

Inference algorithms

Data set (AS paths)

Algorithm independence report

Stability report
Validation: Contributions

- Methodology
- Set of measures
- Software suite
- Validation of [sark02] against [dpp03]

- Publications
  - IPS 2004
Commercial Relationships: Results

- **Algorithm independence** (% consistent assignments on same data set)
  - >90%

- **Stability** (% consistent assignments over consecutive data sets)
  - [dpp03]: 
  - [sark02]:

```
# changes 100
# edges 10
```

# changes
# edges
Traffic Engineering
Traffic Engineering


ILP formulation
- Different objective functions
- Multiple prefixes
- Tie break

Computational geometry

1 2 3

prepending on \( u_i \)
Traffic Engineering: Contribs

- Two formal models
  - Avoid trial-and-error
  - “Pluggable” requirements
  - Algorithmic optimization

- Publications
  - IPS MoMe 2005
Interplay of Routing Policies
Policy Probing

- F. Wang, L. Gao. Inferring and Characterizing Internet Routing Policies. ACM SIGCOMM IM ’03

See commercial relationships
Policy Probing: Contributions

- Path feasibility determination
- Path preference comparison
- Experiments on the IPv4/IPv6 Internet
Stability

- L. Gao, J. Rexford. Stable Internet Routing without Global Coordination. Proc. ACM SIGMETRICS ’00
Stability
Stability: Contributions

- Event timings
- Two kinds of stability
  - strict stability
  - forwarding stability
- Properties
- Transitions & reachability
Emulation of Computer Networks
State of the Art

Royal Institute of Technology, Sweden

University of Zagreb

Technical University of Madrid

Gerd Stolpmann
Netkit

*The poor man's system to experiment computer networking*

- Easy to install and use
- Lightweight
- Easy setup of complex experiences
- Compact all
- Corpus of ready-to-use labs and teaching material

blah blah blah...
Contributions

- Improved user interface
  - Stability
  - Functionalities
  - Usability
- Improved labs
  - Self tests
  - Lecture slides

- Publications
  - Technical report
  - Nearly submitted paper
To Do

- Interdomain topology discovery
- Commercial relationships
- Traffic engineering measurements
- Network measurements
- Policy discovery
- Stability
- Game theory
- Emulation of networking tools
- System characterization
- New features
- New & improved labs
- Integration with other products

complexity & effectiveness of algorithms
validate other algorithms
describe the space of solutions
bounds on complexity
case study
Thank you!