Inter-AS relationships

Peering vs transit

Determining AS relationships
Internet AS- structure

- ISPs or AS provide reachability information to other ASs
- Different sizes (Tier-1, Tier-2, Tier-3)
  - Global/transit, Regional, local
  - Different types (transit, hub, multi-homed)
- Within AS, local routing protocols used (optimize path metric)
- Inter-AS concerned with reachability and policy implementation
  - Usually $$ involved with relationships
AS graphs

- Model links to peers as edges
- Send path probes to various routers
- Find IP -> Name mapping from DNS
- Send probes from multiple vantage points
- Get an idea of out-degree for various AS
- Create internet map based on Route views and other tools
- Two Papers:
  - Heuristics for internet map discovery, Govindan et al., Infocom 2000
  - Measuring ISP topologies with rocket fuel, ACM SIGCOMM 2002
ISP Size Distribution

Total number of ISPs: 2700
Visualize Internet Structure?

- Can we get a google map for the Internet?
- Map view, Traffic view, AS view
- Zoom out; zoom in ???
- Tools
  - www.caida.org
- Trace route
  - www.traceroute.org
- Send path probes, know one way routes
- Send from multiple vantage points
- Collect path data
- Data cleaning, analysis, map IP to names etc
Hierarchy of ISPs

- Coverage, structure forms a hierarchy
- Rank of AS or ISP $\alpha$ out-degree – rank order
Traffic patterns

- **Stub AS**
  - Carry only local traffic

- **Multihomed AS**
  - Connected to more than one AS
  - Still local traffic

- **Transit AS**
  - Carries local and non-local traffic
Traditional Internet Model

- **National Backbone Operators**: Sprint, MCI, AGIS, UUnet, PSInet (Settlement Free)
- **Regional Access Providers**: Pay for BW
- **Local Access Providers**: Pay for access BW
- **Customer IP Networks**: Consumers and business customers
AS Commercial Agreements

- Provider-customer:
  - customer pays its provider for transit services

- Peer-peer:
  - exchange traffic between customers
  - Free of charge

- Sibling-sibling:
  - have mutual transit agreement
  - Reachability for the entire internet (load balancing)
  - Backup connectivity in the event of a failure of one of the providers
AS Relationship Graph

AS1

AS2

AS3

AS4

AS5

provider-to-customer edge
Sibling-sibling edge
Peer-peer edge
Provider-Customer

- Provider needs to provide all known routes to the customer
- Provider needs to announce customer routes to everyone
Peer-Peer

- Peers exchange their route and customer routes
- Peering is not transitive
- E.g., Origin Prefix for P1 is $x$, customer C2 prefix is $y$
- Origin prefix for P3 is $a$ and customer C3 prefix is $b$
- P3 will know $x$ and $y$; P1 will know $a$ and $b$
- P2 will know ....
Transit vs Peering

- Peering ASs provide mutual reachability information about customers
  - Non-transitive relationships
  - Good for mutual agreements/direct connection
- Transit ASs provide global reachability information
  - Involves money for carrying traffic
  - Can reach any destination
Why peer?

• Reduce communication costs
  • Peering allows for sharing telco fees/pain!

• Lower latency
  • Direct connection is better

• Better Quality service
Why not to peer

- Traffic asymmetry/investment asymmetry
- Shared pain does not imply shared burden
- If link is down, who do you call?
- Transit may generate revenue as opposed to peer
- No Service level agreements/contractual obligations
William Norton: A business case for ISP peering
Traditional peering model

William Norton: A business case for ISP peering
Cost of peering vs transit

- Fixed cost of peering (colocation)
- Transit cost coming down
- Peering: better handle on performance
Remote Peering model

Remote Peering VLAN(s) delivered to the router

Remote Peering Provider Equipment

Remote Peering
No Router CapEx
No Colocation Fees
No Deployment/Install Fees
Paperwork Reduction for IXP
Near instant turn up
A New Internet Model

Anatomy of a large European IXP – Anja Feldman SIGCOMM 2013
Anatomy of large European IXP, SIGCOMM 2013

Network map 2012+

- Global Internet Core
  - Global Transit/National Backbones
  - Hyper Giants
    - Large Content, Consumer, Hosting CDN
- Regional / Tier2 Providers
  - IXP
  - AS 1
  - AS 2
- Leaf IP Networks

→ IXP's central component
→ Lots of local peering – rich fabric
→ Even flatter AS topology than assumed
Import Routes

- ‡ provider route
- † peer route
- ♡ customer route
- 😊 ISP route

Figure: BGP tutorial by T Griffin
Export Policy

- An AS exports only best paths to its neighbors
  - Guarantees that once the route is announced the AS is willing to transit traffic on that route
- To Customers
  - Announce all routes learned from peers, providers and customers, and self-origin routes
- To Providers
  - Announce routes learned from customers and self-origin routes; does not export its provider or peer routes
- To Peers
  - Announce routes learned from customers and self-origin routes, but does NOT export its provider routes or peer routes
- To Sibling
  - Announce its routes and routes of customers, and as well as its provider or peer routes
Export Routes

- provider route
- peer route
- customer route
- ISP route
# BGP export rules

<table>
<thead>
<tr>
<th></th>
<th>Own Routes</th>
<th>Customer’s Routes</th>
<th>Sibling’s Route</th>
<th>Provider’s Route</th>
<th>Peer’s Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exporting to a Provider</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Exporting to a Customer</td>
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<td>✗</td>
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<td>✗</td>
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<tr>
<td>Exporting to a Sibling</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td></td>
</tr>
</tbody>
</table>
Inferring Autonomous System Relationships in the Internet
Lixin Gao
ACM Transactions on Networking (TON), Dec 2001
Route Propagation Policy

- Constrained by contractual commercial agreements between administrative domains

  e.g., An AS does not provide transit services between its providers
Determining AS Relationships

• Relationships are confidential
• Bound by contractual agreements
• ISPs hide information about what they do
• Very difficult to get a global view of AS relationship graph
• No facebook account for ISPs!!!
Why Infer AS Relationships?

• Crucial part of Internet structure
  • Connectivity does not imply reachability
  • Connectivity alone can not fully characterize structural properties of Internet

• No registry of AS relationships
  • Many ISPs are not willing to reveal their relationships to others in IRR
  • Relationships are evolving; hard to be up-to-date
Applications of AS Relationships

• Construct distance map
• Place proxy or mirror site servers
• Potentially avoid route divergence

• Help ISPs or domain administrators to achieve load balancing and congestion avoidance
• Help ISPs or companies to plan for future contractual agreements
• Help ISPs to reduce effect of misconfiguration and to debug router configuration files
AS Relationship Graph
## Routing Table Entry

<table>
<thead>
<tr>
<th>Network</th>
<th>Next hop</th>
<th>AS Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.24.0/21</td>
<td>134.24.127.3</td>
<td>1740 1 i</td>
</tr>
<tr>
<td></td>
<td>194.68.130.254</td>
<td>5459 5413 1 i</td>
</tr>
<tr>
<td></td>
<td>158.43.133.48</td>
<td>1849 704 702 701 1 i</td>
</tr>
<tr>
<td></td>
<td>193.0.0.242</td>
<td>3333 286 1 i</td>
</tr>
<tr>
<td></td>
<td>144.228.240.93</td>
<td>1239 1 i</td>
</tr>
</tbody>
</table>

![Routing Table Diagram](image)
Route Propagation/Traffic

• Traffic flows opposite to the direction of route announcements
• Collect AS paths for various prefixes
• AS u and AS v have peering relationships:
  • u and v do not appear in paths for prefixes other than own
• AS u is a provider for AS v
  • u, v appears in prefixes
• AS u and v have sibling relationships:
  • u and v and v and u appear in paths for prefixes
Traversals properties

- If it is provider to customer edge, then it can be followed by another provider to customer or sibling-sibling edge
  - Downhill path
- If it customer to provider edge, then it can be followed by another customer to provider edge or sibling to sibling edge
  - Up hill path
- An uphill path can be followed by a downhill path
- Not allowed: a downhill path followed by another uphill path → Valley free property
Valley-Free
Not Valley-Free

peer-to-peer

peer-to-peer

peer-to-peer
Heuristic Algorithms

• Infer provider-customer and sibling-sibling
  • basic
  • refined
• Infer peer-peer
  • final
Basic Algorithms

• Heuristics
  • Top provider has highest degree
• A routing path with the top provider \((u_1, u_2, u_{top}, u_3, u_4)\) has customer to provider \((u_1, u_2, u_{top})\) or provider to customer \((u_{top}, u_3, u_4)\)
• U2 provides transit services for u1 and u3 provides transit services for u4
• If in another path it is found that u1 provides transit services for u2 then conclude u1, u2 are siblings
Refined Algorithm

- Heuristics
  - What if BGP route announcements don’t adhere to valley-free property
  - BGP misconfigurations
- Assume majority or a significant majority > L are correct
- Majority rules
- If majority concludes that
  - u2 provides transit services for u1, then Ignore paths that say u1 provides transit services u2
  - Conclude u2 provides transit services for u1
  - u2 to u1 is a provider to customer edge
Peering classification

- Heuristics
  - Peers don’t transit each other’s traffic
  - Degree of Peers are about the same
- If every path is in the analysis
- Eliminate AS pairs having transit relationships or not likely to peer
- Atmost one consecutive pair can have peering relationship
Experimental Verification

• Routing table from Route Views
  • Connected to 22 ISPs at 24 locations
  • Daily routing table dump

• Routing table from 3 days
  • 1999/9/27, 2000/1/2, 2000/3/9
  • ~1 million routing entries
## Inference Results

<table>
<thead>
<tr>
<th>Date</th>
<th>Total Routing Entries</th>
<th>Total Edges</th>
<th>Sibling-Sibling Edges Inferred by Basic (Percentage)</th>
<th>Sibling-Sibling Edges Inferred by Refined (Ignored Entries)</th>
<th>Peer-Peer Edges Inferred by Final [R=Infinity] (Percentage)</th>
<th>Peer-Peer Edges Inferred by Final [R=60] (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999/9/27</td>
<td>968674</td>
<td>11288</td>
<td>149 (1.3%)</td>
<td>124 (25)</td>
<td>884 (7.8%)</td>
<td>733 (6.5%)</td>
</tr>
<tr>
<td>2000/1/2</td>
<td>936058</td>
<td>12571</td>
<td>186 (1.47%)</td>
<td>135 (51)</td>
<td>838 (6.7%)</td>
<td>668 (5.3%)</td>
</tr>
<tr>
<td>2000/3/9</td>
<td>1227596</td>
<td>13800</td>
<td>203 (1.47%)</td>
<td>157 (46)</td>
<td>857 (6.2%)</td>
<td>713 (5.7%)</td>
</tr>
</tbody>
</table>

13661 provider-customer edges
**Verification from ATT**

<table>
<thead>
<tr>
<th>Our Inference</th>
<th>AT&amp;T Information</th>
<th>Percentage of ASes</th>
</tr>
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<tbody>
<tr>
<td>Customer</td>
<td>Customer</td>
<td>100%</td>
</tr>
<tr>
<td>Provider(1)</td>
<td>Peer</td>
<td>100%</td>
</tr>
<tr>
<td>Peer</td>
<td>Peer</td>
<td>77.4%</td>
</tr>
<tr>
<td></td>
<td>Customer</td>
<td>22.6%</td>
</tr>
<tr>
<td>Sibling</td>
<td>Sibling</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Peer</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Customer</td>
<td>20%</td>
</tr>
<tr>
<td>Nonexistent</td>
<td>Customer</td>
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<td></td>
<td>Peer</td>
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<tr>
<td>Overall</td>
<td>Confirmed</td>
<td>96.3%</td>
</tr>
<tr>
<td></td>
<td>Unconfirmed</td>
<td>3.7%</td>
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</table>
### ATT verification

<table>
<thead>
<tr>
<th>TABLE IV</th>
<th>TABLE V</th>
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<tbody>
<tr>
<td><strong>COMPARING INFERENCE RESULTS FROM REFINED ((L = 1)) AND FINAL ((R = \infty)) WITH AT&amp;T INTERNAL INFORMATION</strong></td>
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<tr>
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</tr>
</tbody>
</table>
Shape-shifting Internet?
NYT 2010, John Markoff
Conclusions and Further Work

- Basic framework for determining AS relationships
- Heuristic algorithm is based on routing entry pattern derived from policy rules
- More vantage points needed
- Rocket fuel paper in SIGCOMM 2002
- Characterizing the Internet Hierarchy from Multiple Vantage Points, Infocom 2002
- [www.traceroute.org](http://www.traceroute.org)
- Lots of interesting ideas driven by business needs
  - Peering, remote peering, CDN, hybrid, transit
- Peering strategy for operators by William Norton