DisCarte: A Disjunctive Internet Cartographer

Rob Sherwood, Adam Bender, Neil Spring

University of Maryland
Introduction

- Network maps are useful
- Existing maps are small, stale, or inaccurate
- Mapping well requires:
  - lots of measurements (lots of error)
  - many techniques (lots of disagreement)
Contributions

- Show how to use Record Route
- DisCarte
  - Cross-validates measurements to reduce error
- Introduce disjunctive logic programming (DLP)
  - Develop divide and conquer scheme to scale DLP to Internet-sized topologies
- Validate DisCarte against public topologies
Contributions

- Show how to use Record Route
- DisCarte
  - Cross-validates measurements to reduce error
- Introduce disjunctive logic programming (DLP)
  - Develop divide and conquer scheme to scale DLP to Internet-sized topologies
- Validate DisCarte against public topologies
Topology Inference
Topology Inference
Topology Inference
Topology Inference
Topology Inference
Topology Inference
Topology Inference

A

Vantage

B
Topology Inference

A

B

Routers
Topology Inference

A

Links

B
Topology Inference

IP addresses are assigned to interfaces
IP Addresses Are Interfaces

- All routers have multiple interfaces
- Many-to-one mapping from interfaces to routers
IP Addresses Are Interfaces

- All routers have multiple interfaces
- Many-to-one mapping from interfaces to routers
Topology Inference
Topology Inference

IP addresses are assigned to interfaces
Topology Inference
Topology Inference

IP addresses are assigned to interfaces

A

B
Topology Inference

Traceroute discovers incoming interface
Topology Inference
Topology Inference
Topology Inference
Topology Inference
Topology Inference
Topology Inference

Reverse path finds distinct interfaces
Ambiguous Topologies
Ambiguous Topologies
Ambiguous Topologies
Ambiguous Topologies
Ambiguous Topologies

Need to map interfaces to routers
Ambiguous Topologies

Alias resolution

Diagram showing a network topology with nodes A and B.
Alias Resolution

- Direct probing techniques
  - Source IP matching: Mercator
  - IP ID matching: Rocketfuel
  - 32% of IP addresses are unresponsive

- Indirect resolution techniques are incomplete and have false positives

- Bad/missing aliases affect mapping
The Importance of Aliases

Actual

Rocketfuel
The Importance of Aliases

Actual

Rocketfuel
The Importance of Aliases

Actual

Rocketfuel
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases

RR discovers outgoing interfaces
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases
Record Route Finds Aliases

RR and TR addresses are aliases
Record Route Finds Aliases

RR implementations are under-standardized
## RR Implementations

<table>
<thead>
<tr>
<th>Type</th>
<th>TTL decremented before RR field updated</th>
<th>Interface</th>
<th>Decrement TTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Departing (61.9%)</td>
<td>Yes</td>
<td>Outgoing</td>
<td>Yes</td>
</tr>
<tr>
<td>MPLS (13.3%)</td>
<td>Like Departing, but does not implement RR on MPLS interfaces</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NotImpl (9.1%)</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Arriving (7.1%)</td>
<td>No</td>
<td>Outgoing or loopback</td>
<td>Yes</td>
</tr>
<tr>
<td>Lazy (5.8%)</td>
<td>?</td>
<td>?</td>
<td>No if RR is set</td>
</tr>
<tr>
<td>Mixed (2.7%)</td>
<td>No</td>
<td>Outgoing, but incoming if TTL=1</td>
<td>Yes</td>
</tr>
<tr>
<td>Hidden (&lt;1%)</td>
<td>?</td>
<td>--</td>
<td>No</td>
</tr>
</tbody>
</table>
RR Diversity

Src → A → B → C → Dst
RR Diversity
RR Diversity

RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
RR Diversity

Record route

Traceroute
Merged TR and RR
Merged TR and RR
RR is Hard to Use

- Implementation diversity adds ambiguity to RR and TR matching
  - Each traceroute hop adds 0-4 RR addresses
  - 7 implementations times 7 implementations
  - Alias resolution requires implementation classification
  - Bad classifications lead to bad aliases

- RR probes take different paths
Example Merge

TR only

<table>
<thead>
<tr>
<th>S1</th>
<th>R2</th>
<th>Anonymous</th>
<th>R4</th>
<th>R5</th>
<th>E16</th>
</tr>
</thead>
</table>

TR and RR

<table>
<thead>
<tr>
<th>S1</th>
<th>R2</th>
<th>R3 (Departing)</th>
<th>R4 (Departing)</th>
<th>R4 (Lazy)</th>
<th>E16</th>
</tr>
</thead>
<tbody>
<tr>
<td>202.112.38.34</td>
<td>202.112.53.214</td>
<td>202.112.62.213</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202.112.38.26</td>
<td>202.112.53.214</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202.112.38.30</td>
<td>202.112.53.217</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202.112.38.25</td>
<td>202.112.53.213</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202.112.38.29</td>
<td>202.112.53.217</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>202.112.38.25</td>
<td>202.112.53.213</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E16</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>planetlab4.ml.cs.sunysb.edu (130.245.145.153)</td>
<td></td>
</tr>
</tbody>
</table>
TR only

S1
zzu1.6planetlab.edu.cn
(219.243.200.37)

R2
219.243.200.38

Anonymous
??

R4
202.112.62.81

TR and RR

S1
zzu1.6planetlab.edu.cn
(219.243.200.37)

R2 (Arriving)
219.243.200.38
202.112.53.218
202.112.53.214
202.112.38.34
202.112.38.30
202.112.38.26

R3 (Departing)
202.112.62.86
202.112.62.82
202.112.62.210
202.112.53.217
202.112.53.213
202.112.38.33
202.112.38.29
202.112.38.25

R4 (Departing)
202.112.62.85
202.112.62.84
202.112.62.81
202.112.62.209

cdbj3.cernet.net
(202.112.46.16)
DisCarte System
Disjunctive Logic Programs

- **DLP**: Inference engine and constraint solver
- **Facts**: TR and RR measurement
  - probe(src=128.8.128.118, dst=128.208.4.198, ttl=9, resp=206.196.178.90)
- **Inference rules**
  - 0 new RR entries $\rightarrow$ Arriving to Departing, NotImpl to Not Impl, etc...
- **Constraints:**
  - Observed engineering practices
Engineering Practices

Prefer models that violate fewest beliefs

- Routers rarely have self-loops
- Linked IPs are typically off-by-one
- Prior techniques are most often correct
- Hidden routers are uncommon
Scaling Challenges

- Data collections
  - 387 sources, 376,408 destinations
  - 100,256 routers found
- Fact generation
  - 1.3 billion trace facts
- 1475 lines of DLP code
- DLP has exponential runtime
Divide and Conquer

- Collect multiple views of the same topology features
  - Single view results in too many conflicts
- Keep inputs facts sizes manageable
- Aggregate output facts
- Work out potential disagreements
Divide and Conquer

- Collect multiple views of the same topology features
  - Single view results in too many conflicts
- Keep inputs facts sizes manageable
- Aggregate output facts
- Work out potential disagreements
Divide and Conquer

- Collect multiple views of the same topology features
  - Single view results in too many conflicts
- Keep inputs facts sizes manageable
- Aggregate output facts
- Work out potential disagreements
Divide and Conquer Scheme

- Conflicts reduced from 1,547 to 28

**Step #1**

**Two-Clique**

**Step #2**

**Triangle Subset**

Overlap for Cross-Validation
Abilene Network

DisCarte

Actual

Rocketfuel
Abilene Network

DisCarte

Actual

Rocketfuel
Conclusions

- Shown how to use Record Route
- Described DisCarte
  - Cross-validates measurements to reduce error
- Introduced disjunctive logic programming (DLP)
  - Developed divide and conquer scheme to scale DLP to Internet-sized topologies
- Shown DisCarte was more accurate than previous techniques
Conclusions

- Shown how to use Record Route
- Described DisCarte
  - Cross-validates measurements to reduce error
- Introduced disjunctive logic programming (DLP)
  - Developed divide and conquer scheme to scale DLP to Internet-sized topologies
- Shown DisCarte was more accurate than previous techniques
Published Networks

Bar chart showing the distribution of different network types across various categories:
- Abilene
- CANET
- Geant
- NLR

Networks include:
- Discarte
- Rocketfuel
- Passenger
- Reality

Categories for comparison include:
- Missing
- Good
- Merged
- Split

The chart visually represents the proportion of each category for each network type.