Modeling Internet-wide routing and policies

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Agenda

• **Background**
  - Part 1: AS topology and routing
    - Path diversity
    - An agnostic topology model
  - Results

• Part 2: routing policies
  - Bounds on policy granularity
  - Studying the granularity of policies

• Conclusions
A simple Internet

Inter-domain link
Intra-domain link
Advertising a reachable prefix

Inter-domain link
Intra-domain link
Choice of paths towards $p$
AS-paths towards $p$

AS 1

AS 2

AS 3

AS 4

AS 5

AS 6

Effect of policy

AS path

Inter-AS edge
Why modeling the Internet?

- Predicting the traffic flow from one AS to another
- Predicting the impact of topological changes
- Predicting the impact of changes in peering relationships and routing policies

For that we need to know:

- How routes propagate across the network? (part 1)
- Which policies are applied between ASes? (part 2)
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Observed AS-paths

AS5511 (France Telecom)

AS2914 (Verio)

AS3549 (Global Crossing)

AS7911 (Wiltel/Level 3)

AS3356 (Level 3)

AS3561 (C&W)

AS3356 (Level 3)

AS4716 (POWEREDCOM)

AS24249 (JWAY)

AS4694 (IDC)
Required routers per AS

<table>
<thead>
<tr>
<th>Percentile</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>90</th>
<th>95</th>
<th>98</th>
<th>99</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>max unique AS paths</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>23</td>
</tr>
</tbody>
</table>
One router per AS

**Pro’s:**

- Large fraction of the observable AS-paths can still be matched without having multiple routers [Mao’05]
- Some policies seem to be defined on a per neighboring AS basis [Gao’00, Subramanian’02]

**Con’s:**

- ASes do contain multiple routers and propagate multiple paths
- With one router per AS one cannot explain 100% of the observed paths
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Data

• Snapshot of BGP data from more than 1,300 observation points (700 ASes): widest coverage of the Internet ever used!
• 300,000 prefixes (more specifics)
• 4,730,222 unique AS paths
• 21,178 ASes
• 58,903 AS-level edges
• Partitioning of observation points into training and validation:
  • Training: randomly select 2/3 of observation points
  • Validation: take the remaining 1/3 of observation points
• AS-level topology built from the union of all known AS-paths of the data (both training and validation)
Matching simulations and data

- **Best match:** simulation selects a path that was observed in reality
- **RIB-In match:** simulation learns a path that was observed in reality, but did not pick that path as best
- **Not found:** No router at the considered AS in the simulation learns about the path that was observed in reality
Approach

- Build a model of routing paths based on training dataset
- This model must be 100% consistent with observed AS paths from the training dataset (100% best matches)
- Look at how this model performs for validation dataset in terms of the matches
Reproducing observable paths

Assumptions:

• Without policies, shortest paths are propagated
• If a non-shortest path is observed, it means some policy has been applied somewhere
• Only observable paths give us usable information about the AS-level topology and potential routing policies

Goal: Reproduce perfectly observed paths (training set) in the simulation model
Simulation principles

- **Split AS**, if *multiple paths* must be propagated
- **Filter shortest paths**, if *longer paths* must be propagated
- **Get rid of random decisions** (*lowest router-ID*), when supporting information is available
One router per AS and shortest paths are chosen
Split AS into several “quasi-routers” when several paths must be propagated
How to propagate longer paths?

Filter shorter paths when a longer path must be observed
How to propagate longer path?

Filter also on “egress”-part of shorter path router

prefix p
Fix arbitrary decisions when several equal length simulated paths occur
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Training dataset

Training achieves 100% matches

- **RIB-In**
- **Best match**
- **Literature**
Validation dataset

Accuracy: 63% best matches - 94% RIB-In matches
Discussion

• Model achieves what it was supposed to on training:
  • Literature cannot match (RIB-In) more than 87% of the paths because of one router assumption and gnostic policies

• Model performs quite well on validation:
  • 94% of the paths are propagated correctly, 63% correctly predicted
  • Only a single case of validation of AS-topology model in [Mao’05] on 3 observation points
  • We used more than 400 observation points
Discussion

- 63% of the paths in the validation dataset were correctly predicted

**Reasons:**
- Trained paths limit the choice we have to do to predict validation paths
- We do not reverse engineer the actual Internet!
- We do not know the real policies!
- We build simplest policies which are consistent with our observations.

=> **Agnosticism leads to better results than incorrect assumptions**
Discussion

• So far we have been agnostic about routing policies
• Per-prefix filtering is likely to be too fine and not-scalable
• What is the impact of policies and how to implement them in the model?
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Bounds on policy granularity

- Finest: per-prefix
- Coarsest: per-neighbor
BGP atoms

- 2 prefixes belong to the same BGP atom if all observed AS paths are the same

- Limitations:
  - biased by observation points
  - no insight about policies
AS relationships

- Customer-provider or peering
- Defined on a per-neighbor basis
- Properties:
  - valley-free, e.g. don’t export provider routers to providers
  - route preference: customer > peer > provider
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Per-prefix filters: inference

- Simulate route choice with CBGP
- Identify mismatches between paths in data and in simulations
- For each mismatch, find out candidate filters
Per-prefix filters: popularity

- **Experiment:**
  - Simulate 50,000 prefixes and their routes
  - Infer filter candidates
- **Filter popularity:** for how many prefixes was a candidate identified?
- **Results:**
  - 25% of filter candidates useful for less than 236 prefixes
  - 5% of filter candidates useful for more than 8,000 prefixes
AS relationships: consistency with route propagation

• Experiment:
  - Infer AS relationships on our data
  - Run BGP simulation

• Results:
  - check if paths agree with simulations
  - Only 14.5% AS-path agreement

• Causes?
  - Topology too simplistic
  - Wrong AS relationships
AS relationships: reasons for inconsistency

- Valley-free property:
  - 99% of filters are on valleys

- Route preference: insufficient to predict path choice
Studying the granularity of policies

- Related work
  - BGP atoms too fine (origin AS)
  - AS relationships too coarse

- Our approach:
  - Per-prefix filters: consistent with observed route propagation but too detailed
  - AS relationships: bad at predicting path choice

- Next-hop atoms
Next-hop Atoms

- Describes granularity of path choice by an AS:
  - set of neighboring ASs used for best routes
- Possible next-hop atoms: power set of all neighbor ASs
ASs in next-hop atoms

- Most NHAs consist of a few neighboring ASs
- Significant fraction of NHAs with more than 1 neighbor => strict preferences not sufficient
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Conclusions

• Modeling routing diversity requires more than one router per AS
• Proposed a first **agnostic** model that perfectly reproduces observations
• Model also predicts well data from **validation** dataset
• Modeling policies is hard:
  – per-prefix policies are too fine
  – AS relationships do not help
  – Next-hop atoms can describe the solution
Further work

- Testing ability of model to predict paths under topological changes:
- Studying impact of missed details about topology and routing on model accuracy
- Adding traffic to model