Inferring Link Weights using End-to-End Measurements

Ratul Mahajan
Neil Spring
David Wetherall
Tom Anderson

University of Washington
Motivation: topology $\rightarrow$ routing

- Accurate and detailed ISP topologies are now available
- But how to route over them?
  - Hop count and latency based models are poor
- Obtain a link weight based routing model
  - Most common model (OSPF, IS-IS, RIP)
  - Disclaimer: these are not the real weights!
- Also helpful in understanding intra-domain traffic engineering
Problem definition, basic solution

- **Given:**
  - Map of a network w/ weighted shortest path routing
  - Routing - chosen paths between node pairs
- **Wanted:**
  - Weights that characterize routing

- **Keys to the solution**
  - All chosen paths between a node-pair have the same weight (ECMP)
  - This weight is less than that of other possible paths

- **A constraint-based solution**
  1. \( w_{ad} + w_{dg} = w_{ab} + w_{be} + w_{eg} \) \([\text{ADG}=\text{ABEG}]\)
  2. \( w_{ad} + w_{dg} < w_{ac} + w_{cg} \) \([\text{ADG}<\text{ACG}]\)
  3. \( w_{ad} + w_{dg} < w_{ac} + w_{cf} + w_{fg} \) \([\text{ADG}<\text{ACFG}]\)
  4. \( w_{ad} + w_{dg} < w_{ab} + w_{bd} + w_{dg} \) \([\text{ADG}<\text{ABDG}]\)
  5. \( w_{ad} + w_{dg} < w_{ad} + w_{de} + w_{eg} \) \([\text{ADG}<\text{ADEG}]\)
  6. \( w_{ad} + w_{dg} < w_{ab} + w_{bd} + w_{de} + w_{eg} \) \([\text{ADG}<\text{ABDEG}]\)
Making it tractable

Problem: too many constraints
  • Exponential in number of nodes

Solution: use knowledge of chosen paths between other node-pairs to remove redundant constraints

Example
  • CG is a chosen path
  • The following exists in the system
    - \( w_{cg} < w_{cf} + w_{fg} \)

1. \( w_{ad} + w_{dg} = w_{ab} + w_{be} + w_{eg} \)
2. \( w_{ad} + w_{dg} < w_{ac} + w_{cg} \)
3. \( w_{ad} + w_{dg} < w_{ac} + w_{cf} + w_{fg} \)
4. \( w_{ad} + w_{dg} < w_{ab} + w_{bd} + w_{dg} \)
5. \( w_{ad} + w_{dg} < w_{ad} + w_{de} + w_{eg} \)
6. \( w_{ad} + w_{dg} < w_{ab} + w_{bd} + w_{de} + w_{eg} \)
Hello, real world!

Limitations of routing information gathered using traceroute

- **Problem:** some observed paths are non-chosen paths
  - Due to transient events such as failures
  - Renders the constraint system inconsistent
  - **Solution:** use error variables, minimize the weighted sum of errors
    1. $w_{ad} + w_{dg} - e_{adg} = w_{ab} + w_{be} + w_{eg} - e_{abeg}$
    2. $w_{ad} + w_{dg} - e_{adg} < w_{ac} + w_{cg}$

- **Problem:** all chosen paths between a node-pair may not be observed
  - Due to a small number of measurements between the node-pair
  - $w_{ad} + w_{dg} - e_{adg} < w_{ac} + w_{cg}$ (but ACG may also be a chosen path for a→g)
  - **Solution:** $w_{ad} + w_{dg} - e_{adg} \leq w_{ac} + w_{cg}$
Evaluation

- **Dataset**: backbone topologies collected by Rocketfuel
  - 600+ vantage points, 9-200K+ traceroutes
  - Telstra (au), Ebone, Tiscali (eu), Abovenet, Exodus, Sprint (us)

- **Compare the inferred weights with three alternate models**
  - Hops: Minimum hop count path
  - Latency: Minimum latency (geographical) path
  - HopLat: Minimum latency minimum hop count path

- **Criteria**
  1. What fraction of all observed paths fit?
  2. What fraction of dominant paths fit
  3. What is the accuracy of multi-path prediction?
Fraction of all paths that fit

- Weights describe the routing well
  - Weights: 87-99%
  - Hops: 67-92% (best alternate metric)
    - Performance level of hops is misleading (2 slides away)
Fraction of dominant paths that fit

- Dominant path: most common path between a node-pair

- Weights fit more dominant paths
  - Weights: 76-98%
  - Hops: 49-82% (best alternate metric)
Accuracy of multi-path prediction

- Classify routing characterization between a node-pair as one of:
  - Full: all predicted paths were observed (accurate)
  - Partial: some predicted path was not observed (over prediction)
  - None: none of the predicted paths was observed

- Hops tends to predict more paths as being the preferred paths:
  - 4-20% node-pairs are partial, only 47-81% full

- Weights: 84-99% full, 1-3% partial
Conclusions

- A novel constraint-based approach to approximate intra-domain link weights
- The inferred weights characterize intra-domain routing better than hop count and latency based metrics
  - Good predictive power

Future work
- Investigate the “realism” of our weights
  - Predict backup paths
- Understand intra-domain traffic engineering policies
- Study link weight changes and link failures