On routing controls in ISP topologies: A structural perspective

Ryota Fukumoto, Shin'ichi Arakawa, Masayuki Murata
Graduate School of Information Science and Technology
Osaka University, Japan
r-fukumoto@ist.osaka-u.ac.jp

Contents
- Background
  - Structure of Internet topology
- Objectives
- A heuristic routing algorithm
- Simulation
  - Models
  - Results
    - Load distribution
    - Impact of parameter settings
- Conclusion and future works

Power-Law networks
- The connectivity of nodes in the Internet follows power-law
- The probability that a node is connected to \( k \) other nodes:
  \[
  P(k) \approx \alpha k^{-\gamma}
  \]
- A few nodes which have many links
- Most nodes which have only a few links

Related works
- Modeling power-law topology
  - BA (Barabasi-Albert) model
    - Nodes are added incrementally (Incremental growth)
    - Added nodes are connected to the larger degree nodes without considering physical distance (Preferential attachment)
- Evaluating the distributions of link/node load
  - BA model based
  - Minimum hop routing based
- Only the degree distribution does not determine the network structure
- Other various routings have been proposed

Modeling of Internet router level topology
- Power-Law arise [1]
  - For maximizing network throughput
  - Under the router’s technical constraints
- Modeled like Figure.
  - At smaller-degree nodes:
    - Links can have large capacity for backbone
  - At larger-degree nodes:
    - Links must have small capacity for aggregating

ISP networks
- Sprint network
  - Following power-law
  - 467 nodes
  - 1292 links
- Highly clustered [2]
  - The rectangles appear
  - Locally connected like a bottom Figure

Objectives

- Investigate
  - How structural characteristics of Internet's power-law topologies affect the performance of the routing mechanisms
  - Difference between ISP topology and BA model topology

- Evaluate the load distribution of Internet router level topologies from the view point of structural properties
  - Minimum hop routing
  - Optimal routing
    - takes huge time to calculate routes
    - Our heuristic routing

Heuristic routing method

- Select routes following two policies
  - Avoiding the higher-degree nodes
    - At larger-degree nodes, links have small capacity and traffic concentrates due to router's technology constraints
  - Selecting larger capacity links

- Incrementally determine the route of each node-pair
  - After we obtain the route of a node-pair
    - The remaining costs of all links are updated based on the selected routes
    - Added by following expression: $\alpha \frac{C_{max}}{C}$
      ($\alpha$ is parameter, $C_{max}$ is maximum link capacity, and $C$ is link capacity)

Simulation model

- Network models
  - ISP router level topologies
    - Sprint topology, AT&T topology
  - BA model topology
- Traffic model
  - Each node-pair generates the same amount of traffic
- Link capacity
  - Determined based on the technical constraint of router
    - Maximize the throughput with minimum hop routing
- Routing method
  - Minimum hop routing
  - Optimal routing
    - Minimum the maximum link utilization using flow deviation method
  - Heuristic routing

Comparison of network throughput

- The network throughput
  - The amount of traffic that the network can accommodate
- Optimal ratio
  - The ratio of Optimal routing to Minimum hop routing
- Results
  - ISP topologies have lower network throughput
  - ISP topologies have lower Optimal ratio

<table>
<thead>
<tr>
<th></th>
<th>Sprint</th>
<th>AT&amp;T</th>
<th>BA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum hop</td>
<td>408.85</td>
<td>177.38</td>
<td>264.45</td>
</tr>
<tr>
<td>Proposed</td>
<td>405.82</td>
<td>249.95</td>
<td>244.75</td>
</tr>
<tr>
<td>Optimal</td>
<td>627.85</td>
<td>337.34</td>
<td>270.37</td>
</tr>
<tr>
<td>Optimal ratio</td>
<td>2.44</td>
<td>2.37</td>
<td>7.43</td>
</tr>
</tbody>
</table>

Comparison of link load distribution (1/2)

- Minimum hop routing (red line)
  - Some links are congested
- Optimal routing (green line)
  - The utilizations are significantly reduced
  - Most links have almost same utilization on the BA topology

Comparison of link load distribution (2/2)

- Our heuristic routing (blue line)
  - High utilization links are still different from optimal routing on Sprint topology
  - Similar distribution to the optimal routing
- Effects of optimal and heuristic routing
  - Not significant in the Sprint topology
  - ISP topology have following characteristics
    - Higher clustered
    - Locally connected

Congested Not Congested Reduced Almost same
The impact of parameter settings

- Parameter alpha gives priority for selecting routes
  - Large alpha causes shorter hop routes
  - Small alpha causes high bandwidth routes
- When the alpha is between 1 and 10
  - Maximum link utilization is much decreased
- Only on the BA topology and the Level3 topology
  - High maximum link utilization under large alpha

The relation between parameter alpha and maximum link utilization

- The BA topology and the Level3 topology
  - Large-degree nodes are located at “center” of the topologies
  - “Center” means where other nodes reach the nodes within a few hop count
  - Traffic concentrates to the larger degree nodes at center of topology

  - Maximum link utilization increases under large alpha

- The Sprint, AT&T, and Verio topology
  - Large-degree nodes are not located at center of the topologies
  - Average hop count from maximum degree node to the other nodes

    | Topology | Sprint | AT&T | Verio | Level3 | BA |
    |----------|--------|-------|-------|--------|----|
    |          | 2.89   | 3.99  | 3.60  | 2.22   | 2.15 |

Conclusion and future works

- Conclusions
  - We evaluated several routing methods on ISP topologies
    - Minimum hop routing
    - Optimal routing
    - Our heuristic routings
  - Effects of Optimal routing method are not significant in the Sprint topology
  - Since ISP topology have following characteristics
    - Higher clustered
    - Locally connected
  - Our heuristic routing method achieve the similar distribution of link/node load to optimal routing

- Future works
  - Evaluating with more realistic traffic demand
  - Evaluating scalability our heuristic routing method