Modularity Structure and Traffic Dynamics of ISP Router-level Topologies

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Research Background

• The Internet is facing with ever-changing networking technologies and applications
  • Adaptability to traffic fluctuation and various quality demands is required in the Internet
  • Understanding traffic dynamics of the Internet is important for designing future networks
  • Flow control in the transport layer affects the traffic dynamics
  • However, it is not clear how the topological structure impacts on traffic dynamics

Flow Control and Statistical Properties of Traffic

• Internet traffic exhibits long-range dependence (LRD)
  • Traffic fluctuation appears to be independent of measurement time scale
  • One of the reasons is flow control in the transport layer [4]
  • Because of flow control functionality of TCP: slow start, congestion avoidance
  • Stop-and-wait flow control causes LRD, too
  • However, previous studies deal with simple, and small topologies

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Investigating the relationships between traffic dynamics and topologies

Investigation with Large-scale Topologies

• Investigating with small-scale topologies is insufficient
  • In large-scale topologies, competition of sessions occurs not only on the bottleneck link, but also on other links
  • Interactions between multiple competing sessions are difficult to examine

• To reveal the traffic dynamics of real topologies, we discuss how end hosts affect each other in large-scale topologies

Research Purpose

• Focusing on power-law characteristic of ISP topologies
  • Power law: Probability \( P(k) \) that a node has \( k \) links is proportional to \( k^{-\alpha} \)
  • Different topologies having the same degree distribution can exist
  • Difference in structure leads to difference in performance [7]

By comparing the statistical properties of traffic in various topologies, understanding characteristics of Internet traffic dynamics and its causal structure

Network Topologies

• Comparing two types of topologies having power-law characteristics
  • To reveal the relationships between structures and traffic dynamics
  • Measured ISP (router-level) topologies
    • ISP: Internet Service Provider
  • Generated BA topologies

• Two topologies having different structures
  • 523 nodes and 1304 links
  • AT&T Topology: Measured router-level topology of AT&T
  • Measured by Rocketfuel [6]
  • BA (AT&T) Topology: Generated by BA model [5]

Classification of node functions
- Separating a topology into some modules [10]
- Participation coefficient, $P$ ($0 \leq P \leq 1$)
- Within-module degree, $Z$

Comparison the structures of the 2 topologies
$Z_i$ is large, and $Z_j$ is small

The property of structure of the AT&T topology
- The AT&T topology has many “Provincial Hubs”
  - Hub nodes have many links connecting to the nodes in the same module
  - Modules are connected by a few inter-module links (high-modularity structure)
  - Packets are first aggregated at hub nodes, and then forwarded via inter-module links

Simulation Evaluation
- Network model
  - Each link has the uniform link capacity and buffer size
  - Network load is defined by the number of sessions
    - The number of sessions is 100,000
  - Source and destination node pairs are selected randomly
  - Two flow control models
    - Stop and wait and TCP Reno model
- Evaluation metric
  - Queue length fluctuation

Evaluating Queue Length Fluctuation
- Queue length fluctuation impacts on network throughput
  - Drastic queue length fluctuation leads to non-constant queuing delay
- Evaluating fluctuation with Hurst parameter ($H$)
  - Index of Long-range Dependence ($0.5 < H < 1$)
  - Measurement Hurst parameters for each link with R/S plot method

Topologies and Fluctuation
- The number of highly fluctuating links increases by TCP
- Because of flow control functionality of TCP
- In the AT&T topology, the number of highly fluctuating links is smaller than that in the BA topology
  - Structure of the AT&T topology reduces highly fluctuating links
Evaluation of other ISP topologies

- Each ISP topology has higher modularity value and reduces the number of fluctuating links
  - Modularity is calculated using the method in [9]

<table>
<thead>
<tr>
<th>Topology</th>
<th>Nodes</th>
<th>Links</th>
<th>Modularity</th>
<th>Ratio of Fluctuating Links</th>
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</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
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<td>1304</td>
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<tr>
<td>Sprint</td>
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<td>1280</td>
<td>0.63</td>
<td>0.26</td>
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<td>BA</td>
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<td>Teltara</td>
<td>296</td>
<td>594</td>
<td>0.77</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Correlation between Modularity and Fluctuation

- Comparison between the three topologies having different modularity value (Q)
  - Configured by changing the number of inter-module links
  - As the number of inter-module links increases, the modularity value decreases

Relationships between link load and fluctuation

- When a link load is low, the queue length does not fluctuate
  - The number of inter-module links
  - The queue length of the tributary links to the inter-module links fluctuates due to the dynamics of each TCP session

High-modularity Structure Prevents Fluctuation (1/2)

- The large number of TCP sessions is aggregated at a few inter-module links
  - The queue length keeps nearly-constant due to a limit of buffer size

High-modularity Structure Prevents Fluctuation (2/2)

- Fluctuation occurs only around the connector nodes
  - Connector-hub nodes rarely exist in high-modularity structure

Conclusion and Future Work

- Investigating the interaction between the structures of topologies and flow control
  - The functionality of TCP makes the queue length to fluctuate
  - The high-modularity structure of the ISP topologies reduces the ratio of highly fluctuating links
    - As the modularity value decreases, the ratio of highly fluctuating links decreases
    - The modularity structure is essential to reduce fluctuation

Future work

- Developing a topology generation method that reproduces the modularity structure and apply it to performance evaluations