Dynamics of Feedback-induced Packet Delay in Power-law Networks

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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
  - Dynamics of TCP traffic of simple topologies has been revealed [7]
  - However, complex topologies impacts on traffic dynamics

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Evaluating traffic dynamics of realistic topologies is important

[7] K. Park, G. Kim, and M. Crovella, "On the relationship be- tween file sizes, transport protocols, and self-similar network traffic," in Proceedings of the International Conference on Network Protocols (ICNP), pp. 171–180, Oct. 1996.

Relationships between topologies and performance

- The Internet topology has a power-law degree distribution
  - Power-law: Probability $P(k)$ that a node has k links is proportional to $k^{-\gamma}$
  - Traffic dynamics of power-law topologies has been discussed
- Different topologies having the same degree distribution can exist
  - Structure of topologies are defined not only by degree distribution, but also by other factors
  - Difference in structure leads to difference in performance [4]

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The power-law degree distribution is not enough to discuss performance of networks

[4] R. Fukumoto, S. Arakawa, and M. Murata, "On routing controls in ISP topologies: A structural perspective," in Proceedings of Chinacom, Oct. 2006.

Research Purpose

- Understanding traffic dynamics caused by interaction between topologies and end-to-end flow control
  - How topological structures impact on end-to-end delay?
  - How interactions between topologies and flow control impacts on traffic fluctuation?

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Understanding characteristic traffic dynamics and its causal structure of the Internet topology

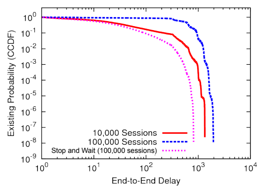
Simulation Evaluation

- Topologies: Two topologies having different structures
  - 523 nodes and 1304 links
  - AT&T Topology: Measured router-level topology of AT&T
  - BA Topology: Generated by BA model [2]
- Network model
  - Each link has the uniform link capacity and buffer size
  - Network load is defined by the number of sessions
  - Source and destination node pairs are selected randomly
  - Two flow control models
    - Stop and wait and TCP Reno model

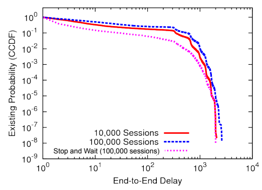
[2] A.-L. Barabási and R. Albert, "Emergence of scaling in random networks," Science, vol. 286, pp. 509–512, Oct. 1999.

End-to-end Delay Distribution

- End-to-end delay distribution of the AT&T topology does not change widely
- Long end-to-end delay in the BA topology
  - Congestion occurs 4 times larger than that in the AT&T topology



BA Topology



AT&T Topology

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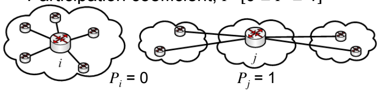
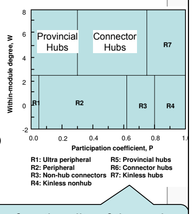
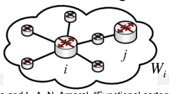
Comparison the structures of the 2 topologies

- Why congestion likely occur in the BA topology?
  - Comparing the structures of the two topologies
- Classification of node functions [12]
  - Separating a topology into some modules
  - Participation coefficient, P $[0 \le P \le 1]$





  - Within-module degree, W



The functionality of the nodes categorized by this figure

[12] R. Guimera and L. A. N. Amaral, "Functional cartography of complex metabolic networks," Nature, vol. 433, pp.895-900, 2005.

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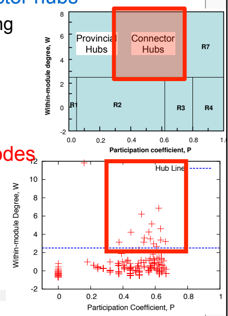
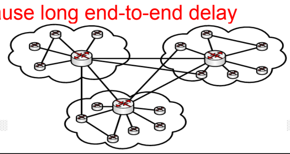
The property of structure of the BA topology

- The BA topology has many "Connector hubs"
  - Hub nodes have many links connecting to other modules
- Hub nodes transfer a large amount of packets between modules

Congestions tend to occur near hub nodes and cause long end-to-end delay





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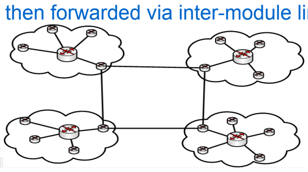
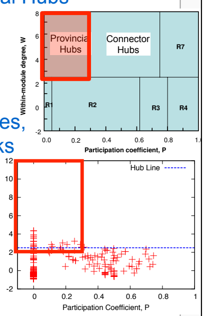
The property of structure of the AT&T topology

- 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
- Packets are first aggregated at hub nodes, and then forwarded via inter-module links





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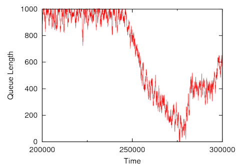
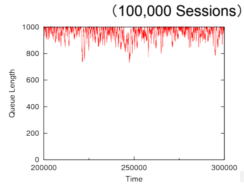
Evaluating Queue Length Fluctuation

- Queue length fluctuation impacts on performance of sessions
  - 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

(100,000 Sessions)



Ex. $H \fallingdotseq 1.0$



Ex. $H \fallingdotseq 0.5$

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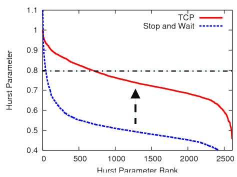
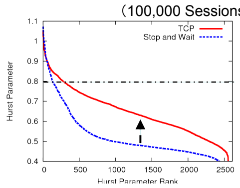
Relationships between Topologies and Fluctuation

- The number of highly fluctuated links increases by TCP
  - Because of flow control functionality of TCP
- In the AT&T topology, the number of highly fluctuated links is smaller than that in the BA topology
  - Structure of the AT&T topology reduces highly fluctuated links

(100,000 Sessions)



BA Topology



AT&T Topology

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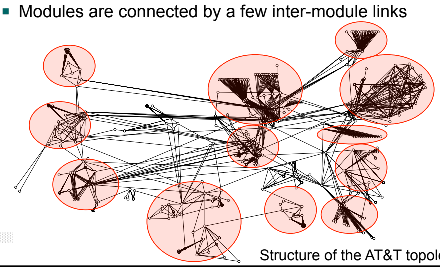
Structure of the AT&T Topology

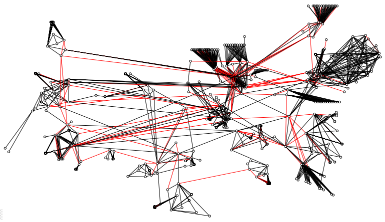
- High-modularity structure
  - Hub nodes have many links connecting to the nodes in the same module
  - Modules are connected by a few inter-module links



Structure of the AT&T topology

Traffic Fluctuation in the AT&T Topology (10,000 Sessions)

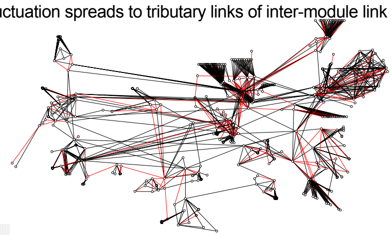
- Inter-module links have high Hurst parameters
  - Packets concentrate on inter-module links
- Intra-module links have low Hurst parameters



The links having high Hurst parameter ($H \geqq 0.8$) (10,000 Sessions)

Traffic Fluctuation in the AT&T Topology (100,000 Sessions)

- As the number of sessions gets higher, highly fluctuated inter-module links decrease
- Part of intra-module links have high Hurst parameters
  - Fluctuation spreads to tributary links of inter-module link



The links having high Hurst parameter ($H \geqq 0.8$) (100,000 Sessions)

Conclusion and Future Work

- Interaction between topologies and end-to-end flow controls
  - TCP improves network throughput
  - TCP makes long delay and drastic queue length fluctuation
- The AT&T topology reduces the highly fluctuated links
  - Low load: Intra-module links have low Hurst parameter
  - High load: Inter-module links have low Hurst parameter
- Future work
  - Link capacity allocation method considering traffic dynamics