

Osaka University Advanced Network Architecture Research Group
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Analyzing and Modeling Router—level Internet Topology

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Outline

- Research background
 - ISP-level topology
- Models for Internet topology
 - BA
 - HOT (Heuristically Optimized Topology)
- Structural analysis
 - Network motifs
- Application to the routing control
- A Model for router-level topologies
- Concluding remarks

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ISP-level topologies

- The degree distribution of Internet topology follows power-law
- Router-level topology
 - Sprint topology measured in Ref. [1]
 - 467 nodes
 - 1292 links
 - Degree distribution: power-law like distribution
- We need to model Internet router level topology
 - To evaluate network control

Degree distribution of Sprint topology

[1] N. Sprint, R. Mahajan, D. Wetherall, and T. Anderson, "Measuring ISP topologies with rocketfuel," *IEEE/ACM Transactions on Networking*, vol. 12, pp. 2–16, Feb. 2004.

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Related works: BA model

- Well-known BA (Barabasi-Albert) model
 - Incremental growth: one-by-one node attachment
 - Preferential link attachment to higher degree nodes
 - Attachment probability to nodes j : $d_j / \sum_i d_i$
 - These two simple rules make topologies being power-law
- Structural properties of BA model
 - Hub-nodes are located at center of the topology
 - Hub-nodes have important role for connecting nodes.

Degree distribution of BA model

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Related works: HOT model

- A Model for router-level topologies
- Heuristically Optimized Topology
 - A network architect tries to maximize the network throughput
 - Link capacity and number of ports are correlated
 - Based on the router's processing capacity and / or number of ports [2]

Degree distribution of HOT

[2] L. Li, D. Alderson, W. Willinger, and J. Doyle, "A first-principles approach to understanding the Internet's router-level topology," in *Proceedings of SIGCOMM*, Aug. 2004.

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Load behavior in BA and HOT topologies

- Degree of node vs. number of node-pairs that pass through each node.
 - BA topology: generated by BA model
 - Positive correlation
 - HOT topology in Ref. [2]
 - Nodes with moderate degree convey many flows

BA topology

HOT topology

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Research purpose

- Even if the degree distribution follows power-law
 - Flow-level behavior is much different
- Appropriate modeling for Internet topology is necessary
 - For evaluating network performance or network control method
- A more recent study tries to model router-level topology
 - Examined on Abilene-topology (scientific network)
 - We will show in following slide that structure of Abilene-topology is quite different from ISP-level topologies

→ how to model ISP-level topologies?

- In our work,
 - Structural analysis of ISP topologies
 - Evaluate whether the structural differences make the performance of network control methods being good (or bad)?
 - Modeling method for ISP-level topologies.

[2] L. Li, D. Alderson, W. Willinger, and J. Doyle, "A first-principles approach to understanding the Internet's router-level topology," in *Proceedings of SIGCOMM*, Aug. 2004.

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Structural analysis of ISP topologies

- Network operators design ISP topologies based on their policy
 - Improve reliability, reduces mileage of fibers (cost)
- Structural analysis by network motif
 - counts frequency of subgraph appearance
 - Use following 4-node subgraphs

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Freq. of 4-node subgraphs (1/3)

- ISP1~ISP8: ISP topologies measured by Ref. [1] (sprint, abovenet, AT&T)
- Model1~4: topologies generated by existing modeling method
- INET: AS topology at Nov. 1997. (Used in INET topology generator)

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Freq. of 4-node sub graphs (2/3)

- ISP1: Sprint topology
- Model1: A topology generated by BA model where there are the same number of nodes/links of Sprint topology
- Model2: HOT topology

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Freq. of 4-node subgraphs (3/3)

- ISP3-ISP8: "Sector" or "umbrella" consist 30-35% of topologies
- Full-mesh appears in ISP topologies, but not appears in Model 1, 2

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Detailed analysis of existing modeling method

- Compare Sprint topology and BA topology in more detail by using following metrics
 - Given a node i , we define
 - Average hop-counts to reach other nodes: $A(i)$
 - Cluster coefficient is remarkable: Sprint is highly-clustered

Sprint has larger hop counts between nodes than BA topology is also connected.

$$\kappa(i) = \frac{2e_i}{d_i(d_i - 1)}$$

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Detailed analysis of existing modeling method, cont'

- Relation of cluster-coefficient and degree, number of nodes-pairs
- Nodes where cluster coefficients are around 0.2
 - Higher degree
 - Large number of node pair which pass through

Cluster coefficient

Higher-degree Large number of node pairs

Betweenness centrality

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Application to the network control method

- How much does the performance differ by modeling method when using network control methods?
- Evaluate network performance using following routing algorithms
 - Minimum hop routing
 - InvCap routing
 - Link cost is given by the inverse of its link capacity
 - Recommended by Cisco.
 - Optimal routing
 - Optimal in terms of the maximum link load
 - We use Flow-deviation method to obtain the optimal route.
- Compare link-load on Sprint topology and BA topology
 - Two topology have the same number of nodes and links
- Assumptions
 - The same amount of traffic between any node-pairs
 - Link capacity is determined based on Cisco 124816 routers

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Sprint vs. BA topology: Minhop routing and Invcap routing

- Compare minimum hop routing and invcap routing
- Link ID is numbered in descending order of link load by min-hop routing
- BA topology
 - Invcap routing achieves good performance; the maximum link load 1.0 → 0.3
- Sprint topology
 - Invcap routing does not work; many link loads get worse than minimum hop routing

link utilization

link ID

BA topology

Sprint topology

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Sprint vs. BA topology: Minhop routing and optimal routing

- Compare minimum hop routing and optimal routing
- BA topology
 - Optimal routing achieves very low maximum link load (0.15)
- Sprint topology
 - The maximum link load with optimal routing becomes 0.4
- The effectiveness of optimal routing in BA topology increases

link utilization

link ID

BA topology

Sprint topology

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Why BA topology can reduce link load so much?

- BA topology
 - The network performance is over-estimated
 - Ignore physical distance
 - Re-routing is more effective
- HOT topology
 - Models Abilene topology very well
 - But, no-redundant link
 - Because of scientific network, there may be no or a little income?
 - The lack of "network enhancement"?

New node (BA)

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Why BA topology can reduce link load so much?

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↑ HOT model
↓ Abilene topology (2003)

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Proposed model

- Incremental Growth
 - One-by-one node attachment
 - A node connects "nearest" node(s)
 - Nearest is defined by weighted physical distance and logical distance
 - A new node connects node(s) which minimize the sum of the weighted physical distance and logical distance
 - A node i connects following node j that satisfies: $\min \alpha \cdot d_{ij} + h_j$
 (alpha is parameter, d_{ij} is distance between node i and j , and h_j is average hop count from node i to the other nodes)
- Network enhancement
 - Add a link based on the number of node-pairs that pass through the nodes
 - New links are added between neighbors of a node with large number of node-pairs
 - Improve reliability for link failure
 - Reroute traffic that has passed through the most utilized node
 - Add a link between node x and node y that satisfies: $\min \beta \cdot d_{xy} + B_x$
 (beta is parameter, node x and y are neighbors of a node with largest number of node pairs, d_{xy} is distance between node x and y , and B_x is the inverse number of node pairs which pass through node x)

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Topological properties of proposed model

Parameter settings: alpha = 25, beta = 200

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Proposed model without network enhancement

- How does the network enhancement affect our proposed model?
 - Proposed model without network enhancement:
 - 40% of all node-pairs traverse the highest degree node (25)
 - Sprint : 20% of all node-pairs traverse the highest degree node (48)
 - Do not match cluster-coefficient

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Application to routing control

↓ Sprint topology	↓ A topology generated by proposed model	↓ Optimal routing
↓ Proposed routing	↓ Proposed routing	

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Concluding remarks

- ISP-level topologies
 - Power-law attribute
 - The performance of routing control are over-estimated on existing models
- Proposed modeling method for ISP-level topologies
 - Physical distance
 - Network enhancement
- Future works
 - Models for link capacities
 - Requires for other network control methods, such as flow control
 - Enhancement of link capacity
 - Hierarchical topologies?
 - Validations: Measurement study
 - the topology of ISP networks in Japan (almost done)
 - the link capacity

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