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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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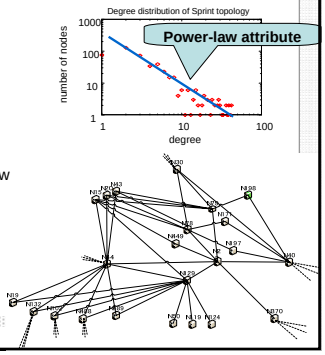
## ISP-level topologies

- 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




[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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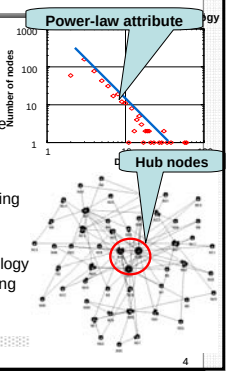
## Related works: BA model

- 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: $d_j / \sum_j d_j$
  - 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.



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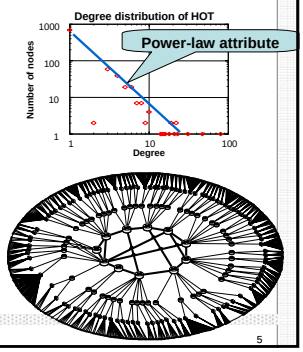
## Related works: HOT model

- 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]




[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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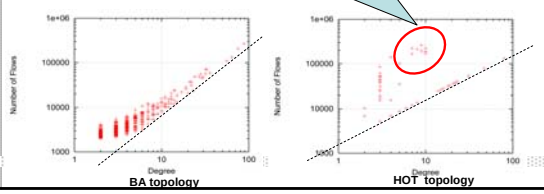
## Load behavior in BA and HOT topologies

- 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



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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,

1. Structural analysis of ISP topologies
2. Evaluate whether the structural differences make the performance of network control methods being good (or bad)?
3. 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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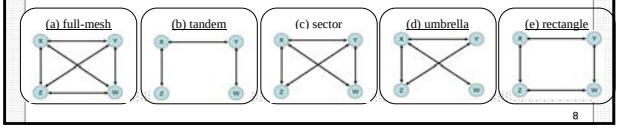
## Structural analysis of ISP topologies

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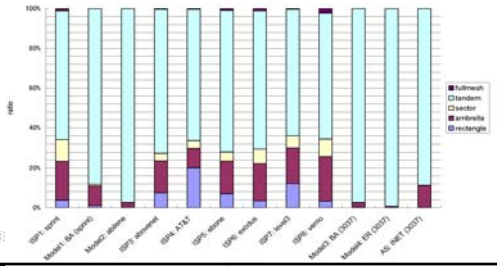
## Freq. of 4-node subgraphs (1/3)

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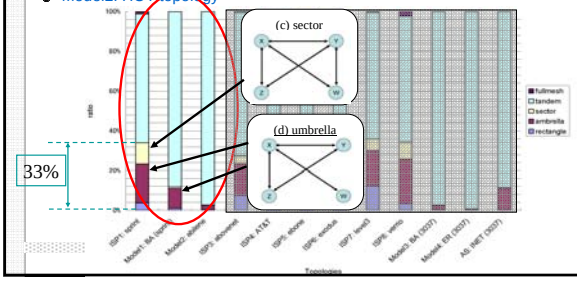
## Freq. of 4-node sub graphs (2/3)

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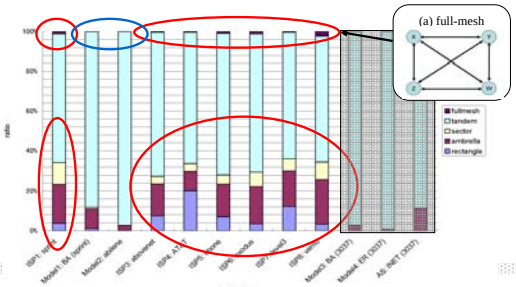
## Freq. of 4-node subgraphs (3/3)

- 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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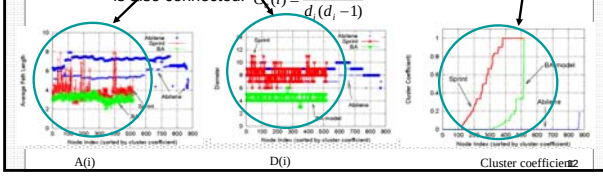
## Detailed analysis of existing modeling method

- 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)
    - Maximum hop-counts to reach all nodes: D(i)
    - o n
    - is also connected. $C_i(i) = \frac{2E_i}{d_i(d_i-1)}$

**Sprint has larger hop counts between nodes than BA topology**

**Cluster-coefficient is remarkable: Sprint is highly-clustered**



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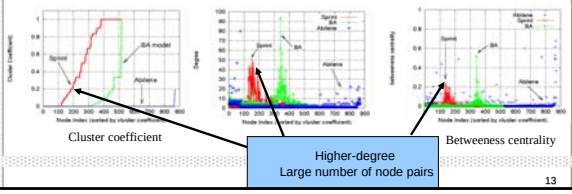
## Detailed analysis of existing modeling method, cont'

- 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



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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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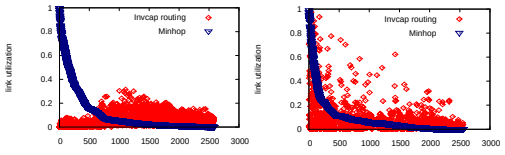
## Sprint vs. BA topology: Minhop routing and Invcap routing

- 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



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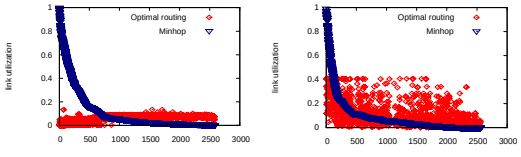
## Sprint vs. BA topology: Minhop routing and optimal routing

- 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



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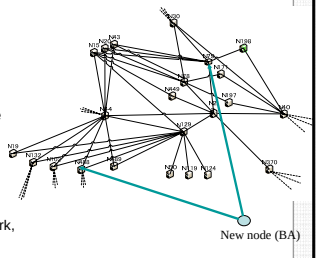
## Why BA topology can reduce link load so much?

- 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"?



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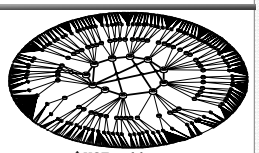

↑ HOT model
↓ Abilene topology (2003)

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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 nodes-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 Bx is the inverse number of node pairs which pass through node x)

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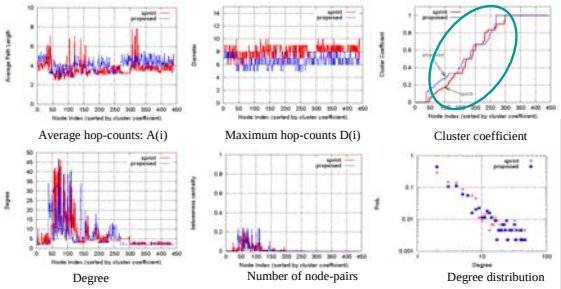
## Topological properties of proposed model



Average hop-counts: A(i) | Maximum hop-counts D(i) | Cluster coefficient

Degree | Number of node-pairs | Degree distribution

Parameter settings: alpha = 25, beta = 200

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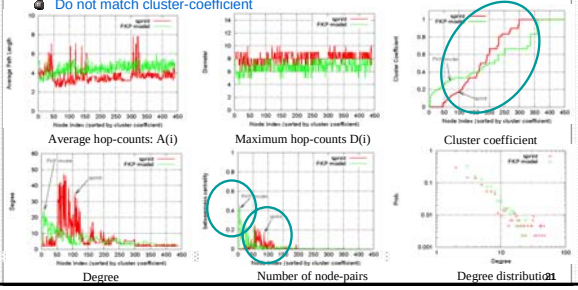
## Proposed model without network enhancement

- 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



Average hop-counts: A(i) | Maximum hop-counts D(i) | Cluster coefficient

Degree | Number of node-pairs | Degree distribution

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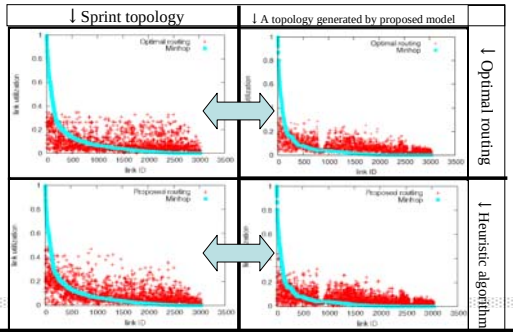
## Application to routing control

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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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