Network Topology Generators: Degree-Based vs. Structural

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Topology Generators before 1999

Random Graph Models Based on Erdos-Renyi random graph

- **Waxman** Link connection probability falls off exponentially with Euclidean distance [Waxman, 88]

Structural Generators Contain structural elements

- **Transit-Stub** *Transit* domains connected to *stubs* [Zegura *et al.*, 97]
- **Tiers** LANs, MANs and WANs [Doar *et al.*, 96]

Transit-Stub and Tiers were state of the art . . .

In 1999 . . .

- [Faloutsos *et al.*, 99] found power-laws in degree distribution
- This changed the thinking about network structure

After 1999: Degree-Based Generators

Generate networks with power-law degree distributions

Growth Define simple node creation and attachment rules that result in power-law graphs [Barabasi *et al.*, 99], [Medina *et al.*, 01], [Bu *et al.*, 02]

Distribution Start with power-law degree distribution, connect nodes randomly [Aiello *et al.*, 00] or heuristically [Jin, 00]

Are we done?

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Are degree-based generators obviously correct? No.

- Degree distribution is a *local* property
- The goal of a network generator is to match the *large-scale* properties of *real* networks
  - Path lengths, tree characteristics, hierarchy . . .

Matching the degree distribution doesn’t guarantee matching the large-scale properties

- Can generate *trees* with power-law degree distribution

Issues

- What do we mean by real networks?
  - AS-level topology and the router-level topology.
  - Caveat: incomplete, particularly the router-level topology
- What are the relevant large-scale properties?
- How do you compare two graphs of different sizes?

Relevant Large-Scale Properties

Two answers:

1. We don’t know (No one does.)
2. Try many *metrics*, and we did . . .
    - Neighborhood size
    - Cut-set size
    - Communication overhead on min-cost trees
    - Vertex cover
    - Biconnectivity
    - Attack tolerance
    - Average path length

Comparing Graphs of Different Sizes

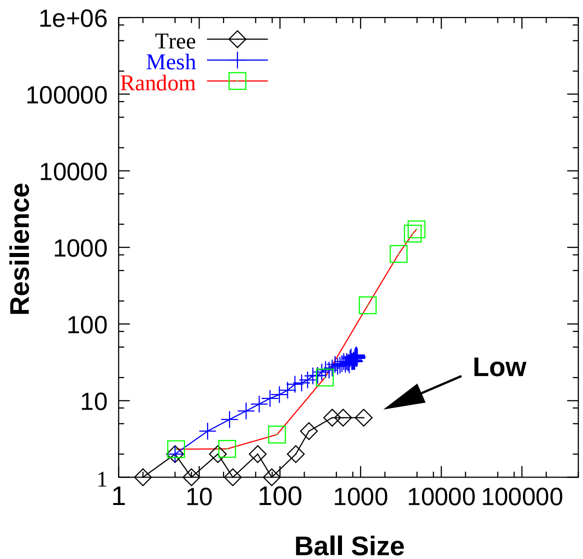
Ball growing: For a given metric M, define $M(n)$ to be the value of the metric for a subgraph (“ball”) of n nodes centered around a node

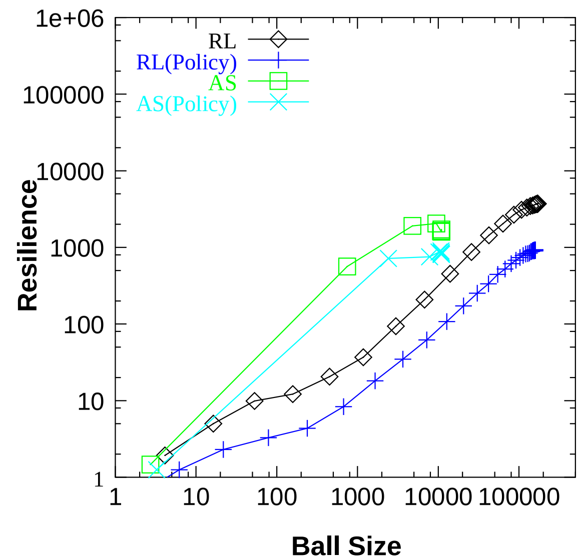
Plot $M(n)$ for different graphs

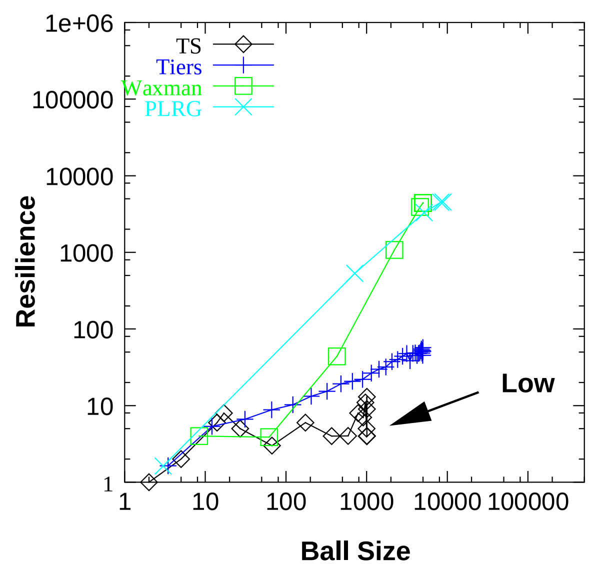
Make qualitative distinctions, using canonical graphs (k-ary Tree, Mesh, Random Graph) for calibration

Use policy routing for the real topologies

Example: Resilience







Three Metrics

Three metrics are sufficient to distinguish the topologies:

Expansion Size of ball (as a function of ball radius)

Resilience Cut-set size for balanced bipartition

Distortion Average path length between ends of a link on a spanning tree

They nicely differentiate our canonical topologies: (H=high, L=low)

Topology	Expansion	Resilience	Distortion
Mesh	L	H	H
Random	H	H	H
Tree	H	L	L

We Were Wrong!

Recall our hypothesis: It couldn't *possibly* be true that matching the degree distribution could match the large-scale properties.

Topology	Expansion	Resilience	Distortion
Mesh	L	H	H
Random	H	H	H
Tree	H	L	L
AS, RL, PLRG	H	H	L
Tiers	L	H	L
TS	H	L	L
Waxman	H	H	H

But, but . . .

The Internet has hierarchy

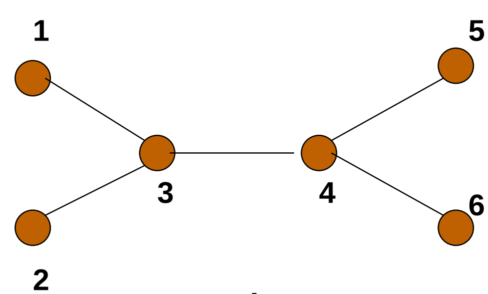
- We speak of tier-1 providers, tier-2 providers, backbones

and degree-based generators don’t.

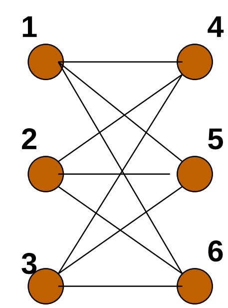
Measuring Hierarchy

One signature of hierarchy in a topology: some links are more important than others

- Measure of importance is set of node pairs that use link to communicate (the traversal set)



Topology

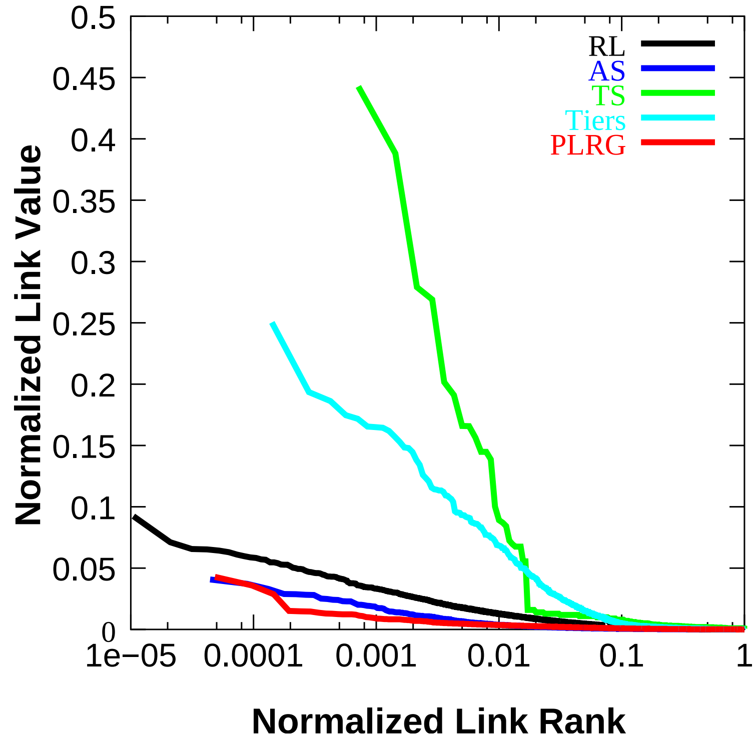


Traversal set for link (3,4)

Link value: size of vertex cover on bipartite graph of traversal set

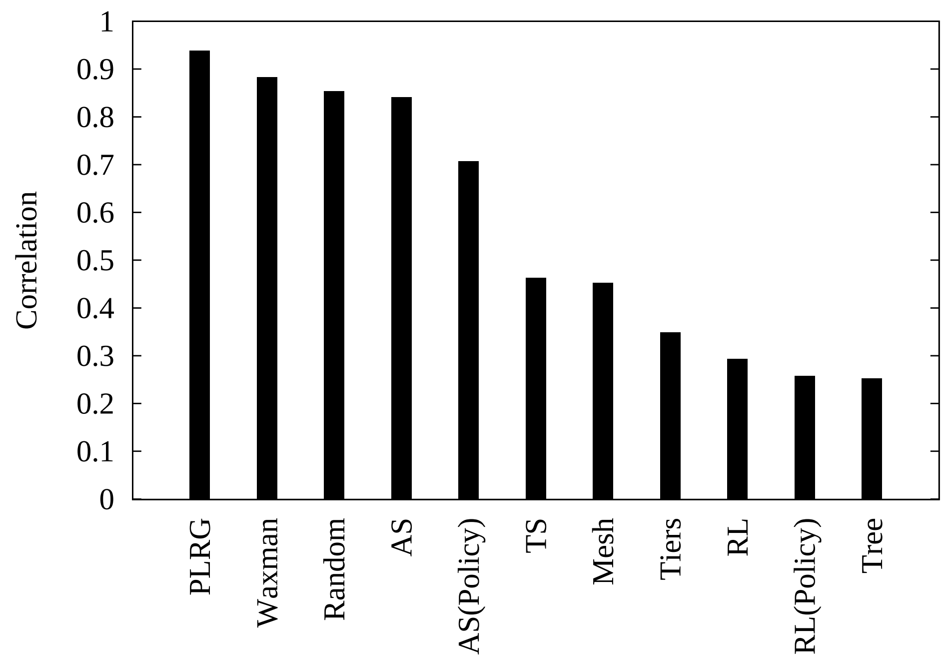
Measure of hierarchy: distribution of link values

Hierarchy



Surprisingly, PLRG closely matches the kind of hierarchy in real networks!

But Why?



High correlation between degree and link-value in PLRG

- Hierarchy arises from its degree distribution!

Summary

Degree-based generators do seem to model real networks better than structural generators

But this is not because they match the degree distribution, but that in doing so, they match the hierarchy in real networks

Explaining the Origin of Power Laws

Finally, a somewhat orthogonal question: How do degree-distribution power laws arise?

At least for the AS graph, we conjecture that degree distribution variability is a manifestation of other highly-variable phenomena: *e.g.*, high variability in company sizes

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Does AS Size Determine AS Degree?, H. Tangmunarunkit, J. Doyle, R. Govindan, S. Jamin, S. Shenker, W. Willinger, ACM Computer Communication Review, October 2001 http://topology.eecs.umich.edu/