Service Restorability in Degree-Based Wavelength Division Multiplexing Networks

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Problem

- Internet is a complex, distributed system
- Better design strategies are required for reliable, high confidence, distributed systems
- Service restorability is one network-wide parameter and depends on the physical and virtual topology
- Previous network topology generator models were structural, but real-world networks follow degree-based models
- How do degree-based models affect restorability?

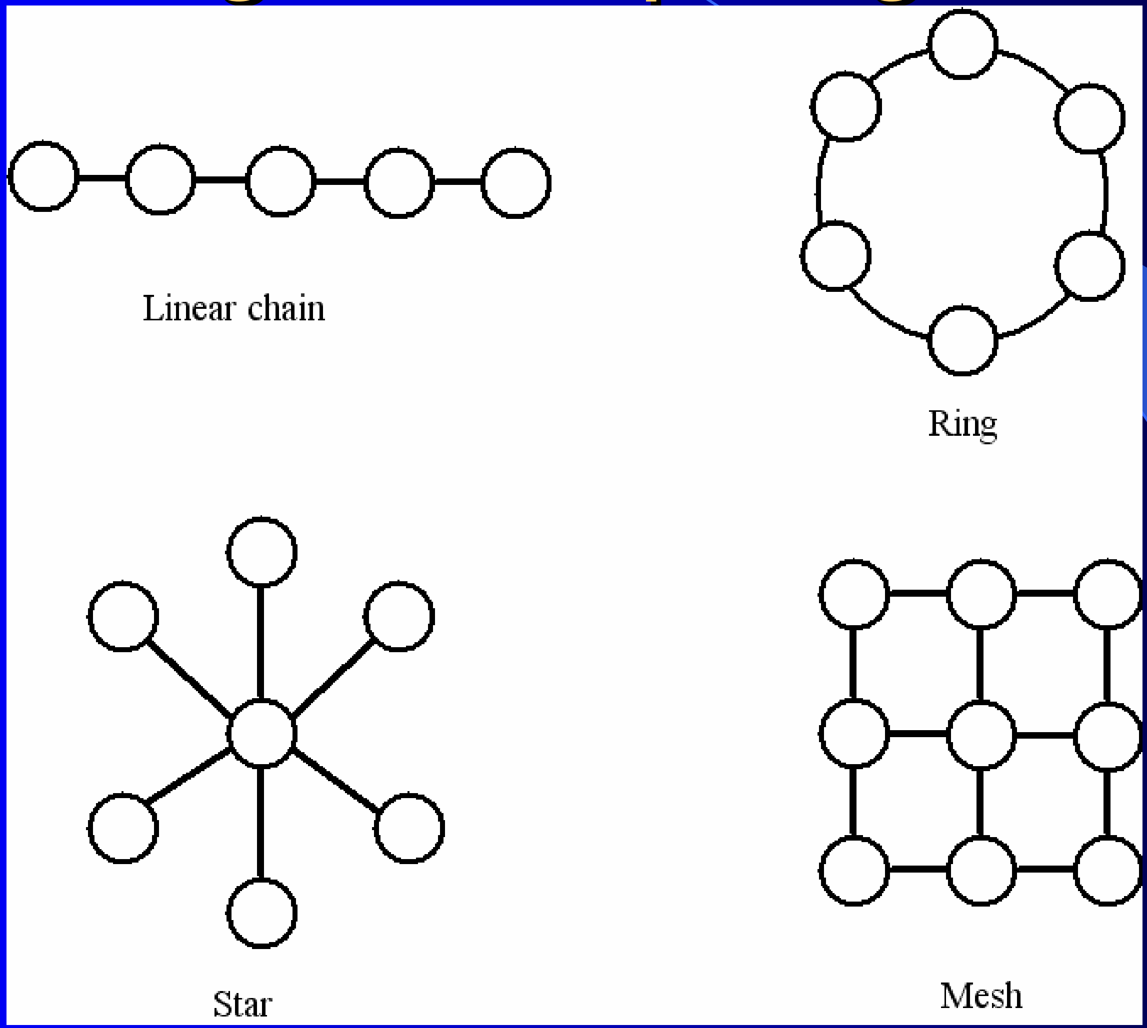
Graph-Based Topology Models

- Random
- Regular
- Well-known
- Structural/Hierarchical
- Degree-based/Power law

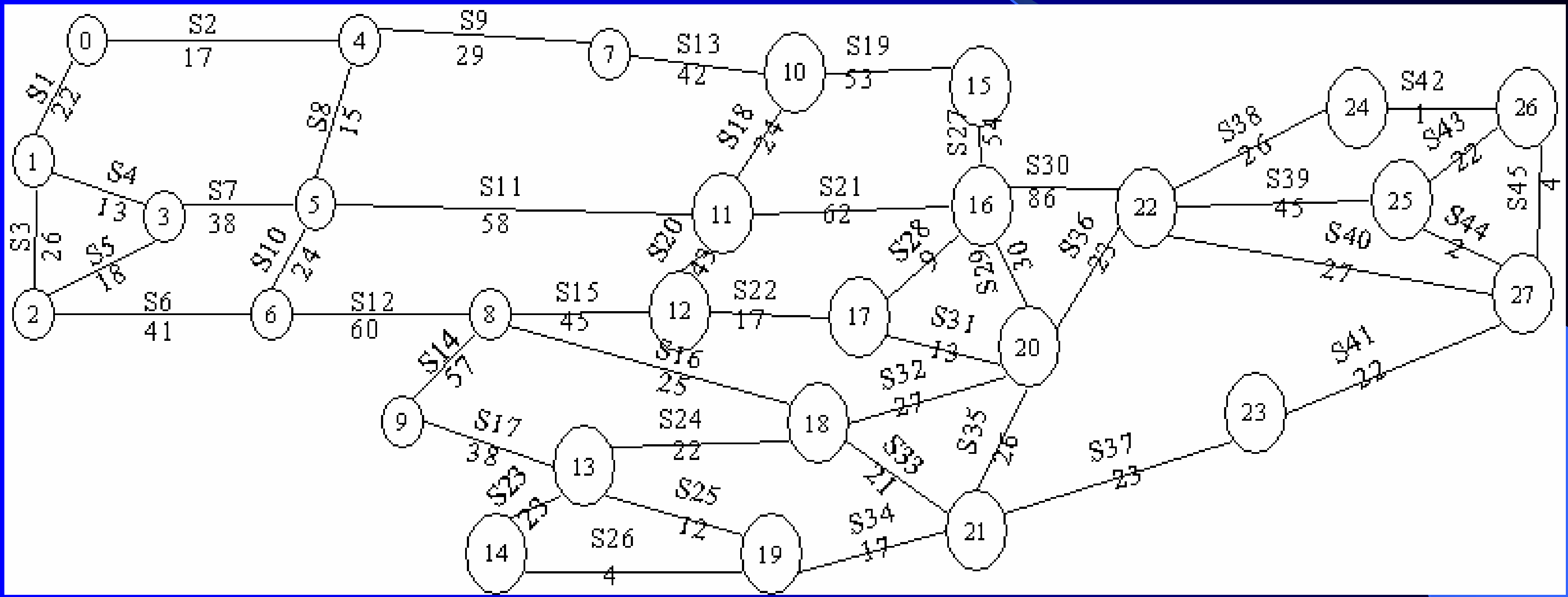
Flat Random Model

Method	Edge Probability	Reference
Pure Random	p	-
Waxman	$\alpha exp(-d/\beta L)$ d = distance L=max. distance $\alpha>0$, $\beta\leq1$	Waxman 1988
Exponential	$\alpha exp(-d/(L-d))$ d = distance L=max. distance $\alpha>0$	Zegura *et al*. 1997
Locality	α, if $d<r$ β, if $d\geq r$	Zegura *et al*. 1997

Regular Topologies



Well-known Topology
NSFnet



Structural/Hierarchical Models

- N-Level (Zegura, Calvert, and Donahoo 1997)
  - Iteratively expand individual nodes into graphs
  - Edges of original graph attached to nodes in replacement graphs
- Transit-Stub (Zegura, Calvert, and Donahoo 1997)
  - Generate connected graph; each node represents a transit domain.
  - Each node replaced by another connected graph, representing backbone topology of one transit domain.
  - For each node in each transit domain, generate connected random graphs representing stub domains.
  - Add "extra" connectivity controlled by parameters.
- Structural models popular for building large networks with low average node degree
- Good attempt to mimic the structure of the Internet

Degree-Based/Power Law Model

- Faloutsos *et al.* 1999

$y \propto x^{\wedge}a$
y and x are metrics
a is a constant
$\propto$: "proportional to"

- Power-Law 2 (outdegree exponent): The frequency, f_d, of an outdegree, d, is proportional to the outdegree to the power of a constant, O:

$f_d \propto d^{\wedge}O$
f_d: frequency of outdegree, d
O: constant
$\propto$: "proportional to"

- O = -2.2 for Internet interdomain *and* router graphs
- Tangmunarunkit *et al.* 2002 compared structural and degree-based models and found that degree-based models model the Internet better even though they make no assumptions about hierarchical structure!

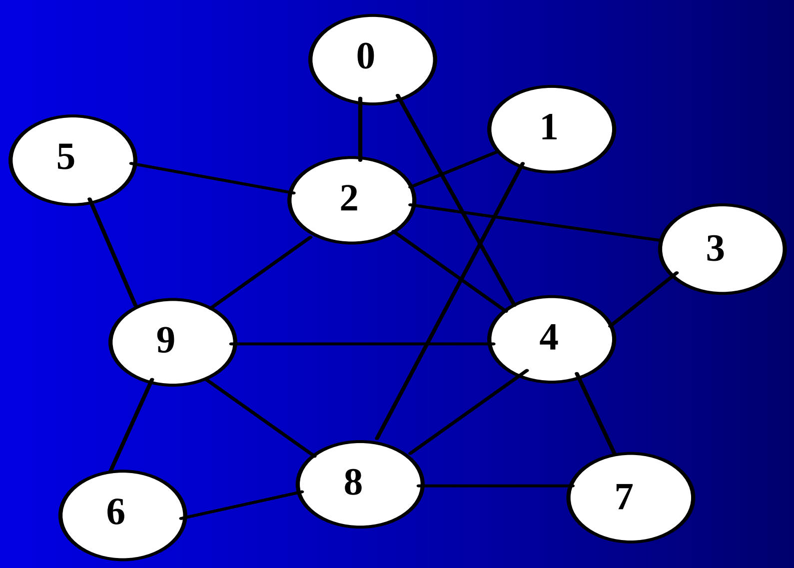
Degree-Based Barabasi model

- Barabasi and Albert 1999
- Generates topologies based on two parameters
  - Incremental growth
    - Add new vertex with *m* edges
  - Preferential connectivity

$$\Pi(k_i) = k_i / \textstyle\sum_j k_j$$
k_i = connectivity of vertex i

- Exponent of resulting networking approx. 2.9
- *BRITE* software implements this model

10-node Barabasi Model Graph



Degree-Based Power-Law Out-Degree (PLOD) Method

- Palmer and Steffan 2000
- Generates topologies based on out-degrees of nodes
- Assigns out-degree numbers to each node based on the expression

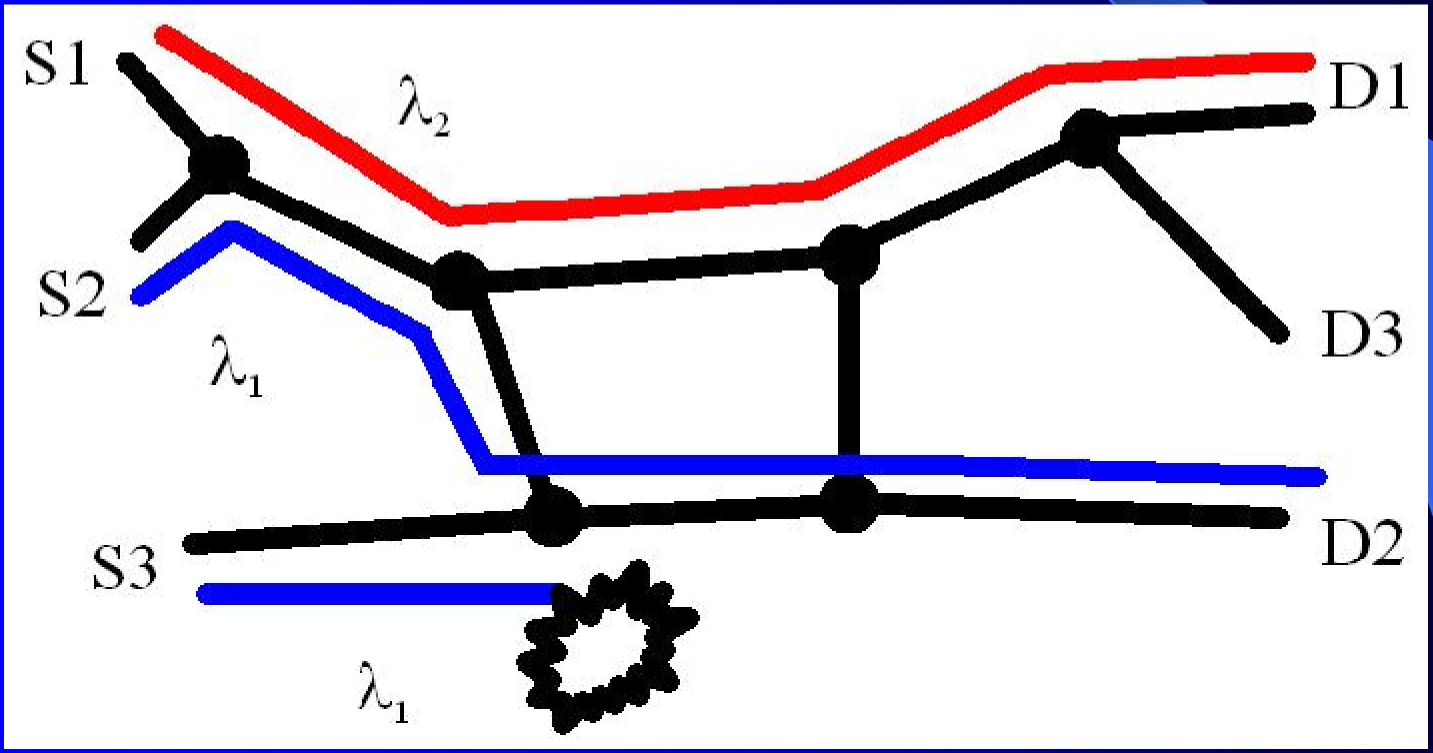
$$\beta x_i^{-\alpha}$$

- Then edges are generated according to the edge placement strategy
- α and β should be carefully adjusted to get the desired number of edges
- *Nem: Network manipulator* software

PLOD cont.

- Edge placement strategy:
  - Two nodes are picked randomly.
  - An edge is generated between these two nodes if there is no edge between them and if their out-degree numbers are not zeros; decrease the out-degree number by 1 if an edge is placed.
  - If the two nodes picked already have an edge between them or if their out-degree numbers are zeros then the process is repeated by picking two more nodes randomly.
  - This is done until all the nodes are assigned edges.

Wavelength Division Multiplexing (WDM)



Service Restorability

- Service Restorability is a network-wide parameter
- Restorability depends on the physical and virtual topology of the network
- The definition of restorability is the average fraction of failed working capacity that is restored for a specific failure scenario

Service Restorability in WDM Networks

- PRSA gives percentage of wavelengths assigned for given traffic.
- In this work, restorability is defined as percentage of the requested wavelengths assigned by PRSA averaged over a specific failure scenario.
- A failure scenario can be single-link failure or dual-link failure.
- A link is a single optical fiber.

Parallel Recombinative Simulated Annealing (PRSA) Algorithm

Initialize the Temperature (SA)

Initialize population with *n* chromosomes (GA)

Repeat for *max* generations

Do n/2 times

- Select 2 parent chromosomes at random (GA)
- Generate 2 children using crossover and mutation (GA)
- Hold competitions using the *Metropolis criterion* between children and parents (SA)
- Overwrite parents with trial winner

Lower the Temperature (SA)

Send/Receive migrants to/from other processors

Objective

- To find service restorability in degree-based wavelength division multiplexing networks

Methodology

- Single-link and dual-link failure simulations are performed to analyze restorability
- Networks with size 10, 15, 20, 25, and 50 nodes are considered for simulations
- Barabasi model graphs were generated with *BRITE* software
- PLOD model graphs were generated with *nem* software

Methodology

Steps involved:

For each topology generated

- Convert the topology file in BRITE/nem format to the format used by PRSA.
- Generate random traffic for this topology.
- Keep scaling the traffic until 100% of wavelengths are assigned by PRSA.
- Once the traffic is scaled, delete one link at a time for single link failures (delete two links at a time for dual link failures) and run the PRSA algorithm.
- Find the average fraction of the failed working capacity that is restored over all single link failure scenarios (dual link failure scenarios). This is the restorability parameter for single-link failures (dual-link failures).

End

Single-link Failure Restorability

Number of Nodes	*Number of Links*	*Average*		*Standard Deviation*	
		Barabasi	*PLOD*	*Barabasi*	*PLOD*
10	**17**	**98.78**	**98.01**	**1.32**	**4.83**
15	**27**	**98.83**	**98.74**	**2.11**	**1.96**
20	**37**	**99.82**	**99.32**	**0.49**	**1.46**
25	**47**	**98.63**	**97.45**	**1.66**	**2.25**
50	**97**	**99.50**	**99.93**	**0.80**	**0.48**

Dual-link Failure Restorability

Number of Nodes	*Number of Links*	*Average*		*Standard Deviation*	
		Barabasi	*PLOD*	*Barabasi*	*PLOD*
10	**17**	**97.32**	**97.05**	**4.58**	**6.53**
15	**27**	**96.38**	**98.16**	**3.34**	**2.88**
20	**37**	**98.91**	**98.32**	**1.88**	**2.11**
25	**47**	**97.72**	**95.83**	**2.39**	**2.88**

Random vs. Degree-Based Models

- A 25-node Waxman's model is compared with degree-based models

Model	***Average***	***Standard Deviation***
Waxman’s	98.42	2.15
Barabasi	98.63	1.66
PLOD	97.45	2.25

- Averages are very similar for all the models
- All the models have high restorability under this metric

Execution Times

Number of nodes	Time taken for each execution by PRSA	Number of executions	
		Single-link	Dual-link
10	40secs	17	136
15	2mins	27	351
20	6mins	37	666
25	12mins	47	1081
50	2hrs	97	4656

Conclusions

- Results show that degree-based models have high restorability even with dual-link failures

Future Work

- Need to extend to a set of networks for a particular number of nodes
- Need to extend to larger networks, which requires sampling
- Comparisons with structural models over larger range
- Study of node failures because degree-based networks have a few nodes with high node degree

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