PSTN

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Overview

- A new historical perspective
- Call scenarios and architectural comparison
  - Static: Network Metrics
  - Dynamic: Pearson's Coefficient in evolving network
- Robustness in new networks
- Constraints and responses
- Contributions and future work

PSTN Economic Regulation (US)

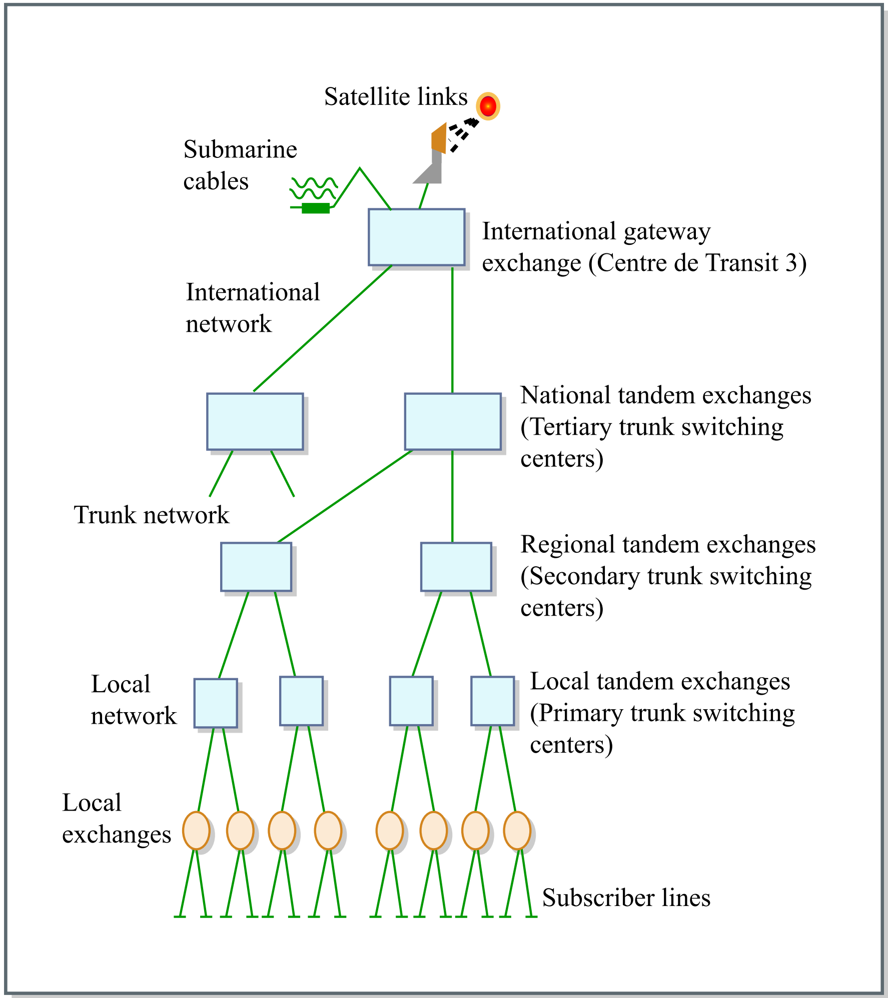
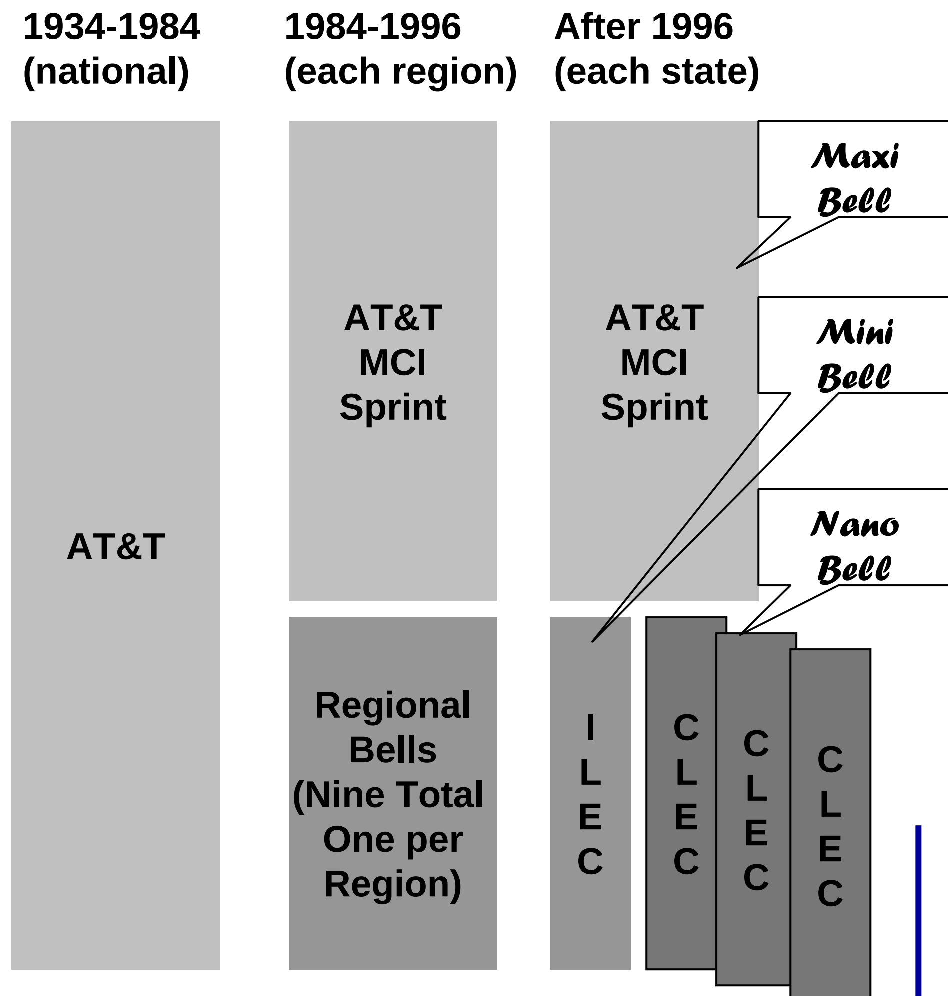


Figure by MIT OCW.



Our analysis focuses on an ILEC and a CLEC for a single state

Level Skipping vs. Dynamic Non-Hierarchical Routing (DNHR) *1980s*

Before DNHR - Level Skipping

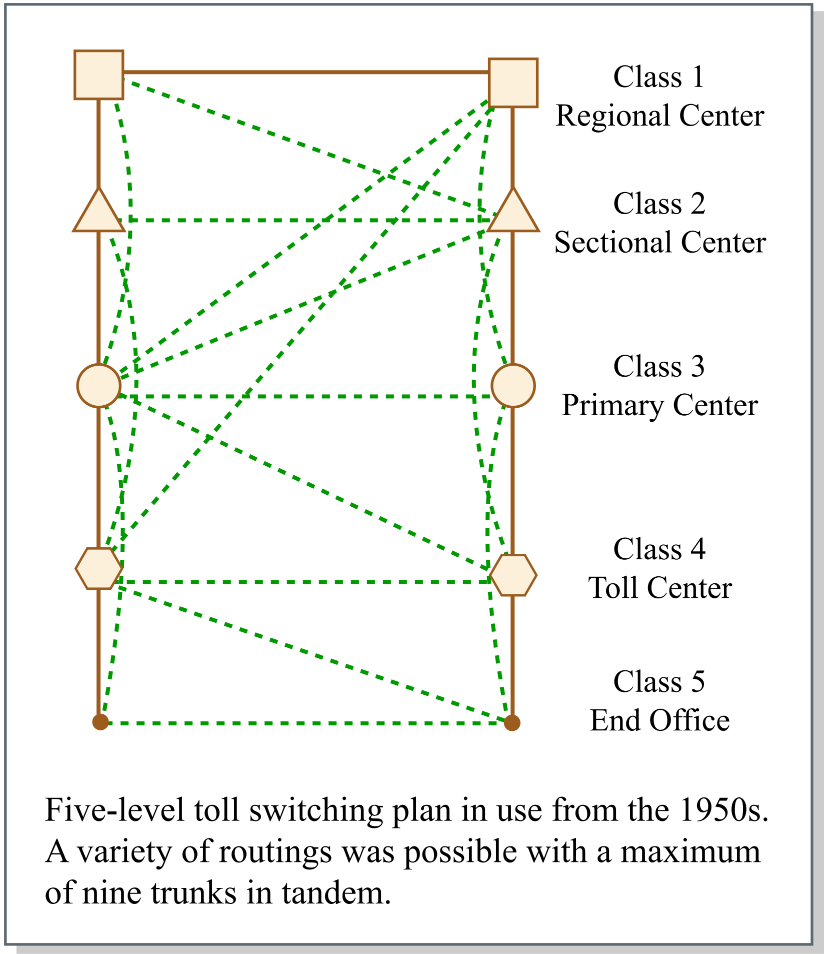
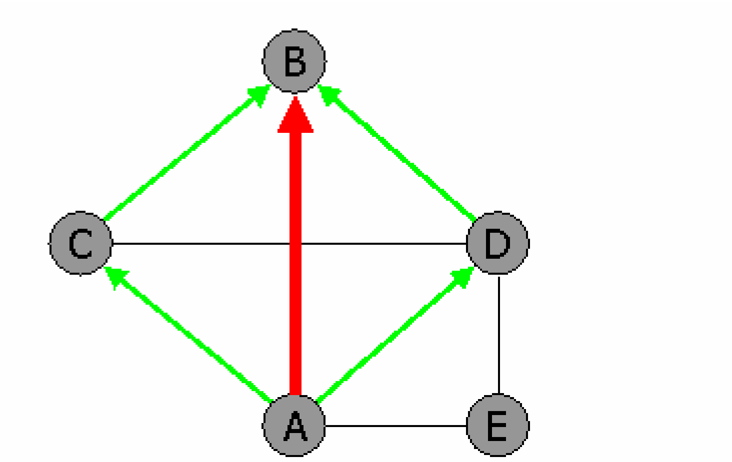


Figure by MIT OCW. After Andrews & Hatch, 1971.

Improved quality via level skipping

DNHR



- **Switch quality no longer main constraint**
- **5-level hierarchy structure no longer required**
- **New constraints are the capacity on the links and switch reliability**
- **Statistical analysis allows for dynamic planning of routes in pre-set time periods**

DNHR – Flattening the Hierarchy (*1980s*)

Architecture influenced by DNHR:

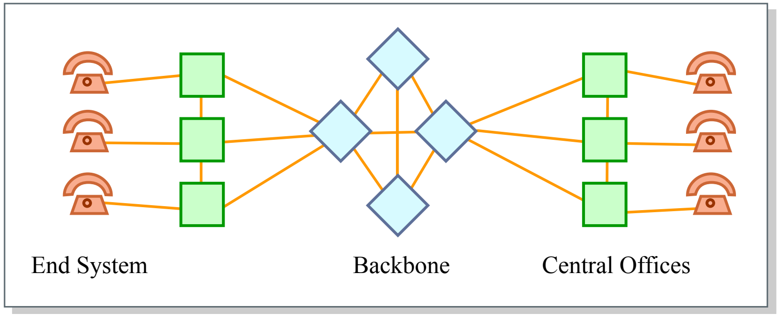


Figure by MIT OCW.

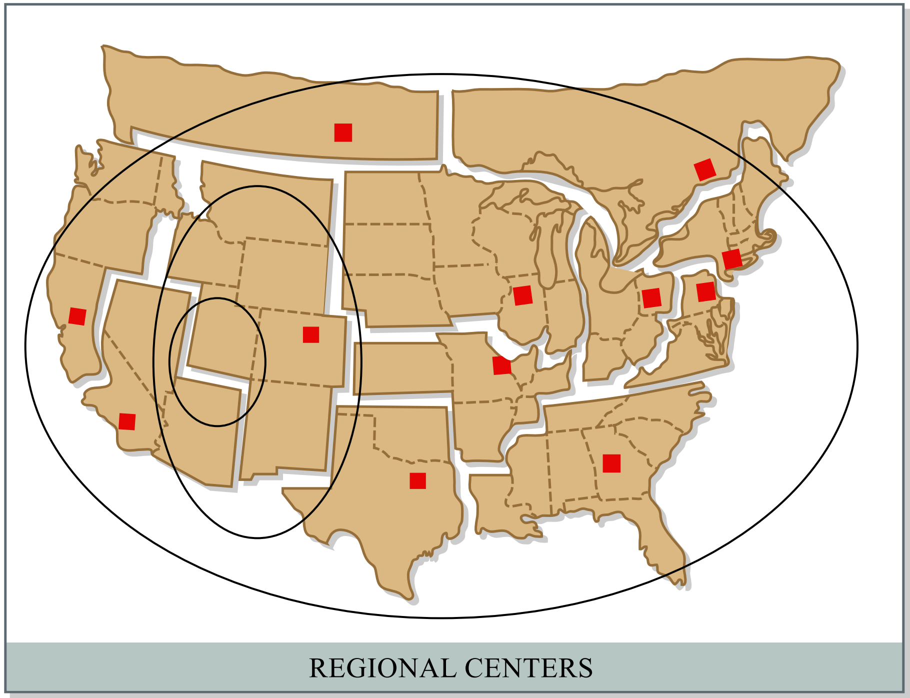


Figure by MIT OCW.

Now Nano, Mini and Maxi can have similar architecture, but different coverage

Call Scenarios

	Nano	Mini
Nano	In-network Local Calls	Inter-network Local & Long-distance Calls
Mini	Inter-network Local & Long-distance Calls	In-network Local Calls

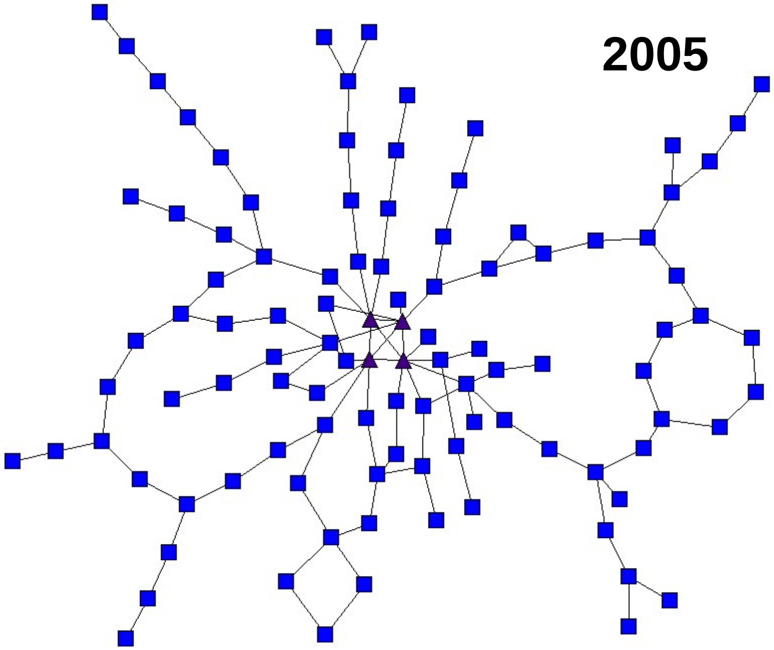
Five Networks

2005 Nano Network
2010 Nano Network
Mini Network
2005 Nano + Mini
2010 Nano + Mini

Between Nano, Mini and Nano + Mini networks, we can study all call scenarios

Architecture of Nano Network *(in-network local calling)*

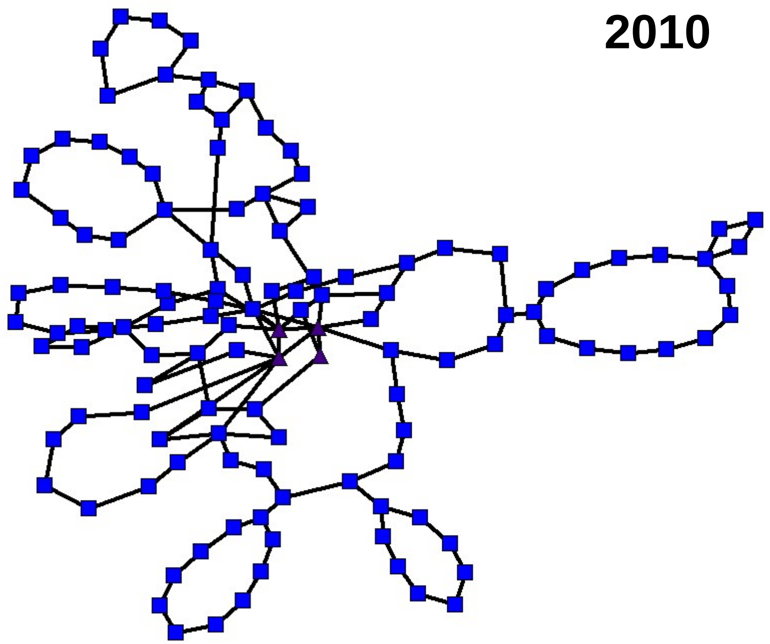
2005



N **= 104**
M **= 121**

z **= 2.327**
l **= 7.308**
C **= 0.0262**

2010



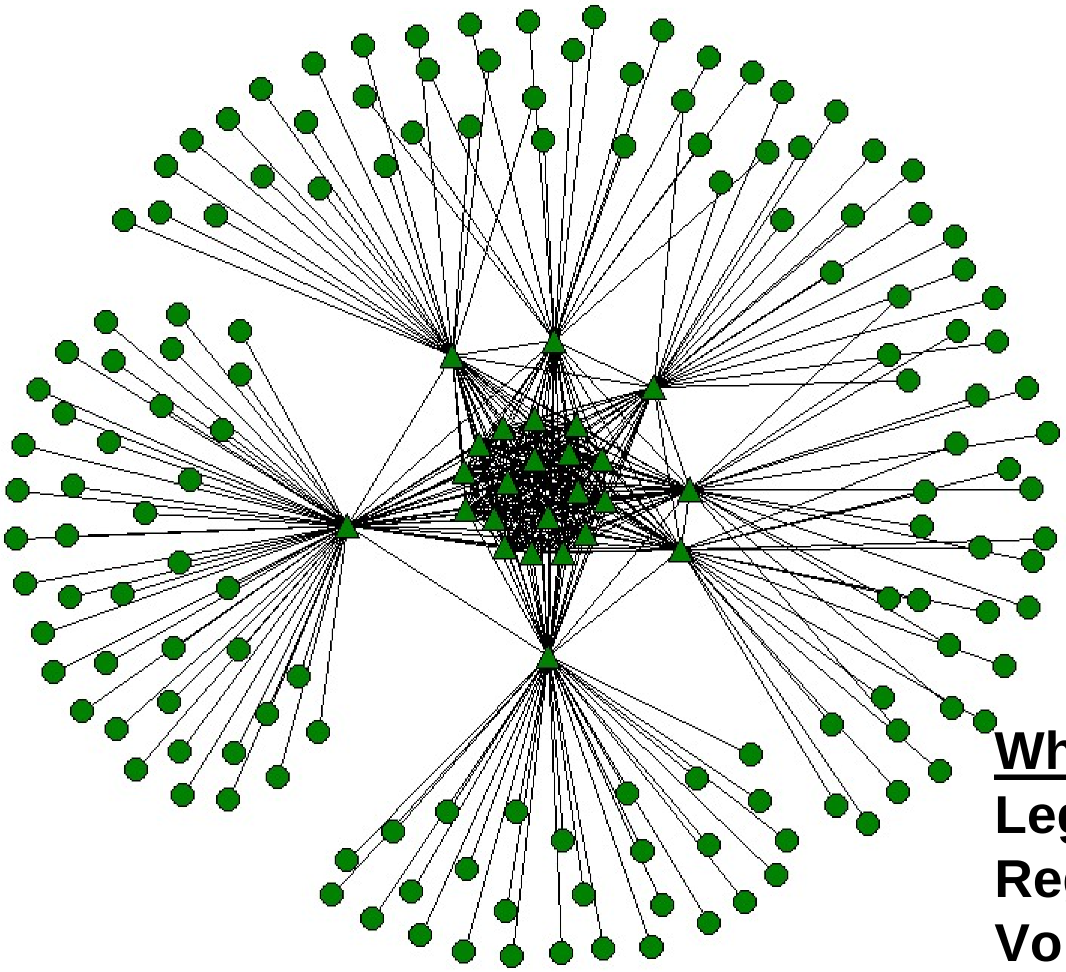
N **= 123**
M **= 152**

z **= 2.452**
l **= 8.729**
C **= 0.0206**

<u>Nano Bell's Plan for Migration from 2005 to 2010</u>

1. **Get redundant fiber outlets**
2. **Get every node on fiber (preferably ring)**

Architecture of Mini Network
(in-network local calling)



N = 171
M = 446

z = 5.218
l = 2.582
C = 0.1179

Four Types of Tandems

Local
Access
Toll
911

Why are Nano and Mini different?

Legacy Architecture
Regulatory Obligations
Voice vs. Data Network

Is there a parameter that indicates the difference in Nano vs. Mini Network?

Nano vs. Mini Networks

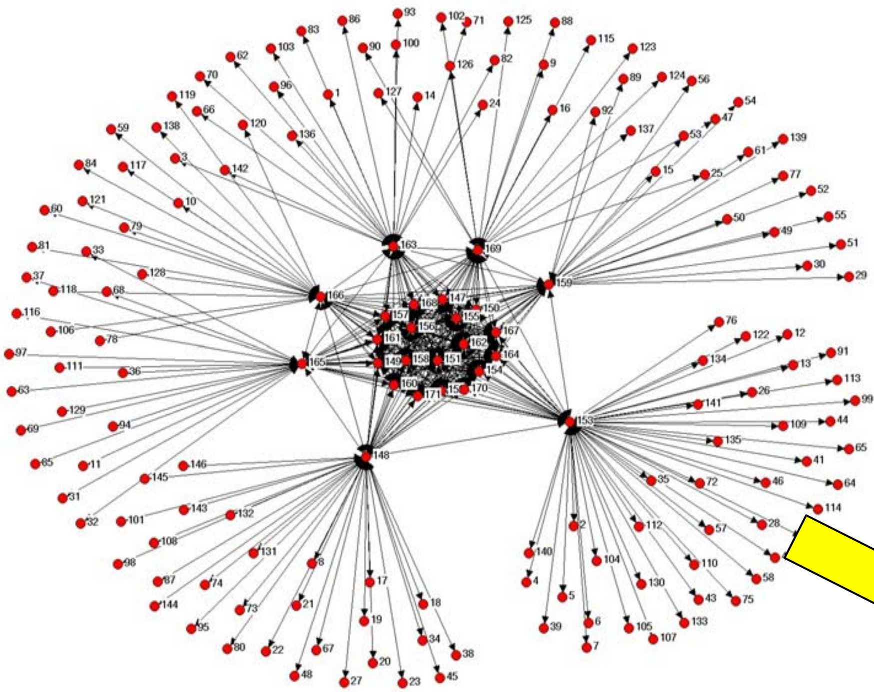
Parameter	Nano 2005	Nano 2010	Mini Only
N	104	123	171
M	121	152	446
z (<*k*>)	2.327	2.452	5.216
l	7.308	8.729	2.582
log n/ log <*k*>	5.499	5.365	3.113
C	0.0262	0.0206	0.1179
<*k*>/*n*	0.022	0.020	0.031
r	0.2196	0.3277	-0.6458

Is sharply different *r* indicative of differences in technology?

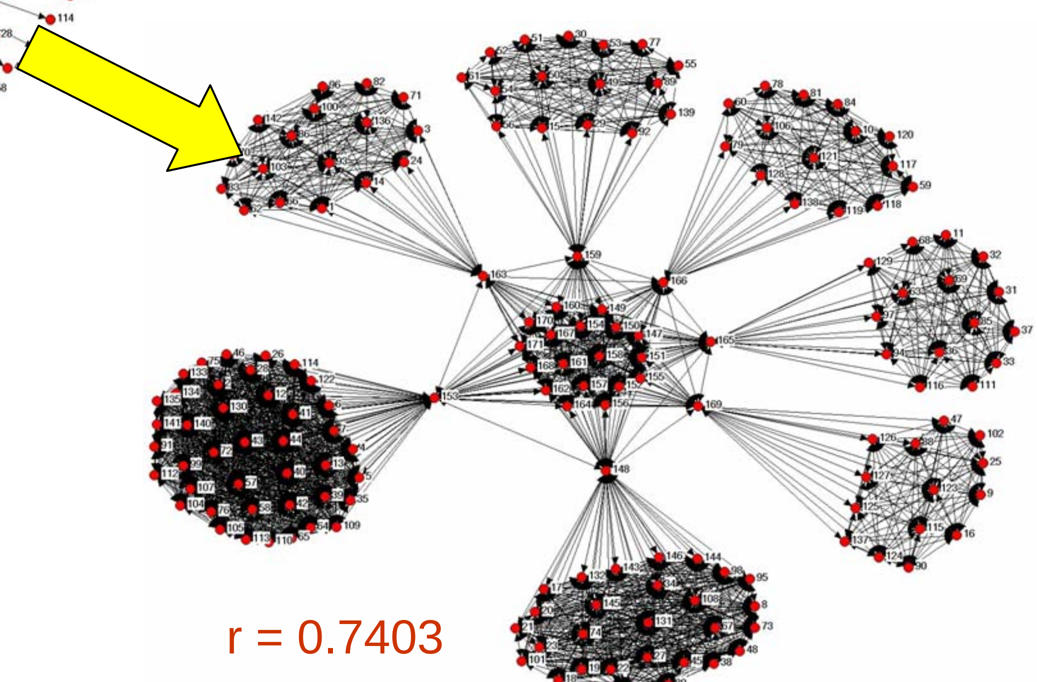
Perhaps not….

We know from level-skipping and DNHR that Central Offices (not just the tandems) are connected in Mini's network, so *r* must be higher. ***But we simply can't get this information because of privacy/competitive reasons.***

What happens to Pearson’s if we had more routing information for Mini Bell?



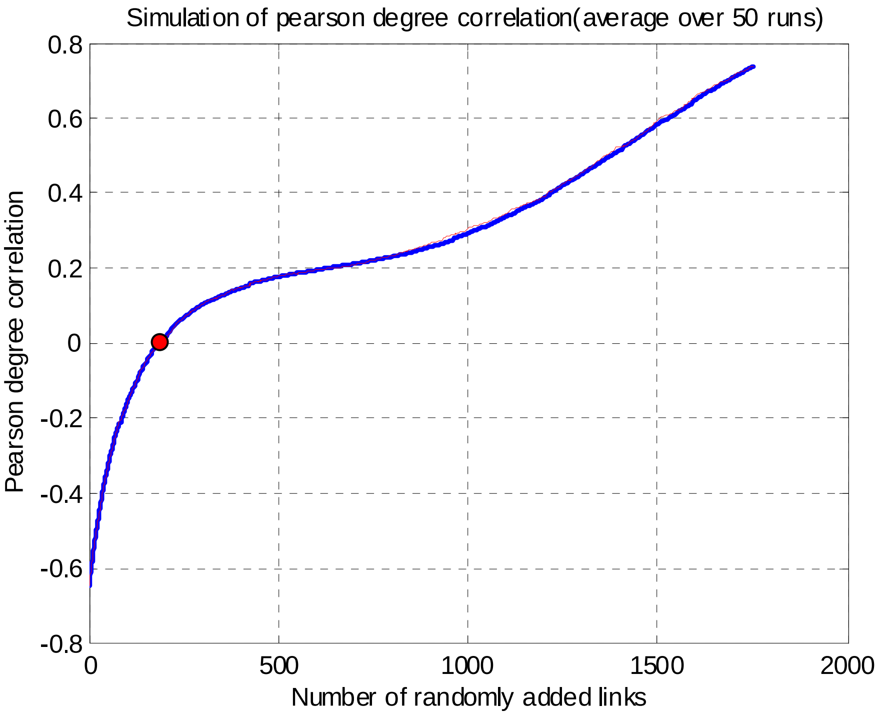
r = -0.6458

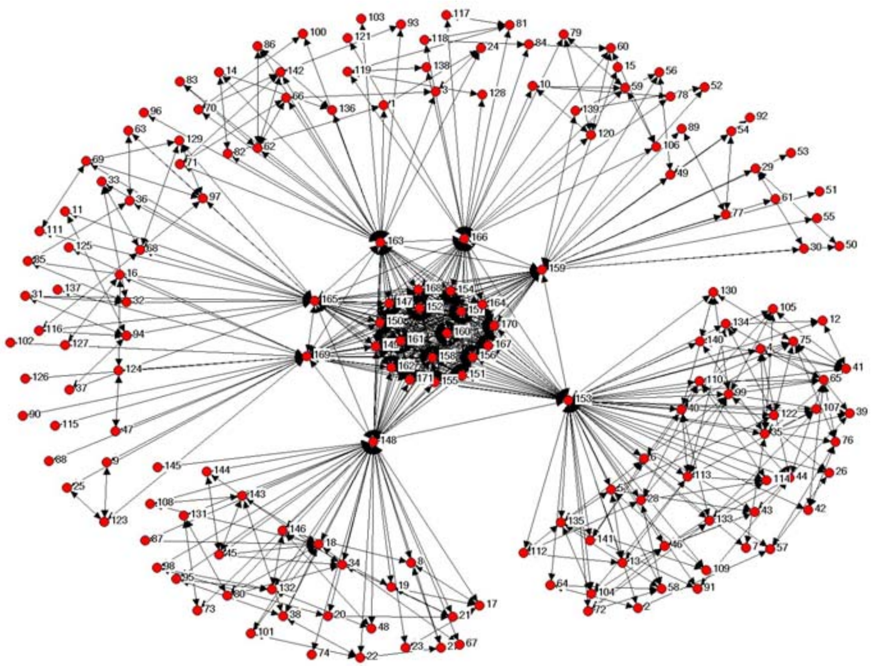


r = 0.7403

What happens to Pearson's if we had more routing information for Mini Bell?

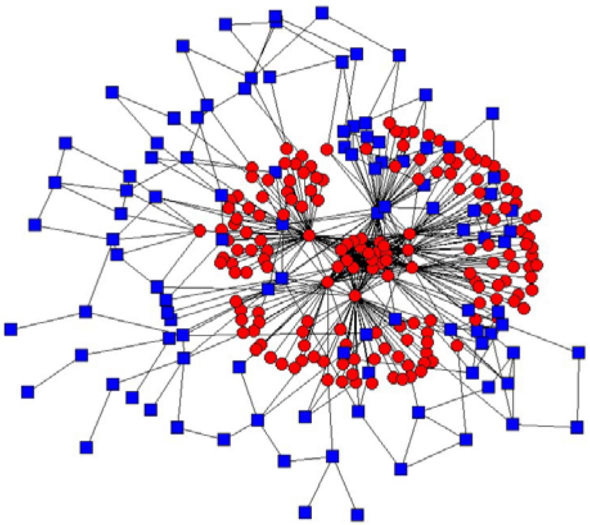
- Degree correlation changes from -0.6458 to 0.7403 by randomly adding 0 up to 1755 edges)
- On average, zero degree correlation happens at adding 185 edges



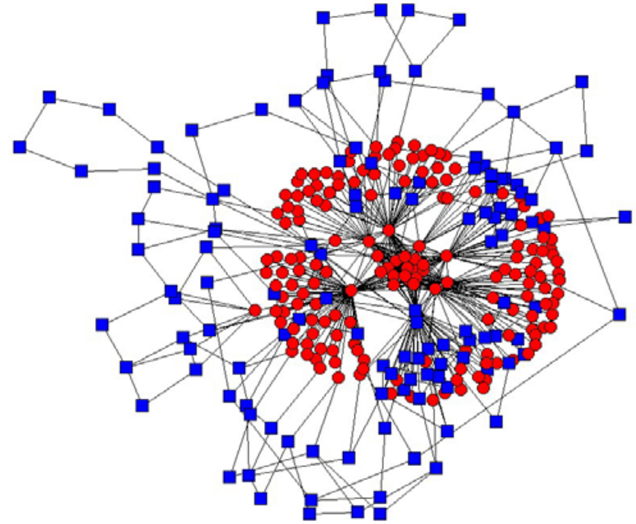


add 182 edges (10.4%)

Nano Connected to Mini Network
(inter-network local or long distance)



2005



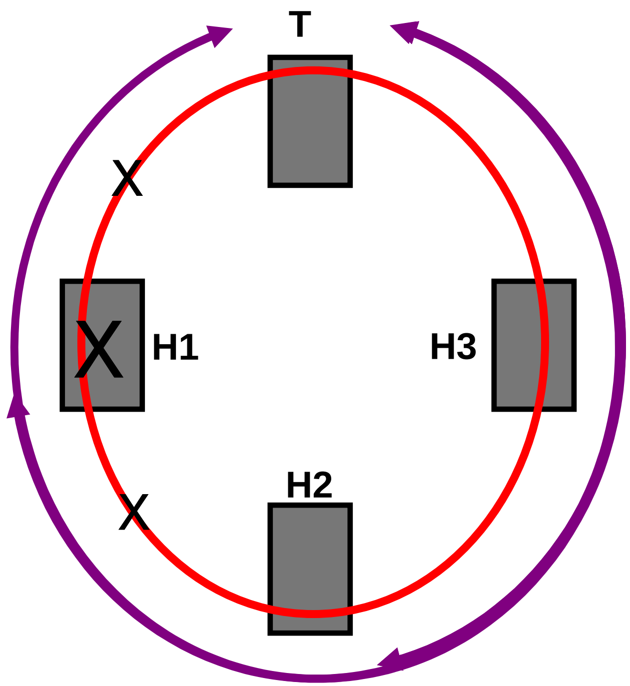
2010

Parameter	Nano 2005	Nano 2010	Mini Only	Mini+Nano 2005	Mini+Nano 2010
N	104	123	171	275	295
M	121	152	446	667	714
z (<k>)	2.327	2.452	5.216	4.85	4.84
l	7.308	8.729	2.582	3.71	4.275
log n/ log <k>	5.499	5.365	3.113	3.557	3.606
C	0.0262	0.0206	0.1179	0.196	0.2136
<k>/n	0.022	0.020	0.031	0.018	0.016
r	0.2196	0.3277	-0.6458	-0.1882	-0.1552

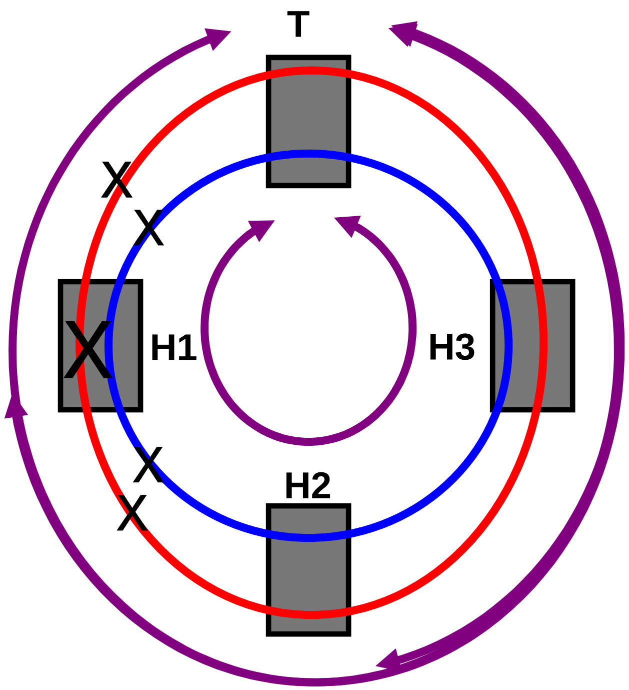
All critical measures of Nano + Mini fall in between Nano and Mini

Robustness in Fiber Rings

collapsed vs. separate SONET rings



Collapsed Rings



Separate Rings

Physically separate SONET rings are at least twice as resilient.
Can we test this?

Robustness to Loss of Nodes or Edges in Nano Bell

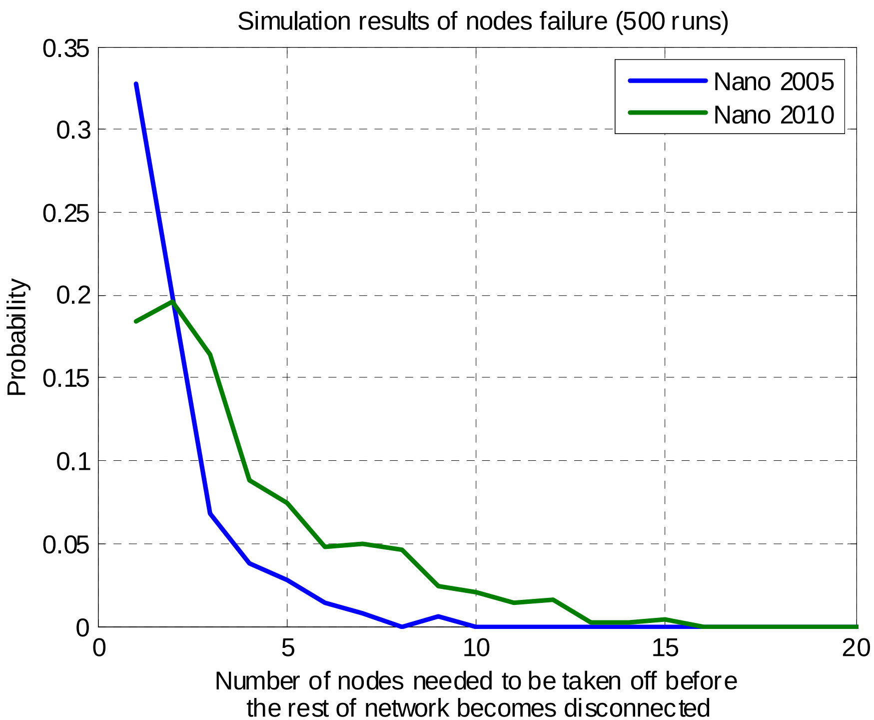
- Algorithms
  – Randomly remove nodes
  – Randomly remove edges
  – Replicate the experiments for 500 times

Max nodes	Nano 2005	Nano 2010
1	0.584	0.902
10	1.068	3.228
20	1.522	3.662

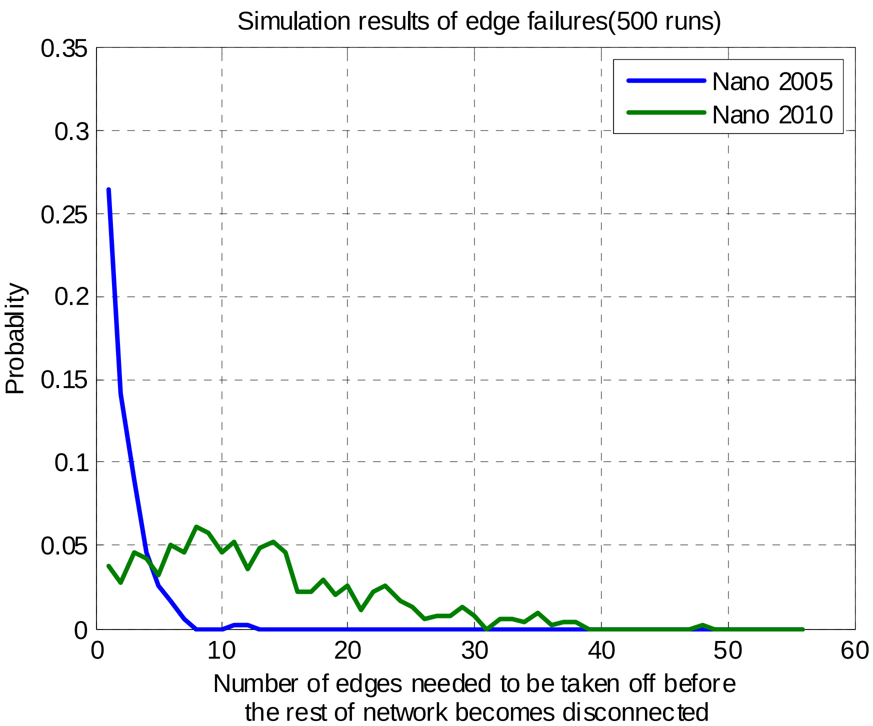
Max edges	Nano 2005	Nano 2010
1	0.57	0.968
5	1.274	4.48
100	1.256	12.252

Robustness to Loss of Nodes or Edges in Nano Bell

Randomly remove nodes



Randomly remove edges



Results shows Nano 2010 is more robust than Nano 2005
In terms of removing nodes and edges

Summary of Constraints

- **Technical**

Constraint	*Improvement*	**Copper**	**Fiber**
Cabling Distance (Attenuation)	SN Ratio	< 1Km (without repeaters)	< 70 Km
Bandwidth (Sampling and Error correction)	Speed of Electronics	< 100 Mbps	< few Gbps

- **Economic**
  - **Cost of Fiber:** Overcome by the economies of scale in fiber manufacturing. A low-end fiber cable costs similar to high-end copper cable
  - **Cost of Electronics:** Still a constraint. Electronics to run fiber network costs 3-4 time higher than electronics for running copper network
- **Regulatory**
  - **Payment of Access Charges:** Overcome by DNHR and flattened hierarchy
  - **Unbundling and Equal Access:** Constraints upgrade of Access (Nano Bell) Tandems
- **Operational**
  - **Cost of Digging:** Overcome by overcapacity
  - **Physical breaks:** Overcome by physically separate rings
  - **Legacy:** Overcome by new companies (Nano Bells) through ground-up ring architecture

Contributions

- The new hierarchy is flat: from 5 to ~3 levels
- The new network is a hybrid of copper and fiber
- The new architecture is a tree structure with rings
- The new routing scheme is DNHR (Dynamic Non-Hierarchical Routing) instead of level skipping
- The Pearson's correlation coefficient has been changing from negative to positive as the network evolves
- The network analysis confirms the increased robustness of the new fiber network architecture

Recommendations for Future Work

- Find more data, preferably electronically
  - The best you can do is to get Telcordia's LERG (~ $1600)
- Enhance PSTN analysis by introducing link and node properties
  - Link Properties: bandwidth, traffic loads
  - Node Properties: switching capacity, customers served, traffic characteristics
- Historical, time-based data would show the network's evolution and the effects of legacy on Mini Bells
- Comparison and joint modeling of PSTN with the Internet
  - What are the structural differences in the networks?
  - What are the different design assumptions (circuit vs. packet switching) that influenced each network?
  - How much overlap occurs between these two networks?