ATM Broadband Network Design: A Case Study

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Agenda

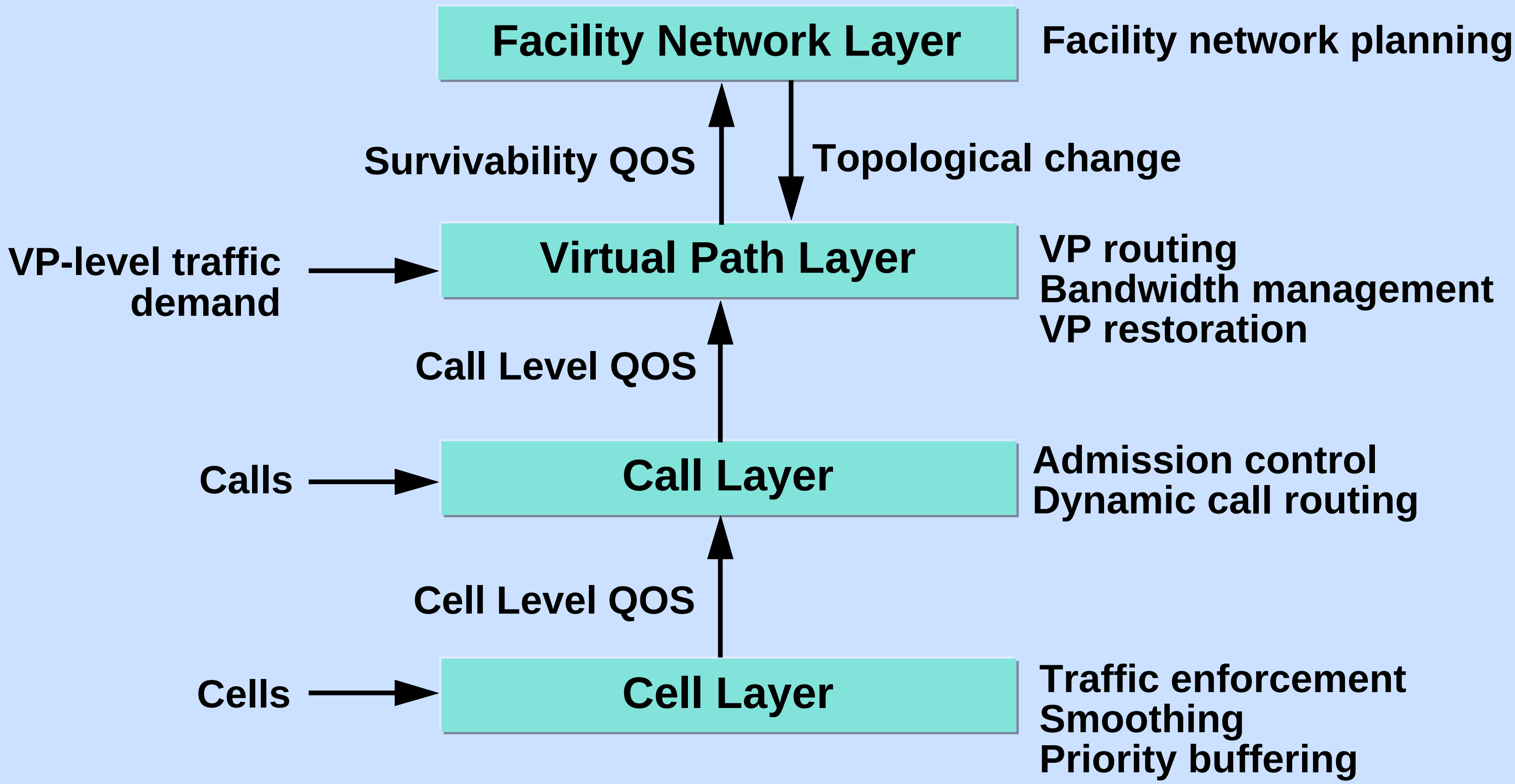
- Where network design fits into ATM
  - overview of a survivable network management architecture
  - meeting QOS at architectural layers
- A case study of network design
  - input provided by customer
  - how the best topology is to be selected
  - the three design approaches used
  - resulting 12 topologies, cost, performance
  - selection of best topology
  - generalizations drawn from case studies

ATM Network Resource Allocation

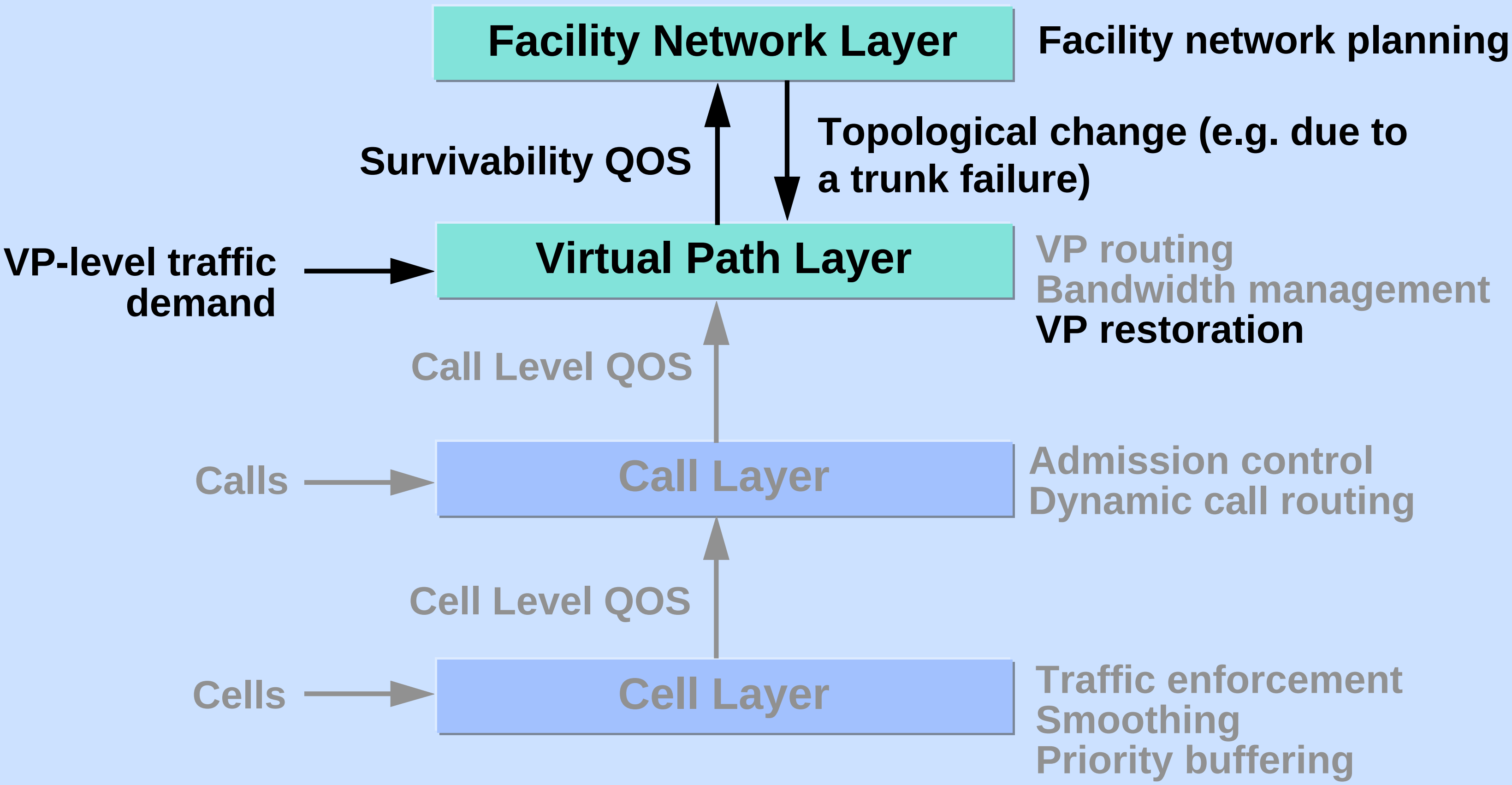
- Resource allocation can be layered by <u>time scales</u> which are separated by at least two orders of magnitude
  - processing time of a <u>cell</u> is microseconds
  - a <u>call</u> session lasts minutes
  - <u>virtual paths</u> are assigned for hours or days
  - <u>physical resource</u> allocation is designed to last a year or more

Network design determines physical resource allocation

A Survivable ATM Network Management Architecture



Survivability QOS Under Trunk Failure



Contrasts Between the Upper Two Layers

- **Facility network layer**
  - largely product independent
  - ultimate provider of network bandwidth
  - partly or largely under manual control
  - can only react slowly to trunk failures or requests for more resources
- **Virtual path layer**
  - potentially significant product dependency
  - must use given bandwidth effectively
  - totally under automatic control
  - must react quickly to trunk failures and to increases in call-level requirements

Role of Network Design in Facilities Layer

- **The activity in which network bandwidth resource placement is assigned to meet**
  - **projected traffic demand and QOS**
  - **network survivability requirements**
  - **lowest possible bandwidth resource cost**

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Case Study Background

- The company is a U.S. public telecommunications service provider of nation-wide voice, data and video services
- The company has 16 major locations being used in this case study, and a large number of smaller locations not being considered here
- The company has sent out a request for quotation of a 16-site ATM network design
- The bidders are asked to design their most cost-effective network using T3, OC-3 and OC-12 inter-nodal connections (trunks)

Network Design Information

- The network is to carry the company's customers' voice, data and video traffic between the 16 locations
- Traffic levels for busy-hour voice, data and video have been estimated and are provided for use in the design
- Costs to be used for T3, OC-3 and OC-12 are provided (next page)
- Each location is to have two or more connections to the network for reliability
- OC-12 trunks can be assumed fully protected by the SONET level
- Trunk utilizations are to be kept below 90% for any trunk when all trunks are functional
- The network must be able to carry 65% of busy period traffic in the event of a single trunk failure

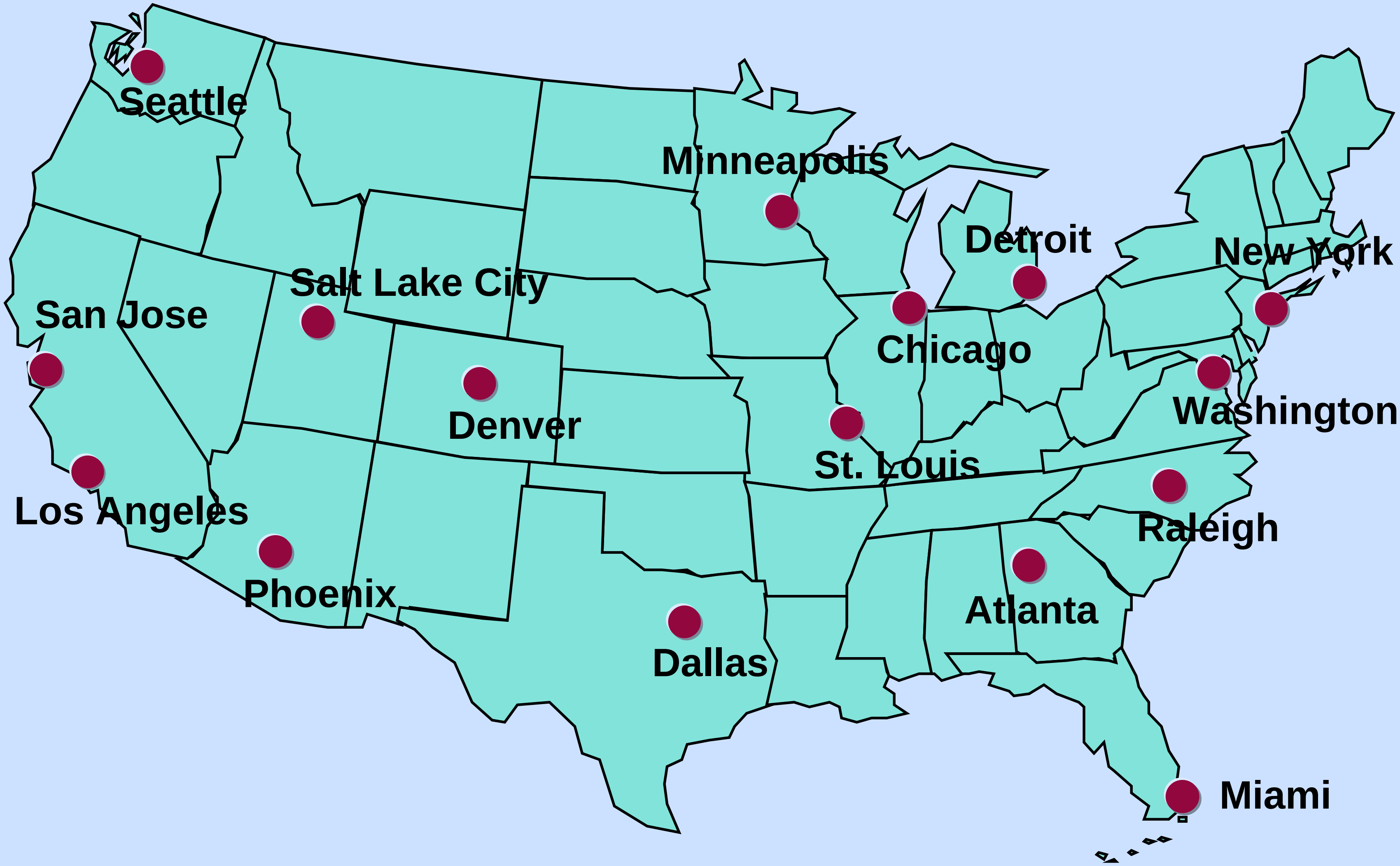
Design a network topology with acceptable service and delay performance and lowest possible internodal trunk cost

Cost of Facilities to be Used in Design

Trunk	Distance	Base Rate	Cost/Mile*
T3	0—50 mi.	$ 10627.47	$ 91.59
	51—100 mi.	$ 11399.97	$ 76.14
	101—500 mi.	$ 12999.97	$ 60.14
	501+ mi.	$ 16864.97	$ 52.41
OC-3	0—50 mi.	$ 21554.95	$ 183.17
	51—100 mi.	$ 23099.94	$ 152.28
	101—500 mi.	$ 26299.94	$ 120.28
	501+ mi.	$ 34029.94	$ 104.83
OC-12	0—50 mi.	$ 54295.84	$ 586.15
	51—100 mi.	$ 59239.81	$ 487.28
	101—500 mi.	$ 69479.81	$ 384.88
	501+ mi.	$ 94215.81	$ 335.45

* For entire distance

Locations of the 16 Node Sites



Part of Offered Traffic Table Provided by Customer

- **Multiply voice channels by 12**
- **Use 2% blocking factor**

	3	4	5	6	7	8	9
8				----------------------- VBR -----------------------			
9							
10	City 1	City 2	Voice Chs	PC kbps	CC kbps	Video kbps	Total VBR kbps
11	Atlanta GA	Chicago IL	10	1000	1000	10000	12000
12	Atlanta GA	Dallas TX	40	1000	1000	10000	12000
13	Atlanta GA	Denver CO	10	1000	1000	10000	12000
14	Atlanta GA	Detroit MI	10	1000	1000	10000	12000
15	Atlanta GA	Los Angeles CA	25	1000	1000	10000	12000
16	Atlanta GA	Miami FL	100	20000	1000	10000	31000
17	Atlanta GA	Minneapolis MN	10	1000	1000	10000	12000
18	Atlanta GA	New York NY	30	25000	1000	10000	36000
19	Atlanta GA	Phoenix AZ	10	1000	1000	10000	12000
20	Atlanta GA	Raleigh NC	15	1000	1000	10000	12000
21	Atlanta GA	Salt Lake City UT	10	1000	1000	10000	12000
22	Atlanta GA	San Jose CA	10	1000	1000	10000	12000
23	Atlanta GA	Seattle WA	10	1000	1000	10000	12000
24	Atlanta GA	St. Louis MO	10	1000	1000	10000	12000
25	Atlanta GA	Washington DC	10	1000	1000	10000	12000
26	Chicago IL	Atlanta GA	10	1000	1000	20000	22000
27	Chicago IL	Dallas TX	60	1000	1000	20000	22000
28	Chicago IL	Denver CO	10	1000	2000	20000	23000
29	Chicago IL	Detroit MI	100	1000	2000	20000	23000

How the Best Topology is Selected

- The design criteria are
  - to meet performance requirements
  - to aim for lowest facilities cost
- In this case study, there will not be much variation in performance because:
  - each design must carry the offered traffic and meet the trunk failure reliability requirements
  - there is no credit given for better performance beyond that
  - the high trunk speeds being used and the large geographic area of the design mean that propagation delays will predominate

- Lowest facilities cost will be the topology success measure
- Note that service providers do assign cost to bandwidth
  - most assign the same cost they could sell it at

What is the Best Design Approach?

Three design approaches often used at Nortel are applied and compared here:

(1) <u>Pruning approach</u>: Start with a full mesh topology and remove connections

- **a methodology is defined for sequence of connection deletion, and when to stop**

(2) <u>Additive approach</u>: Start with zero connections and add connections

- **a methodology is defined to determine sequence of connection addition, and on when to stop**

(3) <u>A four-node hub approach</u>: Select a four-node hub, fully meshed, and add other connections

- **a simple methodology is used to select the hubs and add connections**

Nortel Magellan Network Design

- Nortel has skilled and experienced network designers in many parts of the world
- Nortel uses state-of-the-art programs for quick and accurate designs
  - some programs are internally developed, such as NetCalc2 used in this case study
  - others are externally procured, e.g. automatic topology generators
- The people and the programs are equipped to design networks with many hundreds nodes using various techniques
- Fast design iterations are possible if input requirements change or if the customer expands the network

Results: 12 Topologies were Designed

Twelve topology design iterations were done and results are given in the following pages

(1) Pruning approach:

- **nine iterations of this were done (nine topologies created)**

(2) Additive approach:

- **just one design using this approach was done**

(3) A four-node hub approach

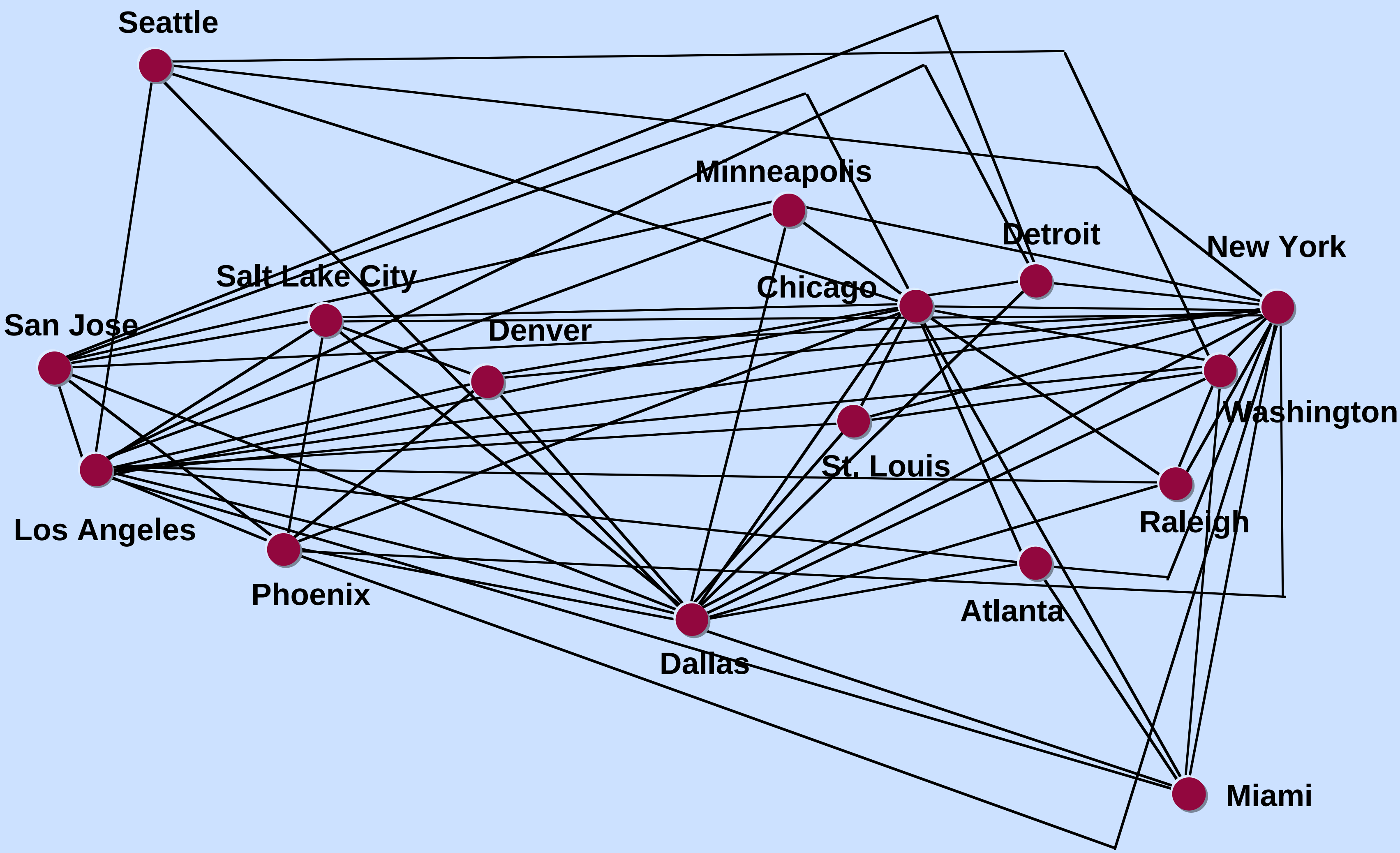
- **two topology variations of this were done**

Pruning Design Approach

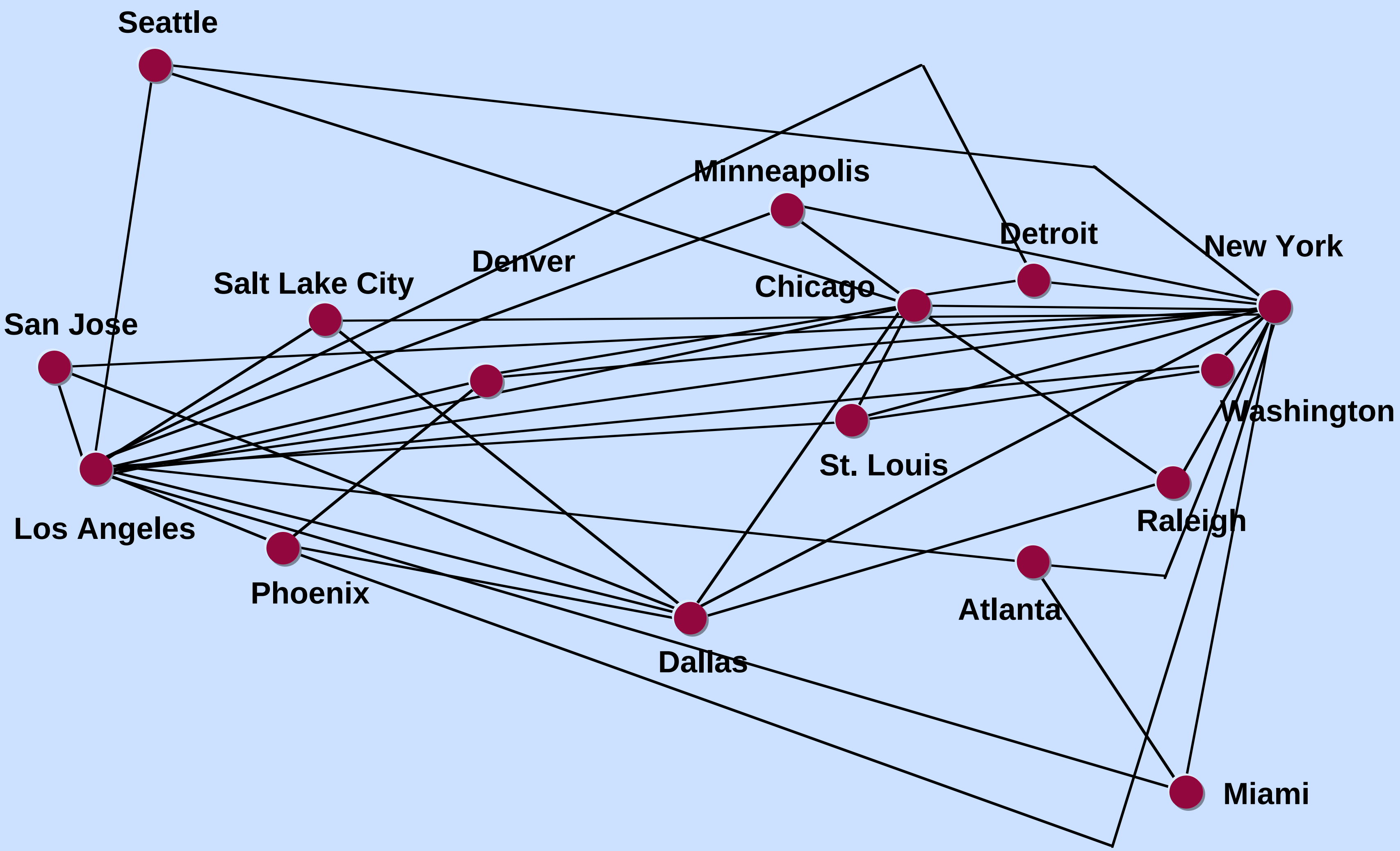
- Enter the offered traffic
- Create a full mesh topology (the 120-trunk topology)
- Create other topologies with fewer trunks by repeating the following:
  - delete connections from the current topology as follows:
    - remove connections starting with lowest traffic (in busier direction), longest connection first to resolve ties
    - stop every 10 or 15 connections to record all topology performance data and cost
    - never leave less than two connections to any node

Three of the nine topologies designed using the pruning method are shown here

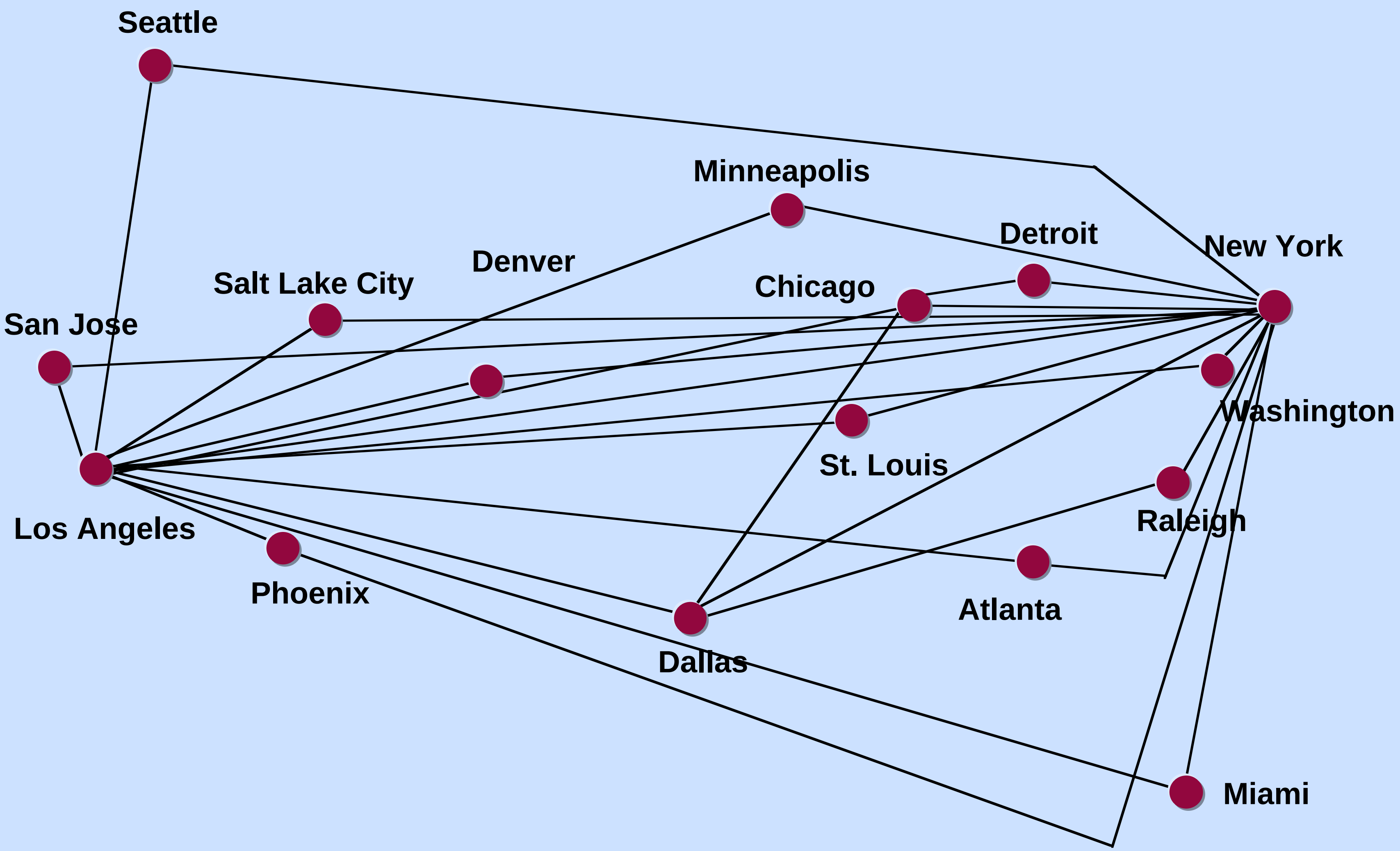
65-trunk Topology (Pruning Method)



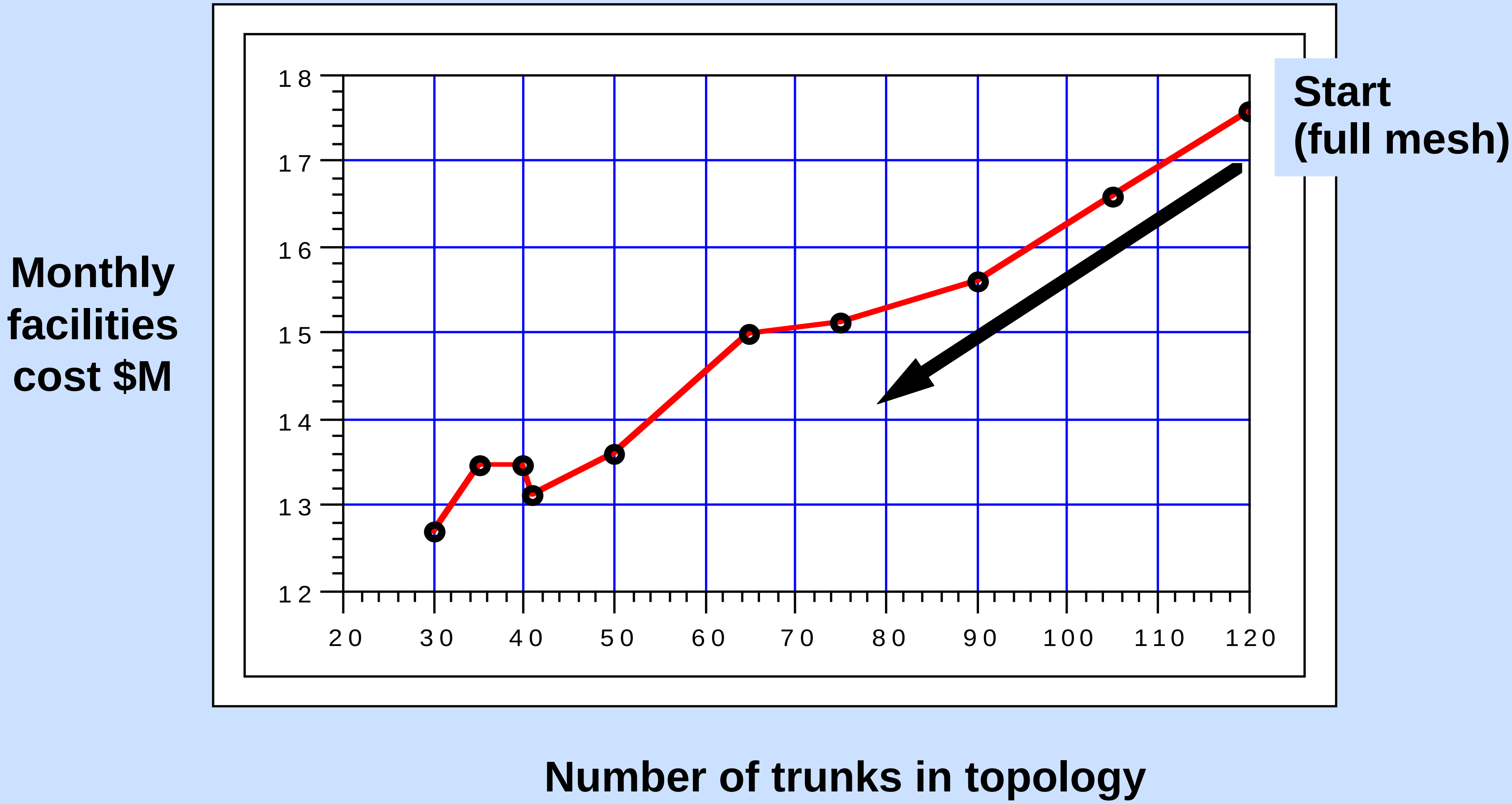
41-trunk Topology (Pruning Method)



30-trunk Topology (Pruning Method)

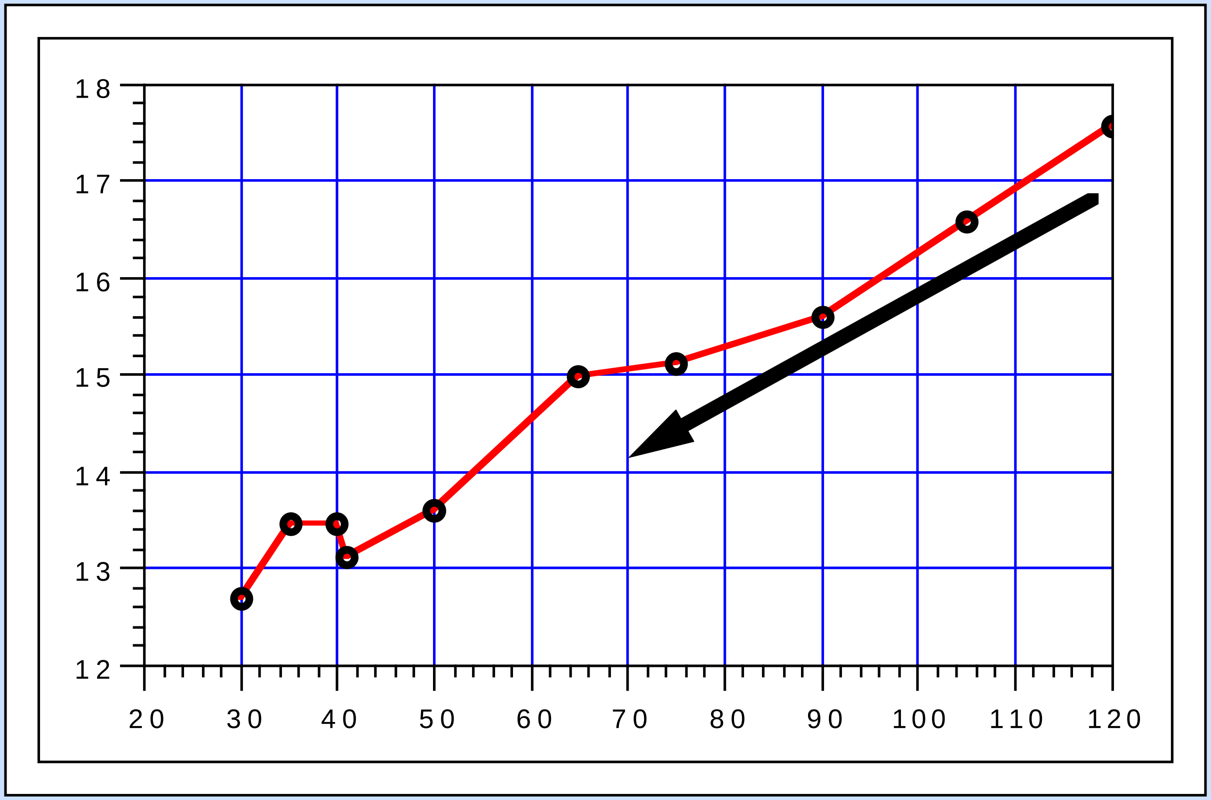


Cost of Topologies Created with Pruning Method



Interpreting Shape of the Cost Chart Curve

Monthly facilities cost $M

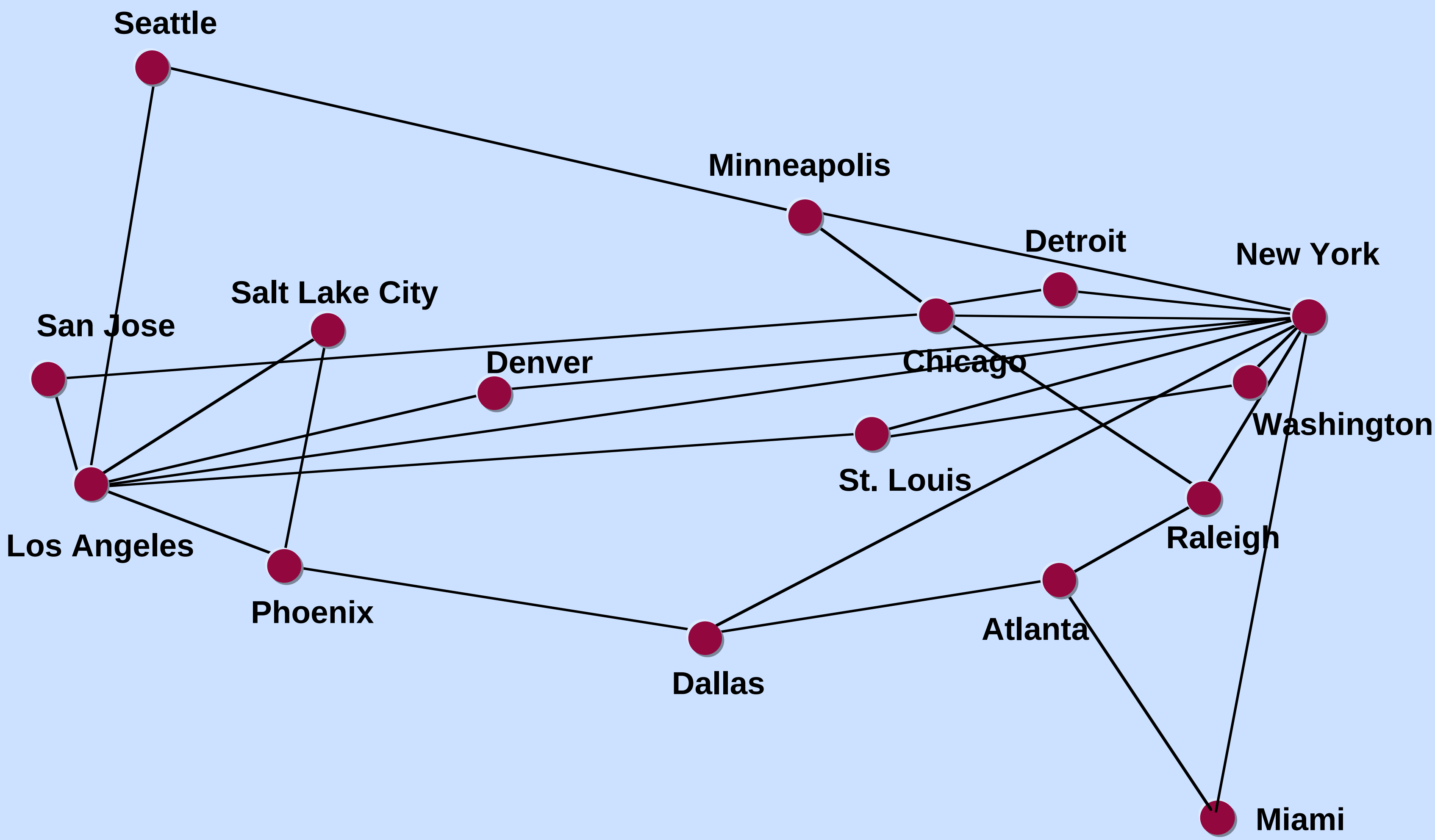


- Fewer, higher bandwidth trunks, reducing cost
- But more tandem traffic is appearing, increasing cost
- Trunk failure also having greater impact, increasing cost

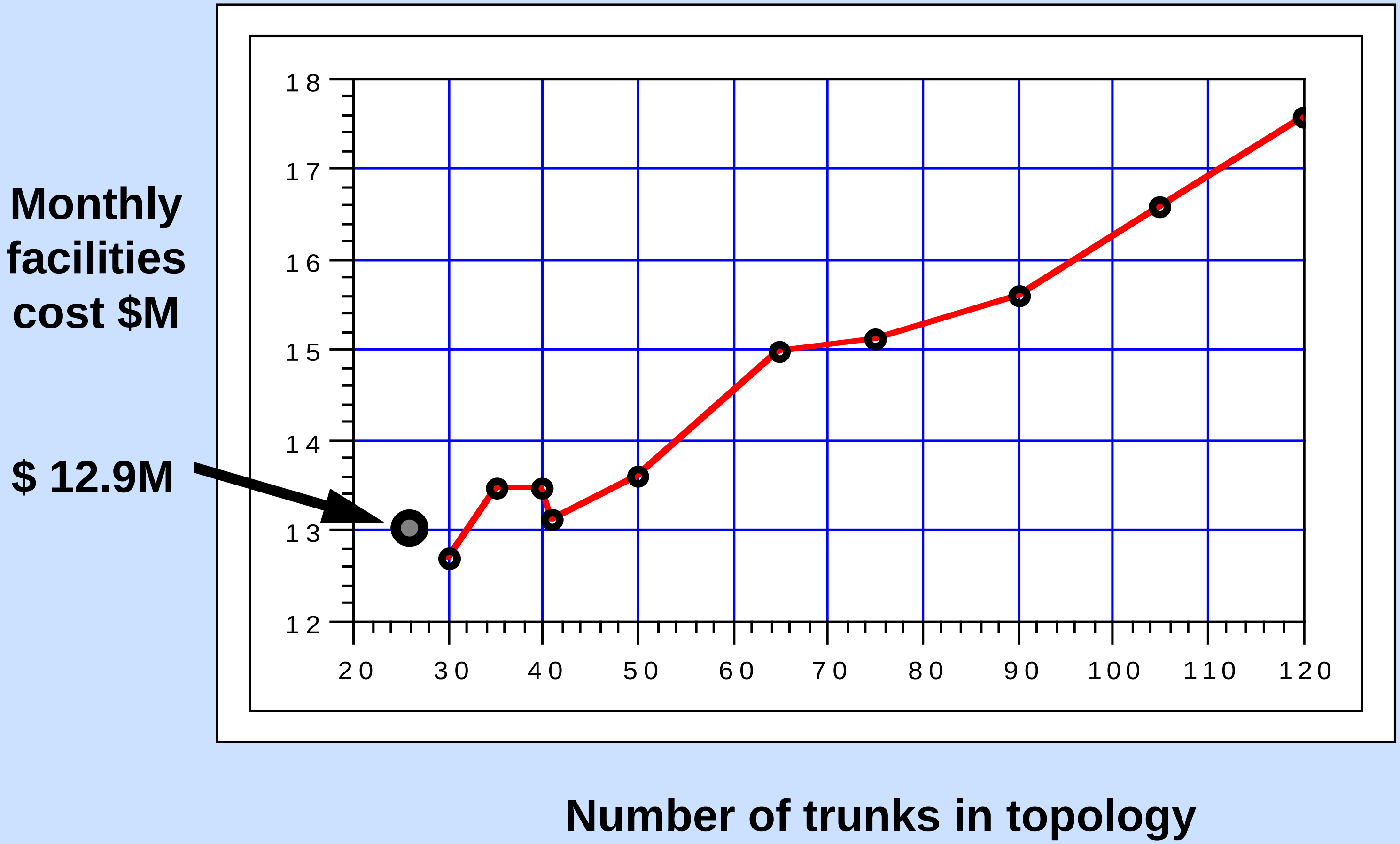
Additive Design Approach

- Enter the offered traffic
- Identify high traffic paths
- Interconnect nodes as follows:
  - put in trunks for the highest-traffic paths
  - for any node with lower traffic levels,
    - consider putting in a trunk to the network node which has the greatest traffic from it (or to it)
    - otherwise, connect it to the nearest two network nodes
- Run the autorouter or load in routes from some other source
- Run through traffic calculations
- Do reliability checks by failing busiest trunks

26-trunk Topology (Additive Method)



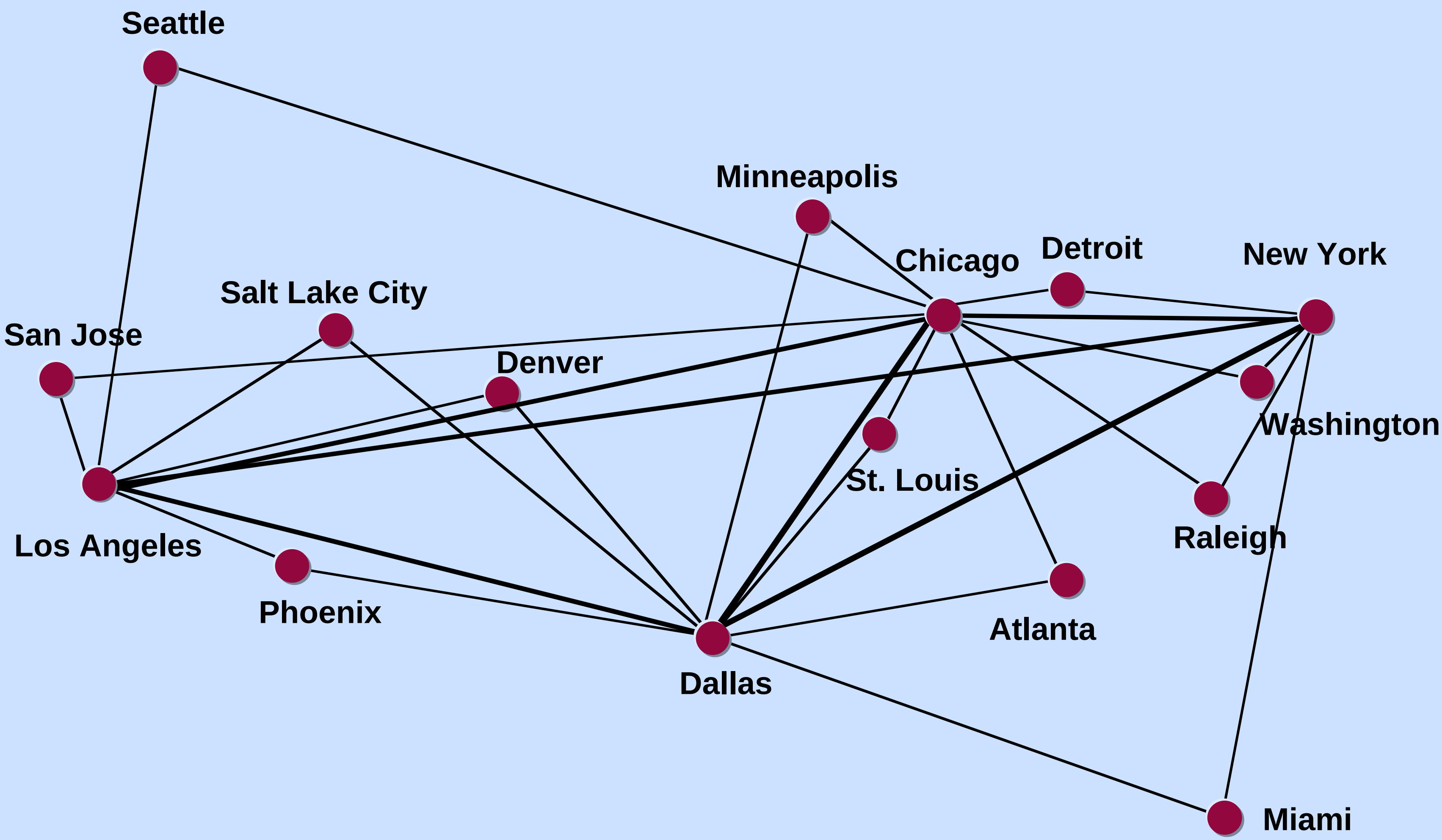
Cost of 26-trunk Topology Created with Additive Method



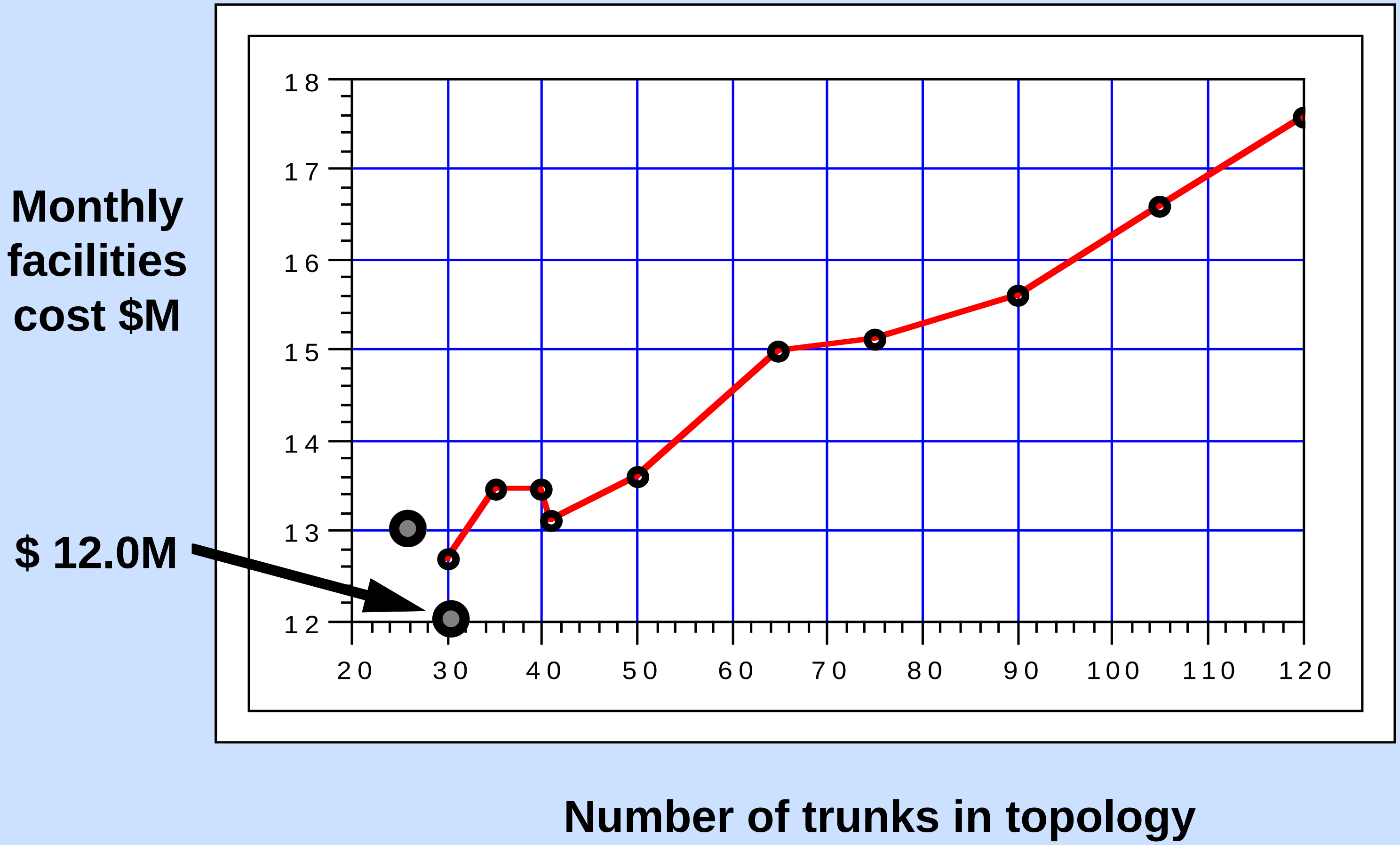
A Four-node Hub Design Approach

- Enter the offered traffic
- Identify high traffic paths
- Interconnect nodes as follows:
  - identify four cities with the highest traffic
  - fully connect those four cities (hub cities) to each other
  - connect all other cities to nearest two hubs
- Run the autorouter or load in routes from some other source
- Run through traffic calculations
- Do reliability checks by failing busiest trunks

30-trunk Topology (#1 Using Four-Hub Method)



Cost of 30-trunk Topology #1 Created with Four-hub Method



Cost and Performance of the Twelve Topologies

Design Method	Trunks	Cost/Mo ($M)*	Delay (ms)**
Pruning	120	17.585	10.2
	105	16.574	10.2
	90	15.592	10.3
	75	15.130	10.5
	65	14.978	10.6
	50	13.607	11.3
	41	13.115	11.5
	40	13.460	11.6
	35	13.478	12.0
	30	12.692	12.3
Additive	26	12.931	13.2
Four-hub	30 (#1)	11.999	11.4 ← Best one
	30 (#2)	12.485	11.4

* Trunk cost per month

** Excluding access delays

How did the 30-trunk Four-hub Topology #1 Win?

- The four cities with the greatest traffic levels to or from other cities are fully connected to each other
- The topology makes good use of the OC-12 tariff for long runs
  - a different tariff could easily result in a different winner
- The average hop count is reasonably low, and the maximum number of hops is only three
  - tandem traffic is still fairly low

The topology has achieved the best balance in cost among:

- **Number of trunks (fewer bigger ones are cheaper)**
- **Tandem traffic (which increases trunk bandwidth and cost)**
- **Spare bandwidth for failure protection (which increases cost)**

How Good is the Winning Trunk Topology?

- **Good, but not necessarily the best possible**
- **It is not easy to gauge whether other algorithms would improve the result <u>significantly</u>**
- **The only way to find out is to perform many more iterations**
  - **for a 16 node network, all iterations are calculable on a desktop computer in a few days**
  - **the hardest part about the iterations is to go through all trunk failure scenarios for each one**

A change is facilities cost formula (which is non-linear) can make a significant change in results

Generalizations Derived from Case Studies

- **The pruning approach starting from a full mesh:**
  - fairly predictable
  - usually time-consuming for large networks
  - can benefit from a more sophisticated algorithm – but only at the expense of more calculation
  - better suited for an automatic topology generation than the additive approach
- **The additive approach starting with no trunks:**
  - often slower convergence toward better results
  - better when having to incrementally expand a network
- **The four-hub approach:**
  - simple, least work
  - usually results in a reasonably good design
  - scales easily

Closing Remarks

- This presentation has focused on the network design part of the facility network layer
- A case study of ATM network design was described, illustrating:
  - three topology design approaches used at Nortel
  - Nortel’s focus on designing to meet network performance requirements at minimum cost
  - Nortel’s ability to quickly create, compare and evaluate many possible topologies using computer-aided design
- Other Inform ‘96 presentations discuss Magellan product attributes which impact the three lower layers in the model
- Another presentation provides valuable insights into ATM network engineering

Presentation References

- **References are listed in the notes**