This workshop profiles the trade-offs between cost and network access. In today's networks, defining network boundaries is an engineering task. This presentation employs current network topologies to determine how boundary design impacts network operating costs. A case study is used to demonstrate the principles presented.

About the presenters:

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Agenda

- Network boundary overview
- Identifying sites for each network tier
- Network cost in relation to boundaries
- Network requirements analysis
- Performance allocation for each tier
- Network boundary optimization
- Summary

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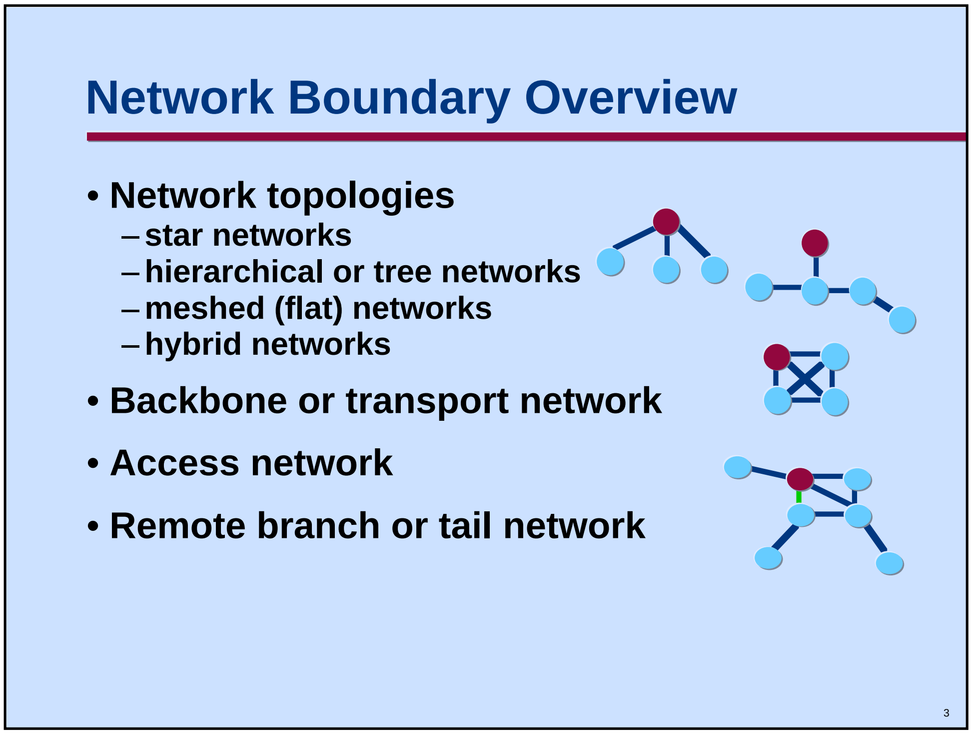
This presentation will look at the various steps required when designing and engineering a network. Those steps include:

- understanding the tiers of the network, what constitutes a backbone, access and tail or remote branch site and identifying which sites are in each of the tiers,
- understanding the total life-cycle network costs, both equipment and facilities, as it relates to each of the tiers in the network,
- understanding the technical and non-technical network requirements, both for today and for the future network, and
- the optimization techniques used in engineering each tier of the network.

A network design case study will be shown to illustrate the practise of the techniques discussed. The case study will concentrate on the access and tail network optimization where 70-80% of the total network costs are spent. In addition, we will show how Magellan switches are used in these two tiers of the network.



Over several decades, WAN topologies evolved from star networks to today's very complex hybrid networks. In early days, networks were small and centralized to access the mainframe. As the number of network users grew, multi-drop or tree networks were adopted to reduce the line costs. Then came multiple mainframe locations to increase both the user performance and host availability. In this era, host locations were fully connected to provide redundancy for service availability and to increase user productivity. This yielded mesh networks. Once meshed networks became available, further line cost reductions were possible by connecting the remote locations to the host locations with cheapest line cost. This gave birth to hybrid networks. The fully connected or the meshed part of the network is called the backbone and the remainder is known as the remote branch or tail network.

In the mid 80's, network switches became cost effective and dedicated lines in North America became cheaper. Switches were used to concentrate the traffic on higher-speed (56K) lines and were connected to the backbone. This resulted in a cheaper life-cycle cost by reducing the recurring line costs creating the concentrator locations.

Wide area networks are generally divided into two or three tiers; backbone, access and tail or remote branch networks. Backbone networks provide transport services in addition to access and limited remote concentration. Access networks provide adaptation and backbone access services to the remote branch or tail sites. The remote branch network connects the user locations to the access or backbone locations that have the cheapest cost and par with the design goals.

This presentation will not spend much time on backbone network design as there are many tools available to produce a cost effective design.

Identifying Sites for Each Tier

- Backbone locations
  - locations with high availability and serviceability
  - user community and its interests
  - location accessibility for maintenance
  - locations place in the organizational hierarchy
- Concentrator or access locations
  - access bandwidth hardware capacity availability
  - access network service cost
  - traffic characteristics or flow
- Remote or tail user locations

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In the past there have been all kinds of papers and books written, and tools developed, for backbone network optimization. **However, the operation networks are NOT designed poorly based on technical and cost parameters where one can spend long time to optimize the network based these two categorize.** In general, designers and users have a sense of where the backbone locations should be based on the above listed categories and traffic flow. These locations are generally related to the organizational structure. For example, locating the backbone locations at regional offices and headquarters are very good possibilities given that regional offices are located in large cities and have 24x7 accessibility. For medium and large enterprise networks, the backbone network is interconnected with dedicated lines from service providers.

Concentrator or access locations can be identified after traffic and performance requirements analysis for each location has been completed. These are the locations that have access bandwidth and hardware capacity which can be shared by the remote locations at a reduced cost. However, there are a lot of service options to consider for connectivity to the backbone. For example, dedicated, packet, frame relay or ATM, SMDS, VSAT, Microwave.... Cost and performance of each option must be evaluated to determine the most cost effective method to provide network services that would meet the customer requirements.

The remote site design is very similar to access or concentrator sites except that the remote site supports only its local users and it connects to either backbone or concentrator location (but not both) based on traffic flow and cost.

Network Cost in Relation to Tiers

- Backbone cost should be limited to 30% (20% is ideal)
- Access cost should be limited to 40%
- Tail cost should be limited to 30%
- Total life-cycle cost includes:
  - design and analysis
  - recurring and non-recurring charges for hardware and carrier services
  - operation and maintenance

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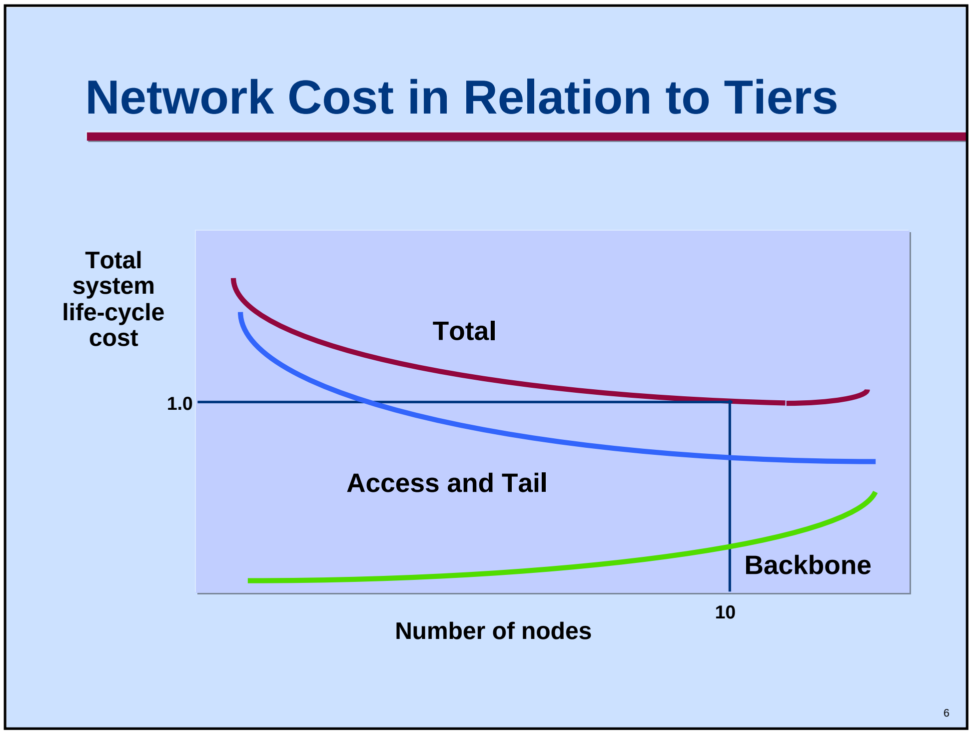
Allocating cost to each tier of the network makes the network design easier. Each tier can be designed independently once the backbone locations are identified. The life-cycle network cost is divided into three pots: Backbone, Access and Tail.

The backbone cost should be between 20% to 30% of the total network life-cycle cost. This percentile would provide an optimum backbone network that would par with the user requirements and provide an efficient transport service.

Access network costs are the largest portion of the total network cost as it concentrates other remote locations and provides backbone access services to the users. It also performs the protocol adaptation, i.e. IBM protocols to X.25, frame relay to ATM. The cost should be limited to 40% to 50% of the total network life-cycle cost.

Tail network cost should be between 20% to 30% of the total network life-cycle cost because its network equipment and circuit or service is for a specific location which is not shared by any other site.



This chart shows the normalized total network cost versus the number of backbone nodes. The life cycle cost decreases as the number of backbone nodes increase up to a certain number. This number is 10 nodes in our case study.

The number of nodes where the total cost starts increasing, is network size dependent. This upswing occurs between 4 to 20 backbone nodes for networks with 50 to 2000 locations. The reason for the cost increase is twofold: the number of backbone trunks increases which adds to the monthly recurring charges; and the large number of backbone nodes requires more hardware/software, support and maintenance services which again increases the overall network costs. Hence, the additional backbone cost will increase the network life cycle cost. The solution is to keep the backbone circuit and equipment cost limited to 30% of the total network life-cycle cost.

Access cost savings are larger than the backbone cost increase until we reach the break point. **After the break point access cost savings are smaller than adding more backbone savings and the access cost keeps decreasing as the number of backbone nodes increase.**

Requirements Analysis

- **User requirements**
  - traffic characteristics
  - connectivity and protocol
  - performance (delay, availability and data accuracy)
- **Network requirements**
  - expandability, scalability and evolution
- **Value-added services**
  - network management, billing, security and etc.
- **Non-technical requirements**
  - budget constraints, politics and etc.

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Users have become smarter and more sophisticated. They no longer stand for the *smoke and mirror* approach of the past. Unlike yesteryear, today's user knows the networking technology and are forming consortiums, forums and other organizations to drive standards. Obviously, users and designers are partners in defining the requirements for the data network.

Traffic comes in may shapes and sizes, conforms to various protocols and formats, travels in many patterns and requires special methods of processing and handling. Data is measured in units or packages transmitted over units of time. Unit or package sizes are determined by the protocols used. Maximum unit size of 4096 byte for X.25, 8096 for frame relay or 48 bytes for ATM.

The full suite of user protocols must be defined for both existing and planned applications. Next the protocols for both the application side and the network side must be defined. Protocol routing, application architecture addressing and naming schemes must be addressed as well.

Decreasing the network delay is a major responsibility of the design engineer. Response time is a two-edged sword. New networks should never increase the current network response time. We must define the tolerable delay, its cost and its effect on throughput.

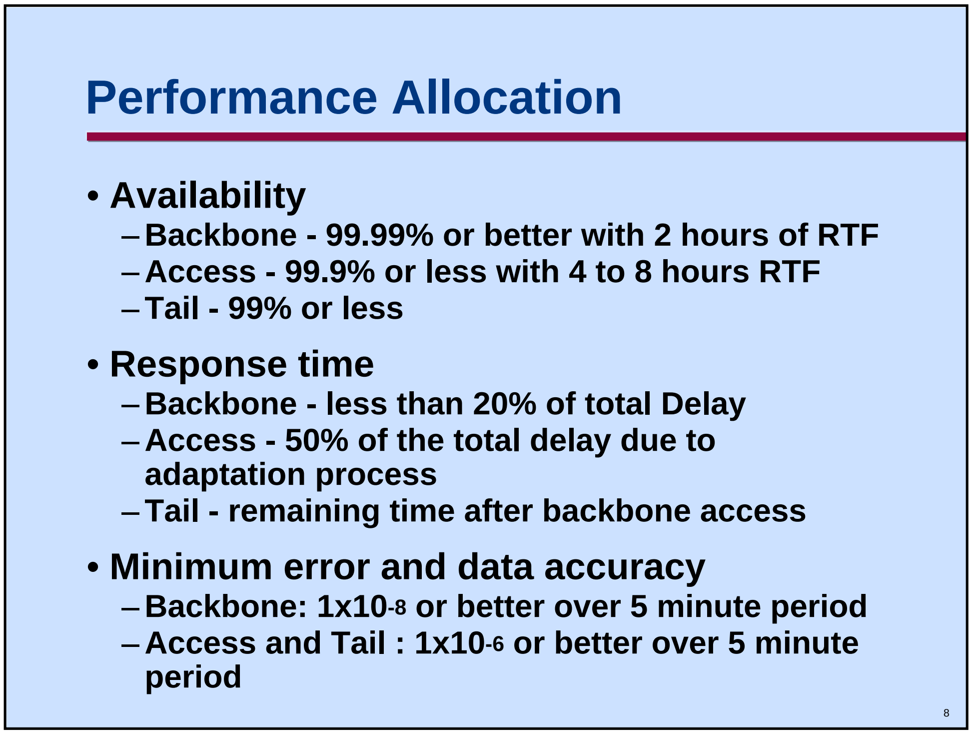
Connectivity includes ports and their associated speeds, types of end devices, distance between DTE and DCE, mode addressing, and physical and data link protocols. Internetworking requirements like point-to-point, concentration, switched, bridged or routed hybrid must be defined.

The network should be designed with the capability to expand, evolve and scale. Using technology like the Magellan family would meet this requirement and can easily evolve to ATM technology.

Value-added services including network management, billing, security, user support, disaster recovery, standard and propriety solutions must also be defined.

Networks must be designed within a given budget. Data network expenditures become cost-justified if they improve operating efficiency and/or save capital, provides a potential revenue increase or avoids larger expenditures.

Politics can cause perfectly good network plans to go awry. Politics are part of the requirements process. Scan the users for hidden political agendas and parameters that are not based on technical or economical factors.



The backbone network is the most stringent tier with the highest reliability and the shortest response time to failures (99.99% or better with 2 hours of RTF) so that transport service outages are minimized.

Backbone tier delay is generally limited by the signal propagation. Switches like Magellan Passport can easily switch one-kilo byte frames in less than 200 microseconds, unlike old switches that are in milliseconds. Enterprise networks in the U.S. typically use T1 circuits as backbone trunks. Thus the delays due line is also very small. This yields a very fast backbone network. However, in the future, the backbone trunks will be T3, OC-1 or OC-3 where delay will be just the propagation delay.

Today switches provide port redundancy as well as the fabric redundancy which exceeds the 99.995% availability.

Service providers are also providing diverse routing, for a small cost, which improves circuit availability.

The service provider backbones are fiber which provides a very accurate data transport because it is immune to noise and nature.

Network Tier Optimization

- **Backbone**
  - use the vendor-specific tools like NetCalc and X-Cel for Magellan to analyze network performance and routing
  - use the design tools like MIND-DATA/PC or any others that optimize the network topology based on traffic patterns, circuit tariff and performance parameters
  - minimize the remote branch concentration at the backbone node
  - baseline design hardware must be sized for modular growth
  - all backbone trunk speed and basic switch hardware configurations should be same

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Vendor-provided tools are specifically designed for their switches and therefore would improve the topology designs created by generic tools like Mind-Data. Generic tools design networks based on tariffs, generic routing and preset delay requirements. These designs must be fine tuned with the vendor-specific tools. For example Nortel's NetCalc is an excellent tool for analyzing various topologies to find the optimum solution for the backbone.

The tail locations should be connected to the access locations, where possible and cost effective. This is so that the tail location capacity and capability is used for access and transport services, not for protocol translation or adaptation. However, using separate switches for adaptation and for backbone will let us concentrate tail users as long as it is cost-effective to do so.

Basic switch hardware must be sized for modular growth so that service disruption is minimized during additions.

Having the same hardware configuration for each backbone node and using the same speed lines will provide predictable and manageable network operations.

Network Tier Optimization

- **Access locations**
  - determine bandwidth requirement from the traffic analysis results
  - determine the excess bandwidth and equipment capacity
  - check for any special requirements
  - find cheapest access connectivity to backbone for all access sites
  - determine total access network service cost and check with budget
  - find cost to increase access capacity to next level
  - monitor the traffic patterns and monthly recurring charges
  - re-optimize the access service when any changes in tail tier
  - re-evaluate total network topology for any major user change
  - mark locations with access capacity to support the tail sites

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Bandwidth requirement is calculated by (traffic volume)x1/(ckt utilization factor): i.e. 23000 bit/s * 1/(0.5) = 46000 bit/s ~ 56K or 64K circuit and it has access capacity for 5-9 kbit/s data.

Special requirements, which are location specific must be considered, for example, dual access to the backbone, and equipment space limitations.

The network design or tariff tools should be used to determine a backbone location at a minimum service cost for access connection that meets the performance budget.

The total equipment and connectivity service cost as it compares to the budgeted cost needs to be determined (should be 40% or less of budget)needs. If the cost is more than 45% of the total budget then more optimization is required.

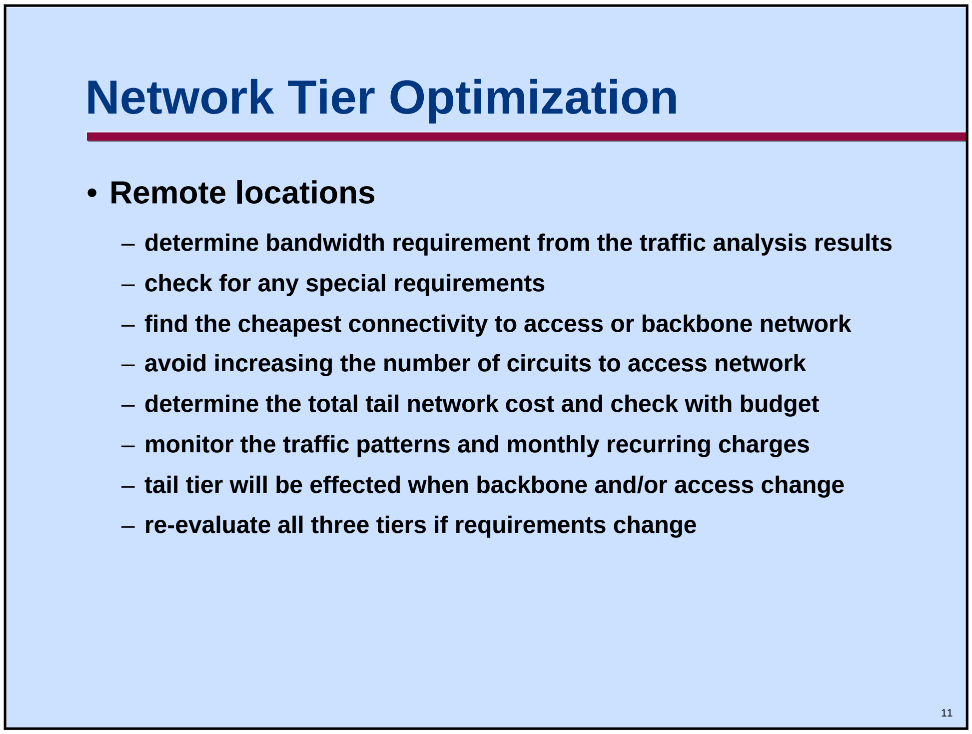
Next the incremental cost to increase the bandwidth and equipment capacity to the next level (i.e. Passport model 50 to model 160 and FT1 to T1) should be considered.

Identify the access locations, access bandwidth and equipment.

Monitoring the traffic patterns and monthly recurring charges for the access locations can ensure a low life cycle cost is maintained. However, if a connectivity change is required then evaluate the change over two periods at a time.

If several of the tail locations are rehomed from any access location then re-optimizing the access locations for any cost savings over the network life-cycle should be done.

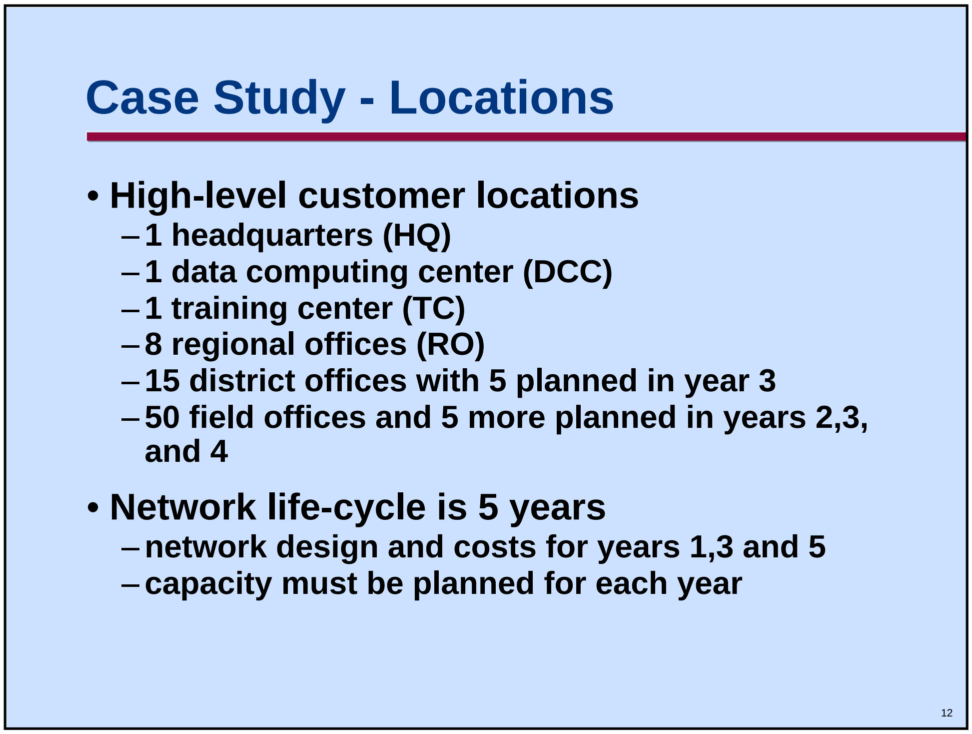
If there is any major change in requirements, such as a corporate merger, then the network design engineer or manager must re-evaluate the total network.



Similar to the access locations, the bandwidth requirement for each location must be determined. Next, network design or tariff tools should be utilized to find an access or backbone location, at a minimum service cost, that has capacity for tail connection that meet with the performance budgets. In the case that the homing point capacity has to be increased, then increase the capacity on the homing point that is shared by many locations. **Do not increase the number of circuits in the access area as this will increase the cost compare to other access locations that have capacity but it may cost little more to connect.**

Next, obtain the total equipment and connectivity service cost and compare it to the budgeted cost (should be 30% or less of budget). If the cost is more than 35% of total budget then more optimization is required.

Changes in both access and backbone tier could effect the life-cycle cost for the tail sites.



The following network design case study will be used to illustrate the practise of the techniques previously discussed.

Most of the locations are in the US. Exceptions are as follows:

- 2-DO in Europe: London, UK and Frankfurt, Germany
- 8-Field offices in Europe: Hanau, Germandy; Burham, Netherlands; Rome, Italy; Goonhilly, United Kingdom; Budapest, Hungary; Vienna, Austria ; Paris, France; and Madrid, Spain
- 1-FO in Tokyo, Japan
- 3-FO in Canada: Vancouver, Ottawa and Toronto

These and the U.S. locations are included in later slides.

Location Classification for Tiers

- **Backbone**
  - 8 regional offices
  - 1 headquarters
  - 1 DCC without any remote location concentration
- **Concentrator location**
  - 20 district offices
  - 1 training center
- **Remote or tail locations**
  - 60 field offices

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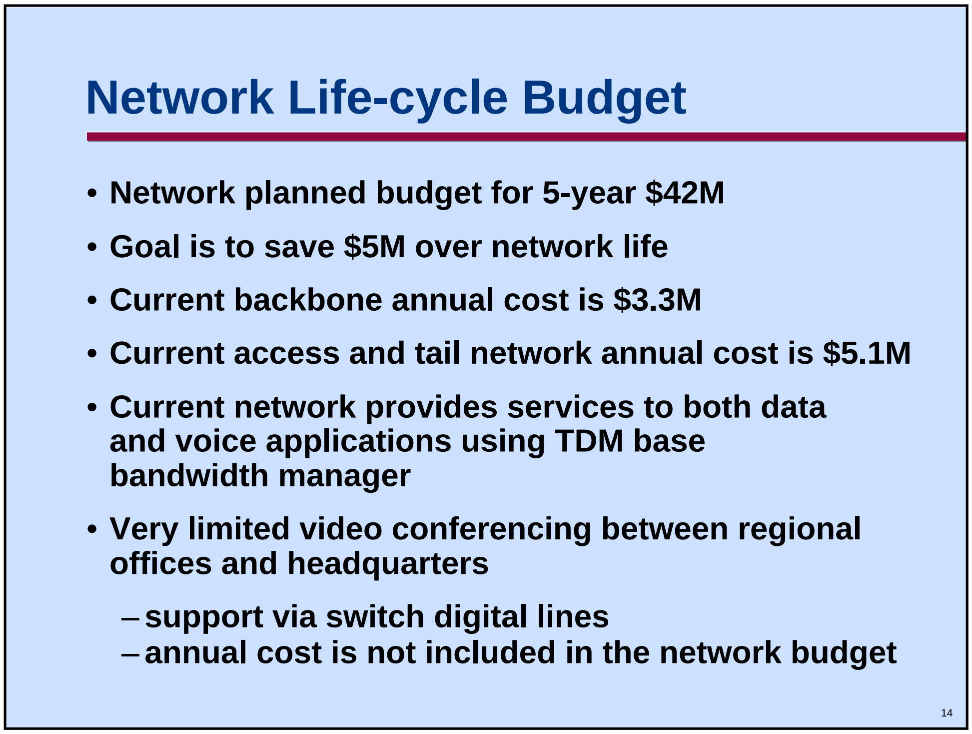
Regional offices are very good candidates for backbone node placement as they are large cities that have access to almost all carrier services. Regional offices generally provide a location access of 24x7 which is very important in maintaining a highly available network. It is also a regional data depository.

The data computing eenter (DCC) has all of the requirements for the backbone location such as very high availability. It is recommended that the remote location concentration should be minimal so that all throughput and port capacity would be available for host access.

District offices are a very good candidates for access concentration because they usually have access throughput capacity to share with field offices and most of the field office traffic is to the district offices. Thus homing field offices to district offices reduces the access and backbone bandwidth requirement. However, if it is more cost effective to home the field offices to another district offices or regional office then it should be done accordingly.



The annual budget figure used for this case study includes the circuit, hardware/software and maintenance cost.

It is the desire of the customer, in this case study, to save $5M over five years and the savings must start no later than year 3. However, the acceptable solution could provide additional service capabilities without increasing the five year budget!

The design engineering goal is to provide a network solution that saves more than $5M with the capability to enhance the existing services, such as providing ATM.

It will show that most of the saving would be obtained by optimizing the access and tail network.

The current network supports PBX’s at regional offices and headquarters. Other networks are served by the public switching networks.

The data traffic uses two protocols. Frame relay is used by routers to support the LAN-to-LAN traffic and X.25 is used to support the asynchronous, IBM and other proprietary protocols. Asynchronous devices will be replaced by LAN access devices over the next two years. However, IBM devices will remain over the network life-cycle.

Video conferencing is limited to the two regional offices and headquarters and to a total of four hours per week. It is provided by a carrier using ISDN. Video cost is not included in the budget at this time because the customer does not want to incorporate video onto the network until they have a better understanding of their video requirements.

Performance Requirements

- Availability
  - 99.99% regional offices, HQ and data computing center
  - 99.9% district offices
  - 99% field offices
- Delay
  - end-to-end busy hour or worse case delay
    - 64 byte Packet - 150 milliseconds
    - 1024 byte Packet - 1 second
- Data accuracy
  - $1x10^{--7}$ for end-to-end transmission over 5 minute period

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Performance requirements apply to locations within the continental US (CONUS).

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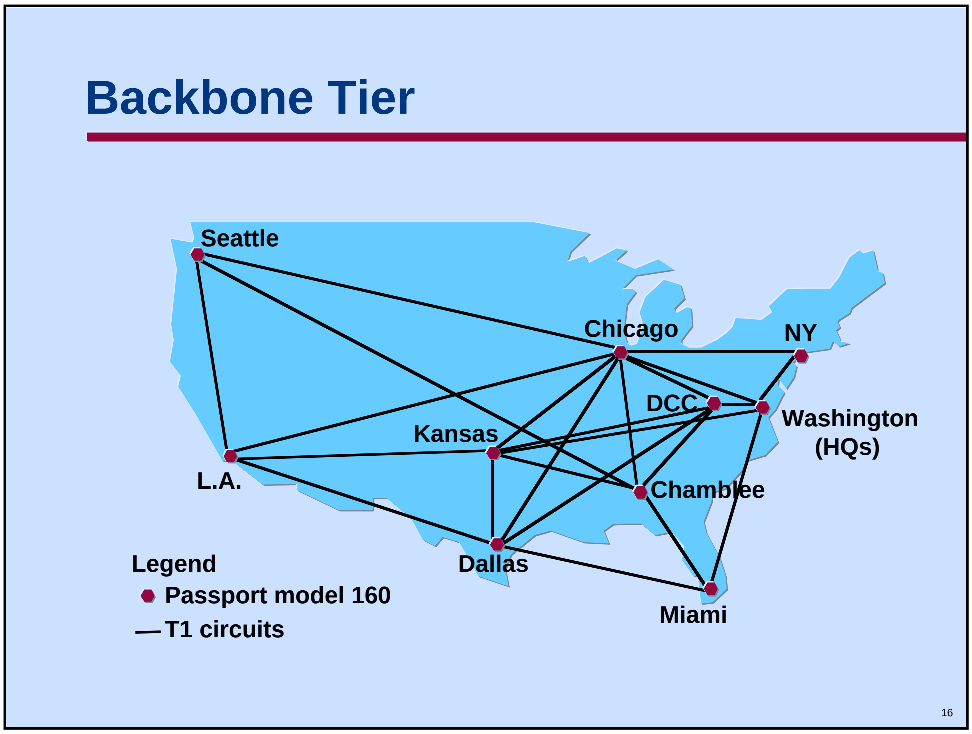
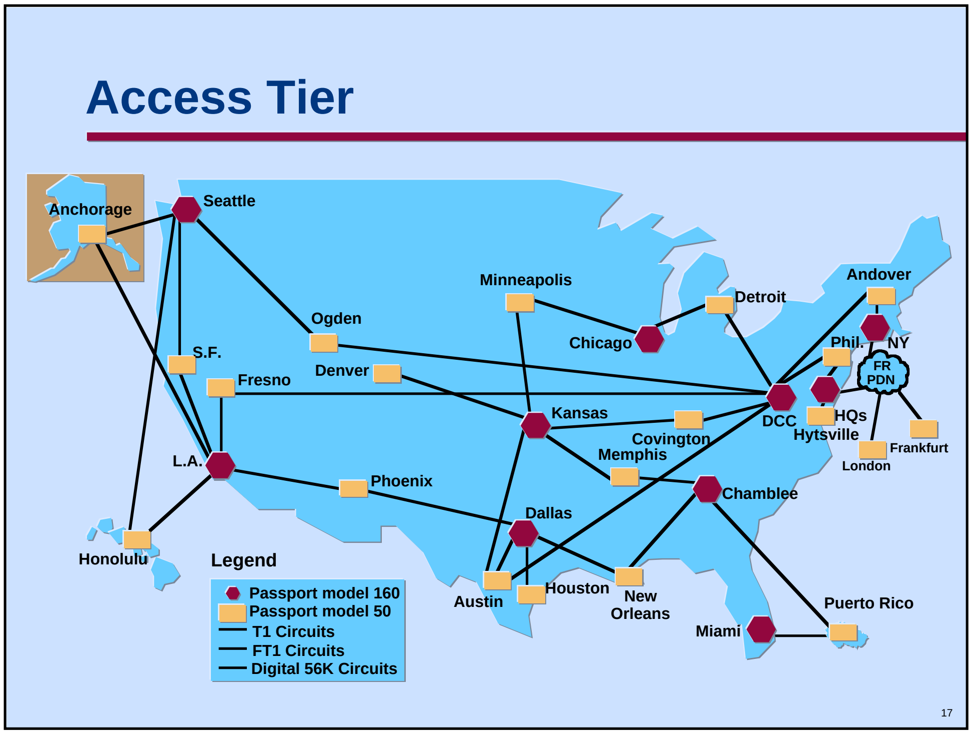
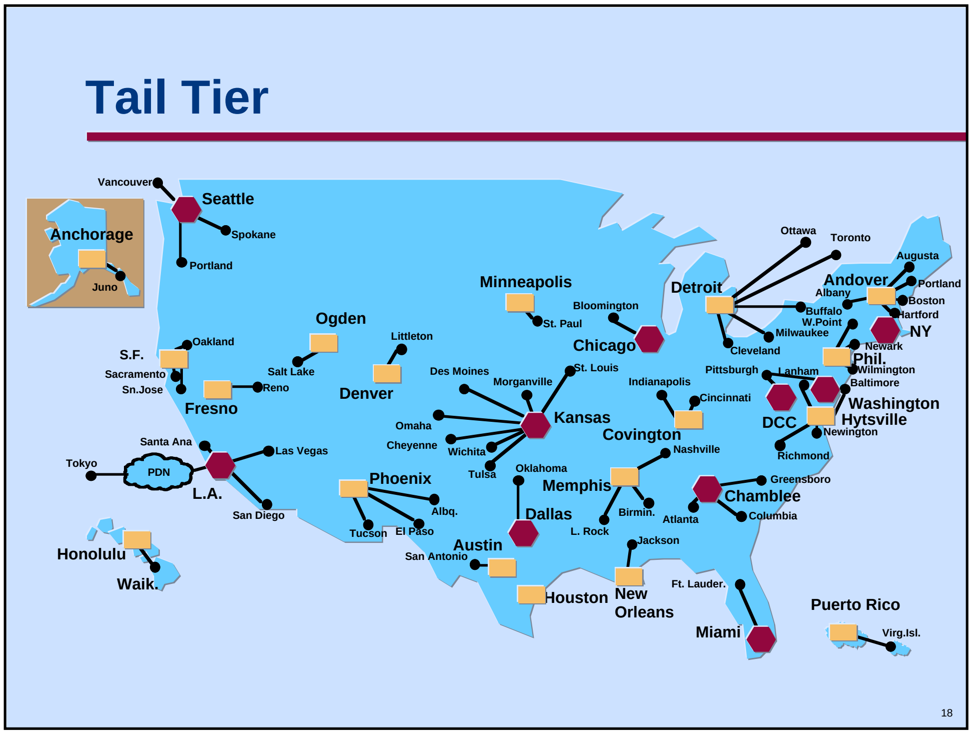


Each regional office has a PBX that is connected to the host PBX via T1 bandwidth in the existing network. Our design uses a 2:1 compression in the backbone for each voice channel when the bandwidth is needed, otherwise it is not compressed.

It should be noted that our backbone topology provides two hops or less between any two backbone locations. This is due to the performance requirements, and also to the planning for possible district office voice application support in the future.

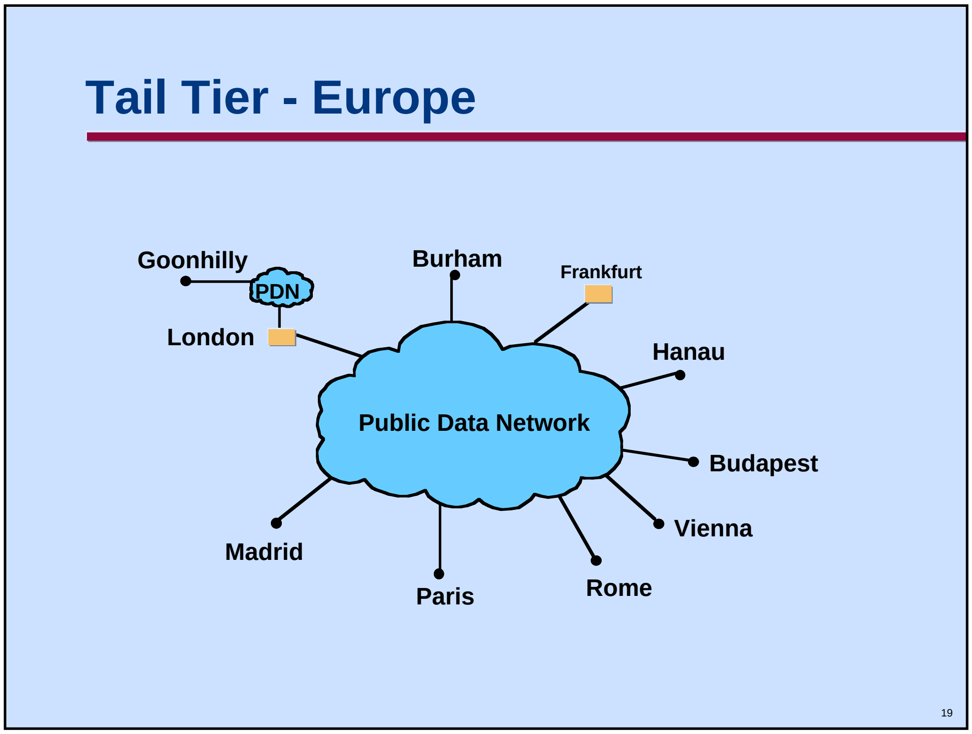


This design provides one hop access connectivity to the backbone. Hence the total hop count for any access location to any access location through the backbone is 4 hops or less. The number of hops depends on the performance requirements for each application.

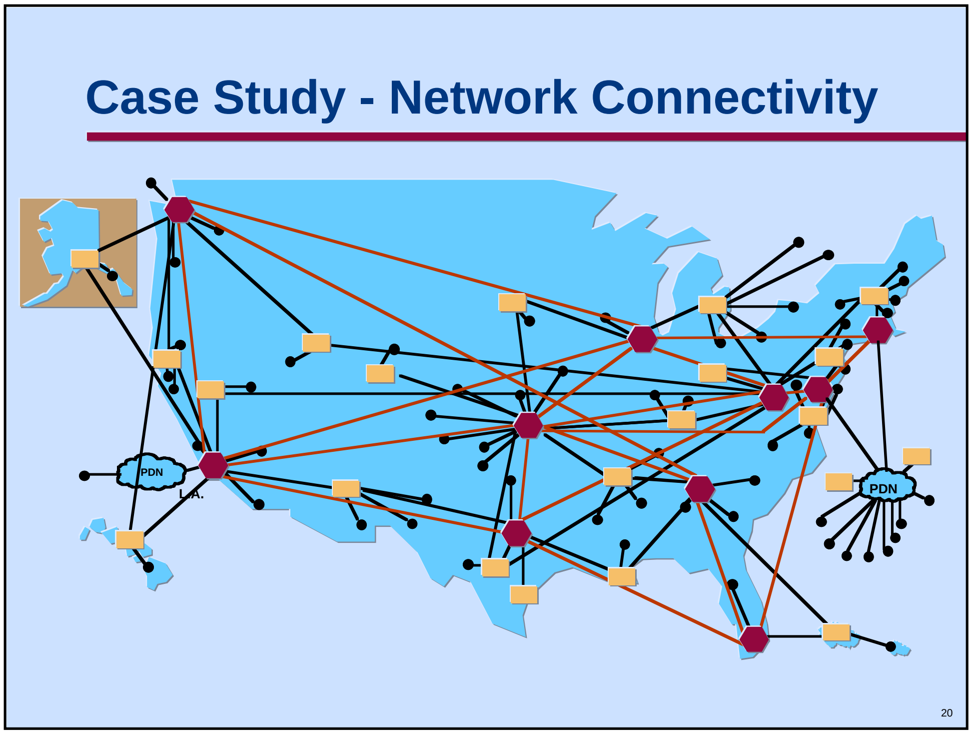


Japan is supported using Infonet data services via a gateway in Los Angeles. All other locations are connected to the access and backbone with dedicated circuits.

Shown above is the remote topology at the end of year 5. Growth locations affect the cost and planning. **Thus the life cycle cost will be according to the growth.**



European locations are designed using X.25 services from public data networks at each host country and Infonet services to connect to the access and backbone network.



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Case Study - Tier Cost and Performance

- **Network life-cycle cost $35.5M**
  - Backbone $9.1M
  - Access $14.1M
  - Tail $12.3M
- **Life-cycle saving is $6.5M**
- **Performance**
  - delay is 10% better than required
  - availability requirement is exceeded
  - data accuracy 1×10^{-8} or better
- **Magellan Passport achieved and exceeded design goals for the case study**

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With an initial investment of $4M to $5M, the case study shows a savings of about $6.5M over five years.

The expected worse case delay for the required pack/frame sizes are as follows:

- 64B - 125 milliseconds
- 1024B - 906 milliseconds

Calculated availability for each tiers is as follows:

- Backbone - 99.993%
- Access - 99.94%
- Remote - 99.2%

Remote and single-connected access locations have either a dial-up or switched digital service for backup of circuit failures. All of the shared hardware components are configured to be redundant.

Accuracy is achieved using X.25 packet level protocols as an access method on all the tail circuits. Trunks will use Nortel's UTP.

Summary

- Network partitioning provides an open architecture such that each subnet could be enhanced, independently
- Selecting appropriate carrier services, the switches like Passport model 50 and model 160 would reduce the network life-cycle cost and provide the transport services
- Access and tail lines cost is the largest and the most topology sensitive
- The cost of network equipment is technology-sensitive and decreasing everyday
- Network design and optimization is more of an art than a mathematical solution

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