Chapter 5.1:
Network Design

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Outline

- **Introduction**
  - Traditional Network Design
  - Network Design Principle
  - Achievable Network Design
- Network Design Methology
- Analyze Requirements

Introduction

- We ave covered
  - The application, transport, network, & link layers
  - Wireless and multimedia technologies
  - Security
  - ..
- Not bad!
- So how does all this come together to help create a network?
  - that's not a small question

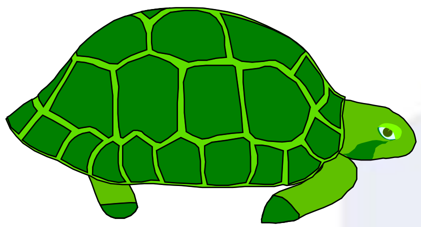
Traditional Network Design

- Answer some pretty basic questions
  - What stuff do we get for the network?
  - How do we connect it all?
  - How do we have to configure it to work right?
- Mostly *capacity planning* – having enough bandwidth to keep data moving
  - Based on a set of **general rules** 80/20
  - May be effective, but result in over engineering
  - No consideration to delay optimization
  - No guarantee of service quality, ..

Network Design Principle

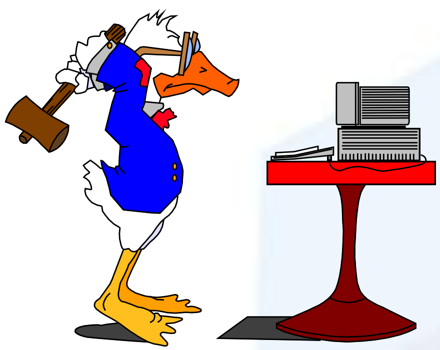
- Network design should be a complete process that matches business needs to available technology to deliver a system that will maximize an organization's success.
  - In the LAN area it is more than just buying a few devices.
  - In the WAN area it is more than just calling the phone company.

Achievable Network Design



Response Time

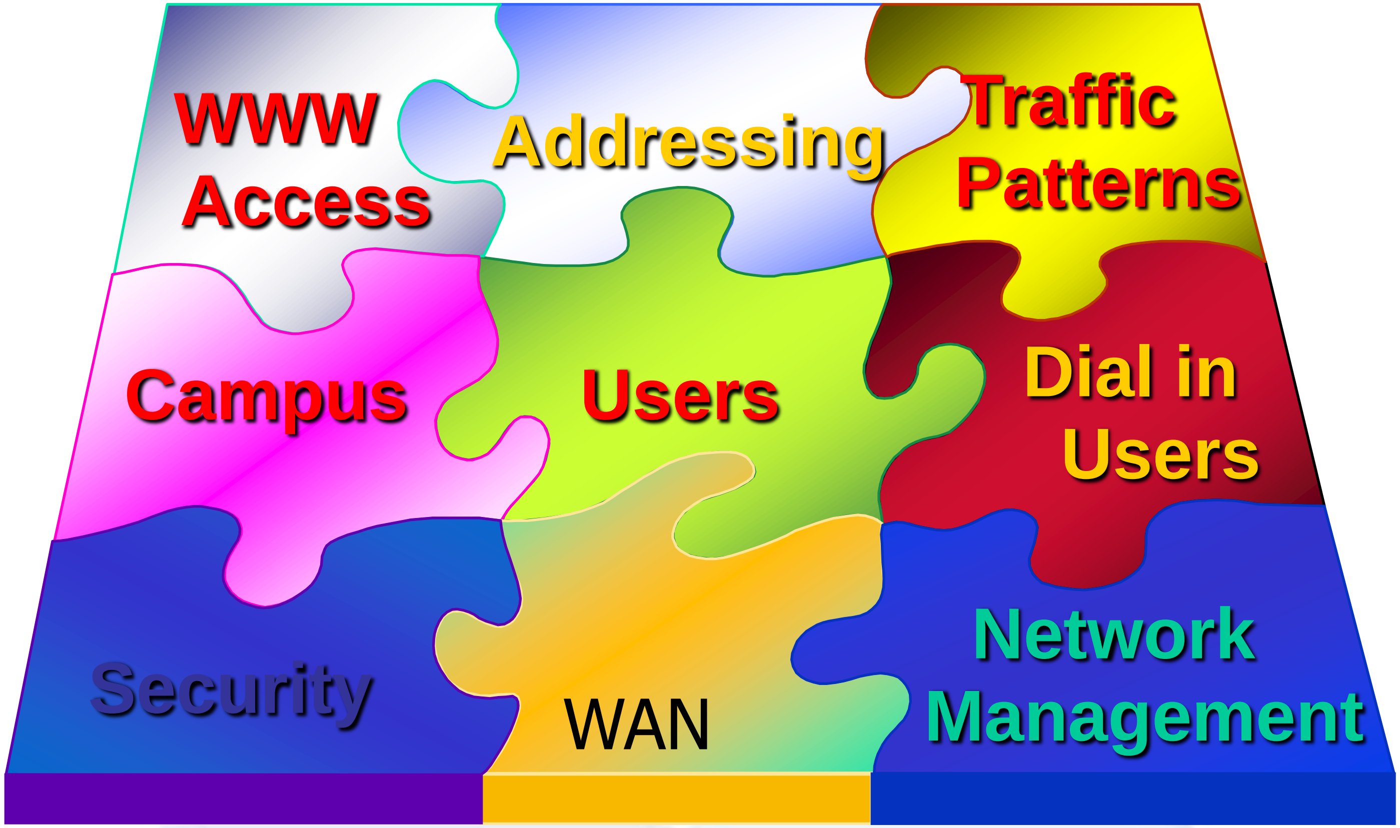
Cost



Reliability

Business Growth

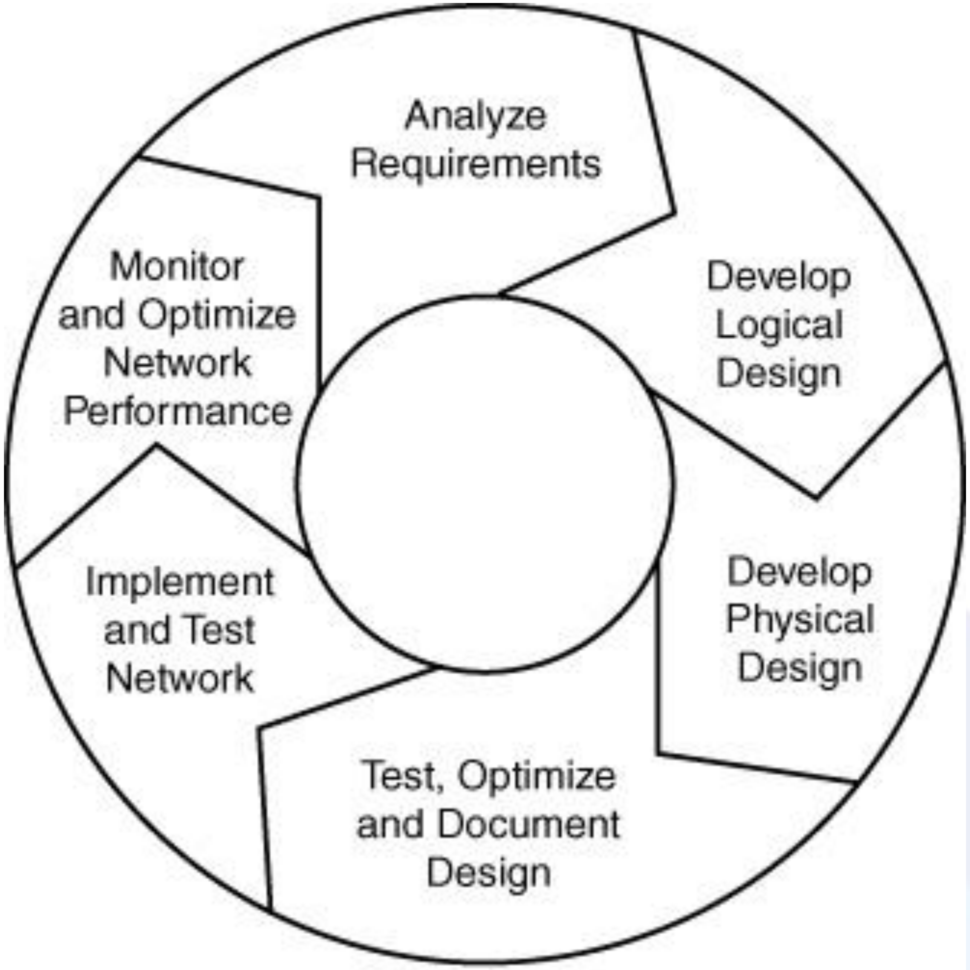
Where to begin?



Outline

- Introduction
- **Network Design Methology**
  - Systems Development Life Cycles
  - Top-Down Network Design
  - PDIOO Network Life Cycle(Cisco)
- Analyze Requirements

Systems Development Life Cycles



Top-Down Network Design

- Phase 1 – Analyze Requirements
  - Analyze business goals and constraints
  - Analyze technical goals and tradeoffs
  - Characterize the existing network
  - Characterize network traffic

Top-Down Network Design

- Phase 2 – Logical Network Design
  - Design a network topology
  - Design models for addressing and naming
  - Select switching and routing protocols
  - Develop network security strategies
  - Develop network management strategies

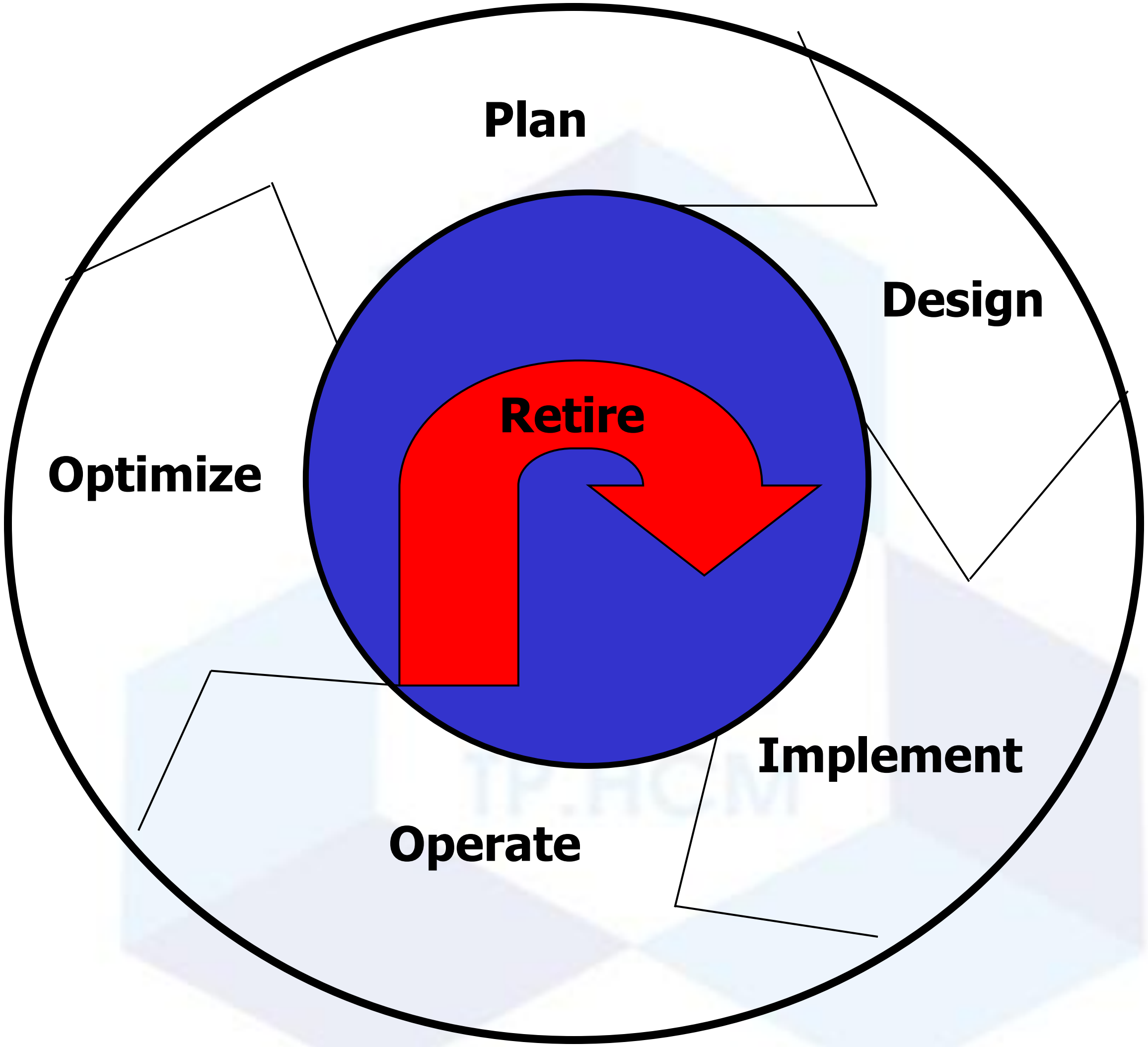
Top-Down Network Design

- Phase 3 – Physical Network Design
  - Select technologies and devices for campus networks
  - Select technologies and devices for enterprise networks

Top-Down Network Design

- Phase 4 – Testing, Optimizing, and Documenting the Network Design
  - Test the network design
  - Optimize the network design
  - Document the network design

PDIOO Network Life Cycle(Cisco)



PDIOO Network Life Cycle(Cisco)

- Plan
  - Network requirements are identified in this phase
  - Analysis of areas where the network will be installed
  - Identification of users who will require network services
- Design
  - Accomplish the logical and physical design, according to requirements gathered during the **Plan** phase
- Implement
  - Network is built according to the **Design** specifications
  - Implementation also serves to verify the design

PDIOO Network Life Cycle(Cisco)

- Operate
  - Operation is the final test of the effectiveness of the design
  - The network is monitored during this phase for performance problems and any faults, to provide input into the **Optimize** phase
- Optimize
  - Based on proactive network management which identifies and resolves problems before network disruptions arise
  - The optimize phase may lead to a network <u>redesign</u>
    - if too many problems arise due to design errors, or
    - as network performance degrades over time as actual use and capabilities diverge
  - Redesign may also be required when requirements change significantly

PDIOO Network Life Cycle(Cisco)

- Retire
  - When the network, or a part of the network, is out-of-date, it may be taken out of production
  - Although Retire is not incorporated into the name of the life cycle (PDIOO), it is nonetheless an important phase

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Business Goals

- Increase revenue
- Reduce operating costs
- Improve communications
- Shorten product development cycle
- Expand into worldwide markets
- Build partnerships with other companies
- Offer better customer support or new customer services

Recent Business Priorities

- Mobility
- Security
- Resiliency (fault tolerance)
- Business continuity after a disaster
- Network projects must be prioritized based on fiscal goals
- Networks must offer the low delay required for real-time applications such as VoIP

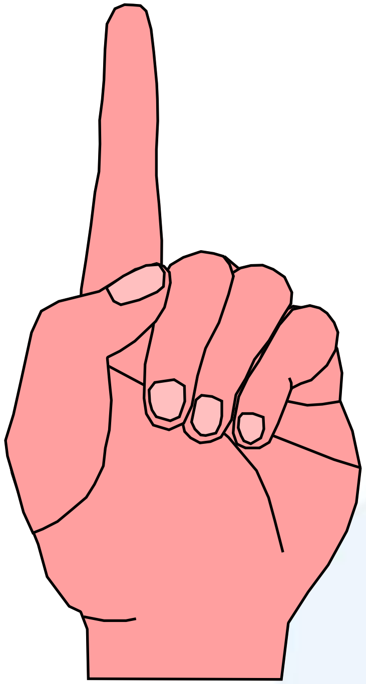
Business Constraints

- Budget
- Staffing
- Schedule
- Politics and policies

Meet With the Customer

- Try to get
  - A concise statement of the goals of the project
    - What problem are they trying to solve?
    - How will new technology help them be more successful in their business?
    - What must happen for the project to succeed?

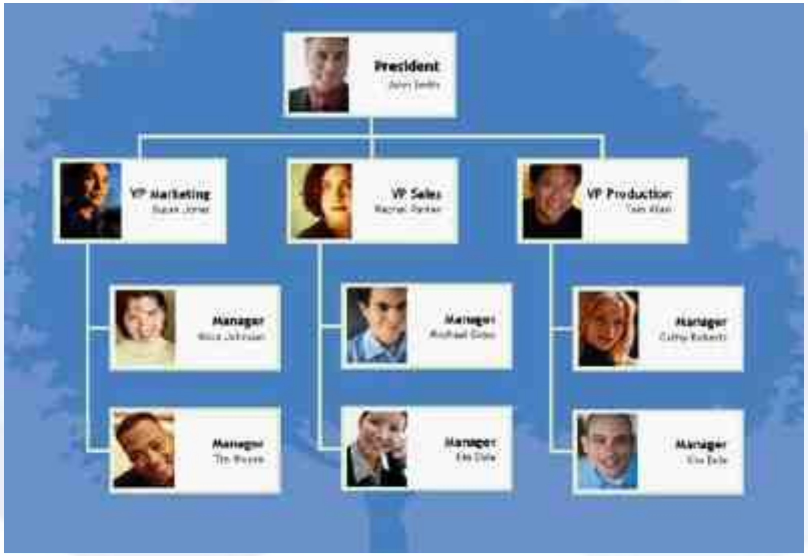
Meet With the Customer



- Discover any biases
  - For example
    - Will they only use certain company's products?
    - Do they avoid certain technologies?
    - Do the data people look down on the voice people or vice versa?
  - Talk to the technical and management staff

Meet With the Customer

- Get a copy of the organization chart
  - This will show the general structure of the organization
  - It will suggest users to account for
  - It will suggest geographical locations to account for



Meet With the Customer

- Get a copy of the security policy
  - How does the policy affect the new design?
  - How does the new design affect the policy?
  - Is the policy so strict that you (the network designer) won’t be able to do your job?
- Start cataloging network assets that security should protect
  - Hardware, software, applications, and data
  - Less obvious, but still important, intellectual property, trade secrets, and a company's reputation

The Scope of the Design Project

- Small in scope?
  - Allow sales people to access network via a VPN
- Large in scope?
  - An entire redesign of an enterprise network
- Use the OSI model to clarify the scope
  - New financial reporting application versus new routing protocol versus new data link (wireless, for example)
- Does the scope fit the budget, capabilities of staff and consultants, schedule?

Gather More Detailed Information

- Applications
  - Now and after the project is completed
  - Include both productivity applications and system management applications
- User communities
- Data stores
- Protocols
- Current logical and physical architecture
- Current performance

Network Applications

Name of Application	Type of Application	New Application ?	Criticality	Comments

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Scalability

- Scalability refers to the ability to grow
- Some technologies are more scalable
  - Flat network designs, for example, don’t scale well
- Try to learn
  - Number of sites to be added
  - What will be needed at each of these sites
  - How many users will be added
  - How many more servers will be added

Availability

- Availability can be expressed as a percent uptime per year, month, week, day, or hour, compared to the total time in that period
  - For example:
    - 24/7 operation
    - Network is up for 165 hours in the 168-hour week
    - Availability is 98.21%
- Different applications may require different levels
- Some enterprises may want 99.999% or "Five Nines" availability

Availability

Downtime in Minutes

	Per Hour	Per Day	Per Week	Per Year
99.999%	.0006	.01	.10	5
99.98%	.012	.29	2	105
99.95%	.03	.72	5	263
99.90%	.06	1.44	10	526
99.70%	.18	4.32	30	1577

Availability

- Availability can also be expressed as a mean time between failure (MTBF) and mean time to repair (MTTR)
- Availability = MTBF/(MTBF + MTTR)
  - For example:
    - The network should not fail more than once every 4,000 hours (166 days) and it should be fixed within one hour
    - 4,000/4,001 = 99.98% availability

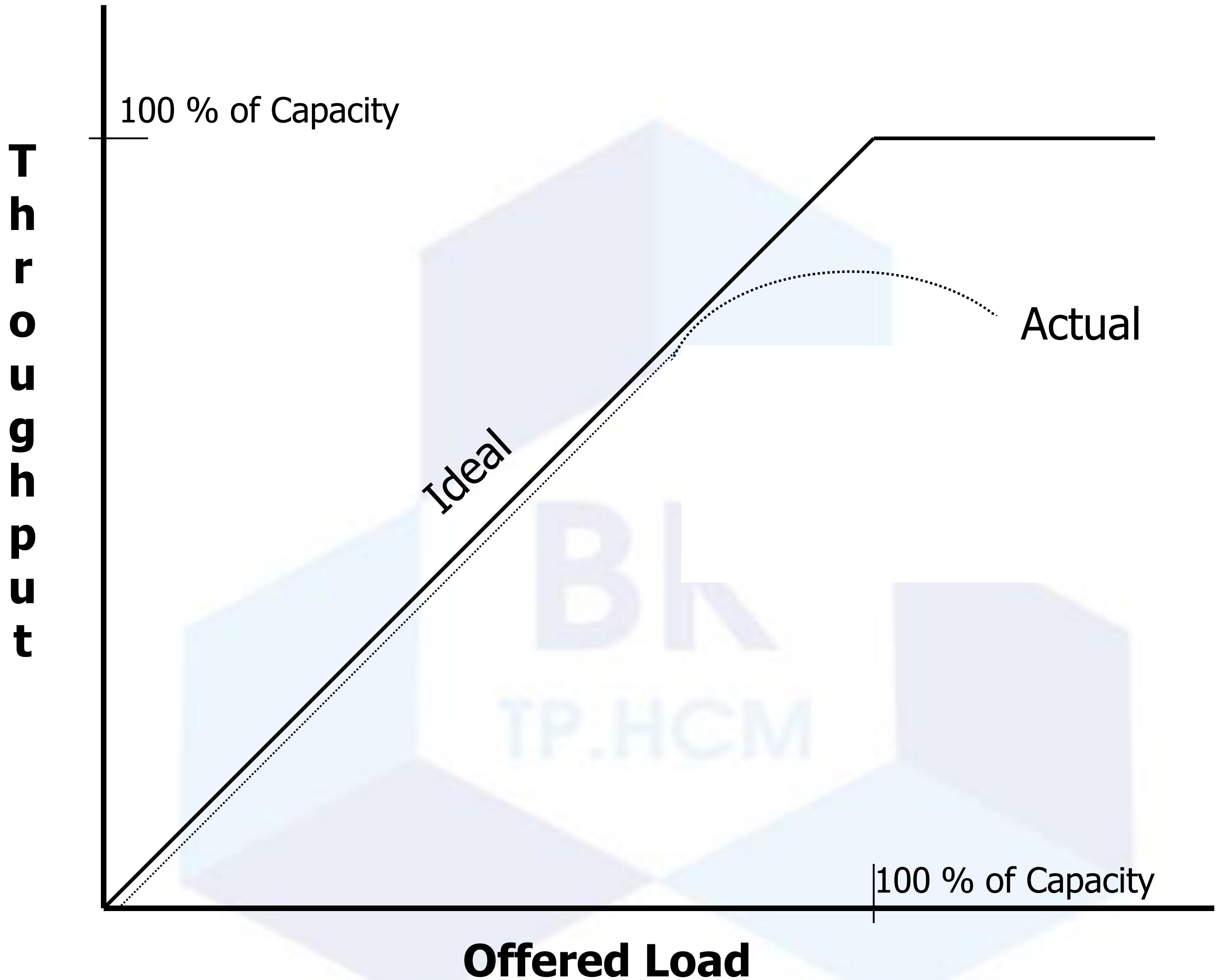
Network Performance

- Common performance factors include
  - Bandwidth
  - Throughput
  - Bandwidth utilization
  - Offered load
  - Accuracy
  - Efficiency
  - Delay (latency) and delay variation
  - Response time

Bandwidth Vs. Throughput

- Bandwidth and throughput are not the same thing
- Bandwidth is the data carrying capacity of a circuit
  - Usually specified in bps
- Throughput is the quantity of error free data transmitted per unit of time
  - Measured in bps, Bps, or packets per second (pps)

Bandwidth, Throughput, Load



Other Factors that Affect Throughput

- The size of packets
- Inter-frame gaps between packets
- Packets-per-second ratings of devices that forward packets
- Client speed (CPU, memory, and HD access speeds)
- Server speed (CPU, memory, and HD access speeds)
- Network design
- Protocols
- Distance
- Errors
- Time of day, etc., etc., etc.

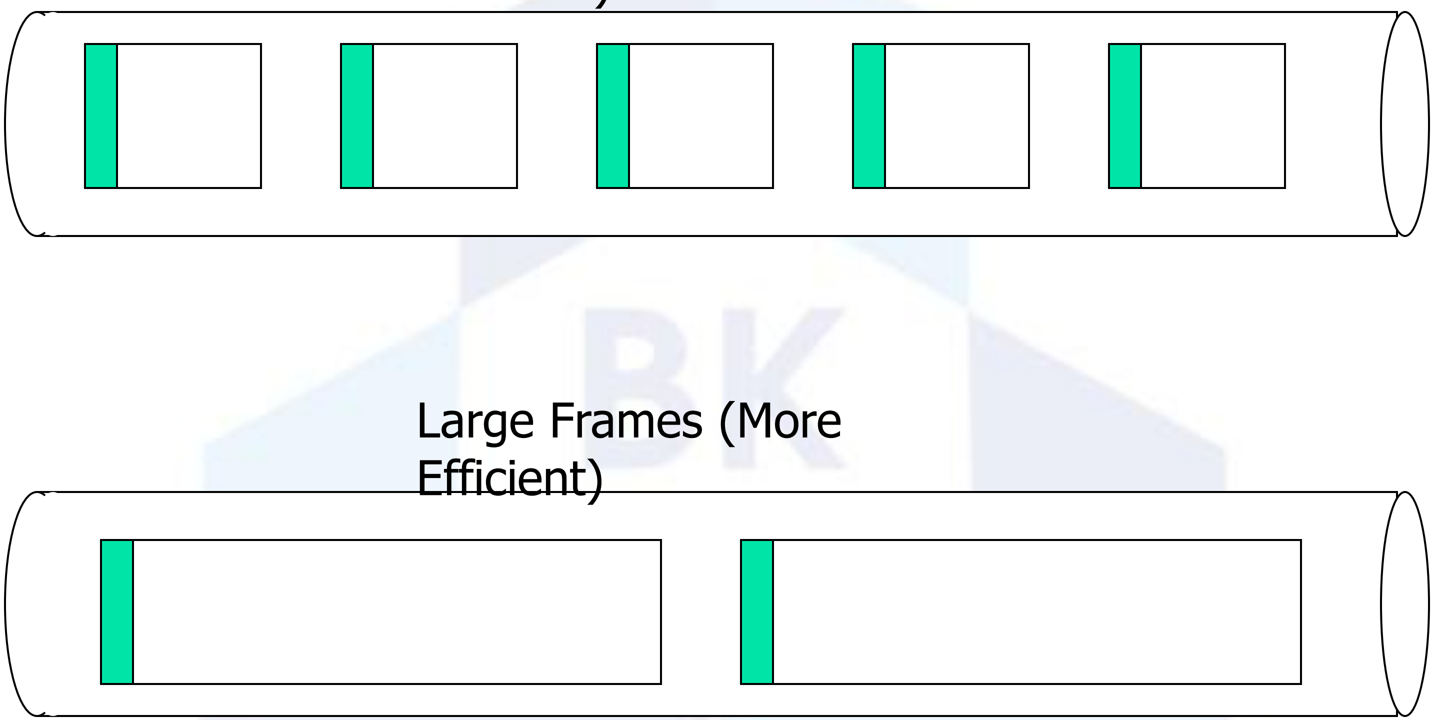
Throughput Vs. Goodput

- You need to decide what you mean by throughput
- Are you referring to bytes per second, regardless of whether the bytes are user data bytes or packet header bytes
  - Or are you concerned with application-layer throughput of user bytes, sometimes called “goodput”
    - In that case, you have to consider that bandwidth is being “wasted” by the headers in every packet

Efficiency

Small Frames (Less Efficient)

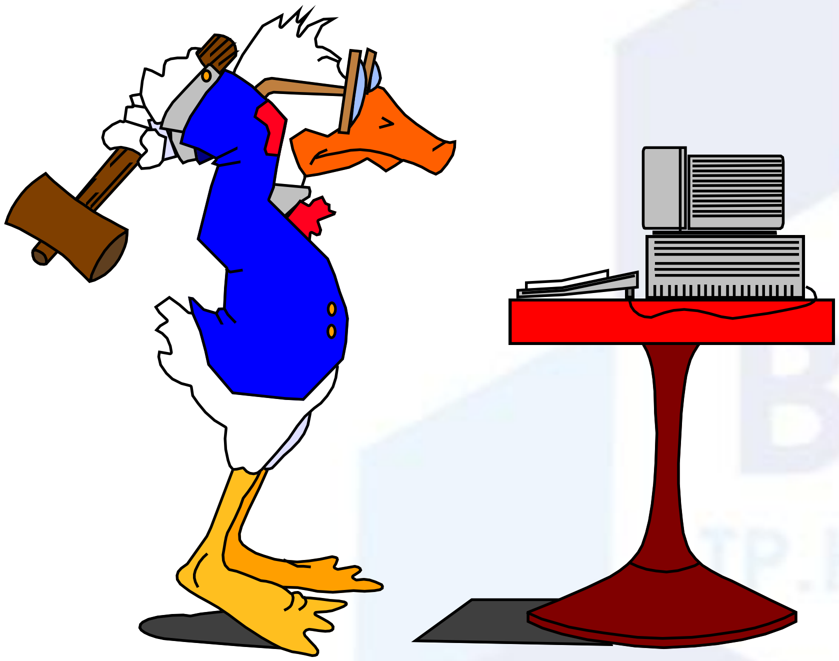
Large Frames (More Efficient)



Efficiency

- Efficiency
  - How much overhead is required to deliver an amount of data?
  - How large can packets be?
    - Larger better for efficiency (and goodput)
    - But too large means too much data is lost if a packet is damaged
    - How many packets can be sent in one bunch without an acknowledgment?

Delay from the User's Point of View

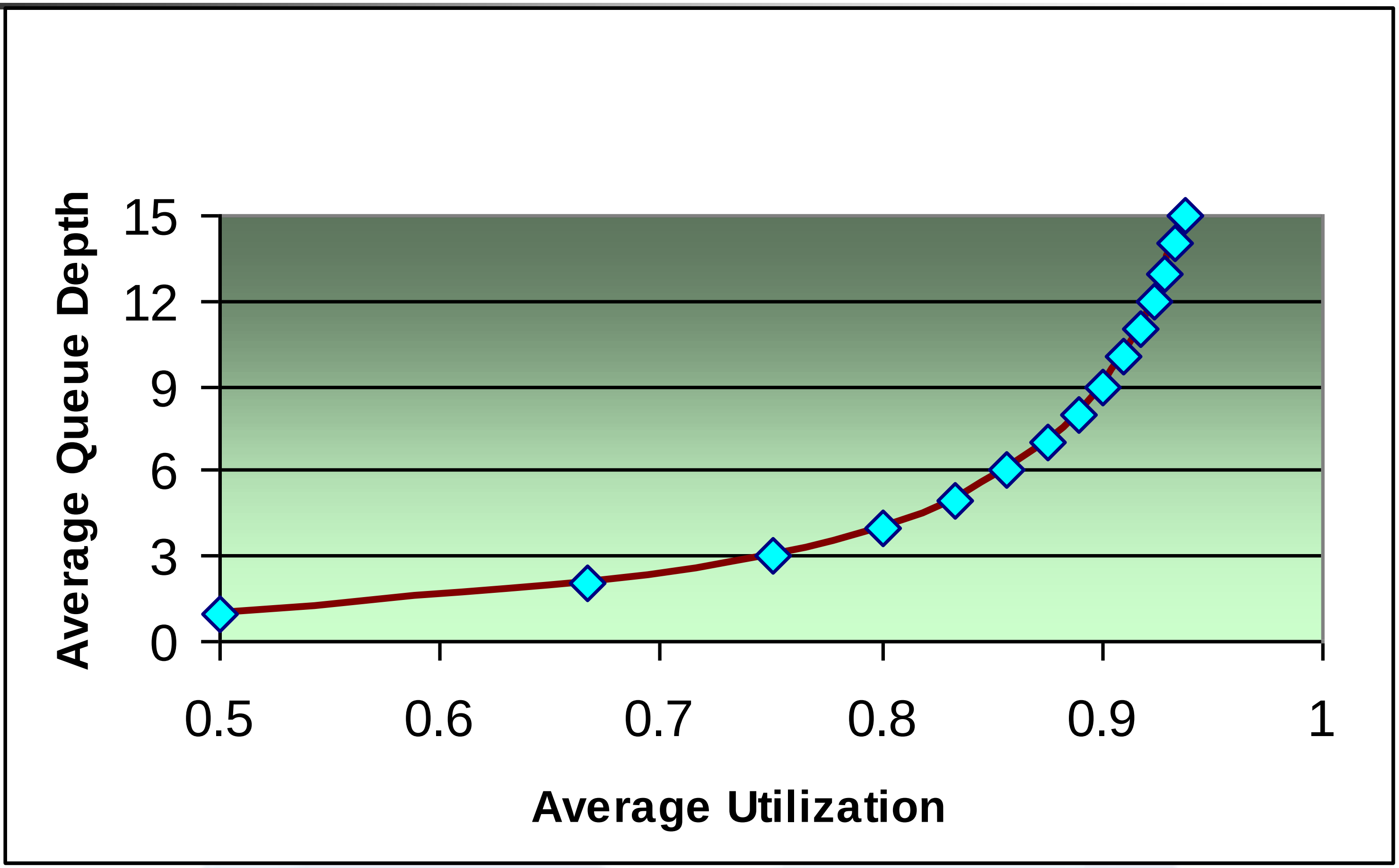


- Response Time
  - A function of the application and the equipment the application is running on, not just the network
  - Most users expect to see something on the screen in 100 to 200 milliseconds

Delay from the Engineer's Point of View

- Propagation delay
  - A signal travels in a cable at about 2/3 the speed of light in a vacuum
- Transmission delay (also known as serialization delay)
  - Time to put digital data onto a transmission line
    - For example, it takes about 5 ms to output a 1,024 byte packet on a 1.544 Mbps T1 line
- Packet-switching delay
- Queuing delay

Queuing Delay and Bandwidth Utilization



- Number of packets in a queue increases exponentially as utilization increases

Example

- A packet switch has 5 users, each offering packets at a rate of 10 packets per second
- The average length of the packets is 1,024 bits
- The packet switch needs to transmit this data over a 56-Kbps WAN circuit
  - Load = 5 x 10 x 1,024 = 51,200 bps
  - Utilization = 51,200/56,000 = 91.4%
  - Average number of packets in queue =
    (0.914)/(1-0.914) = 10.63 packets

Delay Variation

- The amount of time average delay varies
  - Also known as jitter
- Voice, video, and audio are intolerant of delay variation
- So forget everything we said about maximizing packet sizes
  - There are always tradeoffs
  - Efficiency for high-volume applications versus low and non-varying delay for multimedia

Security

- Focus on requirements first
- Identify network assets
  - Including their value and the expected cost associated with losing them due to a security problem
- Analyze security risks

Network Assets

- Hardware
- Software
- Applications
- Data
- Intellectual property
- Trade secrets
- Company's reputation

Security Risks

- Hacked network devices
  - Data can be intercepted, analyzed, altered, or deleted
  - User passwords can be compromised
  - Device configurations can be changed
- Reconnaissance attacks
- Denial-of-service attacks

Manageability

- Fault management
- Configuration management
- Accounting management
- Performance management
- Security management

Usability

- Usability: the ease of use with which network users can access the network and services
- Networks should make users' jobs easier
- Some design decisions will have a negative affect on usability:
  - Strict security, for example ???

Adaptability

- Avoid incorporating any design elements that would make it hard to implement new technologies in the future
- Change can come in the form of new protocols, new business practices, new fiscal goals, new legislation
- A flexible design can adapt to changing traffic patterns and Quality of Service (QoS) requirements

Affordability

- A network should carry the maximum amount of traffic possible for a given financial cost
- Affordability is especially important in campus network designs
- WANs are expected to cost more, but costs can be reduced with the proper use of technology
  - For example ???

Technical Requirements

Name of Application	Cost of Downtime	Acceptable MTBF	Acceptable MTTR	Throughput Goal	Delay Must be Less Than	Delay Variation Must be Less Than:

Making Tradeoffs

Scalability	20
Availability	30
Network performance	15
Security	5
Manageability	5
Usability	5
Adaptability	5
Affordability	15
Total (must add up to 100)	100

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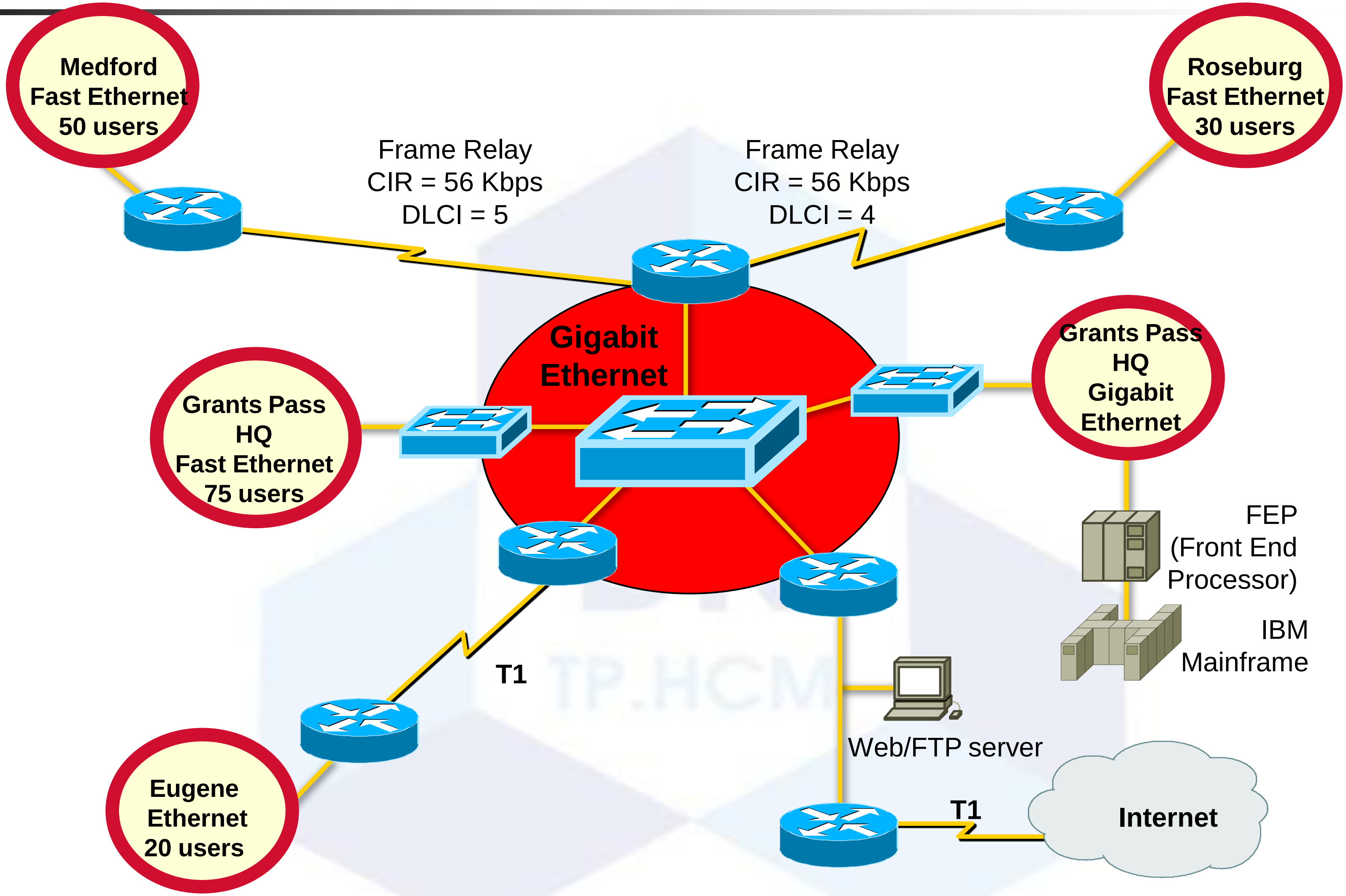
Characterizing the Existing Internetwork

- Characterize the existing internetwork before designing enhancements
- Helps you verify that a customer's design goals are realistic
- Helps you locate where new equipment will go
- Helps you cover yourself if the new network has problems due to unresolved problems in the old network

Characterize the existing internetwork

- Characterize the existing internetwork in terms of:
  - Its infrastructure
    - Logical structure (modularity, hierarchy, topology)
    - Physical structure
  - Addressing and naming
  - Wiring and media
  - Architectural and environmental constraints
  - Health

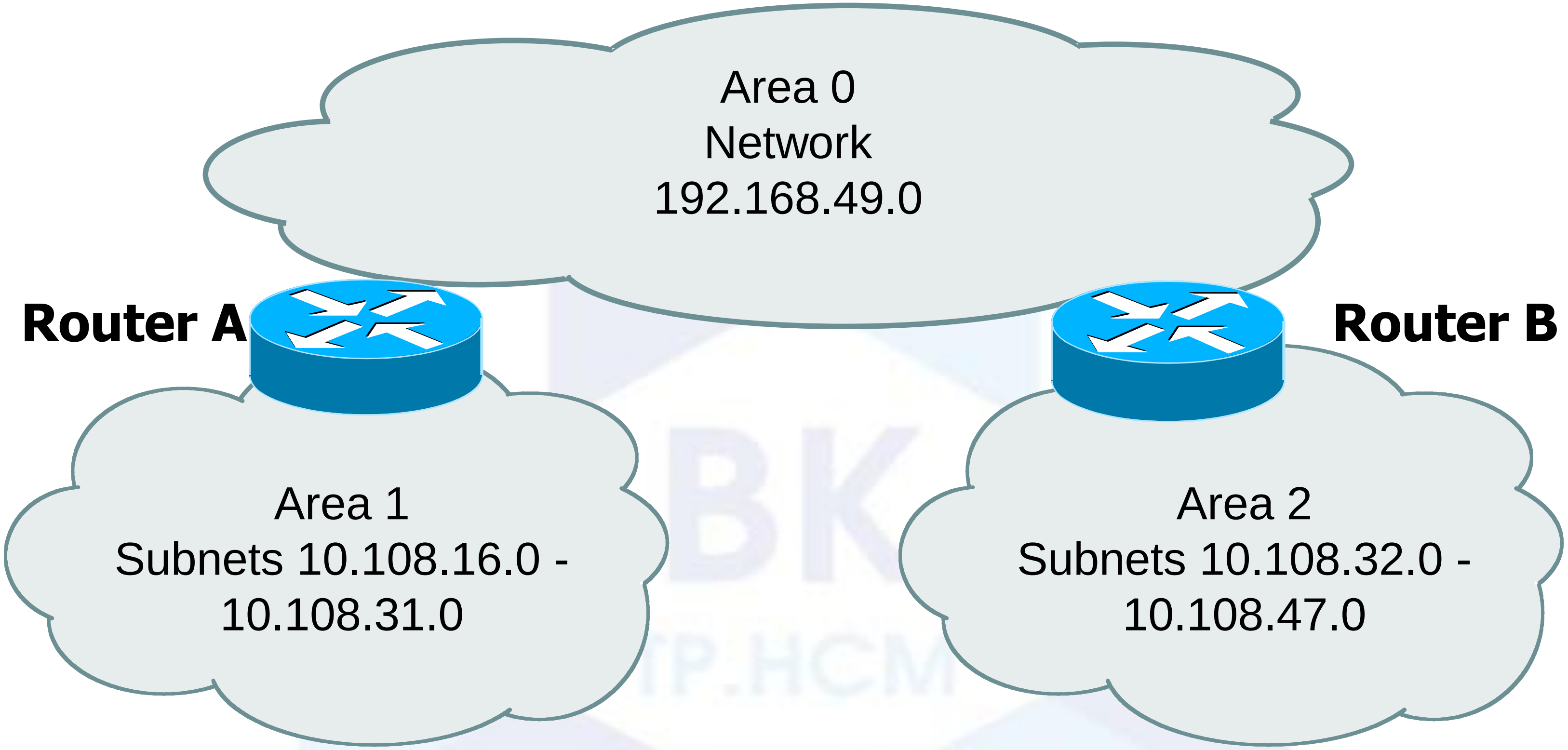
Get a Network Map



Characterize Addressing and Naming

- IP addressing for major devices, client networks, server networks, and so on
- Any addressing oddities, such as discontiguous subnets?
- Any strategies for addressing and naming?
  - For example, sites may be named using airport codes
    - San Francisco = SFO, Oakland = OAK

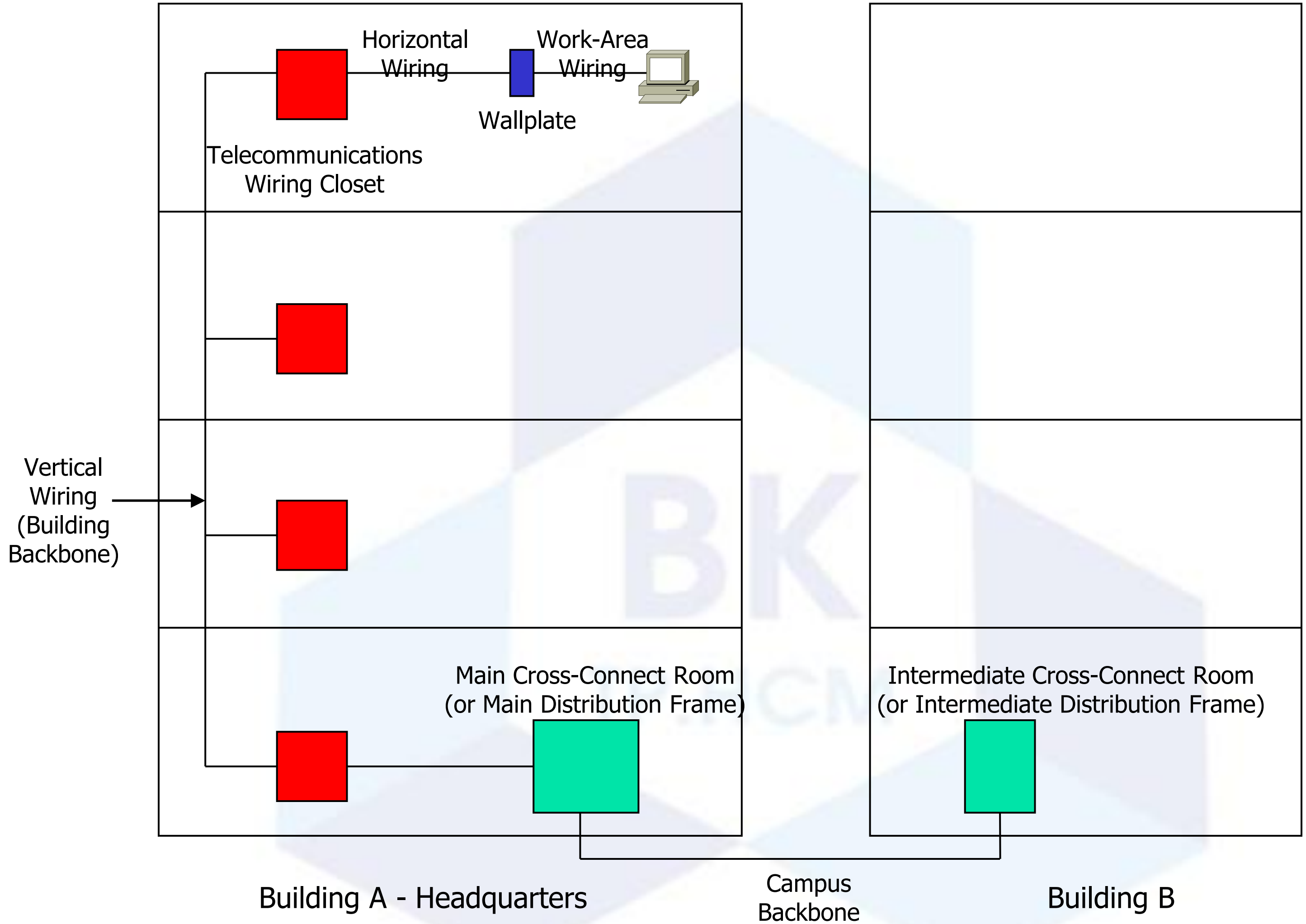
Discontiguous Subnets



Characterize the Wiring and Media

- Single-mode fiber
- Multi-mode fiber
- Shielded twisted pair (STP) copper
- Unshielded-twisted-pair (UTP) copper
- Coaxial cable
- Microwave
- Laser
- Radio
- Infra-red

Campus Network Wiring



Architectural Constraints

- Make sure the following are sufficient
  - Air conditioning
  - Heating
  - Ventilation
  - Power
  - Protection from electromagnetic interference
  - Doors that can lock
- Make sure there's space for:
  - Cabling conduits
  - Patch panels
  - Equipment racks
  - Work areas for technicians installing and troubleshooting equipment

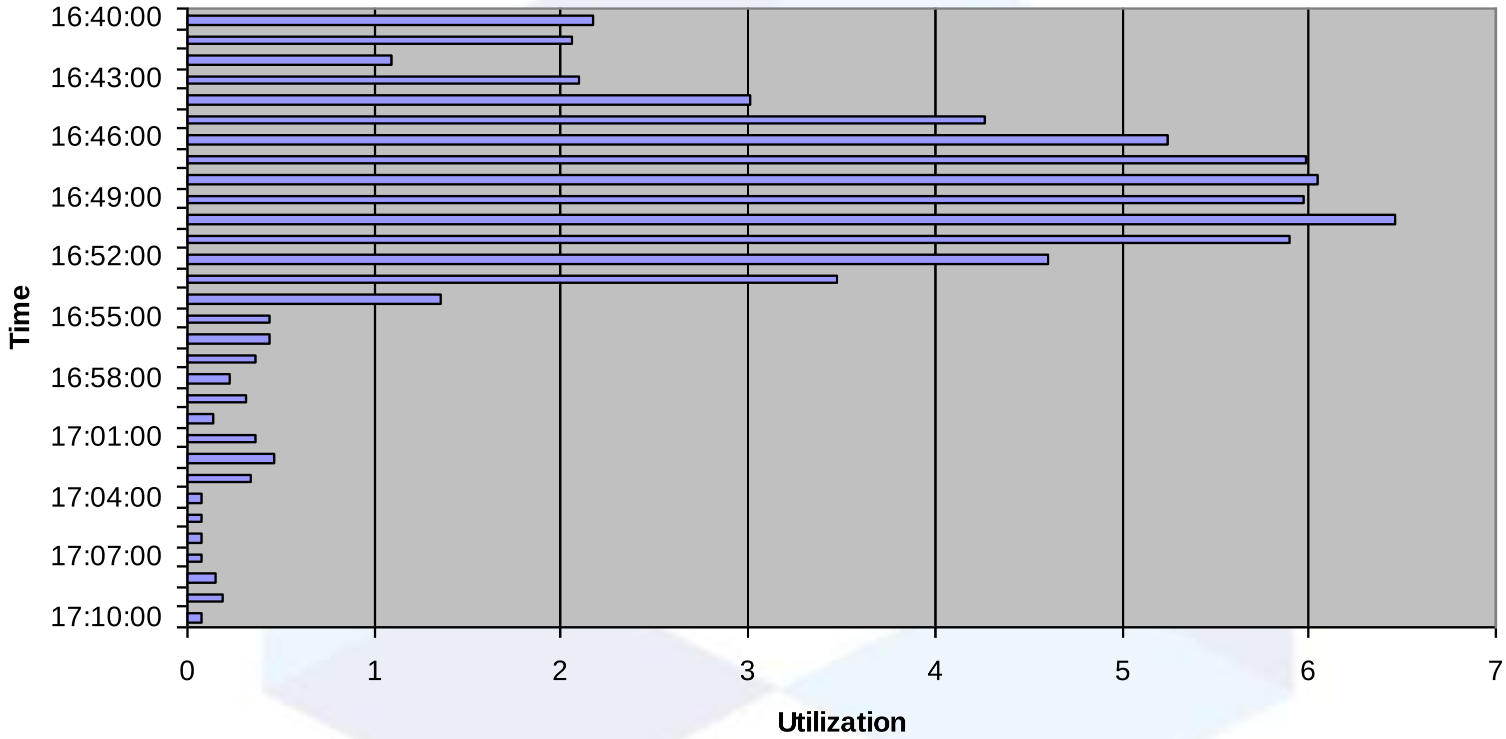
Check the Health of the Existing Internetwork

- Performance
- Availability
- Bandwidth utilization
- Accuracy
- Efficiency
- Response time
- Status of major routers, switches, and firewalls

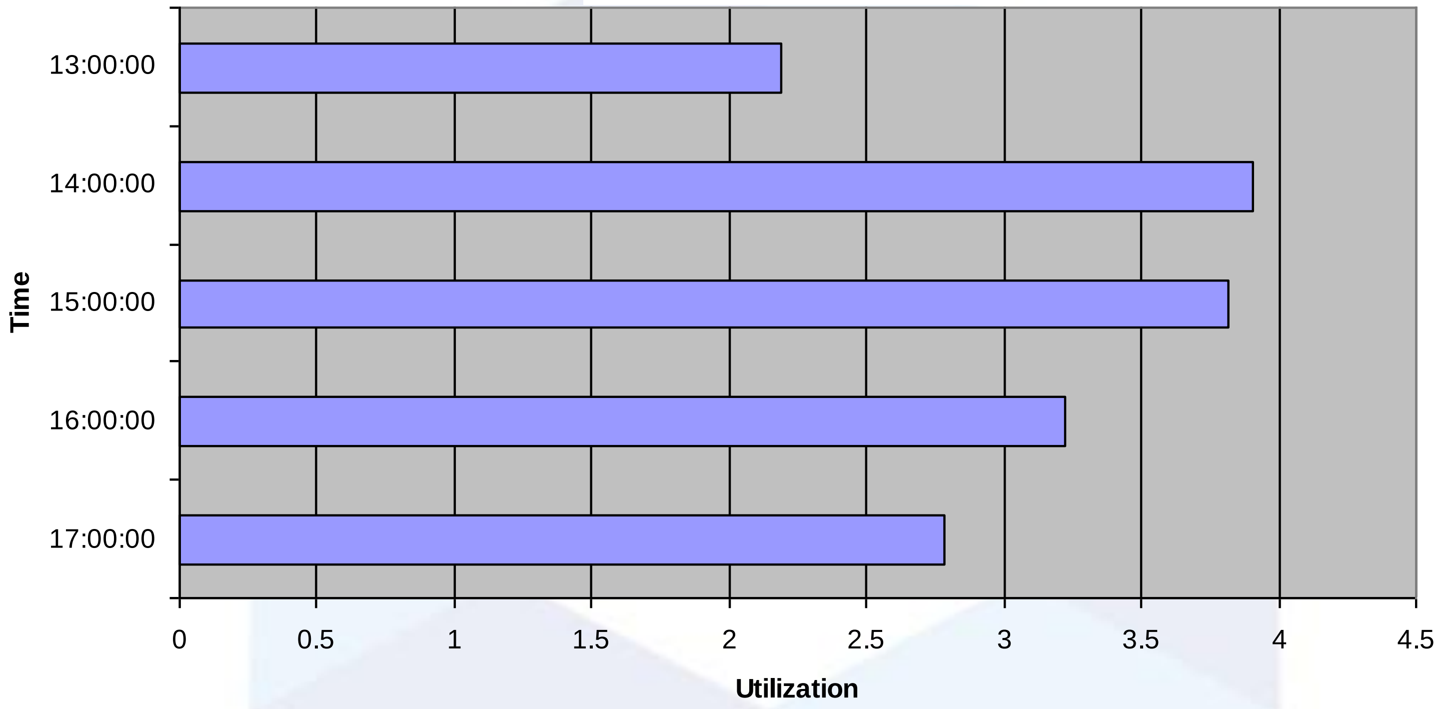
Characterize Availability

	MTBF	MTTR	Date and Duration of Last Major Downtime	Cause of Last Major Downtime	Fix for Last Major Downtime
Enterprise					
Segment 1					
Segment 2					
Segment *n*					

Network Utilization in Minute Intervals



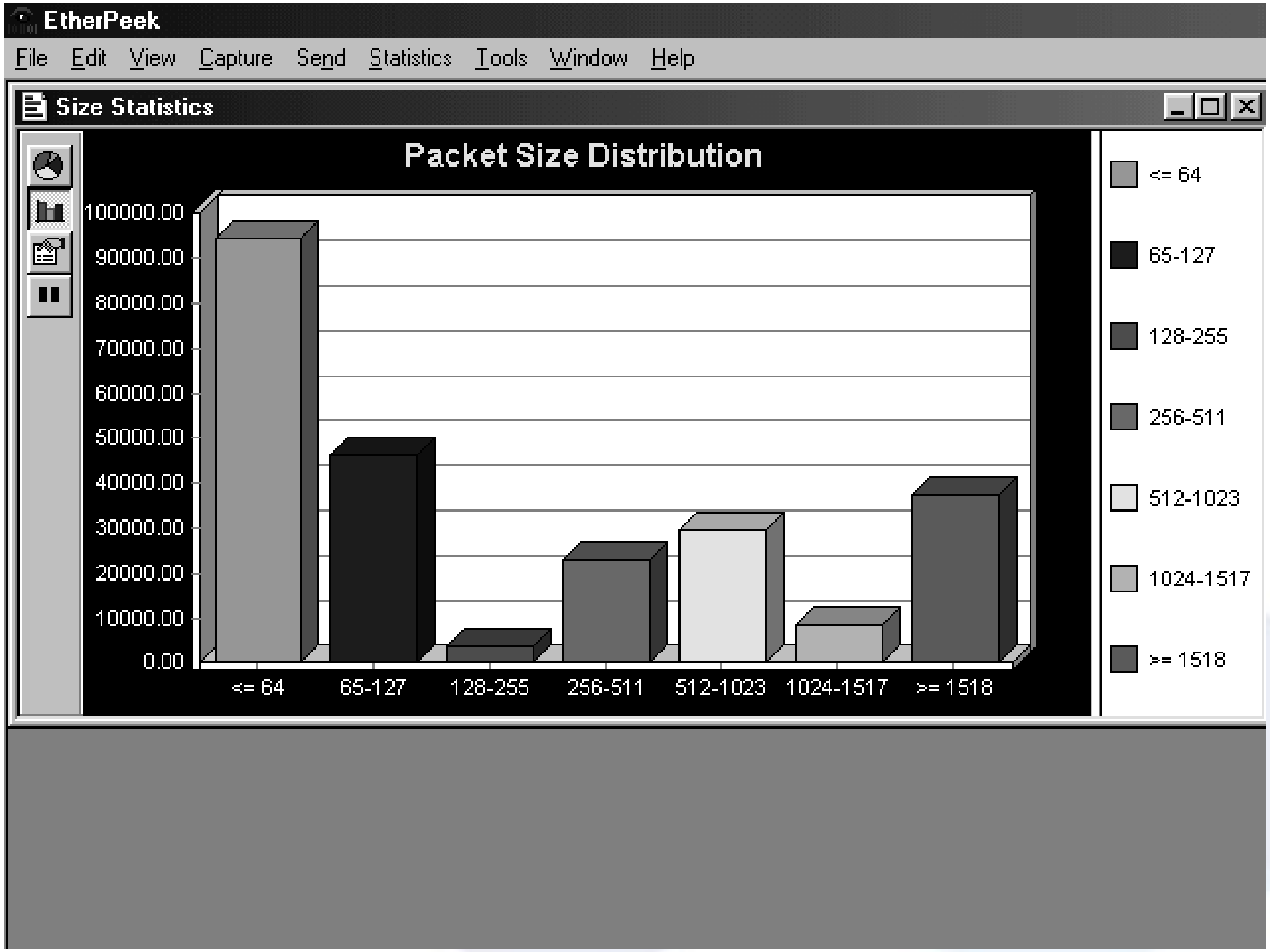
Network Utilization in Hour Intervals



Bandwidth Utilization by Protocol

	Relative Network Utilization	Absolute Network Utilization	Broadcast Rate	Multicast Rate
Protocol 1				
Protocol 2				
Protocol 3				
Protocol *n*				

Characterize Packet Sizes



Characterize Response Time

	Node A	Node B	Node C	Node D
Node A	X			
Node B		X		
Node C			X	
Node D				X

Check the Status of Major Routers, Switches, and Firewalls

- show buffers
- show environment
- show interfaces
- show memory
- show processes
- show running-config
- show version

Tools

- Protocol analyzers
- Multi Router Traffic Grapher (MRTG)
- Remote monitoring (RMON) probes
- NetFlow technology
- Cisco Discovery Protocol (CDP)
- CiscoWorks

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Network Traffic Factors

- Traffic flow
- Location of traffic sources and data stores
- Traffic load
- Traffic behavior
- Quality of Service (QoS) requirements

User Communities

User Community Name	Size of Community (Number of Users)	Location(s) of Community	Application(s) Used by Community

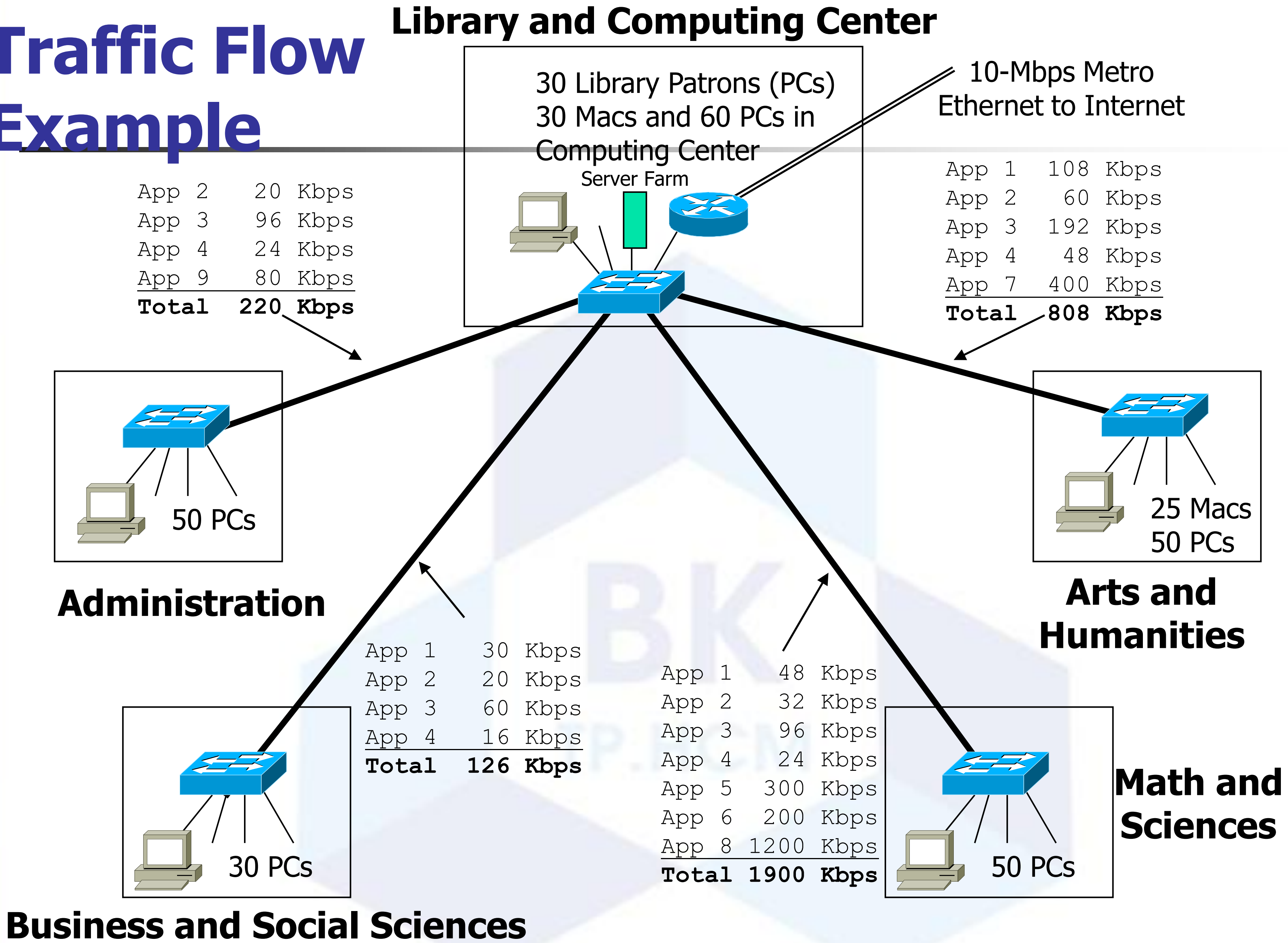
Data Stores

Data Store	Location	Application(s)	Used by User Community (Communities)

Traffic Flow

	Destination 1 MB/sec	Destination 2 MB/sec	Destination 3 MB/sec	Destination 4 MB/sec
Source 1				
Source 2				
Source 3				
Source *n*				

Traffic Flow Example



Types of Traffic Flow

- Terminal/host
- Client/server
- Thin client
- Peer-to-peer
- Server/server
- Distributed computing

Traffic Flow for Voice over IP

- The flow associated with transmitting the audio voice is separate from the flows associated with call setup and teardown.
  - The flow for transmitting the digital voice is essentially peer-to-peer.
  - Call setup and teardown is a client/server flow
    - A phone needs to talk to a server or phone switch that understands phone numbers, IP addresses, capabilities negotiation, and so on.

Network Applications

Traffic Characteristics

Name of Application	Type of Traffic Flow	Protocol(s) Used by Application	User Communities That Use the Application	Data Stores (Servers, Hosts, and so on)	Approximate Bandwidth Requirements	QoS Requirements

Traffic Load

- To calculate whether capacity is sufficient, you should know:
  - The number of stations
  - The average time that a station is idle between sending frames
  - The time required to transmit a message once medium access is gained
- That level of detailed information can be hard to gather, however

Size of Objects on Networks

- Terminal screen: 4 Kbytes
- Simple e-mail: 10 Kbytes
- Simple web page: 50 Kbytes
- High-quality image: 50,000 Kbytes
- Database backup: 1,000,000 Kbytes or more

Traffic Behavior

- Broadcasts
  - All ones data-link layer destination address
    - FF: FF: FF: FF: FF: FF
  - Doesn't necessarily use huge amounts of bandwidth
  - But does disturb every CPU in the broadcast domain
- Multicasts
  - First bit sent is a one
    - For example: 01:00:0C:CC:CC:CC
  - Should just disturb NICs that have registered to receive it
  - Requires multicast routing protocol on internetworks

Network Efficiency

- Frame size
- Protocol interaction
- Windowing and flow control
- Error-recovery mechanisms

QoS Requirements

- ATM service specifications
  - Constant bit rate (CBR)
  - Realtime variable bit rate (rt-VBR)
  - Non-realtime variable bit rate (nrt-VBR)
  - Unspecified bit rate (UBR)
  - Available bit rate (ABR)
  - Guaranteed frame rate (GFR)

QoS Requirements per IETF

- IETF integrated services working group specifications
  - Controlled load service
    - Provides client data flow with a QoS closely approximating the QoS that same flow would receive on an unloaded network
  - Guaranteed service
    - Provides firm (mathematically provable) bounds on end-to-end packet-queuing delays
- IETF differentiated services working group specifications
  - RFC 2475
  - IP packets can be marked with a differentiated services codepoint (DSCP) to influence queuing and packet-dropping decisions for IP datagrams on an output interface of a router