Top-Down Network Design

Chapter One

Analyzing Business Goals and Constraints

Top-Down Network Design

- 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

Start at the Top

- Don’t just start connecting the dots
- Analyze business and technical goals first
- Explore divisional and group structures to find out who the network serves and where they reside
- Determine what applications will run on the network and how those applications behave on a network
- Focus on Layer 7 and above first

Layers of the OSI Model

Layer 7	Application
Layer 6	Presentation
Layer 5	Session
Layer 4	Transport
Layer 3	Network
Layer 2	Data Link
Layer 1	Physical

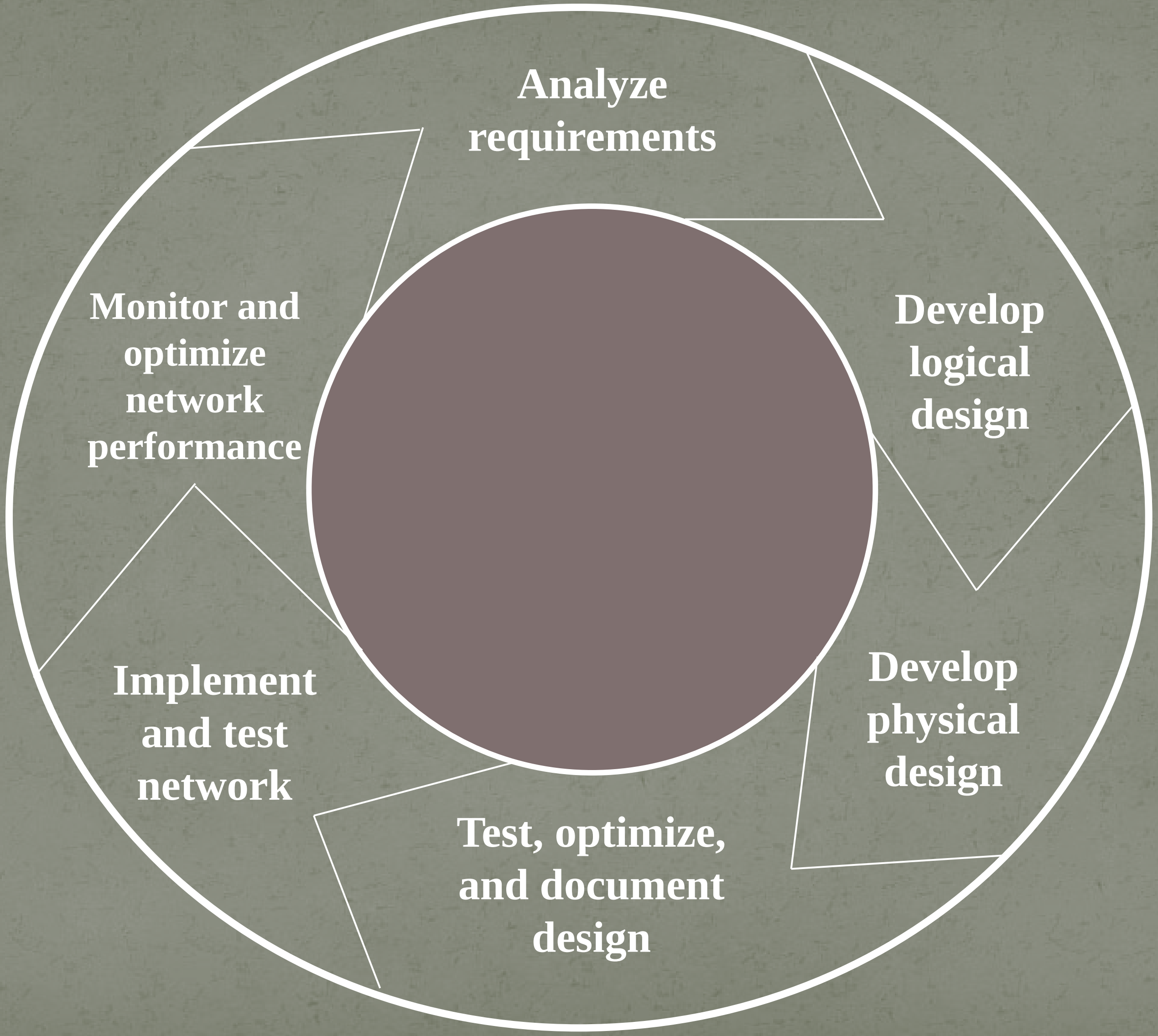
Structured Design

- A focus is placed on understanding data flow, data types, and processes that access or change the data.
- A focus is placed on understanding the location and needs of user communities that access or change data and processes.
- Several techniques and models can be used to characterize the existing system, new user requirements, and a structure for the future system.
- A logical model is developed before the physical model.
  - The logical model represents the basic building blocks, divided by function, and the structure of the system.
  - The physical model represents devices and specific technologies and implementations.

Systems Development Life Cycles

- SDLC: Does it mean Synchronous Data Link Control or Systems Development Life Cycle?
- The latter for the purposes of this class!
- Typical systems are developed and continue to exist over a period of time, often called a systems development life cycle (SDLC)

Top-Down Network Design Steps


Analyze requirements

Develop logical design

Develop physical design

Test, optimize, and document design

Implement and test network

Monitor and optimize network performance

Network Design Steps

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

Network Design Steps

- 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

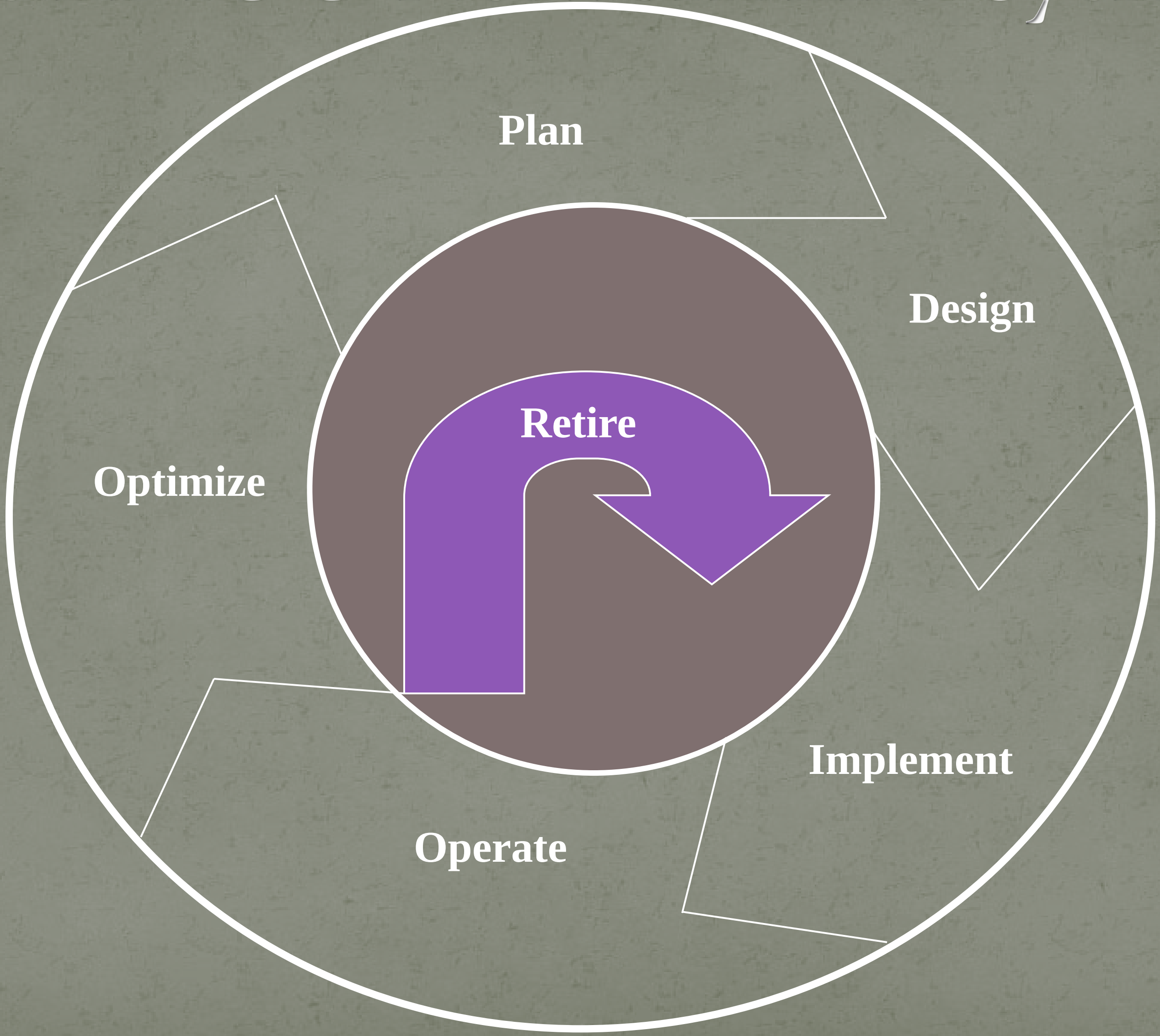
Network Design Steps

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

Network Design Steps

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

The PDIOO Network Life Cycle



Business Goals

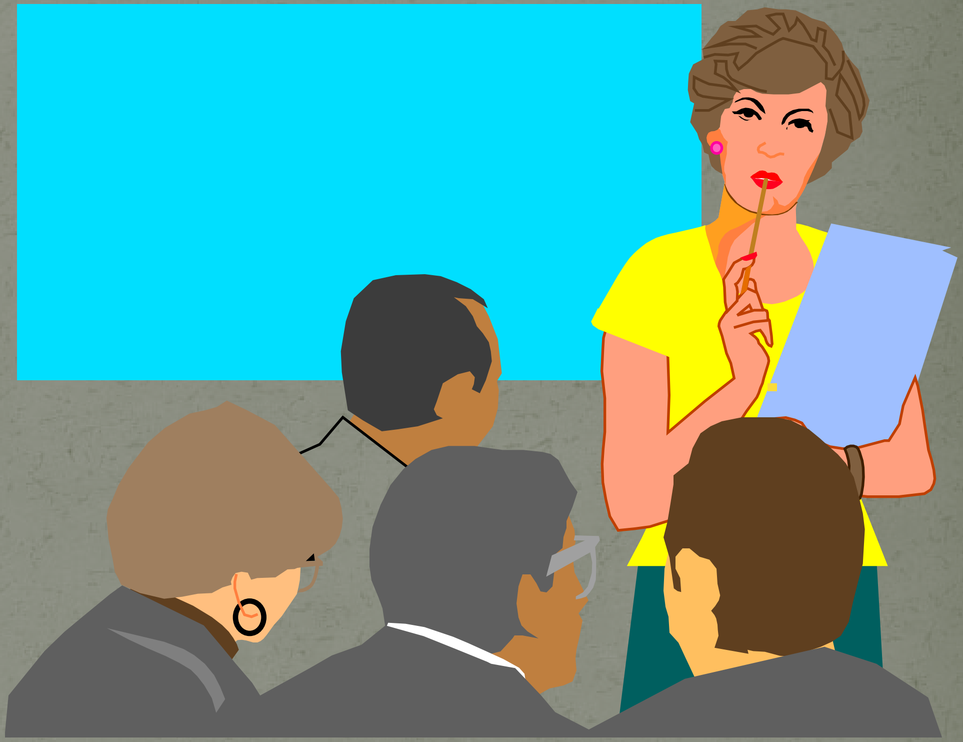
- Increase revenue
- Reduce operating costs
- Improve communications
- Shorten product development cycle
- Expand into worldwide markets
- Build partnerships with other companies
- Offer better customer support or new customer services

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



Collect Information Before the First Meeting

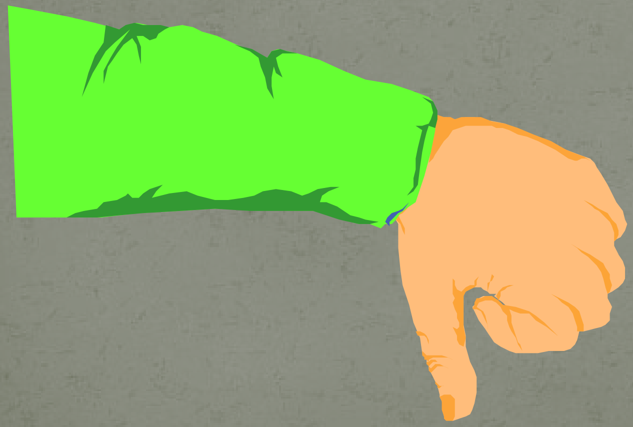
- Before meeting with the client, whether internal or external, collect some basic business-related information
- Such as
  - Products produced/Services supplied
  - Financial viability
  - Customers, suppliers, competitors
  - Competitive advantage

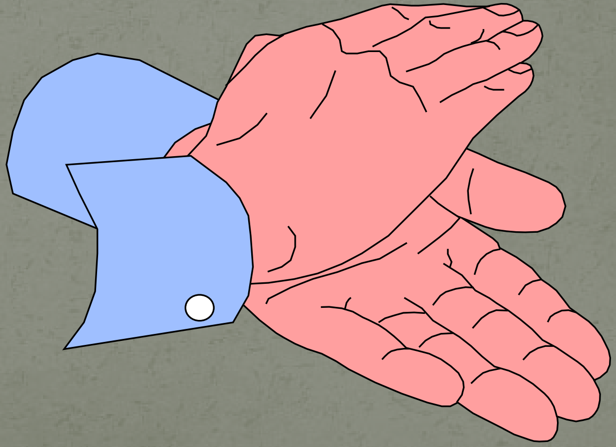
Meet With the Customer

- 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?

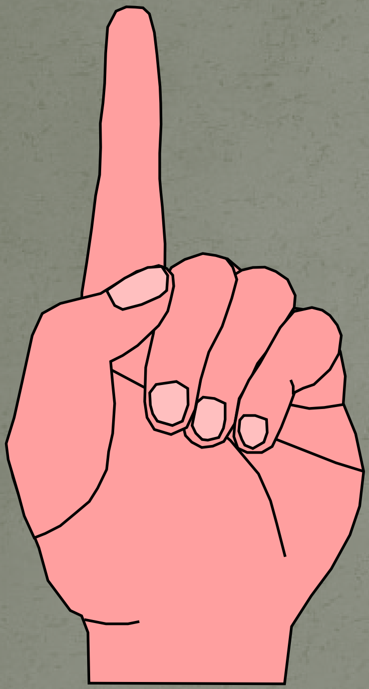
Meet With the Customer

- What will happen if the project is a failure?
  - Is this a critical business function?
  - Is this project visible to upper management?
  - Who’s on your side?





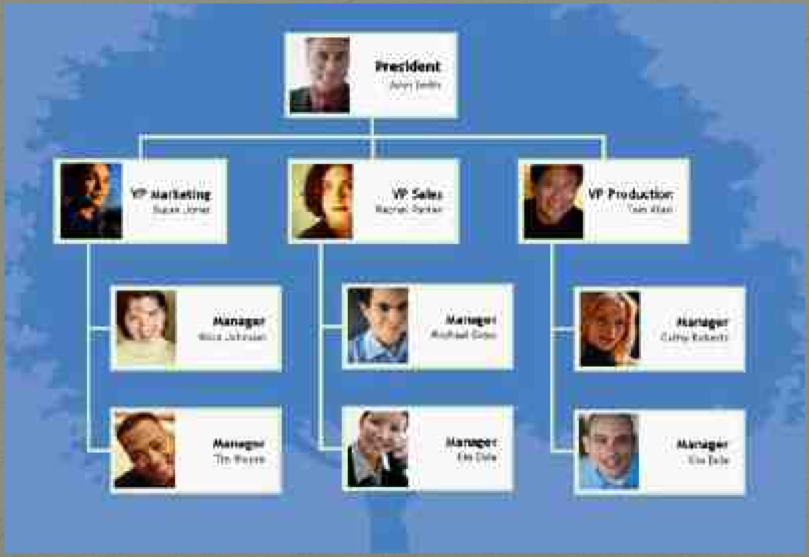
Meet With the Customer



- 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

Summary

- Systematic approach
- Focus first on business requirements and constraints, and applications
- Gain an understanding of the customer’s corporate structure
- Gain an understanding of the customer’s business style

Review Questions

- What are the main phases of network design per the top-down network design approach?
- What are the main phases of network design per the PDIOO approach?
- Why is it important to understand your customer's business style?
- What are some typical business goals for organizations today?

Top-Down Network Design

Chapter Two

Analyzing Technical Goals and Tradeoffs

Technical Goals

- Scalability
- Availability
- Performance
- Security
- Manageability
- Usability
- Adaptability
- Affordability

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

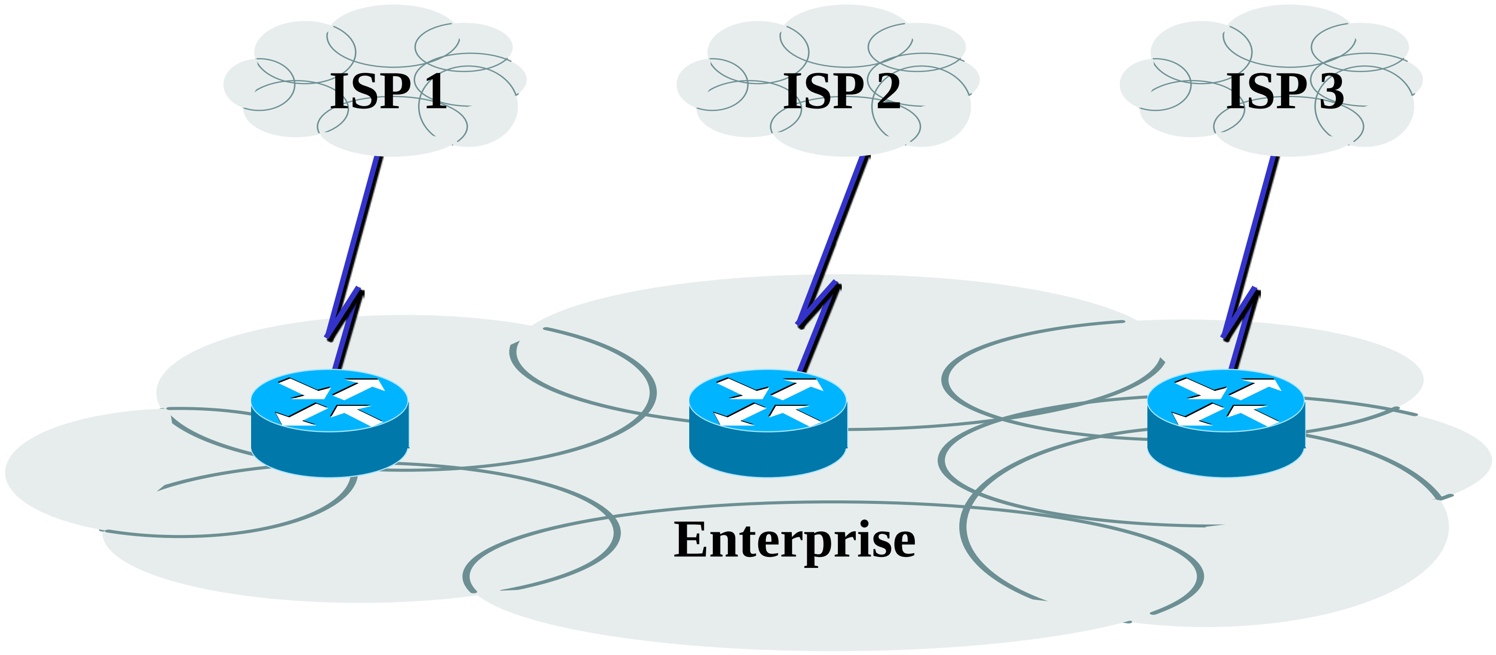
Availability

- 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

99.999% Availability May Require Triple Redundancy



- Can the customer afford this?

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

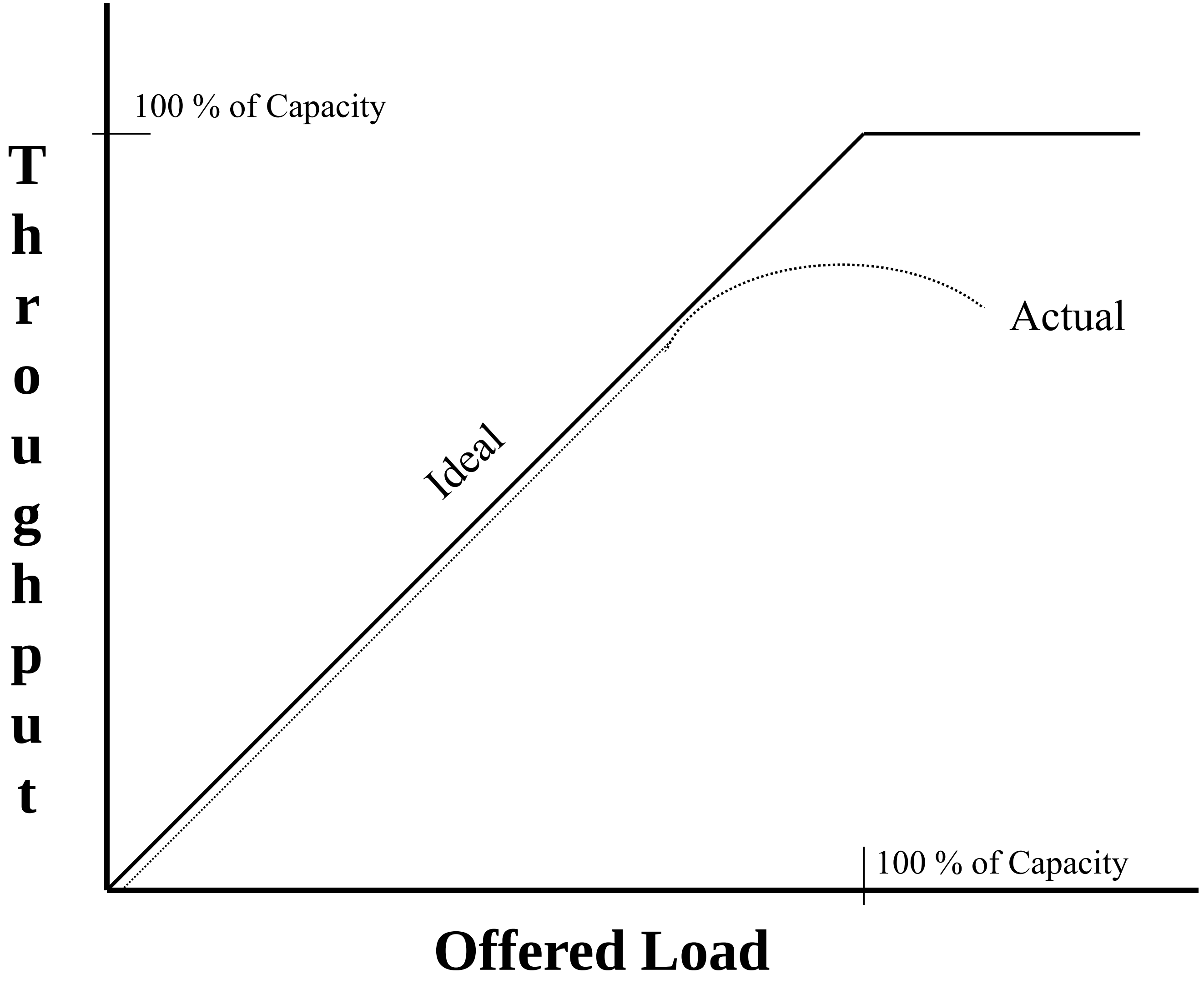
Network Performance

- 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 bits per second
- 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

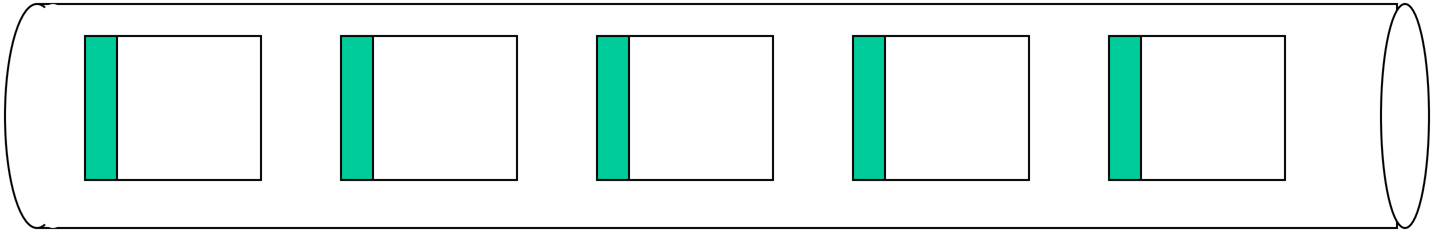
- You need to decide what you mean by throughput
- Are you referring to bytes per second, regardless of whether the bytes are user data bytes or packet header bytes
  - Or are you concerned with application-layer throughput of user bytes, sometimes called "goodput"
    - In that case, you have to consider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

Performance (continued)

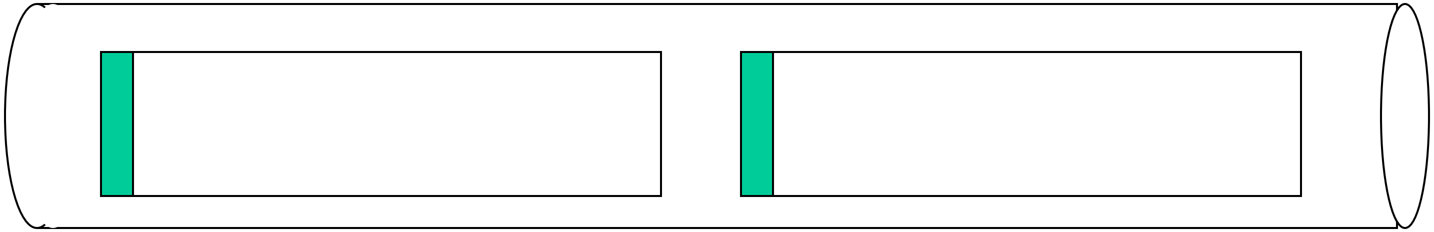
- Efficiency
  - How much overhead is required to deliver an amount of data?
  - How large can packets be?
    - Larger better for efficiency (and goodput)
    - But too large means too much data is lost if a packet is damaged
    - How many packets can be sent in one bunch without an acknowledgment?

Efficiency

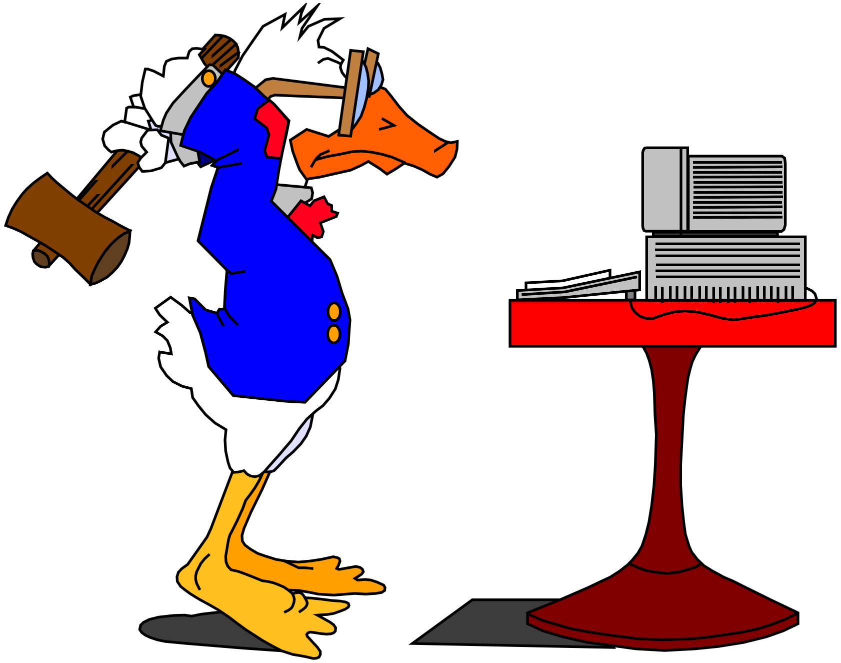
Small Frames (Less Efficient)



Large Frames (More Efficient)



Delay from the User's Point of View

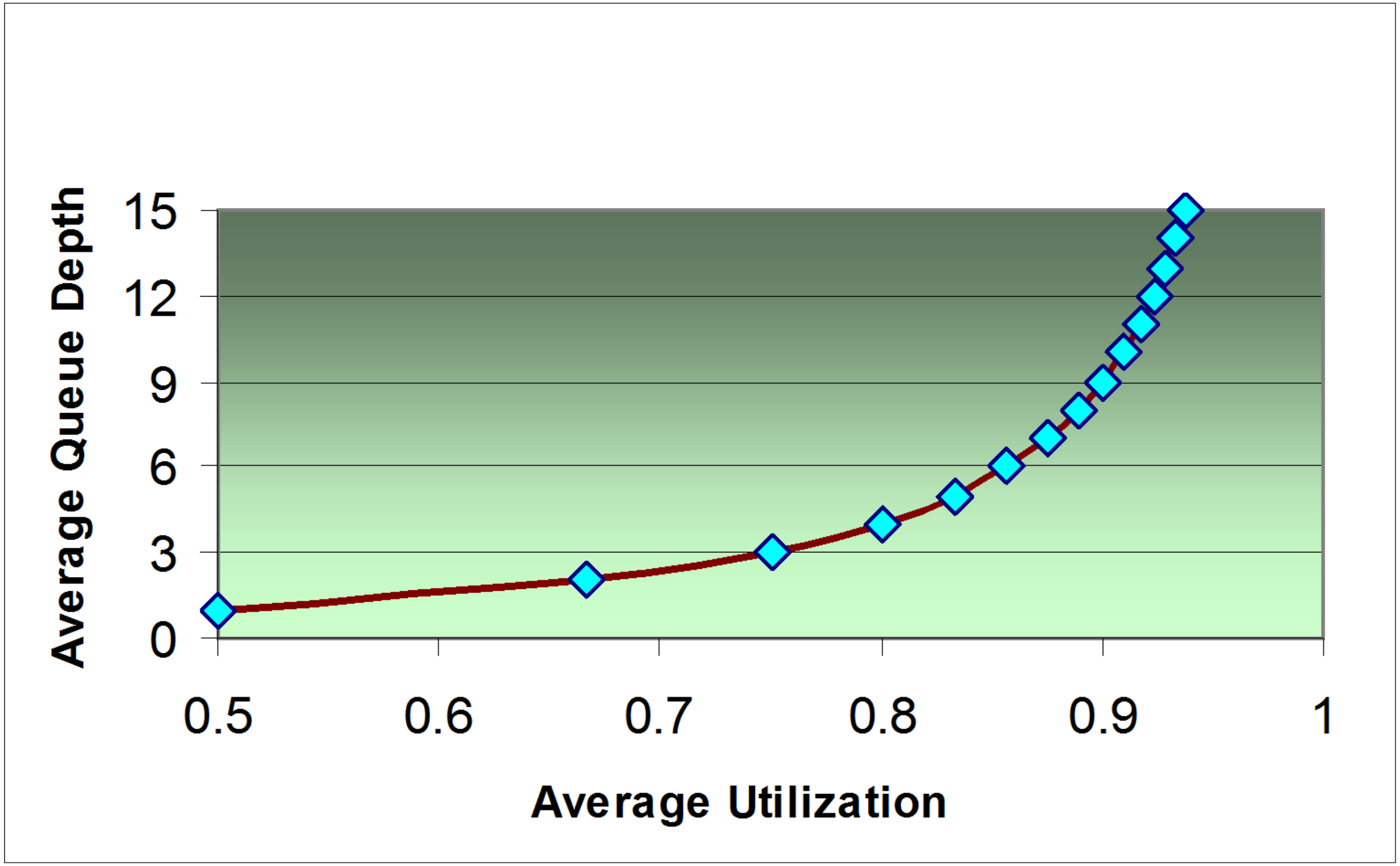


- Response Time
  - A function of the application and the equipment the application is running on, not just the network
  - Most users expect to see something on the screen in 100 to 200 milliseconds

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

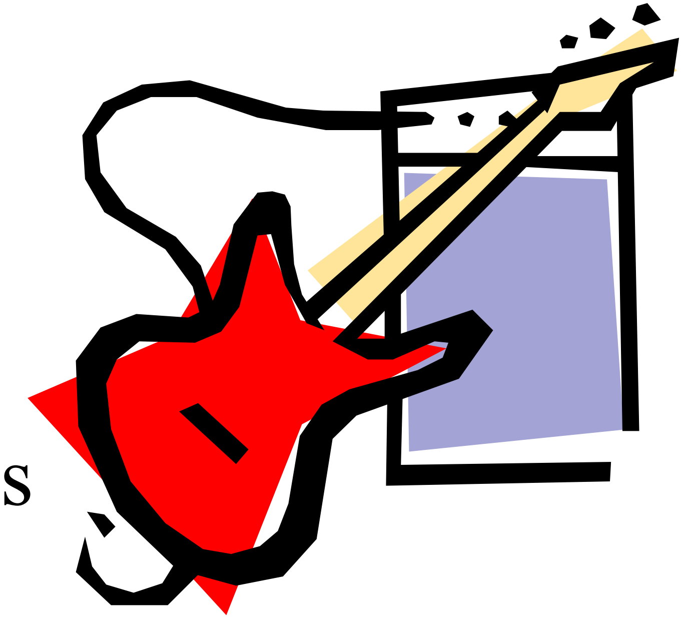
Example

- 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
- Detailed security planning later (Chapter 8)
- 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

- Performance management
- Fault management
- Configuration management
- Security management
- Accounting 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
  - Quiet routing protocols, for example

Network Applications
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

Summary

- Continue to use a systematic, top-down approach
- Don’t select products until you understand goals for scalability, availability, performance, security, manageability, usability, adaptability, and affordability
- Tradeoffs are almost always necessary

Review Questions

- What are some typical technical goals for organizations today?
- How do bandwidth and throughput differ?
- How can one improve network efficiency?
- What tradeoffs may be necessary in order to improve network efficiency?

Top-Down Network Design

Chapter Three

Characterizing the Existing Internetwork

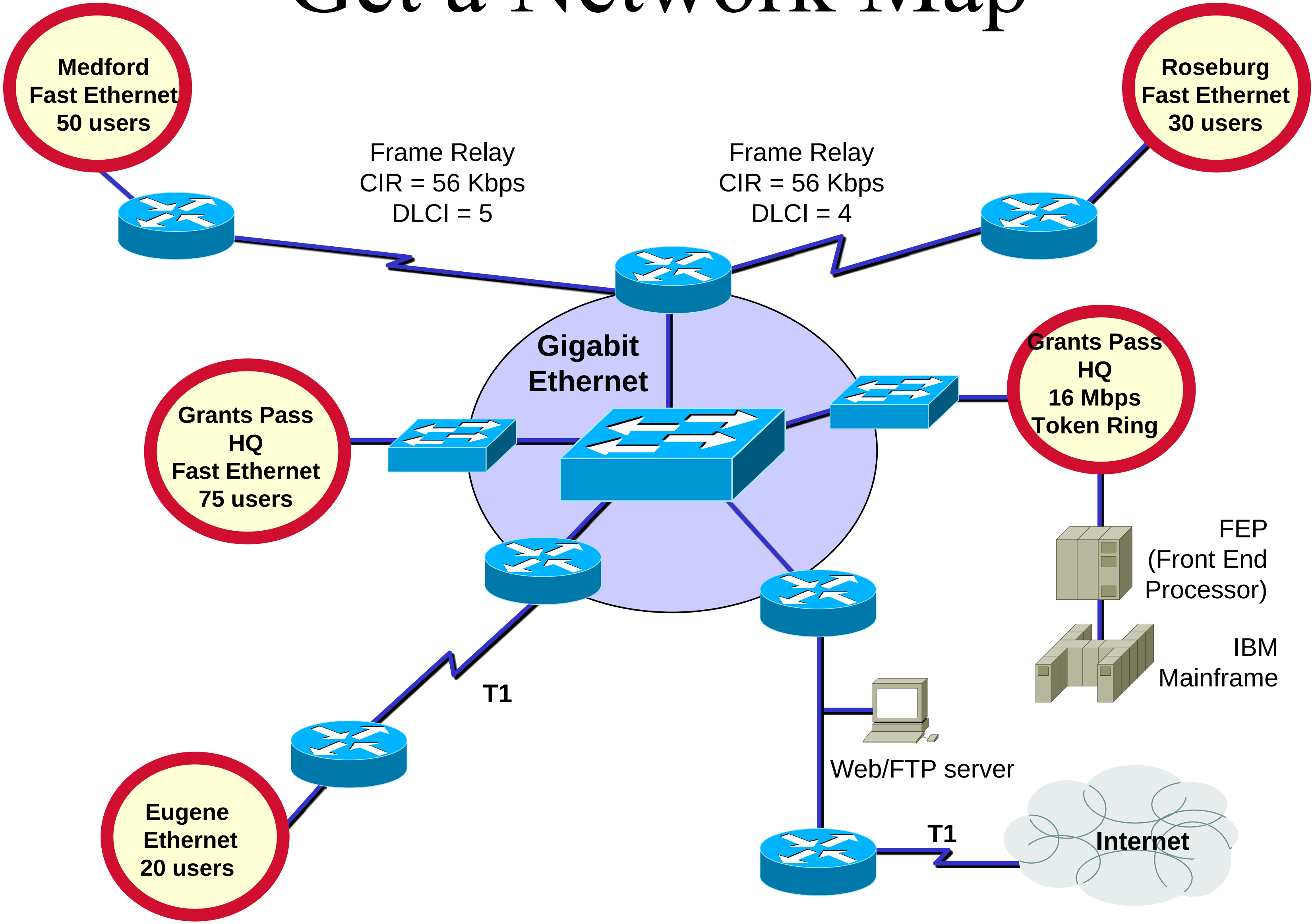
What’s the Starting Point?

- According to Abraham Lincoln:
  - “If we could first know where we are and whither we are tending, we could better judge what to do and how to do it.”

Where Are We?

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

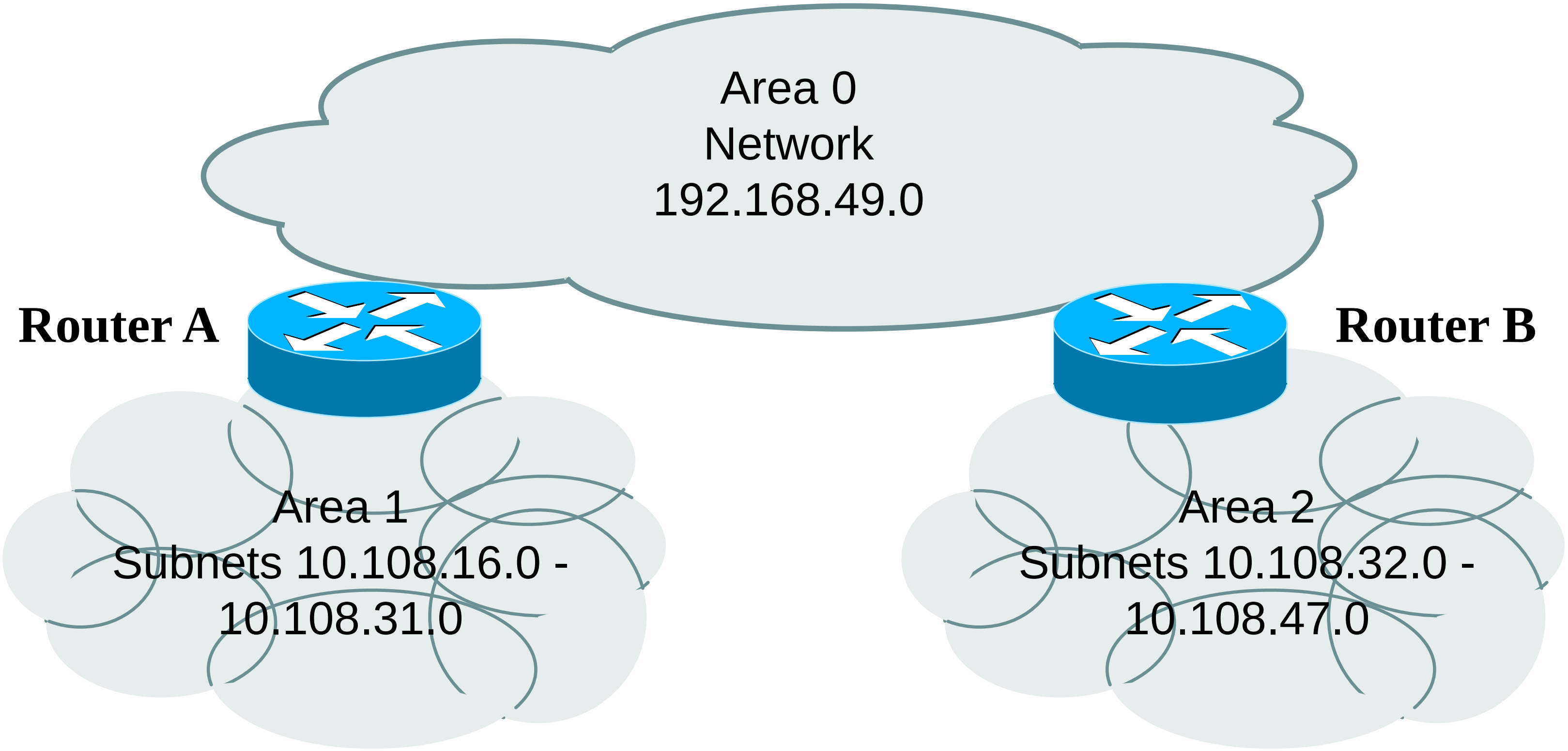
Get a Network Map



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



Area 0
Network
192.168.49.0

Router A

Router B

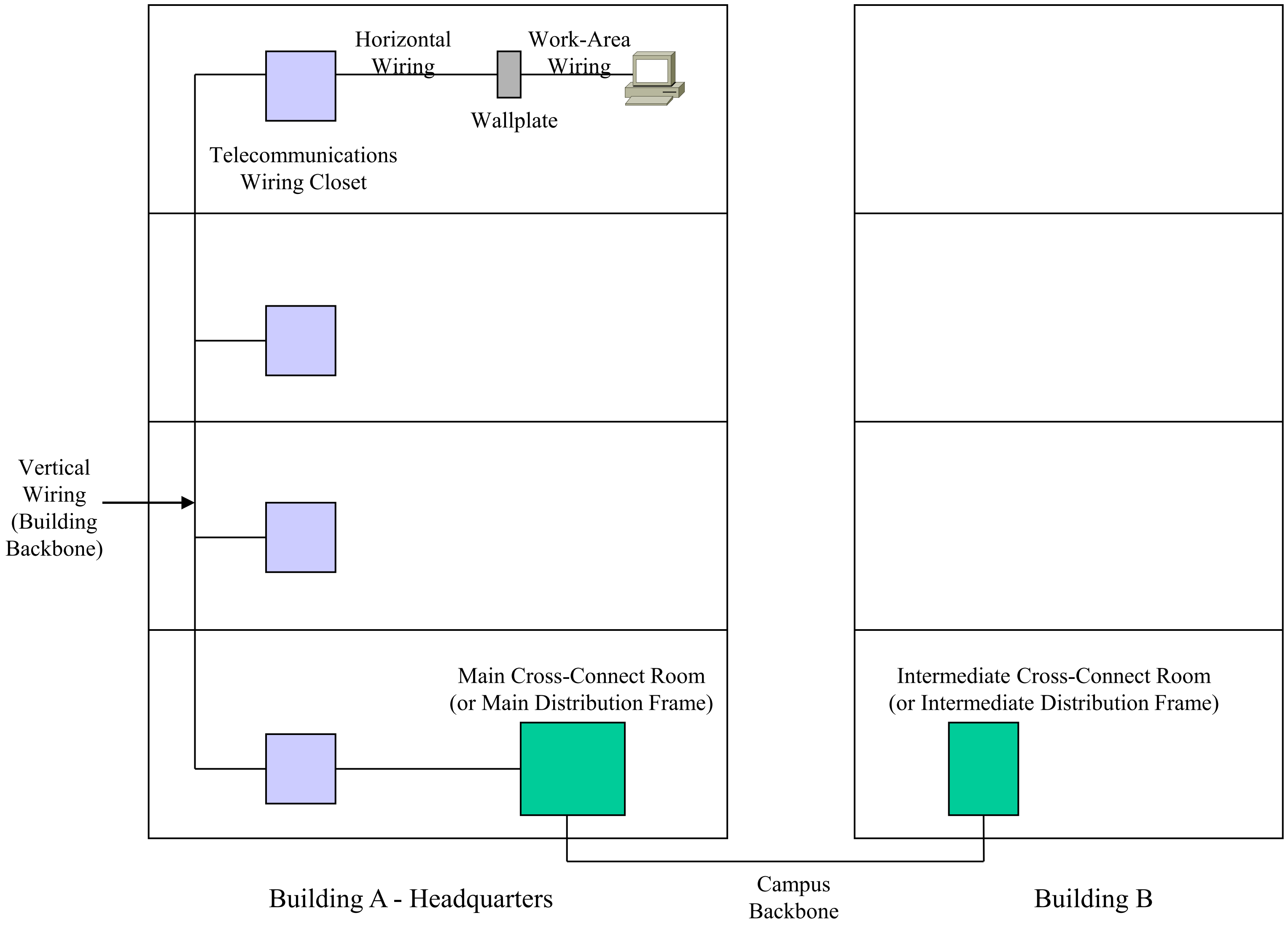
Area 1
Subnets 10.108.16.0 -
10.108.31.0

Area 2
Subnets 10.108.32.0 -
10.108.47.0

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



Horizontal Wiring
Work-Area Wiring
Wallplate
Telecommunications Wiring Closet
Vertical Wiring (Building Backbone)
Main Cross-Connect Room (or Main Distribution Frame)
Intermediate Cross-Connect Room (or Intermediate Distribution Frame)
Building A - Headquarters
Campus Backbone
Building B

Architectural Constraints

- Make sure the following are sufficient
  - Air conditioning
  - Heating
  - Ventilation
  - Power
  - Protection from electromagnetic interference
  - Doors that can lock

Architectural Constraints

- Make sure there’s space for:
  - Cabling conduits
  - Patch panels
  - Equipment racks
  - Work areas for technicians installing and troubleshooting equipment

Issues for Wireless Installations

- Reflection
- Absorption
- Refraction
- Diffraction

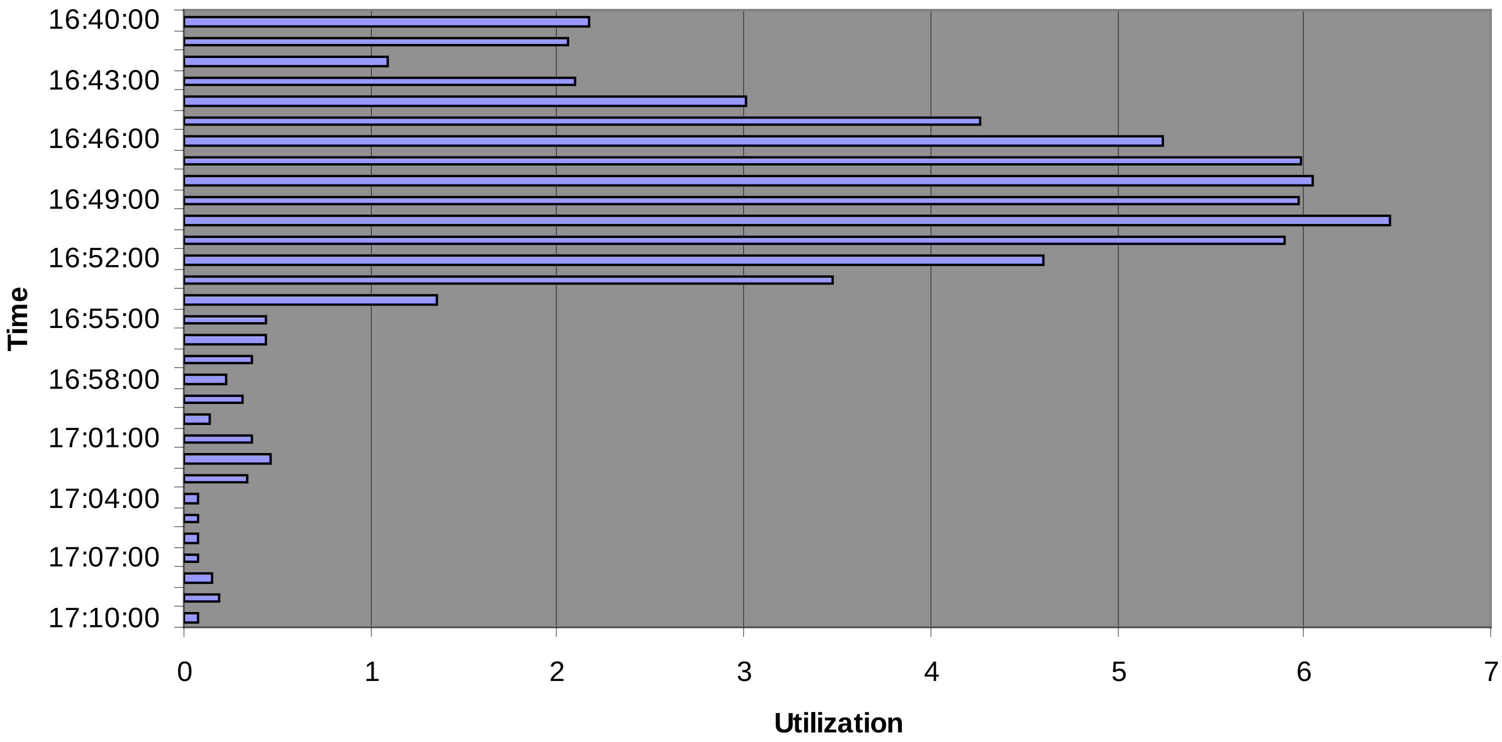
Check the Health of the Existing Internetwork

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

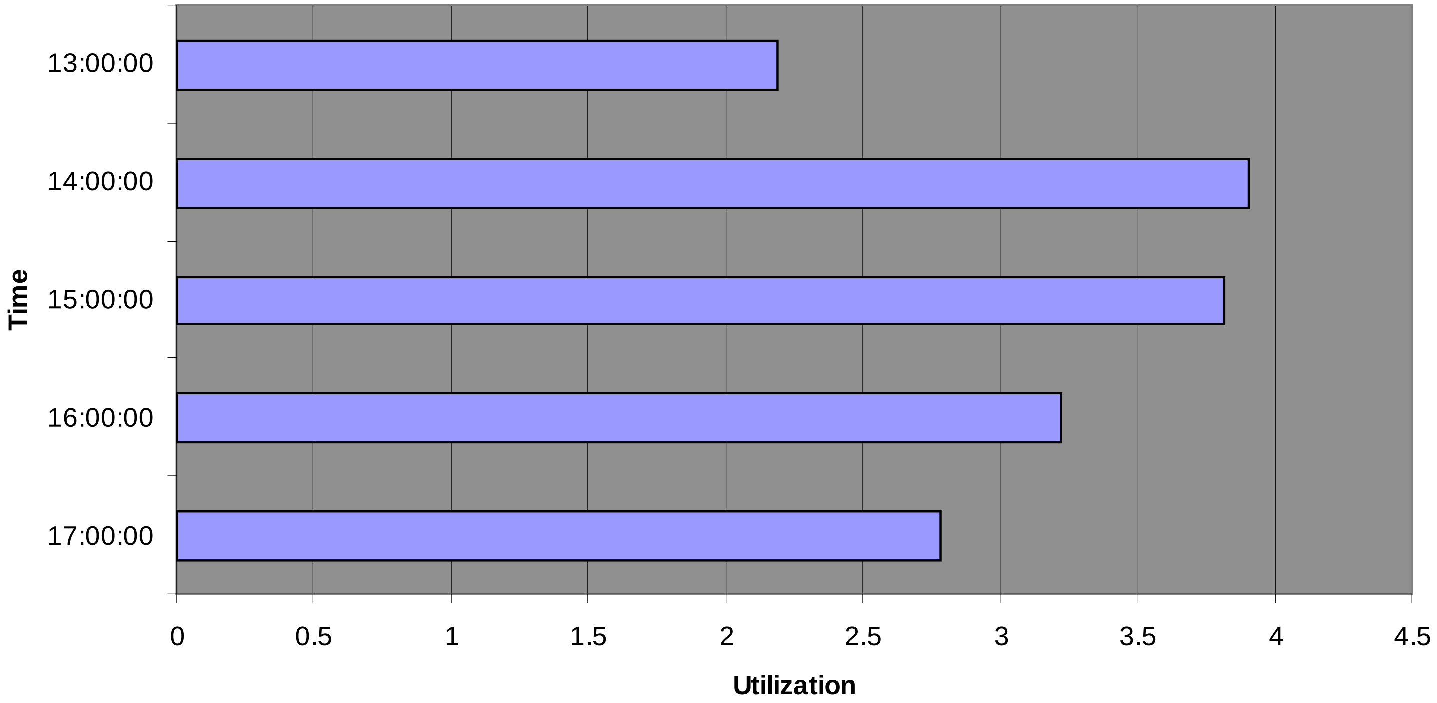
Characterize Availability

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

Network Utilization in Minute Intervals



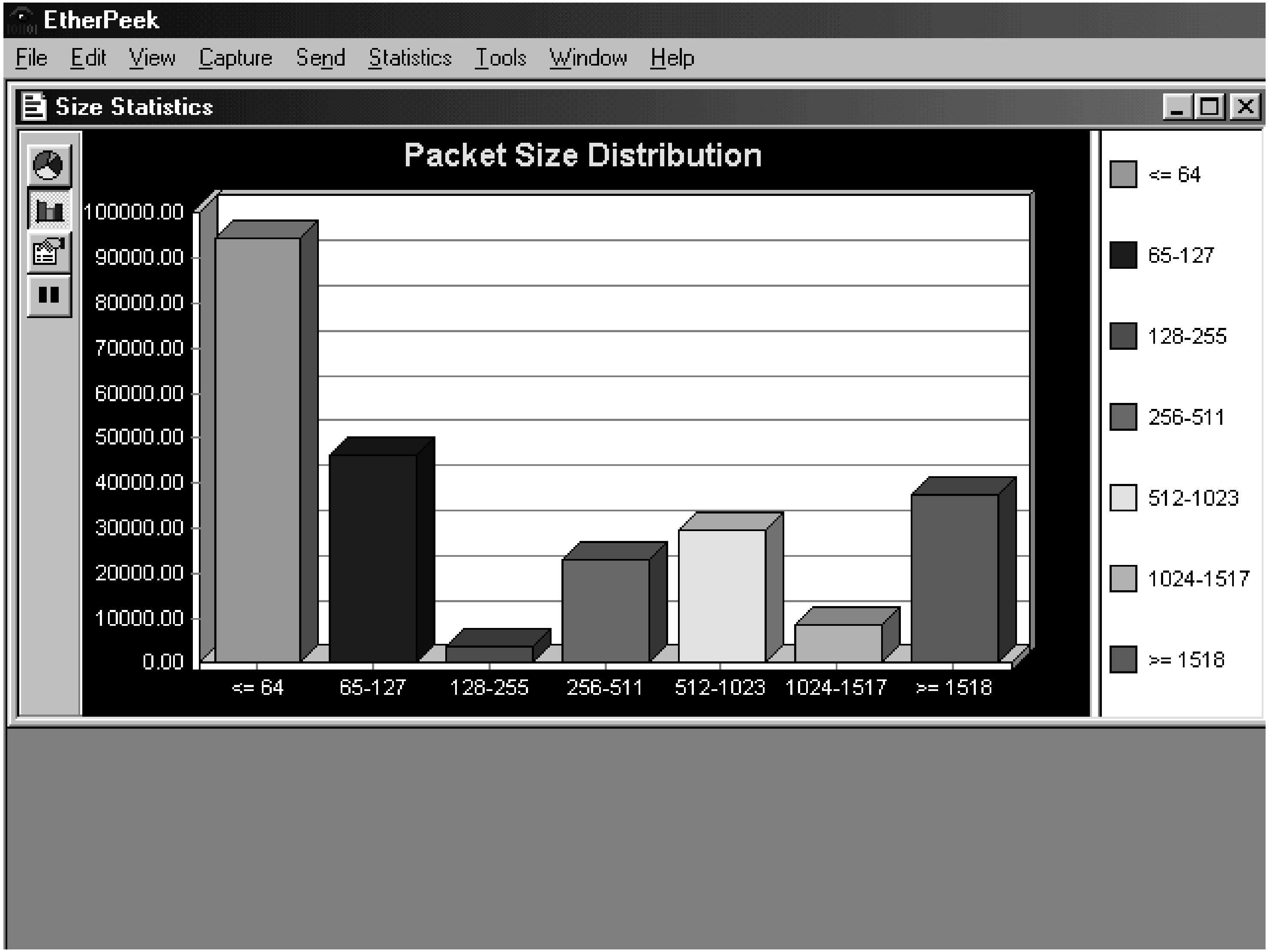
Network Utilization in Hour Intervals



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
- Cisco Discovery Protocol (CDP)
- Cisco IOS NetFlow technology
- CiscoWorks
- Cisco IOS Service Assurance Agent (SAA)
- Cisco Internetwork Performance Monitor (IPM)

Summary

- Characterize the exiting 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

Review Questions

- What factors will help you decide if the existing internetwork is in good enough shape to support new enhancements?
- When considering protocol behavior, what is the difference between relative network utilization and absolute network utilization?
- Why should you characterize the logical structure of an internetwork and not just the physical structure?
- What architectural and environmental factors should you consider for a new wireless installation?

Top-Down Network Design

Chapter Four

Characterizing Network Traffic

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

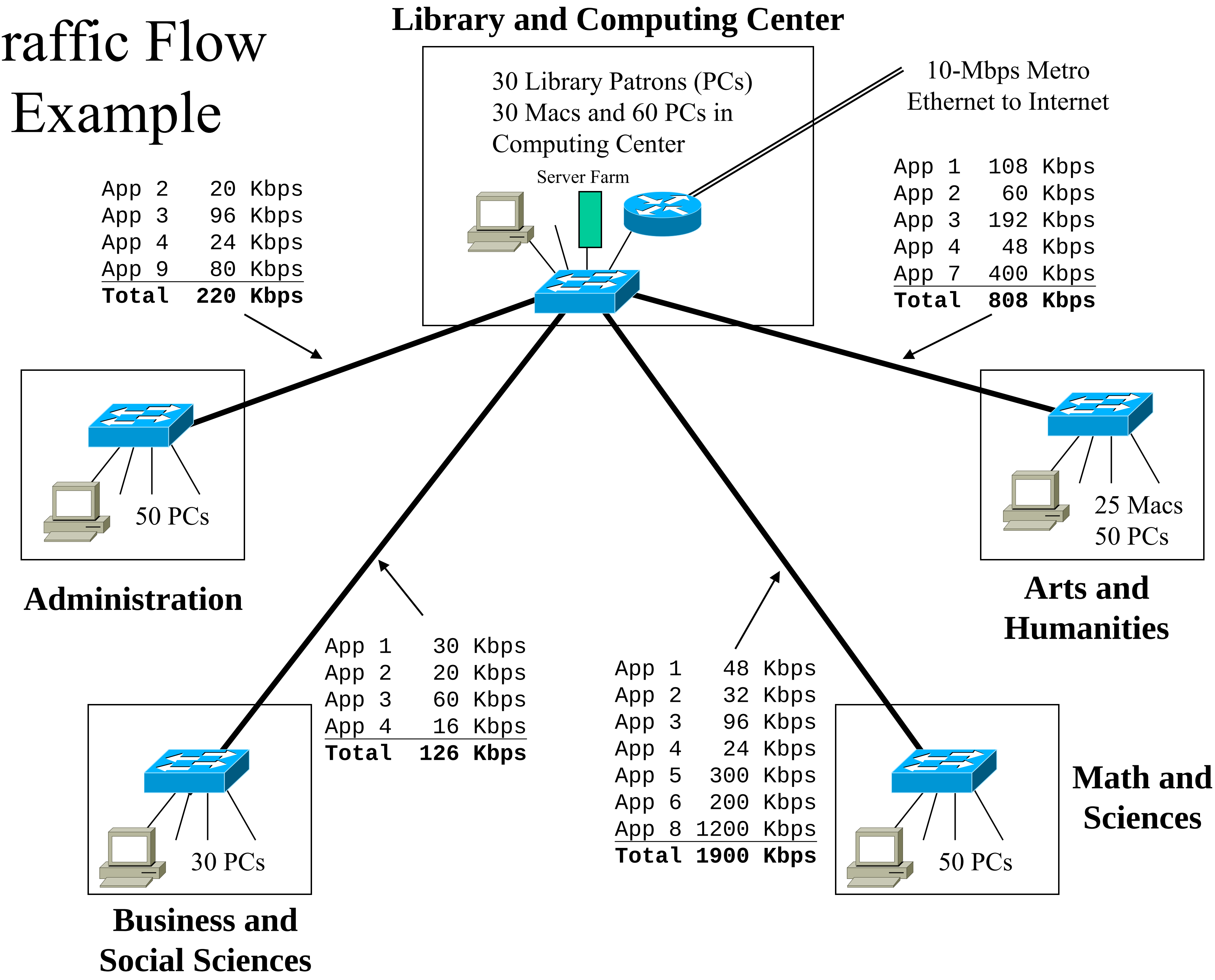
Data Stores

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

Traffic Flow

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

Traffic Flow Example



Library and Computing Center

30 Library Patrons (PCs)
30 Macs and 60 PCs in
Computing Center

10-Mbps Metro
Ethernet to Internet

App 2	20 Kbps
App 3	96 Kbps
App 4	24 Kbps
App 9	80 Kbps
Total	**220 Kbps**

App 1	108 Kbps
App 2	60 Kbps
App 3	192 Kbps
App 4	48 Kbps
App 7	400 Kbps
Total	**808 Kbps**

50 PCs

Administration

25 Macs
50 PCs

Arts and Humanities

App 1	30 Kbps
App 2	20 Kbps
App 3	60 Kbps
App 4	16 Kbps
Total	**126 Kbps**

App 1	48 Kbps
App 2	32 Kbps
App 3	96 Kbps
App 4	24 Kbps
App 5	300 Kbps
App 6	200 Kbps
App 8	1200 Kbps
Total	**1900 Kbps**

30 PCs

Business and Social Sciences

50 PCs

Math and Sciences

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
    - 01:00:0C:CC:CC:CC (Cisco Discovery Protocol)
  - 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

QoS Requirements per IETF

- 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

Summary

- Continue to use a systematic, top-down approach
- Don’t select products until you understand network traffic in terms of:
  - Flow
  - Load
  - Behavior
  - QoS requirements

Review Questions

- List and describe six different types of traffic flows.
- What makes traffic flow in voice over IP networks challenging to characterize and plan for?
- Why should you be concerned about broadcast traffic?
- How do ATM and IETF specifications for QoS differ?

Top-Down Network Design

Chapter Five

Designing a Network Topology

Topology

- A branch of mathematics concerned with those properties of geometric configurations that are unaltered by elastic deformations such as stretching or twisting
- A term used in the computer networking field to describe the structure of a network

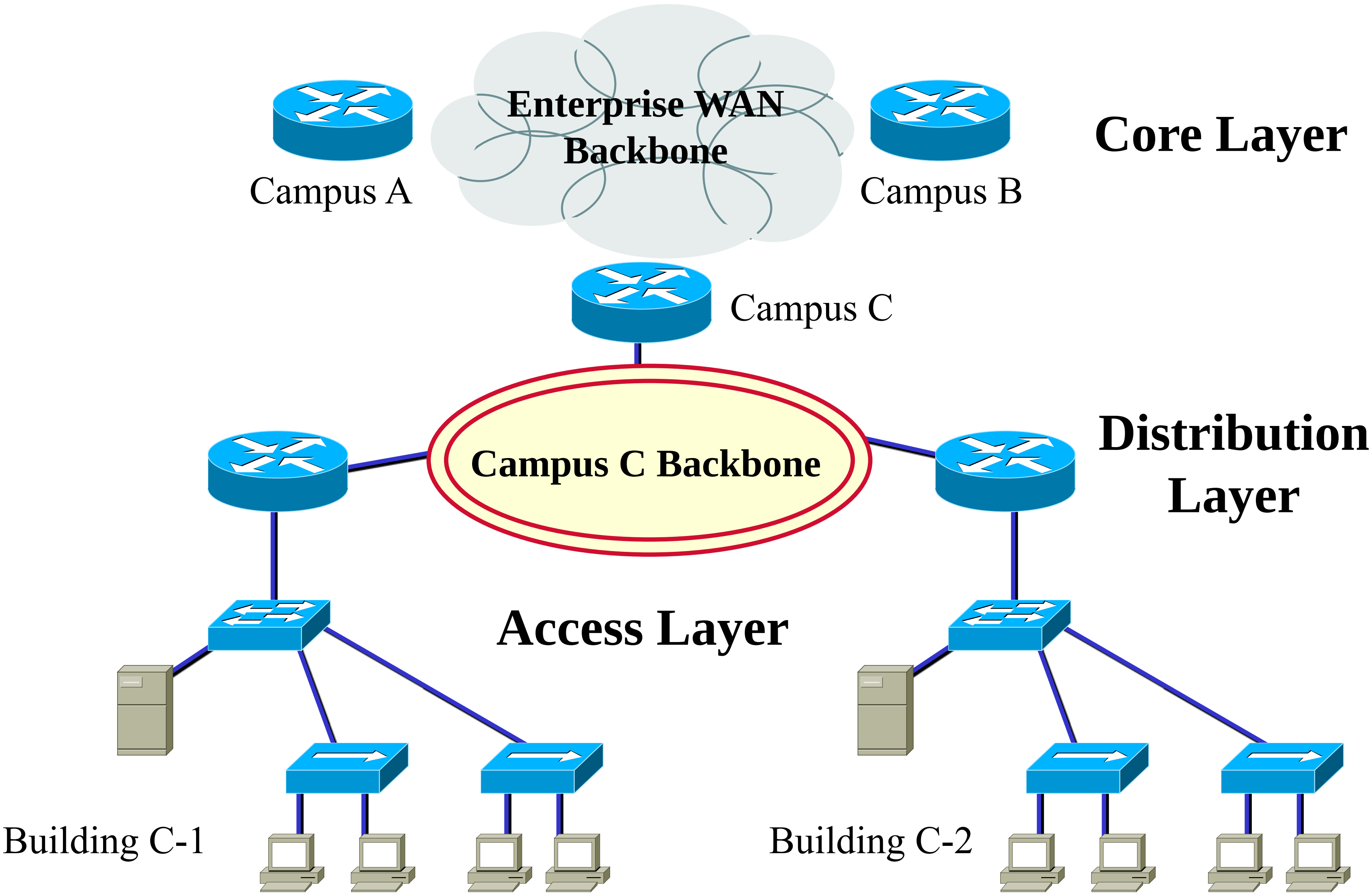
Network Topology Design Themes

- Hierarchy
- Redundancy
- Modularity
- Well-defined entries and exits
- Protected perimeters

Why Use a Hierarchical Model?

- Reduces workload on network devices
  - Avoids devices having to communicate with too many other devices (reduces “CPU adjacencies”)
- Constrains broadcast domains
- Enhances simplicity and understanding
- Facilitates changes
- Facilitates scaling to a larger size

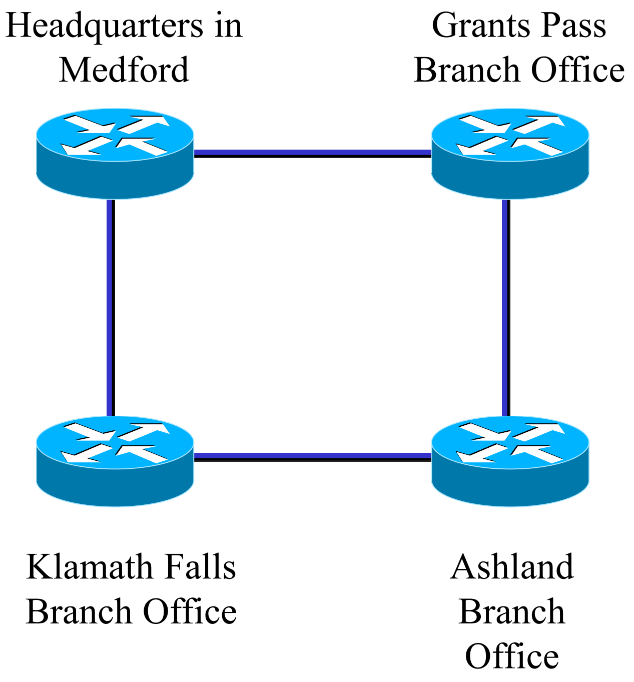
Hierarchical Network Design



Cisco’s Hierarchical Design Model

- A core layer of high-end routers and switches that are optimized for availability and speed
- A distribution layer of routers and switches that implement policies and segment traffic
- An access layer that connects users via hubs, switches, and other devices

Flat Versus Hierarchy



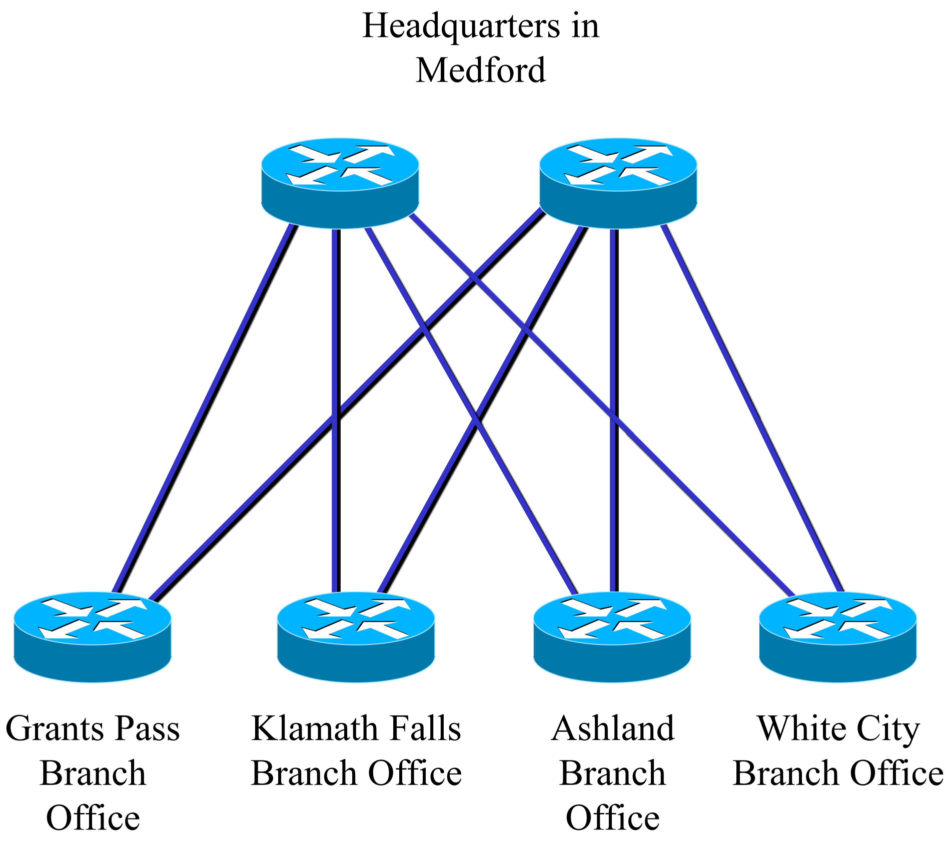
Headquarters in Medford

Grants Pass Branch Office

Klamath Falls Branch Office

Ashland Branch Office

Flat Loop Topology



Headquarters in Medford

Grants Pass Branch Office

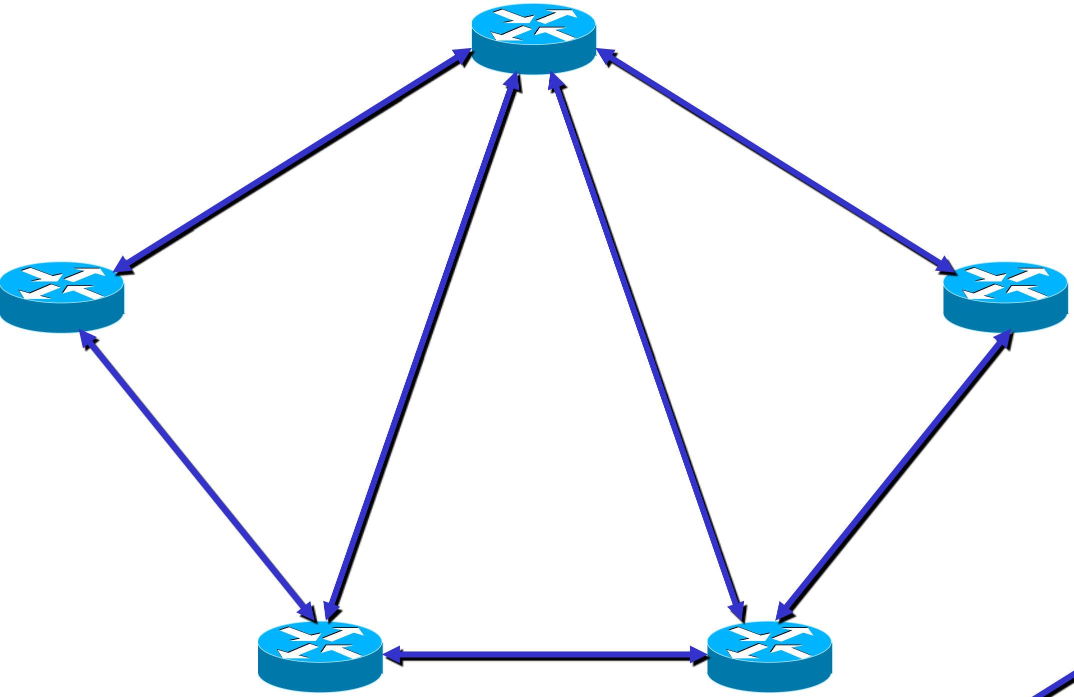
Klamath Falls Branch Office

Ashland Branch Office

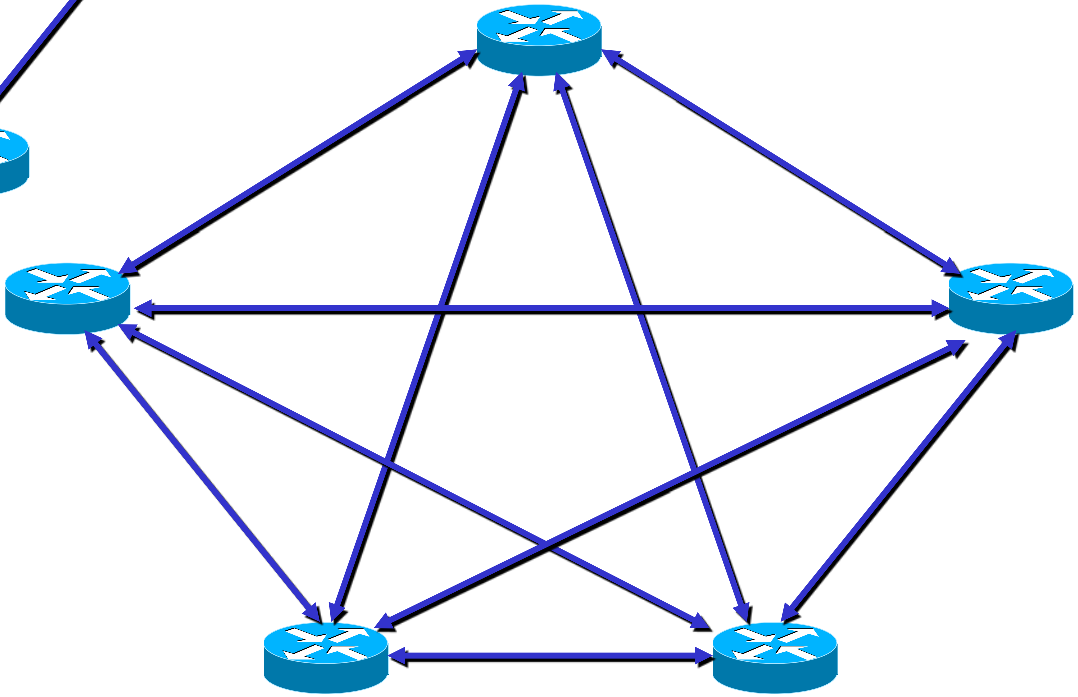
White City Branch Office

Hierarchical Redundant Topology

Mesh Designs

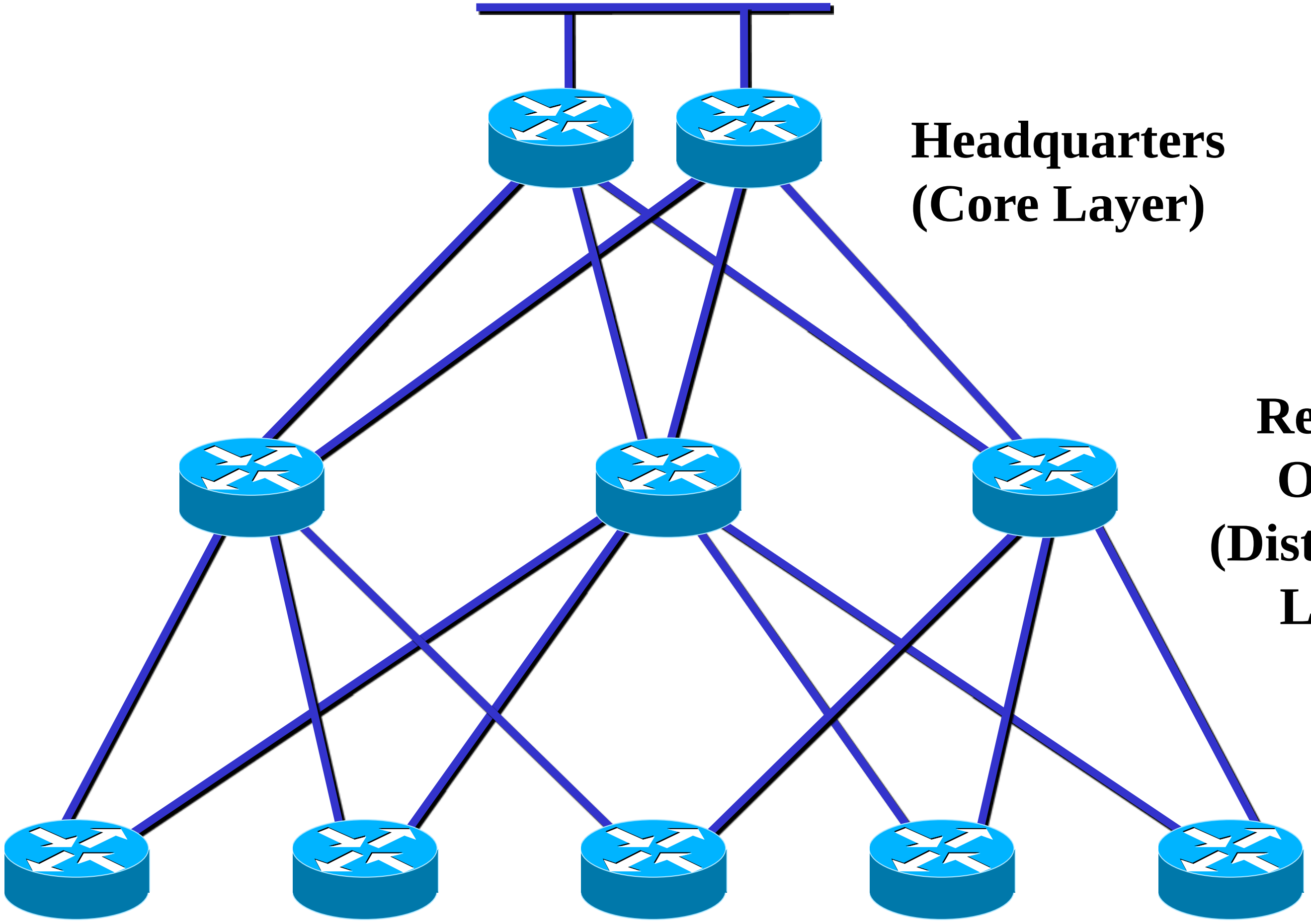


Partial-Mesh Topology



Full-Mesh Topology

A Partial-Mesh Hierarchical Design

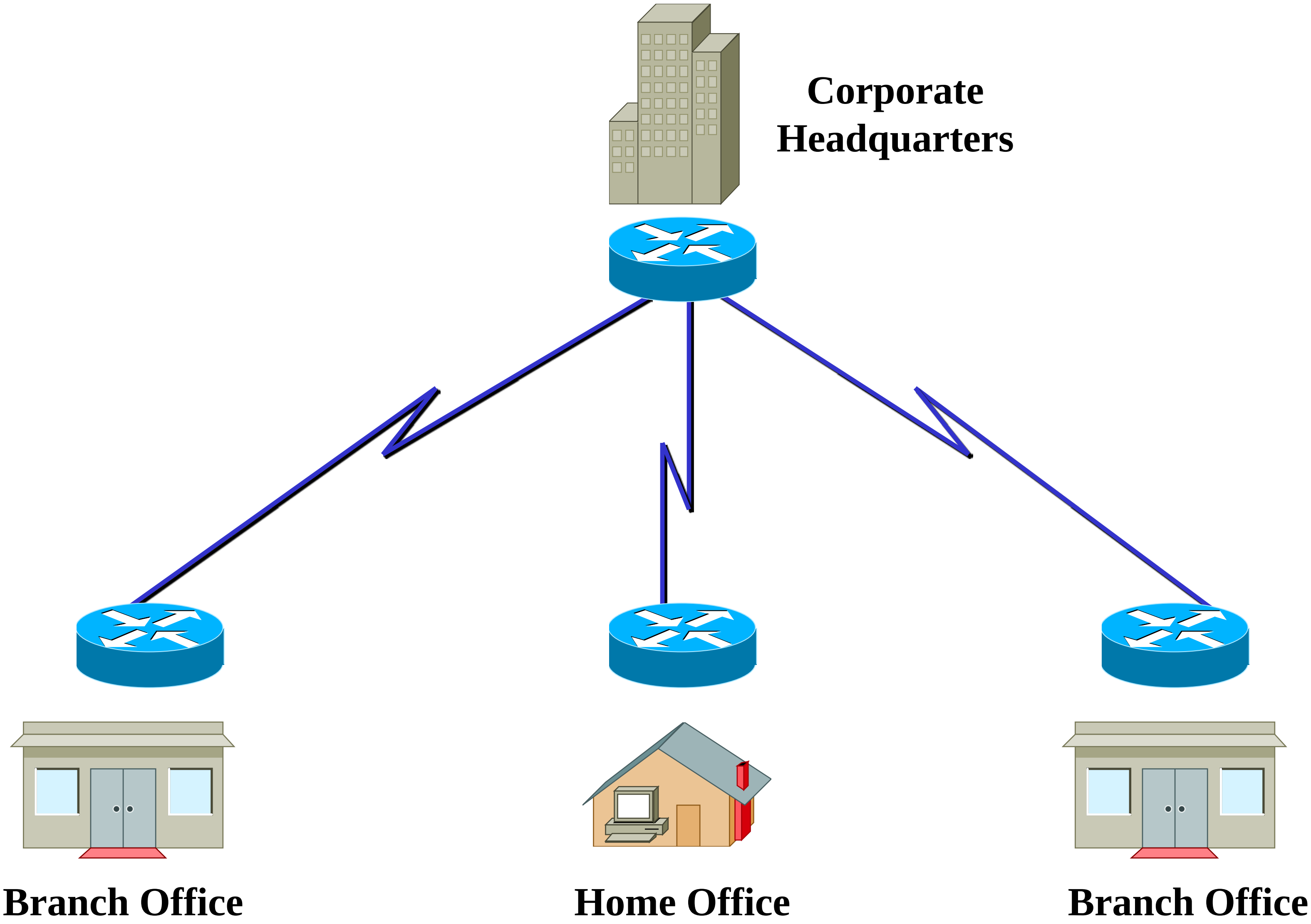


Headquarters (Core Layer)

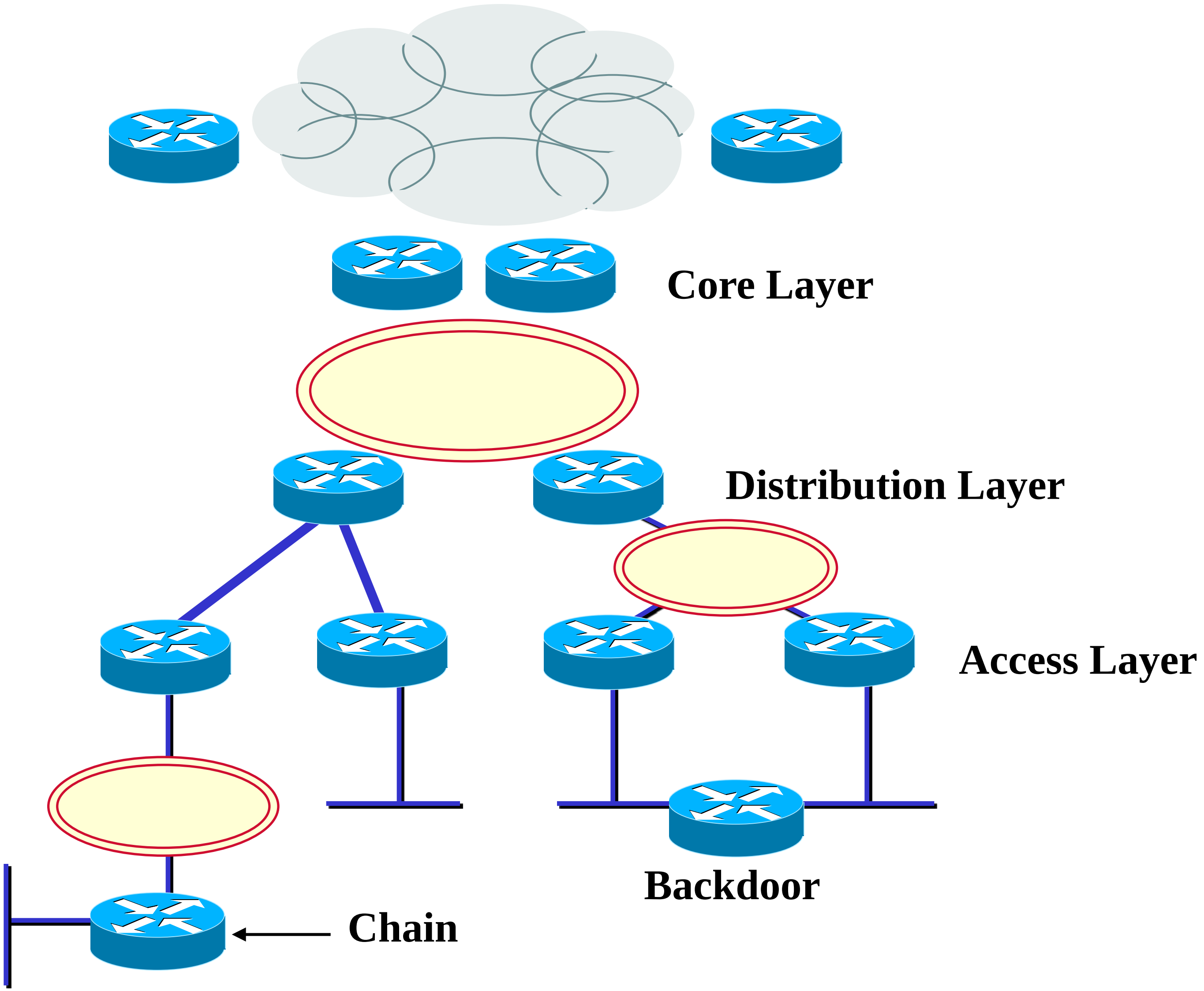
Regional Offices (Distribution Layer)

Branch Offices (Access Layer)

A Hub-and-Spoke Hierarchical Topology



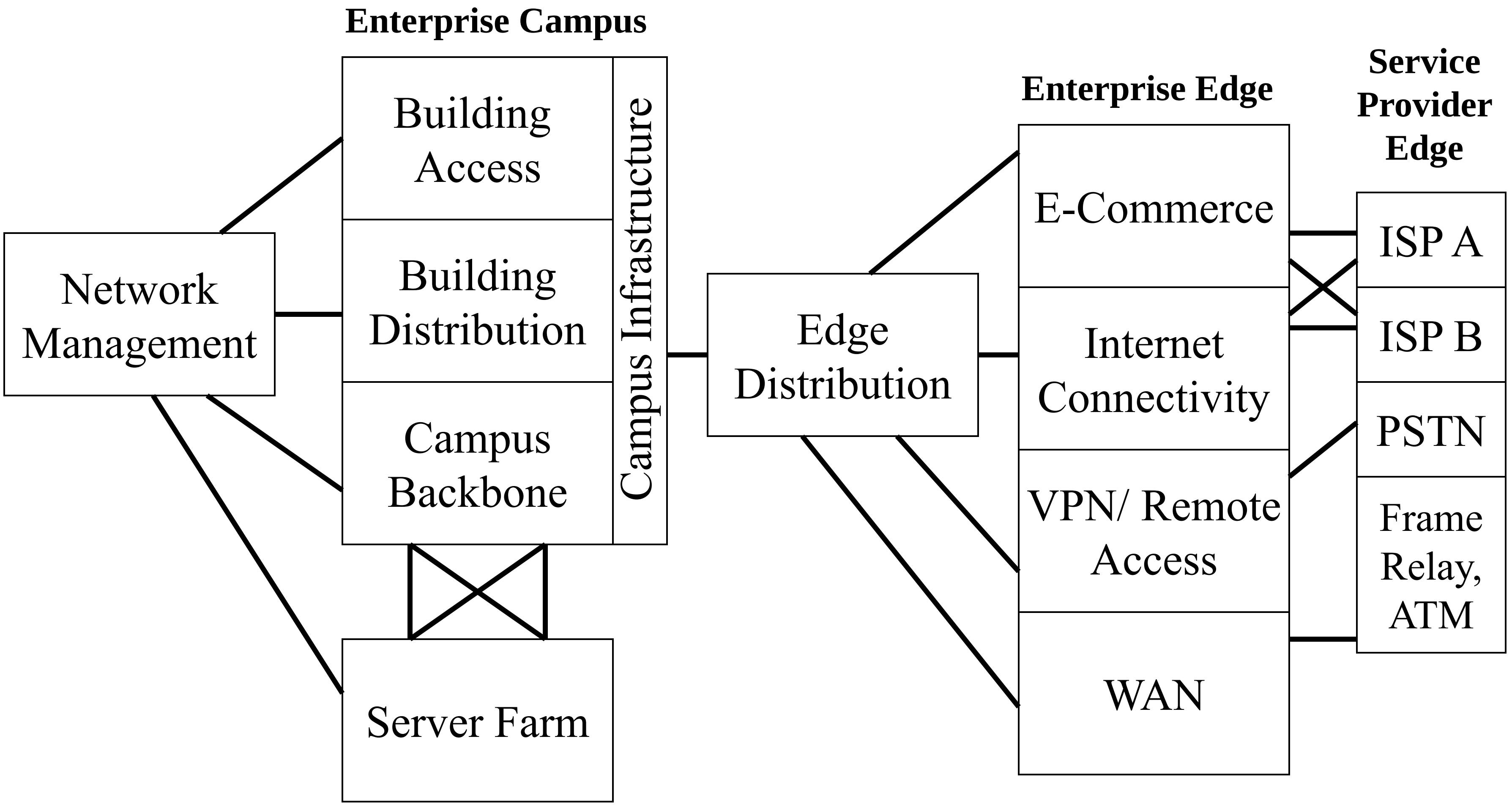
Avoid Chains and Backdoors



How Do You Know When You Have a Good Design?

- When you already know how to add a new building, floor, WAN link, remote site, e-commerce service, and so on
- When new additions cause only local change, to the directly-connected devices
- When your network can double or triple in size without major design changes
- When troubleshooting is easy because there are no complex protocol interactions to wrap your brain around

Cisco's Enterprise Composite Network Model



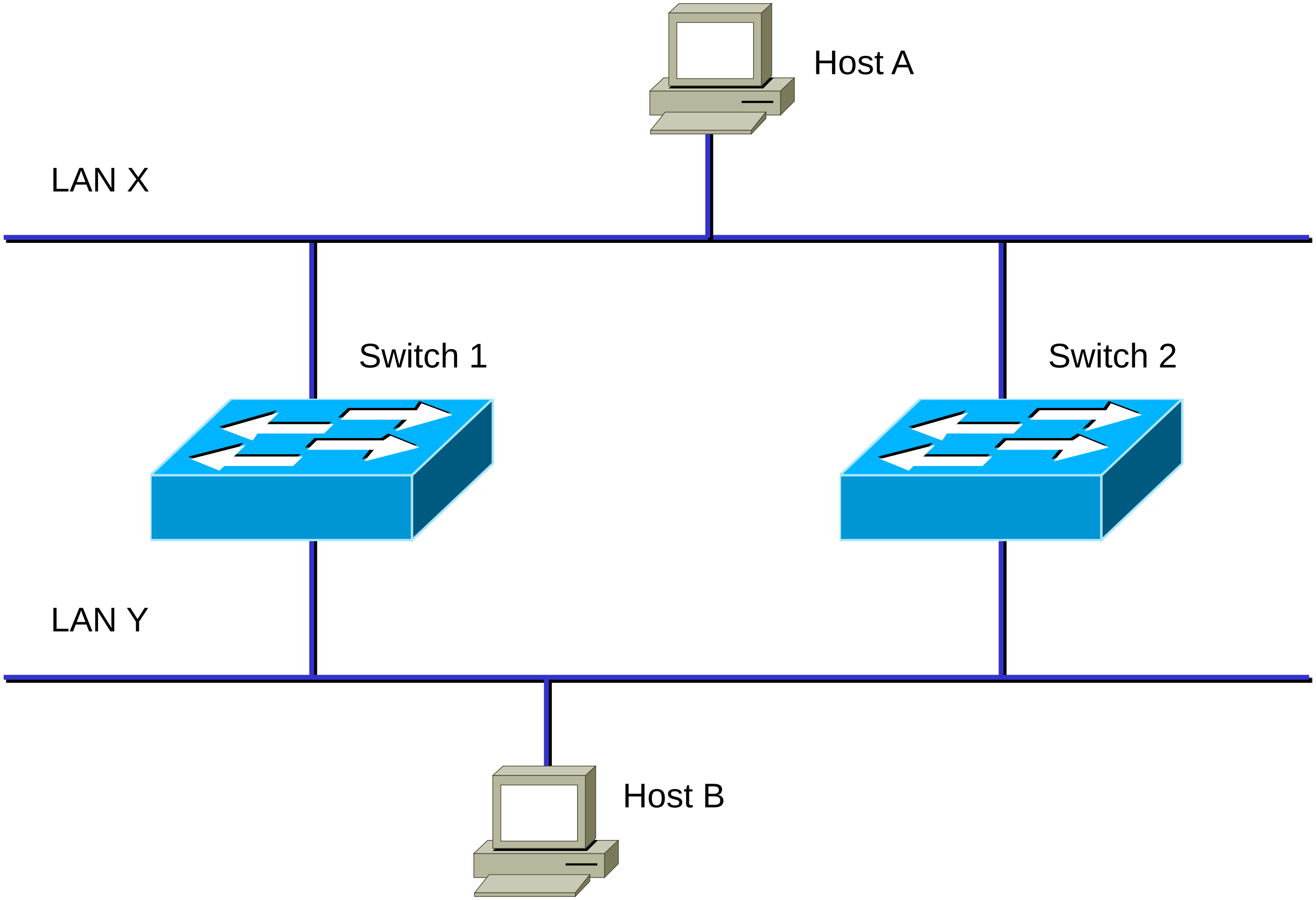
Campus Topology Design

- Use a hierarchical, modular approach
- Minimize the size of bandwidth domains
- Minimize the size of broadcast domains
- Provide redundancy
  - Mirrored servers
  - Multiple ways for workstations to reach a router for off-net communications

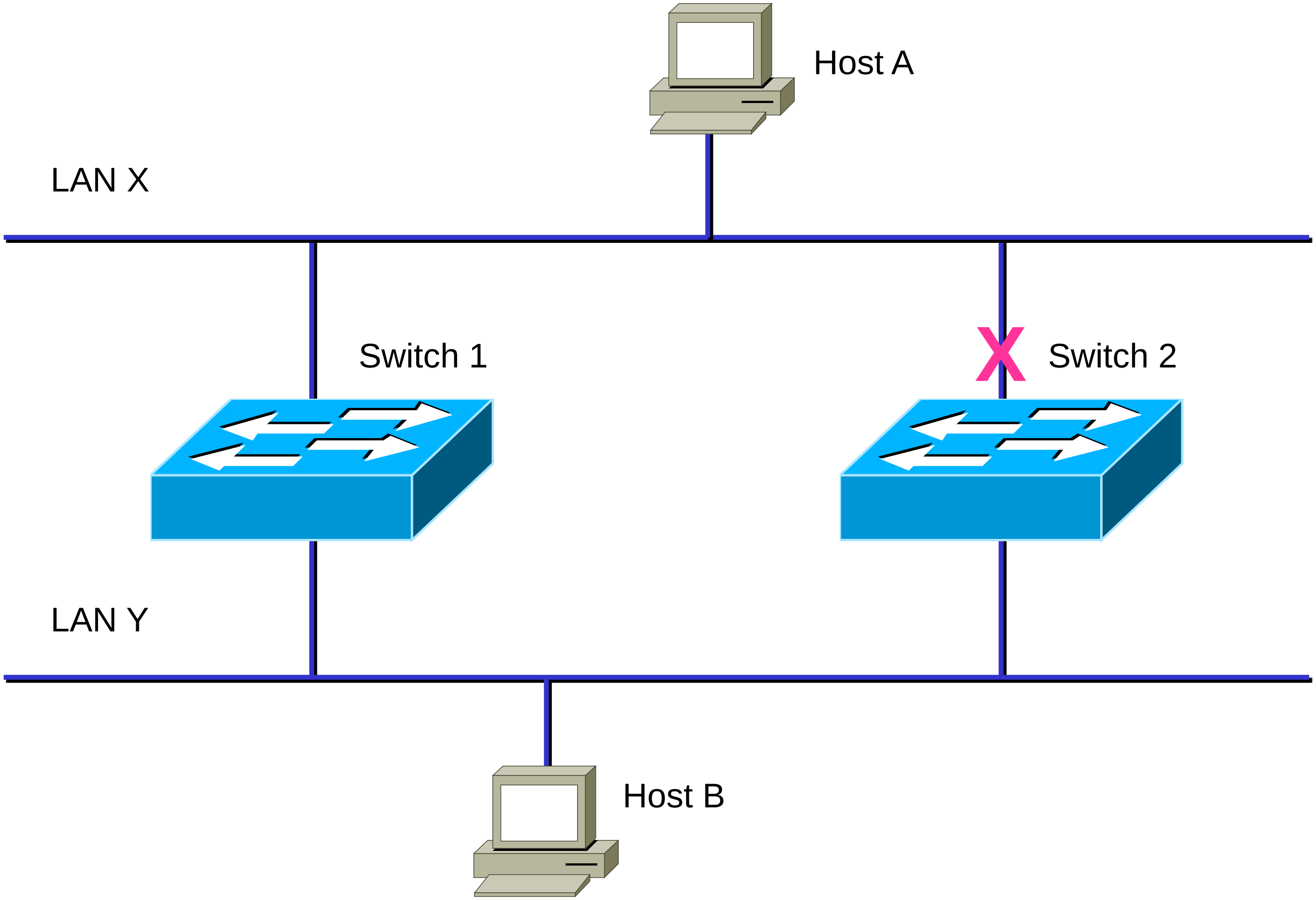
Enterprise Campus Modules

- Server farm
- Network management module
- Edge distribution module for connectivity to the rest of the world
- Campus infrastructure module:
  - Building access submodule
  - Building distribution submodule
  - Campus backbone

A Simple Campus Redundant Design



Bridges and Switches use Spanning-Tree Protocol (STP) to Avoid Loops

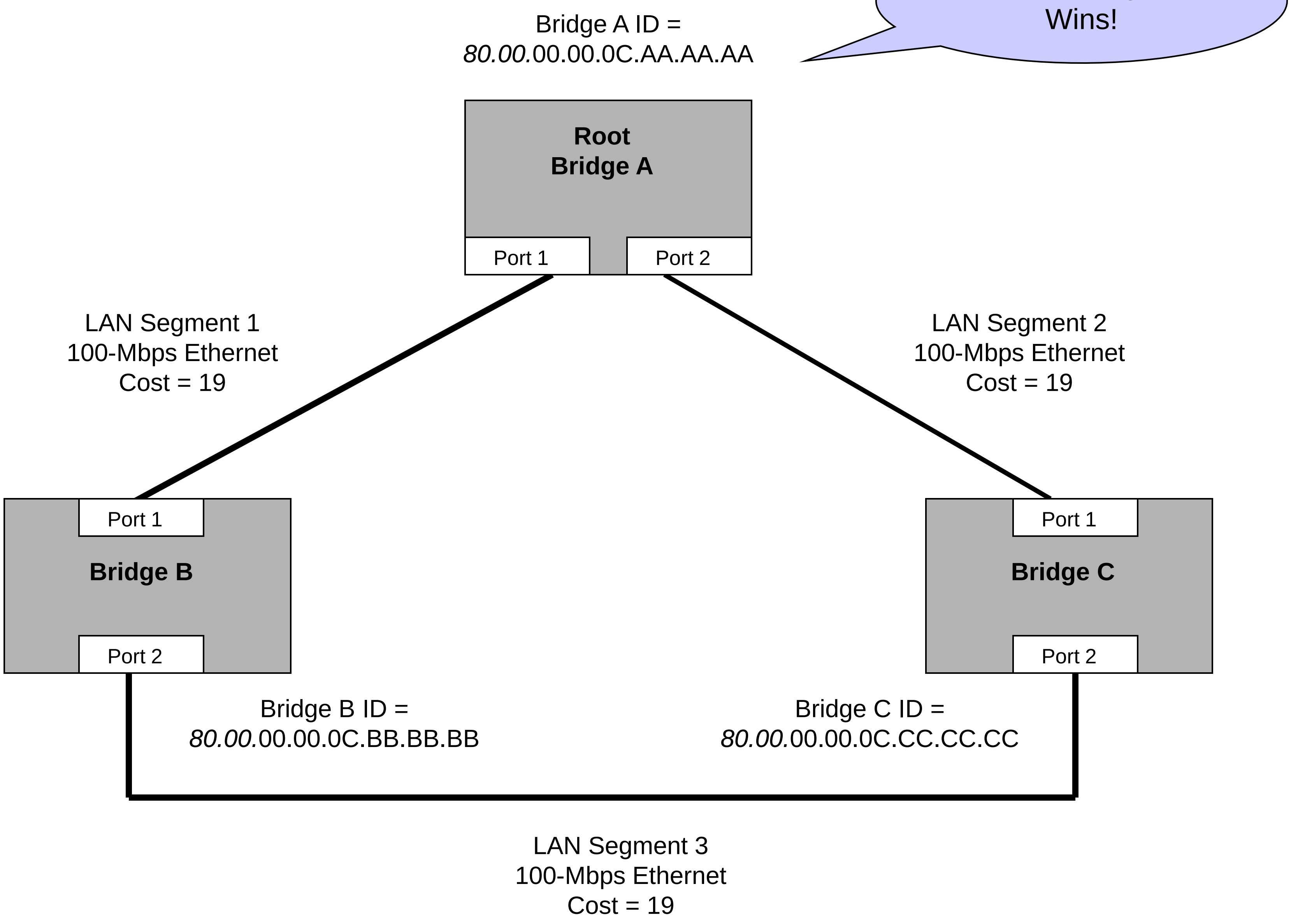


Bridges (Switches) Running STP

- Participate with other bridges in the election of a single bridge as the Root Bridge.
- Calculate the distance of the shortest path to the Root Bridge and choose a port (known as the Root Port) that provides the shortest path to the Root Bridge.
- For each LAN segment, elect a Designated Bridge and a Designated Port on that bridge. The Designated Port is a port on the LAN segment that is closest to the Root Bridge. (All ports on the Root Bridge are Designated Ports.)
- Select bridge ports to be included in the spanning tree. The ports selected are the Root Ports and Designated Ports. These ports forward traffic. Other ports block traffic.

Elect a Root

Lowest Bridge ID
Wins!



Bridge A ID =
*80.00.*00.00.0C.AA.AA.AA

Root
Bridge A

Port 1

Port 2

LAN Segment 1
100-Mbps Ethernet
Cost = 19

LAN Segment 2
100-Mbps Ethernet
Cost = 19

Port 1

Bridge B

Port 2

Port 1

Bridge C

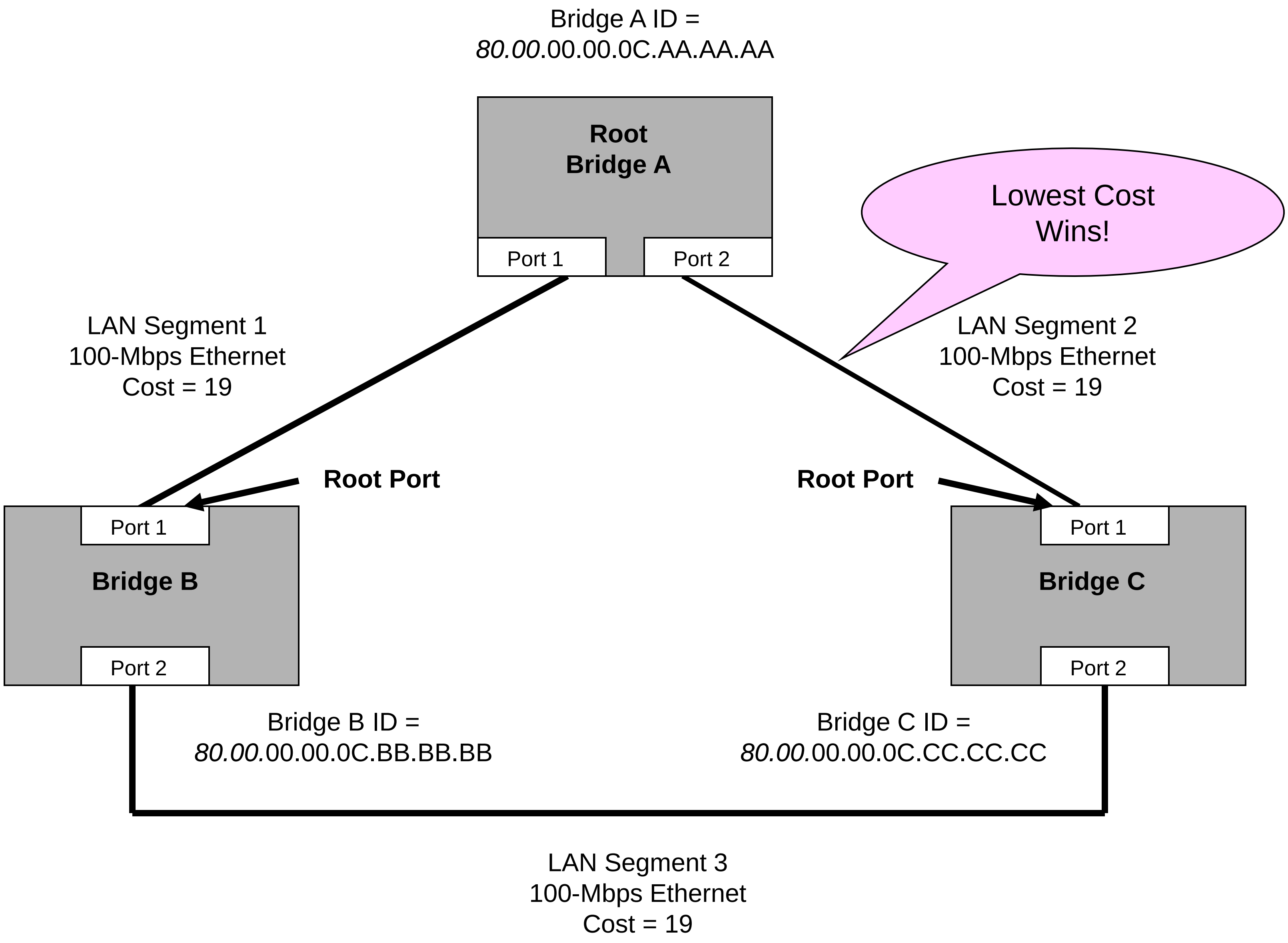
Port 2

Bridge B ID =
*80.00.*00.00.0C.BB.BB.BB

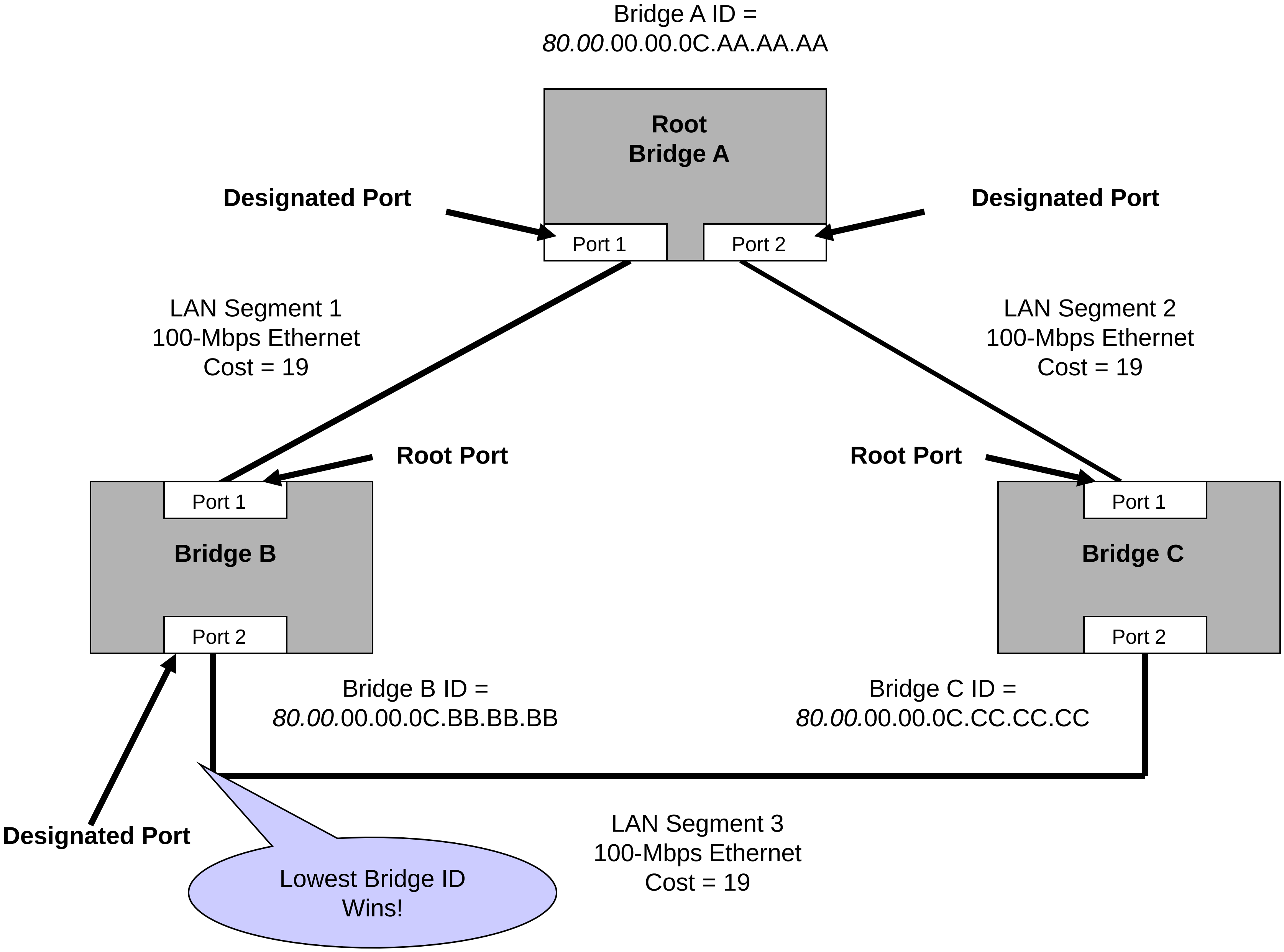
Bridge C ID =
*80.00.*00.00.0C.CC.CC.CC

LAN Segment 3
100-Mbps Ethernet
Cost = 19

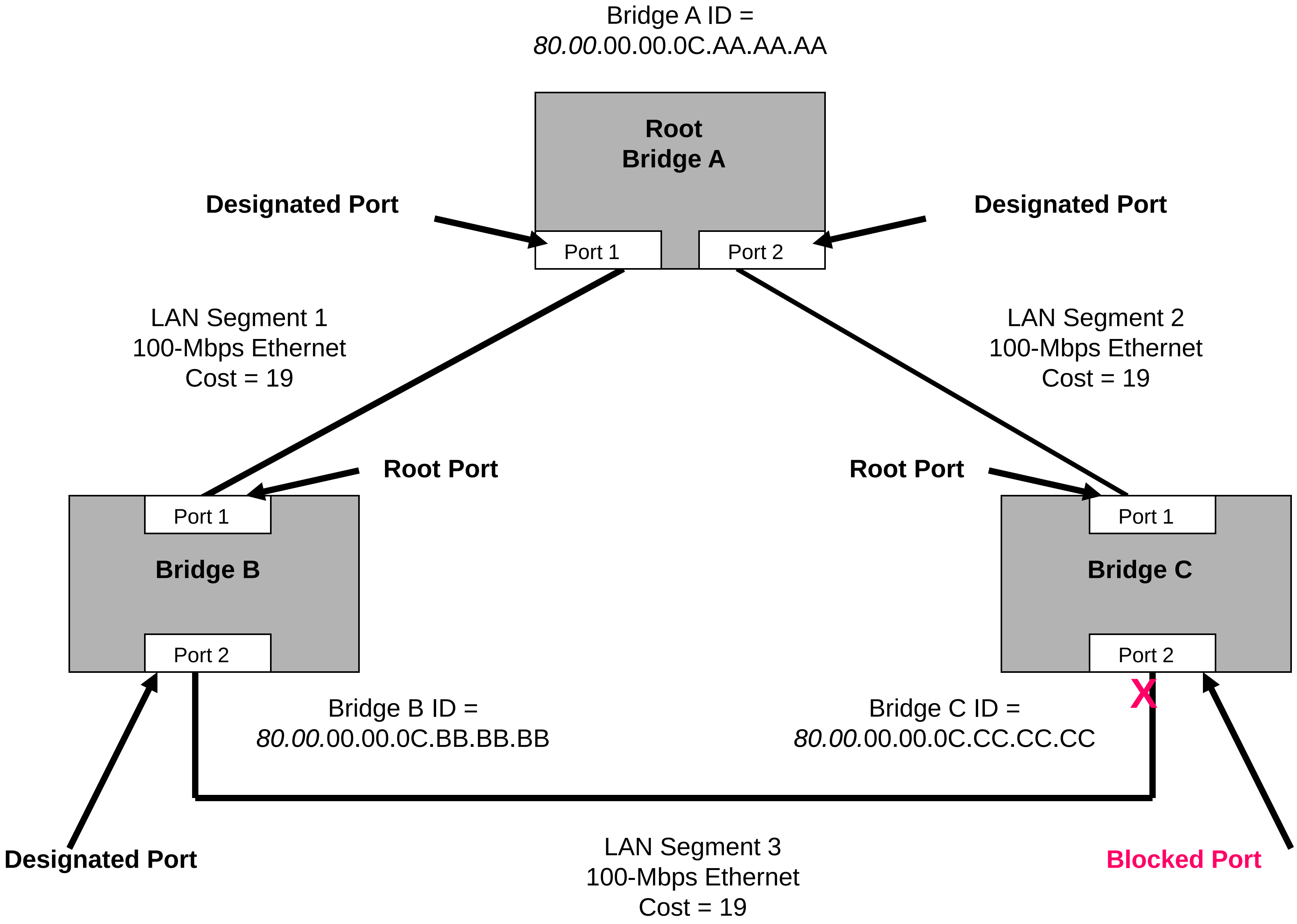
Determine Root Ports



Determine Designated Ports



Prune Topology into a Tree!



Bridge A ID =
80.00.00.00.0C.AA.AA.AA

Root
Bridge A

Designated Port

Port 1

Port 2

Designated Port

LAN Segment 1
100-Mbps Ethernet
Cost = 19

LAN Segment 2
100-Mbps Ethernet
Cost = 19

Root Port

Root Port

Port 1

Bridge B

Port 2

Port 1

Bridge C

Port 2

X

Bridge B ID =
80.00.00.00.0C.BB.BB.BB

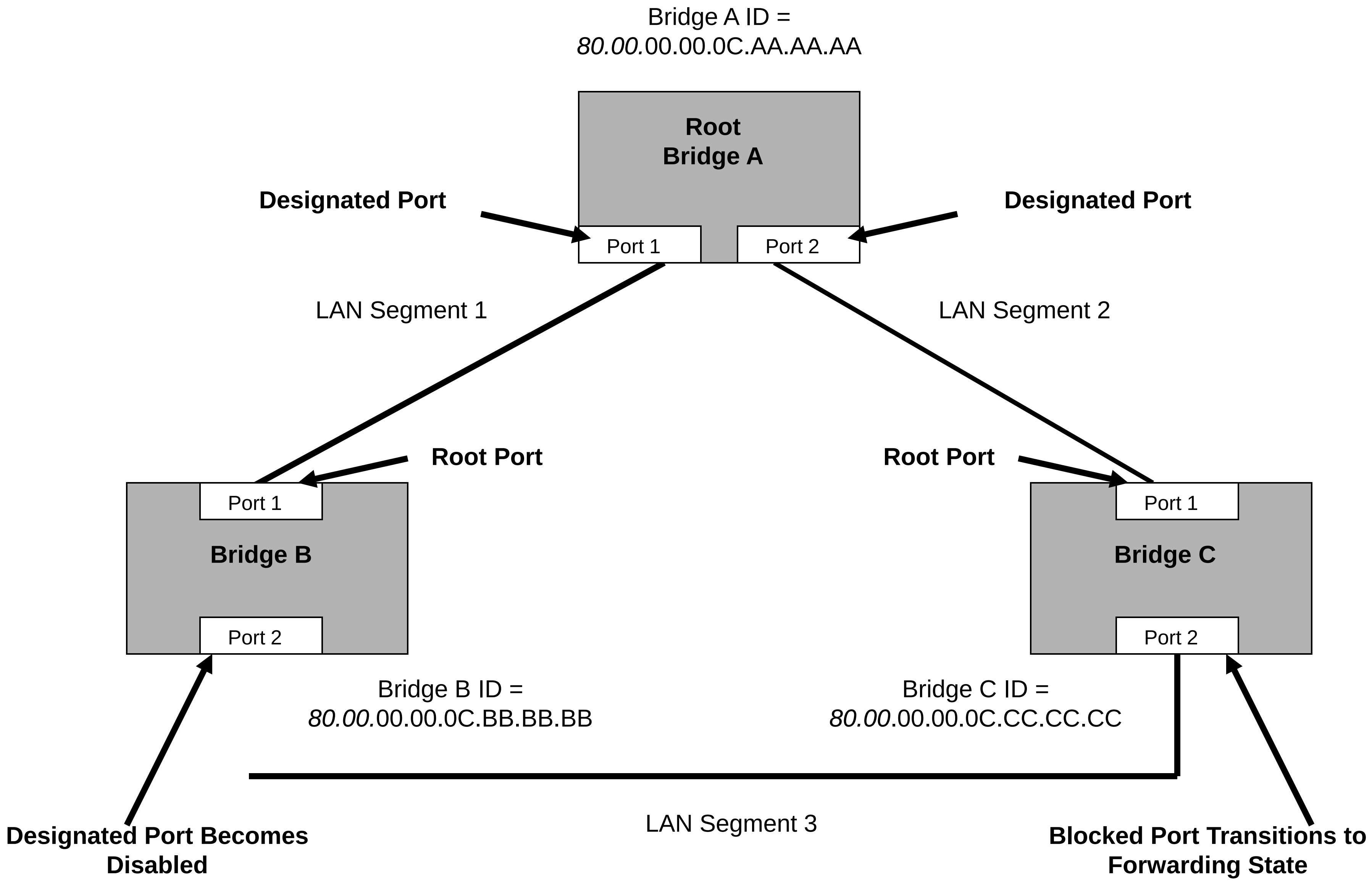
Bridge C ID =
80.00.00.00.0C.CC.CC.CC

Designated Port

LAN Segment 3
100-Mbps Ethernet
Cost = 19

Blocked Port

React to Changes



Scaling the Spanning Tree Protocol

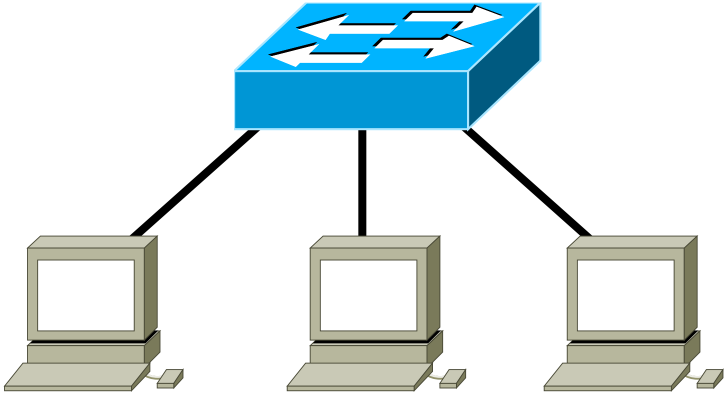
- Keep the switched network small
  - It shouldn’t span more than seven switches
- Use BPDU skew detection on Cisco switches
- Use IEEE 802.1w
  - Provides rapid reconfiguration of the spanning tree
  - Also known as RSTP

Virtual LANs (VLANs)

- An emulation of a standard LAN that allows data transfer to take place without the traditional physical restraints placed on a network
- A set of devices that belong to an administrative group
- Designers use VLANs to constrain broadcast traffic

VLANs versus Real LANs

Switch A



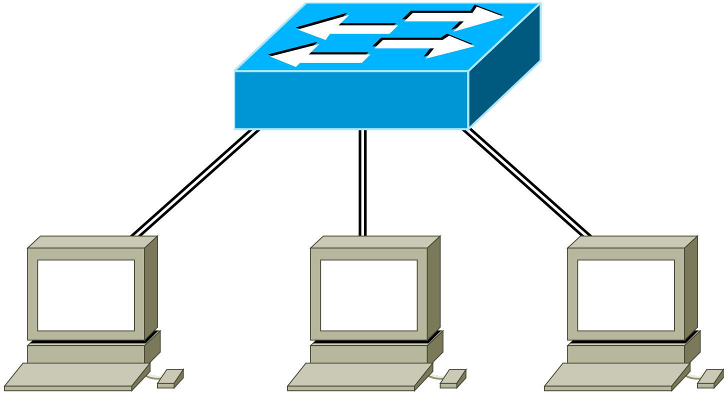
Station A1

Station A2

Station A3

Network A

Switch B



Station B1

Station B2

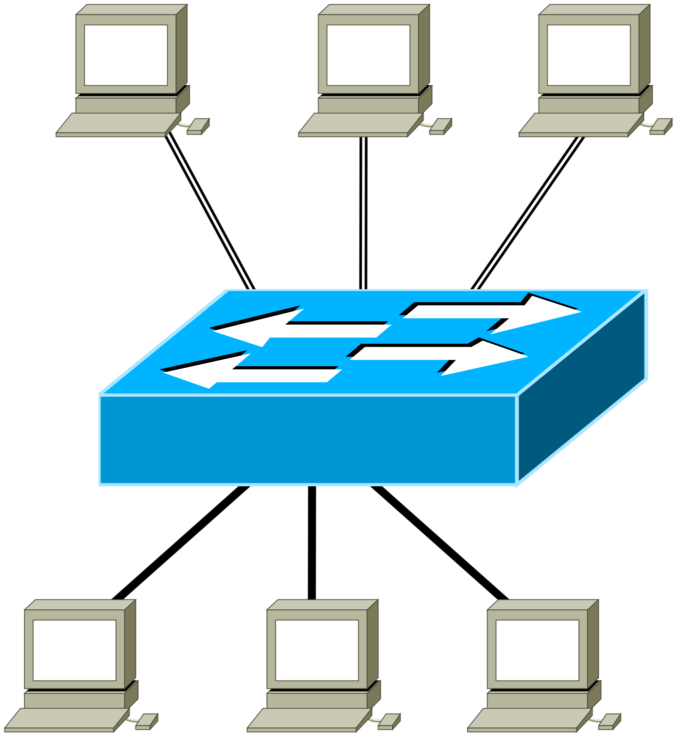
Station B3

Network B

A Switch with VLANs

VLAN A

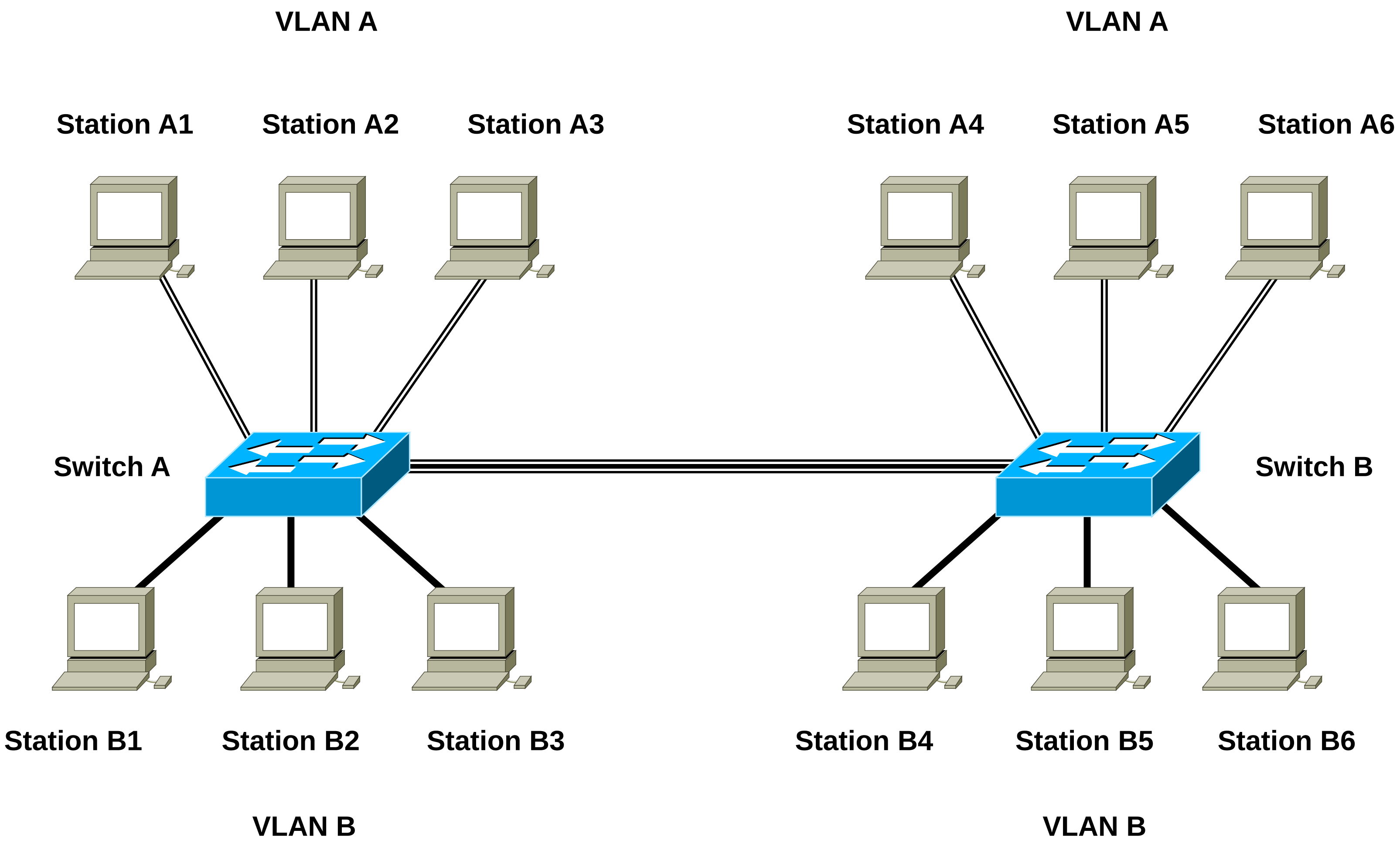
Station A1 Station A2 Station A3



Station B1 Station B2 Station B3

VLAN B

VLANs Span Switches



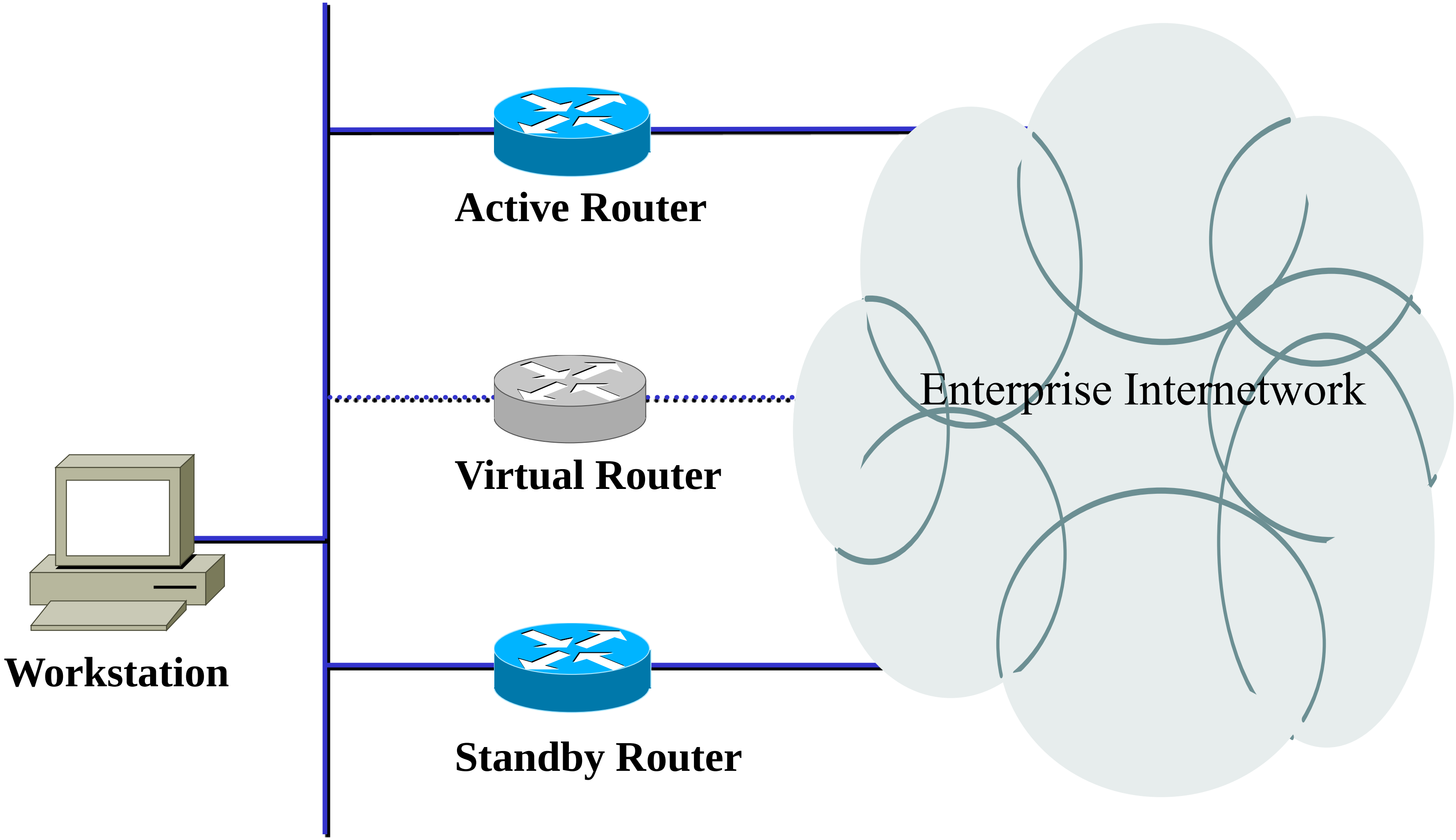
WLANs and VLANs

- A wireless LAN (WLAN) is often implemented as a VLAN
- Facilitates roaming
- Users remain in the same VLAN and IP subnet as they roam, so there's no need to change addressing information
- Also makes it easier to set up filters (access control lists) to protect the wired network from wireless users

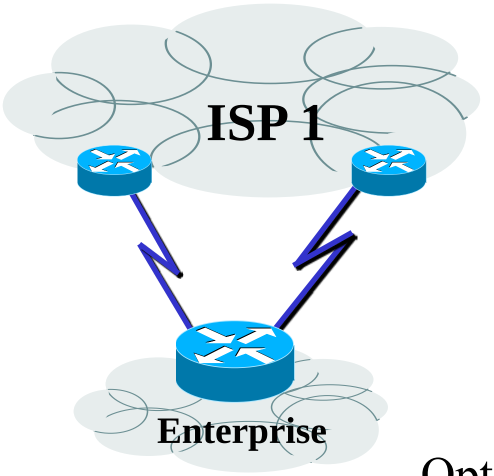
Workstation-to-Router Communication

- Proxy ARP (not a good idea)
- Listen for route advertisements (not a great idea either)
- ICMP router solicitations (not widely used)
- Default gateway provided by DHCP (better idea but no redundancy)
  - Use Hot Standby Router Protocol (HSRP) for redundancy

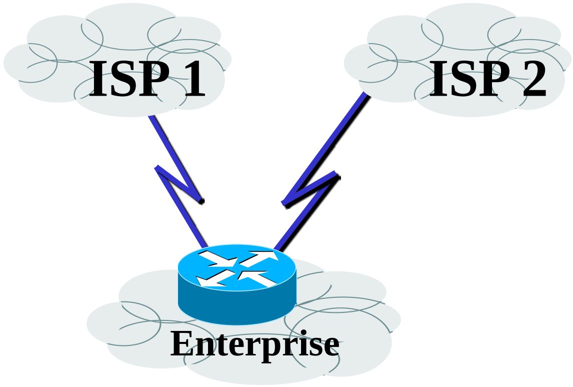
HSRP


Active Router
Virtual Router
Workstation
Standby Router
Enterprise Internetwork

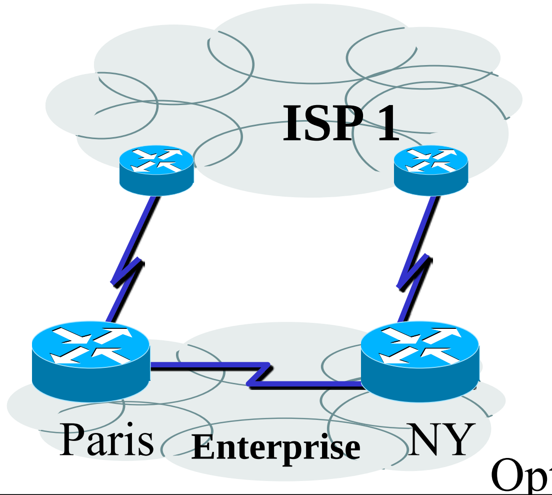
Multihoming the Internet Connection



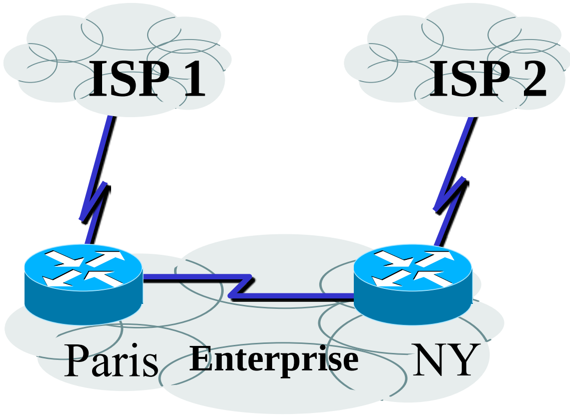
Option A



Option B

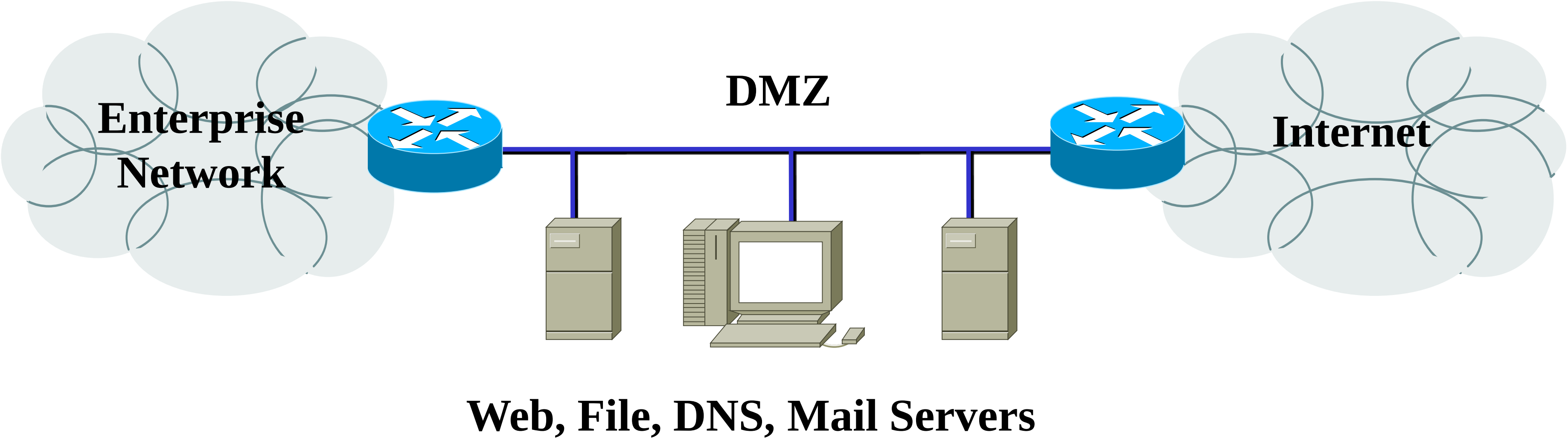


Option C

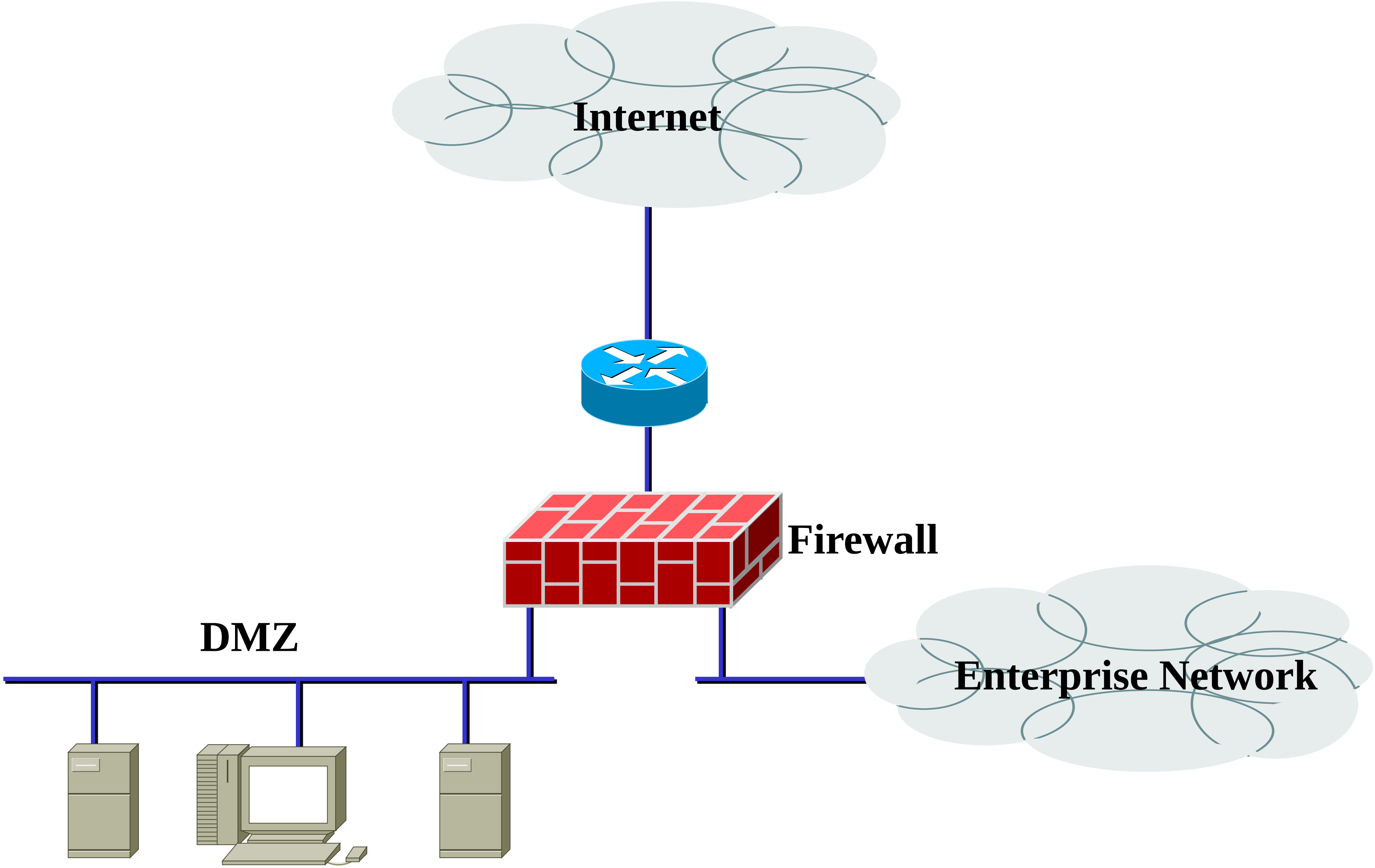


Option D

Security Topologies



Security Topologies



Web, File, DNS, Mail Servers

Summary

- Use a systematic, top-down approach
- Plan the logical design before the physical design
- Topology design should feature hierarchy, redundancy, modularity, and security

Review Questions

- Why are hierarchy and modularity important for network designs?
- What are the three layers of Cisco’s hierarchical network design?
- What are the major components of Cisco’s enterprise composite network model?
- What are the advantages and disadvantages of the various options for multihoming an Internet connection?

Top-Down Network Design

Chapter Six

Designing Models for Addressing and Naming

Guidelines for Addressing and Naming

- Use a structured model for addressing and naming
- Assign addresses and names hierarchically
- Decide in advance if you will use
  - Central or distributed authority for addressing and naming
  - Public or private addressing
  - Static or dynamic addressing and naming

Advantages of Structured Models for Addressing & Naming

- It makes it easier to
  - Read network maps
  - Operate network management software
  - Recognize devices in protocol analyzer traces
  - Meet goals for usability
  - Design filters on firewalls and routers
  - Implement route summarization

Public IP Addresses

- Managed by the Internet Assigned Numbers Authority (IANA)
- Users are assigned IP addresses by Internet service providers (ISPs).
- ISPs obtain allocations of IP addresses from their appropriate Regional Internet Registry (RIR)

Regional Internet Registries (RIR)

- APNIC (Asia Pacific Network Information Centre) – Asia/Pacific Region
- ARIN (American Registry for Internet Numbers) – North America and Sub-Sahara Africa
- LACNIC (Regional Latin-American and Caribbean IP Address Registry) – Latin America and some Caribbean Islands
- RIPE NCC (Réseaux IP Européens) – Europe, the Middle East, Central Asia, and African countries located north of the equator

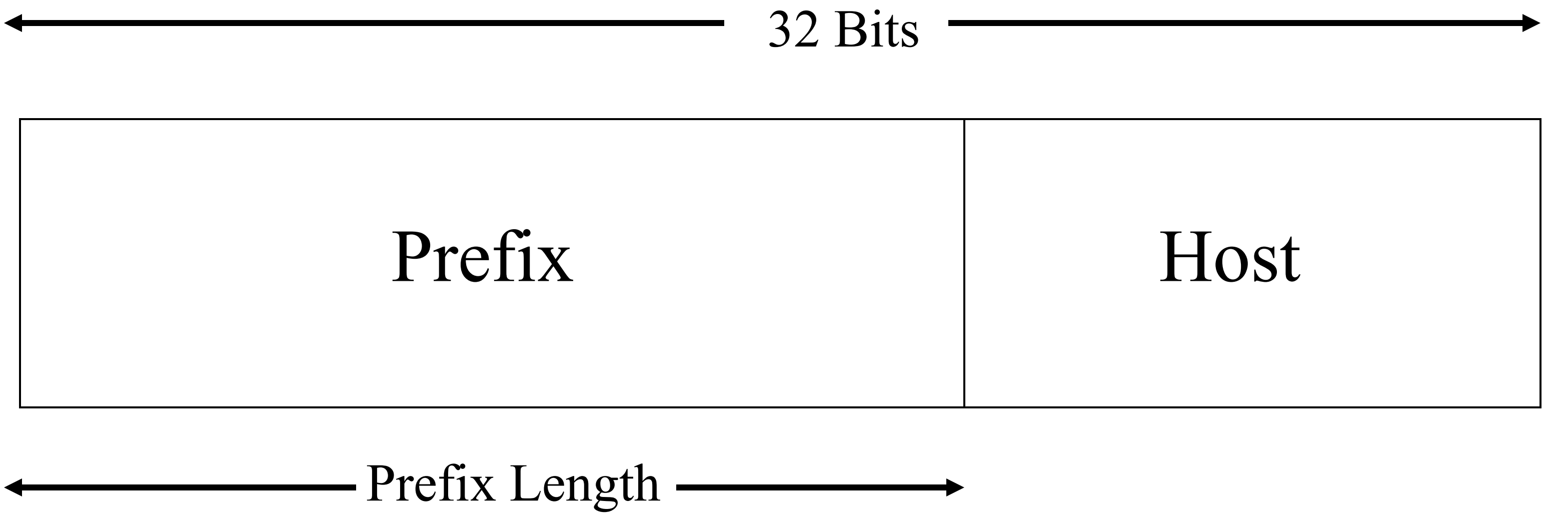
Private Addressing

- 10.0.0.0 – 10.255.255.255
- 172.16.0.0 – 172.31.255.255
- 192.168.0.0 – 192.168.255.255

Criteria for Using Static Vs. Dynamic Addressing

- The number of end systems
- The likelihood of needing to renumber
- The need for high availability
- Security requirements
- The importance of tracking addresses
- Whether end systems need additional information
  - (DHCP can provide more than just an address)

The Two Parts of an IP Address



Prefix Length

- An IP address is accompanied by an indication of the prefix length
  - Subnet mask
  - /Length
- Examples
  - 192.168.10.1 255.255.255.0
  - 192.168.10.1/24

Subnet Mask

- 32 bits long
- Specifies which part of an IP address is the network/subnet field and which part is the host field
  - The network/subnet portion of the mask is all 1s in binary.
  - The host portion of the mask is all 0s in binary.
  - Convert the binary expression back to dotted-decimal notation for entering into configurations.
- Alternative
  - Use slash notation (for example /24)
  - Specifies the number of 1s

Subnet Mask Example

- 11111111 11111111 11111111 00000000
- What is this in slash notation?
- What is this in dotted-decimal notation?

Another Subnet Mask Example

- 11111111 11111111 11110000 00000000
- What is this in slash notation?
- What is this in dotted-decimal notation?

One More Subnet Mask Example

- 11111111 11111111 11111000 00000000
- What is this in slash notation?
- What is this in dotted-decimal notation?

Designing Networks with Subnets

- Determining subnet size
- Computing subnet mask
- Computing IP addresses

Addresses to Avoid When Subnetting

- A node address of all ones (broadcast)
- A node address of all zeros (network)
- A subnet address of all ones (all subnets)
- A subnet address of all zeros (confusing)
  - Cisco IOS configuration permits a subnet address of all zeros with the **ip subnet-zero** command

Practice

- Network is 172.16.0.0
- You want to divide the network into subnets.
- You will allow 600 nodes per subnet.
- What subnet mask should you use?
- What is the address of the first node on the first subnet?
- What address would this node use to send to all devices on its subnet?

More Practice

- Network is 172.16.0.0
- You have eight LANs, each of which will be its own subnet.
- What subnet mask should you use?
- What is the address of the first node on the first subnet?
- What address would this node use to send to all devices on its subnet?

One More

- Network is 192.168.55.0
- You want to divide the network into subnets.
- You will have approximately 25 nodes per subnet.
- What subnet mask should you use?
- What is the address of the last node on the last subnet?
- What address would this node use to send to all devices on its subnet?

IP Address Classes

- Classes are now considered obsolete
- But you have to learn them because
  - Everyone in the industry still talks about them!
  - You may run into a device whose configuration is affected by the classful system

Classful IP Addressing

Class	**First Few Bits**	**First Byte**	**Prefix Length**	**Intent**
A	0	1-126*	8	Very large networks
B	10	128-191	16	Large networks
C	110	192-223	24	Small networks
D	1110	224-239	NA	IP multicast
E	1111	240-255	NA	Experimental

*Addresses starting with 127 are reserved for IP traffic local to a host.

Division of the Classful Address Space

Class	Prefix Length	Number of Addresses per Network
A	8	2^{24}-2 = 16,777,214
B	16	2^{16}-2 = 65,534
C	24	2^{8}-2 = 254

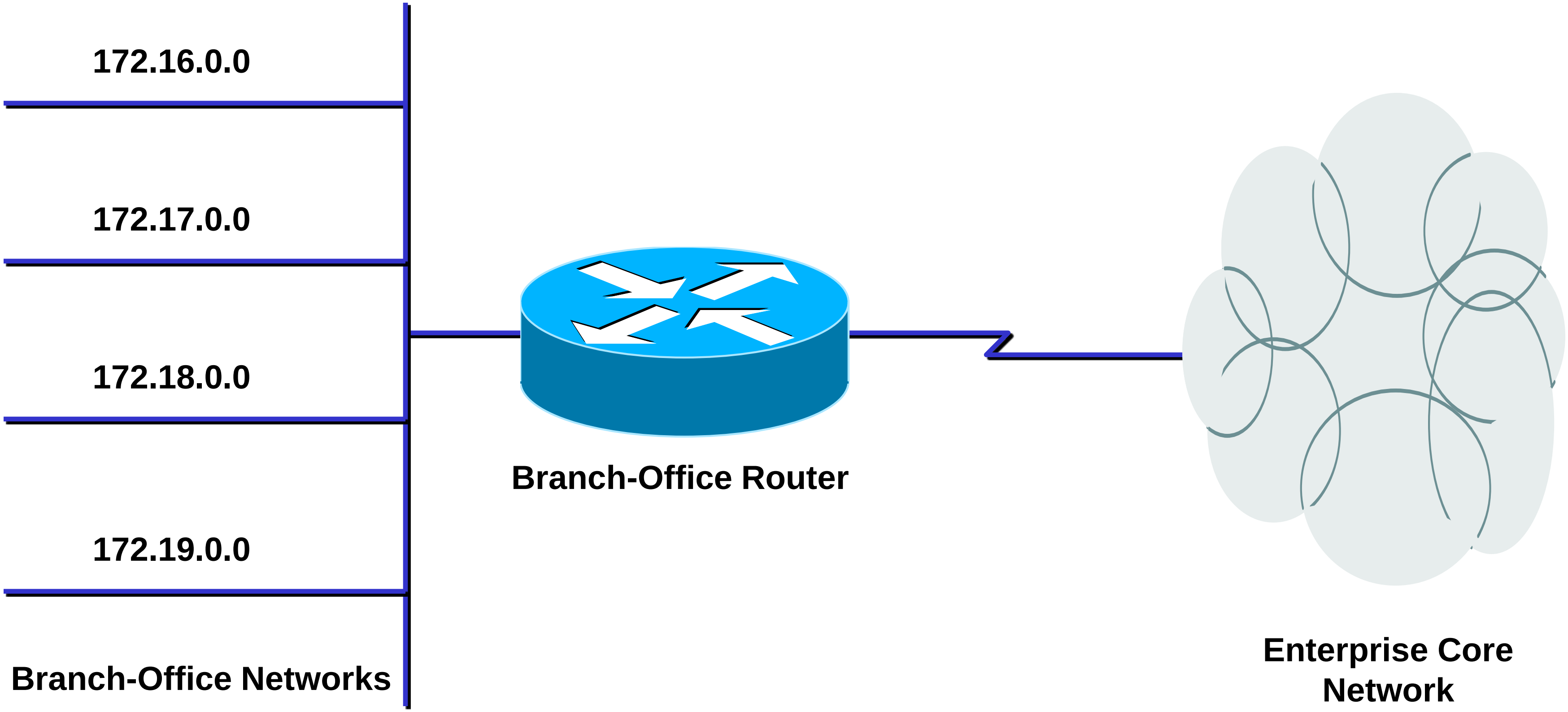
Classful IP is Wasteful

- Class A uses 50% of address space
- Class B uses 25% of address space
- Class C uses 12.5% of address space
- Class D and E use 12.5% of address space

Classless Addressing

- Prefix/host boundary can be anywhere
- Less wasteful
- Supports route summarization
  - Also known as
    - Aggregation
    - Supernetting
    - Classless routing
    - Classless inter-domain routing (CIDR)
    - Prefix routing

Supernetting

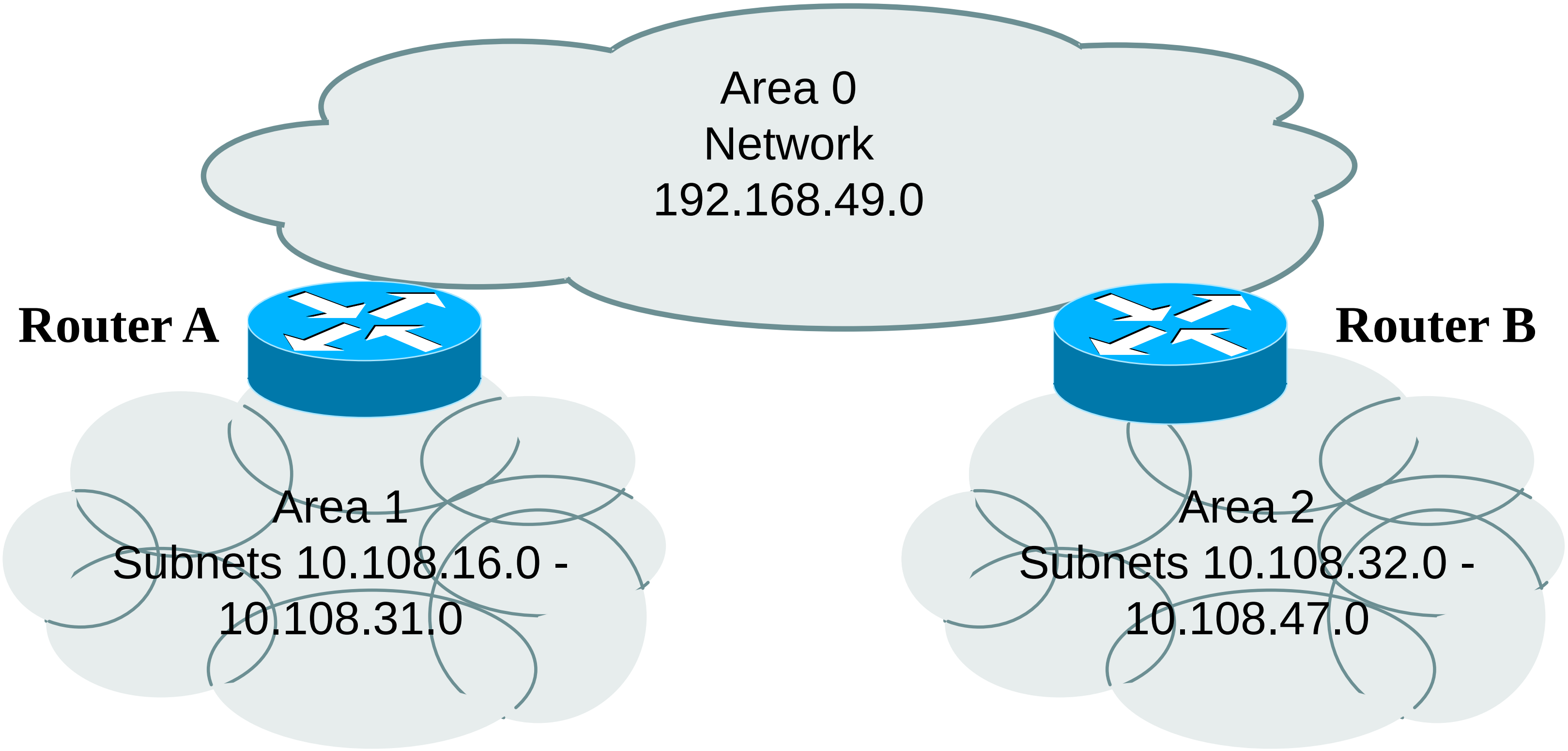


- Move prefix boundary to the left
- Branch office advertises 172.16.0.0/14

172.16.0.0/14 Summarization

Second Octet in Decimal	**Second Octet in Binary**
16	**000100**00
17	**000100**01
18	**000100**10
19	**000100**11

Discontiguous Subnets



Area 0
Network
192.168.49.0

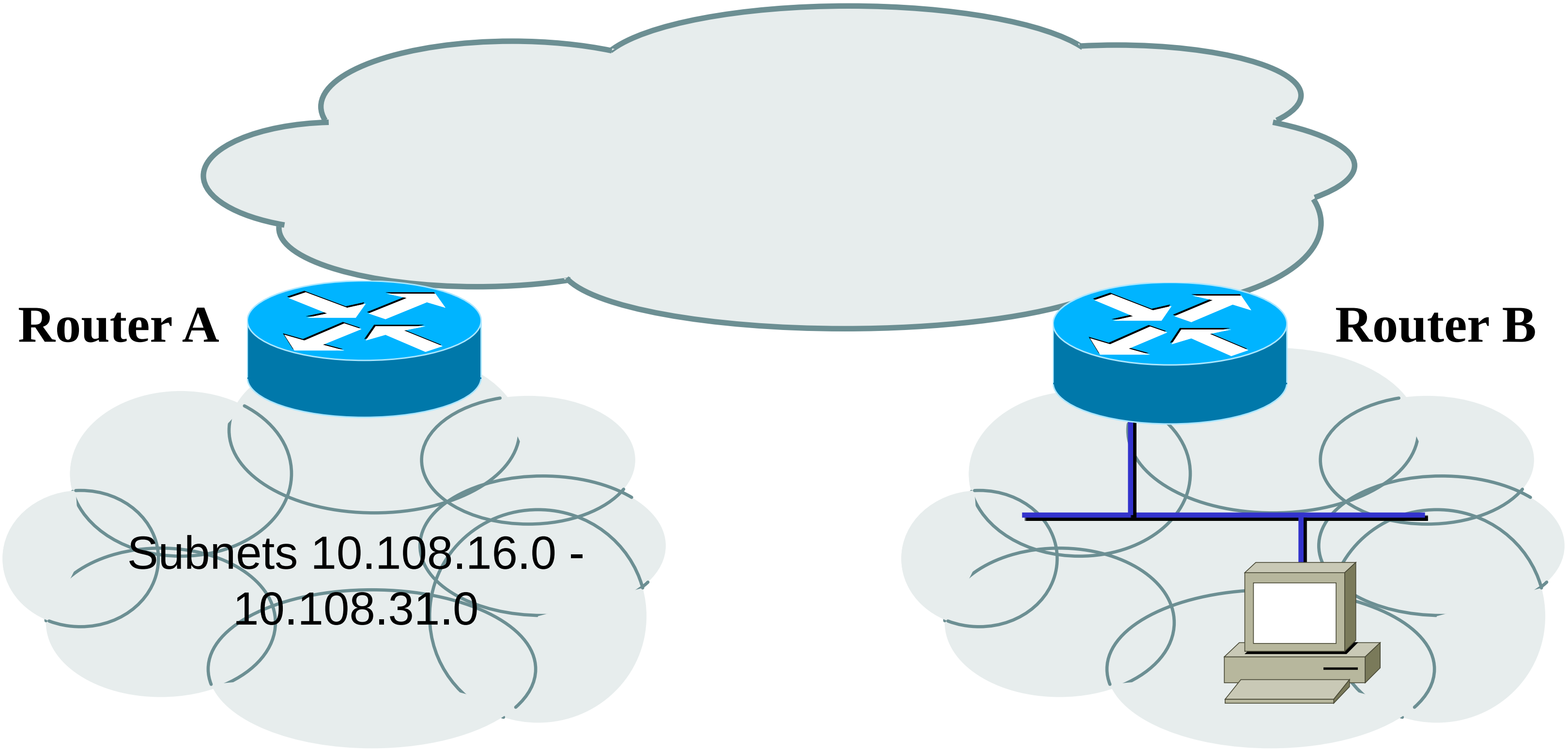
Router A

Router B

Area 1
Subnets 10.108.16.0 - 10.108.31.0

Area 2
Subnets 10.108.32.0 - 10.108.47.0

A Mobile Host



Router A

Router B

Subnets 10.108.16.0 - 10.108.31.0

Host 10.108.16.1

IPv6 Aggregatable Global Unicast Address Format

3	13	8	24	16	64 bits
FP	TLA ID	RES	NLA ID	SLA ID	Interface ID

← Public topology →

Site
Topology

• FP	Format Prefix (001)
• TLA ID	Top-Level Aggregation Identifier
• RES	Reserved for future use
• NLA ID	Next-Level Aggregation Identifier
• SLA ID	Site-Level Aggregation Identifier
• Interface ID	Interface Identifier

Upgrading to IPv6

- Dual stack
- Tunneling
- Translation

Guidelines for Assigning Names

- Names should be
  - Short
  - Meaningful
  - Unambiguous
  - Distinct
  - Case insensitive
- Avoid names with unusual characters
  - Hyphens, underscores, asterisks, and so on

Domain Name System (DNS)

- Maps names to IP addresses
- Supports hierarchical naming
  - example: frodo.rivendell.middle-earth.com
- A DNS server has a database of resource records (RRs) that maps names to addresses in the server's "zone of authority"
- Client queries server
  - Uses UDP port 53 for name queries and replies
  - Uses TCP port 53 for zone transfers

DNS Details

- Client/server model
- Client is configured with the IP address of a DNS server
  - Manually or DHCP can provide the address
- DNS *resolver software* on the client machine sends a query to the DNS server. Client may ask for *recursive lookup*.

DNS Recursion

- A DNS server may offer *recursion*, which allows the server to ask other servers
  - Each server is configured with the IP address of one or more root DNS servers.
- When a DNS server receives a response from another server, it replies to the resolver client software. The server also caches the information for future requests.
  - The network administrator of the authoritative DNS server for a name defines the length of time that a non-authoritative server may cache information.

Summary

- Use a systematic, structured, top-down approach to addressing and naming
- Assign addresses in a hierarchical fashion
- Distribute authority for addressing and naming where appropriate
- IPv6 looms in our future

Review Questions

- Why is it important to use a structured model for addressing and naming?
- When is it appropriate to use IP private addressing versus public addressing?
- When is it appropriate to use static versus dynamic addressing?
- What are some approaches to upgrading to IPv6?

Top-Down Network Design

Chapter Seven

Selecting Switching and Routing Protocols

Switching and Routing Choices

- Switching
  - Layer 2 transparent bridging (switching)
  - Multilayer switching
  - Spanning Tree Protocol enhancements
  - VLAN technologies
- Routing
  - Static or dynamic
  - Distance-vector and link-state protocols
  - Interior and exterior
  - Etc.

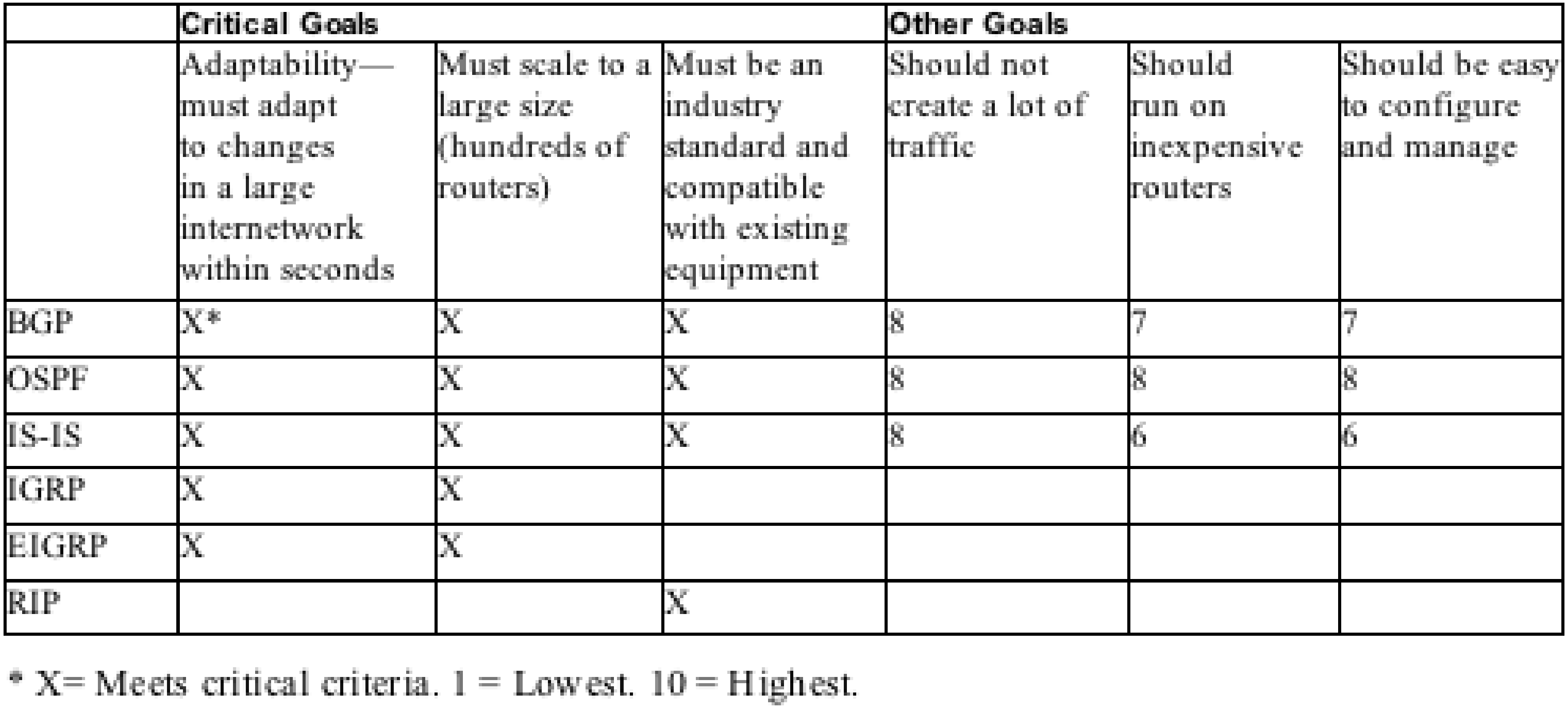
Selection Criteria for Switching and Routing Protocols

- Network traffic characteristics
- Bandwidth, memory, and CPU usage
- The number of peers supported
- The capability to adapt to changes quickly
- Support for authentication

Making Decisions

- Goals must be established
- Many options should be explored
- The consequences of the decision should be investigated
- Contingency plans should be made
- A decision table can be used

Example Decision Table



	Critical Goals			Other Goals		
	Adaptability—must adapt to changes in a large internetwork within seconds	Must scale to a large size (hundreds of routers)	Must be an industry standard and compatible with existing equipment	Should not create a lot of traffic	Should run on inexpensive routers	Should be easy to configure and manage
BGP	X*	X	X	8	7	7
OSPF	X	X	X	8	8	8
IS-IS	X	X	X	8	6	6
IGRP	X	X				
EIGRP	X	X				
RIP			X			

* X= Meets critical criteria. 1 = Lowest. 10 = Highest.

Transparent Bridging (Switching) Tasks

- Forward frames transparently
- Learn which port to use for each MAC address
- Flood frames when the destination unicast address hasn’t been learned yet
- Filter frames from going out ports that don’t include the destination address
- Flood broadcasts and multicasts

Switching Table on a Bridge or Switch

MAC Address	**Port**
08-00-07-06-41-B9	1
00-00-0C-60-7C-01	2
00-80-24-07-8C-02	3

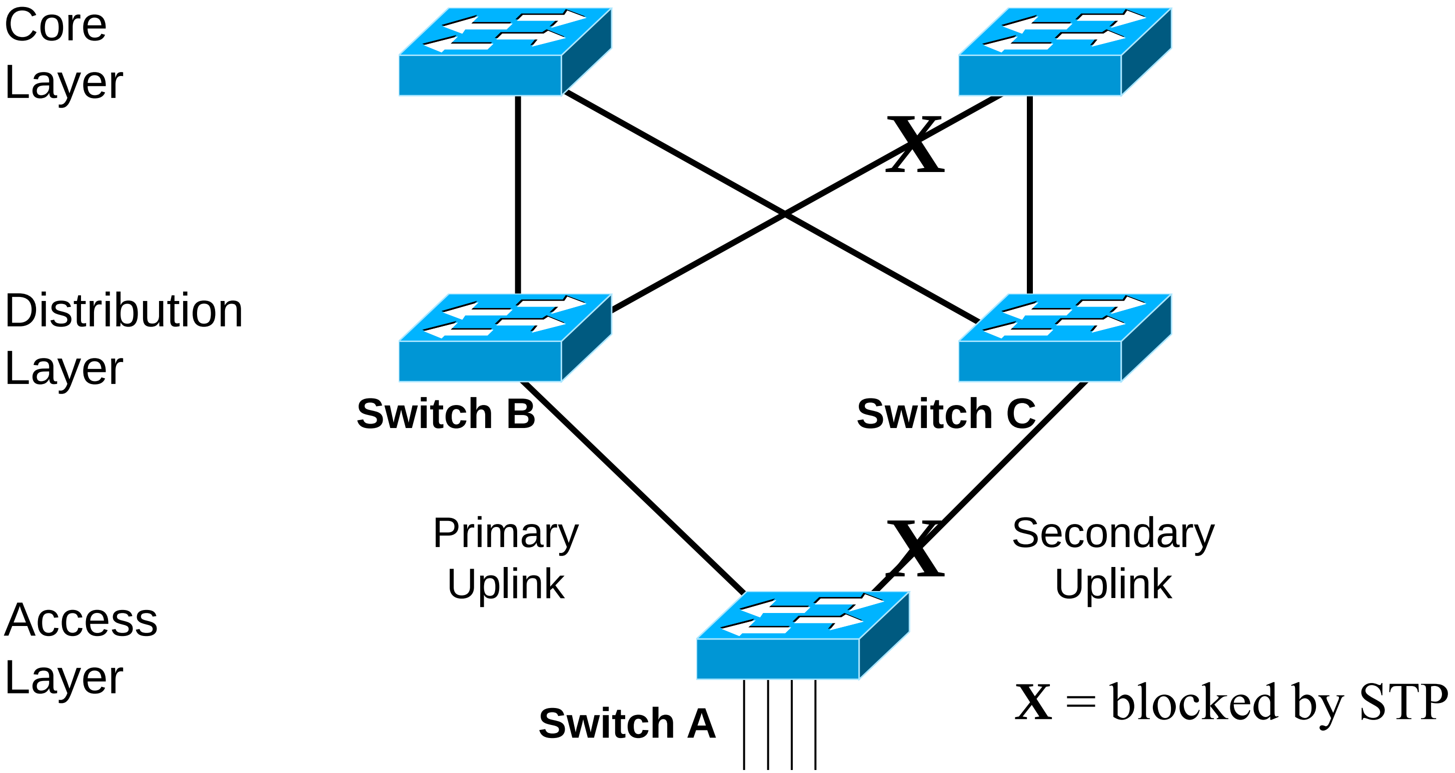
Cisco Multilayer Switching

- Route processor or router
- Switching engine
- The Multilayer Switching Protocol (MLSP)

Cisco Spanning Tree Protocol Enhancements

- PortFast
- UplinkFast and Backbone Fast
- Unidirectional link detection
- Loop Guard

Redundant Uplinks



- If a link fails, how long will STP take to recover?
- Use UplinkFast to speed convergence

Protocols for Transporting VLAN Information

- Inter-Switch Link (ISL)
  - Tagging protocol
  - Cisco proprietary
- IEEE 802.1Q
  - Tagging protocol
  - IEEE standard
- VLAN Trunk Protocol (VTP)
  - VLAN management protocol

Selecting Routing Protocols

- They all have the same general goal:
  - To share network reachability information among routers
- They differ in many ways:
  - Interior versus exterior
  - Metrics supported
  - Dynamic versus static and default
  - Distance-vector versus link-sate
  - Classful versus classless
  - Scalability

Interior Versus Exterior Routing Protocols

- Interior routing protocols are used within an autonomous system
- Exterior routing protocols are used between autonomous systems

Autonomous system (two definitions that are often used):

“A set of routers that presents a common routing policy to the internetwork”

“A network or set of networks that are under the administrative control of a single entity”

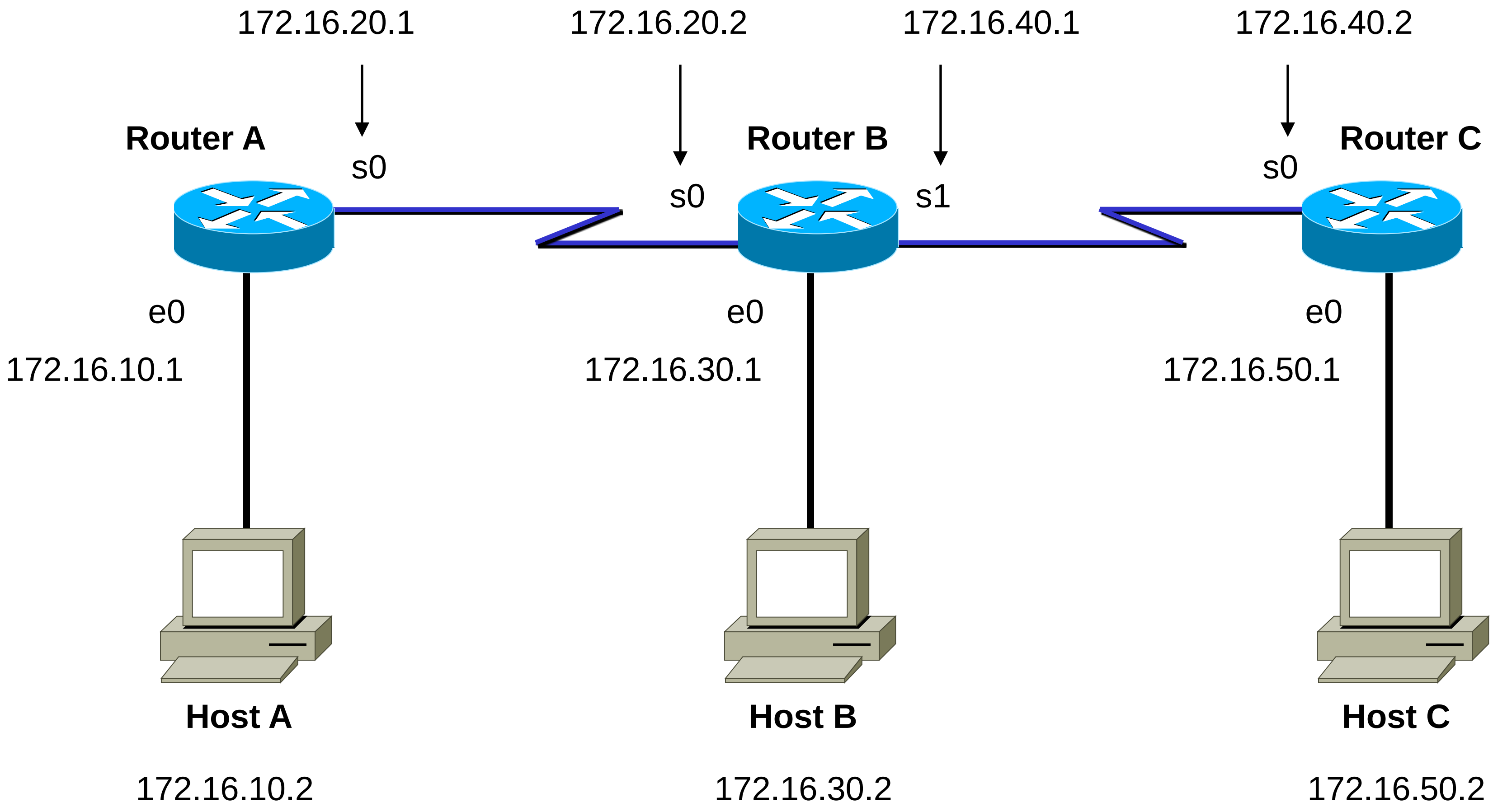
Routing Protocol Metrics

- Metric: the determining factor used by a routing algorithm to decide which route to a network is better than another
- Examples of metrics:
  - Bandwidth - capacity
  - Delay - time
  - Load - amount of network traffic
  - Reliability - error rate
  - Hop count - number of routers that a packet must travel through before reaching the destination network
  - Cost - arbitrary value defined by the protocol or administrator

Routing Algorithms

- Static routing
  - Calculated beforehand, offline
- Default routing
  - “If I don’t recognize the destination, just send the packet to Router X”
- Cisco’s On-Demand Routing
  - Routing for stub networks
  - Uses Cisco Discovery Protocol (CDP)
- Dynamic routing protocol
  - Distance-vector algorithms
  - Link-state algorithms

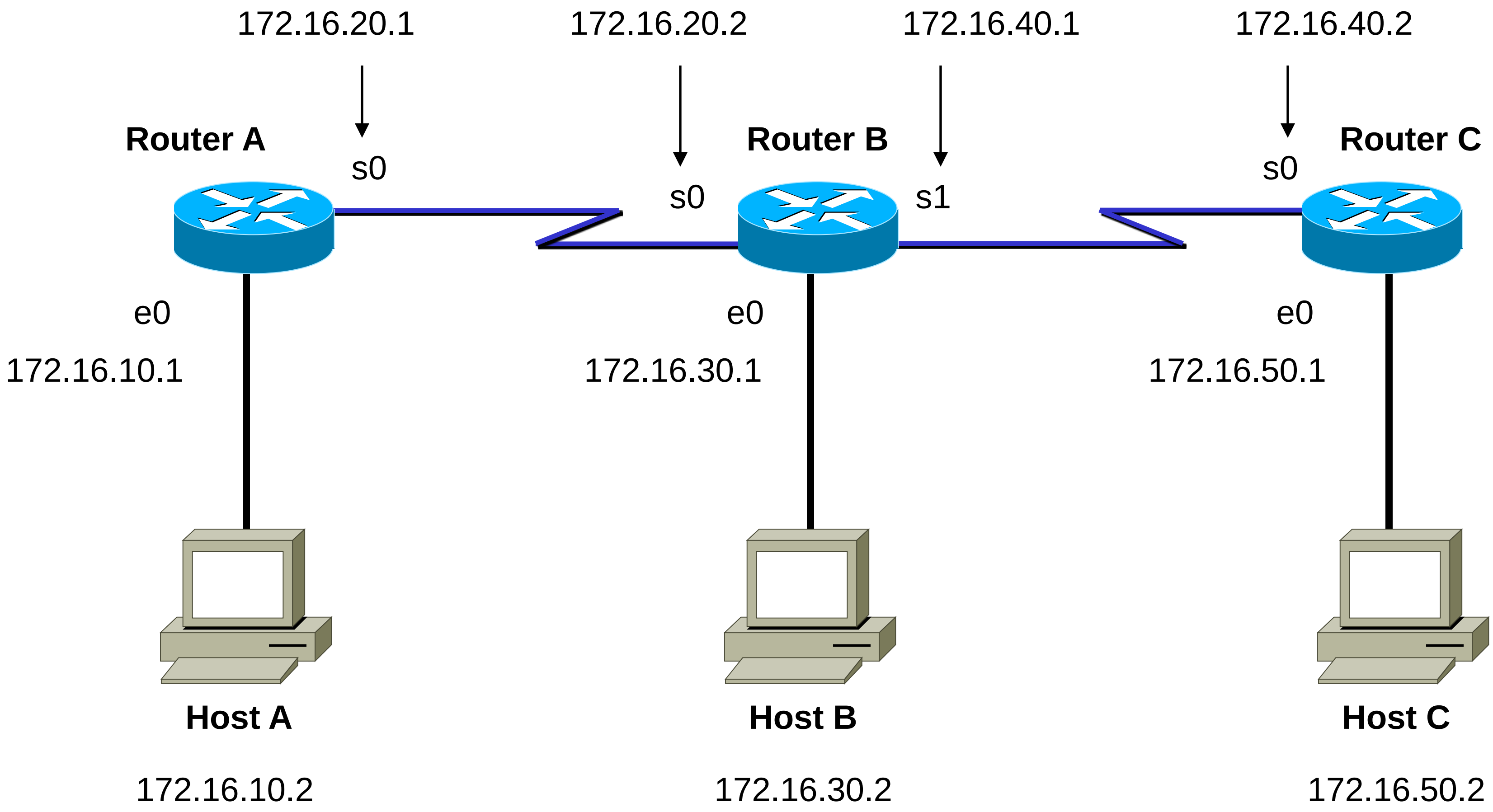
Static Routing Example



RouterA(config)#**ip route 172.16.50.0 255.255.255.0 172.16.20.2**

Send packets for subnet 50 to 172.16.20.2 (Router B)

Default Routing Example



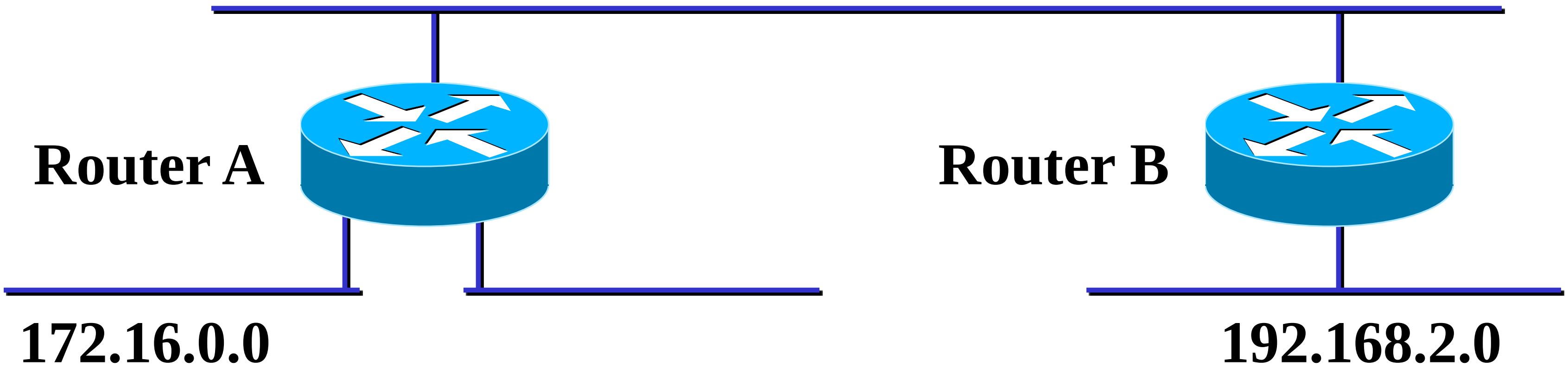
```
RouterA(config)#ip route 0.0.0.0  0.0.0.0  172.16.20.2
```

If it’s not local, send it to 172.16.20.2 (Router B)

Distance-Vector Routing

- Router maintains a routing table that lists known networks, direction (vector) to each network, and the distance to each network
- Router periodically (every 30 seconds, for example) transmits the routing table via a broadcast packet that reaches all other routers on the local segments
- Router updates the routing table, if necessary, based on received broadcasts

Distance-Vector Routing Tables



Router A's Routing Table

Network To	Distance	Send
172.16.0.0	0	Port 1
192.168.2.0	1	Router B

Router B's Routing Table

Network To	Distance	Send
192.168.2.0	0	Port 1
172.16.0.0	1	Router A

Link-State Routing

- Routers send updates only when there’s a change
- Router that detects change creates a link-state advertisement (LSA) and sends it to neighbors
- Neighbors propagate the change to their neighbors
- Routers update their topological database if necessary

Distance-Vector Vs. Link-State

- Distance-vector algorithms keep a list of networks, with next hop and distance (metric) information
- Link-state algorithms keep a database of routers and links between them
  - Link-state algorithms think of the internetwork as a graph instead of a list
  - When changes occur, link-state algorithms apply Dijkstra’s shortest-path algorithm to find the shortest path between any two nodes

Choosing Between Distance-Vector and Link-State

Choose Distance-Vector

- Simple, flat topology
- Hub-and-spoke topology
- Junior network administrators
- Convergence time not a big concern

Choose Link-State

- Hierarchical topology
- More senior network administrators
- Fast convergence is critical

Dynamic IP Routing Protocols

Distance-Vector

- Routing Information Protocol (RIP) Version 1 and 2
- Interior Gateway Routing Protocol (IGRP)
- Enhanced IGRP
- Border Gateway Protocol (BGP)

Link-State

- Open Shortest Path First (OSPF)
- Intermediate System-to-Intermediate System (IS-IS)

Routing Information Protocol (RIP)

- First standard routing protocol developed for TCP/IP environments
  - RIP Version 1 is documented in RFC 1058 (1988)
  - RIP Version 2 is documented in RFC 2453 (1998)
- Easy to configure and troubleshoot
- Broadcasts its routing table every 30 seconds; 25 routes per packet
- Uses a single routing metric (hop count) to measure the distance to a destination network; max hop count is 15

RIP V2 Features

- Includes the subnet mask with route updates
  - Supports prefix routing (classless routing, supernetting)
  - Supports variable-length subnet masking (VLSM)
- Includes simple authentication to foil crackers sending routing updates

IGRP Solved Problems with RIP

- 15-hop limitation in RIP
  - IGRP supports 255 hops
- Reliance on just one metric (hop count)
  - IGRP uses bandwidth, delay, reliability, load
  - (By default just uses bandwidth and delay)
- RIP's 30-second update timer
  - IGRP uses 90 seconds

EIGRP

- Adjusts to changes in internetwork very quickly
- Incremental updates contain only changes, not full routing table
- Updates are delivered reliably
- Router keeps track of neighbors’ routing tables and uses them as feasible successor
- Same metric as IGRP, but more granularity (32 bits instead of 24 bits)

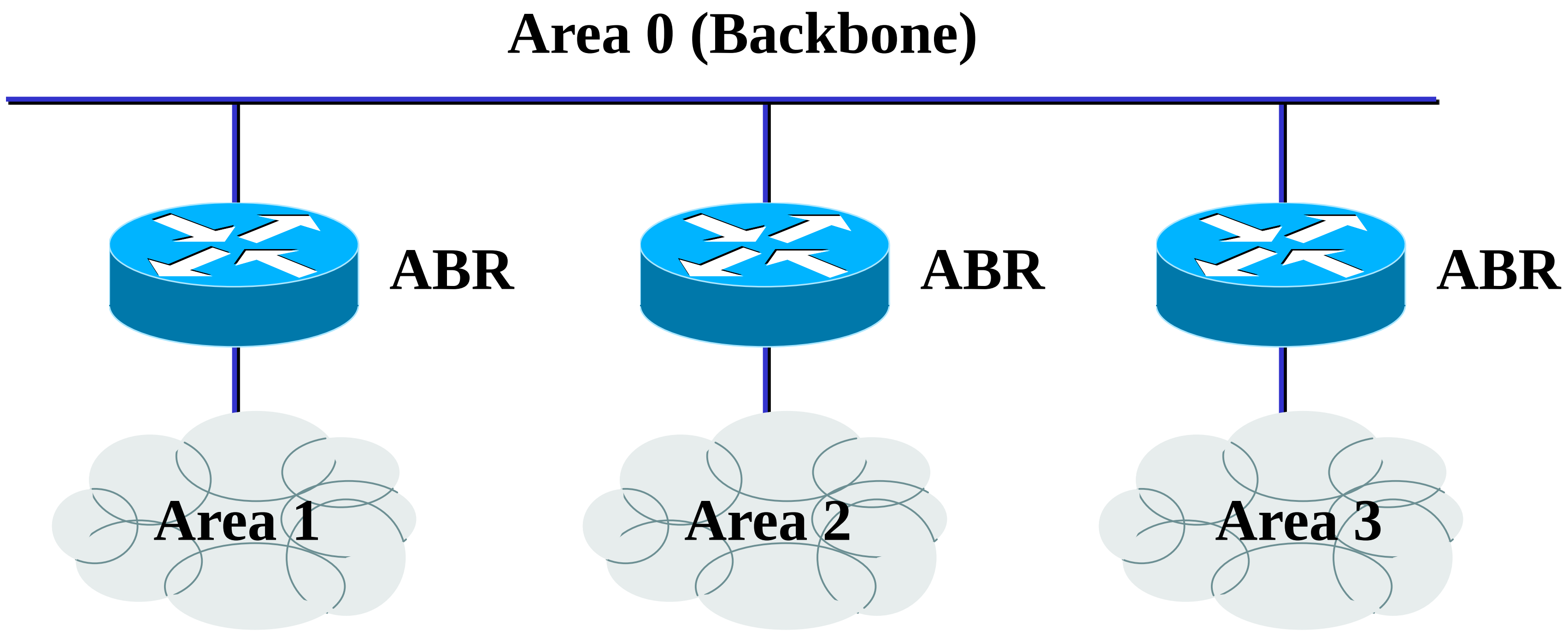
Open Shortest Path First (OSPF)

- Open standard, defined in RFC 2328
- Adjusts to changes quickly
- Supports very large internetworks
- Does not use a lot of bandwidth
- Authenticates protocol exchanges to meet security goals

OSPF Metric

- A single dimensionless value called *cost*. A network administrator assigns an OSPF cost to each router interface on the path to a network. The lower the cost, the more likely the interface is to be used to forward data traffic.
- On a Cisco router, the cost of an interface defaults to 100,000,000 divided by the bandwidth for the interface. For example, a 100-Mbps Ethernet interface has a cost of 1.

OSPF Areas Connected via Area Border Routers (ABRs)



IS-IS

- Intermediate System-to-Intermediate System
- Link-state routing protocol
- Designed by the ISO for the OSI protocols
- Integrated IS-IS handles IP also

Border Gateway Protocol (BGP)

- Allows routers in different autonomous systems to exchange routing information
  - Exterior routing protocol
  - Used on the Internet among large ISPs and major companies
- Supports route aggregation
- Main metric is the length of the list of autonomous system numbers, but BGP also supports routing based on policies

Summary

- The selection of switching and routing protocols should be based on an analysis of
  - Goals
  - Scalability and performance characteristics of the protocols
- Transparent bridging is used on modern switches
  - But other choices involve enhancements to STP and protocols for transporting VLAN information
- There are many types of routing protocols and many choices within each type

Review Questions

- What are some options for enhancing the Spanning Tree Protocol?
- What factors will help you decide whether distance-vector or link-state routing is best for your design customer?
- What factors will help you select a specific routing protocol?
- Why do static and default routing still play a role in many modern network designs?

Top-Down Network Design

Chapter Eight

Developing Network Security Strategies

Network Security Design
The 12 Step Program

1. Identify network assets
2. Analyze security risks
3. Analyze security requirements and tradeoffs
4. Develop a security plan
5. Define a security policy
6. Develop procedures for applying security policies

The 12 Step Program (continued)

7. Develop a technical implementation strategy
8. Achieve buy-in from users, managers, and technical staff
9. Train users, managers, and technical staff
10. Implement the technical strategy and security procedures
11. Test the security and update it if any problems are found
12. Maintain security

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

Security Tradeoffs

- Tradeoffs must be made between security goals and other goals:
  - Affordability
  - Usability
  - Performance
  - Availability
  - Manageability

A Security Plan

- High-level document that proposes what an organization is going to do to meet security requirements
- Specifies time, people, and other resources that will be required to develop a security policy and achieve implementation of the policy

A Security Policy

- Per RFC 2196, “The Site Security Handbook,” a security policy is a
  - “Formal statement of the rules by which people who are given access to an organization’s technology and information assets must abide.”
- The policy should address
  - Access, accountability, authentication, privacy, and computer technology purchasing guidelines

Security Mechanisms

- Physical security
- Authentication
- Authorization
- Accounting (Auditing)
- Data encryption
- Packet filters
- Firewalls
- Intrusion Detection Systems (IDSs)

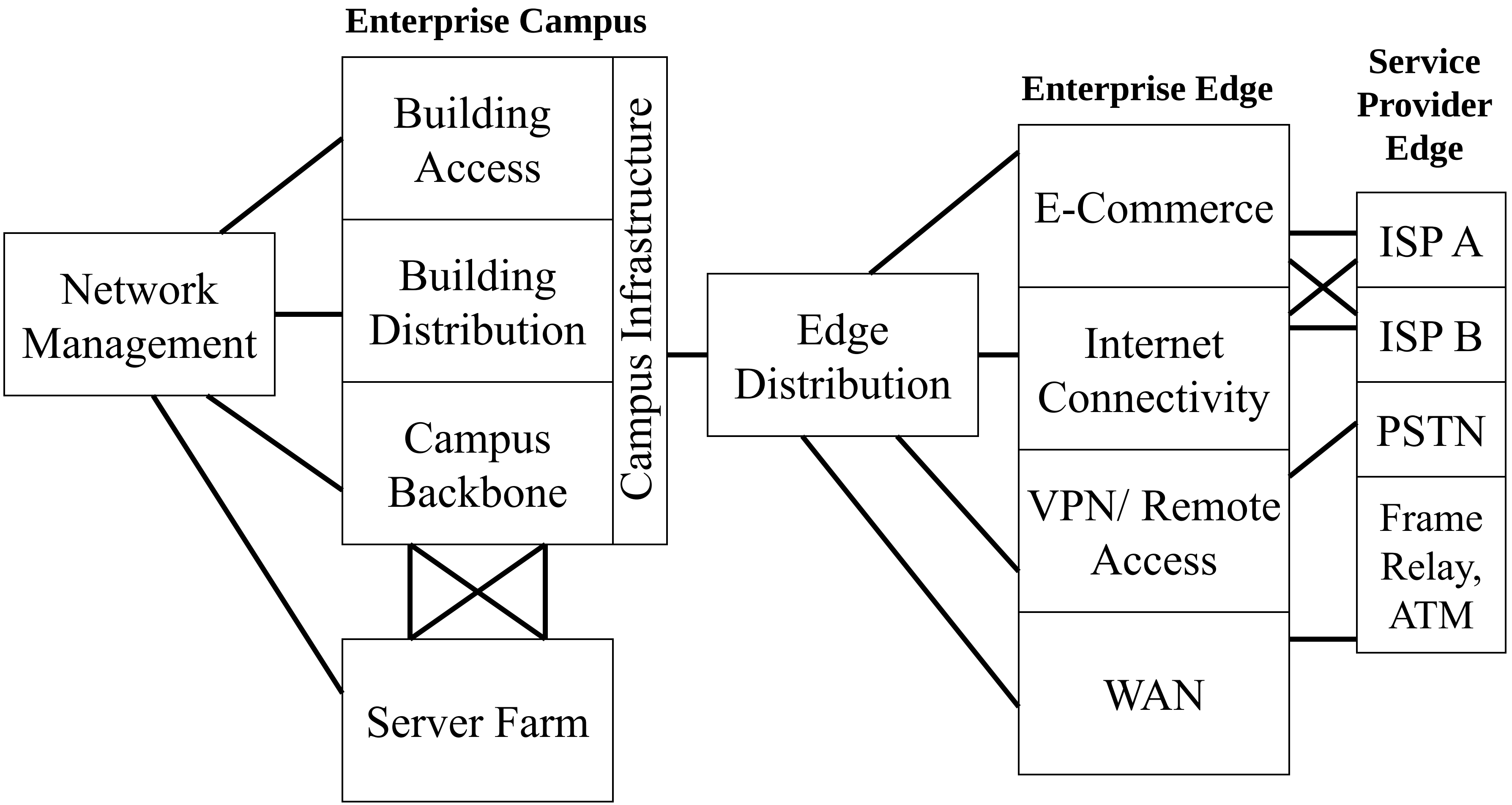
Modularizing Security Design

- Security defense in depth
  - Network security should be multilayered with many different techniques used to protect the network
- Belt-and-suspenders approach
  - Don’t get caught with your pants down

Modularizing Security Design

- Secure all components of a modular design:
  - Internet connections
  - Public servers and e-commerce servers
  - Remote access networks and VPNs
  - Network services and network management
  - Server farms
  - User services
  - Wireless networks

Cisco's Enterprise Composite Network Model



Cisco SAFE

- Cisco SAFE Blueprint addresses security in every module of a modular network architecture.

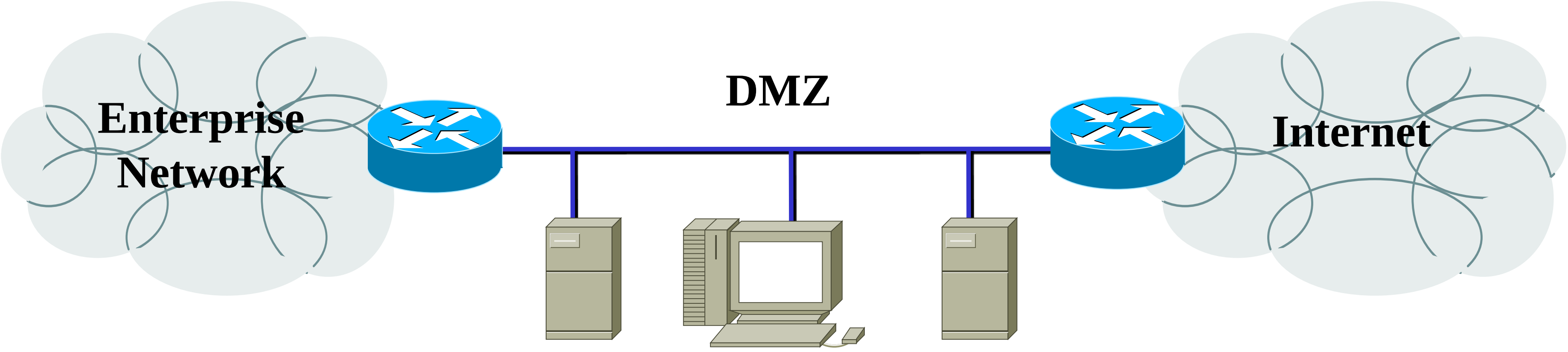
Securing Internet Connections

- Physical security
- Firewalls and packet filters
- Audit logs, authentication, authorization
- Well-defined exit and entry points
- Routing protocols that support authentication

Securing Public Servers

- Place servers in a DMZ that is protected via firewalls
- Run a firewall on the server itself
- Enable DoS protection
  - Limit the number of connections per timeframe
- Use reliable operating systems with the latest security patches
- Maintain modularity
  - Front-end Web server doesn’t also run other services

Security Topologies



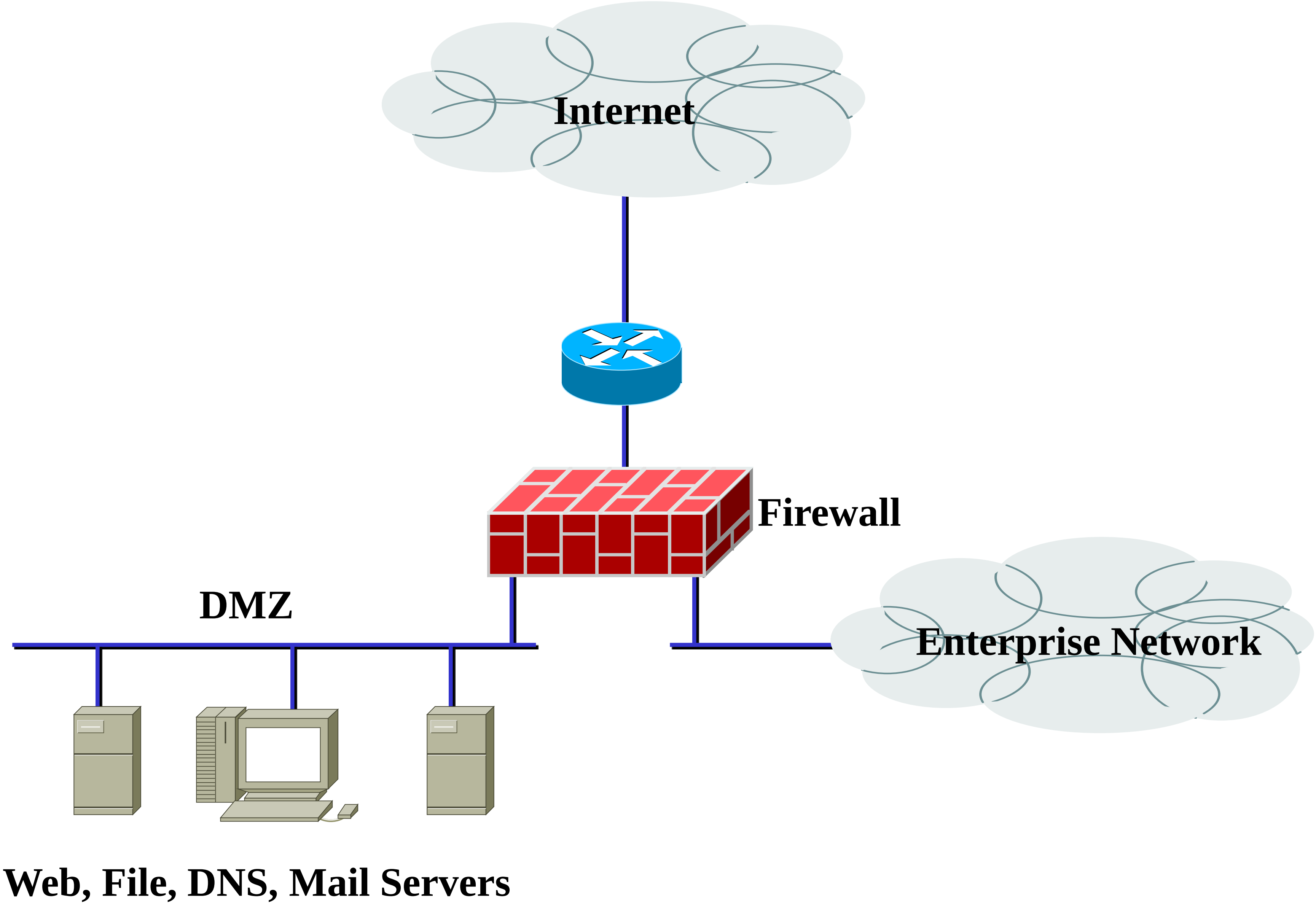
Enterprise Network

DMZ

Internet

Web, File, DNS, Mail Servers

Security Topologies



Securing Remote-Access and Virtual Private Networks

- Physical security
- Firewalls
- Authentication, authorization, and auditing
- Encryption
- One-time passwords
- Security protocols
  - CHAP
  - RADIUS
  - IPSec

Securing Network Services

- Treat each network device (routers, switches, and so on) as a high-value host and harden it against possible intrusions
- Require login IDs and passwords for accessing devices
  - Require extra authorization for risky configuration commands
- Use SSH rather than Telnet
- Change the welcome banner to be less welcoming

Securing Server Farms

- Deploy network and host IDSs to monitor server subnets and individual servers
- Configure filters that limit connectivity from the server in case the server is compromised
- Fix known security bugs in server operating systems
- Require authentication and authorization for server access and management
- Limit root password to a few people
- Avoid guest accounts

Securing User Services

- Specify which applications are allowed to run on networked PCs in the security policy
- Require personal firewalls and antivirus software on networked PCs
  - Implement written procedures that specify how the software is installed and kept current
- Encourage users to log out when leaving their desks
- Consider using 802.1X port-based security on switches

Securing Wireless Networks

- Place wireless LANs (WLANs) in their own subnet or VLAN
  - Simplifies addressing and makes it easier to configure packet filters
- Require all wireless (and wired) laptops to run personal firewall and antivirus software
- Disable beacons that broadcast the SSID, and require MAC address authentication
  - Except in cases where the WLAN is used by visitors

WLAN Security Options

- Wired Equivalent Privacy (WEP)
- IEEE 802.11i
- Wi-Fi Protected Access (WPA)
- IEEE 802.1X Extensible Authentication Protocol (EAP)
  - Lightweight EAP or LEAP (Cisco)
  - Protected EAP (PEAP)
- Virtual Private Networks (VPNs)
- Any other acronyms we can think of? :-)

Wired Equivalent Privacy (WEP)

- Defined by IEEE 802.11
- Users must possess the appropriate WEP key that is also configured on the access point
  - 64 or 128-bit key (or passphrase)
- WEP encrypts the data using the RC4 stream cipher method
- Infamous for being crackable

WEP Alternatives

- Vendor enhancements to WEP
- Temporal Key Integrity Protocol (TKIP)
  - Every frame has a new and unique WEP key
- Advanced Encryption Standard (AES)
- IEEE 802.11i
- Wi-Fi Protected Access (WPA) from the Wi-Fi Alliance
  - Realistic parts of IEEE 802.11i now!

Extensible Authentication Protocol (EAP)

- With 802.1X and EAP, devices take on one of three roles:
  - The supplicant resides on the wireless LAN client
  - The authenticator resides on the access point
  - An authentication server resides on a RADIUS server

EAP (Continued)

- An EAP supplicant on the client obtains credentials from the user, which could be a user ID and password
- The credentials are passed by the authenticator to the server and a session key is developed
- Periodically the client must reauthenticate to maintain network connectivity
- Reauthentication generates a new, dynamic WEP key

Cisco’s Lightweight EAP (LEAP)

- Standard EAP plus mutual authentication
  - The user and the access point must authenticate
- Used on Cisco and other vendors’ products

Other EAPs

- EAP-Transport Layer Security (EAP-TLS) was developed by Microsoft
  - Requires certificates for clients and servers.
- Protected EAP (PEAP) is supported by Cisco, Microsoft, and RSA Security
  - Uses a certificate for the client to authenticate the RADIUS server
  - The server uses a username and password to authenticate the client
- EAP-MD5 has no key management features or dynamic key generation
  - Uses challenge text like basic WEP authentication
  - Authentication is handled by RADIUS server

VPN Software on Wireless Clients

- Safest way to do wireless networking for corporations
- Wireless client requires VPN software
- Connects to VPN concentrator at HQ
- Creates a tunnel for sending all traffic
- VPN security provides:
  - User authentication
  - Strong encryption of data
  - Data integrity

Summary

- Use a top-down approach
  - Chapter 2 talks about identifying assets and risks and developing security requirements
  - Chapter 5 talks about logical design for security (secure topologies)
  - Chapter 8 talks about the security plan, policy, and procedures
  - Chapter 8 also covers security mechanisms and selecting the right mechanisms for the different components of a modular network design

Review Questions

- How does a security plan differ from a security policy?
- Why is it important to achieve buy-in from users, managers, and technical staff for the security policy?
- What are some methods for keeping hackers from viewing and changing router and switch configuration information?
- How can a network manager secure a wireless network?

Top-Down Network Design

Chapter Nine

Developing Network Management Strategies

Network Management

- Helps an organization achieve availability, performance, and security goals
- Helps an organization measure how well design goals are being met and adjust network parameters if they are not being met
- Facilitates scalability
  - Helps an organization analyze current network behavior, apply upgrades appropriately, and troubleshoot any problems with upgrades

Network Management Design

- Consider scalability, traffic patterns, data formats, cost/benefit tradeoffs
- Determine which resources should be monitored
- Determine metrics for measuring performance
- Determine which and how much data to collect

Proactive Network Management

- Plan to check the health of the network during normal operation, not just when there are problems
- Recognize potential problems as they develop
- Optimize performance
- Plan upgrades appropriately

Network Management Processes According to the ISO

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

Performance Management

- Monitor end-to-end performance
- Also monitor component performance (individual links and devices)
- Test reachability
- Measure response times
- Measure traffic flow and volume
- Record route changes

Fault Management

- Detect, isolate, diagnose, and correct problems
- Report status to end users and managers
- Track trends related to problems

Configuration Management

- Keep track of network devices and their configurations
- Maintain an inventory of network assets
- Log versions of operating systems and applications

Security Management

- Maintain and distribute user names and passwords
- Generate, distribute, and store encryption keys
- Analyze router, switch, and server configurations for compliance with security policies and procedures
- Collect, store, and examine security audit logs

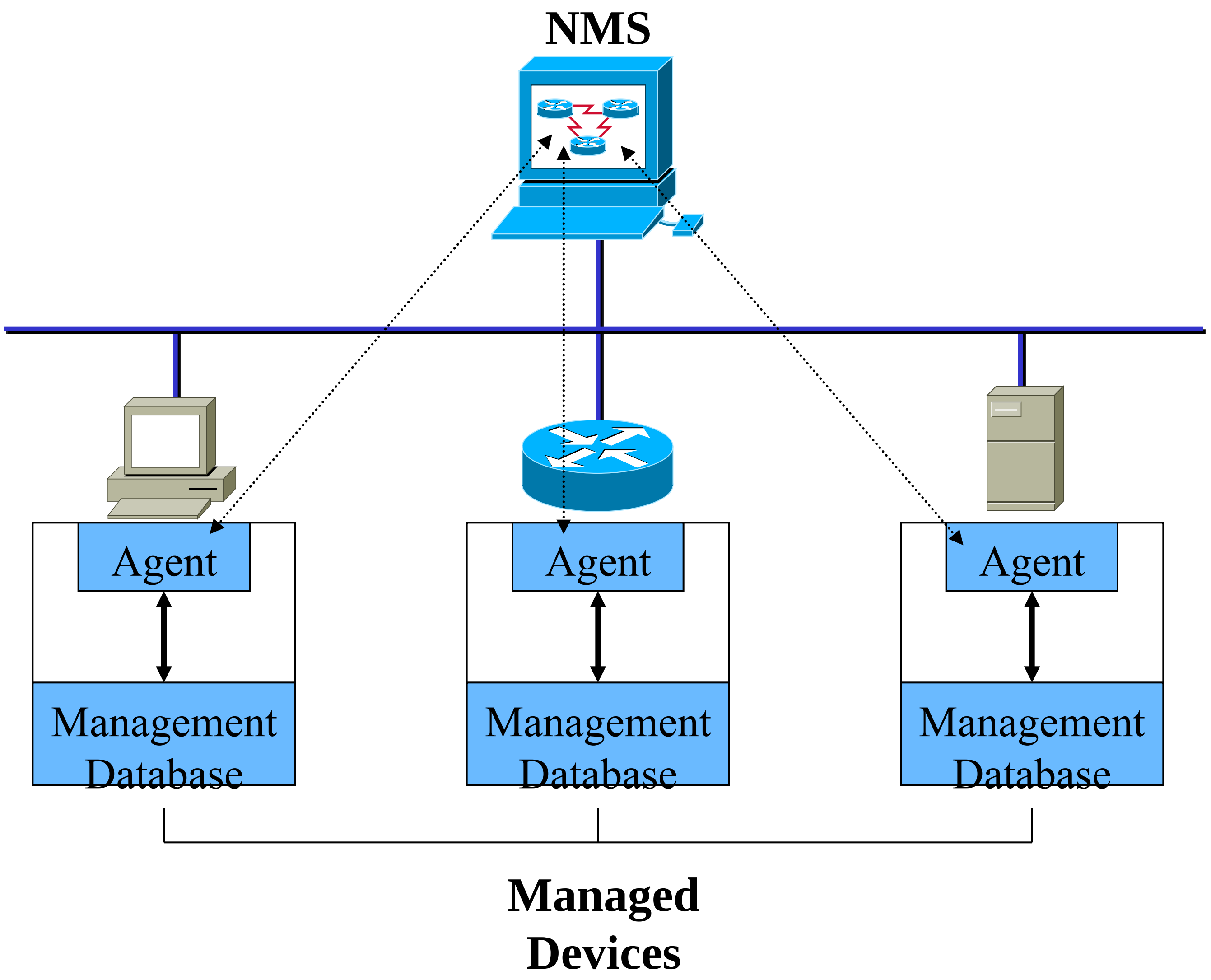
Accounting Management

- Keep track of network usage by departments or individuals
- Facilitate usage-based billing
- Find abusers who use more resources than they should

Network Management Components

- A **managed device** is a network node that collects and stores management information
- An **agent** is network-management software that resides in a managed device
- A **network-management system (NMS)** runs applications to display management data, monitor and control managed devices, and communicate with agents

Network Management Architecture



Architecture Concerns

- In-band versus out-of-band monitoring
  - In-band is easier to develop, but results in management data being impacted by network problems
- Centralized versus distributed monitoring
  - Centralized management is simpler to develop and maintain, but may require huge amounts of information to travel back to a centralized network operations center (NOC)

Simple Network Management Protocol (SNMP)

- Most popular network management protocol
- SNMPv3 should gradually supplant versions 1 and 2 because it offers better authentication
- SNMP works with Management Information Bases (MIBs)

Remote Monitoring (RMON)

- Developed by the IETF in the early 1990s to address shortcomings in standard MIBs
  - Provides information on data link and physical layer parameters
  - Nine groups of data for Ethernet
  - The statistics group tracks packets, octets, packet-size distribution, broadcasts, collisions, dropped packets, fragments, CRC and alignment errors, jabbers, and undersized and oversized packets

Cisco Tools

- Cisco Discovery Protocol
- NetFlow Accounting
- Service Assurance Agent (SAA)

Summary

- Determine which resources to monitor, which data about these resources to collect, and how to interpret that data
- Develop processes that address performance, fault, configuration, security, and accounting management
- Develop a network management architecture
- Select management protocols and tools

Review Questions

- Why is network management design important?
- Define the five types of network management processes according to the ISO.
- What are some advantages and disadvantages of using in-band network management versus out-of-band network management?
- What are some advantages and disadvantages of using centralized network management versus distributed network management?

Top-Down Network Design

Chapter Ten

Selecting Technologies and Devices for Campus Networks

Selecting Technologies and Devices

- We now know what the network will look like
- We also know what capabilities the network will need
- We are now ready to start picking out technologies and devices
- Chapter 10 has guidelines for campus networks

Campus Network Design Steps

- Develop a cabling plant design
- Select the types of cabling
- Select the data-link-layer technologies
- Select internetworking devices
  - Meet with vendors

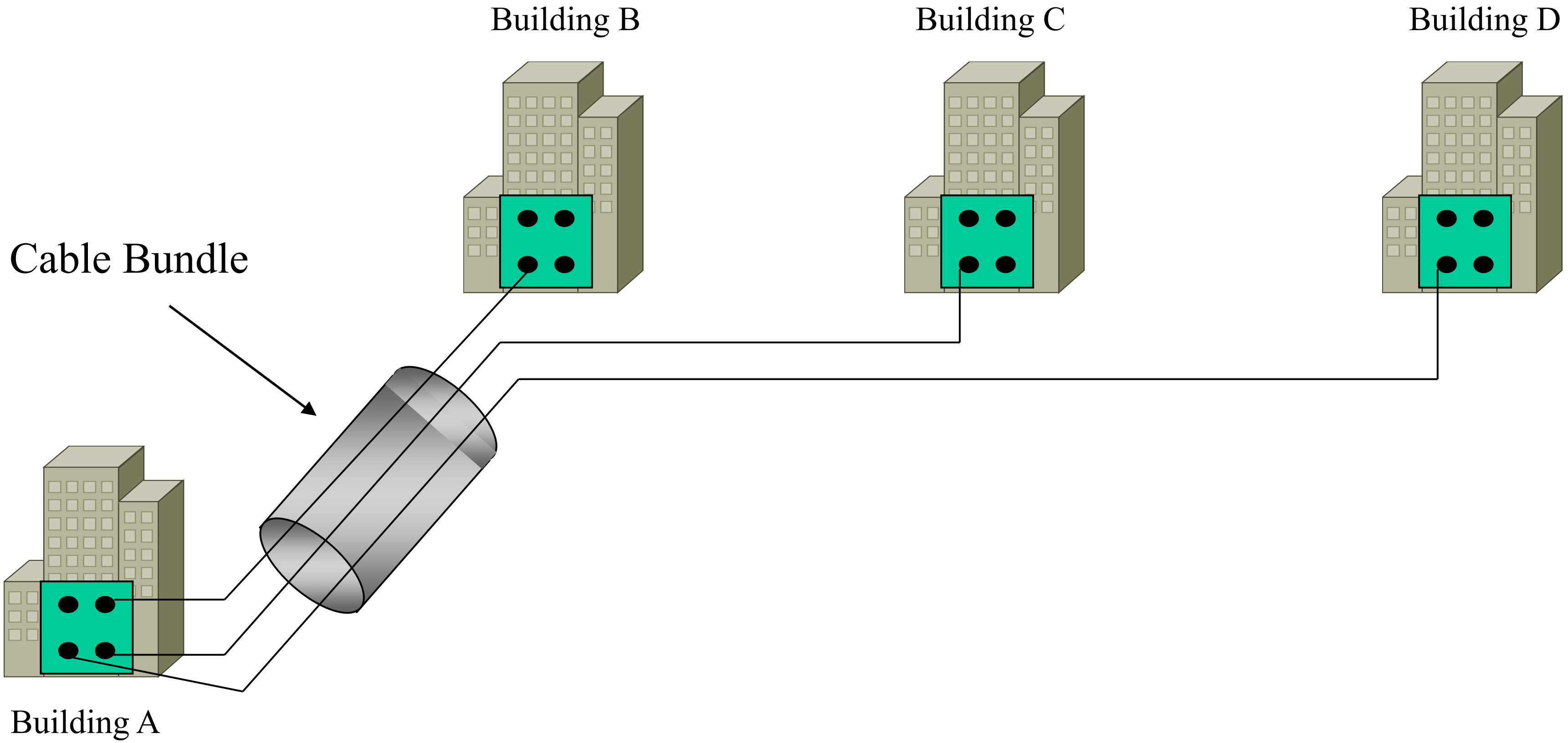
Cabling Plant Design Considerations

- Campus and building cabling topologies
- The types and lengths of cables between buildings
- Within buildings
  - The location of telecommunications closets and cross-connect rooms
  - The types and lengths of cables for vertical cabling between floors
  - The types and lengths of cables for horizontal cabling within floors
  - The types and lengths of cables for work-area cabling going from telecommunications closets to workstations

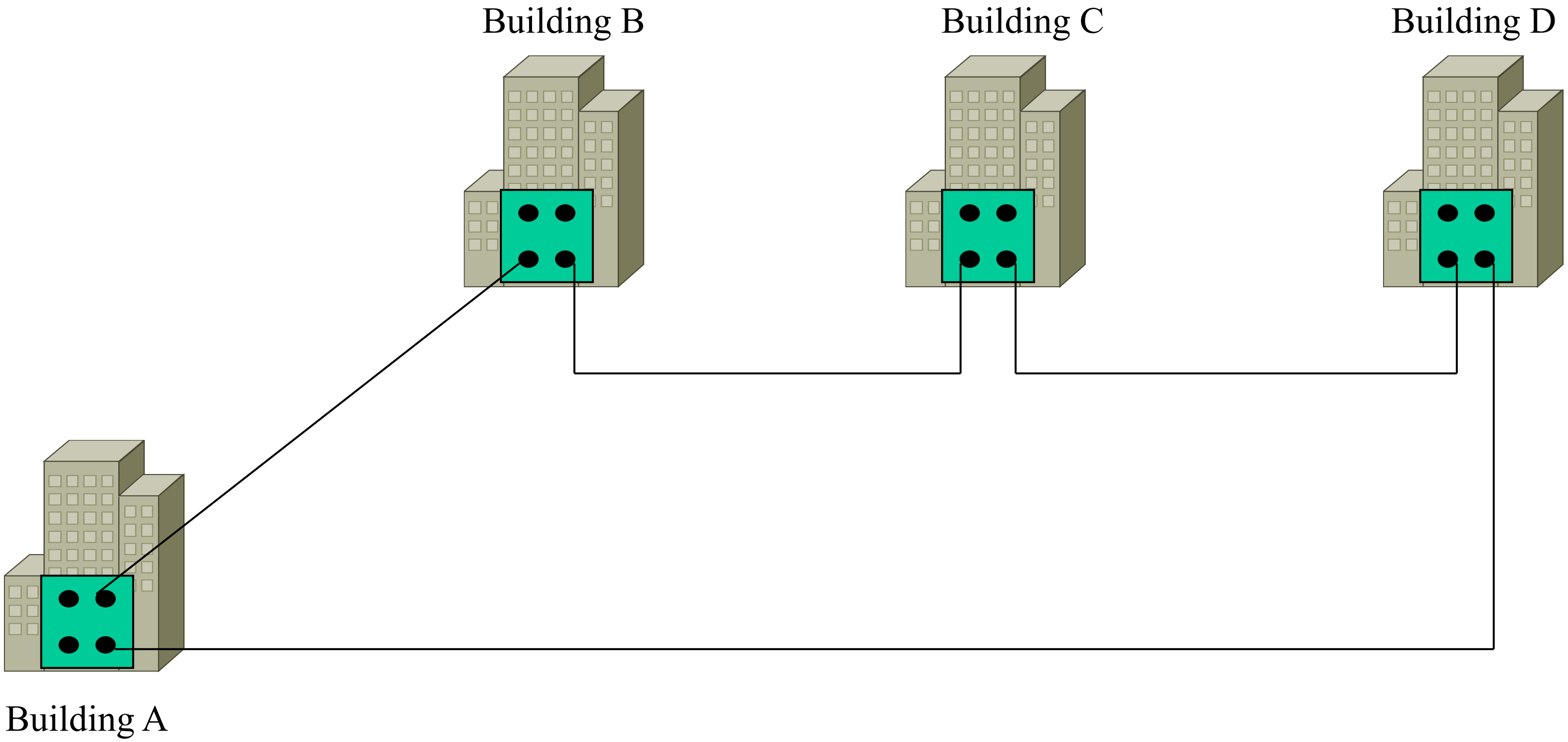
Centralized Versus Distributed Cabling Topologies

- A centralized cabling scheme terminates most or all of the cable runs in one area of the design environment. A star topology is an example of a centralized system.
- A distributed cabling scheme terminates cable runs throughout the design environment. Ring, bus, and tree topologies are examples of distributed systems.

Centralized Campus Cabling



Distributed Campus Cabling

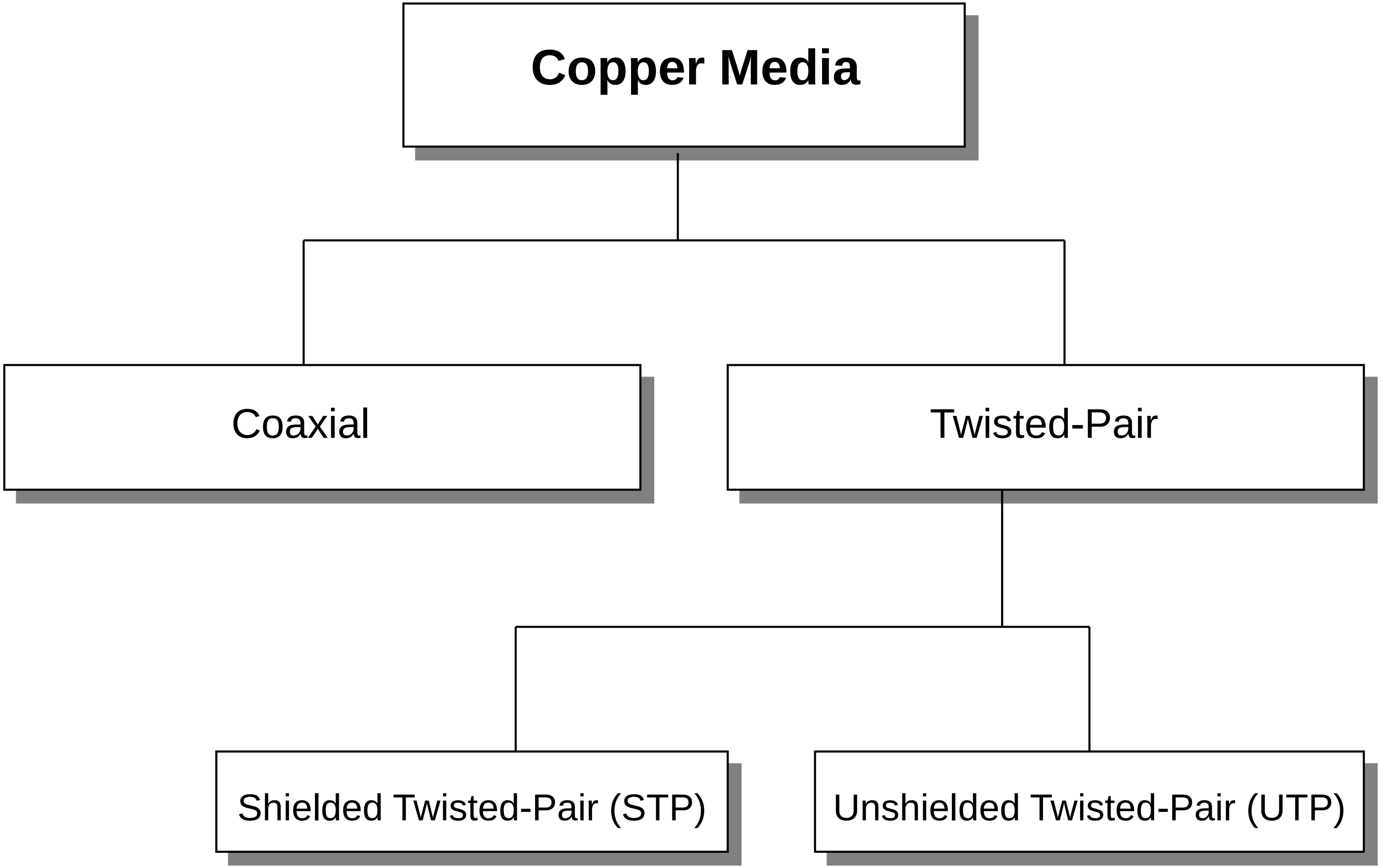


Types of Media Used in Campus Networks

- Copper media
- Optical media
- Wireless media

Copper Media Advantages

- Conducts electric current well
- Does not rust
- Can be drawn into thin wires
- Easy to shape
- Hard to break



Copper Media

Coaxial

Twisted-Pair

Shielded Twisted-Pair (STP)

Unshielded Twisted-Pair (UTP)

Coaxial Cable

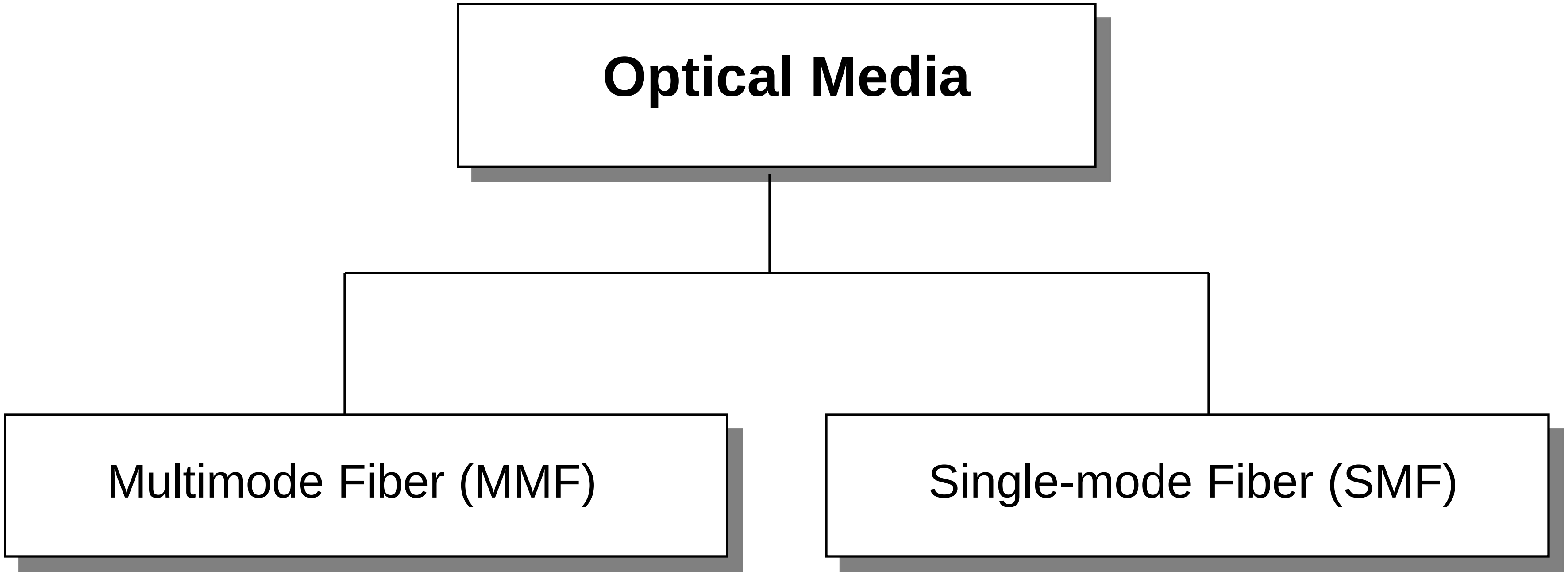
- Solid copper conductor, surrounded by:
  - Flexible plastic insulation
  - Braided copper shielding
  - Outer jacket
- Can be run without as many boosts from repeaters, for longer distances between network nodes, than either STP or UTP cable
  - Nonetheless, it’s no longer widely used

Twisted-Pair Cabling

- A “twisted pair” consists of two copper conductors twisted together
- Each conductor has plastic insulation
- Shielded Twisted Pair (STP)
  - Has metal foil or braided-mesh covering that encases each pair
- Unshielded Twisted Pair (UTP)
  - No metal foil or braided-mesh covering around pairs, so it’s less expensive

UTP Categories

- **Category 1.** Used for voice communication
- **Category 2.** Used for voice and data, up to 4 Mbps
- **Category 3.** Used for data, up to 10 Mbps
  - Required to have at least 3 twists per foot
  - Standard cable for most telephone systems
  - Also used in 10-Mbps Ethernet (10Base-T Ethernet)
- **Category 4.** Used for data, up to 16 Mbps
  - Must also have at least 3 twists per foot as well as other features
  - Used in Token Ring
- **Category 5.** Used for data, up to 100 Mbps
  - Must have 3 twists per *inch*!
- **Category 5e.** Used in Gigabit Ethernet
- **Category 6.** Used in Gigabit Ethernet and future technologies



Optical Media

Multimode Fiber (MMF)

Single-mode Fiber (SMF)

Copper Vs Fiber-Optic Cabling

- Twisted-pair and coax cable transmit network signals in the form of current
- Fiber-optic cable transmits network signals in the form of light
- Fiber-optic cable is made of glass
  - Not susceptible to electromagnetic or radio frequency interference
  - Not as susceptible to attenuation, which means longer cables are possible
  - Supports very high bandwidth (10 Gbps or greater)
  - For long distances, fiber costs less than copper

Multimode	Single-mode
• Larger core diameter	• Smaller core diameter
• Beams of light bounce off cladding in multiple ways	• Less bouncing around; single, focused beam of light
• Usually uses LED source	• Usually uses LASER source
• Less expensive	• More expensive
• Shorter distances	• Very long distances

Wireless Media

- IEEE 802.11a, b, and g
- Laser
- Microwave
- Cellular
- Satellite

Cabling Guidelines

- At the access layer use
  - Copper UTP rated for Category 5 or 5e, unless there is a good reason not to
  - To future proof the network
    - Use 5e instead of 5
    - Install UTP Category 6 rated cable and terminate the cable with Cat 5 or 5e connectors
    - Then only the connectors need to be changed to move up in speed
  - In special cases
    - Use MMF for bandwidth intensive applications
    - Or install fiber along with the copper

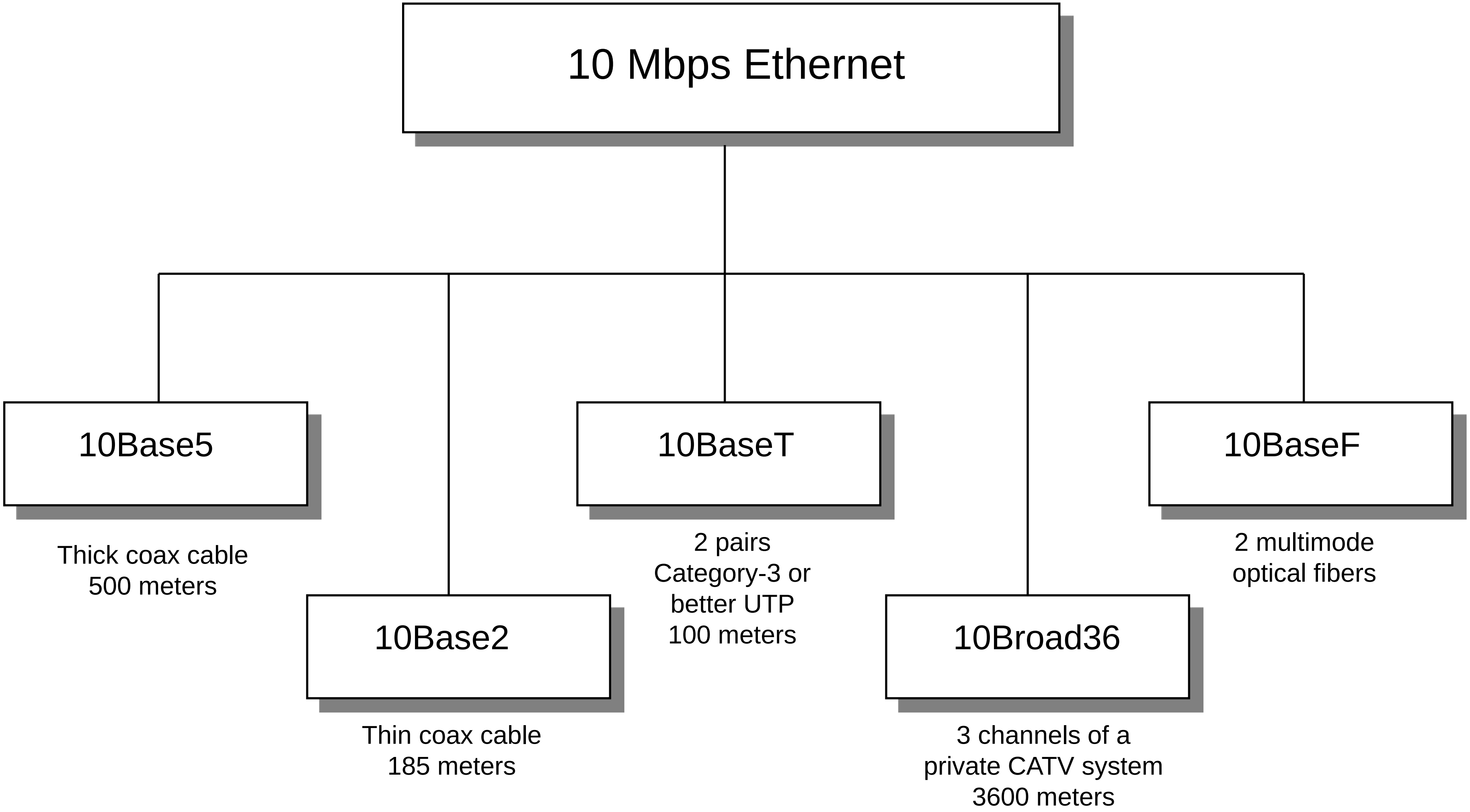
Cabling Guidelines

- At the distribution layer use
  - MMF if distance allows
  - SMF otherwise
  - Unless unusual circumstances occur and cable cannot be run, then use a wireless method
  - To future proof the network
    - Run both MMF and SMF

LAN Technologies

- Half-duplex Ethernet (becoming obsolete)
- Full-duplex Ethernet
- 10-Mbps Ethernet (becoming obsolete)
- 100-Mbps Ethernet
- 1000-Mbps (1-Gbps or Gigabit) Ethernet
- 10-Gbps Ethernet
- Metro Ethernet
- Long Range Ethernet (LRE)
- Cisco’s EtherChannel

IEEE 802.3 10-Mbps Ethernet



10 Mbps Ethernet

10Base5

Thick coax cable
500 meters

10Base2

Thin coax cable
185 meters

10BaseT

2 pairs
Category-3 or
better UTP
100 meters

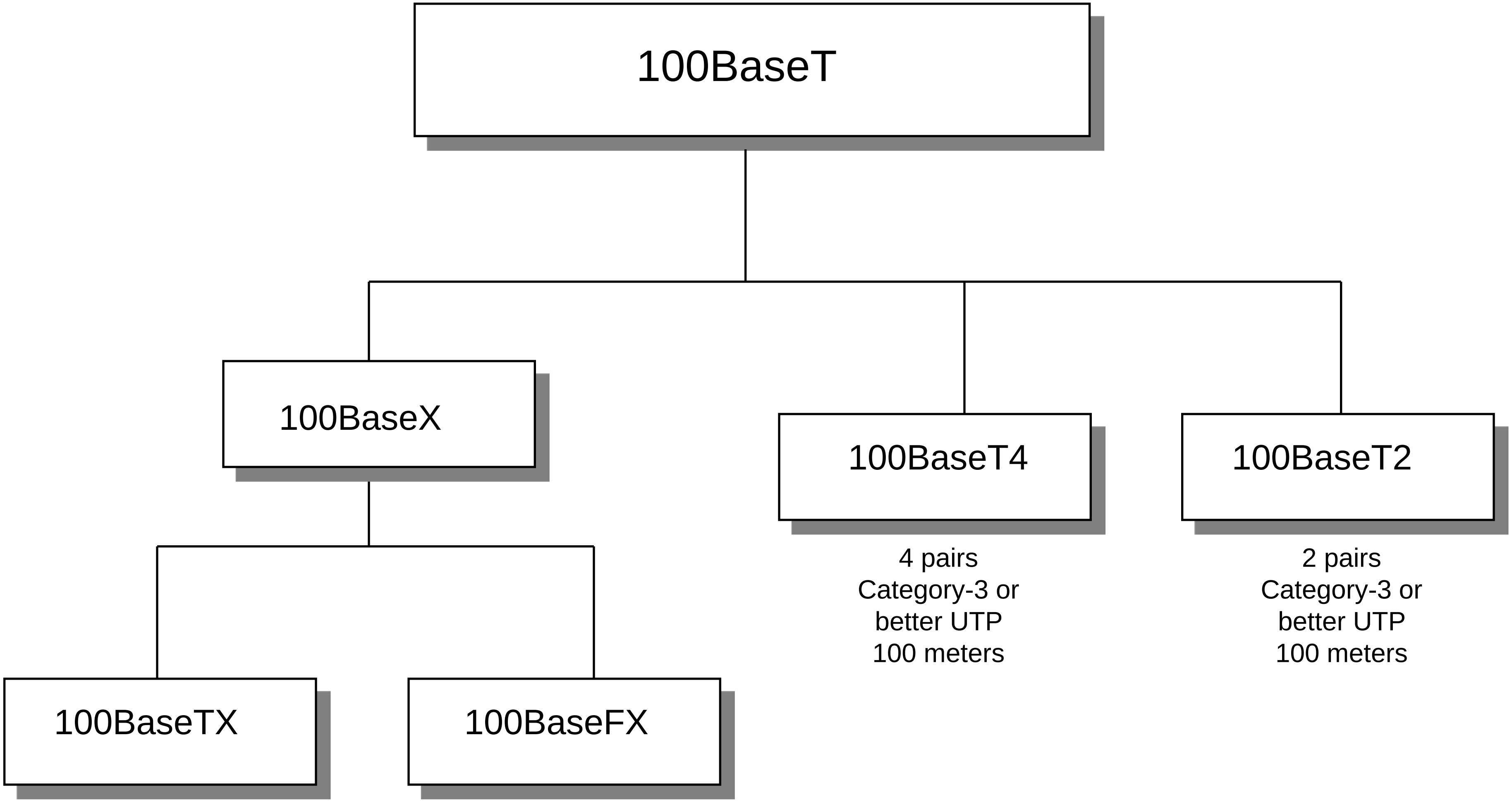
10Broad36

3 channels of a
private CATV system
3600 meters

10BaseF

2 multimode
optical fibers

IEEE 802.3 100-Mbps Ethernet



100BaseT

100BaseX

100BaseT4

4 pairs
Category-3 or
better UTP
100 meters

100BaseT2

2 pairs
Category-3 or
better UTP
100 meters

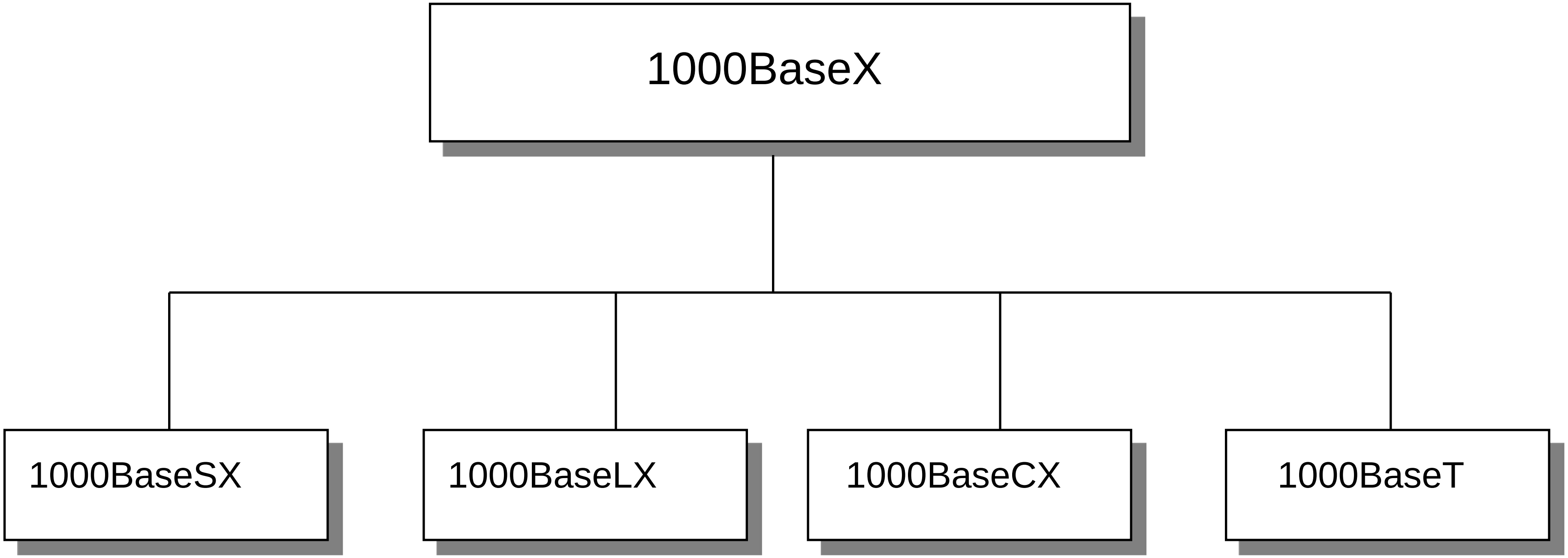
100BaseTX

2 pairs Category-5 or
better UTP
100 meters

100BaseFX

2 multimode optical fibers
2000 meters (full duplex)

IEEE 802.3 Gigabit Ethernet



1000BaseX

1000BaseSX

2 multimode optical fibers
using shortwave laser optics
550 meters

1000BaseLX

2 multimode or single-mode
optical fibers using longwave
laser optics
550 meters multimode, 5000
meters single-mode

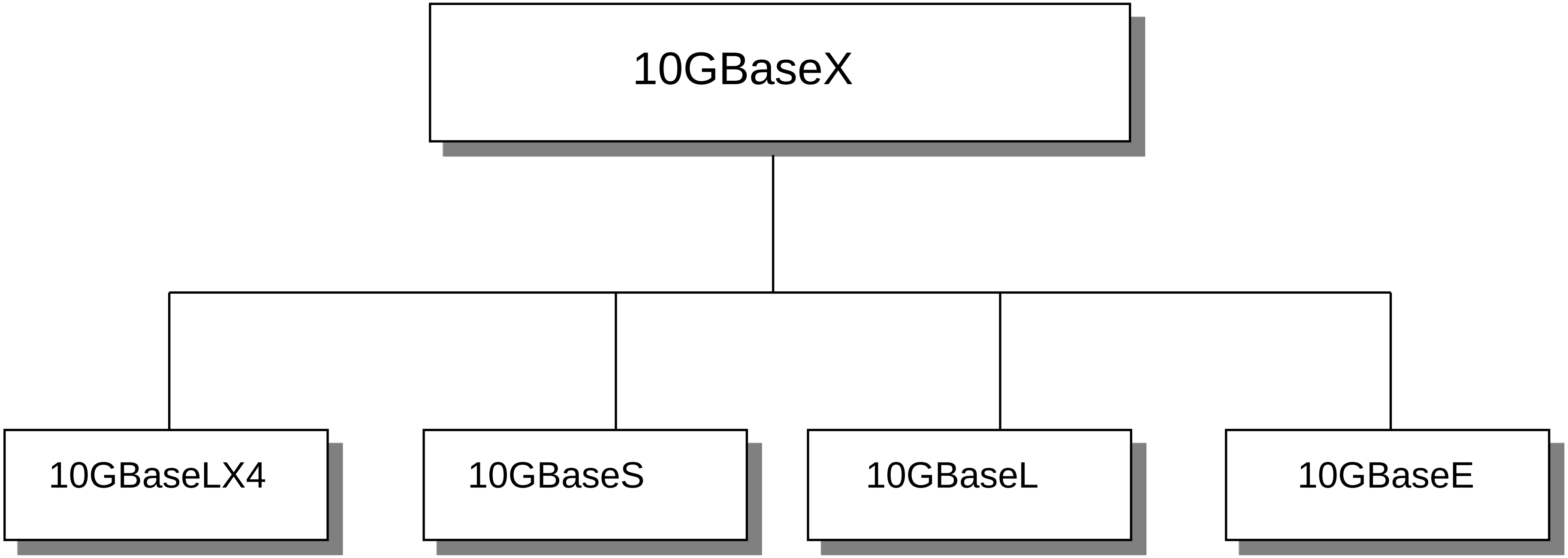
1000BaseCX

2 pairs STP
25 meters

1000BaseT

4 pairs Category-5 UTP
100 meters

IEEE 802.3 10-Gbps Ethernet



10GBaseX

10GBaseLX4

Multimode or single-mode
optical fibers
300 meters multimode,
10 km single-mode

10GBaseS

Multimode optical
fibers
300 meters

10GBaseL

Single-mode
optical fibers
10 km

10GBaseE

Single-mode
optical fibers
40 km

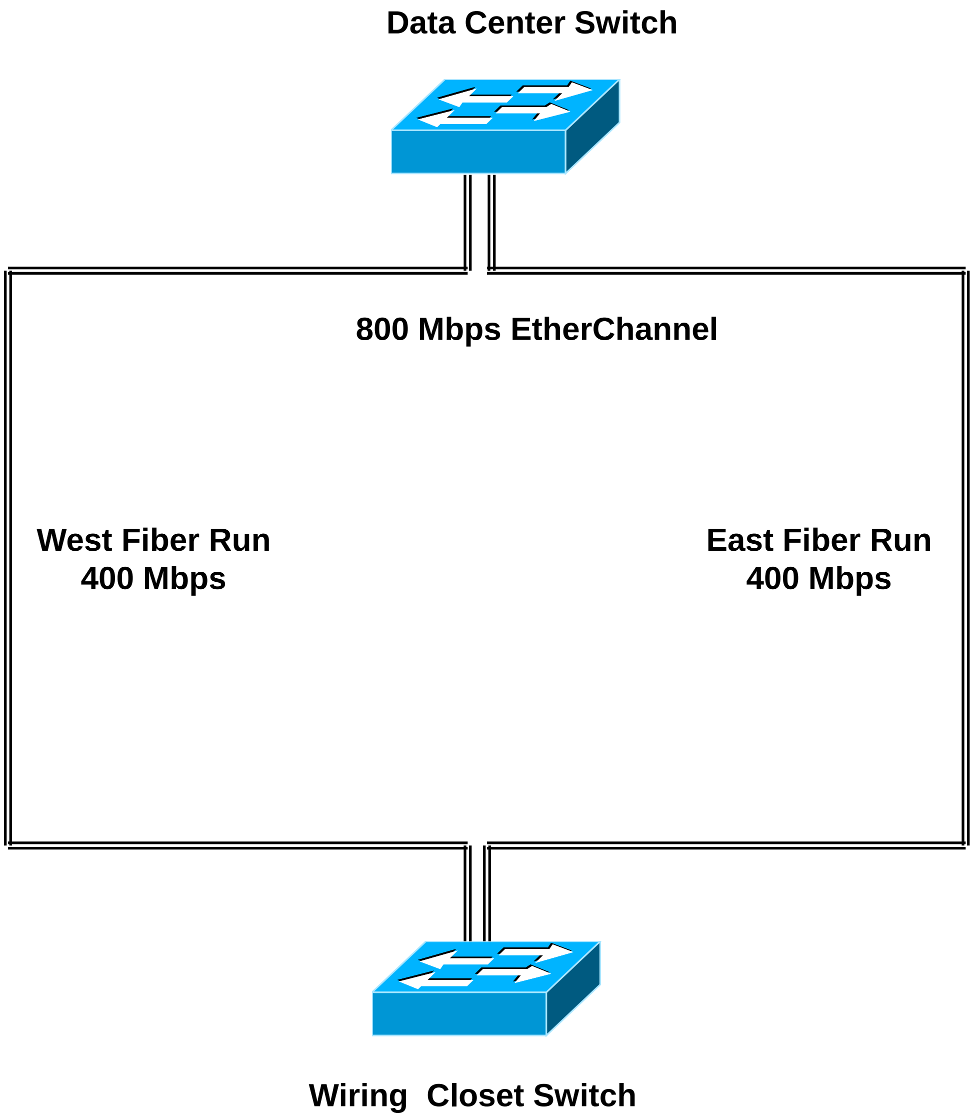
Metro Ethernet

- Service offered by providers and carriers that traditionally had only classic WAN offerings
- The customer can use a standard Ethernet interface to reach a MAN or WAN
- The customer can add bandwidth as needed with a simple configuration change

Long-Reach Ethernet

- Enables the use of Ethernet over existing, unconditioned, voice-grade copper twisted-pair cabling
- Used to connect buildings and rooms within buildings
  - Rural areas
  - Old cities where upgrading cabling is impractical
  - Multi-unit structures such as hotels, apartment complexes, business complexes, and government agencies

Cisco's EtherChannel



Data Center Switch

800 Mbps EtherChannel

West Fiber Run
400 Mbps

East Fiber Run
400 Mbps

Wiring Closet Switch

Internetworking Devices for Campus Networks

- Hubs (becoming obsolete)
- Switches
- Routers
- Wireless access points
- Wireless bridges

Selection Criteria for Internetworking Devices

- The number of ports
- Processing speed
- The amount of memory
- Latency when device relays data
- Throughput when device relays data
- LAN and WAN technologies supported
- Media supported

More Selection Criteria for Internetworking Devices

- Cost
- Ease of configuration and management
- MTBF and MTTR
- Support for hot-swappable components
- Support for redundant power supplies
- Quality of technical support, documentation, and training
- Etc.

Summary

- Once the logical design is completed, the physical design can start
- A major task during physical design is selecting technologies and devices for campus networks
  - Media
  - Data-link layer technology
  - Internetworking devices
- Also, at this point, the logical topology design can be developed further by specifying cabling topologies

Review Questions

- What are three fundamental media types used in campus networks?
- What selection criteria can you use to select an Ethernet variety for your design customer?
- What selection criteria can you use when purchasing internetworking devices for your design customer?
- Some people think Metro Ethernet will replace traditional WANs. Do you agree or disagree and why?

Top-Down Network Design

Chapter Eleven

Selecting Technologies and Devices for Enterprise Networks

Enterprise Technologies and Devices

- Remote access networks
- Wide area networks (WANs)
- Devices
  - End user remote access devices
  - Central site remote access devices
  - VPN concentrators
  - Routers

Selection Criteria

- Business requirements and constraints
- Cost
- Technical goals
- Bandwidth requirements
- QoS requirements
- Network topology
- Traffic flow and load
- Etc.

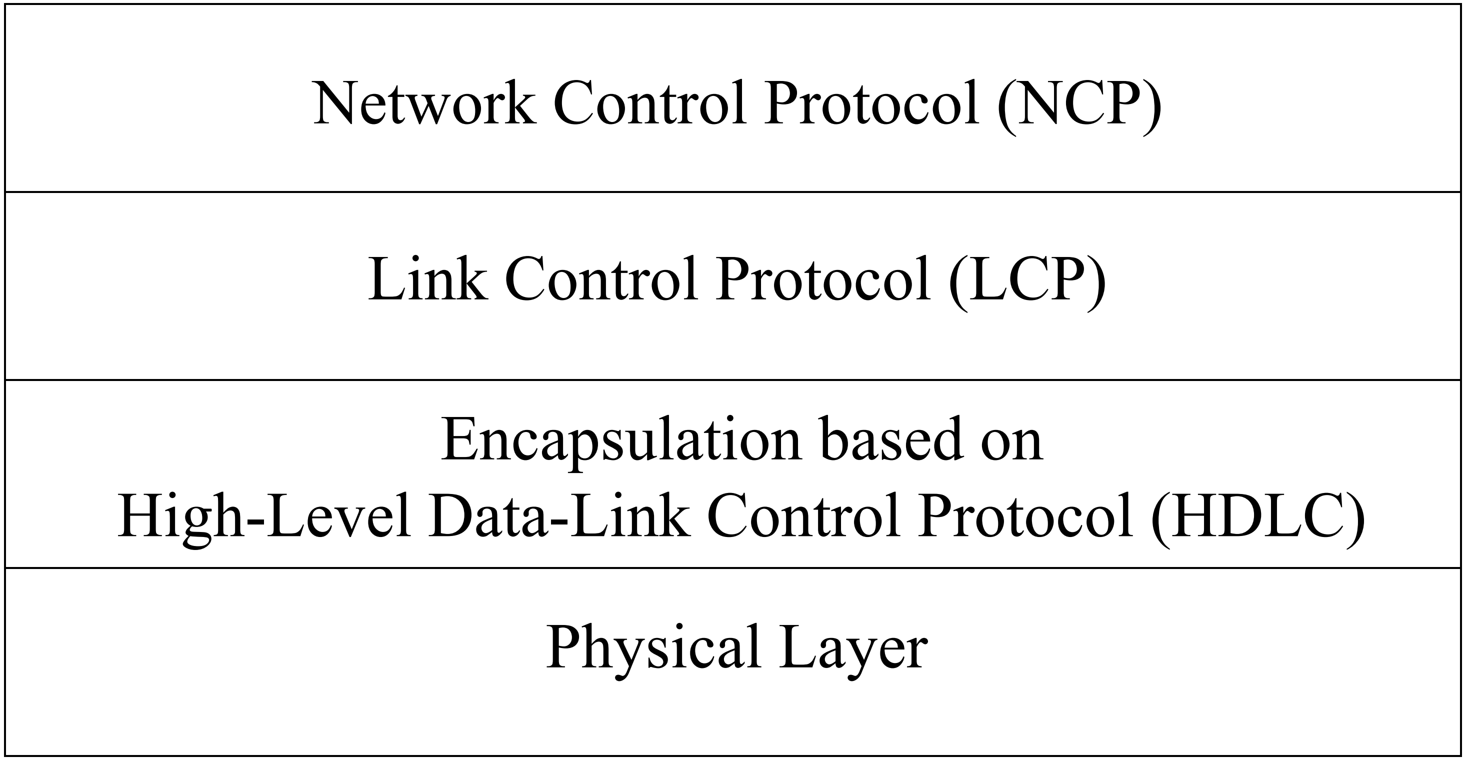
Remote Access Technologies

- The Point-to-Point Protocol (PPP)
- Integrated Services Digital Network (ISDN)
- Cable modems
- Digital Subscriber Line (DSL)

Point-to-Point Protocol (PPP)

- Used with synchronous, asynchronous, dial-up, and ISDN links
- Defines encapsulation scheme for transport of different network-layer protocols
- Supports authentication:
  - Password Authentication Protocol (PAP)
  - Challenge Handshake Authentication Protocol (CHAP)
    - CHAP more secure than PAP

PPP Layers



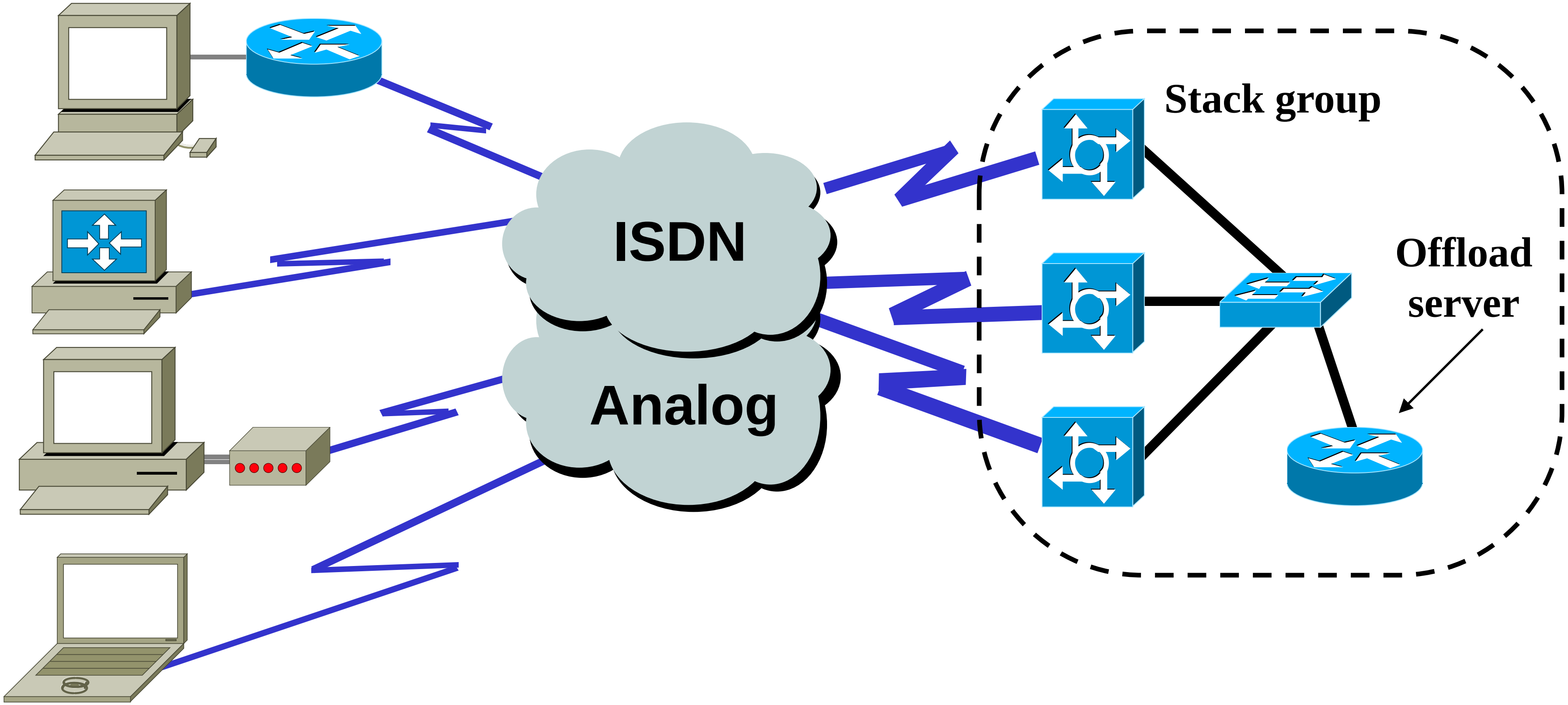
Network Control Protocol (NCP)

Link Control Protocol (LCP)

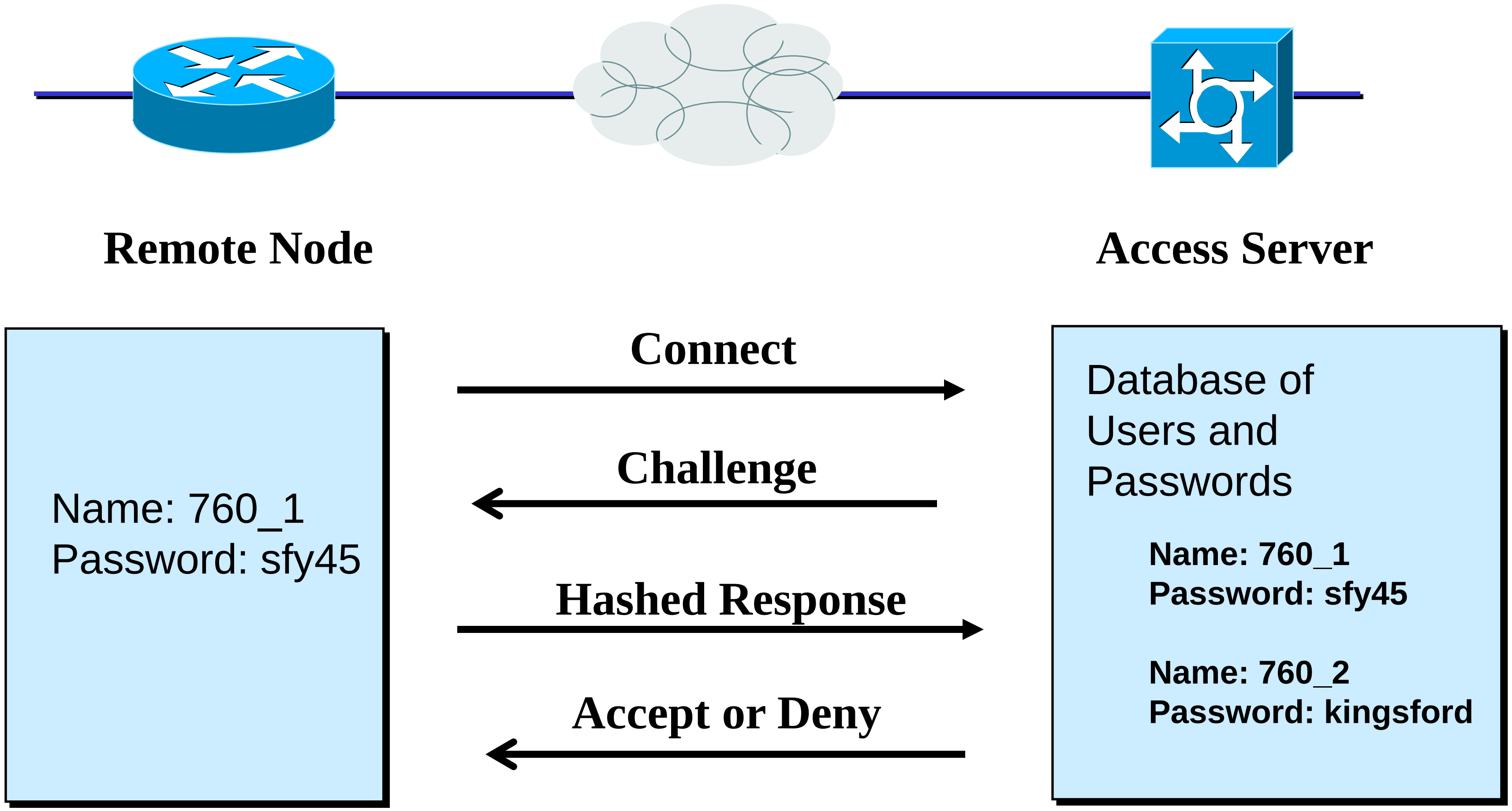
Encapsulation based on
High-Level Data-Link Control Protocol (HDLC)

Physical Layer

Multichassis Multilink PPP



CHAP



Remote Node

Access Server

Name: 760_1
Password: sfy45

Connect

Challenge

Hashed Response

Accept or Deny

Database of
Users and
Passwords

Name: 760_1
Password: sfy45

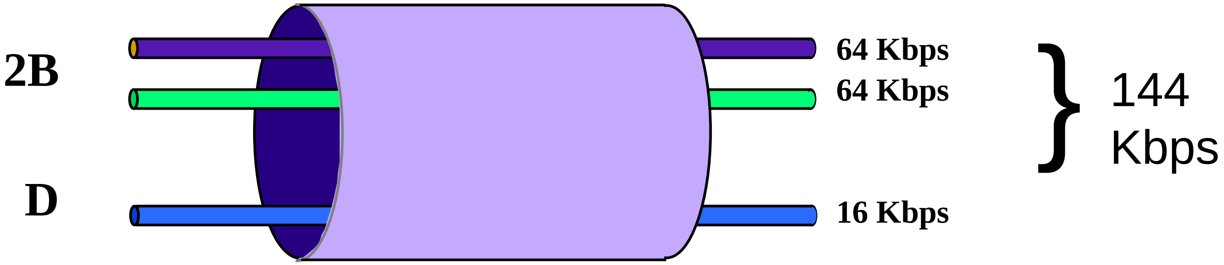
Name: 760_2
Password: kingsford

ISDN

- Digital data-transport service offered by regional telephone carriers (telcos)
- Circuit-switched service that carries voice and data
- Cost-effective remote-access solution for telecommuters and remote offices
  - Cost of an ISDN circuit is usually based on a monthly fee plus usage time
- Good choice as a backup link for another type of link, for example, Frame Relay

ISDN Interfaces

Basic Rate Interface (BRI)



2B

D

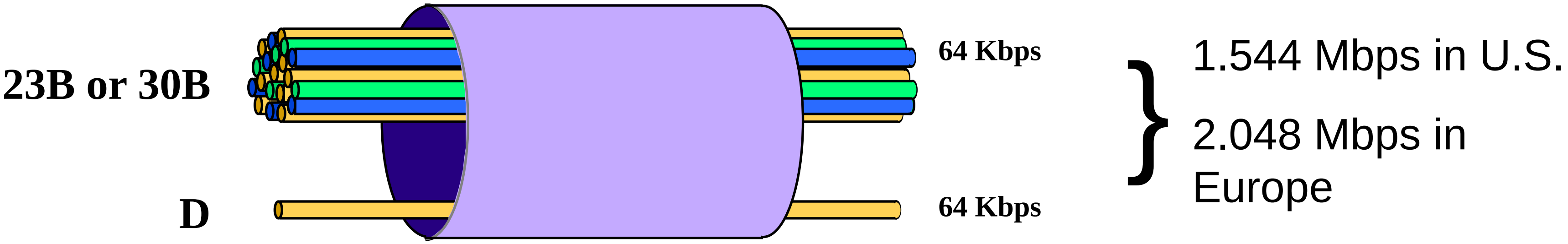
64 Kbps

64 Kbps

16 Kbps

} 144 Kbps

Primary Rate Interface (PRI)



23B or 30B

D

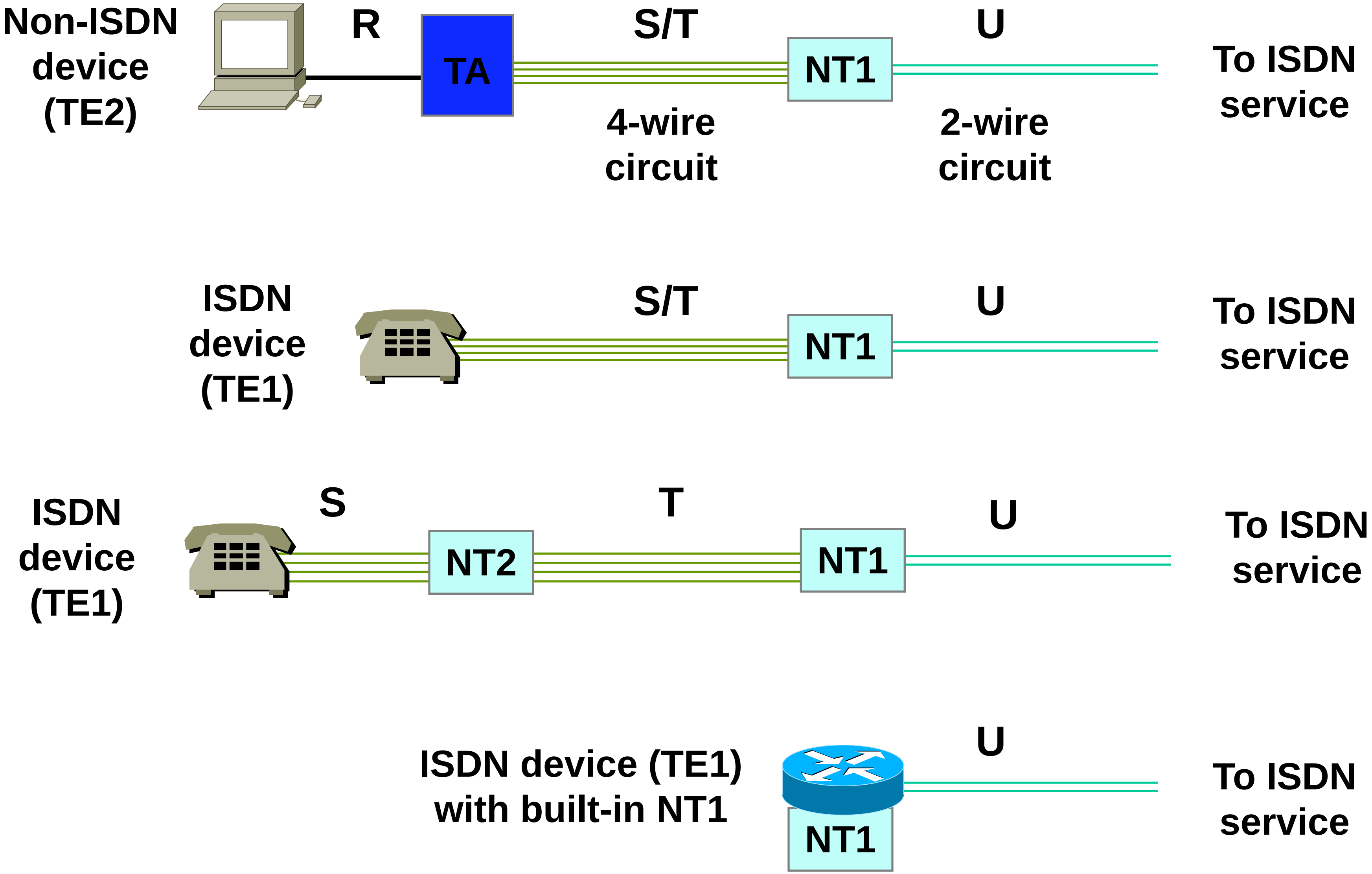
64 Kbps

64 Kbps

} 1.544 Mbps in U.S.

2.048 Mbps in Europe

ISDN Components



Cable Modem Service

- Operates over the coax cable used by cable TV
- Much faster than analog modems, and usually much faster than ISDN (depending on how many users share the cable)
  - 25 to 50 Mbps downstream from the head end
  - 2 to 3 Mbps upstream from end users
- Standard = Data Over Cable Service Interface Specification (DOCSIS)

DSL

- High-speed digital data traffic over ordinary telephone wires
- Sophisticated modulation schemes mean higher speeds than ISDN
  - Speeds range from 1.544 to 9 Mbps
- Actual bandwidth depends on type of DSL service, DSL modem, and many physical-layer factors
- Asymmetric DSL (ADSL) very popular
  - Downstream faster than upstream

WAN Technologies

- Leased lines
- Synchronous Optical Network (SONET)
- Frame Relay
- Asynchronous Transfer Mode (ATM)

Leased Lines

- Dedicated digital, copper circuits that a customer leases from a carrier for a predetermined amount of time, usually for months or years
- Speeds range from 64 Kbps to 45 Mbps
- Enterprises use leased lines for both voice and data traffic

The North American Digital Hierarchy

Signal	**Capacity**	**Number of DS0s**	**Colloquial Name**
DS0	64 Kbps	1	Channel
DS1	1.544 Mbps	24	T-1
DS1C	3.152 Mbps	48	T-1C
DS2	6.312 Mbps	96	T-2
DS3	44.736 Mbps	672	T-3
DS4	274.176 Mbps	4032	T-4

Synchronous Optical Network (SONET)

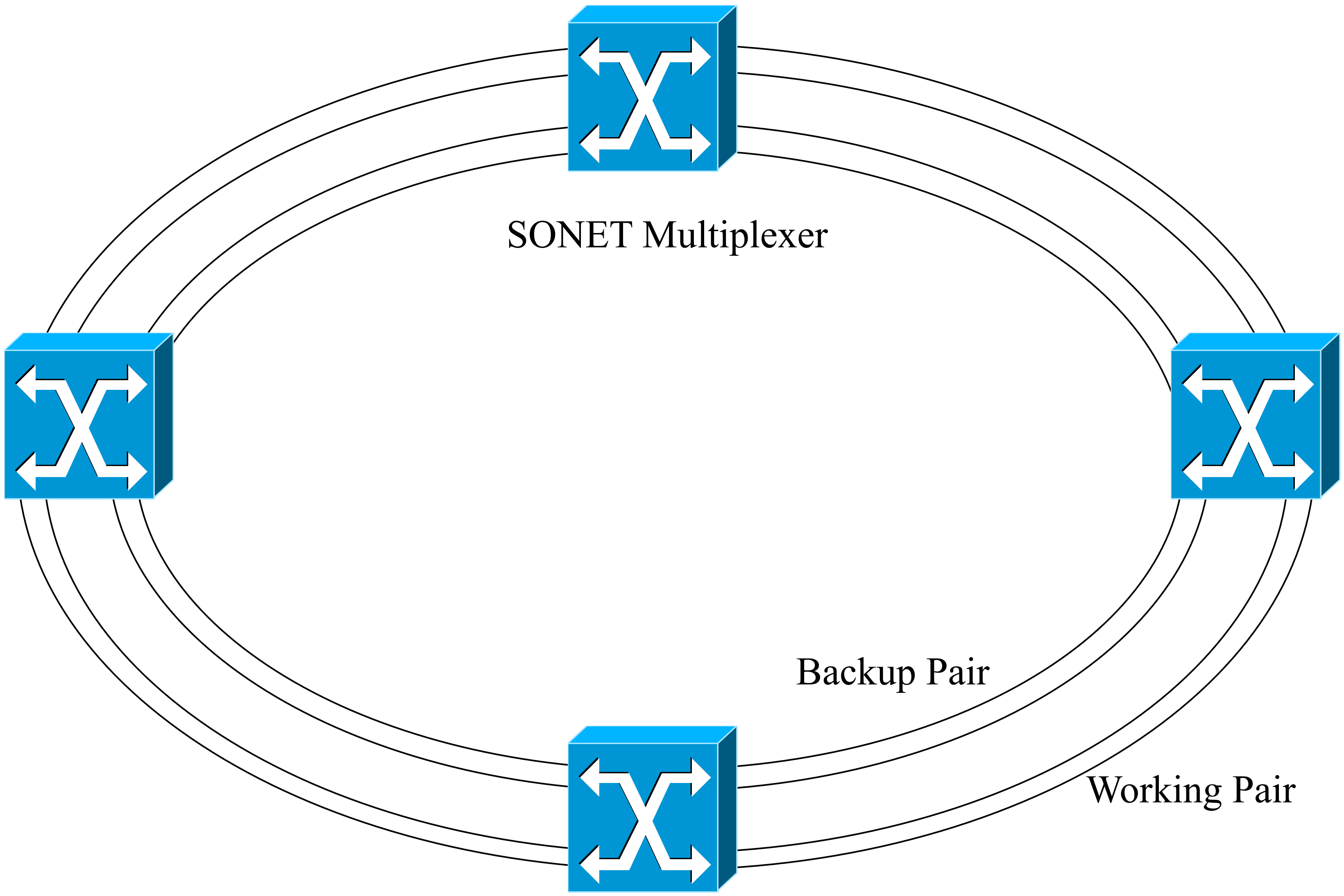
- Physical-layer specification for high-speed synchronous transmission of packets or cells over fiber-optic cabling
- Service providers and carriers make wide use of SONET in their internal networks
- Gaining popularity within private networks

SONET Optical Carrier (OC) Levels

aka Synchronous Transport Signal (STS) Levels

STS Rate	OC Level	Speed
STS-1	OC-1	51.84 Mbps
STS-3	OC-3	155.52 Mbps
STS-12	OC-12	622.08 Mbps
STS-24	OC-24	1.244 Gbps
STS-48	OC-48	2.488 Gbps
STS-96	OC-96	4.976 Gbps
STS-192	OC-192	9.952 Gbps

Typical SONET Topology



SONET Multiplexer

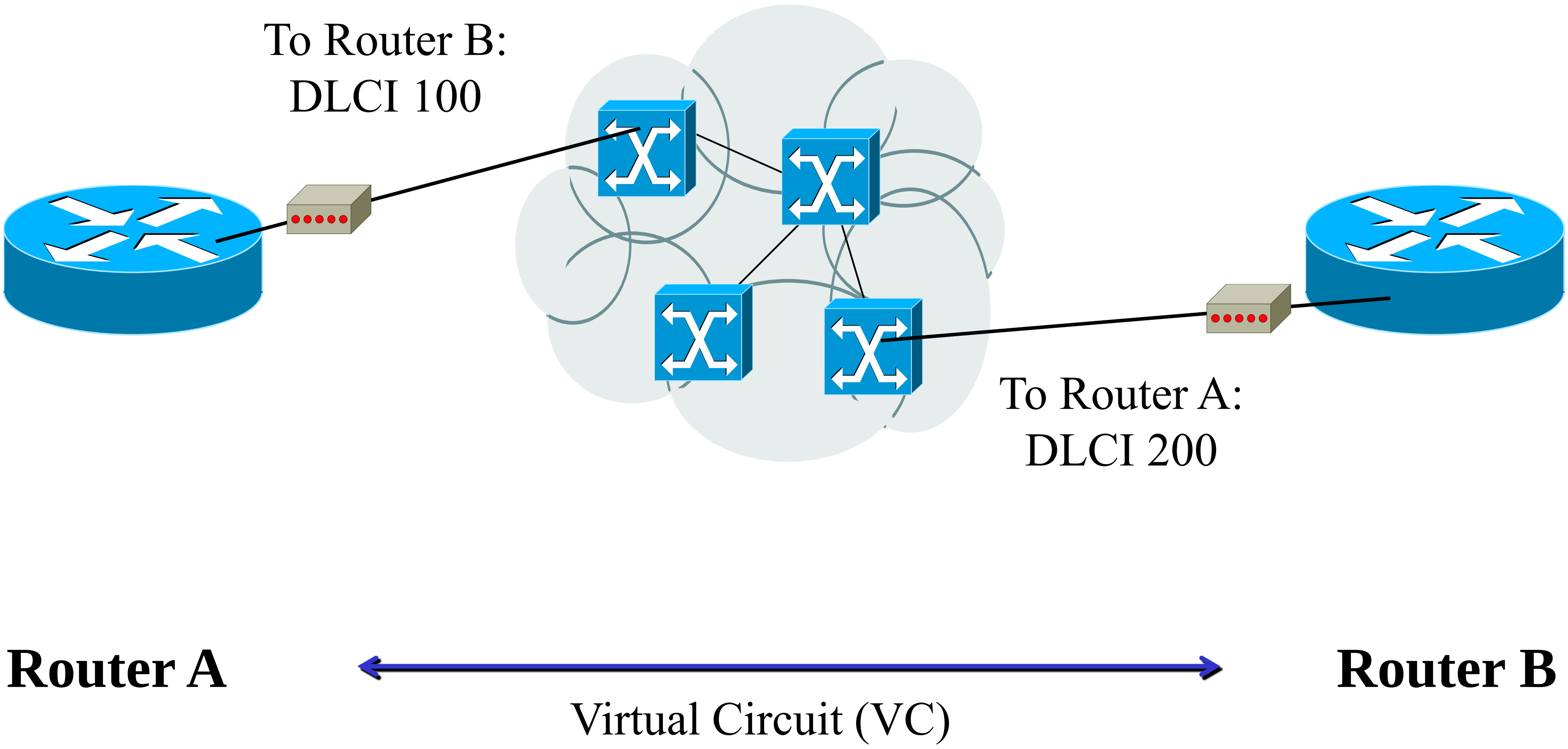
Backup Pair

Working Pair

Frame Relay

- Industry-standard data-link-layer protocol for transporting traffic across wide-area virtual circuits
- Optimized for efficiency on circuits with low error rates
- Attractively-priced in most parts of the world
- Carriers agree to forward traffic at a Committed Information Rate (CIR)

Frame Relay (continued)



To Router B:
DLCI 100

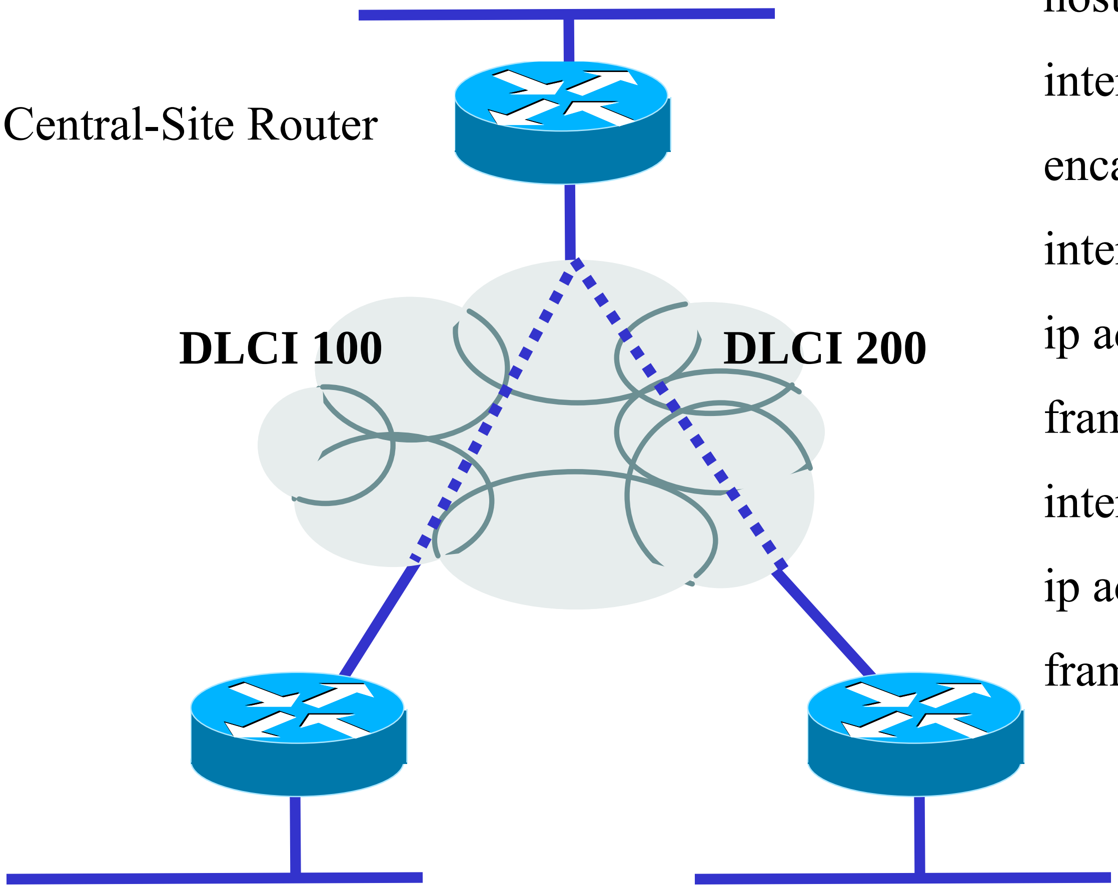
To Router A:
DLCI 200

Router A

Router B

Virtual Circuit (VC)

Frame Relay Hub-and-Spoke Uses Subinterfaces



```
hostname centralsite
interface serial 0
encapsulation frame-relay
interface serial 0.1
ip address 10.0.1.1 255.255.255.0
frame-relay interface-dlci 100
interface serial 0.2
ip address 10.0.2.1 255.255.255.0
frame-relay interface-dlci 200
```

Asynchronous Transfer Mode (ATM)

- Used in service provider internal networks
- Gaining popularity within private networks, both WANs and sometimes LANs
- Supports very high bandwidth requirements
  - Copper cabling: 45 Mbps or more
  - Fiber-optic cabling: OC-192 (9.952 Gbps) and beyond, especially if technologies such as wave-division multiplexing (WDM) are used

ATM (continued)

- Provides efficient sharing of bandwidth among applications with various Quality of Service (QoS) requirements
  - Cell-based system inherently better for QoS than frames
- Application can specify upon connection establishment the QoS it requires
- Peak and minimum cell rates, cell-loss ratio, and cell-transfer delay

Ethernet over ATM

- ATM router interfaces are expensive
- Some providers allow a customer to use an Ethernet interface to access the provider's ATM WAN
- May require a converter
- Expected to gain popularity because it has the advantages of both worlds
  - Easy-to-use LAN
  - QoS-aware WAN

Selection Criteria for Remote Access Devices

- Support for VPN features
- Support for NAT
- Reliability
- Cost
- Ease of configuration and management
- Support for one or more high-speed Ethernet interfaces
- If desired, wireless support
- Etc.

Selection Criteria for VPN Concentrators

- Support for:
  - Tunneling protocols such as IPSec, PPTP, and L2TP
  - Encryption algorithms such as 168-bit Triple DES, Microsoft Encryption (MPPE), RC4, AES
  - Authentication algorithms, including MD5, SHA-1, HMAC
  - Network system protocols, such as DNS, RADIUS, Kerberos, LDAP
  - Routing protocols
  - Certificate authorities
  - Network management using SSH or HTTP with SSL
  - Etc.

Selection Criteria for Enterprise Routers

- Number of ports
- Processing speed
- Media and technologies supported
- MTTR and MTBF
- Throughput
- Optimization features
- Etc

Selection Criteria for a WAN Service Provider

- Extent of services and technologies
- Geographical areas covered
- Reliability and performance characteristics of the provider’s internal network
- The level of security offered by the provider
- The level of technical support offered by the provider
- The likelihood that the provider will continue to stay in business

Selecting a Provider (continued)

- The provider’s willingness to work with you to meet your needs
- The physical routing of network links
- Redundancy within the network
- The extent to which the provider relies on other providers for redundancy
- The level of oversubscription on the network
- QoS support
- Etc.

Summary

- A major task during the physical design phase is selecting technologies and devices for enterprise networks
  - Remote access networks
  - WANs
  - Service providers
  - Devices
    - End user remote access devices
    - Central site remote access devices
    - VPN concentrators
    - Routers

Review Questions

- Compare and contrast technologies for supporting remote users.
- Compare and contrast WAN technologies.
- What selection criteria can you use when purchasing internetworking devices for enterprise network customers?
- What criteria can you use when selecting a WAN service provider?

Top-Down Network Design

Chapter Twelve

Testing Your Network Design

Reasons to Test

- Verify that the design meets key business and technical goals
- Validate LAN and WAN technology and device selections
- Verify that a service provider provides the agreed-up service
- Identify bottlenecks or connectivity problems
- Determine optimization techniques that will be necessary

Testing Your Network Design

- Use industry testing services
- Build and test a prototype system
- Use third-party and Cisco tools

Industry Testing Services

- The Interoperability Lab at the University of New Hampshire (IOL)
- ICSA Labs
- Miercom Labs
- KeyLabs
- The Tolly Group

Scope of a Prototype System

- It’s not generally practical to implement a full-scale system
- A prototype should verify important capabilities and functions that might not perform adequately
- Risky functions include complex, intricate functions and functions that were influenced by the need to make tradeoffs

Components of a Test Plan

- Test objectives and acceptance criteria
- The types of tests that will be run
- Network equipment and other resources required
- Testing scripts
- The timeline and milestones for the testing project

Test Objectives and Acceptance Criteria

- Specific and concrete
- Based on business and technical goals
- Clear criteria for declaring that a test passed or failed
- Avoid biases and preconceived notions about outcomes
- If appropriate, reference a baseline

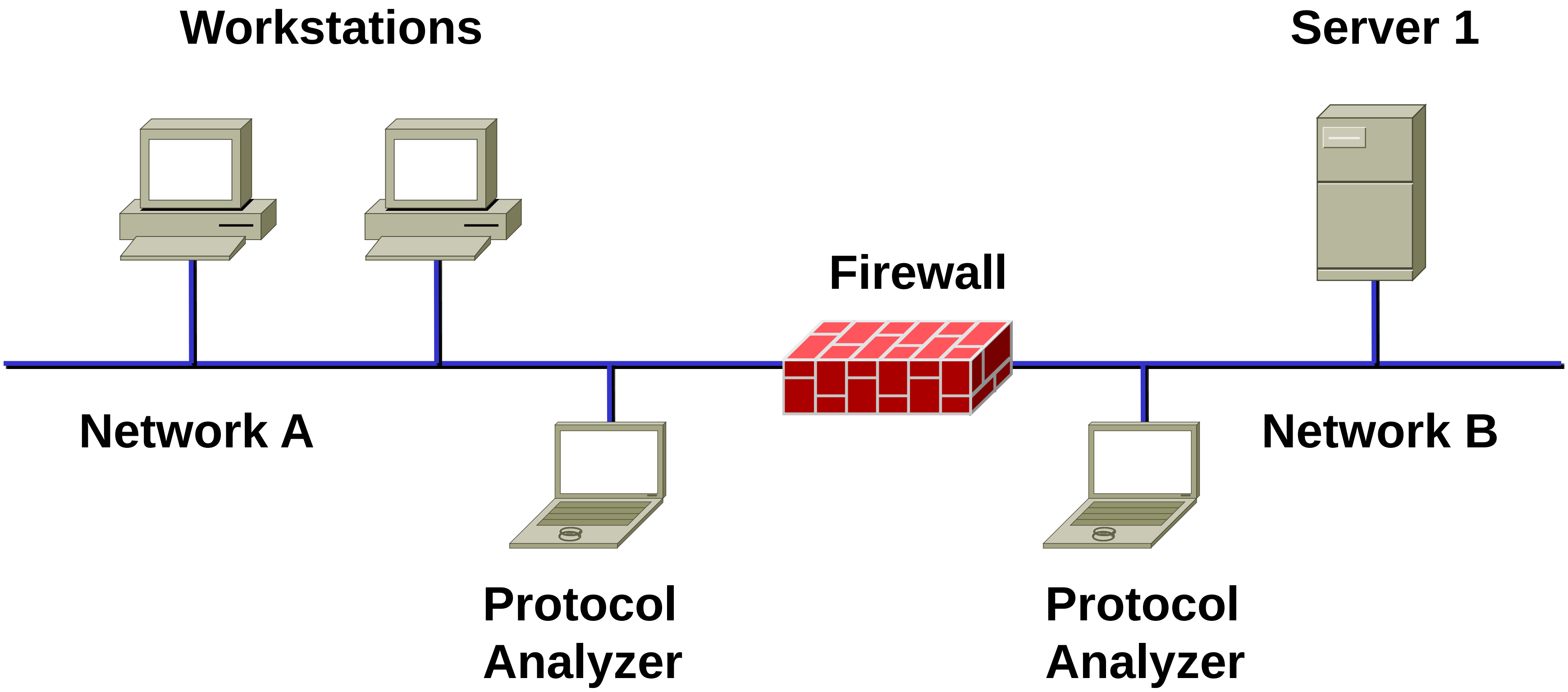
Types of Tests

- Application response-time tests
- Throughput tests
- Availability tests
- Regression tests

Resources Needed for Testing

- Scheduled time in a lab either at your site or the customer’s site
- Power, air conditioning, rack space, and other physical resources
- Help from coworkers or customer staff
- Help from users to test applications
- Network addresses and names

Example Test Script



Example Test Script (continued)

- Test objective. Assess the firewall’s capability to block Application ABC traffic, during both light and moderately heavy load conditions.
- Acceptance criterion. The firewall should block the TCP SYN request from every workstation on Network A that attempts to set up an Application ABC session with Server 1 on Network B. The firewall should send each workstation a TCP RST (reset) packet.

Example Test Script (continued)

1. Start capturing network traffic on the protocol analyzer on Network A.
2. Start capturing network traffic on the protocol analyzer on Network B.
3. Run Application ABC on a workstation located on Network A and access Server 1 on Network B.
4. Stop capturing network traffic on the protocol analyzers.
5. Display data on Network A’s protocol analyzer and verify that the analyzer captured a TCP SYN packet from the workstation. Verify that the network layer destination address is Server 1 on Network B, and the destination port is port 1234 (the port number for Application ABC). Verify that the firewall responded to the workstation with a TCP RST packet.

Example Test Script (continued)

6. Display data on Network B's protocol analyzer and verify that the analyzer did not capture any Application-ABC traffic from the workstation.
7. Log the results of the test in the project log file.
8. Save the protocol-analyzer trace files to the project trace-file directory.
9. Gradually increase the workload on the firewall, by increasing the number of workstations on Network A one at a time, until 50 workstations are running Application ABC and attempting to reach Server 1. Repeat steps 1 through 8 after each workstation is added to the test.

Tools for Testing a Network Design

- Network-management and monitoring tools
- Traffic generation tools
- Modeling and simulation tools
- QoS and service-level management tools
- http://www.topdownbook.com/tools.html

Summary

- An untested network design probably won’t work
- It’s often not practical to test the entire design
- However, by using industry testing services and tools, as well as your own testing scripts, you can (and should) test the complex, risky, and key components of a network design

Review Questions

- Why is it important to test your network design?
- Why is regression testing important?
- What are some characteristics of well-written acceptance criteria?
- What are some characteristics of a good network simulation tool?

Top-Down Network Design

Chapter Thirteen

Optimizing Your Network Design

Reasons to Optimize

- Meet key business and technical goals
- Use bandwidth efficiently
- Control delay and jitter
- Reduce serialization delay
- Support preferential service for essential applications
- Meet Quality of Service (QoS) requirements

IP Multicast Helps Optimize Bandwidth Usage

- With IP multicast, you can send a high-volume multimedia stream just once instead of once for each user
- Requires support for
  - Multicast addressing
  - Multicast registration (IGMP)
  - Multicast routing protocols

IP Multicast Addressing

- Uses Class D multicast destination address
  - 224.0.0.0 to 239.255.255.255
- Converted to a MAC-layer multicast destination address
  - The low-order 23 bits of the Class D address become the low-order 23 bits of the MAC-layer address
  - The top 9 bits of the Class D address are not used
  - The top 25 bits of the MAC-layer address are 0x01:00:5E followed by a binary 0

Internet Group Management Protocol (IGMP)

- Allows a host to join a multicast group
- Host transmits a *membership-report* message to inform routers on the segment that traffic for a group should be multicast to the host’s segment
- IGMPv2 has support for a router more quickly learning that the last host on a segment has left a group

Multicast Routing Protocols

- Becoming obsolete
  - Multicast OSPF (MOSPF)
  - Distance Vector Multicast Routing Protocol (DVMRP)
- Still used
  - Protocol Independent Multicast (PIM)
    - Dense-Mode PIM
    - Sparse-Mode PIM

Reducing Serialization Delay

- Link-layer fragmentation and interleaving
  - Breaks up and reassembles frames
  - Multilink PPP
  - Frame Relay FRF.12
- Compressed Real Time Protocol
  - RTP is used for voice and video
  - Compressed RTP compresses the RTP, UDP, and IP header from 40 bytes to 2 to 4 bytes

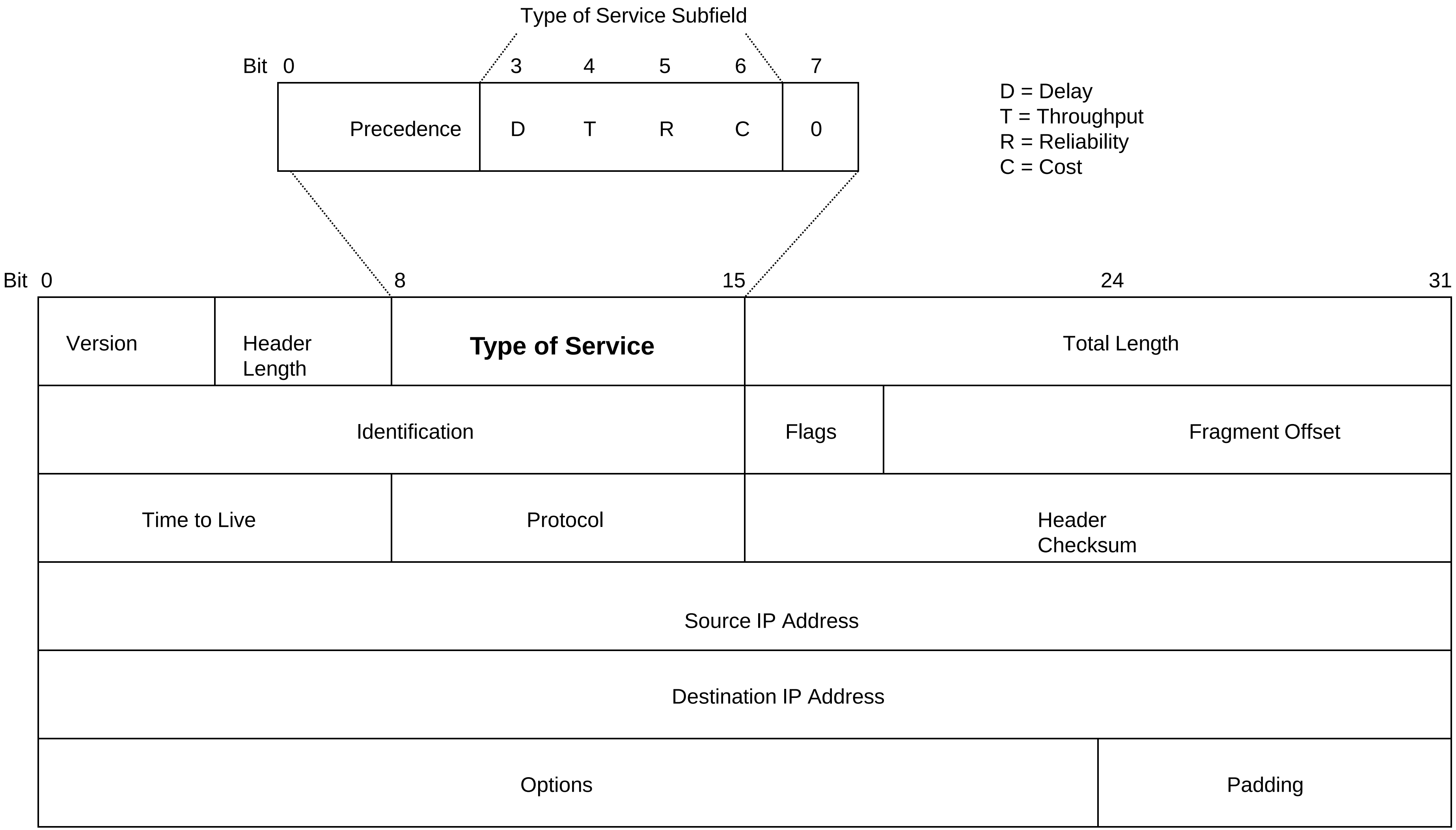
A Few Technologies for Meeting QoS Requirements

- IETF controlled load service
- IETF guaranteed service
- IP precedence
- IP differentiated services

IP Type of Service Field

- The type of service field in the IP header is divided into two subfields
  - The 3-bit precedence subfield supports eight levels of priority
  - The 4-bit type of service subfield supports four types of service
- Although IP precedence is still used, the type of service subfield was hardly ever used

IP Type of Service Field



Type of Service Subfield

Bit 0 3 4 5 6 7

Precedence | D | T | R | C | 0

D = Delay
T = Throughput
R = Reliability
C = Cost

Bit 0 8 15 24 31

Version | Header Length | **Type of Service** | Total Length

Identification | Flags | Fragment Offset

Time to Live | Protocol | Header Checksum

Source IP Address

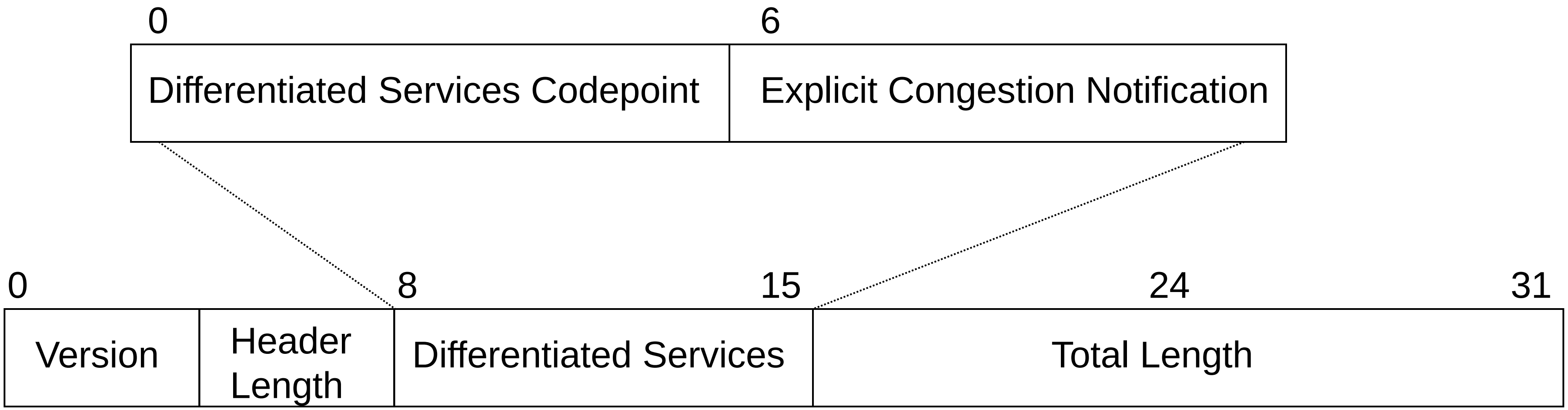
Destination IP Address

Options | Padding

IP Differentiated Services (DS) Field

- RFC 2474 redefines the type of service field as the Differentiated Services (DS) field
  - Bits 0 through 5 are the Differentiated Services Codepoint (DSCP) subfield
    - Has essentially the same goal as the precedence subfield
    - Influences queuing and packet dropping decisions for IP packets at a router output interface
  - Bits 6 and 7 are the Explicit Congestion Notification (ECN) subfield

IP Differentiated Services (DS) Field



0
6
Differentiated Services Codepoint
Explicit Congestion Notification

0
8
15
24
31
Version
Header Length
Differentiated Services
Total Length

Classifying LAN Traffic

- IEEE 802.1p
- Classifies traffic at the data-link layer
- Supports eight classes of service
- A switch can have a separate queue for each class and service the highest-priority queues first

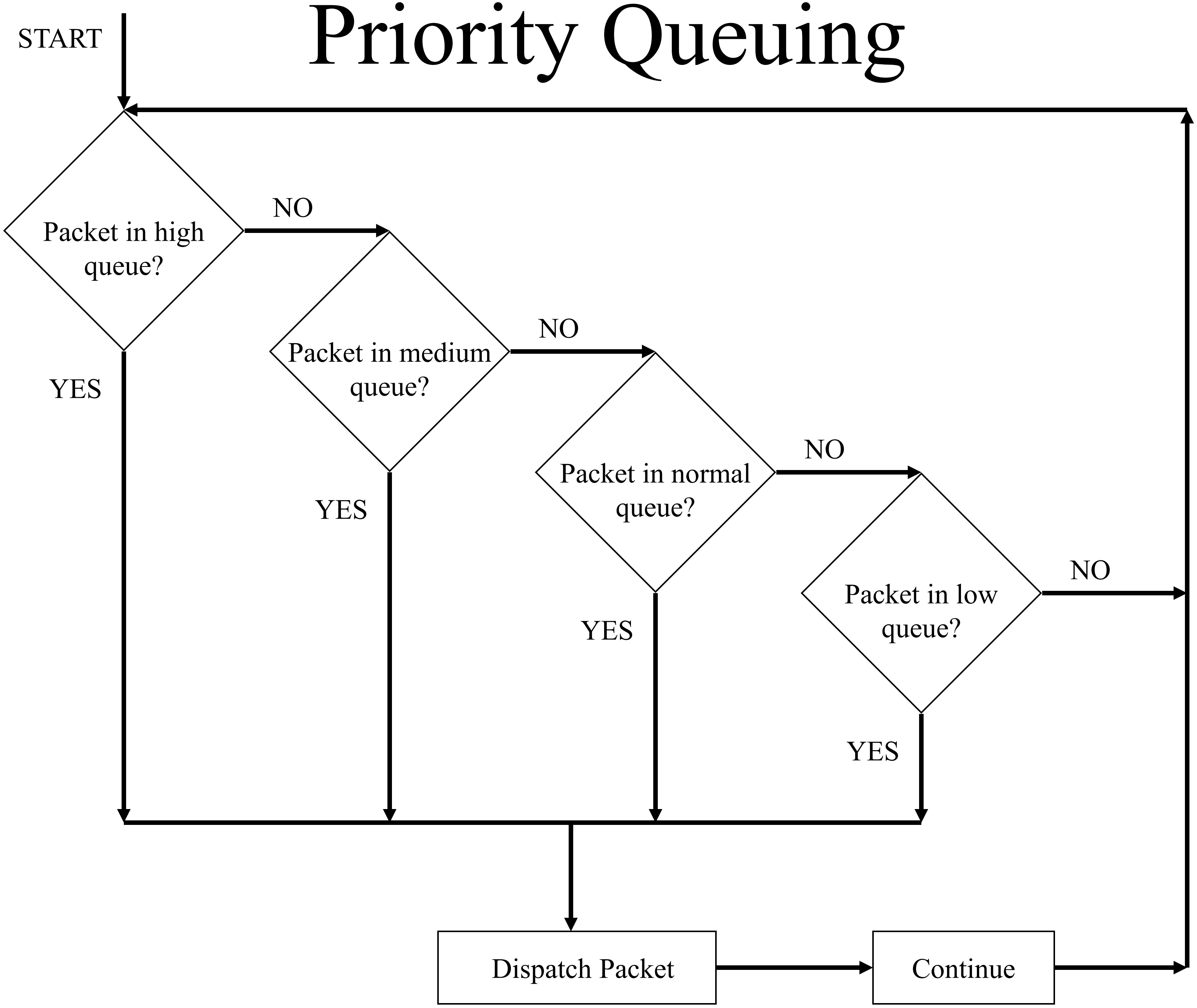
Cisco Switching Techniques

- Process switching
- Fast switching
- Autonomous, silicon, and optimum switching
- NetFlow switching
- Cisco Express Forwarding (CEF)

Cisco Queuing Services

- First in, first out (FIFO) queuing
- Priority queuing
- Custom queuing
- Weighted fair queuing (WFQ)
- Class-based WFQ (CBWFQ)
- Low latency queuing (LLQ)

Priority Queuing



START

Packet in high queue?

NO

YES

Packet in medium queue?

NO

YES

Packet in normal queue?

NO

YES

Packet in low queue?

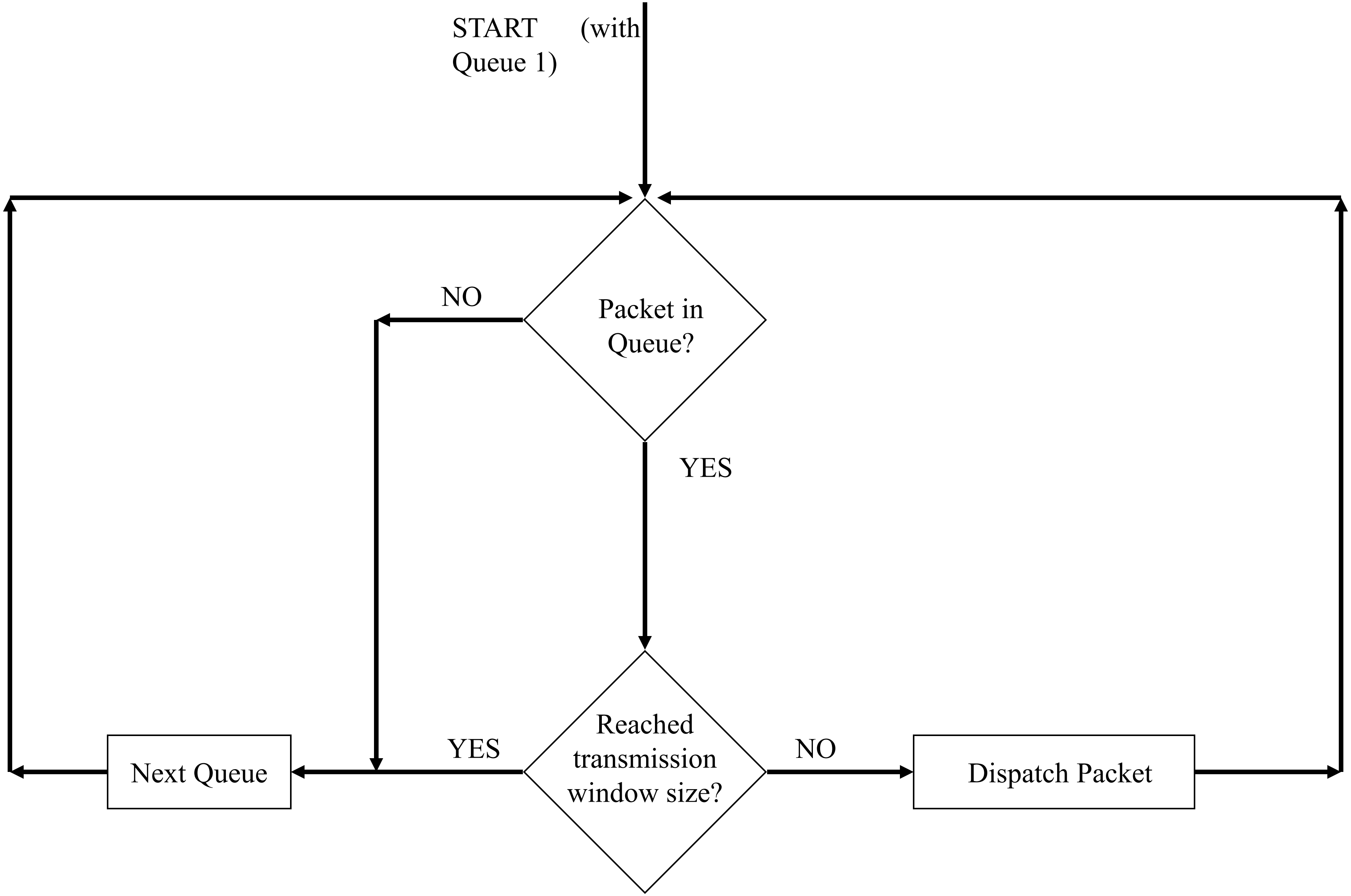
NO

YES

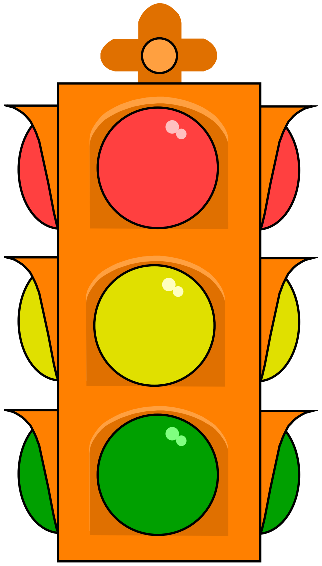
Dispatch Packet

Continue

Custom Queuing



Low-Latency Queuing



- One queue always gets the green light
  - Use this for voice
- Combine this with class-based weighted fair queuing
  - Define traffic classes based on protocols, access control lists, and input interfaces
  - Assign characteristics to classes such as bandwidth required and the maximum number of packets that can be queued for the class

Random Early Detection (RED)

- Congestion avoidance rather than congestion management
- Monitors traffic loads and randomly discards packets if congestion increases
- Source nodes detect dropped packets and slow down
  - Works best with TCP
- Weighted Random Early Detection
    - Cisco's implementation uses IP precedence or the DS field instead of just randomly dropping packets

Traffic Shaping

- Manage and control network traffic to avoid bottlenecks
- Avoid overwhelming a downstream router or link
- Reduce outbound traffic for a flow to a configured bit rate
  - Queue bursts of traffic for that flow

Committed Access Rate (CAR)

- Cisco feature for classifying and policing traffic on an incoming interface
- Supports policies regarding how traffic that exceeds a certain bandwidth allocation should be handled
- Can drop a packet or change the IP precedence or DSCP bits

Summary

- Optimization provides the high bandwidth, low delay, and controlled jitter required by many critical business applications
- To minimize bandwidth utilization by multimedia applications, use IP multicast
- To reduce serialization delay, use link fragmentation and compressed RTP
- To support QoS and optimize performance, use IP precedence, DSCP, 802.1p. advanced switching and queuing methods, RED, CAR, etc.

Review Questions

- Why is it important to optimize your network?
- What has become of the IP type of service field?
- What are some methods for marking packets to identify the need for priority handling?
- Compare and contrast Cisco queuing services.

Top-Down Network Design

Chapter Fourteen

Documenting Your Network Design

Documenting Your Design

- If you are given a request for proposal (RFP), respond to the request in the exact format that the RFP specifies
- If no RFP, you should still write a design document
  - Describe your customer’s requirements and how your design meets those requirements
  - Document the budget for the project
  - Explain plans for implementing the design

Typical RFP Response Topics

- A network topology for the new design
- Information on the protocols, technologies, and products that form the design
- An implementation plan
- A training plan
- Support and service information
- Prices and payment options
- Qualifications of the responding vendor or supplier
- Recommendations from other customers
- Legal contractual terms and conditions

Contents of a Network Design Document

- Executive summary
- Project goal
- Project scope
- Design requirements
- Current state of the network
- New logical and physical design
- Results of network design testing
- Implementation plan
- Project budget

Design Requirements

- Business goals explain the role the network design will play in helping an organization succeed
- Technical goals include scalability, performance, security, manageability, usability, adaptability, and affordability

Logical and Physical Design

- Logical design
  - Topology
  - Models for addressing and naming
  - Switching and routing protocols
  - Security strategies
  - Network management strategies
- Physical design
  - Actual technologies and devices

Implementation Plan

- Recommendations for deploying the network design
- Project schedule
  - Including any dates and times for service provider installations
- Any plans for outsourcing
- Training
- Risks
- A fallback plan if the implementation should fail
- A plan for evolving the design as new requirements arise

Possible Appendixes

- Detailed topology maps
- Device configurations
- Addressing and naming details
- Network design testing results
- Contact information
- Pricing and payment options
- More information about the company that is presenting the design
  - Annual reports, product catalogs, press releases
- Legal contractual terms and conditions

Summary

- When a customer provides an RFP, make sure to follow the prescribed format
- When not bound by an RFP, develop a design document that describes requirements, the existing network, the logical and physical design, an implementation plan, and the budget
- Be sure to include an executive summary
- In some cases, you should also include appendixes with detailed information

Review Questions

- Why is it important to document your network design?
- Why is it important to submit an RFP proposal in the exact format prescribed?
- What are the major topics in a design document?
- What are some possible appendixes for a design document?