Computer Networks Design & Planning

Dr.-Ing. Ali Diab

Outline

- Goals & Objectives
- Design Approaches
  - Traditional analytic design
  - Building block approach
- Requirements: Boring, However Essential
- Campus Networks Design

Goals & Objectives

Key Questions

- Our network design must answer some pretty basic questions
  - What stuff do we get for the network?
  - How do we connect it all?
  - How do we have to configure it to work right?

- This meant mostly capacity planning
  - Having enough bandwidth to keep data moving
    - May be effective, but result in over engineering

- While some uses of the network will need a lot of bandwidth (multimedia), we may also need to address
  - Security
    - Considering both internal and external threats
  - Possible wireless connectivity
  - Reliability and/or availability
    - Like speed for a car, how much are you willing to afford?

Goals & Objectives

- **Good designs should**
  - Deliver services requested by users
  - Deliver acceptable throughput and response times
  - Be within budget and maximize cost efficiencies
  - Be reliable
  - Be expandable without major re-design
  - Be manageable by maintenance and support staff
  - Be well documented

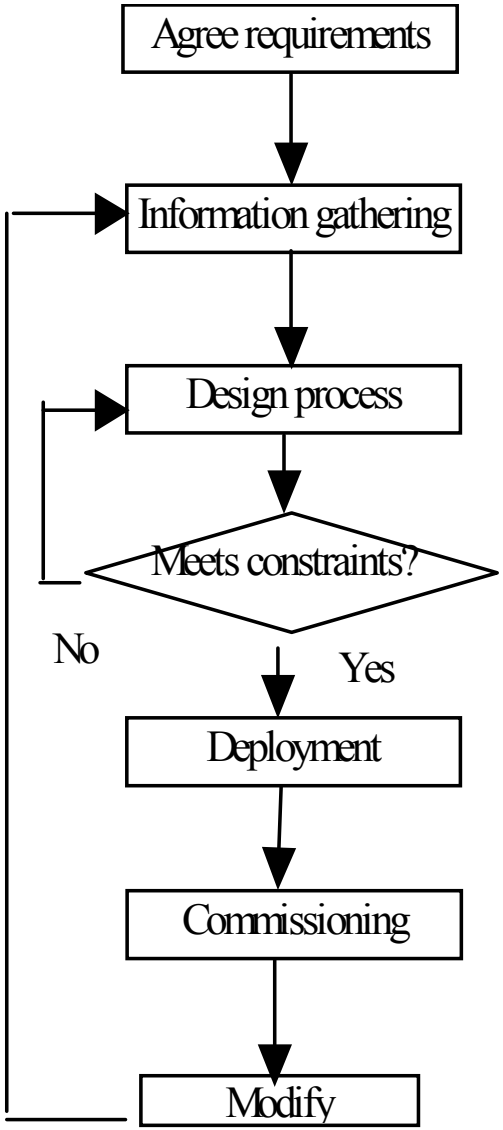
Design Approaches

Basic Approaches

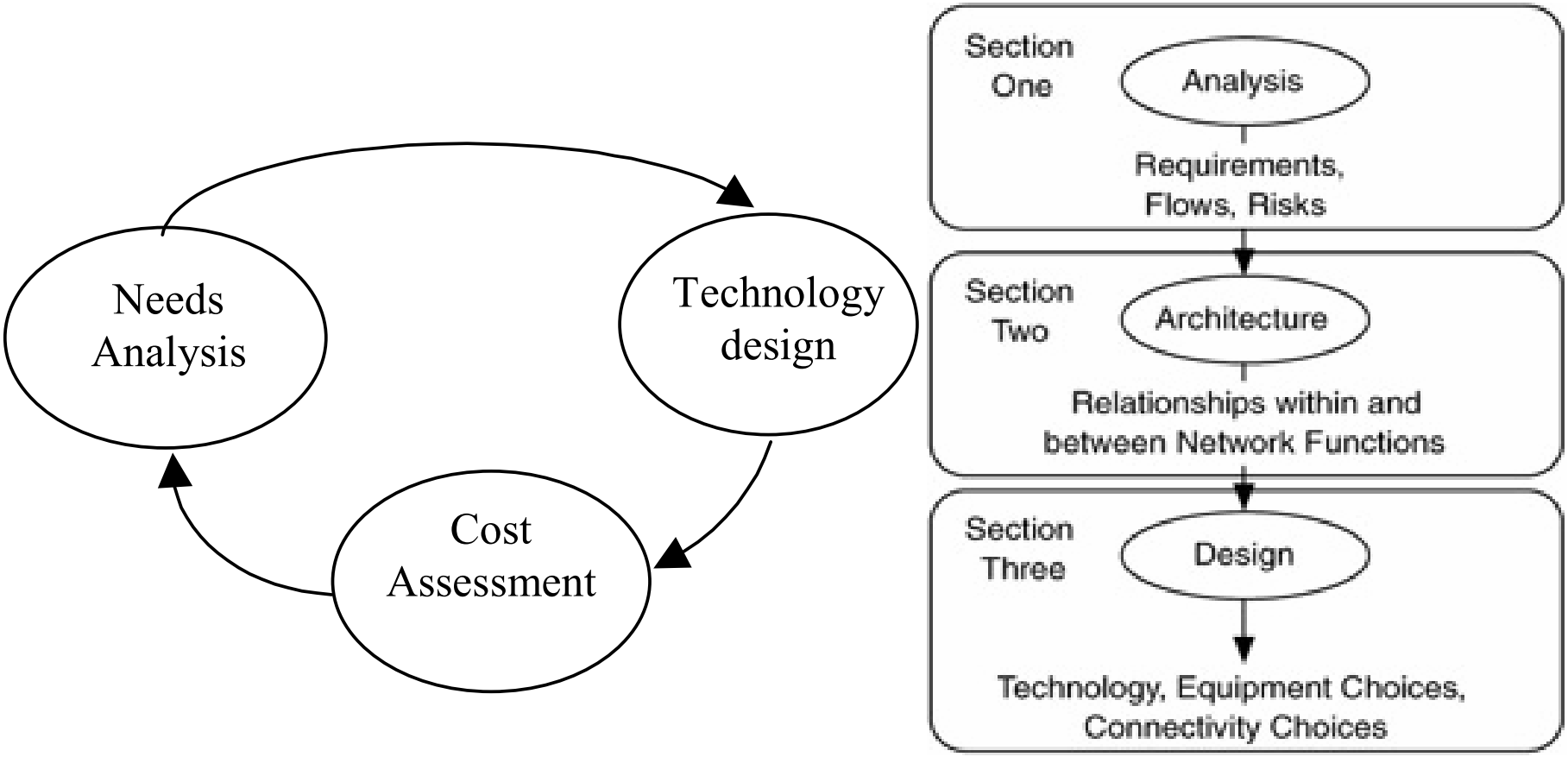
- Two typical methods
  - Traditional analytic design
  - Building block approach

- Both use a similar iterative approach

Traditional Design Process



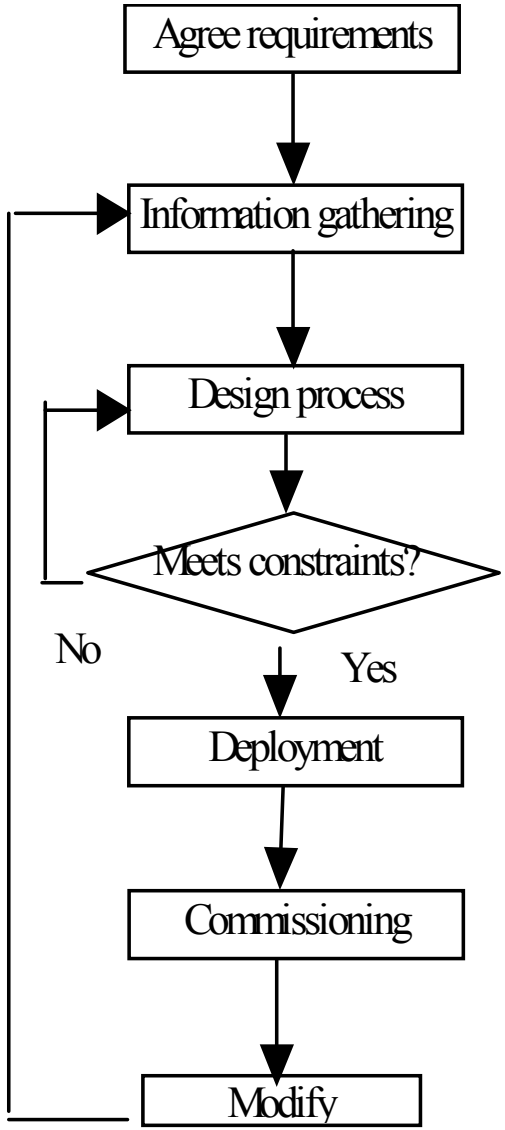
Building Block Approaches



Design Approaches

Traditional Design Process

Traditional Design Process



Agree Requirements

- Engage end users
- Translate requirements
  - Business objectives → technical specification
- Phasing the requirements
  - Right level of detail at each design stage
- Designing the requirements
  - Aim for completeness
  - Prioritise with a hierarchical system such as
    - [M] - Mandatory
    - [H] – Highly desirable
    - [D] - Desirable
    - [N] - Note

Information Gathering

- Need to find details of user behaviour, application use and location information, e.g.
  - User: location, numbers, services used, typical access
  - Sites: number, location, constraints on traffic (security, political or cost)
  - Servers and services: location, level of distribution
  - WAN/backbone predicted link traffic
  - Protocol support: bridged, routed or switched – Gateways needed?
  - Legacy support: equipment, protocols or services
  - Specific availability needs? 24-hour/backup links, etc.
  - Five-year plan – changes to population or business requirements
  - Budgetary constraints
  - Greenfield or existing site

- Information is refined and leads to a requirements database and capacity plan

Site Constraints

- Greenfield site
  - Greenfield sites have no legacy constraints
    - It is difficult to determine the real network loads and stresses
    - Needs more detail of application use and underlying protocols
    - Could use simulation to predict performance

- Existing site
  - Limited access
  - Access to live network could be restricted
    - Bottlenecks more obvious
    - Can use traffic/network analysis tools

Planning

- Uses information on
  - Hosts, users, services, and their internetworking needs
- Iterative process of
  - Conceptual design
  - Analysis
  - Refinement
- Involving
  - Brainstorming, design reviews, modelling tools
- Leading to final draft design

Design Specification & Implementation

- Detailed document of the design
  - Acts as a benchmark for design changes
  - Final design choices and changes need justification and documenting
  - Should include change history to aid maintenance
  - Used for the implementation

- Needs a project plan to include
  - Phased introduction of new technology
  - Educating the users (what to expect)
  - Pilot installation (test for possible problems)
  - Acceptance testing (to prove performance meets requirements)
  - Deployment (provide support on going live and provide fall-back position)

Connectivity Options

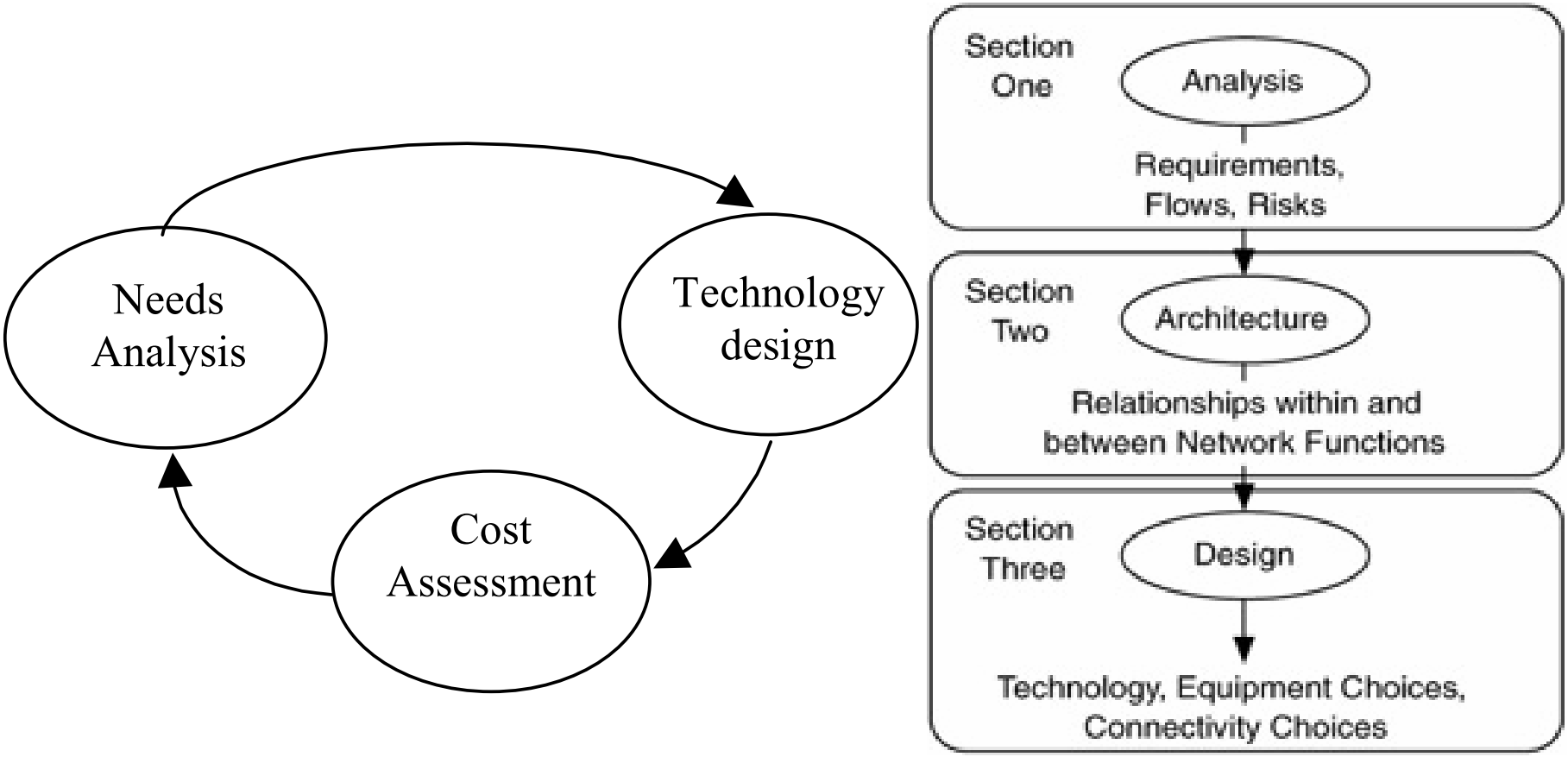
- Technology choices
  - LANs (Ethernet, Token ring, ATM)
  - MANs (FDDI, SMDS, ATM, SONET/SDH)
  - WANS (Frame relay, ATM, ISDN, X.25, PDCs, Satellite)
  - Wireless (802.11, Bluetooth, GPRS, GSM)
  - Dial-up lines
  - Serial links

- Determinants
  - Packet, cell or circuit switching
  - Wired or wireless
  - Distance
  - Performance
  - Bandwidth
  - Quality of Service
  - Availability

Design Approaches

Building Block Approaches

Building Block Approaches



Requirements: Boring, However Essential

Requirements?

- Determining the requirements for a network probably isn't as much fun as shopping for really expensive hardware
  - that may be why many networks are poorly designed – no one bothered to think through heir requirements!
  - Many people will jump to a specific technology or hardware solution, without fully considering other options – the obvious solution may not be the best one

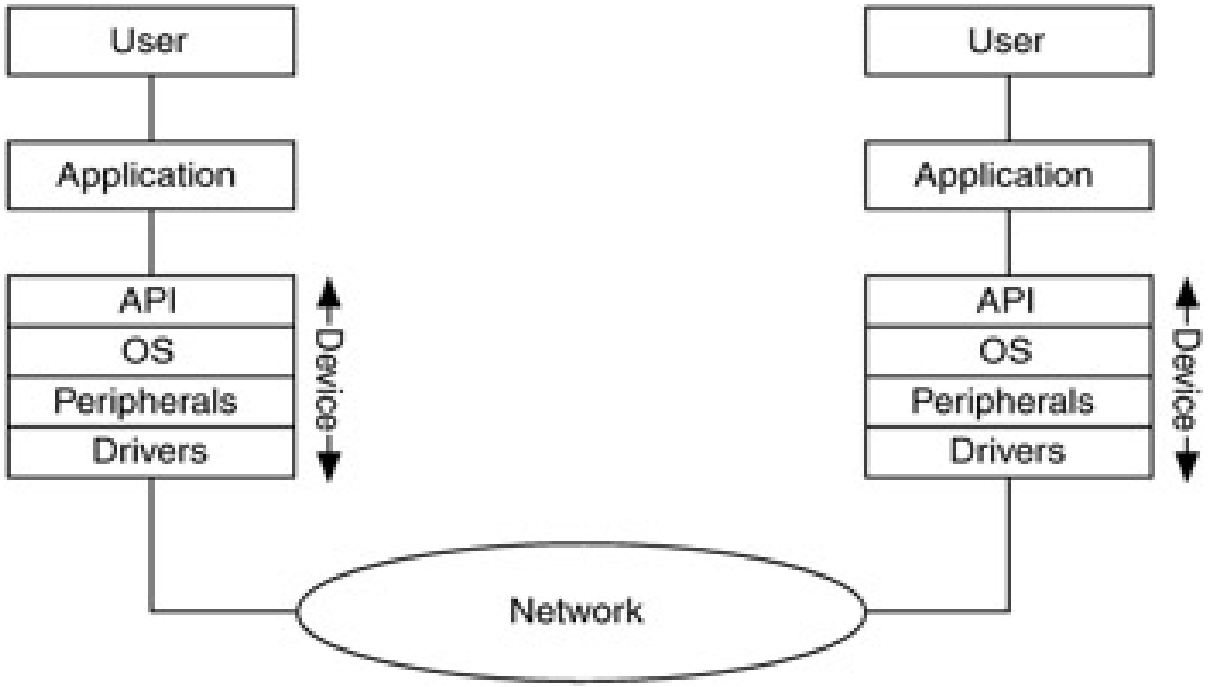
- **Low level** design and **higher level** architecture must be developed
  - The environment in which the network operates is important
- The design chosen must be proved that it is '**just right**'
  - Is that $2 million network backbone really enough to meet our needs?
  - How do we know $500,000 wouldn't have been good enough?

Requirements?

- Part of this process is managing the customer's expectations
- A system approach must be used for understanding the network
  - The system goes far beyond the network hardware, software, etc.
  - Also includes understanding the users, applications or services, and external environment
- How do these need to interact?
- What does the rest of the organization expect from the network?

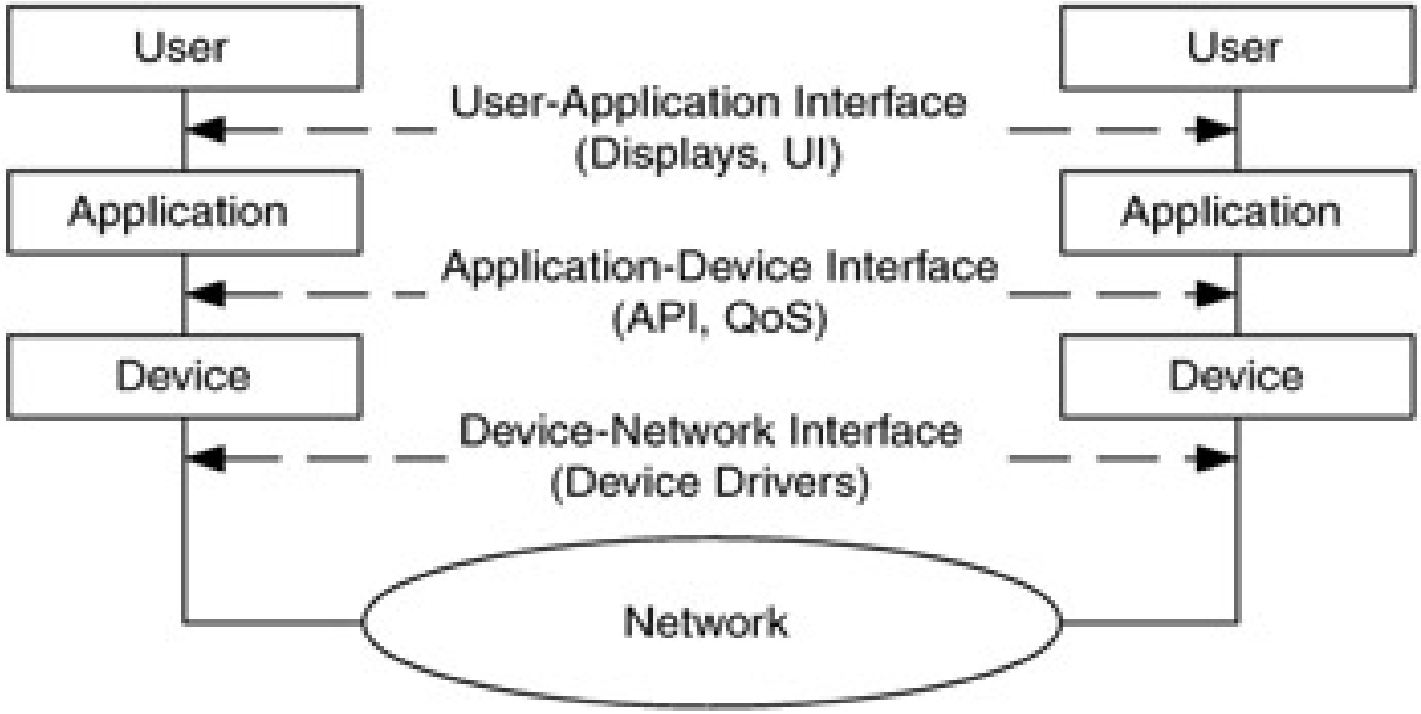
Requirements?

- Consider how devices communicate



Requirements?

- Consider how devices communicate

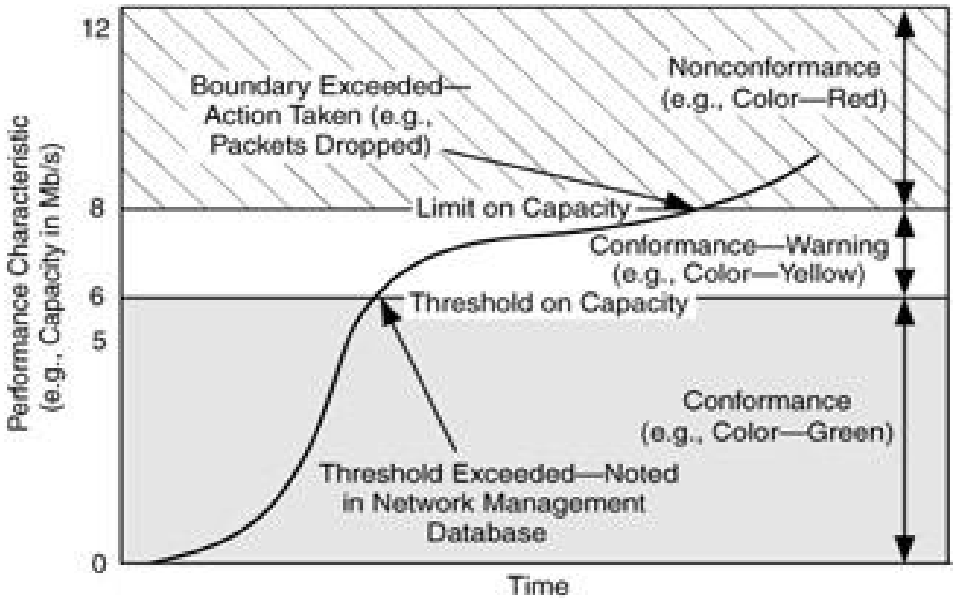


Requirements?

- What services are expected from the network?
  - Typical performance levels might include capacity, delay time, reliability, etc.
    - Providing 1.5 Mb/s peak capacity to a remote user
    - Guaranteeing a maximum round-trip delay of 100 ms
    - ...
- Functions include
  - Security, accounting, scheduling, management, etc.
  - Defining a security or privacy level for a group of users or an organization

Requirements?

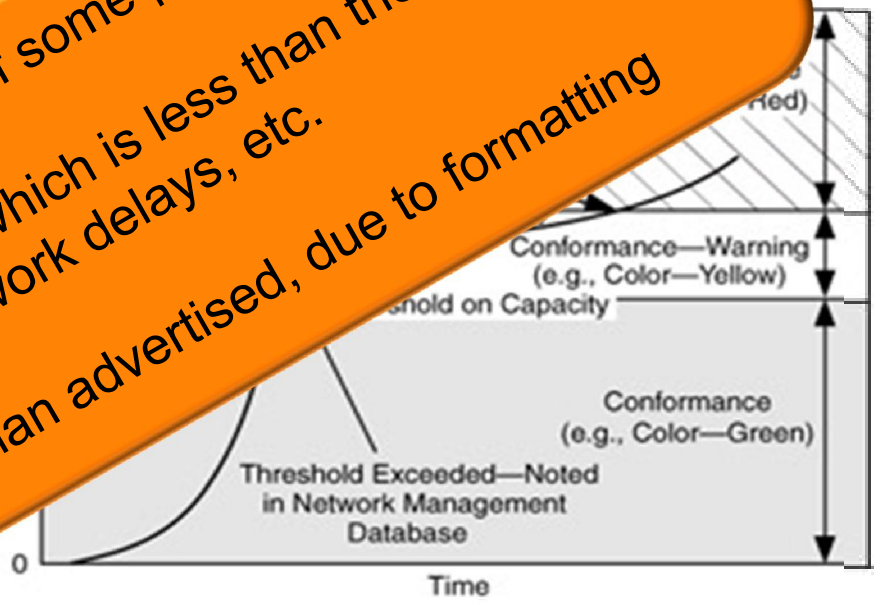
- Service requirements could include the QoS guarantees
  - ATM
  - Intserv
  - Diffserv
  - …
- This connects to network management monitoring of network performance



Requirements?

- Service requirements could include the QoS guarantees
  - ATM
  - Intserv
  - Diffserv
  - …
- This

- **Bandwidth** is the theoretical capacity of some part of the network
- **Throughput** is the actual capacity, which is less than the bandwidth
  - Due to protocol overhead, network delays, etc.
- Actual capacity is always less than advertised, due to formatting

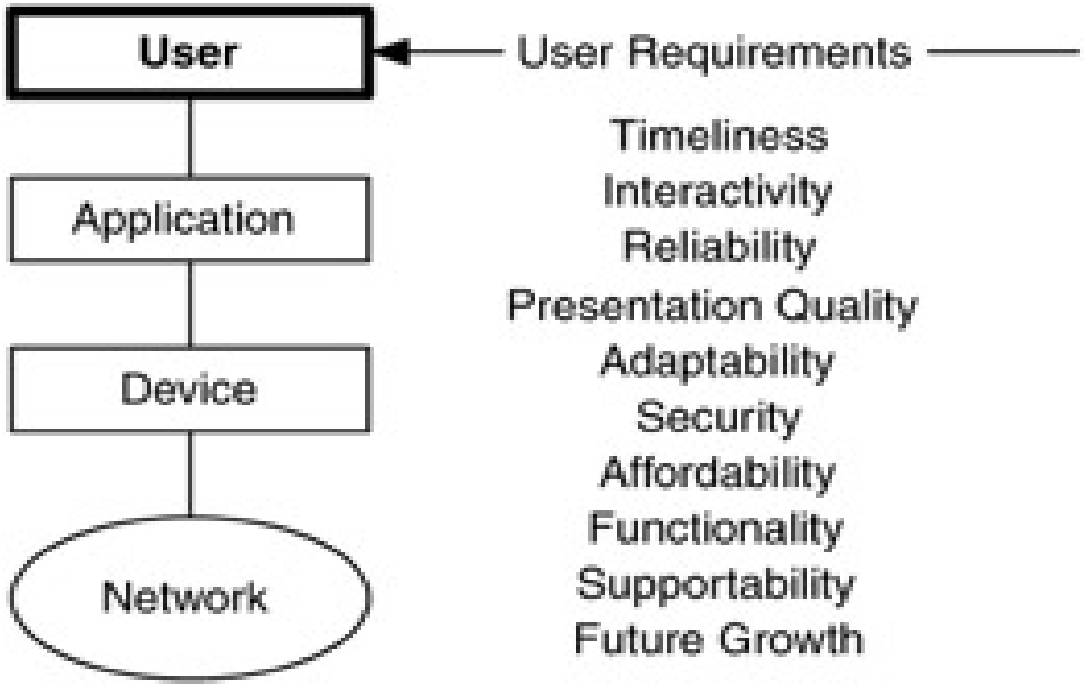


Requirements Analysis

- Requirements can come from many aspects of the network system
  - User Requirements
  - Application Requirements
  - Device Requirements
  - Network Requirements
  - Other Requirements

User Requirements

- User requirements are often qualitative and very high level
  - What is ‘fast enough’ for download? System response (RTT)?
  - How good does video need to be?
  - What’s my budget?
  - .....

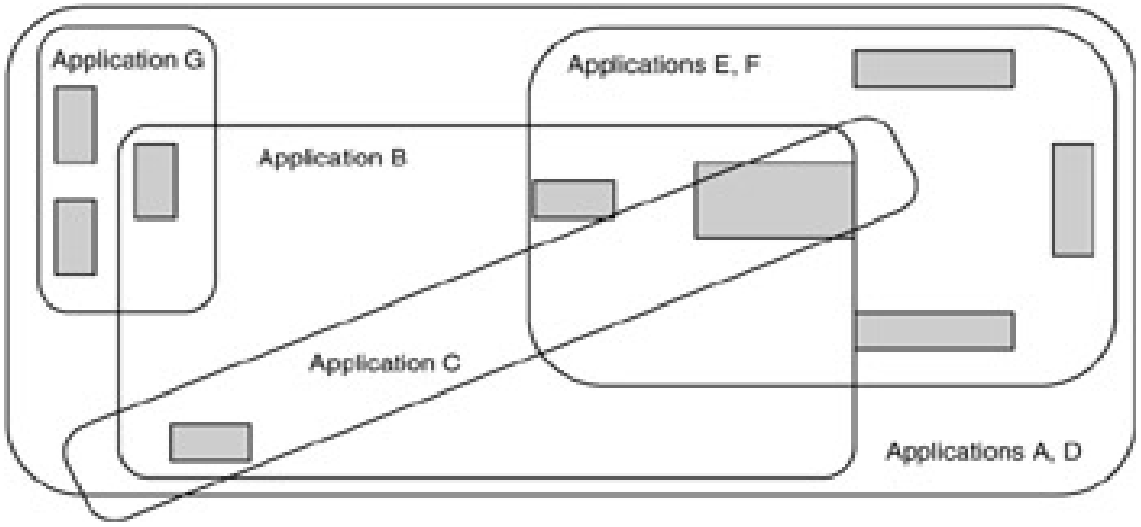


Application Requirements

- What types of applications are we using?
  - Mission-critical
  - Rate-critical
  - Real-time and/or interactive
- How sensitive are applications to remote access (reliability, maintainability, availability)?
- What capacity is needed?
- What delay time is acceptable?

Application Requirements

- What groups of applications are being used?
  - Telemetry/command and control - remote devices
  - Visualization and simulation
  - Distributed computing, web development,
  - ...
- Where are the applications located?
  - Are some only used in certain locations?

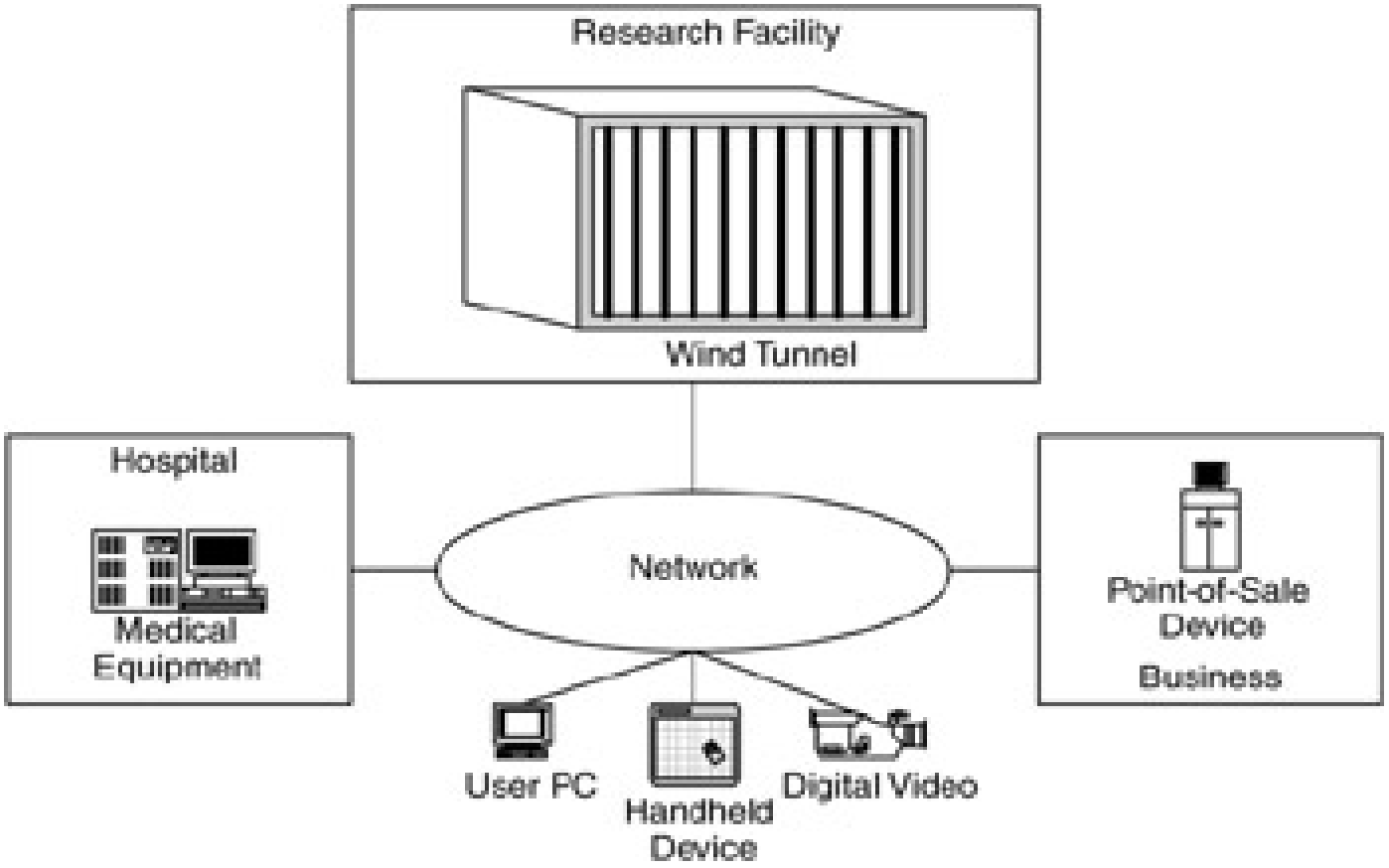


Device Requirements

- What kinds of devices are on your network?
  - Generic computing devices include
    - Normal PCs, Macs, laptops, handheld computers, workstations, etc.
  - Servers include all flavors of server
    - File, print, app/computation, and backup
  - Specialized devices include extreme servers (supercomputers, massively parallel servers), data collection systems, industry-specific devices, networked devices (cameras, tools), stoplights, ATMs, etc.

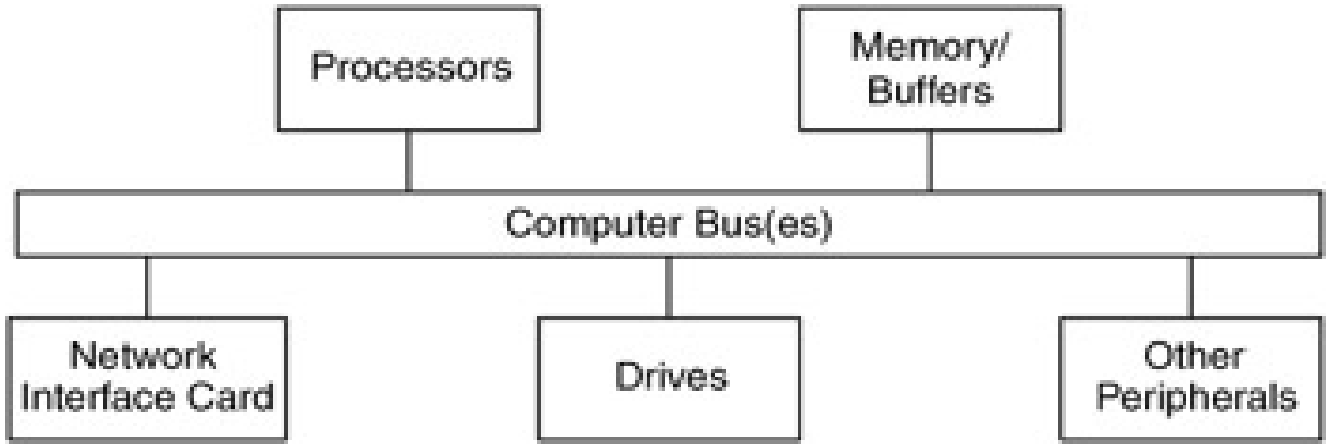
Device Requirements

- Specialized devices are often location-specific



Device Requirements

- We want an understanding of the device's performance – its ability to process data from the network
  - Device I/O rates
  - Delay time for performing a given application function

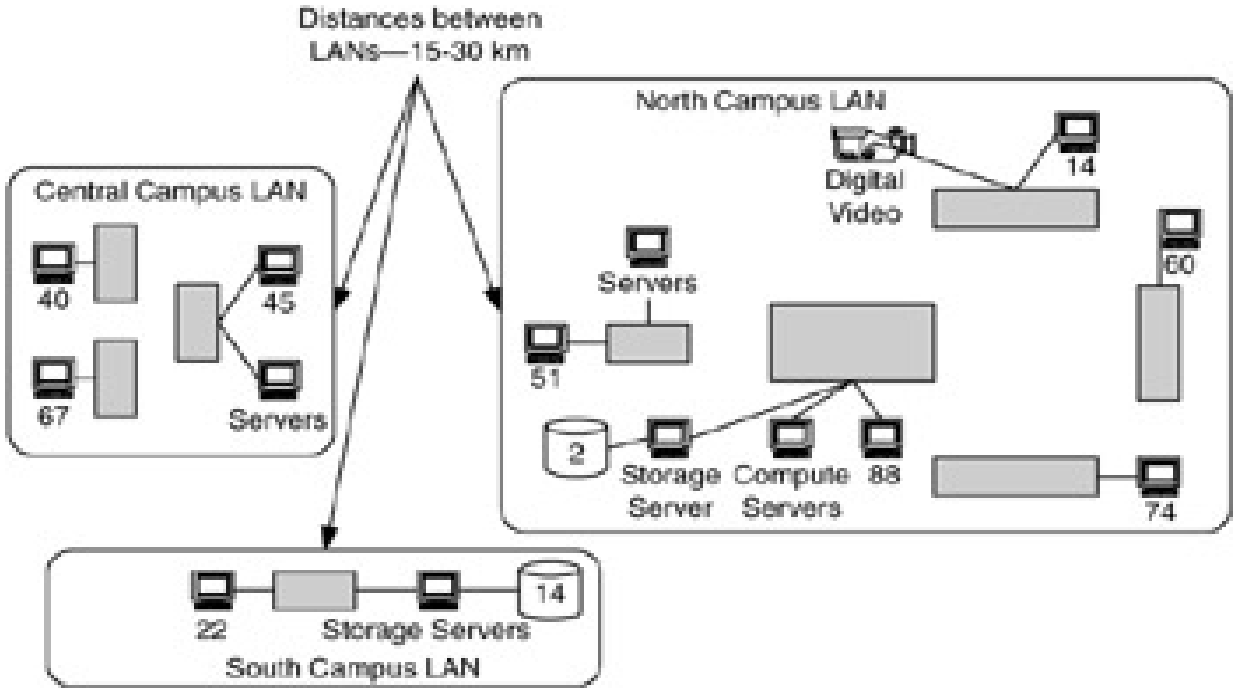


Device Requirements

- Performance results from many factors
  - Storage performance, that is, flash, disk drive, or tape performance
  - Processor (CPU) performance
  - Memory performance (access times)
  - Bus performance (bus capacity and arbitration efficiency)
  - OS performance (effectiveness of the protocol stack and APIs)
  - Device driver performance

Device Requirements

- The device locations are also critical
  - Often generic devices can be grouped by their quantity
  - Servers and specialized stuff are shown individually



Network Requirements

- Network requirements are the requirements for interacting with existing network(s) and network management concerns
- Most networks have to integrate into an existing network, and plan for the future evolution of the network
- Issues with network integration include
  - Scaling dependencies
    - How will the size of the existing network affect the new one?
    - Will the existing network change structure, or just add on a new wing?
  - Location dependencies
    - Interaction between old and new networks could change the location of key components

Network Requirements

- Performance constraints
  - Existing network could limit performance of the new one
- Network, system, and support service dependencies
  - Addressing, security, routing protocols and network management can all be affected by the existing network
- Interoperability dependencies
  - Changes in technology or media at the interfaces between networks need to be accounted for, as well as QoS guarantees, if any
- Network obsolescence
  - Do protocols or technologies become obsolete during transition?

- Network management and security issues need to be addressed throughout development

Network Requirements

- Network management and security issues need to be addressed throughout development
  - How will the network be monitored for events?
  - Monitoring for network performance?
    - What is the hierarchy for management data flow?
  - Network configuration?
  - Troubleshoot support?
- Security analysis can include the severity (effect) of an attack, and its probability of occurrence

Other Requirements

- Requirements can come from other outside sources
  - Your customer, legal requirements, larger scale organization (enterprise) requirements, etc.

- Additional requirements can include
  - Operational suitability
    - How well can the customer configure and monitor the system?
  - Supportability
    - How well can the customer maintain the system?
  - Confidence
    - What is the data loss rate when the system is running at its required throughput?

Other Requirements

- Financial requirements can include not only the initial system cost, but also ongoing maintenance costs
  - System architecture may be altered to remain within cost constraints
    - This is a good reason to present the customer with design choices, so they see the impact of cost versus performance

- Enterprise requirements
  - Typically include integration of your network with existing standards for voice, data, or other protocols

Requirements Specification & Map

- A requirements specification is a document which summarizes the requirements for (here) a network
  - Often it becomes a contractual obligation, so assumptions, estimates, etc. should be carefully spelled out
- Requirements are classified by Status, as noted earlier (core/current, future, rejected, or informational requirement)
- Priority can provide additional numeric distinction within a given Status (typically on a 1-3 or 1-5 scale)
- Sources for Gathering requirements can be identified, or give basis for Deriving it
- Type is user, app, device, network or other

Requirements Specification & Map

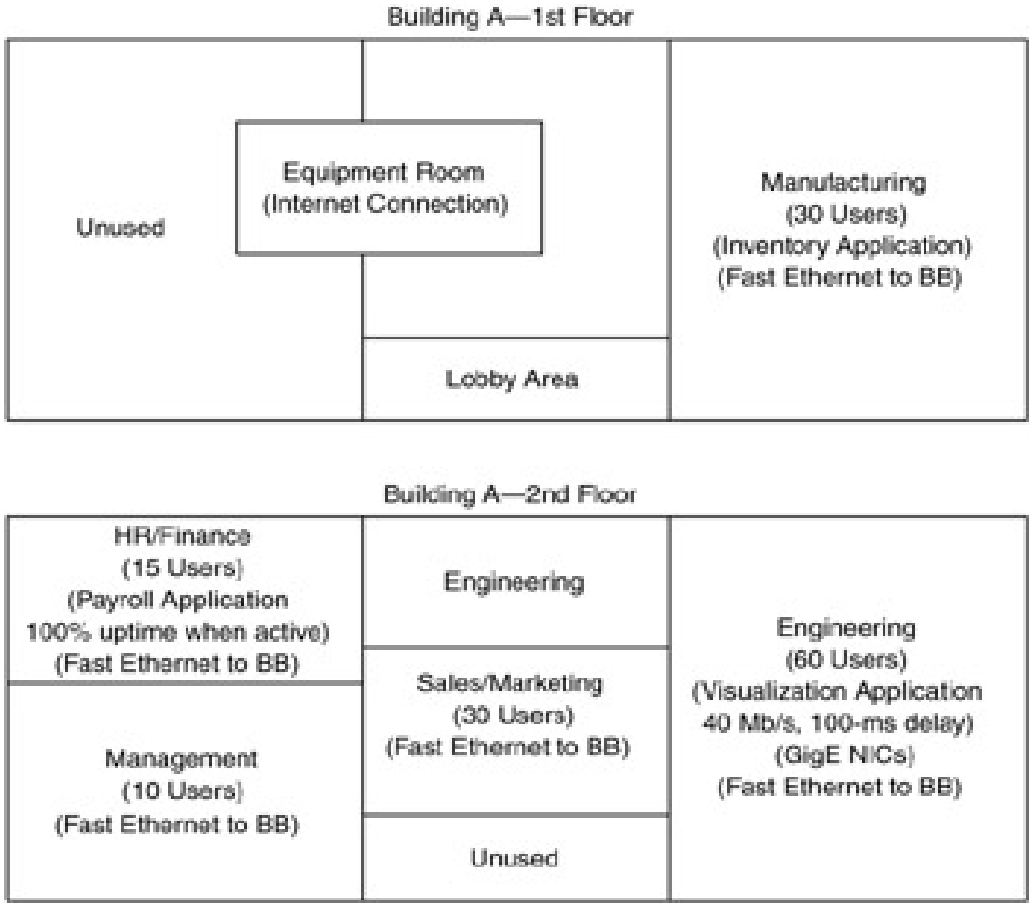
- A requirements specification is a document which summarizes the requirements for (here) a network
  - Often it becomes a contractual obligation, so assumptions, estimates, etc. should be carefully spelled out
- Requirements are classified by Status, as noted earlier (core/current, future, rejected, on a 1-3 or 1-5 scale)

Requirements Specification							
ID/Name	**Date**	**Type**	**Description**	**Gathered/Derived**	**Locations**	**Status**	**Priority**

- Sources for Gathering requirements can be identified, or give basis for Deriving it
- Type is user, app, device, network or other

Requirements Specification & Map

- Requirements Mapping can show graphically where stuff is, what kind of apps are used, and existing connectivity



Campus Networks Design

Terminology

- How does switch work?
- How does Hub work?
- How does bridge work?
- How does router work?

Terminology

- **Workgroup switch**
  - In a local area network (LAN), a **workgroup switch** is a relatively low capacity switch that serves the needs of a **workgroup**, or **small group of workers** who generally are geographically clustered
  - A workgroup switch is the LAN equivalent of an edge switch in a public wide area network (WAN)

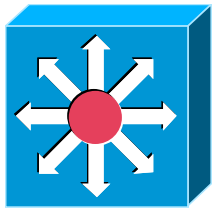
Used symbol

Samples

Terminology

- **High-End switch / Network switch**
  - A network switch (also called **switching hub**, **bridging hub**, officially **MAC bridge**) is a computer networking device that connects devices together on a computer network by using **packet switching** to receive, process, and forward data to the destination device
  - Ethernet switches are the most common form of network switch

Used symbol

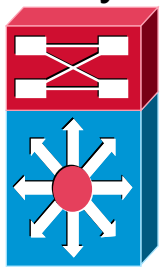


Samples

Terminology

- **Multilayer switch**
  - A multilayer switch is a network device that has the ability to operate at higher layers of the OSI reference model
  - Unlike the Data Link Layer (DLL) traditionally used by switches. A multilayer switch can perform the functions of a **switch** as well as that of a **router** at incredibly fast speeds

Used symbol



Samples

Route Architecture

- Where do we route?
  - At the point where we want to limit our layer-2 broadcast domain
  - At IP subnet boundary
  - We can create more complex topologies using routers and at the same time keep things simple
  - If we start with the right topology it will make our network more stable
  - Use a hierarchical approach that makes good use of your traffic patterns and IP address allocations
  - Be aware that topology and logical design are not the same

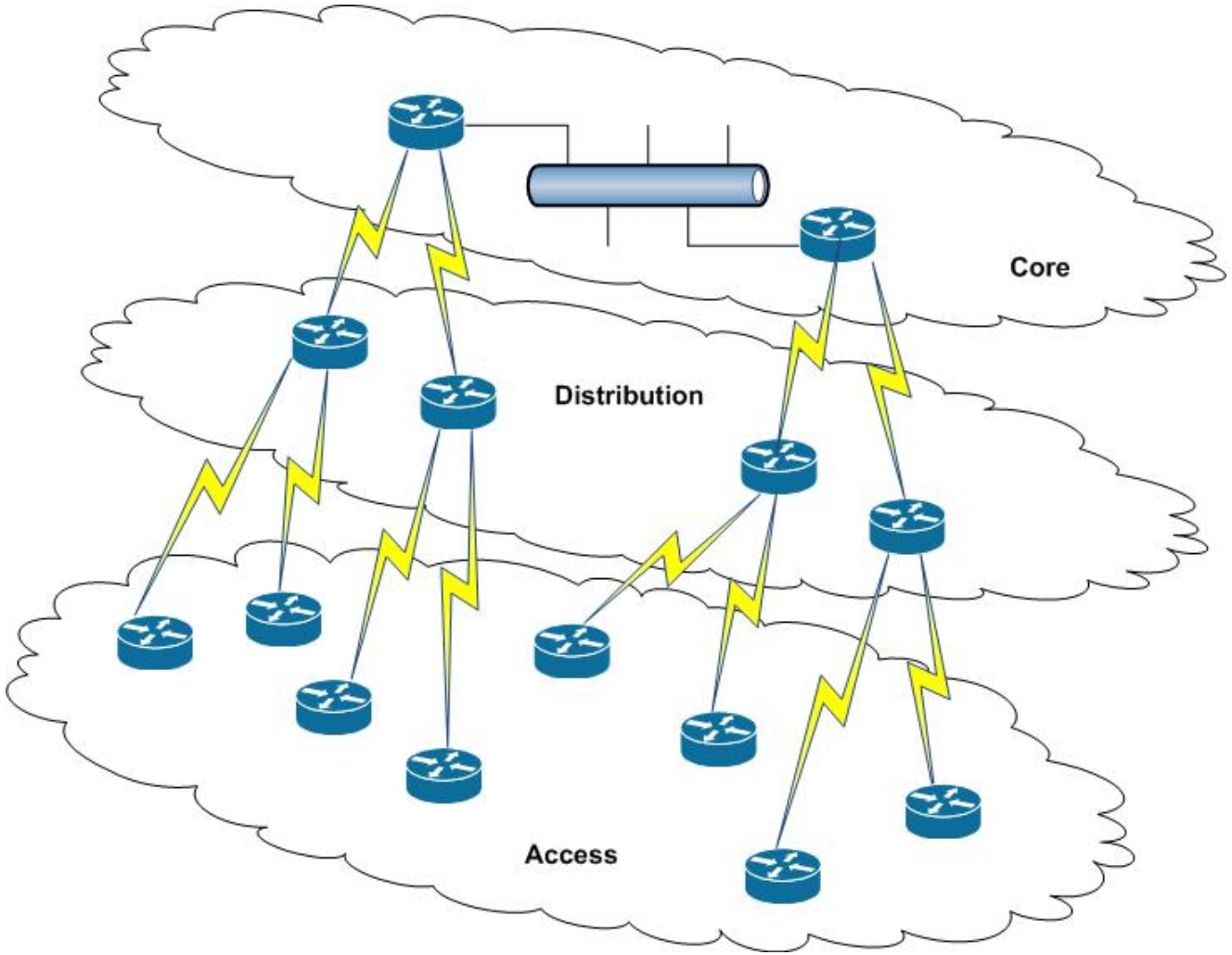
Route Architecture

- What is the right topology?

- Continue to think of three layers
  - Access
  - Distribution
  - Core

- Thinking of layers helps reduce convergence time because of the scope of information to process These layers should not be confused with your L2 architecture

Route Architecture



Route Architecture

- **Access Layer**
  - Minimum routing information
  - Feeds traffic into the network
    - Link sizing
  - Provides network access control
    - No spoofing
    - No broadcast sources
    - No directed broadcasts
  - Provides other edge services
    - Tagging for QoS
    - Tunnel termination
    - Traffic metering and accounting
    - Policy-based routing

Route Architecture

- **Distribution Layer**
  - Goals
    - Isolates topology changes
    - Controls the routing table size
    - Aggregates traffic
  - Strategies
    - Route summarization
    - Minimize the number of connections to the core

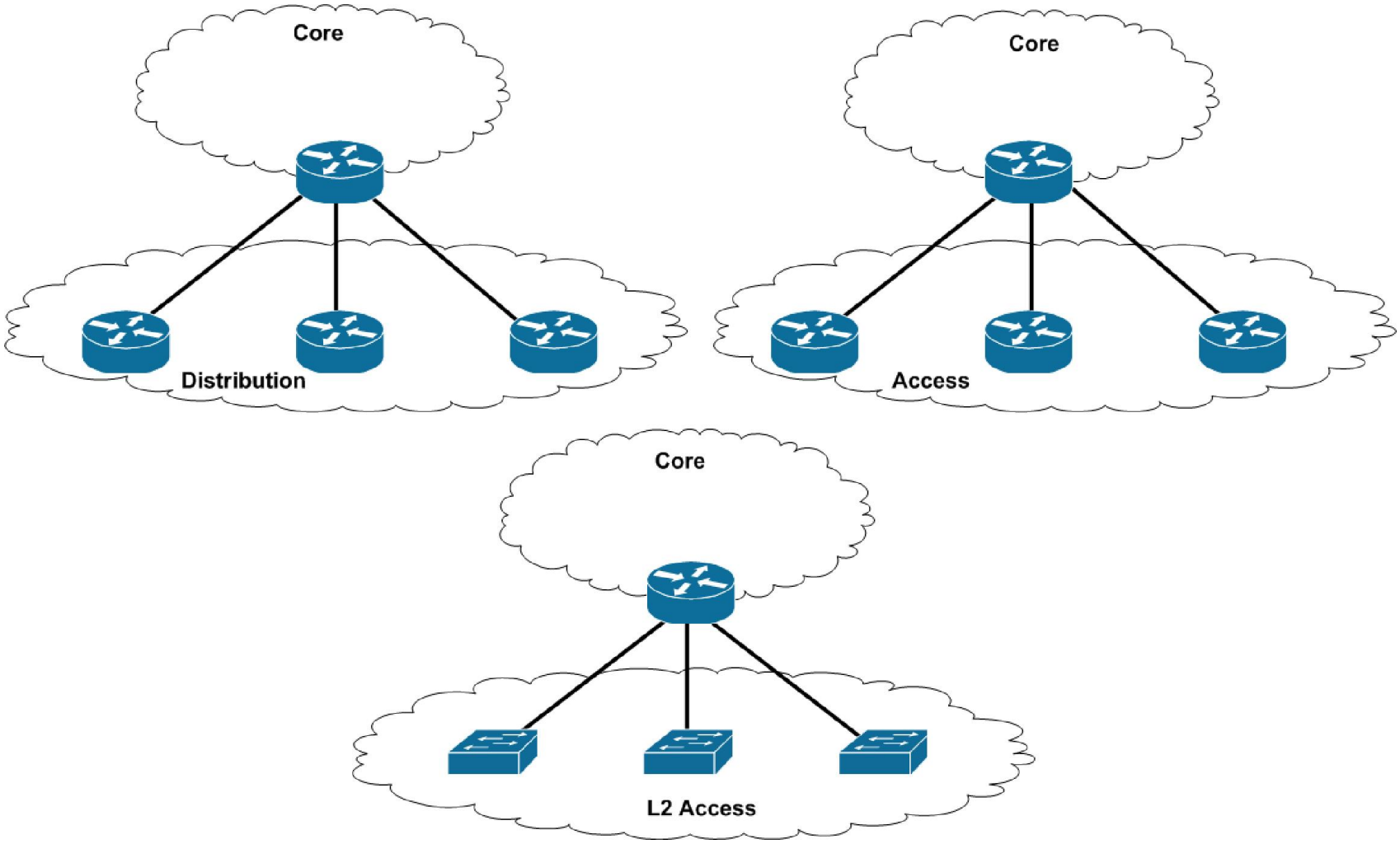
Route Architecture

- **Core Layer**
  - Goal
    - Forwarding packets fast
  - Strategies
    - Clear of network policies
    - Every device has full reachability to every destination
      - Facilitates core redundancy
      - Reduces suboptimal routing
      - Prevents routing loops

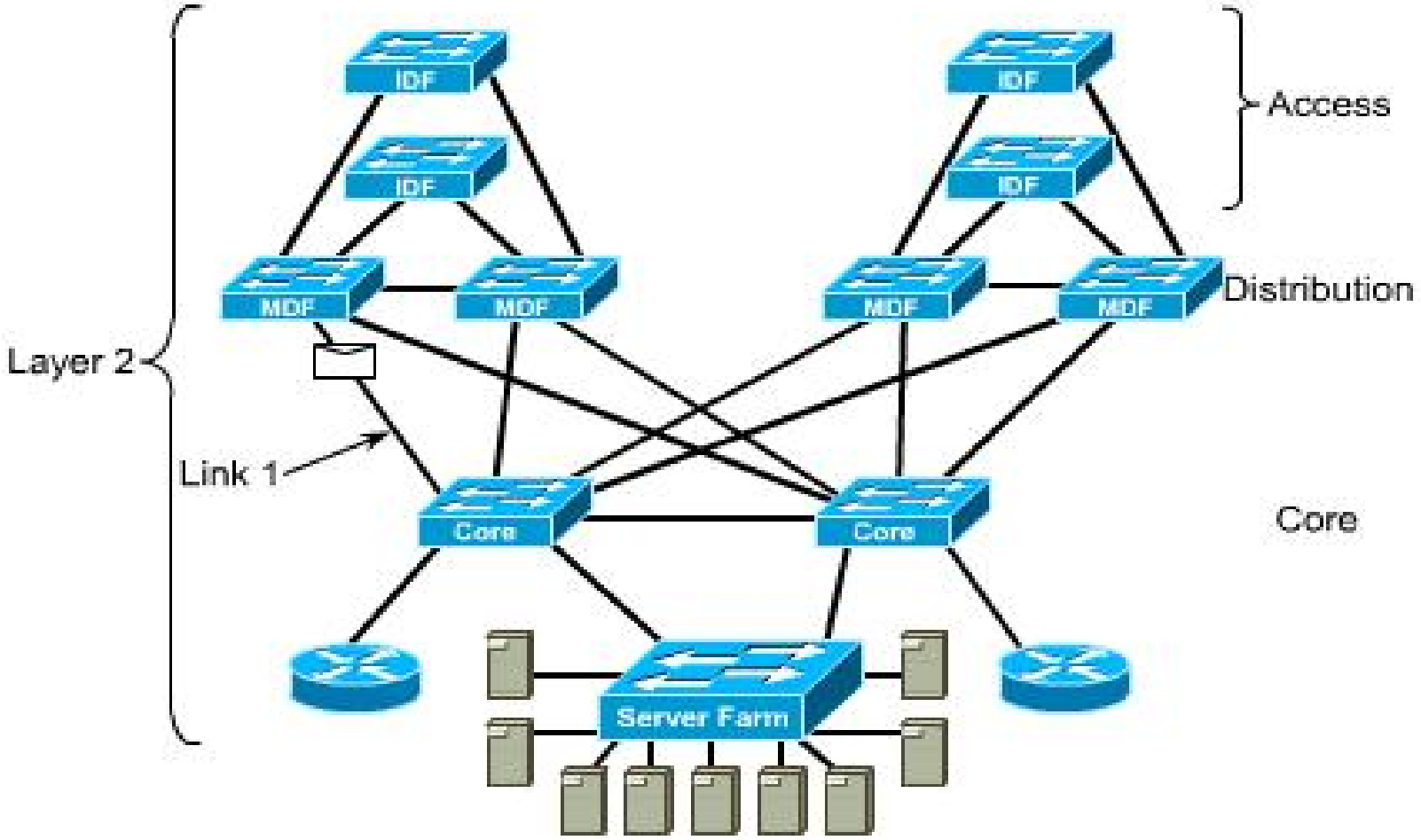
Route Architecture

- Depending in how large your campus is you could use the typical hierarchical model or a subset
  - Two collapse core models
    - Single router acts as the network core
      - All other routers in the distribution layer
    - Single router acts as the network core
      - No distribution layer
      - All access layer routers connected to the core

Route Architecture



Traditional Campus Networks



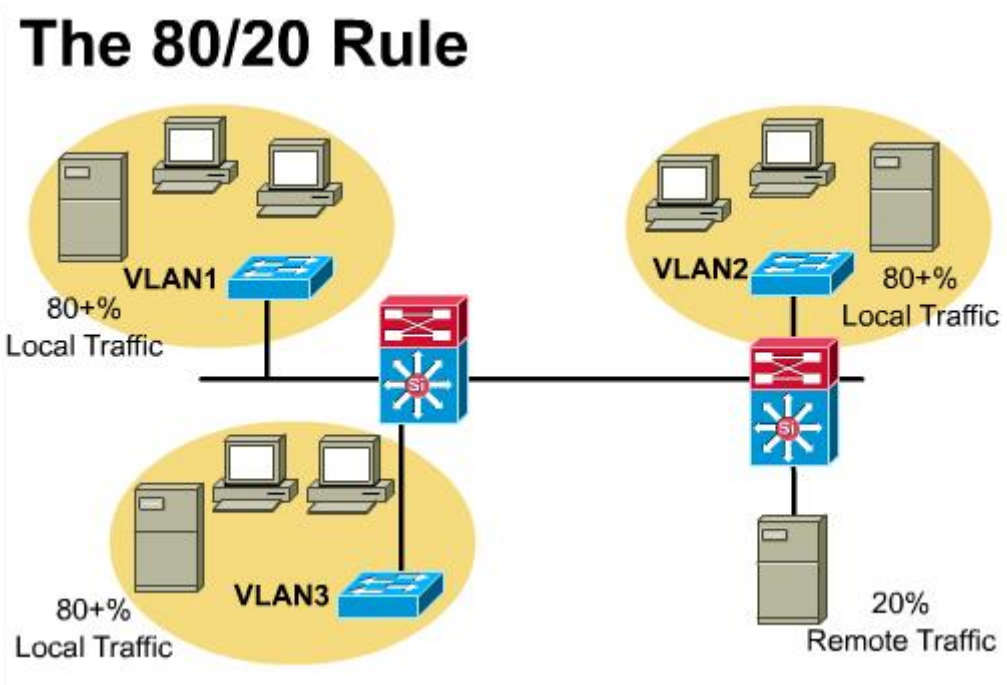
Traditional Campus Networks

- Campus Network
  - A building or group of buildings connected into one enterprise network that consists of or more LANs
  - Generally deploy a campus design that is optimized for the fastest functional architecture over existing wire

- Network Administrator Challenges
  - LAN run effectively and efficiently
    - Availability and performance impacted by the amount of bandwidth in the network
  - Understand, implement and manage traffic flow

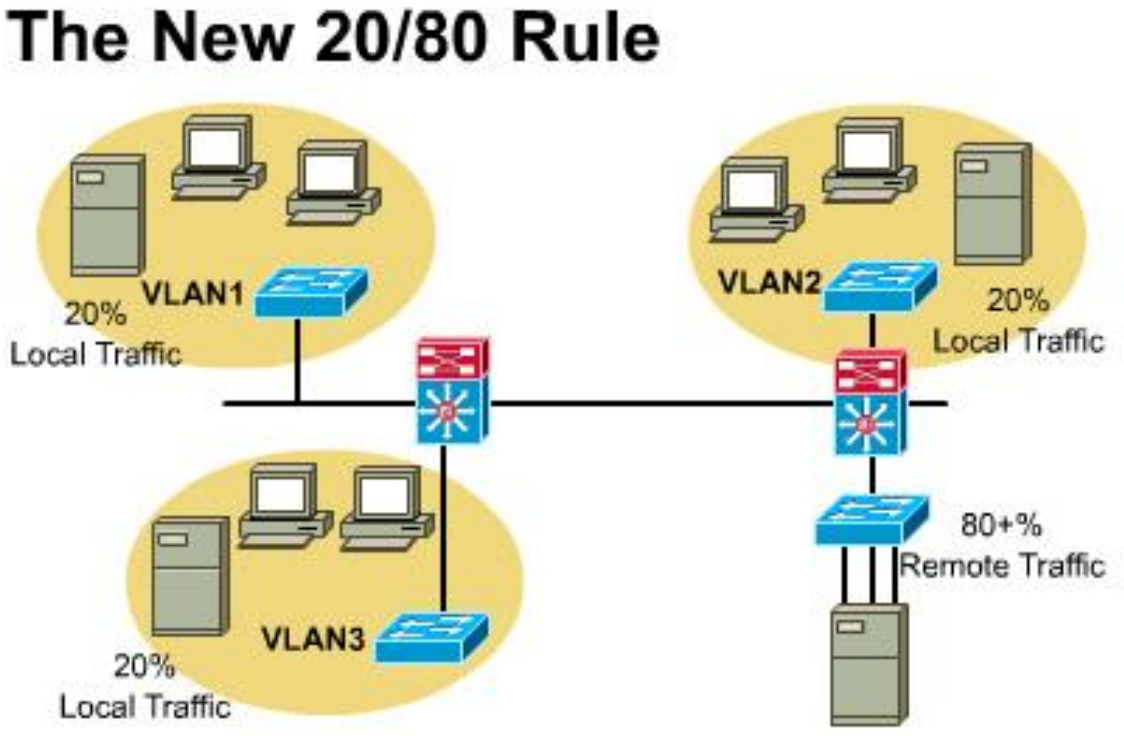
- Useful services
  - Broadcasts, multicast traffic (traffic propagated to a specific group of users on a subnet), video conferencing, multimedia traffic
  - Security and traffic flow

80/20 or 20/80 Rule



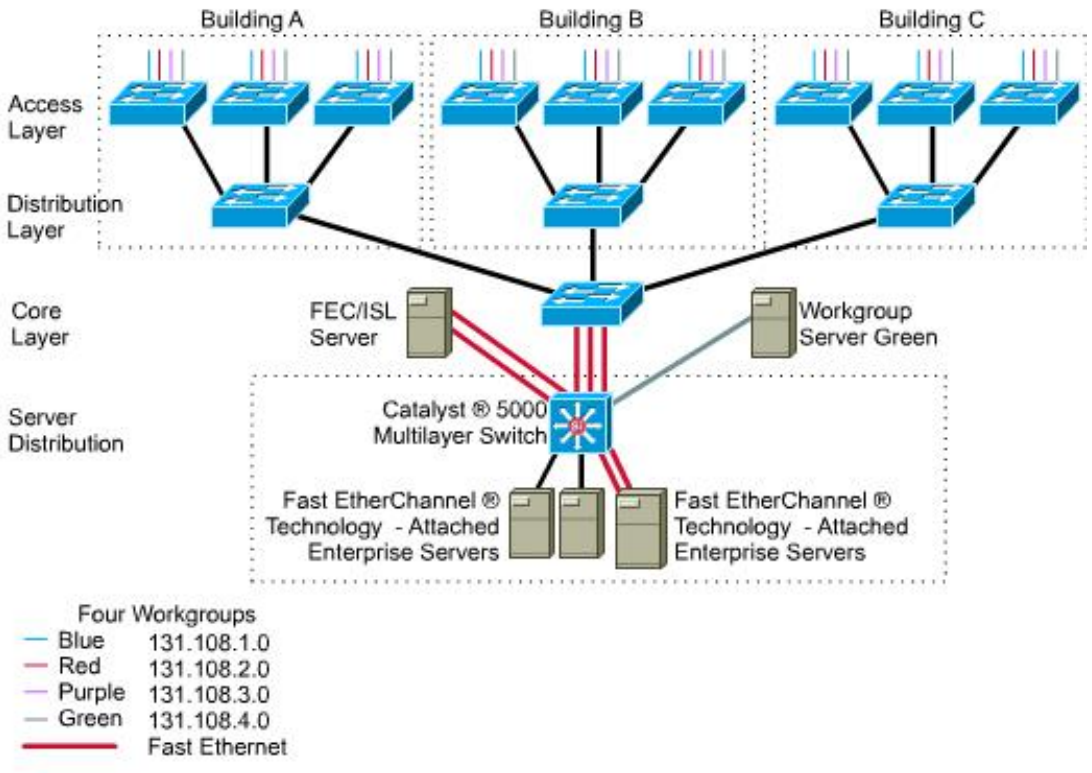
- Traditional 80/20 rule
  - 80% traffic local to subnet, 20% remote
- Remote traffic
  - Traffic across the backbone or core to enterprise servers, Internet, remote sites, other subnets (more coming)

80/20 or 20/80 Rule



- New 20/80 rule
  - 20% traffic local to subnet, 80% remote
- Traffic moving towards new 20/80 rule due to
  - Web based computing, servers consolidation of enterprise and workgroup servers into centralized server farms due to reduced TCO, security and ease of management

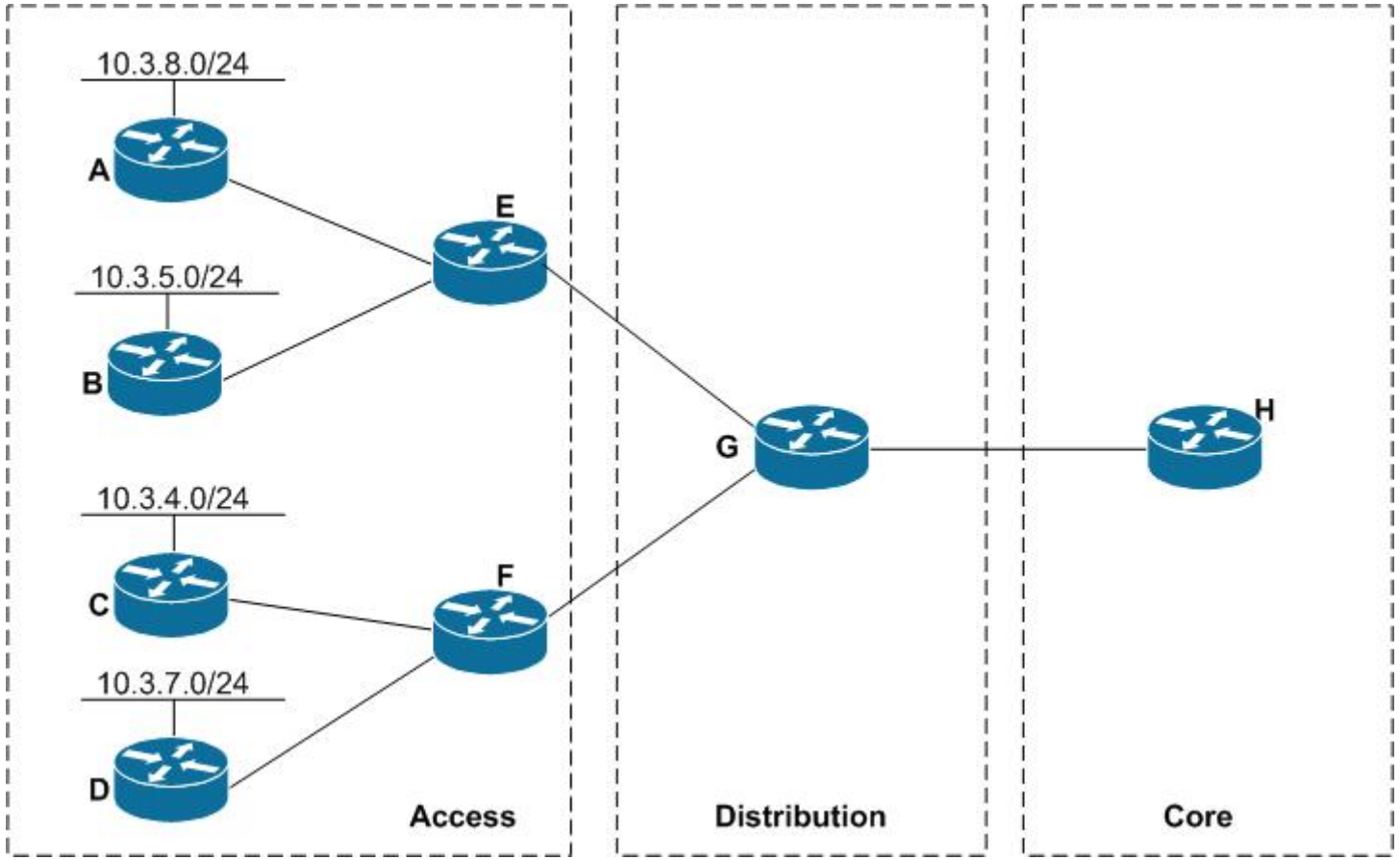
Evolving Campus Structure



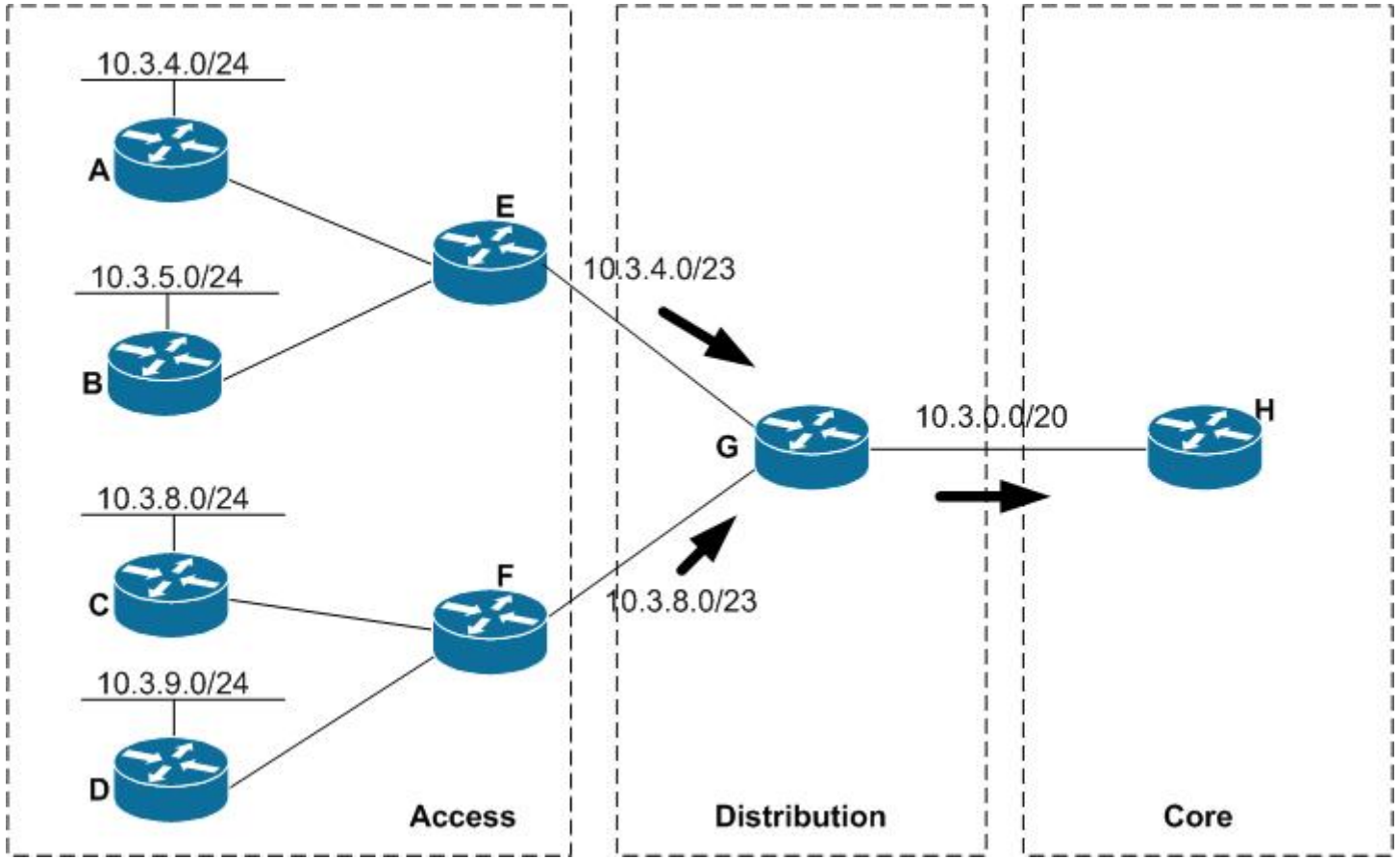
Address Space

- What to do about your address space
  - Assign it as you need it ….. WRONG!
    - Poor summarization has an impact on your network's stability
    - Very difficult to correct poor allocations
  - Spend some time thinking about how you will assign address space
    - Routing stability is affected by the number of routes propagated through your network

Address Space



Address Space



Address Space

- Where should you summarize?
  - Only provide full topology where it is needed
    - Core routers don't need to know about every single network
    - Access routers don't need to know how to get to every other network
      - They should only carry enough information to reach one (or a couple of) distribution router(s)
  - Summarize at the hierarchy edges
    - Distribution layer to core
    - Distribution layer to access

Address Space

- Strategies for Successful Addressing
  - First come, first serve
    - Start with a large pool and hand them out as needed
  - Politically
    - Divide the space so each group with in the organization have a pool of addresses available
  - Geographically
    - Divide the space so that every location has a pool of addresses available
  - Topologically
    - Assign addresses based on the point of attachment to the network (maybe same as geographically)

High Availability

- How can we achieve high availability?
  - Introduce hardware resiliency and backup paths into your network
  - Depending on the layer, you will use techniques differently
  - The idea is to protect your network against a single device failure affecting all of your network
  - Direct relationship between reliability, complexity and costs
  - The trick is to balance all variables and come up ahead

High Availability

- Evaluate your needs
  - Minimal need
    - Network just needs to be up for a portion of the day
    - Downtime is easily schedule after working hours

    - Business is not impacted if the network is down
    - Users' productivity is not impacted by a network failure

  - Medium need
    - Network needs to be available for most of the day
    - Only centralized servers need to be up 24 hours/day

    - Downtime needs to be scheduled on weekends
    - If critical parts of the network fail, the business operation is impacted
    - A network failure affects user productivity

High Availability

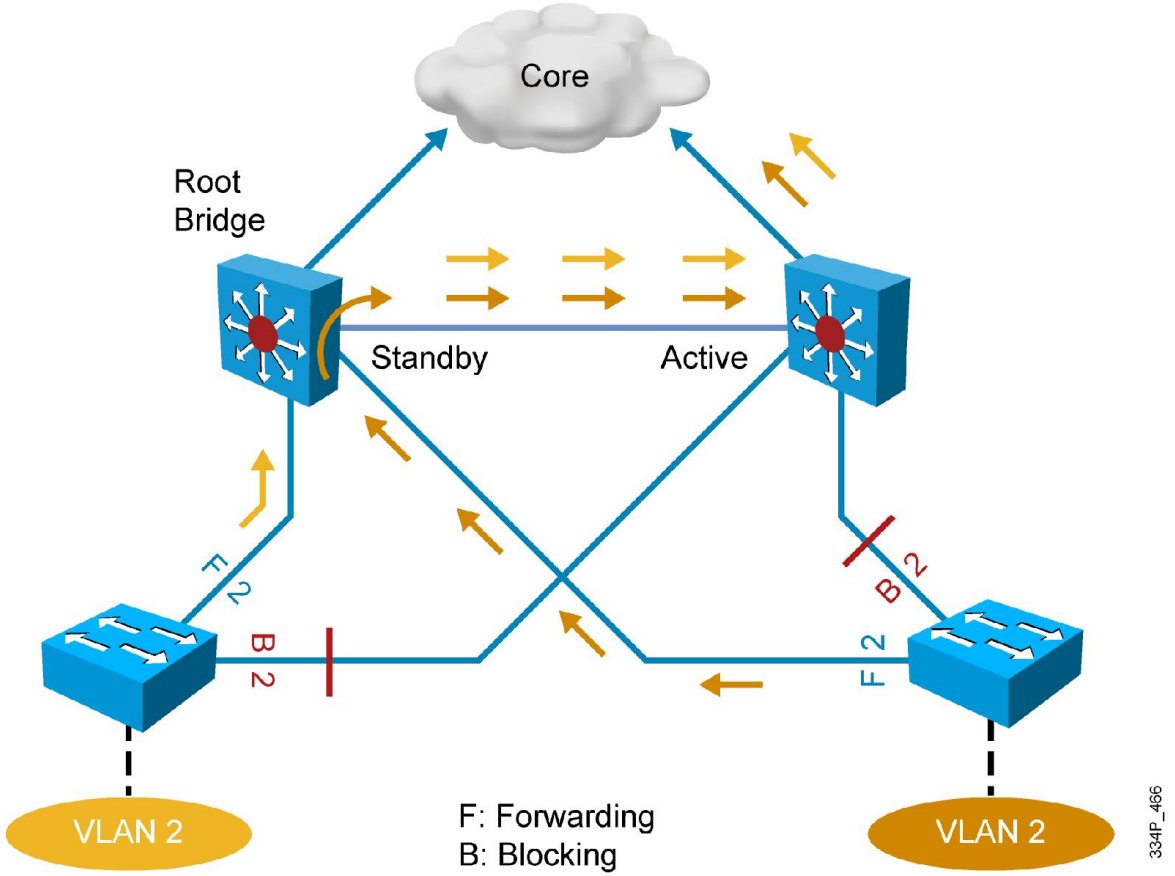
- High need
  - Network needs to be up 24x7
  - Downtime are scheduled well in advance and completed within schedule
  - A network failure causes major loss of business
  - User productivity drastically impacted by a network failure

High Availability

- Methods
  - Component Redundancy
    - Duplicate or backup parts
      - Power supplies, fans, processors, etc.
    - Have spares handy
  - Server Redundancy
    - Protect your data with backups
    - Use of hot standby servers
    - Or better yet use load balancers to distribute access
  - Network Link & Data Path Redundancy
    - Provide physical redundant connections between devices
    - Allow for hot backup paths (STP) and parallelism (routing)

High Availability

- Configured active router should be the same as STP root bridge
- Blocked uplink caused traffic to take less-than-optimal path



High Availability

- Core layer
  - Build a dual router core and provide dual paths to it from your distribution layer
    - These could be either L2 or L3 paths
  - Make sure that you have redundant power supplies in your devices
    - This also assumes two different sources of power
    - Think of UPS protected circuits
    - Maybe even a power inverter solution for emergencies
  - Think about the possibility of dual routing/forwarding engines
    - Weight this against the use of two devices
    - Or just throw that in there as yet another layer of reliability

High Availability

- You want to also balance
  - Reduction of the hop count
  - Reduction of the available paths
  - Increase of the number of failures to withstand

- Easy to do in a single location but complexity and costs directly proportional to the number and distance between the locations

High Availability

- Distribution Layer
  - Provide dual connections to the core
    - Or provide a redundant link to other distribution layer devices
      - Doubles the core's routing table size
      - Possible use of the redundant path for traffic transiting the core
      - Preferring the redundant link to the core path
      - Routing information leaks
  - Allow for dual-homing of Access layer devices

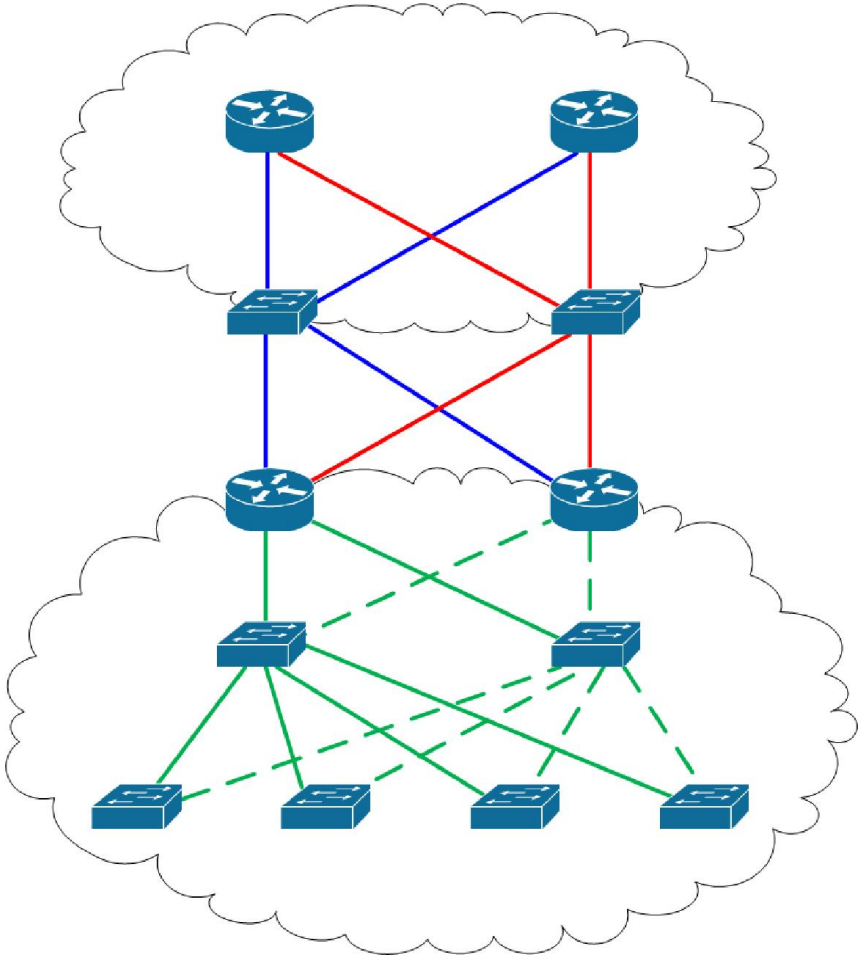
High Availability

- Make sure that you have redundant power supplies in your devices
  - This also assumes two different sources of power
  - Think of UPS protected circuits
  - Maybe even a power inverter solution for emergencies
- Think about the possibility of dual routing/forwarding engines
  - Weigh this against the use of two devices
  - Or just throw that in there as yet another layer of reliability
  - Increases the cost of the distribution layer

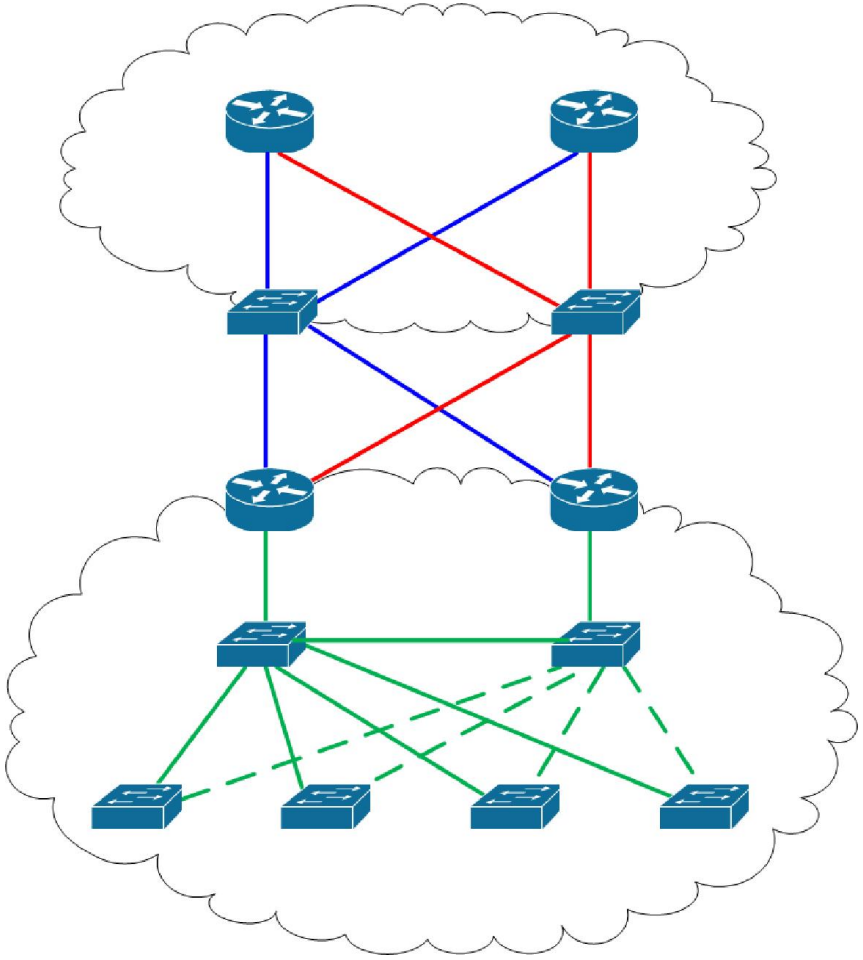
High Availability

- Access Layer
  - Same challenges and solutions as the distribution layer
    - Dual home to the same distribution layer branch
      - Make sure to restrict destinations advertised to prevent transit traffic through the access layer router
    - Alternate path to another access layer device
      - Don’t use the redundant link for normal traffic
      - Make sure to restrict destinations advertised to prevent transit traffic through the access layer router
    - Dual home to different distribution layer branches
      - Don’t use the redundant link for normal traffic
      - Make sure to restrict destinations advertised to prevent transit traffic through the access layer router

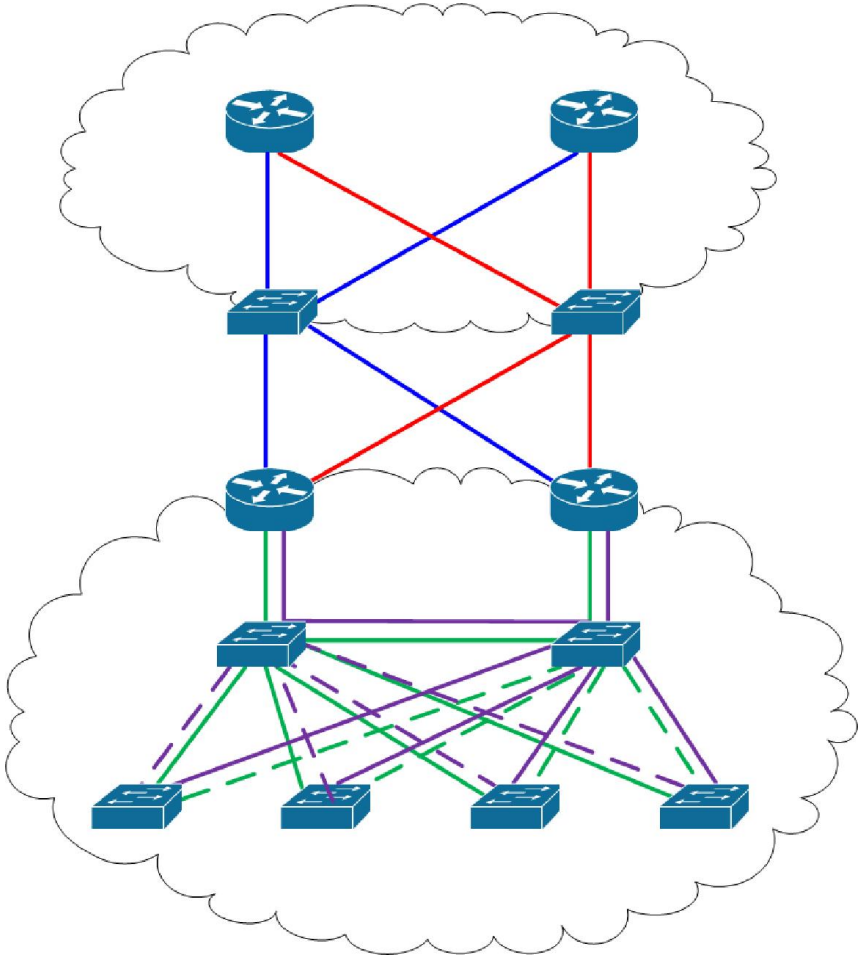
High Availability



High Availability



High Availability



High Availability

- So I built all this redundancy and high availability in my network, how can my end users take advantage of it?
- You are already providing more than one router for a segment
- You want to provide your users with a way to move their traffic from one default gateway to another
- If one of the routers fails the other one will continue to provide services to the segment
- Be aware that redundancy is not the same as load balancing

High Availability

- How can we accomplish that?
  - Have the routers do proxy-ARP
  - Run a routing protocol between your workstations and the routers
  - Split your workstations into two groups
    - One uses one router as its default gateway
    - The other group uses the other router
  - Use ICMP Router Discovery Protocol (IRDP)
  - There is got to bit a better and simpler way to do this

High Availability

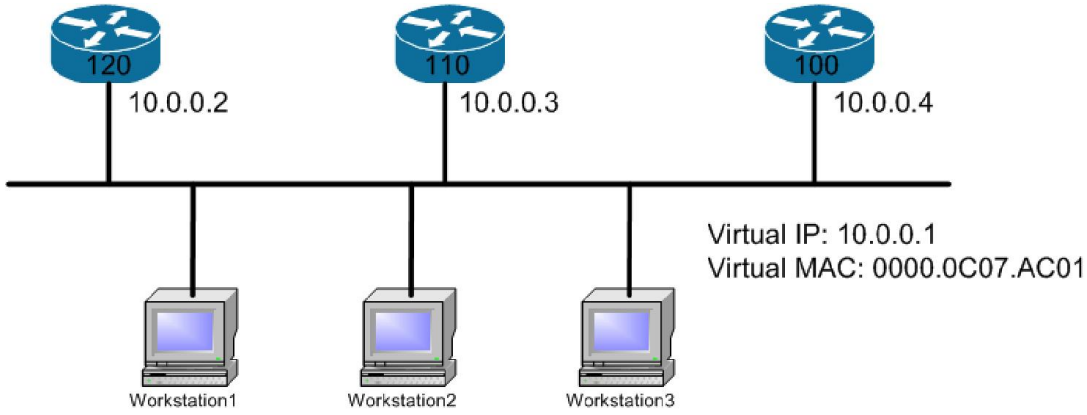
- Current solutions:
  - Hot Standby Redundancy Protocol – HSRP (Cisco Proprietary, RFC2281)
  - Virtual Router Redundancy Protocol – VRRP (RFC3768)
  - Gateway Load Balancing Protocol – GLBP (Cisco Proprietary)

High Availability

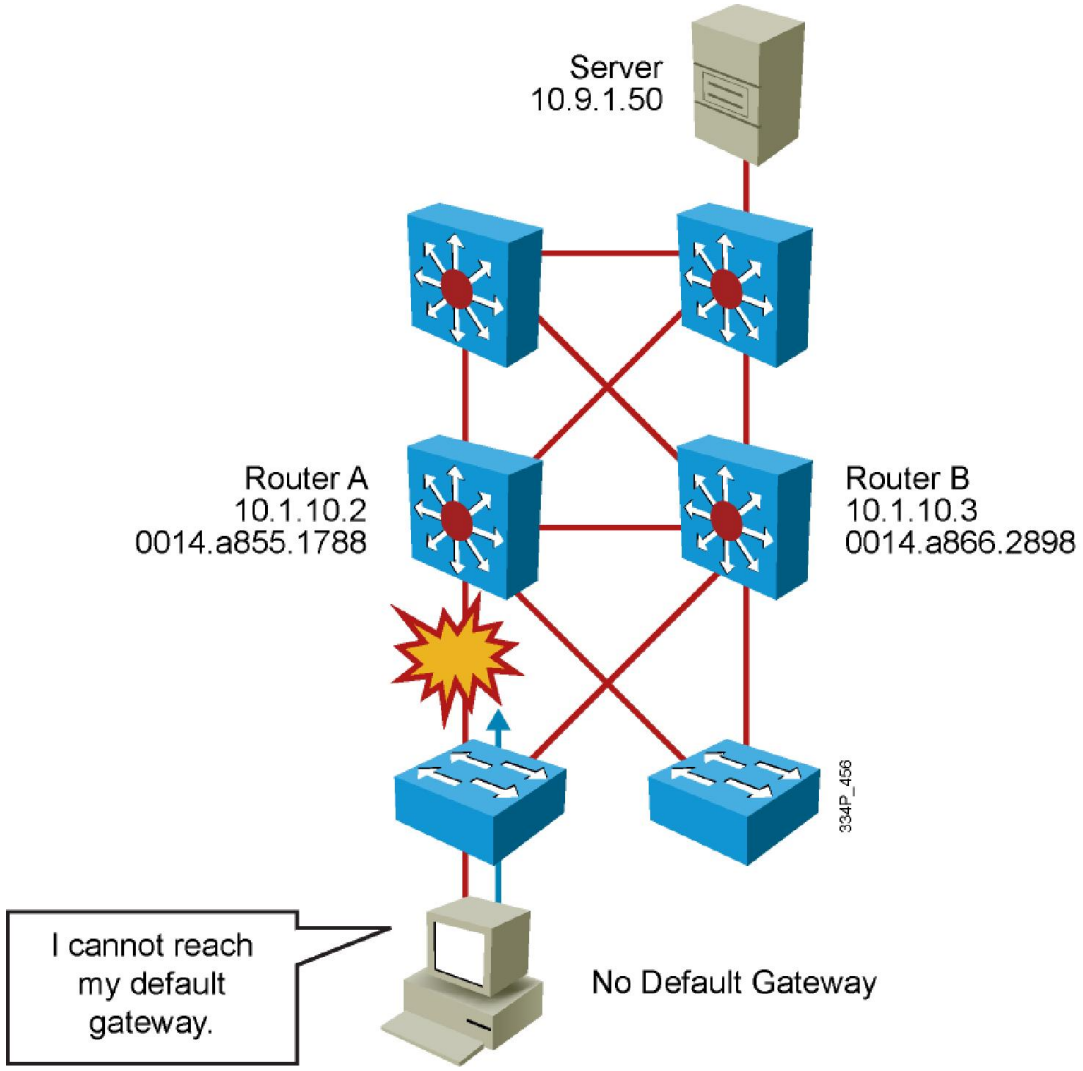
- The concept is very similar
  - Workstations get configured with a single default gateway
  - The routers in the segment will negotiate who will provide services to the workstations and keep track of the state of the other routers
  - In the event of a primary/active router failure, one of the standby routers will take over the task of forwarding traffic for the workstations and become the primary/active
  - Traffic to the workstations will go to the primary/active router
  - Incoming traffic into the segment will follow the routing decisions made by routers in the network

High Availability

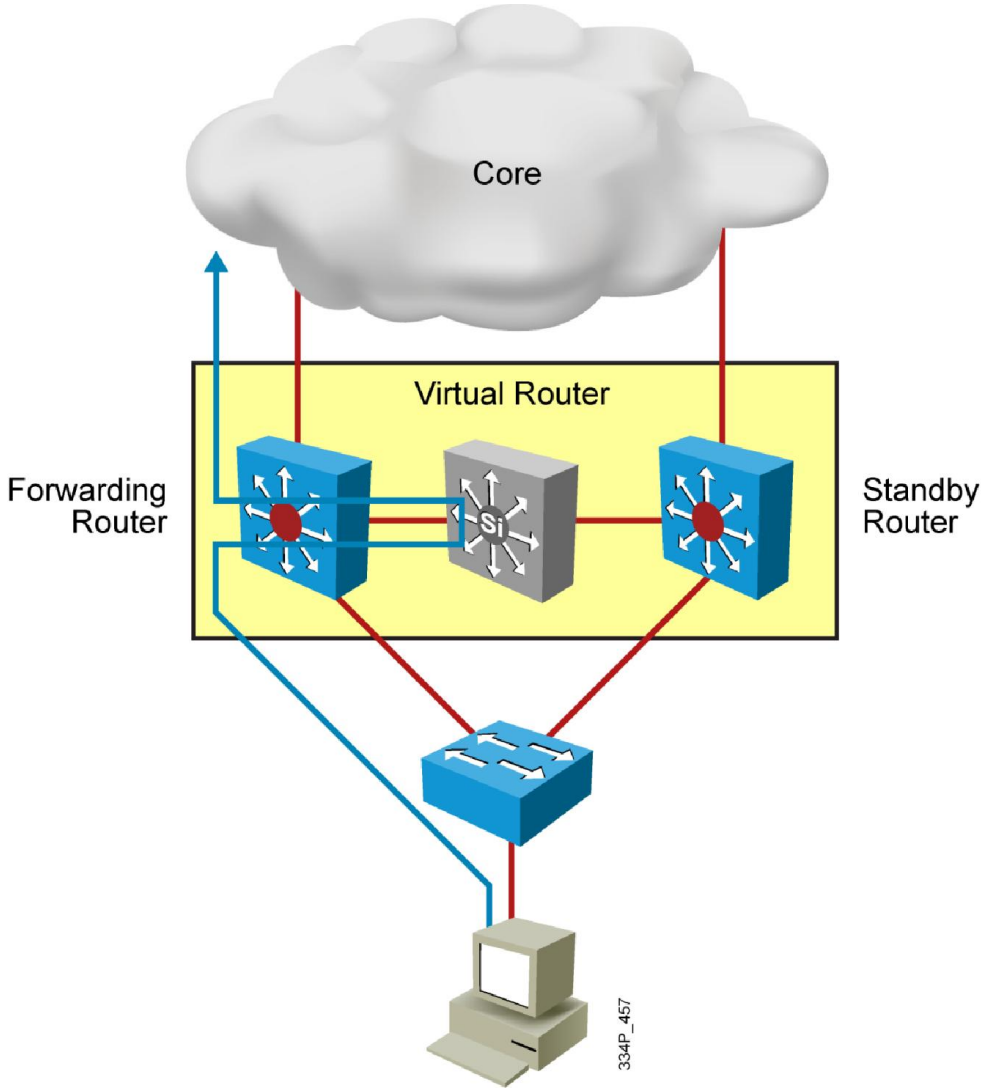
- HSRP



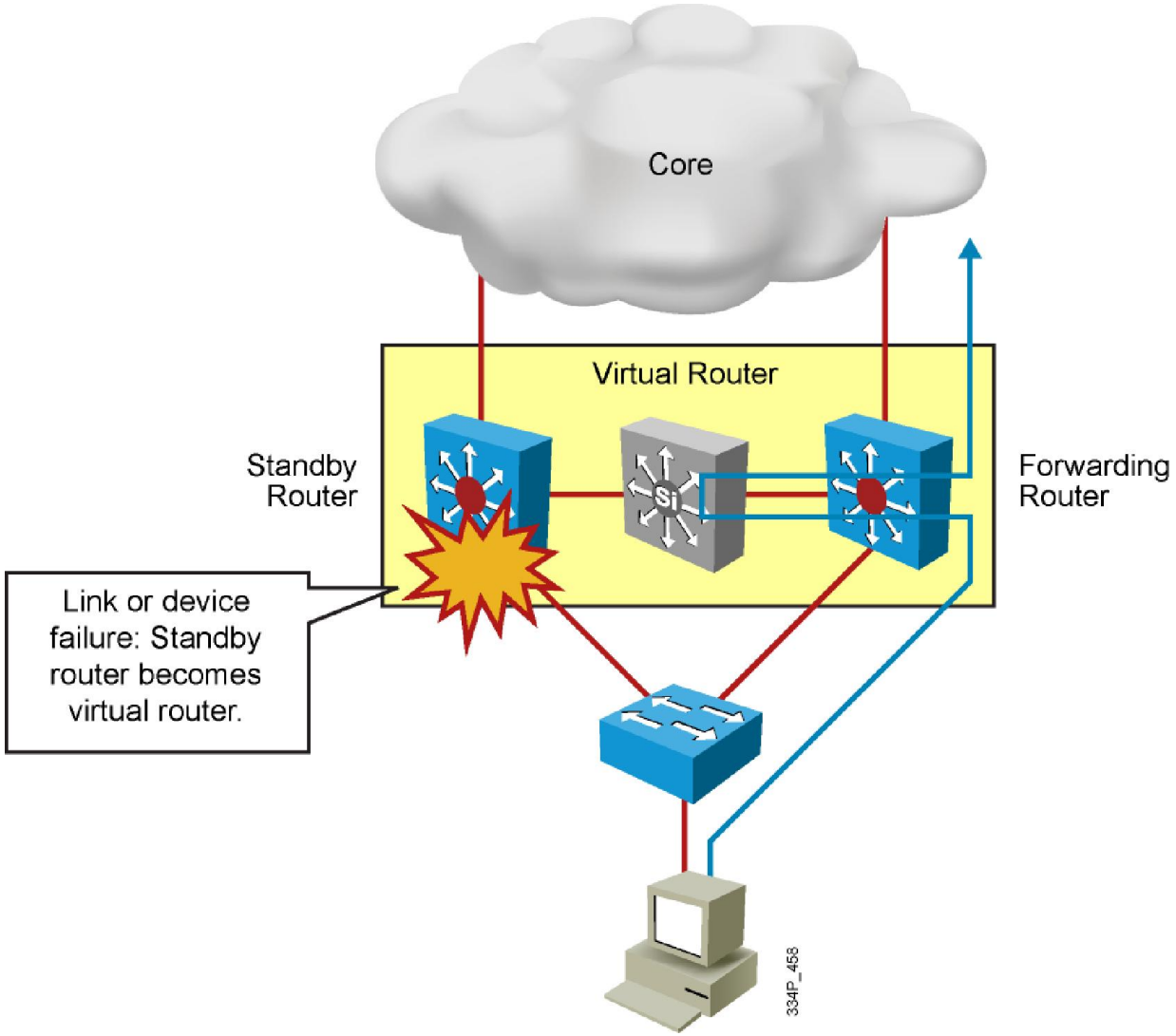
High Availability



High Availability

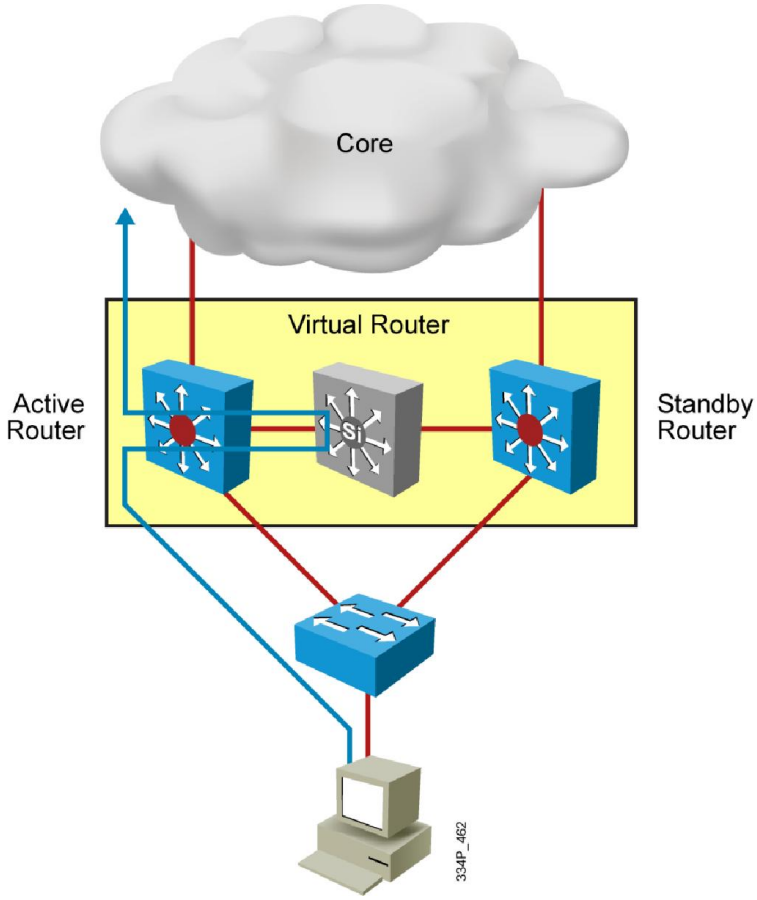


High Availability



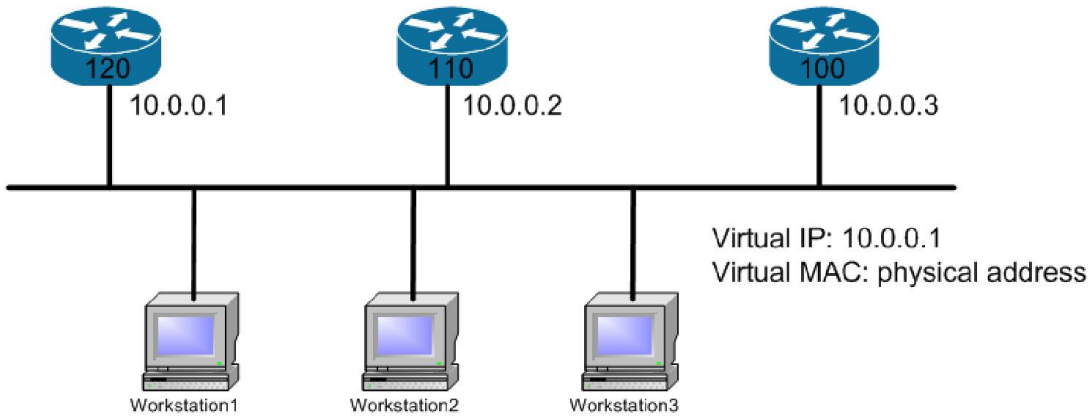
High Availability

- Active and Standby Routers
  - Active router
    - Responds to ARP requests of the default gateway with the MAC address of the virtual router
    - Assumes the active forwarding of packets for the virtual router
    - Sends hello messages
    - Knows the virtual router IP address
  - Standby router
    - Listens for periodic hello messages
    - Assumes the active forwarding of packets if no messages heard from active router



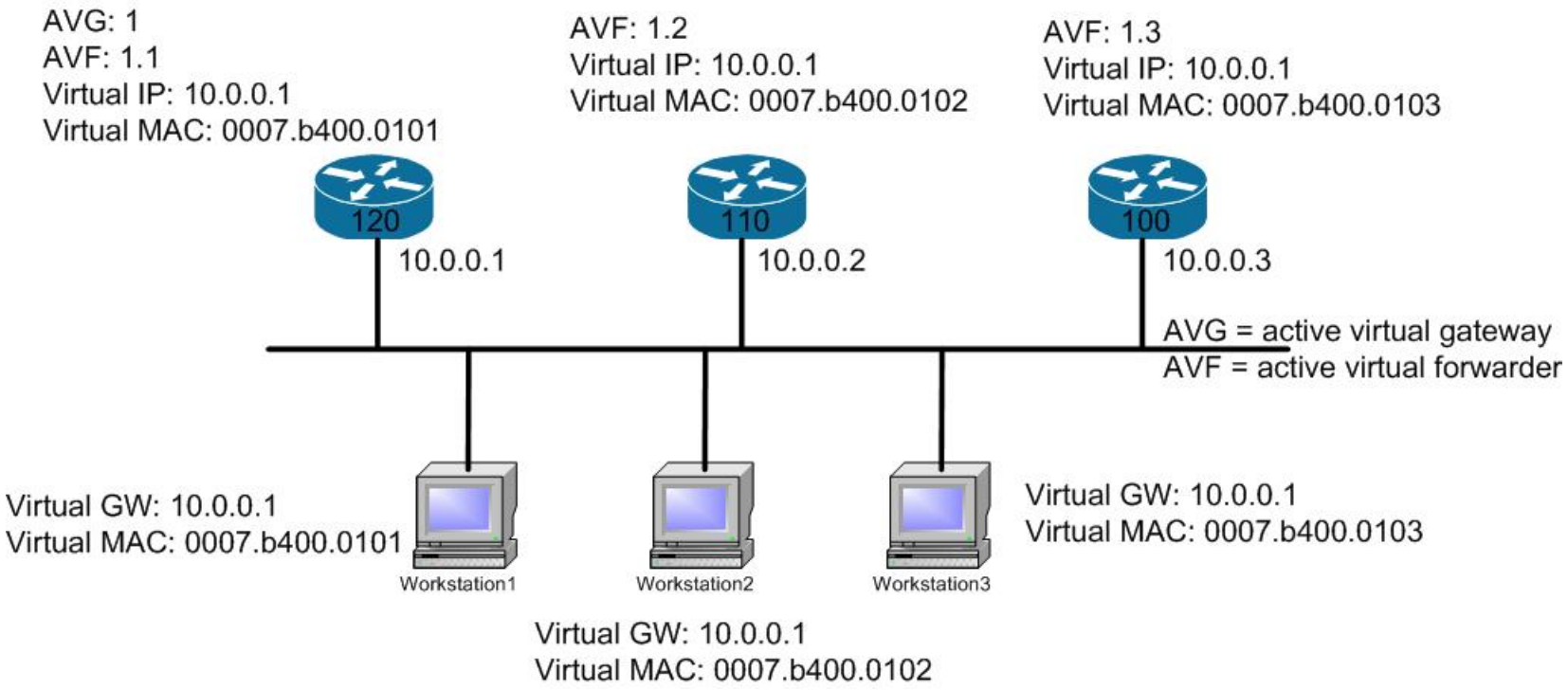
High Availability

- VRRP



High Availability

- GLPR



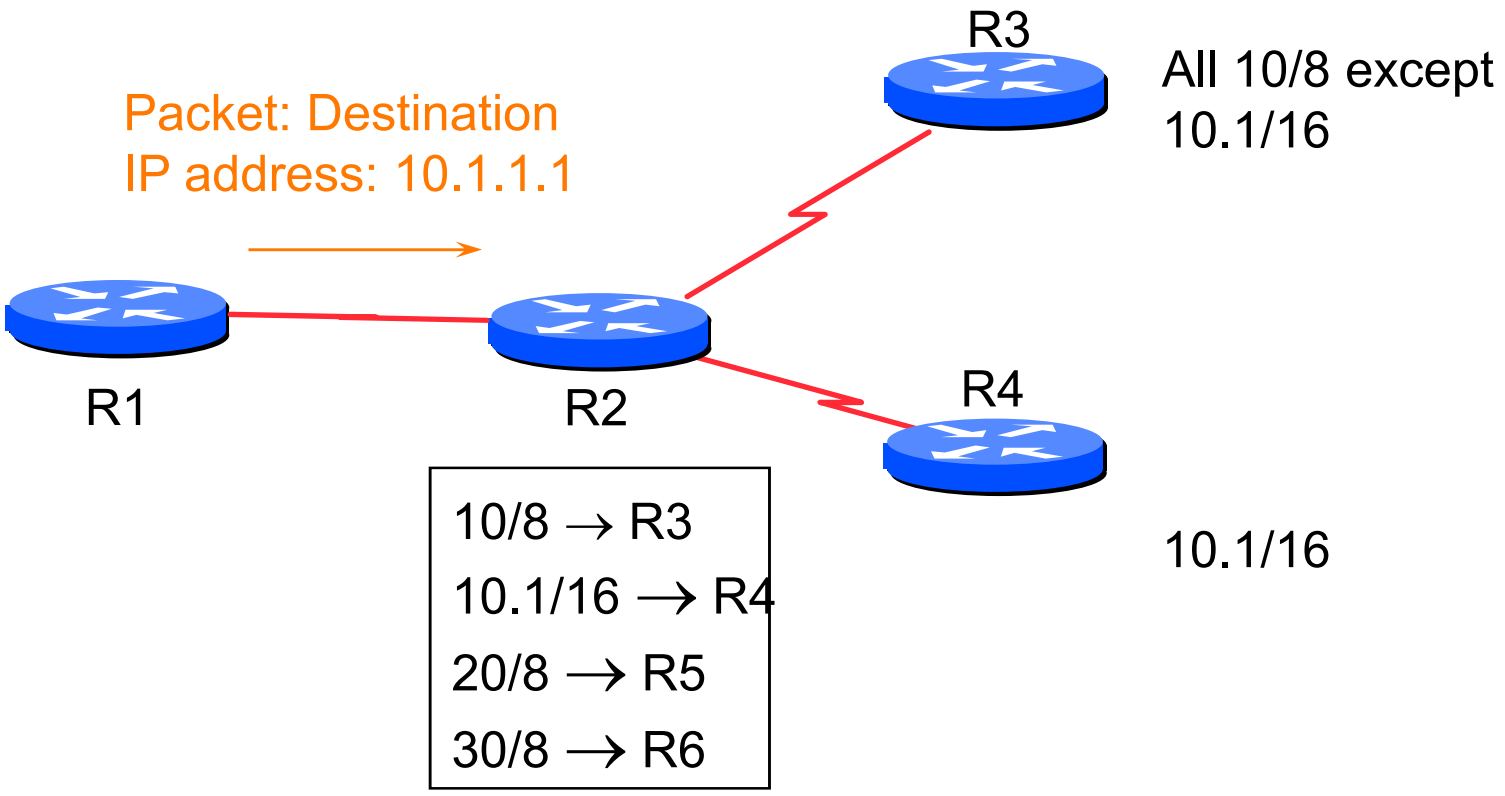
High Availability

- Which one should I use?
  - They all allow for a common default gateway and MAC address
  - VRRP is standardized
    - HSRP/GLBP are Cisco proprietary
  - GLBP provides load balancing
    - HSRP/VRRP do not (without introducing complexity)
  - GLBP/HSRP can track an uplink interface
    - VRRP does not

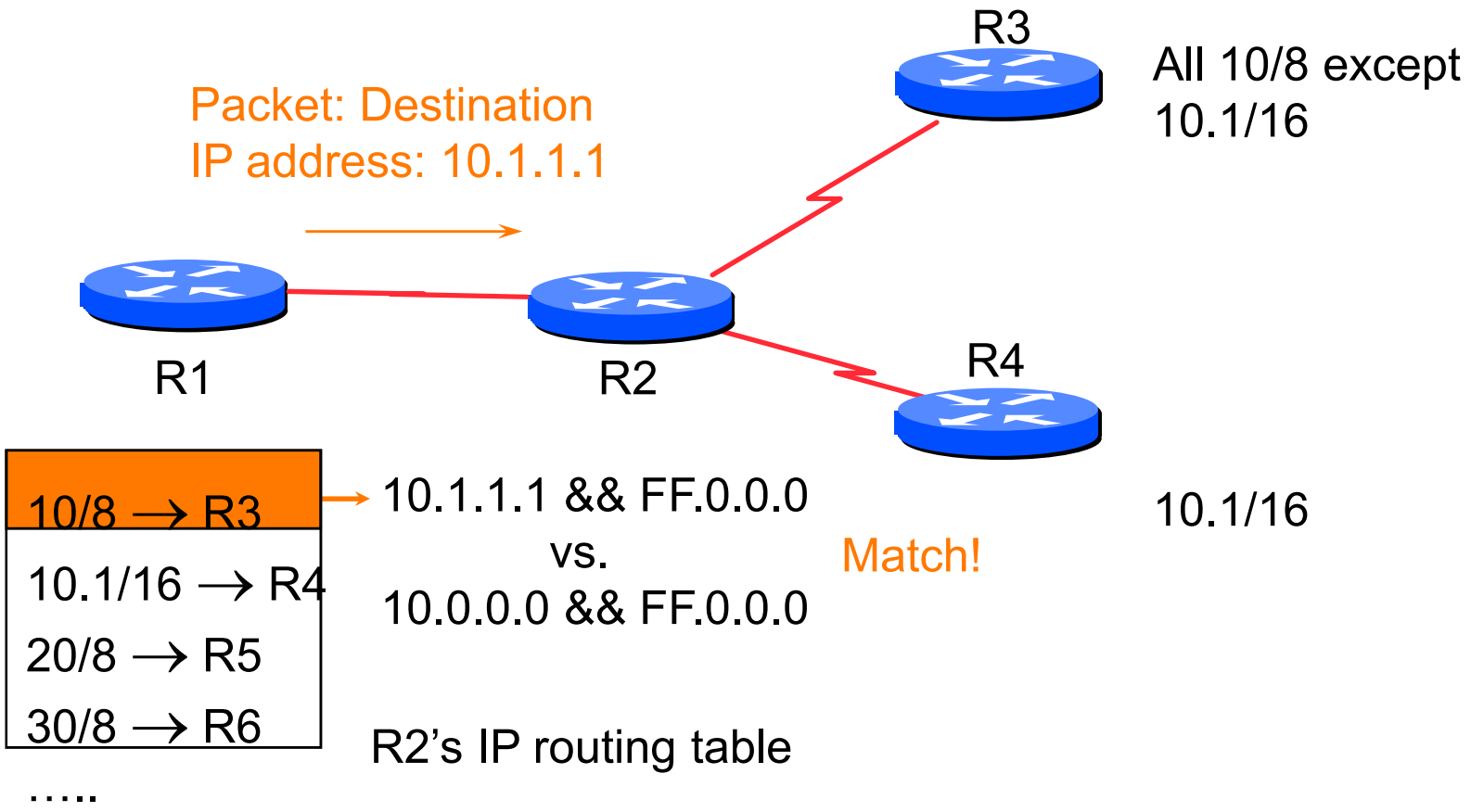
High Availability

- VRRP can reuse the default gateway IP
  - HSRP does not
- HSRP/GLBP support IPv6
  - VRRP does not yet
- VRRP uses protocol 112 & 224.0.0.18
  - HSRP uses UDP/1985 & 224.0.0.2
  - GLBP uses UDP/3222 & 224.0.0.102

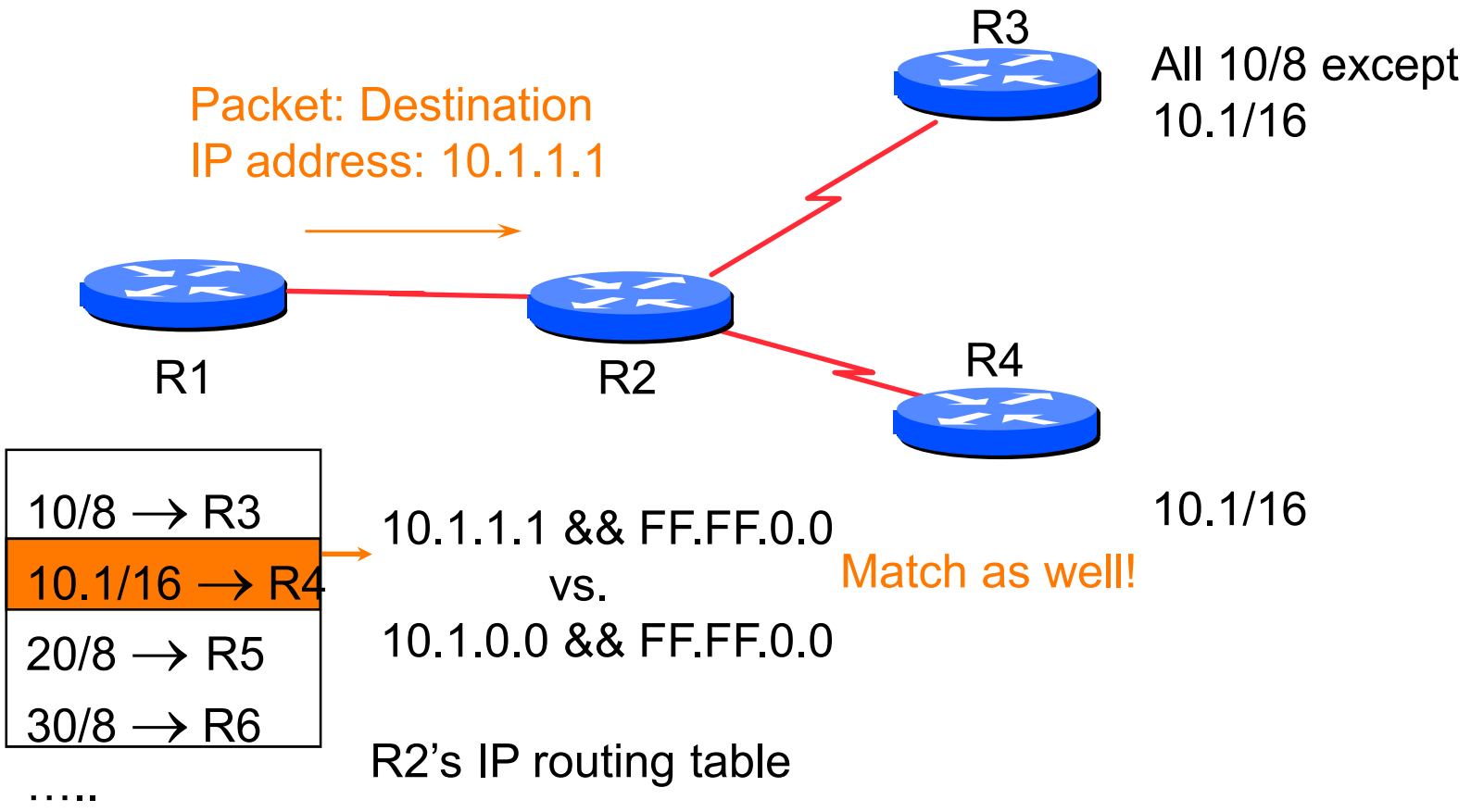
IP Route Lookup



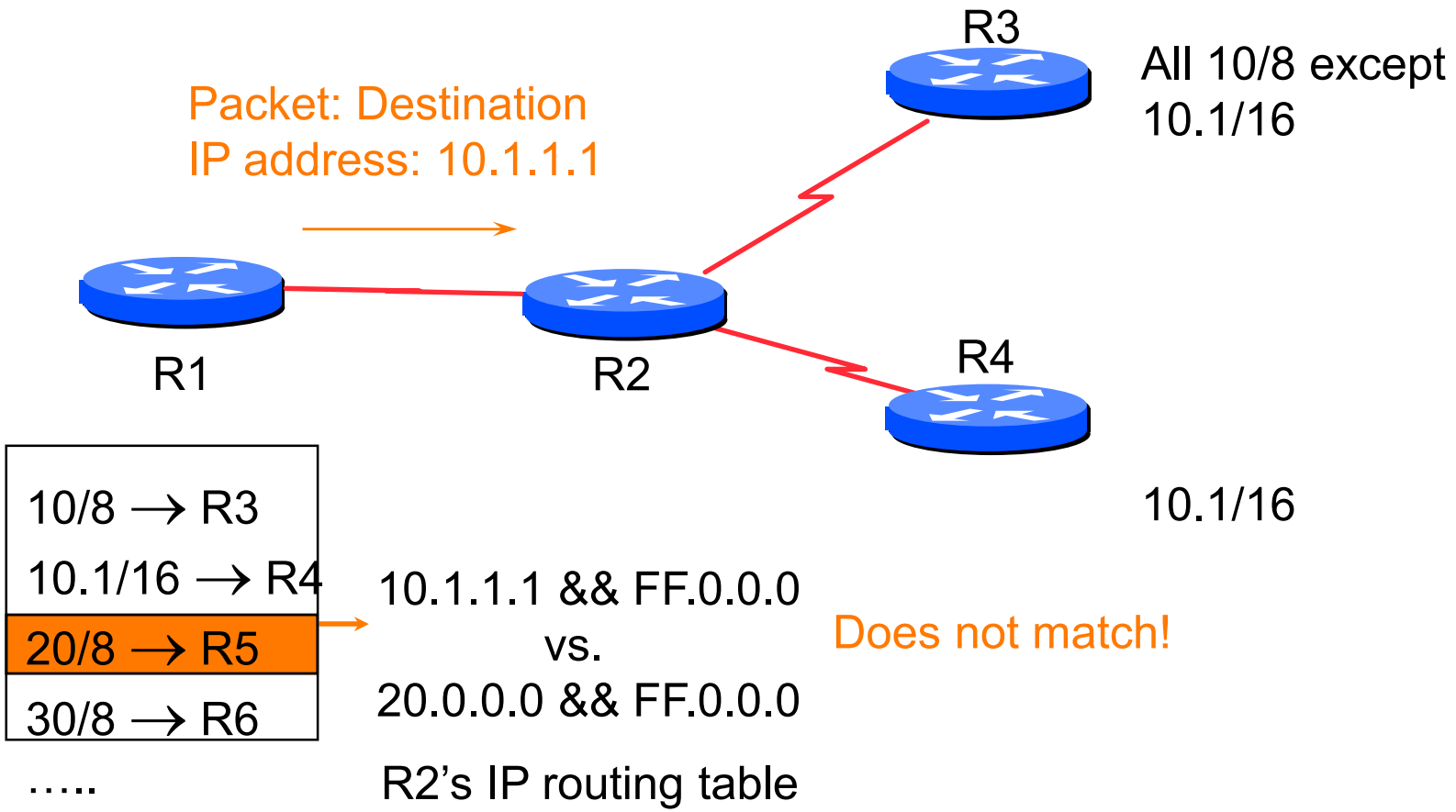
IP Route Lookup



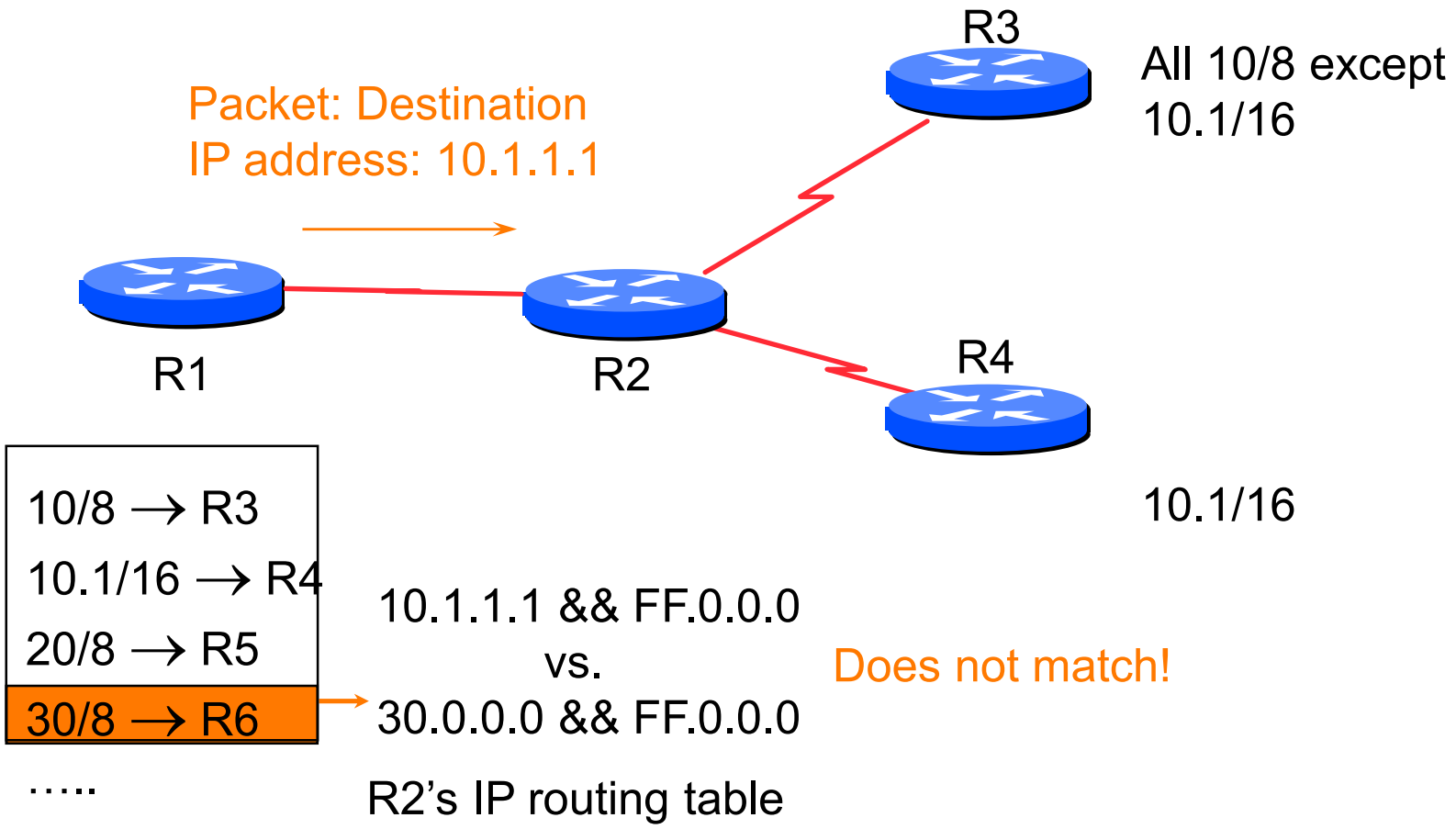
IP Route Lookup



IP Route Lookup



IP Route Lookup



IP Route Lookup