

Computer Networks - Comprehensive Exam Notes

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Network Topologies & Transmission

MAC Broadcast Address

- **Standard:** `FF:FF:FF:FF:FF:FF` (48-bit address, all 1s)
- **Purpose:** Forces all devices on a LAN to process the frame
- **Layer:** Data Link Layer (Layer 2)
- **Frame Processing:** All NICs must examine the frame content

Network Topologies

Bus Topology

- **Physical Structure:** Single coaxial cable with BNC terminators (50Ω)
- **Collision Domain:** One shared collision domain for entire network
- **Access Control:** CSMA/CD (Carrier Sense Multiple Access/Collision Detection)
- **Advantages:**
 - Simple to implement
 - Cost-effective for small networks
 - No central point of failure
- **Disadvantages:**
 - **Security:** All nodes see all traffic (promiscuous mode)

- **Scalability:** Performance degrades with more devices
- **Reliability:** Cable break affects entire network
- **Collision Rate:** Increases exponentially with network size

Star Topology

- **Central Device Options:**
 - **Hub:** Repeater at Physical Layer (L1) - extends collision domain
 - **Switch:** Operates at Data Link Layer (L2) - creates separate collision domains
- **Switch Advantages:**
 - **Microsegmentation:** Each port = separate collision domain
 - **Full-duplex:** Simultaneous send/receive capability
 - **Buffering:** Store-and-forward eliminates collisions
- **Variations:**
 - **Extended Star:** Multiple switches connected hierarchically
 - **Distributed Star:** Switches connected in mesh pattern

Mesh Topology

- **Full Mesh:** Every node connects to all others
 - **Connections:** $n(n-1)/2$ links required
 - **Redundancy:** Multiple paths between any two nodes
 - **Cost:** Expensive due to cabling requirements
- **Partial Mesh:** Strategic connections based on traffic patterns
- **Applications:** Internet backbone, WAN connections, data centers

Hybrid Topologies

- **Star-Bus:** Ethernet switches connected via backbone bus
- **Star-Ring:** Token Ring MAUs connected in star configuration
- **Hierarchical:** Three-tier architecture (Core-Distribution-Access)

Transmission Modes

Unicast (1:1)

- **Examples:** HTTP, HTTPS, SSH, Telnet
- **Addressing:** Specific MAC/IP address
- **Bandwidth:** Dedicated per session

Multicast (1:Many)

- **IP Range:** 224.0.0.0 to 239.255.255.255 (Class D)
- **Examples:** Video streaming, software updates, routing protocols
- **Protocols:** IGMP (Internet Group Management Protocol)
- **Efficiency:** Single stream serves multiple recipients

Broadcast (1:All)

- **Layer 2:** MAC broadcast (FF:FF:FF:FF:FF:FF)
- **Layer 3:** IP directed broadcast (subnet broadcast address)
- **Examples:** ARP requests, DHCP discovery, NetBIOS name resolution
- **Limitation:** Causes network congestion in large networks

Collision Domains

- **Hub:** All ports share one collision domain
 - **Switch:** Each port creates separate collision domain
 - **Bridge:** Separates collision domains (legacy)
 - **Router:** Separates both collision and broadcast domains
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Switching & Network Devices

Switch Types & Capabilities

Unmanaged Switches (Layer 2)

- **Function:** Basic MAC address learning and forwarding
- **MAC Address Table:**
 - Learning: Associates MAC addresses with ports
 - Aging: Removes old entries (default 300 seconds)
 - Flooding: Broadcasts unknown unicast frames
- **Forwarding Methods:**
 - **Store-and-Forward:** Receives entire frame, checks for errors
 - **Cut-Through:** Forwards after reading destination MAC
 - **Fragment-Free:** Forwards after reading first 64 bytes

Managed Switches (Layer 3+)

Layer 3 Switches

- **Routing:** IP-based forwarding decisions
- **Features:**
 - Inter-VLAN routing
 - Static and dynamic routing protocols
 - Access Control Lists (ACLs)
 - Quality of Service (QoS)

Layer 4 Switches

- **Port-Based Decisions:** TCP/UDP port analysis
- **Applications:**
 - Load balancing
 - Traffic prioritization
 - Application-specific routing

Layer 5+ Switches

- **Application Awareness:** Deep packet inspection
- **Features:**
 - Session persistence
 - SSL termination
 - Content-based routing
 - Application firewalling

VLANs (Virtual Local Area Networks)

- **Purpose:** Logical segmentation of physical networks
- **Benefits:**
 - Broadcast domain separation
 - Security isolation
 - Traffic management
 - Simplified administration
- **VLAN Tagging:** IEEE 802.1Q standard
- **Trunk Ports:** Carry multiple VLANs between switches
- **Access Ports:** Belong to single VLAN

Spanning Tree Protocol (STP)

- **Purpose:** Prevents switching loops in redundant topologies
- **Algorithm:** Selects root bridge, blocks redundant paths
- **Variants:**
 - **STP:** Original IEEE 802.1D (slow convergence)
 - **RSTP:** Rapid STP (IEEE 802.1w)
 - **MSTP:** Multiple STP (IEEE 802.1s)
- **Port States:** Blocking, Listening, Learning, Forwarding, Disabled

Distributed Processing

Fault Tolerance

- **Redundancy:** Multiple paths, devices, or services
- **Failover:** Automatic switching to backup systems
- **Load Balancing:** Distribution of traffic across multiple paths

Distributed Databases

- **Replication:** Data copied across multiple nodes
 - **Sharding:** Data partitioned across nodes
 - **Consistency Models:** Strong, eventual, weak consistency
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Protocols & Security

Transport Layer Protocols

TCP (Transmission Control Protocol)

- **Characteristics:**
 - Connection-oriented
 - Reliable delivery
 - Flow control
 - Congestion control
- **Header Fields:**
 - Source/Destination ports (16 bits each)
 - Sequence number (32 bits)
 - Acknowledgment number (32 bits)
 - Window size (16 bits)
 - Checksum (16 bits)
- **Three-Way Handshake:** SYN → SYN-ACK → ACK
- **Connection Termination:** FIN → ACK → FIN → ACK

UDP (User Datagram Protocol)

- **Characteristics:**
 - Connectionless
 - Unreliable delivery
 - Low overhead
 - No flow control
- **Header Fields:**
 - Source/Destination ports (16 bits each)
 - Length (16 bits)
 - Checksum (16 bits)
- **Applications:** DNS, DHCP, streaming media, gaming

Network Layer Protocols

IP (Internet Protocol)

- **IPv4:**
 - 32-bit addresses
 - Address classes (A, B, C, D, E)
 - Subnet masking
 - NAT/PAT for address conservation
- **IPv6:**
 - 128-bit addresses
 - Simplified header
 - Built-in security (IPSec)
 - Auto-configuration

ICMP (Internet Control Message Protocol)

- **Purpose:** Error reporting and network diagnostics
- **Message Types:**
 - Echo Request/Reply (ping)
 - Destination Unreachable
 - Time Exceeded
 - Redirect

Data Link Layer Protocols

Ethernet (IEEE 802.3)

- **Frame Format:**
 - Preamble (7 bytes)
 - Start of Frame Delimiter (1 byte)
 - Destination MAC (6 bytes)
 - Source MAC (6 bytes)
 - EtherType/Length (2 bytes)
 - Data (46-1500 bytes)
 - Frame Check Sequence (4 bytes)
- **Standards:**
 - 10BASE-T (10 Mbps)
 - 100BASE-TX (100 Mbps)
 - 1000BASE-T (1 Gbps)
 - 10GBASE-T (10 Gbps)

Wi-Fi (IEEE 802.11)

- **Access Method:** CSMA/CA (Collision Avoidance)
- **Standards:**
 - 802.11a (54 Mbps, 5 GHz)
 - 802.11b (11 Mbps, 2.4 GHz)
 - 802.11g (54 Mbps, 2.4 GHz)

- 802.11n (600 Mbps, MIMO)
 - 802.11ac (6.93 Gbps, MU-MIMO)
 - 802.11ax (9.6 Gbps, OFDMA)
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Broadcast Domains & Scalability

Broadcast Domain Boundaries

- **Layer 2 Devices:** Extend broadcast domains
 - Hubs, bridges, switches
- **Layer 3 Devices:** Separate broadcast domains
 - Routers, layer 3 switches
- **VLANs:** Logical broadcast domain separation

Broadcast Storm Prevention

- **Causes:**
 - Switching loops
 - Excessive broadcasts
 - Faulty network cards
- **Solutions:**
 - Spanning Tree Protocol
 - Broadcast storm control
 - Rate limiting
 - VLAN segmentation

Subnetting

- **Purpose:** Divide large networks into smaller segments
- **Benefits:**
 - Reduced broadcast traffic
 - Improved security
 - Better performance
 - Simplified management
- **CIDR Notation:** /24, /25, /26, etc.
- **Subnet Mask:** Determines network and host portions

Scalability Solutions

- **Hierarchical Design:** Core-Distribution-Access layers
- **Load Balancing:** Distribute traffic across multiple paths
- **Caching:** Reduce bandwidth usage

- **Content Delivery Networks (CDN):** Geographically distributed content
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OSI Model Deep Dive

Layer 1 - Physical

- **Function:** Transmission of raw bits
- **Devices:** Hubs, repeaters, cables, connectors
- **Specifications:**
 - Electrical signals
 - Mechanical connectors
 - Timing synchronization
- **Media Types:**
 - Copper (twisted pair, coaxial)
 - Fiber optic (single-mode, multi-mode)
 - Wireless (radio, microwave, infrared)

Layer 2 - Data Link

- **Sublayers:**
 - **LLC:** Logical Link Control (error detection, flow control)
 - **MAC:** Media Access Control (addressing, channel access)
- **Functions:**
 - Frame synchronization
 - Error detection/correction
 - Flow control
 - Access control
- **Protocols:** Ethernet, Wi-Fi, PPP, Frame Relay

Layer 3 - Network

- **Functions:**
 - Logical addressing (IP addresses)
 - Routing
 - Path determination
 - Packet forwarding
- **Protocols:** IP, ICMP, ARP, OSPF, BGP
- **Devices:** Routers, layer 3 switches

Layer 4 - Transport

- **Functions:**

- End-to-end communication
- Segmentation/reassembly
- Flow control
- Error recovery
- **Protocols:** TCP, UDP, SCTP
- **Port Numbers:** 0-65535 (well-known: 0-1023)

Layer 5 - Session

- **Functions:**
 - Session establishment/termination
 - Session management
 - Synchronization
- **Protocols:** NetBIOS, RPC, SQL sessions

Layer 6 - Presentation

- **Functions:**
 - Data encryption/decryption
 - Compression/decompression
 - Data format conversion
- **Standards:** SSL/TLS, JPEG, MPEG, ASCII

Layer 7 - Application

- **Functions:**
 - Network services to applications
 - User interface
 - File transfer
- **Protocols:** HTTP, FTP, SMTP, DNS, DHCP

TCP/IP Protocol Suite

Application Layer Protocols

HTTP/HTTPS

- **Port:** 80 (HTTP), 443 (HTTPS)
- **Methods:** GET, POST, PUT, DELETE, HEAD, OPTIONS
- **Status Codes:** 200 (OK), 404 (Not Found), 500 (Server Error)
- **Headers:** Content-Type, Content-Length, User-Agent

DNS (Domain Name System)

- **Port:** 53 (UDP/TCP)
- **Record Types:**
 - A: IPv4 address
 - AAAA: IPv6 address
 - CNAME: Canonical name
 - MX: Mail exchange
 - NS: Name server
- **Resolution Process:** Recursive and iterative queries

DHCP (Dynamic Host Configuration Protocol)

- **Ports:** 67 (server), 68 (client)
- **Process:** DISCOVER → OFFER → REQUEST → ACK
- **Options:** IP address, subnet mask, gateway, DNS servers

FTP (File Transfer Protocol)

- **Ports:** 21 (control), 20 (data)
- **Modes:** Active, Passive
- **Commands:** USER, PASS, LIST, RETR, STOR

Network Layer Protocols

ARP (Address Resolution Protocol)

- **Purpose:** Resolve IP addresses to MAC addresses
- **Types:** ARP Request (broadcast), ARP Reply (unicast)
- **ARP Table:** Cache of IP-to-MAC mappings
- **Variants:** RARP, Gratuitous ARP

Routing Protocols

- **Distance Vector:** RIP, EIGRP
- **Link State:** OSPF, IS-IS
- **Path Vector:** BGP
- **Metrics:** Hop count, bandwidth, delay, reliability

Network Performance & Optimization

Performance Metrics

Latency

- **Definition:** Time for data to travel from source to destination
- **Components:**
 - Propagation delay
 - Transmission delay
 - Processing delay
 - Queuing delay
- **Measurement:** Round-Trip Time (RTT)

Bandwidth

- **Definition:** Maximum data transfer rate
- **Units:** bps, Kbps, Mbps, Gbps
- **Factors:** Physical medium, protocol overhead, congestion

Throughput

- **Definition:** Actual data transfer rate achieved
- **Relationship:** $\text{Throughput} \leq \text{Bandwidth}$
- **Factors:** Network congestion, protocol efficiency, errors

Jitter

- **Definition:** Variation in packet arrival times
- **Impact:** Critical for real-time applications (VoIP, video)
- **Measurement:** Standard deviation of latency
- **Mitigation:** QoS, traffic shaping, buffering

Quality of Service (QoS)

Traffic Classification

- **Layer 3:** DSCP markings in IP header
- **Layer 2:** 802.1p priority bits in VLAN tags
- **Application-based:** Deep packet inspection

QoS Mechanisms

- **Traffic Shaping:** Rate limiting, burst control
- **Traffic Policing:** Discard excess traffic
- **Priority Queuing:** Multiple queues with different priorities
- **Weighted Fair Queuing:** Bandwidth allocation based on weights

Network Optimization Techniques

Caching

- **Web Caching:** Proxy servers, CDN
- **DNS Caching:** Recursive resolver caches
- **ARP Caching:** MAC address tables

Load Balancing

- **Algorithms:** Round-robin, least connections, weighted
- **Types:** Layer 4 (transport), Layer 7 (application)
- **Health Checks:** Monitor server availability

Compression

- **Header Compression:** Reduce protocol overhead
 - **Data Compression:** Reduce payload size
 - **Link Compression:** Compress entire frames
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Security & Attack Vectors

Network Attacks

Denial of Service (DoS)

- **Types:**
 - **Volumetric:** Overwhelm bandwidth
 - **Protocol:** Exploit protocol weaknesses
 - **Application:** Target application resources
- **Distributed DoS (DDoS):** Multiple attack sources
- **Amplification:** DNS, NTP, memcached amplification

Man-in-the-Middle (MITM)

- **Techniques:**
 - ARP spoofing
 - DNS spoofing
 - SSL stripping
 - Rogue access points
- **Prevention:** Encryption, certificate validation, network monitoring

Network Scanning

- **Port Scanning:** Identify open services

- **Network Mapping:** Discover network topology
- **Vulnerability Scanning:** Identify security weaknesses
- **Tools:** Nmap, Nessus, OpenVAS

Packet Sniffing

- **Purpose:** Capture and analyze network traffic
- **Techniques:** Promiscuous mode, switch port mirroring
- **Tools:** Wireshark, tcpdump, Ettercap
- **Prevention:** Encryption, switched networks, physical security

Security Protocols

IPSec

- **Components:** AH (Authentication Header), ESP (Encapsulating Security Payload)
- **Modes:** Transport, Tunnel
- **Key Management:** IKE (Internet Key Exchange)

SSL/TLS

- **Purpose:** Secure communication over TCP
- **Handshake:** Certificate exchange, key negotiation
- **Encryption:** Symmetric encryption for data, asymmetric for keys

VPN (Virtual Private Network)

- **Types:** Site-to-site, remote access
- **Protocols:** PPTP, L2TP, OpenVPN, IPSec
- **Benefits:** Secure remote access, encrypted tunnels

Network Security Best Practices

Access Control

- **Authentication:** Username/password, certificates, biometrics
- **Authorization:** Role-based access control (RBAC)
- **Accounting:** Log and audit access attempts

Firewall Configuration

- **Types:** Packet filtering, stateful inspection, application proxy
- **Rules:** Default deny, least privilege principle
- **Placement:** Network perimeter, host-based, DMZ

Intrusion Detection/Prevention

- **IDS:** Monitor and alert on suspicious activity
 - **IPS:** Actively block malicious traffic
 - **Signatures:** Known attack patterns
 - **Anomaly Detection:** Behavioral analysis
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Exam Quick Reference

Key Formulas

- **Full Mesh Connections:** $n(n-1)/2$
- **RTT:** Transit Time + Processing Time
- **Bandwidth-Delay Product:** Bandwidth \times RTT
- **Ethernet Efficiency:** (Data Size) / (Frame Size + IFG)

Important Port Numbers

- **HTTP:** 80
- **HTTPS:** 443
- **FTP:** 21 (control), 20 (data)
- **SSH:** 22
- **Telnet:** 23
- **SMTP:** 25
- **DNS:** 53
- **DHCP:** 67/68
- **POP3:** 110
- **IMAP:** 143
- **SNMP:** 161

Common Subnet Masks

- **/24:** 255.255.255.0 (256 addresses)
- **/25:** 255.255.255.128 (128 addresses)
- **/26:** 255.255.255.192 (64 addresses)
- **/27:** 255.255.255.224 (32 addresses)
- **/28:** 255.255.255.240 (16 addresses)
- **/30:** 255.255.255.252 (4 addresses)

MAC Address Formats

- **Broadcast:** FF:FF:FF:FF:FF:FF
- **Multicast:** 01:00:5E:xx:xx:xx (IPv4 multicast)
- **Unicast:** First bit of first octet = 0

- **Local:** Second bit of first octet = 1

Troubleshooting Commands

- **ping:** Test connectivity
- **tracert/traceroute:** Trace packet path
- **nslookup/dig:** DNS resolution
- **netstat:** Network connections
- **arp:** ARP table
- **ipconfig/ifconfig:** IP configuration

Protocol Stack Summary

Application | HTTP, FTP, SMTP, DNS

Transport | TCP, UDP

Network | IP, ICMP, ARP

Data Link | Ethernet, Wi-Fi

Physical | Cables, Signals

Remember for Exams

- **Collision domains:** Separated by switches
- **Broadcast domains:** Separated by routers
- **VLANs:** Logical broadcast domain separation
- **STP:** Prevents switching loops
- **CSMA/CD:** Ethernet collision detection
- **CSMA/CA:** Wi-Fi collision avoidance
- **TCP:** Reliable, connection-oriented
- **UDP:** Unreliable, connectionless
- **Subnetting:** Reduces broadcast traffic
- **QoS:** Prioritizes critical traffic

Good luck on your mid-semester exam! Review these concepts thoroughly and practice with network diagrams and protocol analysis.