BEGINNER STUDY GUIDE • COMPLETE 25-PART SERIES

# Computer Networks Complete Notes

Foundations & Topologies • OSI & TCP/IP Models • IPv4/IPv6 & Subnetting • Routing, TCP/UDP, DNS, HTTP & Security

## 1. What Is a Computer Network?

A computer network consists of two or more devices connected together to share data and resources such as files, printers, and internet access.

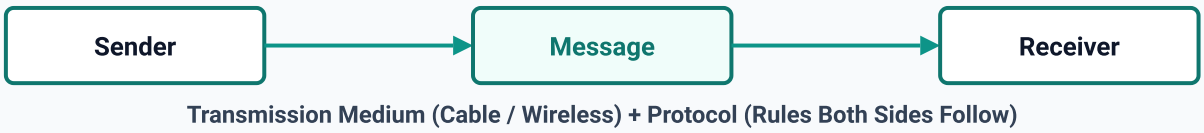



Figure 1: The five essential components of data communication.

- **Node:** Any device connected to the network (computer, phone, printer, router).
- **Link:** The physical or wireless communication pathway connecting nodes.
- **Bandwidth:** Maximum data transfer capacity per second, measured in bits per second (bps).
- **Latency:** Time delay required for data to travel from source to destination.

> **Key Takeaway: Network = Devices + Links + Protocols.**

## 2. Types of Networks

| Type | Full Form | Coverage Area | Real-World Example |
|---|---|---|---|
| **PAN** | Personal Area Network | ~10 metres | Bluetooth earbuds, smartwatch |
| **LAN** | Local Area Network | Room / building | College computer lab, home Wi-Fi |
| **MAN** | Metropolitan Area Network | Across a city | City cable TV network |
| **WAN** | Wide Area Network | Countries / global | The Internet (largest WAN) |

**Operational Characteristics:** A **LAN** is high-speed and privately owned by a single organisation, whereas a **WAN** spans large distances using public or leased telecom links at lower speeds.

> **Key Takeaway: Scale by geographic area: PAN < LAN < MAN < WAN.**

## 3. Network Topologies

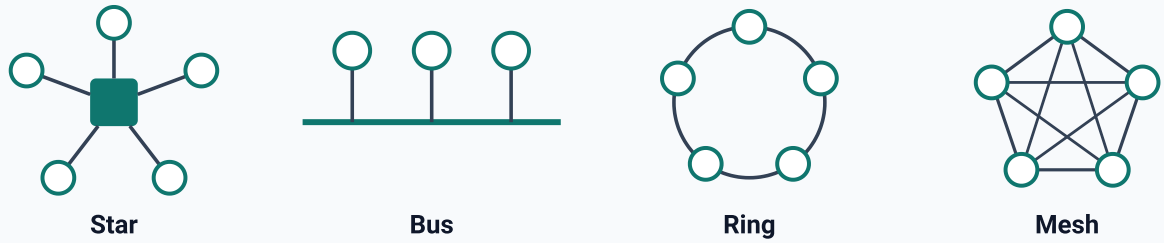



Figure 2: Common physical and logical network layouts.

| Topology | Advantages (Plus) | Disadvantages (Minus) |
|---|---|---|
| **Bus** | Cheap, easy to install | Main backbone cable fails → entire network fails |
| **Star** | Easy to manage and isolate faults | Central hub/switch fails → all nodes fail |
| **Ring** | Orderly, predictable data flow | A single break in the ring stops communication |
| **Mesh** | Very reliable with redundant paths | Requires many cables and ports |

**Mesh Link Formula:** A full mesh network with *n* devices requires **n(n − 1) / 2** dedicated links.

> **Key Takeaway: Star is the most common topology in modern LANs.**

## 4. Transmission Modes & Media

| Mode | Data Direction | Example |
|---|---|---|
| **Simplex** | One way only (unidirectional) | Keyboard → PC, television broadcast |
| **Half-duplex** | Both ways, one device at a time | Walkie-talkie |
| **Full-duplex** | Both ways simultaneously | Telephone call, switched Ethernet |

- **Guided (Wired) Media:** Twisted pair (Ethernet LAN cable), coaxial cable, and optical fibre. Optical fibre transmits pulses of light, offering the highest speed and longest distance.
- **Unguided (Wireless) Media:** Radio waves (Wi-Fi, Bluetooth), microwaves, and infrared.

> **Key Takeaway: Fibre = maximum speed; Wireless = mobility.**

## 5. Network Devices

| Device | OSI Layer | Primary Function |
|---|---|---|
| **Repeater** | Layer 1 (Physical) | Regenerates and boosts a weak signal over distance |
| **Hub** | Layer 1 (Physical) | Broadcasts incoming data blindly to ALL connected ports |
| **Bridge** | Layer 2 (Data Link) | Connects and filters traffic between two LAN segments |
| **Switch** | Layer 2 (Data Link) | Delivers frames selectively to the destination MAC address |
| **Router** | Layer 3 (Network) | Routes packets between networks using logical IP addresses |
| **Gateway** | All Layers (1–7) | Translates protocols to connect dissimilar networks |
| **Modem** | Layer 1 (Physical) | Modulates/demodulates digital ↔ analog signals |

> **Key Takeaway: Hub = broadcast; Switch = smart delivery (MAC); Router = inter-network routing (IP).**

## 6. OSI Model: 7 Layers

| # | Layer | Core Responsibility | Data Unit (PDU) | Examples |
|---|---|---|---|---|
| 7 | **Application** | End-user network services | Data | HTTP, DNS, SMTP |
| 6 | **Presentation** | Data formatting, compression, encryption | Data | TLS/SSL, JPEG |
| 5 | **Session** | Starts, manages, and ends communication sessions | Data | RPC, NetBIOS |
| 4 | **Transport** | End-to-end delivery, ports, reliability | Segment / Datagram | TCP, UDP |
| 3 | **Network** | Logical addressing and path routing | Packet | IP, ICMP, OSPF |
| 2 | **Data Link** | Framing, MAC addressing, error detection | Frame | Ethernet, Wi-Fi |
| 1 | **Physical** | Transmits raw binary bits over physical media | Bits | Cables, Hub, Fibre |

**Top-to-Bottom Mnemonic (Layers 7 → 1):** **A**ll **P**eople **S**eem **T**o **N**eed **D**ata **P**rocessing.

> **Key Takeaway: Encapsulation moves down the stack at the sender; decapsulation moves up at the receiver.**

## 7. TCP/IP Model

The practical 4-layer protocol suite that powers the real Internet.

| TCP/IP Layer | Equivalent OSI Layers | Core Protocols |
|---|---|---|
| **Application** | Layers 7, 6, 5 | HTTP, HTTPS, FTP, DNS, SMTP, SSH |
| **Transport** | Layer 4 | TCP, UDP |
| **Internet** | Layer 3 | IP (IPv4/IPv6), ICMP, ARP |
| **Network Access** | Layers 2, 1 | Ethernet, Wi-Fi (IEEE 802.11) |

> **Key Takeaway: Learn networking concepts with OSI (7 layers); build real systems with TCP/IP (4 layers).**

## 8. Data Link Layer (Layer 2)

- **Framing:** Wraps Layer 3 packets into Layer 2 frames with header and trailer delimiters.
- **MAC Addressing:** Identifies the next physical hop on the local link using a 48-bit hardware address burned into the NIC (e.g., `00:1A:2B:3C:4D:5E`).
- **Error Detection:**
  - **Parity Bit:** Appends a single bit so the total count of 1s is even (or odd). Example: `1011001` (four 1s) → even parity → `1011001 0`.
  - **CRC & Checksum:** Stronger mathematical checks used in Ethernet frames to detect burst errors.
- **Flow Control:** Regulates frame transmission pace using Stop-and-Wait and Sliding Window protocols.

> **Key Takeaway: MAC = permanent physical address; IP = changeable logical address.**

## 9. Medium Access Control (Who Talks When?)

When multiple devices share a single communication channel, access control protocols prevent or handle data collisions.

| Method | Mechanism | Efficiency / Used In |
|---|---|---|
| **Pure ALOHA** | Transmit anytime data is ready | Max 18.4% channel efficiency |
| **Slotted ALOHA** | Transmit only at the start of synchronized time slots | Max 36.8% channel efficiency |
| **CSMA/CD** | Listen before talking; detect collisions and back off | Wired Ethernet (legacy) |

| Method | Mechanism | Efficiency / Used In |
|---|---|---|
| **CSMA/CA** | Listen before talking; actively avoid collisions via ACK/RTS-CTS | Wi-Fi (Wireless LANs) |

**CSMA** stands for *Carrier Sense Multiple Access* ("listen before you talk").

> **Key Takeaway: Wired Ethernet detects collisions (CD); Wi-Fi avoids them (CA).**

## 10. IPv4 Addresses & Classes

An IPv4 address is 32 bits long, written in dotted-decimal notation as four 8-bit octets (e.g., `192.168.1.10`).

| Class | First Octet Range | Default Mask | Intended Use |
|---|---|---|---|
| **A** | 1 – 126 | `/8` | Very large enterprise/ISP networks |
| **B** | 128 – 191 | `/16` | Medium-sized networks |
| **C** | 192 – 223 | `/24` | Small networks |
| **D** | 224 – 239 | – | Multicast groups |
| **E** | 240 – 255 | – | Experimental / research |

- **Loopback Range:** `127.0.0.0/8` is reserved for local host testing (`127.0.0.1` = localhost).
- **Private IPv4 Ranges (non-routable on public Internet):** `10.0.0.0/8`, `172.16.0.0/12`, and `192.168.0.0/16`.

> **Key Takeaway: Each octet in an IPv4 address ranges from 0 to 255.**

## 11. Subnet Mask & CIDR

A subnet mask divides an IP address into a **Network portion** and a **Host portion**.

- **Example:** IP `192.168.1.10` with subnet mask `255.255.255.0` (`/24`) uses the first 24 bits for the network and the remaining 8 bits for hosts.
- **Usable Hosts Formula: $2^h - 2$**, where *h* is the number of host bits (subtracting 2 for the network ID and broadcast address).
- `/24` (8 host bits) → $2^8 - 2$ = **254 usable hosts**
- `/26` (6 host bits) → $2^6 - 2$ = **62 usable hosts**
- `/30` (2 host bits) → $2^2 - 2$ = **2 usable hosts** (ideal for point-to-point router links)

> **Key Takeaway: Larger CIDR prefix (/number) = more network bits = smaller host subnet.**

## 12. Subnetting: Worked Example

**Task:** Split `192.168.1.0/24` into 4 equal subnets. Borrowing 2 host bits yields $2^2 = 4$ subnets with prefix `/26` (mask `255.255.255.192`) and block size **256 − 192 = 64**.

| Subnet ID | Usable Host Range | Broadcast Address |
|---|---|---|
| `192.168.1.0/26` | `192.168.1.1 – 192.168.1.62` | `192.168.1.63` |
| `192.168.1.64/26` | `192.168.1.65 – 192.168.1.126` | `192.168.1.127` |
| `192.168.1.128/26` | `192.168.1.129 – 192.168.1.190` | `192.168.1.191` |
| `192.168.1.192/26` | `192.168.1.193 – 192.168.1.254` | `192.168.1.255` |

> **Key Takeaway: Subnet network IDs always start at multiples of the block size (0, 64, 128, 192).**

## 13. IPv4 vs IPv6

| Feature | IPv4 | IPv6 |
|---|---|---|
| **Address Size** | 32 bits | 128 bits |
| **Notation** | Dotted decimal ( `192.168.1.1` ) | Hexadecimal ( `2001:db8::1` ) |
| **Address Space** | ~4.3 billion addresses | ~$3.4 \times 10^{38}$ addresses |
| **Configuration** | Manual or DHCP | Built-in stateless auto-config (SLAAC) |
| **Packet Header** | Variable length, includes checksum | Fixed 40-byte length, simpler processing |

**Zero Compression:** Double colons ( `::` ) compress consecutive blocks of zeros: `2001:db8::1` expands to `2001:0db8:0000:0000:0000:0000:0000:0001`.

> **Key Takeaway: IPv6 solves IPv4 address exhaustion while streamlining router packet forwarding.**

## 14. Routing

A router selects the best path to forward each packet toward its destination network. **Static routing** relies on manually configured routes, whereas **dynamic routing** enables routers to learn and adapt paths automatically.

| Algorithm Type | Protocol | Core Routing Logic |
|---|---|---|
| **Distance Vector** | **RIP** | Uses hop count as metric; maximum limit of 15 hops |
| **Link State** | **OSPF** | Builds complete topology map; runs Dijkstra's shortest path algorithm |

| Algorithm Type | Protocol | Core Routing Logic |
|---|---|---|
| **Path Vector** | **BGP** | Exchanges reachability paths between autonomous systems (ISPs) |

**Scope:** **RIP** and **OSPF** operate inside a single organization/network (Interior Gateway Protocols), while **BGP** routes traffic between networks across the global Internet.

> **Key Takeaway: Routers forward packets hop by hop using routing tables.**

## 15. ARP, ICMP, NAT & DHCP

| Protocol | Function |
|---|---|
| **ARP** | Address Resolution Protocol — resolves a known IPv4 address to its local MAC address |
| **ICMP** | Internet Control Message Protocol — sends diagnostic and error messages (used by `ping`) |
| **NAT** | Network Address Translation — maps multiple private LAN IPs to a single public IP |
| **DHCP** | Dynamic Host Configuration Protocol — assigns IP, mask, gateway, and DNS automatically |

- **DHCP 4-Step Process (DORA):** **D**iscover → **O**ffer → **R**equest → **A**cknowledge.
- **CLI Diagnostics:** Run `ping google.com` to test reachability via ICMP, and `arp -a` to inspect the local IP-to-MAC cache.

> **Key Takeaway: Your home router performs both NAT and DHCP for your local devices.**

## 16. TCP vs UDP & Port Numbers

| Characteristic | TCP | UDP |
|---|---|---|
| **Connection** | Connection-oriented (3-way handshake) | Connectionless |
| **Reliability** | Reliable (acknowledges and retransmits lost packets) | Unreliable (best-effort delivery) |
| **Packet Ordering** | Guaranteed in-order delivery via sequence numbers | Packets may arrive out of order |
| **Speed / Overhead** | Slower due to connection & error control | Faster with minimal overhead |
| **Header Size** | 20–60 bytes | 8 bytes (fixed) |
| **Common Uses** | Web browsing (HTTP/S), email, file transfers | Live video calls, online gaming, DNS queries |

**Port Numbers:** An IP address identifies the target device, while a 16-bit port number (`0 – 65535`) identifies the specific application or service on that device.

> **Key Takeaway: Choose TCP when accuracy matters; choose UDP when speed matters.**

## 17. TCP 3-Way Handshake & Flow Control

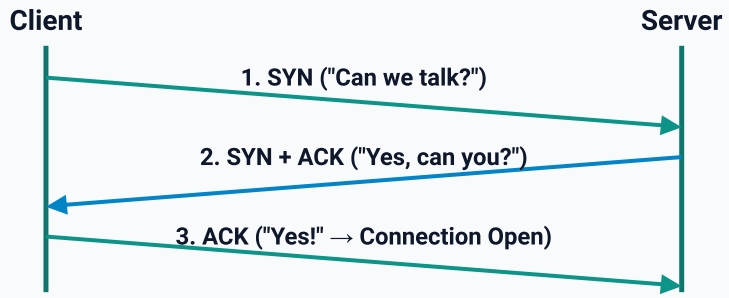



Figure 3: Establishing a reliable TCP session in three steps.

- **4-Way Connection Termination:** `FIN` → `ACK` → `FIN` → `ACK`.
- **Flow Control:** Uses a sliding receive window so a fast sender does not overwhelm a slower receiver.
- **Congestion Control:** Starts cautiously (Slow Start) and scales transmission rate based on network capacity.

> **Key Takeaway: Open a TCP connection in 3 steps; close it in 4 steps.**

## 18. Essential Application Protocols & Ports

| Protocol | Port(s) | Primary Purpose |
|---|---|---|
| **HTTP** | 80 | Unencrypted web page transfer |
| **HTTPS** | 443 | Encrypted web page transfer (HTTP + TLS) |
| **FTP** | 20, 21 | File Transfer Protocol (20 data, 21 control) |
| **SSH** | 22 | Encrypted remote command-line login |
| **Telnet** | 23 | Unencrypted remote login (insecure) |
| **SMTP** | 25 | Sending/relaying outgoing email |
| **DNS** | 53 | Domain name → IP address resolution |
| **DHCP** | 67, 68 | Automatic IP address assignment (67 server, 68 client) |
| **POP3 / IMAP** | 110 / 143 | Retrieving/receiving email from mail servers |

> **Key Takeaway: Well-known port numbers (0–1023) are high-frequency exam and interview questions.**

## 19. DNS: The Internet's Phone Book

The Domain Name System translates human-readable domain names ( `google.com` ) into machine-routable IP addresses.

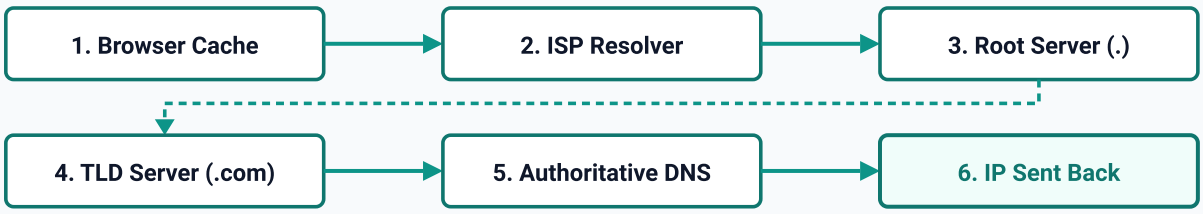



**Figure 4: Step-by-step recursive and iterative DNS resolution chain.**

- **A Record:** Maps domain name → IPv4 address. | **AAAA Record:** Maps domain name → IPv6 address.
- **CNAME Record:** Maps an alias domain name → canonical domain name.
- **MX Record:** Specifies the mail exchange server responsible for accepting email for the domain.
- **Transport:** DNS primarily uses **UDP port 53** for fast queries (and TCP 53 for zone transfers/large responses).

> **Key Takeaway: Domain names are for humans; IP addresses are for computers.**

## 20. What Happens When You Visit google.com?

*Classic networking systems interview walkthrough:*

1. **DNS Lookup:** Browser resolves `google.com` to an IP address.
2. **ARP Resolution:** Host uses ARP to find the default gateway router's MAC address.
3. **TCP Handshake:** Client completes a 3-way TCP handshake with Google's server on port 443.
4. **TLS Handshake:** Client and server negotiate cryptographic keys to establish an encrypted HTTPS channel.
5. **HTTP Request:** Browser transmits an encrypted `HTTP GET /` request.
6. **HTTP Response:** Server replies with status `200 OK` and the HTML payload.
7. **Page Rendering:** Browser parses the HTML DOM and fetches/renders linked CSS, JavaScript, and images.

> **Key Takeaway: End-to-end sequence: DNS → ARP → TCP → TLS → HTTP → Render.**

## 21. HTTP & HTTPS

| Method | Action | Status Code | Meaning |
|---|---|---|---|
| **GET** | Read / retrieve data | **200** | OK (request succeeded) |
| **POST** | Create / submit new data | **301** | Moved Permanently (redirect) |
| **PUT** | Update / replace existing data | **404** | Not Found (resource missing) |
| **DELETE** | Remove data | **500** | Internal Server Error |

**Status Code Families:** `2xx` Success • `3xx` Redirection • `4xx` Client Error • `5xx` Server Error.
**HTTPS** wraps HTTP inside TLS encryption on port 443.

> **Key Takeaway: HTTP is stateless by design; cookies and tokens maintain user session state.**

## 22. Network Security Basics

| Concept / Tool | How It Protects Networks |
|---|---|
| **Firewall** | Inspects and allows or blocks network traffic based on security rules |
| **VPN** | Creates an encrypted virtual tunnel over an untrusted public network |
| **Symmetric Key** | Uses the same shared secret key to encrypt and decrypt data (e.g., AES) |
| **Asymmetric Key** | Uses a mathematically linked public key + private key pair (e.g., RSA) |
| **Hashing** | Produces a fixed-length, one-way integrity fingerprint (e.g., SHA-256) |

- **DoS / DDoS:** Overwhelms a target server or network with massive traffic floods to deny legitimate service.
- **Phishing:** Deceptive emails or spoofed websites designed to trick users into revealing credentials.
- **Man-in-the-Middle (MitM):** Attacker secretly intercepts or alters traffic between two communicating parties.

> **Key Takeaway: Encrypt sensitive data in transit, verify links, and keep software patched.**

## 23. Exam & Interview Quick Facts

| Topic | Must-Know Fact / Formula |
|---|---|
| **Layer Devices** | Switch operates at Layer 2 (MAC); Router operates at Layer 3 (IP) |
| **Address Bit Lengths** | MAC = 48 bits \| IPv4 = 32 bits \| IPv6 = 128 bits |
| **Key Formulas** | Full mesh links = **$n(n-1)/2$** \| Usable subnet hosts = **$2^h - 2$** |

| Topic | Must-Know Fact / Formula |
|---|---|
| **Channel Efficiency** | Pure ALOHA max = 18.4% \| Slotted ALOHA max = 36.8% |
| **Routing Metrics** | RIP max hop count = 15 \| OSPF uses Dijkstra's shortest path |
| **Transport Headers** | TCP header = 20+ bytes \| UDP header = 8 bytes |
| **Core Ports & Resolution** | DNS 53, HTTP 80, HTTPS 443, SSH 22 \| ARP: IP → MAC \| DHCP: DORA |

## 24. Recap & Self-Assessment Test

**Series Recap:** Network types & topologies → Transmission media & devices → OSI (7 layers) & TCP/IP (4 layers) → Data link & access control → IPv4 classes, CIDR subnetting & IPv6 → Routing, ARP, DHCP, NAT → TCP vs UDP, DNS, HTTP/S & security.

### Quick Test — Try Without Looking Back

1. Name the 7 OSI layers in order from top (Layer 7) to bottom (Layer 1).
2. What is the core difference between a hub and a switch?
3. How many usable host addresses are available in a `/27` IPv4 network?
4. Between TCP and UDP, which protocol is faster and why?
5. What are the 3 steps of the TCP connection handshake?
6. What are the standard port numbers for DNS and HTTPS?

### Quick Test Answer Key

1. **7 OSI Layers (Top → Bottom):** 7. Application, 6. Presentation, 5. Session, 4. Transport, 3. Network, 2. Data Link, 1. Physical.
2. **Hub vs Switch:** A hub (Layer 1) broadcasts incoming signals blindly to all ports, whereas a switch (Layer 2) inspects MAC addresses and forwards frames only to the intended destination port.
3. **Usable hosts in `/27`:** Host bits = 32 − 27 = 5. Usable hosts = $2^5 - 2 = 32 - 2 =$ **30 hosts**.
4. **TCP vs UDP speed: UDP** is faster because it is connectionless, has a compact 8-byte header, and skips handshakes, acknowledgments, and retransmissions.
5. **TCP 3-Way Handshake:** 1. Client sends `SYN` → 2. Server replies `SYN + ACK` → 3. Client sends `ACK`.
6. **Port numbers:** DNS uses port **53**; HTTPS uses port **443**.

> **Keep revising: computer networks power every connected system.**