

What is a Network?



- In its simplest form, a network is nothing more than “two connected computers sharing resources with one another.”
- It is composed of two main aspects:
 - **Physical Connection** (wires, cables, wireless media)
 - **Logical Connection** (data transporting across the physical media)

Some Basic Networking Rules

- The computers in a network must use the same procedures for sending and receiving data. We call these **communication protocols**.
- Data must be delivered uncorrupted. If it is corrupted, it's useless. (There are Exceptions)
- Computers in a network must be capable of determining the **origin** and **destination** of a piece of information, i.e., its **IP** and **Mac Address**.

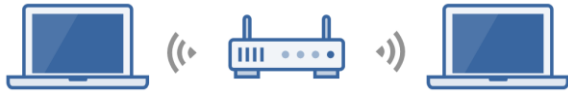
Types of Computer Networks (by Size)

- Personal Area Network (PAN)
- Local Area Network (LAN)
- Wireless Local Area Network (WLAN)
- Campus Area Network (CAN)
- Metropolitan Area Network (MAN)
- Wide Area Network (WAN)

Network Architecture

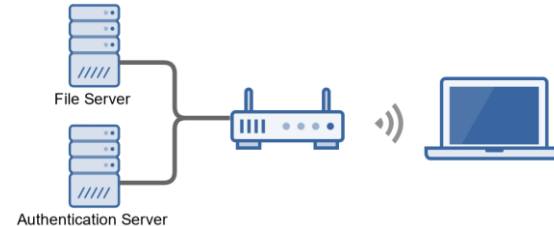
Peer-to-Peer

- All computers on the network are peers
 - No dedicated servers
 - There's no centralized control over shared resources
- Any device can share its resources as it pleases
- All computers can act as either a client or a server
- Easy to set-up, and common in homes and small businesses



Client-Server

- The network is composed of client and servers
 - Servers provide resources
 - Clients receive resources
- Servers provide centralized control over network resources (files, printers, etc.)
- Centralizes user accounts, security, and access controls to simplify network administration
- More difficult to setup and requires an IT administrator



Why Build a Computer Network?

- Before computer networks, people sent and received information by hand, using the postal service. This is slow and can be unreliable.
- Computer networks enable faster, more efficient modes of communication, i.e., email, video conferencing, etc.
- Computer networks and the sharing of electronic data encourage the use of standard policies and procedures.
- Computer networks provide backup and recovery support for our data, i.e., redundancy.
- Computer networks lead to cost savings.

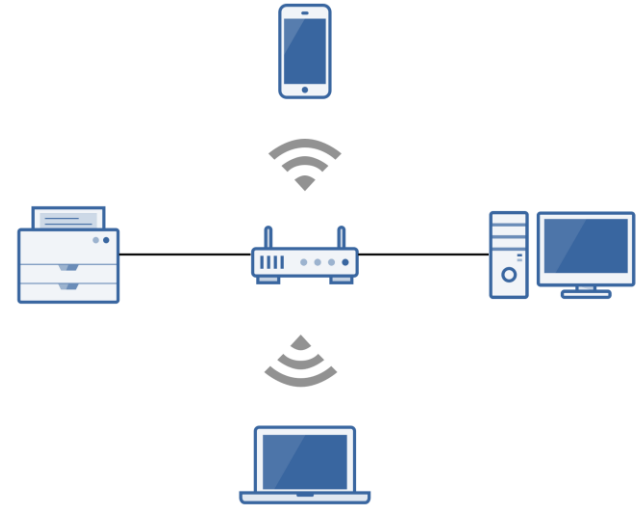
Personal Area Network (PAN)

- Ultra-small networks used for personal use to share data from one device to another.
- Can be wired (PAN) or wireless (WPAN):
 - USB
 - Bluetooth
 - NFC
 - ANT+
- Examples:
 - Smart Phone to Laptop
 - Smart Watch to Smart Phone
 - Smart Phone Hands-Free Car Calling
 - Heart Rate Monitor to Smart Phone



Local Area Network (LAN)

- A computer network within a small geographical area, such as a single room, building or group of buildings.
- Considered to be self-contained:
 - All devices are directly connected via cables and/or short-range wireless technology.
 - Doesn't require a leased telecommunications line from an Internet Service Provider (ISP).
- Examples:
 - Home Network
 - Small Business or Office Network



Wireless Local Area Network (WLAN)

- A LAN that's dependent on wireless connectivity or one that extends a traditional wired LAN to a wireless LAN.
- Most home networks are WLANs.



Campus Area Network (CAN)

- A computer network of multiple interconnected LANs in a limited geographical area, such as a corporate business park, government agency, or university campus.
- Typically owned or used by a single entity.



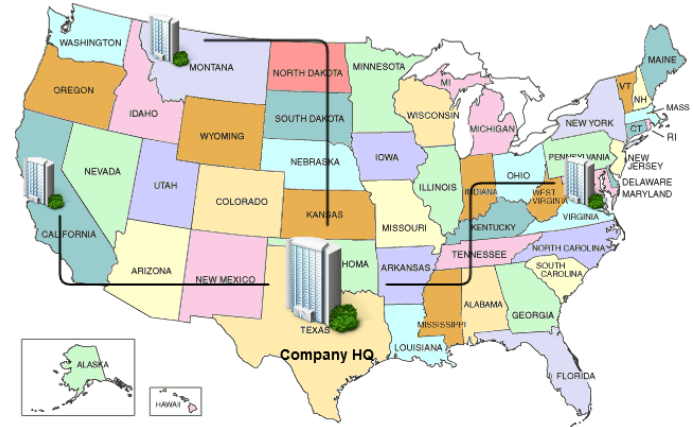
Metropolitan Area Network (MAN)

- A computer network that interconnects users with computer resources in a city.
- Larger than a campus area network, but smaller than a wide area network.



Wide Area Network (WAN)

- A computer network that extends over a large geographical distance, typically multiple cities and countries.
- WANs connect geographically distant LANs.
- Typically use leased telecommunications lines from ISPs.
- Examples:
 - The Internet
 - Corporate Offices in Different States



Some Basic Networking Rules

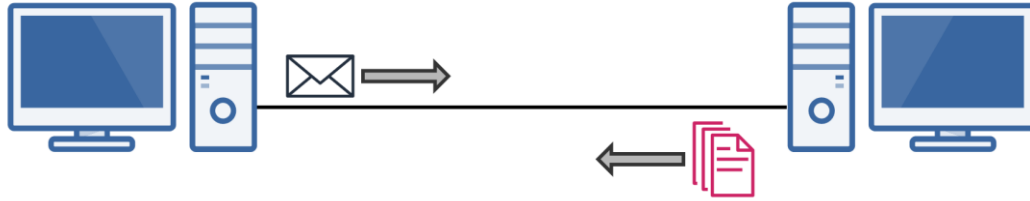
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Computer Networking Protocols



- Computers communicate with each other with network protocols.
- Protocols are rules governing how machines exchange data and enable effective communication.
- **Some Everyday Examples**
 - When you call somebody, you pick up the phone, ensure there is a dial tone, and if there is, you dial the number.
 - When you drive your car, you obey the rules of the road.

Protocols Continued

- **Physical Protocols:** describe the medium (wiring), the connections (RJ-45 port), and the signal (voltage level on a wire).
- **Logical Protocols:** software controlling how and when data is sent and received to computers, supporting physical protocols.
- Computer networks depend on many different types of protocols in order to work properly.
- Example Common TCP/IP Suite of Protocols:
 - **Web Communication:** HTTP
 - **E-mail:** POP3, SMTP, IMAP
 - **File Transfers:** FTP

The OSI Model

What is it?

The *Open Systems Interconnection (OSI) Reference Model*

- A **conceptual** framework showing us how data moves throughout a network.
- Developed by the International Organization for Standardization (ISO) in 1977.

It's Purpose

- Gives us a guide to understanding how networks operate.

It's only a **reference model**, so don't get wrapped up in the details.

- Wasn't implemented in the **real world**, TCP/IP is.

The OSI Model Stack

The OSI Model breaks down the complex task of computer-to-computer network communications into seven layers.

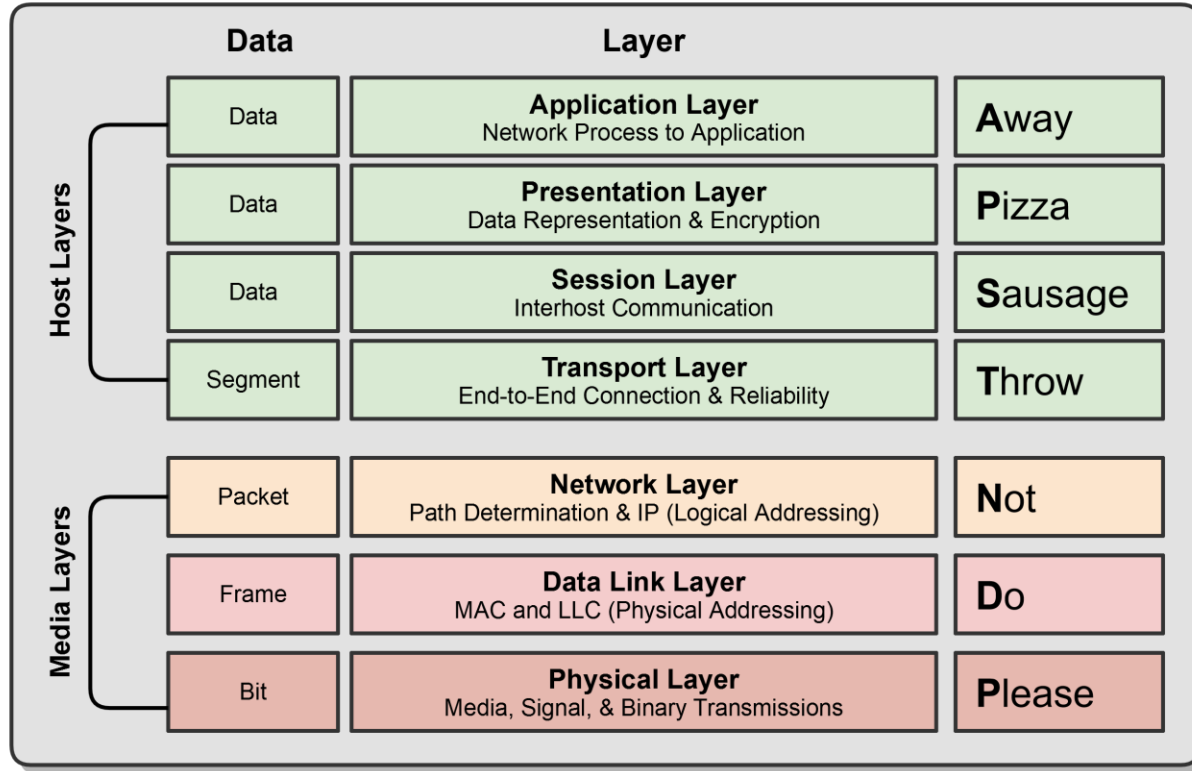
Upper Layers (Host Layers)

- Handled by the host computer and performs application-specific functions, such as data formatting, encryption, and connection management.

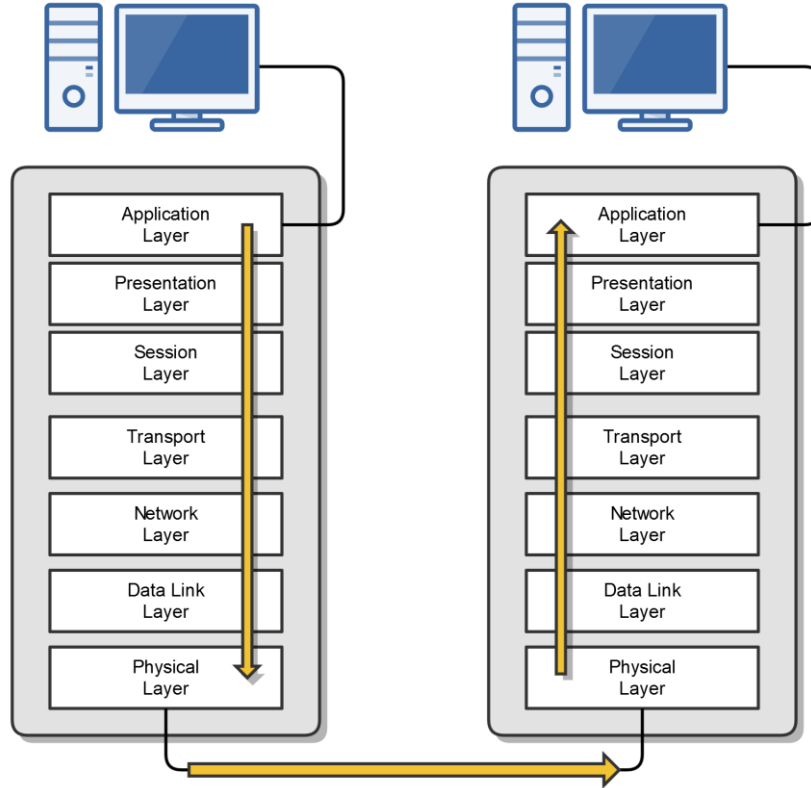
Lower Layers (Media Layers)

- Provide network-specific functions, such as routing, addressing, and flow control.

The OSI Model Visualized

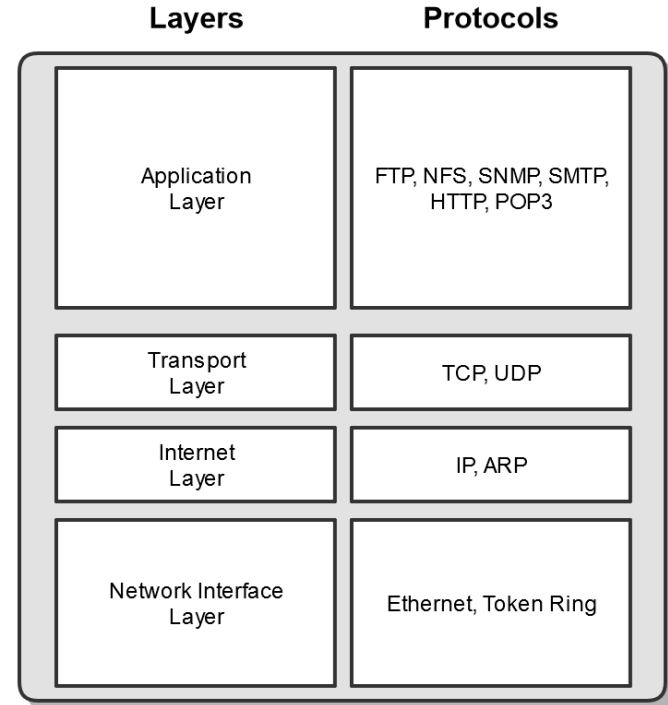


OSI Communication

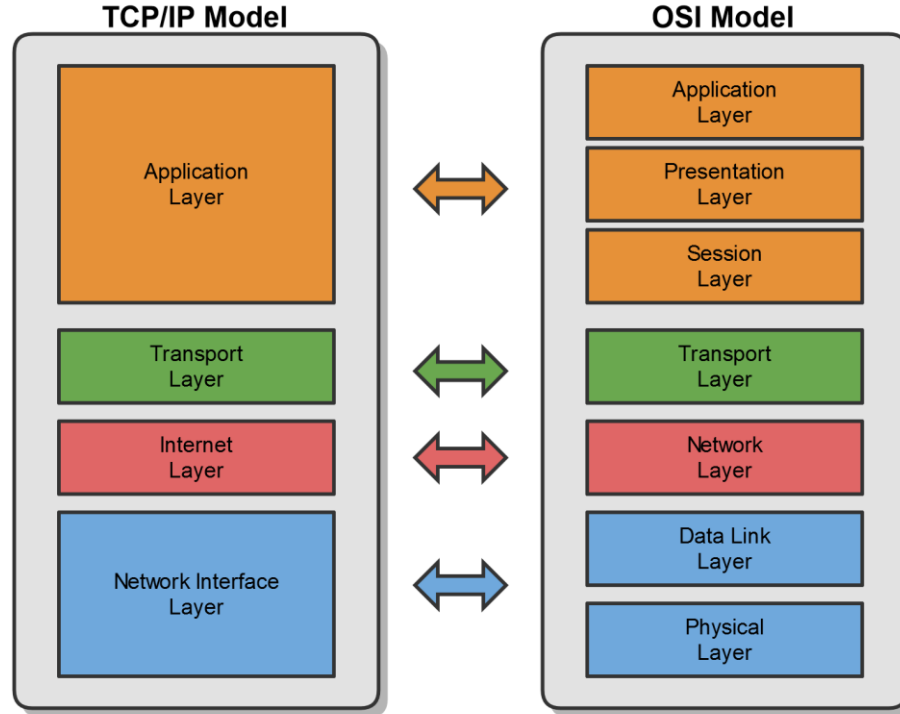


The TCP/IP Model

- The TCP/IP suite is the most commonly used protocol suite in the networking world.
- It's essentially the protocol suite in which the Internet was built.
- It's the standard for computer networking.
- It is based on a 4-layer model that is similar to the OSI model.
- History of TCP/IP:
 - Developed by the United States Department of Defense (DoD) in the early 1970s.
 - In 1982, the DOD declared TCP/IP as the standard for all military computer networking.
 - In 1984, broad adoption of TCP/IP began (IBM, AT&T, etc.).



TCP/IP & OSI Models Side-by-Side



MAC Addresses

Media Access Control (MAC)

- Physical address of the network adapter card
- **OSI Layer 2** (Data Link) Layer Address
- **TCP/IP Layer 1** (Network Interface) Layer Address



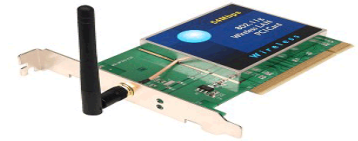
Six bytes (48 bits), Usually Represented Hexadecimal

- First three bytes (24 bits) are assigned by the IEEE to the manufacturer
 - Organizationally Unique Identifier (OUI) assigned by IEEE (ex: Dell or HP)
- Last three bytes (24 bits) are usually assigned sequentially:
 - Unique Numbers

00:21:70:6f:06:f2

00-21-70-6F-06-F2

$2^{24} = \sim 16.7$ Million Unique Addresses



IP Addresses

- An IP Address is a **logical** address used in order to **uniquely identify** a device on an IP network.
- It's a **Network Layer** address associated with routing.
 - **OSI Layer 3:** Network Layer
 - **TCP/IP Layer 2:** Internet Layer
- There are two versions:
 - **IP version 4 (IPv4)**
 - Example: 192.168.0.1
 - **IP version 6 (IPv6)**
 - Example: 2001:DB8:85A3:0:0:8A2E:370:7334
- We'll be discussing both versions in this course.

Comparing IP and MAC Addresses

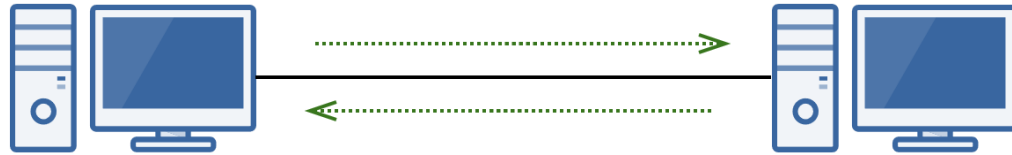
IP Addresses

- Network (OSI Layer 3) Addresses
- Logical Addresses
- Assigned in Operating System
- Allows network-to-network communication via routers
- WAN communication

MAC Addresses

- Data Link (OSI Layer 2) Addresses
- Physical Addresses
- Physically burned on NIC
- Allows internetwork communication via hubs, switches, and routers
- Local LAN communication

Half vs. Full Duplex Communication

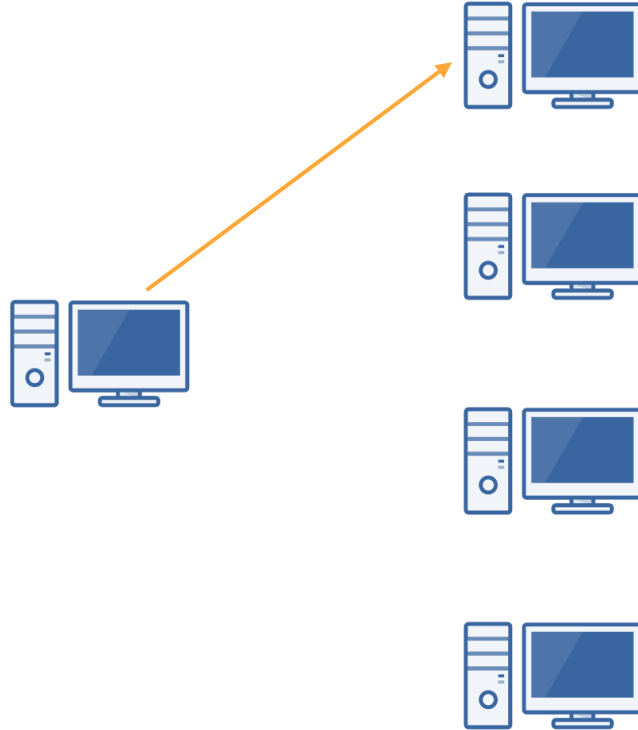


- Network communication will occur in either full or half duplex mode:
 - **Half Duplex:** Can send and receive data, but not at the same time.
 - **Full Duplex:** Can send and receive data simultaneously.

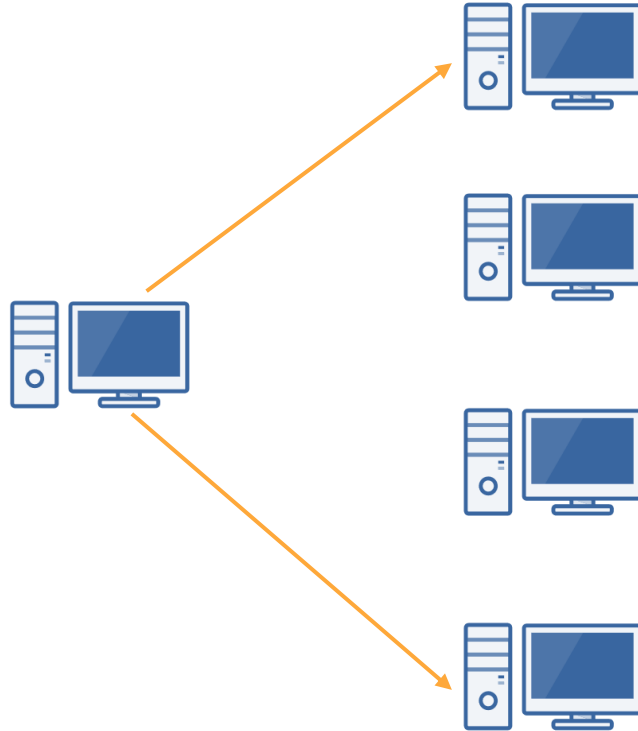
Network Transmission Types

- Unicast
- Multicast
- Broadcast

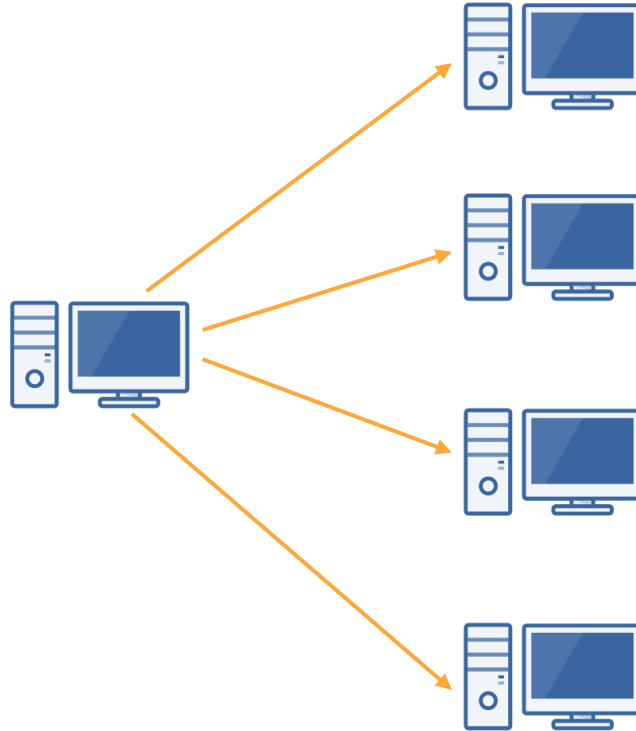
Unicast (One-to-One)



Multicast (One-to-Many)



Broadcast (One-to-All)



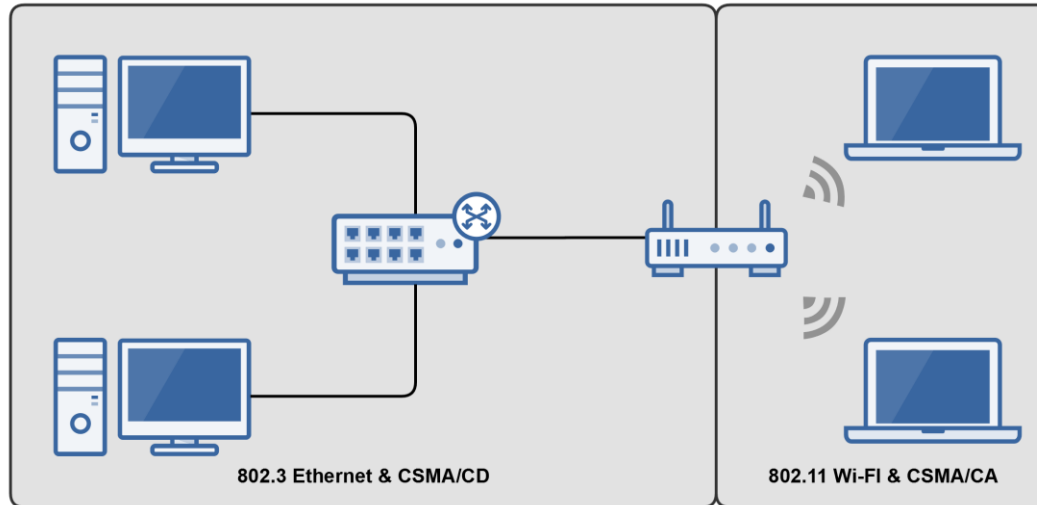
Introduction to Ethernet

- The most popular networking technology in the world!
- Refers to a family of standards that define the **physical** and **logical** aspects of the world's most popular type of LAN.
- The standard communications protocol for building a local area network (LAN).
- **Physical**
 - Cabling, Connectors, Equipment, etc.
- **Logical**
 - Network Access Method, i.e., Carrier Sense Multiple Access (CSMA)

Physical vs. Logical Topologies

Physical topologies describe the placement of network devices and how they are physically connected.

Logical topologies describe how data flows throughout a network.

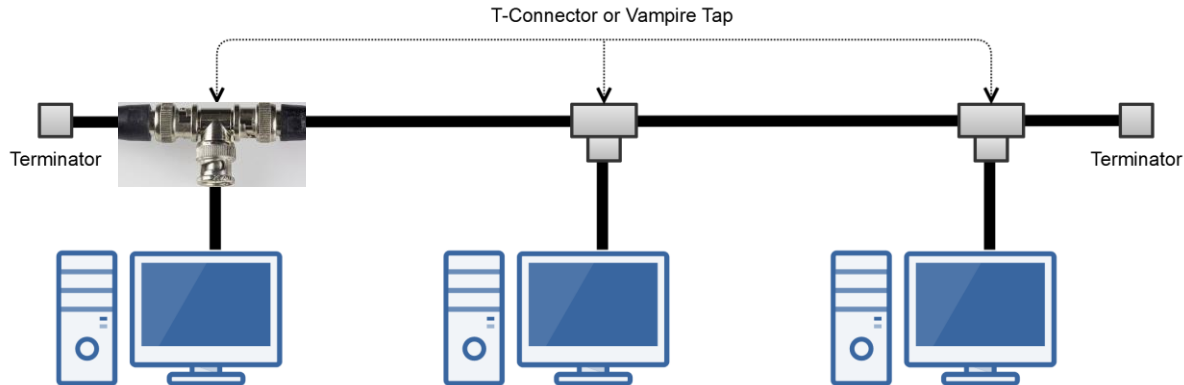


Wired Network Topologies

- Four Specific Topologies:
 - Bus
 - Ring
 - Star
 - Mesh

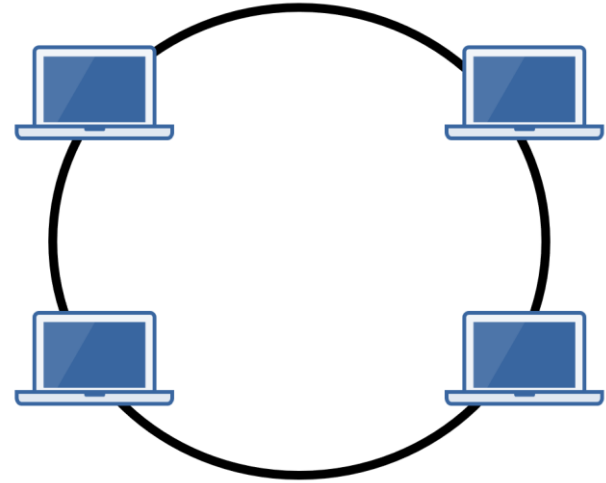
Bus Topology

- All devices are connected to a single coaxial network cable.
 - Devices are connected via a vampire tap or T-Connector.
 - Terminators are required at both ends of the cable to prevent signal bounce.
 - Antiquated technology.
- Only one end device can be active on the network at a time.
 - Data signals travel in both directions and are received by all devices on the network.
- A single break in the cable can take down the entire network.



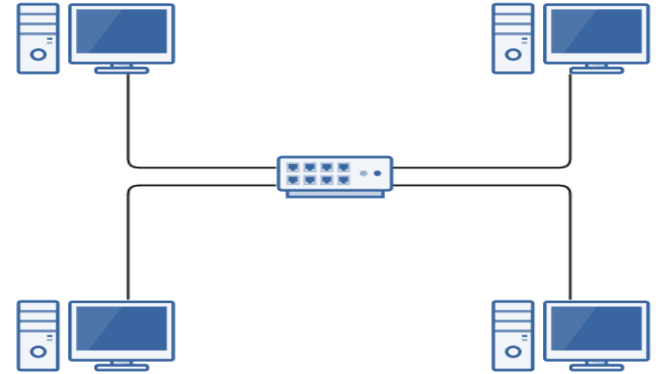
Ring Topology

- All devices are connected in a circular fashion.
- Each computer is connected to two other computers.
- Data travels from node-to-node with each computer handling data, either unidirectional or bidirectional.
- Each device (node) in the ring regenerates the signal, acting as a repeater.
- Failure of a single node can take down the entire network.
- Fiber Distributed Data Interface (FDDI) uses two counter-rotating ring topologies for redundancy.



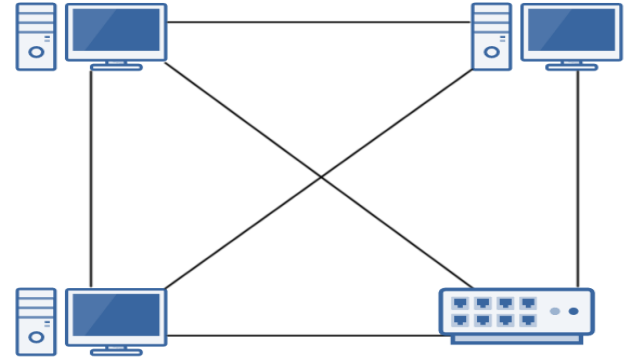
Star Topology

- All devices are connected to a central connecting device, which is usually a switch.
- Devices send data to the switch, which forwards it to the appropriate destination device.
- Popular topology in today's networks.
- Used in most large and small networks.
- Central device is a single point of failure.



Mesh Topology

- Each device is connected to every other device by separate cabling.
- Highly redundant and fault-tolerance.
- Expensive to install.
- Commonly used in Enterprise Networks & WANs.
- Two Types:
 - Partial Mesh
 - Full Mesh



Wireless Network Topologies

- Wireless networks utilize radio frequencies (RF) to communicate.
- Three Specific Topologies:
 - Ad hoc
 - Infrastructure
 - Mesh

Ad hoc

- Peer-to-peer (P2P) wireless network where no wireless access point (WAP) infrastructure exists.
- The devices communicate directly with one another.
- Personal area networks (PANs) are a common example of Ad hoc wireless networks.



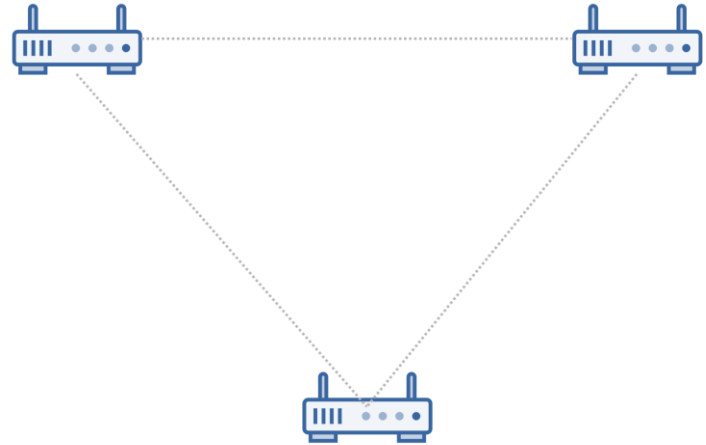
Infrastructure

- Wireless network that uses a wireless access point (WAP) as its central connecting device.
- Infrastructure wireless networks (WLANs) are commonly used in homes and small offices.



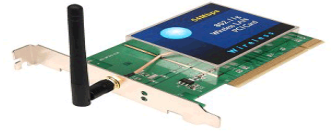
Mesh

- Just like a wired mesh design, wireless mesh networks utilize several wireless access points (nodes) to create a robust wireless network that is:
 - Scalable
 - Self-Healing
 - Reliable (redundancy)
- Common in larger homes and businesses.



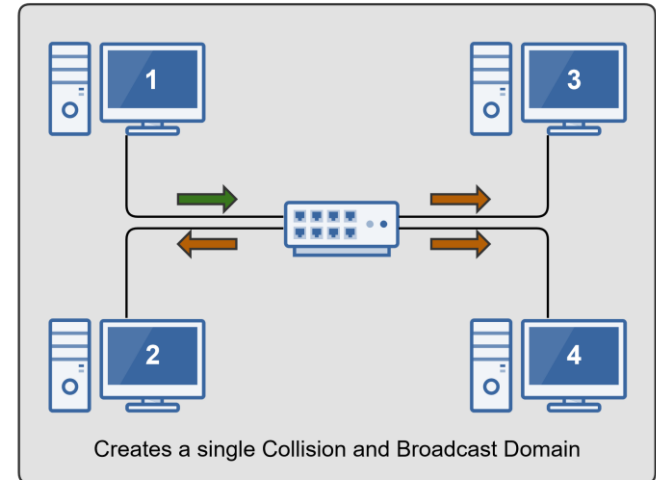
Network Interface Card (NIC)

- The network adapter installed on your network device.
- Provides the physical and electrical, light or radio frequency connections to the network media.
- It can either be an expansion card, USB devices or built directly into the motherboard.



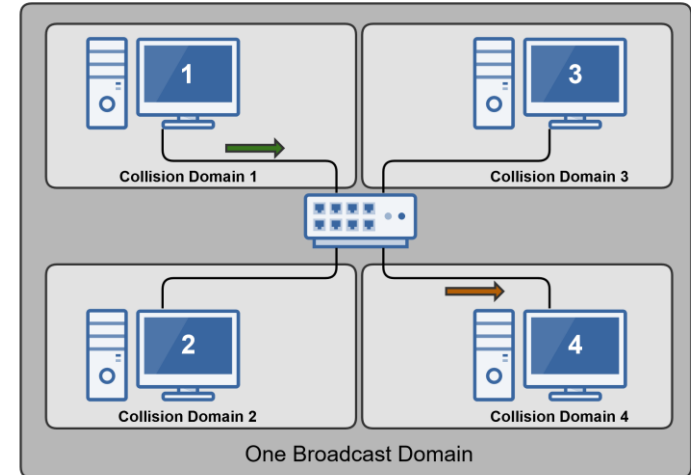
Hubs

- Used to Connect Devices Together Within a Network
- Used in Early Networks; Replaced by Switches
- “Multi-Port Repeater”
 - Traffic goes in one port and is repeated (broadcasted) out every other port
 - OSI Layer 1 Device
 - Dumb Network Device
 - Causes increased network collision errors
- Much Less Efficient than a Switch
- Legacy Equipment No Longer Used



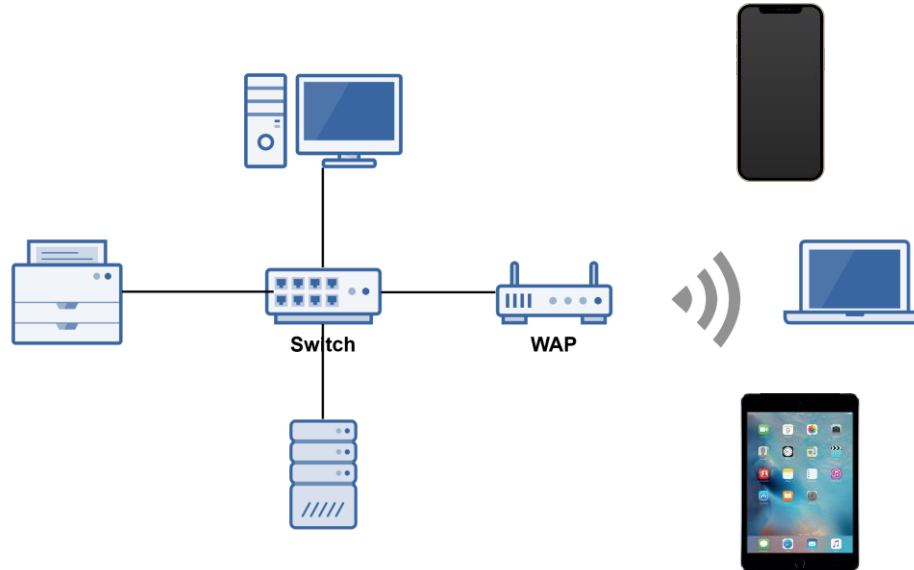
Switches

- Connects Devices Together Just Like a Hub
- Intelligent Network Device (OSI Layer 2)
- Memorizes the **MAC Address** of Each Device Connected to It via a **MAC Address Table**, sometimes called a **Content Addressable Memory (CAM) Table**
- Pays attention to *Source* and *Destination* **MAC addresses** during Communication Process
- Use Application-Specific Integrated Circuitry (**ASIC**), which makes them Extremely Fast
- Breaks up Collision Domains
 - Traffic Goes in One Port and Is Repeated out to Only Destination Port
 - Designed for High Bandwidth
 - Standard in Today's Network Infrastructure



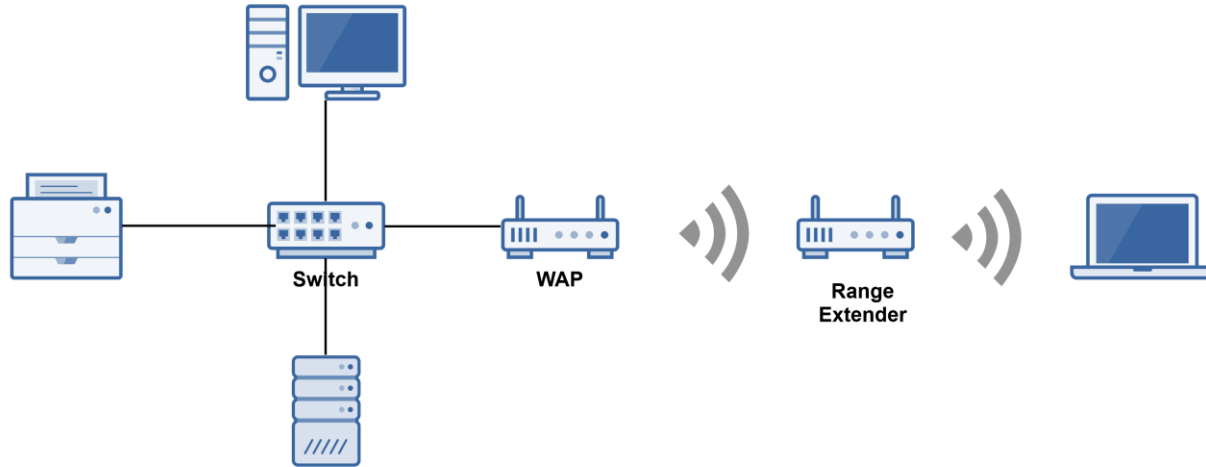
Wireless Access Point (WAP)

- A wireless access point (WAP) is a bridge that extends the wired network to the wireless network.
- Just like a switch, it's a Data Link Layer 2 device.
- **Note:** A WAP is not a router.



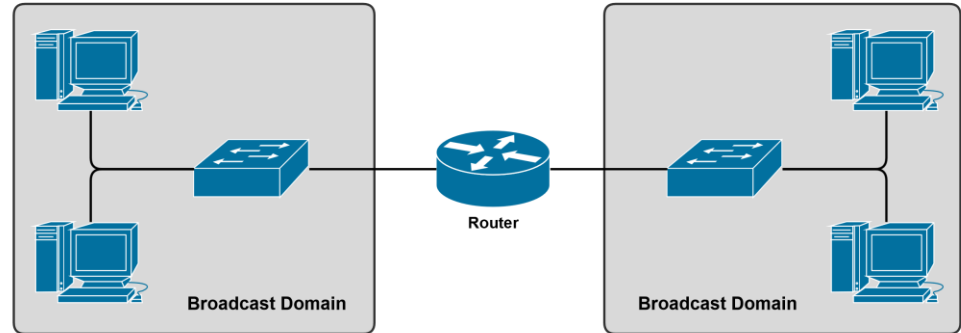
Wireless Ranger Extender

- Extends the range of a wireless network by acting as a wireless repeater.
- Rebroadcasts radio frequencies from the wireless network it is associated with



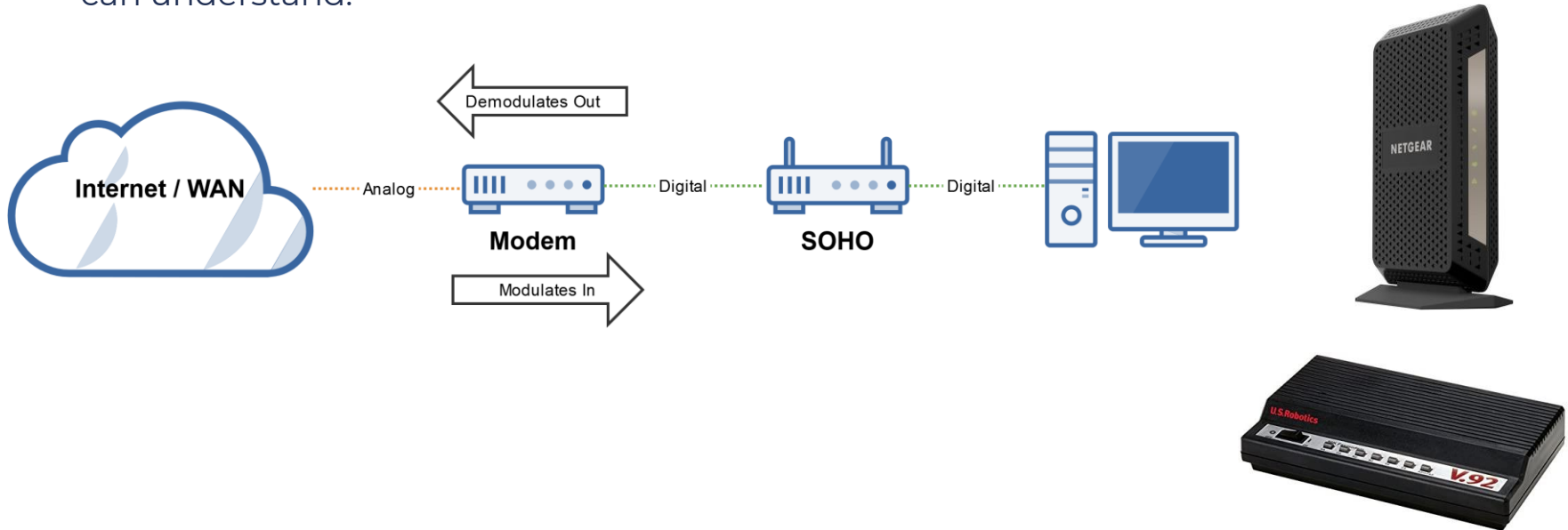
Routers

- Used to Connect Different Networks Together
- Routes Traffic Between Networks using **IP Addresses**
- Uses Intelligent Decisions (Routing Protocols) to Find the Best Way to Get a Packet of Information from One Network to Another.
- Break Up Broadcast Domains
- **OSI Layer 3 Device**
 - Layer 3 = Router
 - Layer 2 = Switch
 - Layer 1 = Hub



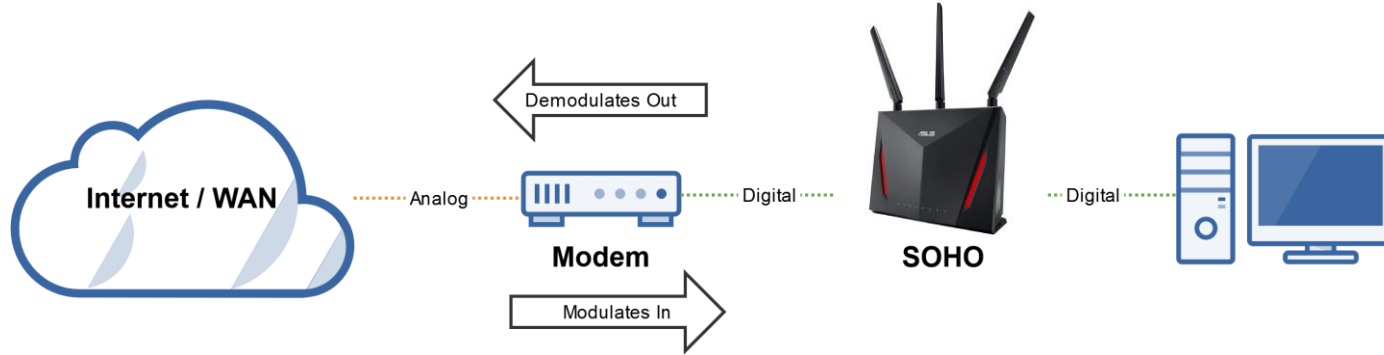
Modems (Modulators/Demodulators)

- Modems modulate one signal to another, such as analog to digital.
- For example, modulating a telephone analog signal into a digital signal that a router can understand.



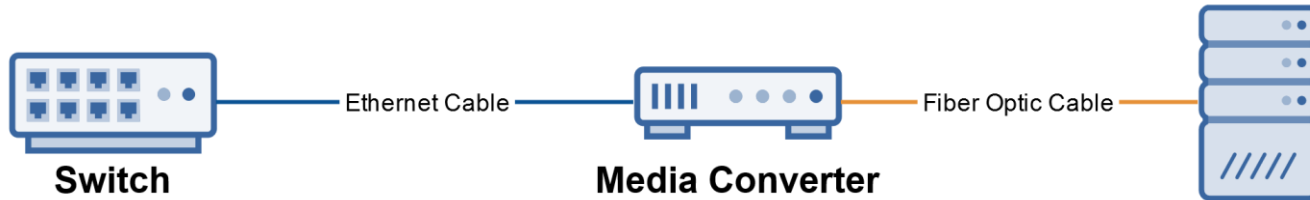
Small Office Home Office (SOHO) Device

- All-In-One Wireless Router with Expanded Capabilities:
 - Router, Wireless Access Point, Firewall, Switch, DHCP Server, NAT Device, File Server, etc.



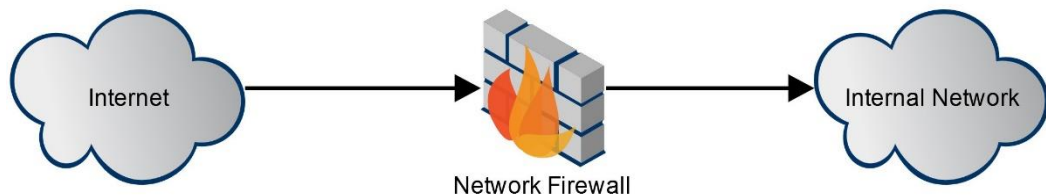
Media Converters

- Like its name implies, it converts one media type to another.
- **Layer 1 Device:** Performs physical layer signal conversion.
- Ethernet to fiber optic media converters are commonly used.



Firewalls

- Firewalls are the foundation of a defense-in-depth network security strategy.
- They protect your network from malicious activity on the Internet.
- Prevent unwanted network traffic on different networks from accessing your network.
- Firewalls do this by filtering data packets that go through them.
- They can be a standalone network device or software on a computer system, meaning **network-based (hardware)** or **host-based (software)**.



Types of Firewalls

Packet Filtering Firewalls

- 1st Generation & Most Basic
- Basic Filtering Rules

Circuit-Level Firewalls

- 2nd Generation
- Monitors Valid/Invalid TCP Sessions

Application Layer 7 (NGFW) Firewalls

- 3rd Generation
- Much more Advanced; Covered Later in Course

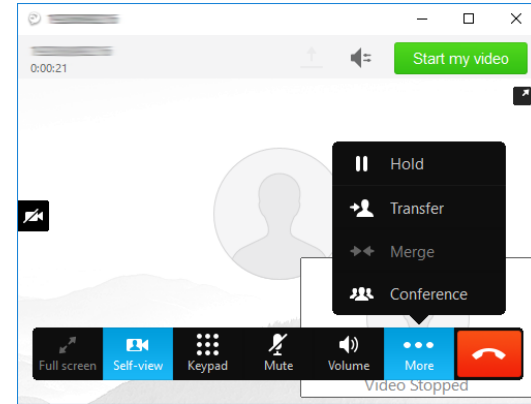
DHCP Server

- Dynamic Host Configuration Protocol (DHCP) Server
- Automatically Assigns IP Addresses to Hosts
- Makes Administering a Network Much Easier
- An Alternative is Static IP addressing
- We'll Talk More About DHCP Later in the Course



Voice over IP (VoIP) Endpoints

- Most phone systems run over IP networks via dedicated protocols, such as the Session Initiation Protocol (SIP), both in-home and office environments.
- VoIP endpoint devices are hardware devices (phones) or software, such as Cisco Jabber, that allow you to make phone calls.



Types of Network Cabling

- Coaxial
- Twisted Pair
- Fiber Optic



Ethernet Explained

- Ethernet is a network protocol that controls how data is transmitted over a LAN.
- It's referred to as the Institute of Electrical and Electronics Engineers (IEEE) 802.3 Standard.
- It supports networks built with coaxial, twisted-pair, and fiber-optic cabling.
- The original Ethernet standard supported 10Mbps speeds, but the latest supports much faster gigabit speeds.
- Ethernet uses CSMA/CD & CSMA/CA access methodology.



Ethernet N<Signaling>-X Naming

- Ethernet uses an “xx Base T” naming convention: **10Base-T**
 - **N**: Signaling Rate, i.e., Speed of the cable.
 - **<Signaling>**: Signaling Type: Baseband (Base) communication.
 - **X**: Type of cable (twisted pair or fiber).

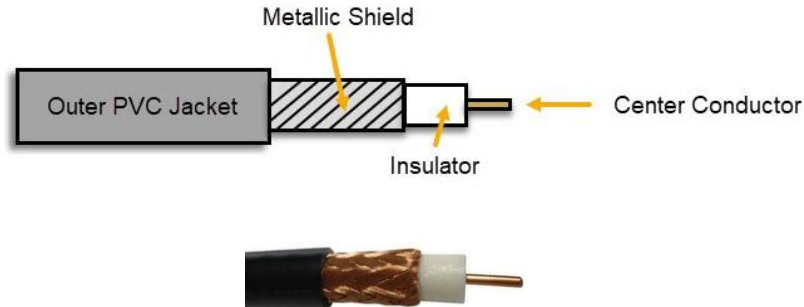
Twisted Pair Standards

Cat	Network Type	Ethernet Standard	Speed	Max. Distance
Cat 3	Ethernet	10Base-T	10Mbps	100 meters
Cat 5	Fast Ethernet	100Base-TX	100Mbps	100 meters
Cat 5e	Gigabit Ethernet	1000Base-T	1Gbps	100 meters
Cat 6	Gigabit Ethernet	1000Base-T	1Gbps	100 meters
	10 Gigabit Ethernet	10GBase-T	10Gbps	55 meters
Cat 6a	10 Gigabit Ethernet	10GBase-T	10Gbps	100 meters
Cat 7	10 Gigabit Ethernet	10GBase-T	10Gbps	100 meters

Cat: Copper Cabling Standard.

Coaxial Cable

- Antiquated technology used in the 1980s. Coaxial cables are rarely used today, except for cable modem connections.
- Categorized as Radio Grade (RG)
 - **RG-6:** Used for modern cable TV and broadband cable modems.
 - **RG-8:** Used in early 10Base5 “Thick-net” Ethernet networks.
 - **RG-58:** Used in early 10Base2 “Thin-net” Ethernet networks.
 - **RG-59:** Used for closed-circuit TV (CCTV) networks
- Metallic shield helps protect against electromagnetic interference (EMI)



Coaxial Cable Connectors

F-Connector

- Screw-on connection
- RG-6 Cable TV and Broadband Cable Applications.



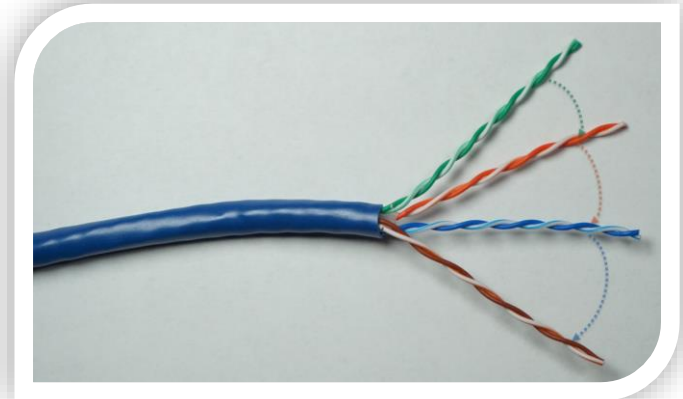
BNC Connector

- Tension spring twist-on connection
- RG-8 “Thick-net” and RG-58 “Thin-net” network applications.



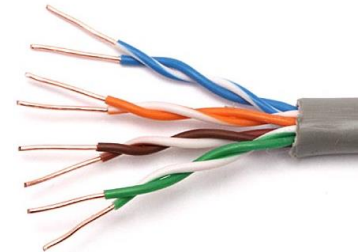
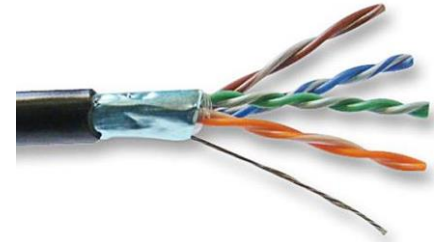
Twisted Pair Copper Cabling

- 4 Twisted Pairs of Wires with RJ-45 Connector
- Balanced pair operation
 - + & - Signals
 - Equal & Opposite Signal
- Why are they twisted?
 - To Help Reduce Interference
 - Crosstalk
 - Noise (Electromagnetic Interference)
- Security concerns
 - Signal Emanations
- 100 Meters Maximum Distance
 - Signal Attenuation



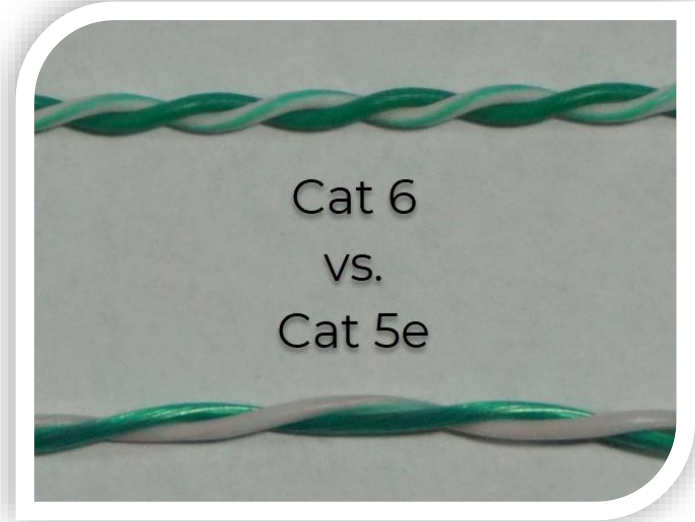
Shielded vs. Unshielded & EMI

- **Unshielded Twisted Pair (UTP)**
 - More susceptible to electromagnetic interference (EMI).
- **Shielded Twisted Pair (STP)**
 - Less susceptible to EMI & Crosstalk (if each pair shielded).
- **Electromagnetic Interference**
 - The disruption of an electronic device's operation when it's in the vicinity of an electromagnetic field caused by another electronic device (manufacturing equipment, microwave ovens, etc.).



Roles of Twists

- Increased twists per inch:
 - Reduces Crosstalk
 - Increases Signals
 - Supports Faster Speeds



Twisted Pair Standards

Cat	Network Type	Ethernet Standard	Speed	Max. Distance	Frequency
Cat 3	Ethernet	10Base-T	10Mbps	100 meters	16 MHz
Cat 5	Fast Ethernet	100Base-TX	100Mbps	100 meters	100 MHz
Cat 5e	Gigabit Ethernet	1000Base-T	1Gbps	100 meters	100 MHz
Cat 6	Gigabit Ethernet 10 Gigabit Ethernet	1000Base-T 10GBase-T	1Gbps 10Gbps	100 meters 55 meters	250 MHz
Cat 6a	10 Gigabit Ethernet	10GBase-T	10Gbps	100 meters	500 MHz
Cat 7	10 Gigabit Ethernet	10GBase-T	10Gbps	100 meters	600 MHz

Cat: Copper Cabling Standard.

Other Copper Cable Connectors

RJ-11

- 4-pin connection used for telephone connections.



DB-9

- 9-pin connection used for serial connections on networking devices



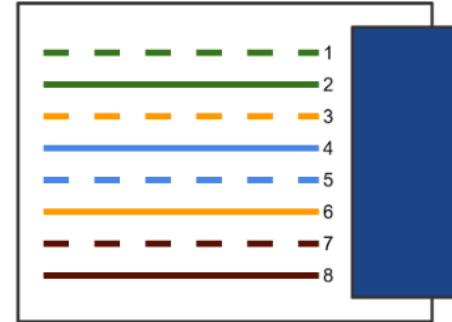
DB-25

- 25-pin connection previously commonly used for serial printer connections.

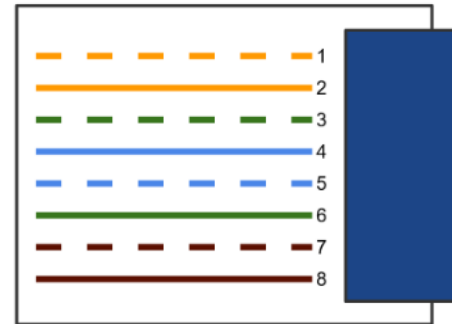


TIA/EIA 568A & 568B Wiring Standards

- Industry-standard that specifies the pin arrangement for RJ-45 connectors.
- Two Standards:
 - 568A & 568B
- 568B is newer and the recommended standard.
- Either can be used.
- Why are standards important?
 - Lower Costs
 - Increase Interoperability
 - Easier Maintenance



TIA/EIA 568A



TIA/EIA 568B

Straight-Through & Crossover Cables

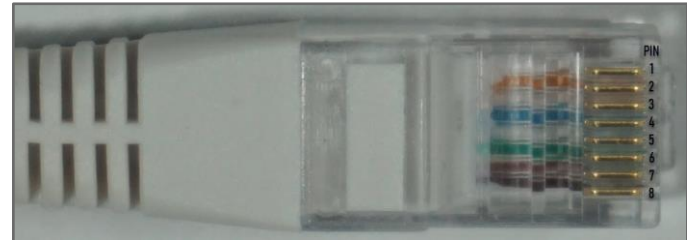
Straight-Through Cable

- Connecting “Unlike” Devices
 - Computer to Switch
 - Switch to Router



Crossover Cable

- Connecting “Like” Devices
 - Router to Router
 - Computer to Computer



Which Twisted Pairs Are Used?

Ethernet & Fast Ethernet

Cat 3 and Cat 5

Only Green and Orange Pairs Used:

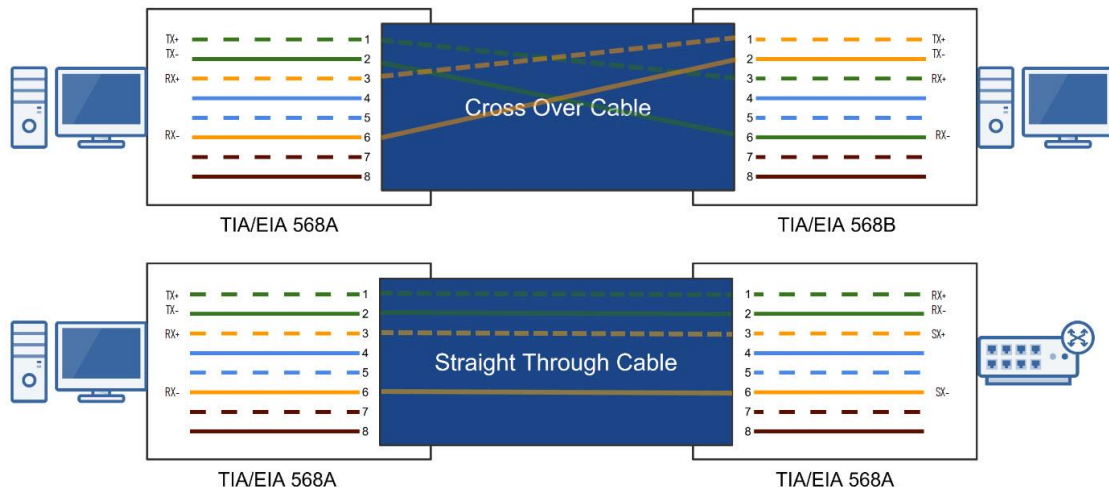
- Pins 1, 2, 3, and 6
 - One Pair to Transmit Data (TX)
 - One Pair to Receive Data (RX)

Gigabit & 10 Gigabit Ethernet

Cat 5e & Faster

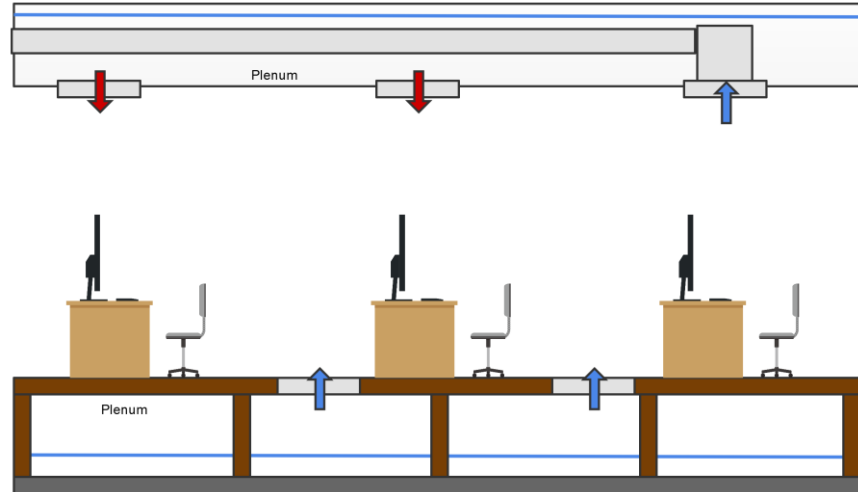
All Four Pairs Used:

- Supports bi-directional data transmission on each pair of wires.



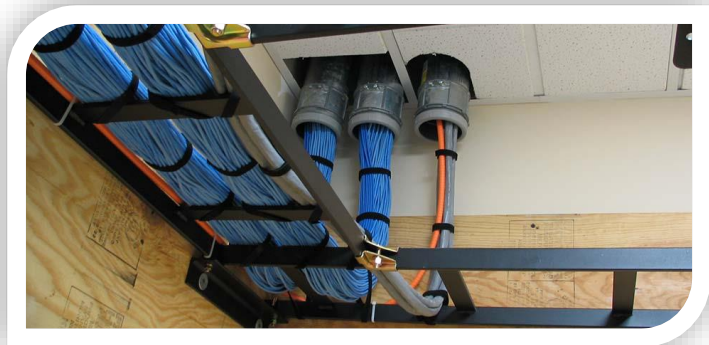
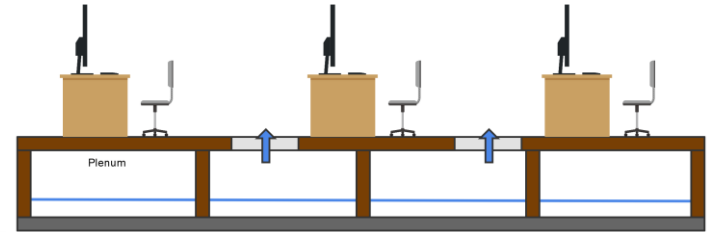
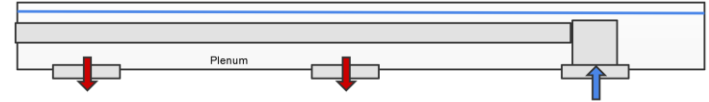
The Plenum

- The plenum is the open space above the ceiling or below a raised floor.
- A “plenum space” is the part of a building that enables air circulation by providing pathways for heated/air-conditioned and return airflows at a higher pressure than normal.
- All network cabling placed in the plenum should be “plenum-rated.”



Non-Plenum-Rated & Fire Hazard

- Non-plenum cable or polyvinyl chloride (PVC) cable is often much less expensive than plenum-rated cable.
- When PVC burns or smolders, it releases toxic fumes into the air (Hydrochloric Acid and Dioxin).
- The plenum air return would unknowingly circulate toxic air throughout an office.
- Sprinkler systems typically can't access the plenum area.
- Building codes often require Plenum Rated cable installed through any plenum space.

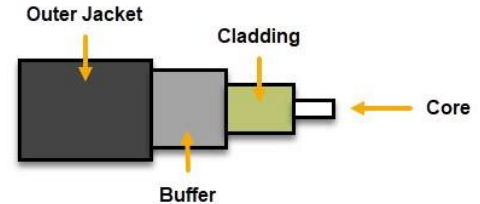


Plenum-Rated Cables

- Plenum-rated cables have a special insulation that has low smoke, low flame and non-toxic characteristics.
- Coated with nonflammable materials that minimize toxic fumes:
 - Teflon
 - Fluorinated ethylene polymer (FEP)
 - Low-Smoke PVC

Fiber Optic Cabling

- Glass or plastic fiber that carries light (photons)
 - **High Bandwidth:** Photons travel faster than electrons.
 - **Long Distances:** Less attenuation.
 - Immune to Electromagnetic Interference (EMI)
 - Doesn't Emit Signals
- Two Types
 - **Multi-mode Fiber (MMF)**
 - Shorter Distances (LAN / Building-to-Building)
 - Up to 2 Kilometers
 - **Single-mode Fiber (SMF)**
 - More expensive than multi-mode
 - Longer Distances (WAN / Across Town)
 - Up to 200 Kilometers

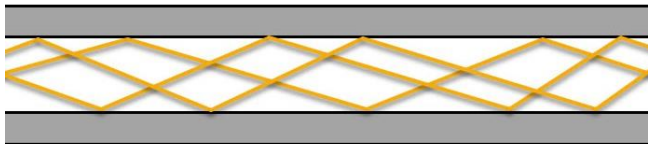


Informational Note: 9-micron Single-Mode Fiber can travel 75 miles at 400 Gbps

MMF versus SMF

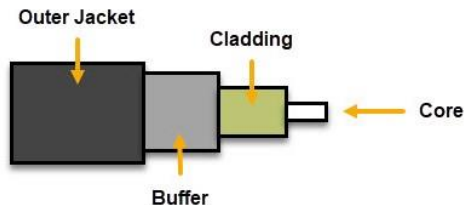
Multi-Mode Fiber (MMF)

- Many photons of light travel through the cable at once, and bounce off the walls, which reduces the distance and speed.
- Larger Core:** 50 to 62.5 microns



Single-Mode Fiber (SMF)

- A single direct photon of light travels through the cable, which allows greater distances and speed.
- Smaller Core:** 8 to 10 microns



Fiber Optic Cable Connectors

Lucent Connector (LC)

- Small form-factor design that has a flange on the top, similar to an RJ-45 connector.
- Commonly used in MMF & SMF gigabit and 10-gigabit Ethernet networks.



Subscriber Connector (SC)

- Square connector that uses a push-pull connector similar to A/V equipment.
- Commonly used in MMF & SMF gigabit Ethernet networks.



Straight Tip (ST)

- BNC style connector with a half-twist bayonet locking mechanism.
- Was used in MMF networks but not commonly used anymore.



Mech. Transfer Register Jack (MTRJ)

- Similar to the RJ-45 connector, and houses two fiber optics cables.
- Designed for MMF networks.



Why use Fiber?

- Fiber cable is more expensive than twisted pair, as is the equipment
- But you can perform much longer network cable runs with fiber.
 - 100m versus up to 200 Kilometers
- So you have decreased network equipment costs
 - Switches, routers, etc.
- Plus fiber is:
 - Immune to EMI and signal emanations
 - Has lower signal attenuation
 - Making it more reliable and secure
- Costs are steadily decreasing as more people adopt fiber

Cable Selection Criteria

Cost Constraints

- What is your budget?

Transmission Speed Requirements

- How fast does your network need to be?
- 10Mbps, 100Mbps, 1Gbps, 10Gbps?

Distance Requirements

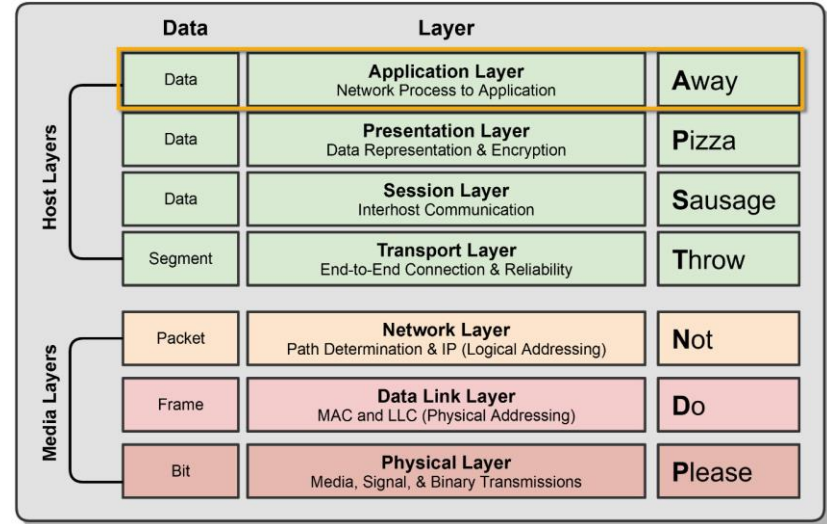
- Electrical signals degrade relatively quickly (100 meters)
- Fiber can transmit over long distances

Noise & Interference Immunity (Crosstalk, EMI, Security)

- Interference is all around us: power cables, microwaves, mobile phones, motors, etc.

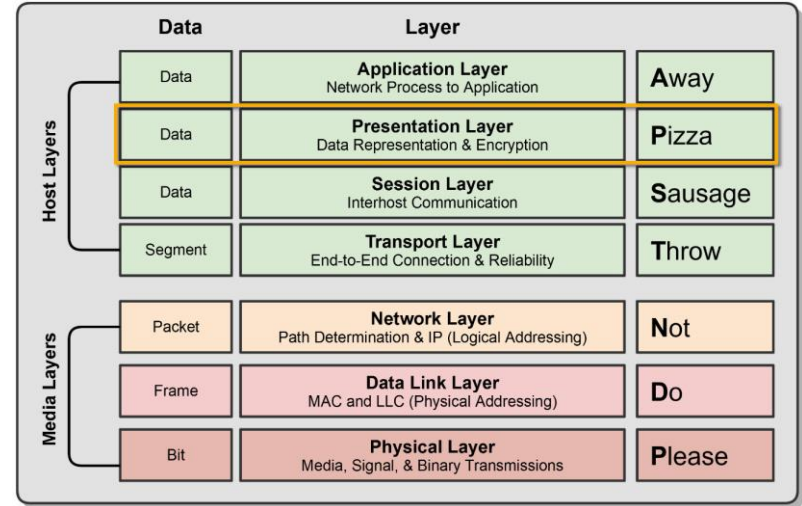
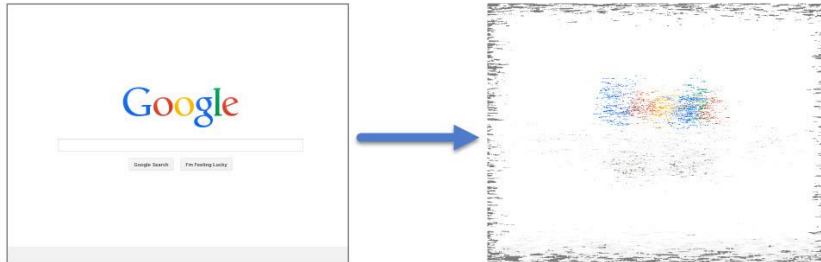
Layer 7 – Application Layer

- Where users interact with the computer.
- Acts as an interface between an application and end-user protocols.
- Provides an interface to communicate with the network (Outlook, Chrome, etc.).
- Applications don't reside in the application layer but instead interfaces with application-layer protocols.
- Example Application Layer Protocols:
 - **E-Mail:** IMAP4, POP3, SMTP
 - **Web Browsers:** HTTP, HTTPS
 - **Remote Access:** SSH, Telnet



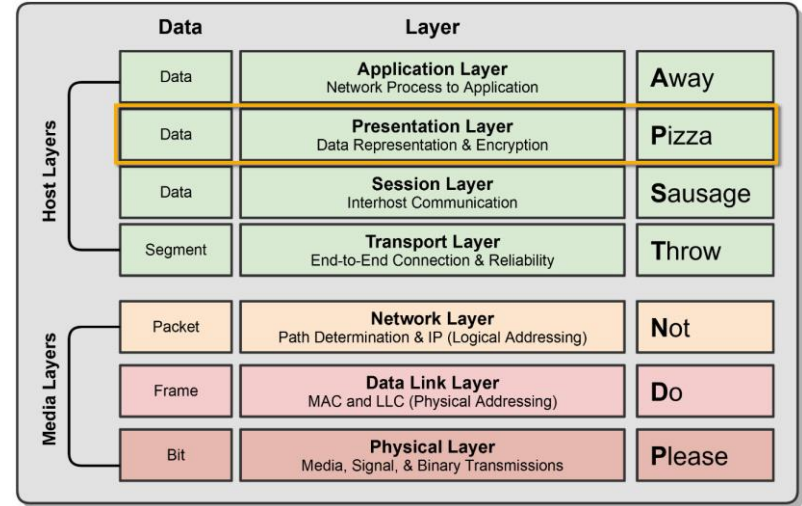
Layer 6 – Presentation Layer

- Ensures that data transferred from one system's Application Layer can be read by the Application Layer on another one.
- Provides character code conversion, data compression, and data encryption/decryption.
- Example:** Google Chrome HTML converted to ASCII Format.



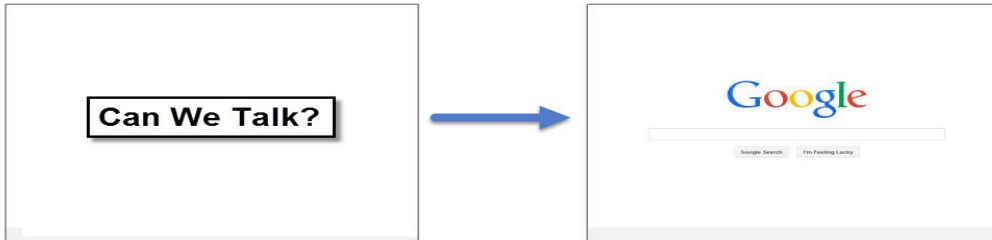
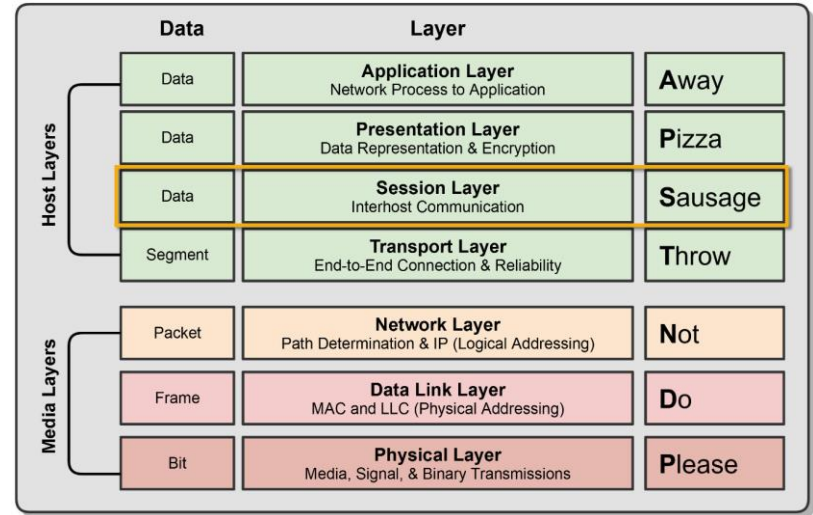
Layer 6 – Presentation Layer

- Example Layer 6 File Formats:
 - **Web Browser:** HTML, XML, JavaScript
 - **Graphics Files:** JPEG, GIF, PNG
 - **Audio/Video:** MPEG, MP3
 - **Encryption:** TLS, SSL
 - **Text/Data:** ASCII, EBCDIC



Layer 5 - Session Layer

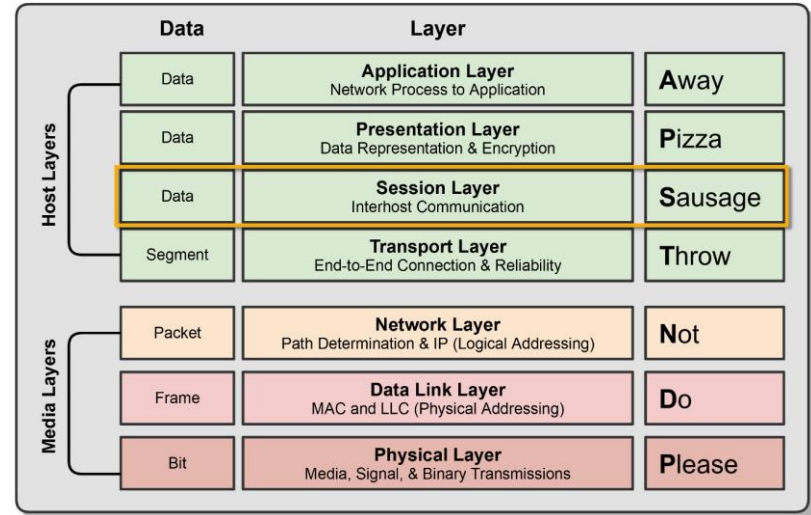
- Responsible for setting up, managing, and then tearing down sessions between network devices.
- Ensures data from different application sessions are kept separate.
- Utilizes Application Program Interfaces (APIs) to communicate with TCP/IP protocols.
- Coordinates communication between systems.
 - Start, Stop, Restart



Layer 5 - Session Layer

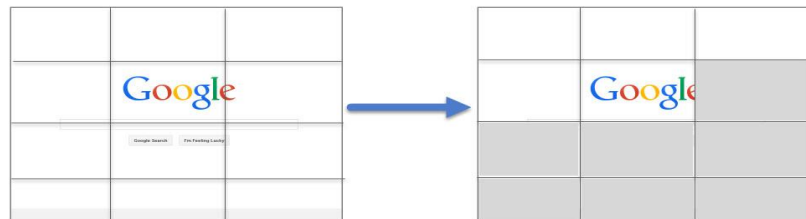
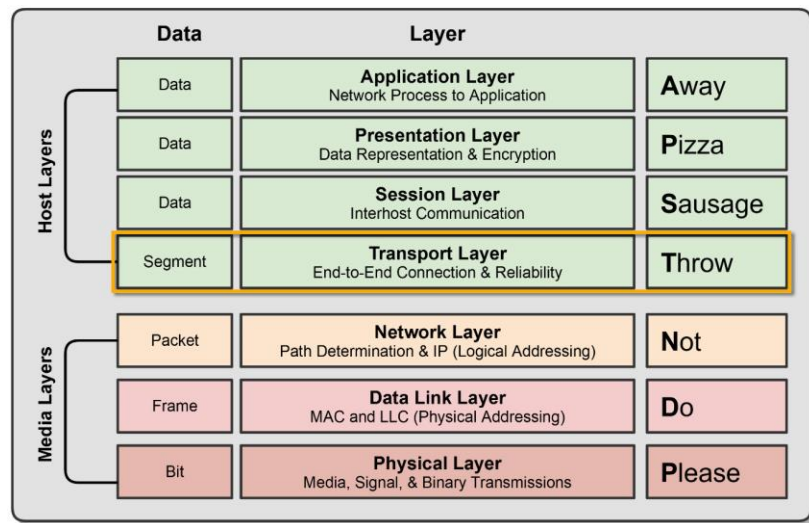
Can provide three different methods of communication between devices:

- **Simplex:** One-way communication between two devices, like listening to a radio station.
- **Half Duplex:** Two-way communication between two devices, but only one device can communicate at a time.
- **Full Duplex:** Two-way communication between two devices, where both sides can communicate at the same time.



Layer 4 - Transport Layer

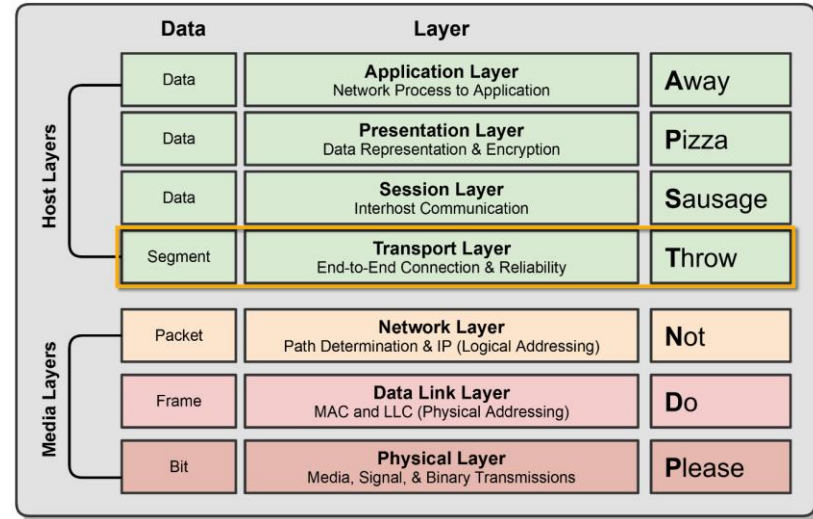
- Ensures data is delivered error-free and in sequence.
- Segments data and reassembles correctly.
- Can be connection-oriented or connectionless.
- Considered the “Post Office” Layer
 - **TCP** (Transmission Control Protocol)
 - **UDP** (User Datagram Protocol)
 - Covered in detail in the next section.



Layer 4 - Transport Layer

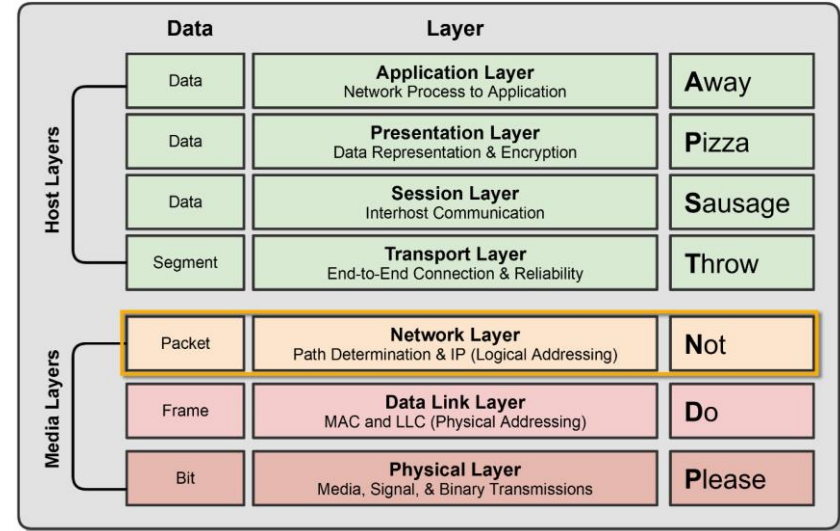
Responsible for two data flow control measures:

- **Buffering**
 - Stores data in memory buffers until destination device is available.
- **Windowing**
 - Allows devices in session to determine the “window” size of data segments sent.



Layer 3 - Network Layer

- The “Routing” Layer
- Provides logical addressing (IP Addressing) and routing services.
- Places two IP addresses into a packet:
 - Source Address & Destination IP Address
- Internet Protocol (IP)
 - The primary network protocol used on the Internet, IPv4, IPv6 Logical Addresses



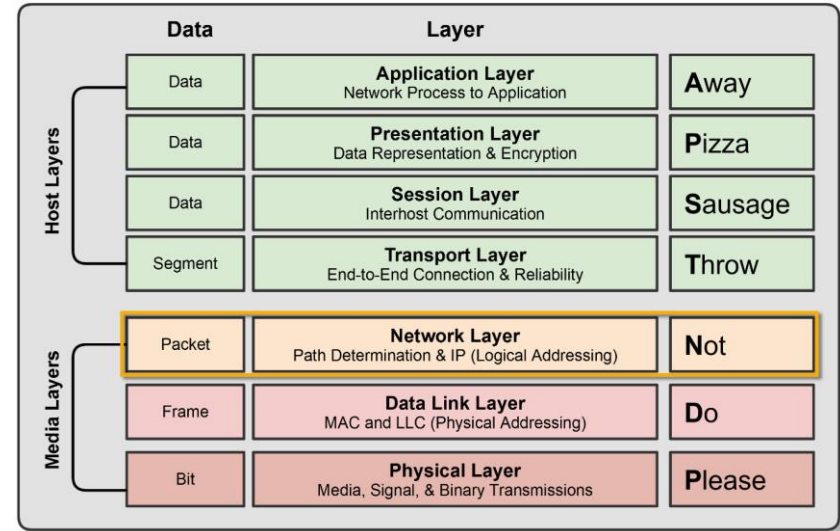
Layer 3 - Network Layer

Types of Packets at Network Layer:

- **Data Packets**
 - Routed Internet Protocol (IP) data packets.
 - IPv4 & IPv6
- **Route-Update Packets**
 - Routing protocols designed to update neighboring routers with router information for path determination.
 - RIP, OSPF, EIGRP, etc.

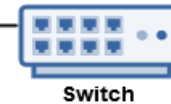
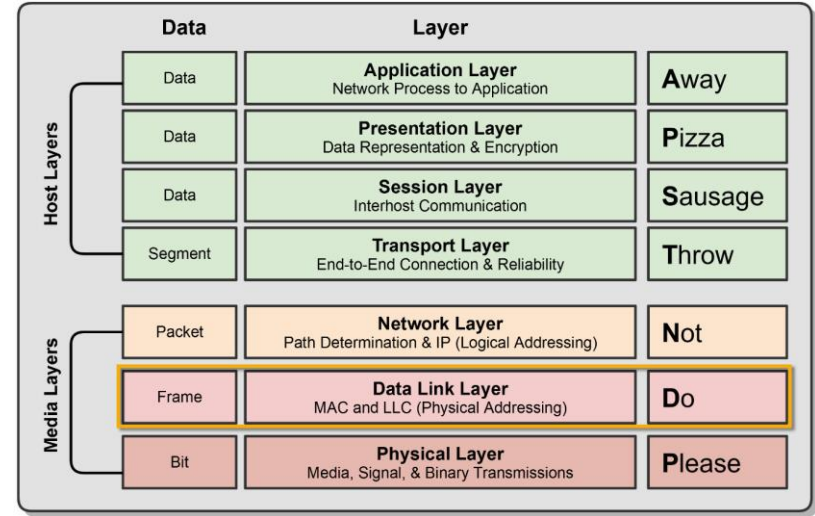
Layer 3 Devices & Protocols:

- Routers & Multi-Layer Switches
- IPv4 & IPv6
- Internet Control Message Protocol (ICMP), i.e., Ping



Layer 2 – Data Link Layer

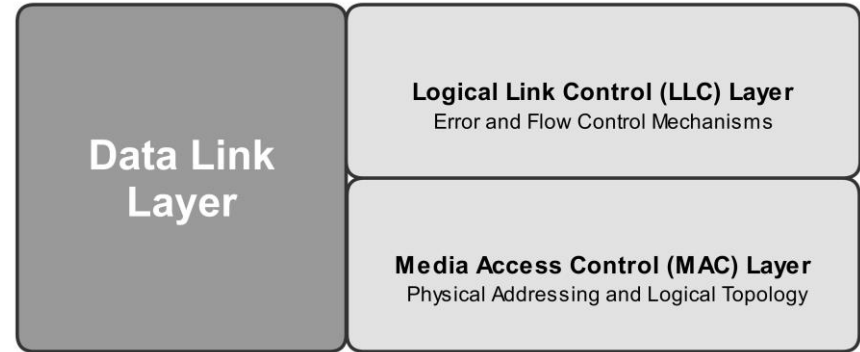
- The “Switching” Layer
- Ensures that messages are delivered to the proper device on a LAN using hardware addresses.
 - MAC (Media Access Control) Address
 - Only concerned with the local delivery of frames on the same network.
- Responsible for packaging the data into frames for the physical layer.
- Translates messages from the Network layer into bits for the Physical layer.



Layer 2 – Data Link Layer

Has two Sub-Layers

- **Logical Link Control (LLC) Layer**
 - Error Control and Flow Control
 - Detect and correct corrupted data frames.
 - Limits amount of data sent so devices aren't overwhelmed.
- **Media Access Control (MAC) Layer**
 - Physical Addressing (MAC Address)
 - 48-Bit MAC Address burned on NIC.
 - Logical Topology and Media Access
 - Ethernet, Token Ring, etc.
 - CSMA/CD & CSMA/CA

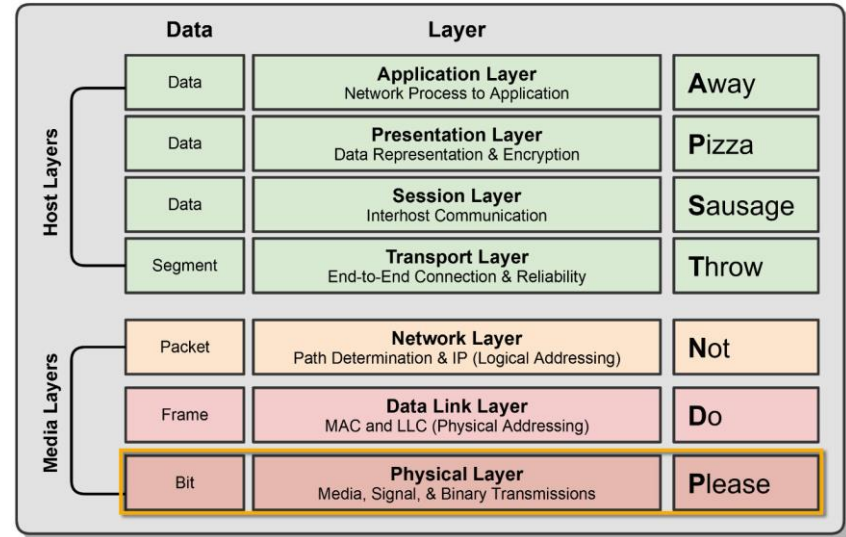


Layer 1 – Physical Layer

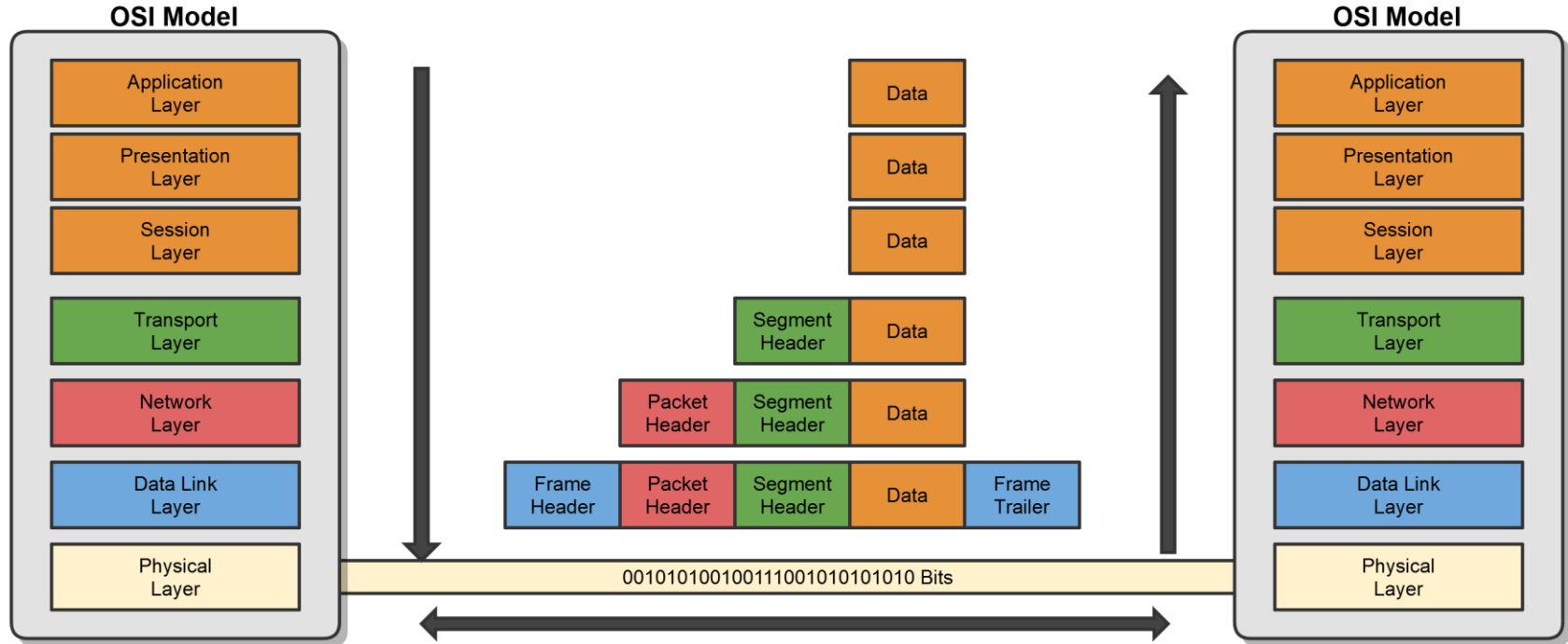
Defines the physical and electrical medium for network communication:

- Sending and receiving bits (1 or 0)
- Encoding Signal Types
 - Electricity, radio waves, light
- Network Cabling, Jacks, Patch Panels, etc.
 - Copper or Fiber
- Physical Network Topology
 - Star, Mesh, Ring, etc.
- Ethernet IEEE 802.3 Standard
- Layer 1 Equipment
 - Hubs, Media Converters, Modems

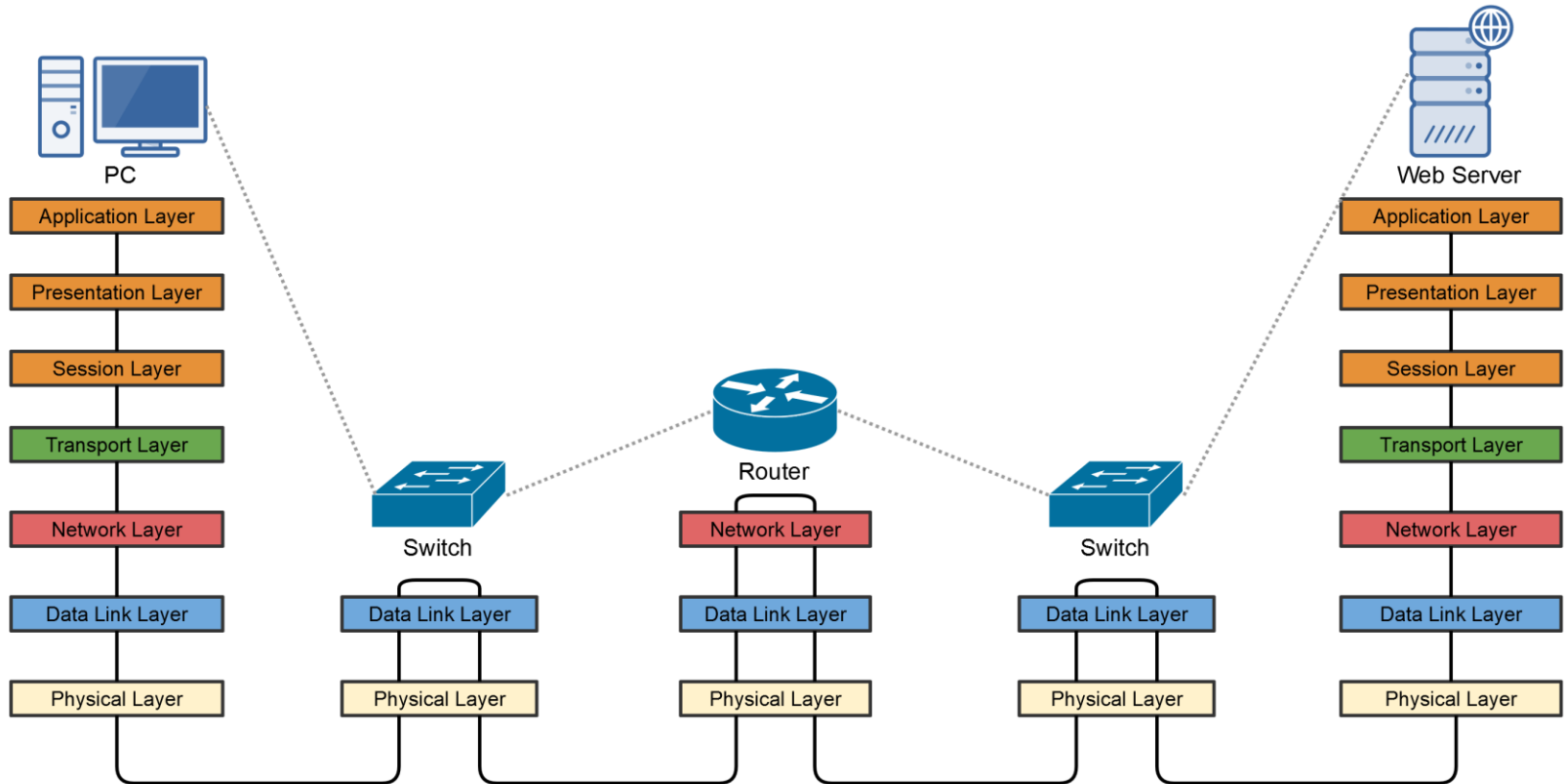
It's responsible for the network hardware and physical topology.



OSI Encapsulation & De-Encapsulation

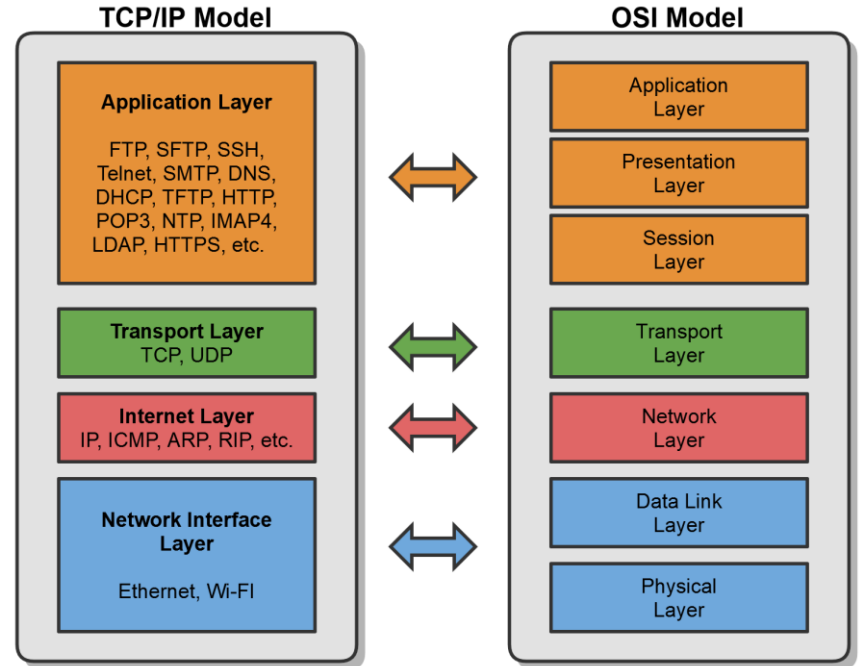


OSI Encapsulation & De-Encapsulation



What is TCP/IP?

- Transmission Control Protocol/Internet Protocol
- Commonly called the **Internet Protocol** suite because it was designed for the Internet, but LANs use it too.
- First Two Protocols Defined in the Suite Were:
 - TCP & IP, hence TCP/IP
- Similar to the OSI Model, but Simpler:
 - OSI is Conceptual
 - TCP/IP was Implemented



TCP/IP Protocols

Layer	Protocols
Application	FTP, TFTP, DNS, HTTP(S), TLS/SSL, SSH, POP3, IMAP4, NTP, Telnet, SMTP, SNMP
Transport	TCP, UDP and Ports
Internet	IP Addressing (Routing), ICMP, ARP
Network Interface	Ethernet, Token Ring

These protocols work together to provide communication, management, diagnostics, and troubleshooting for a TCP/IP network.

Network Access Methods

CSMA

- Carrier Sense
 - Checks network for communication.
- Multiple Access
 - Multiple devices using the network.
- Collision Detection
 - Wired Network
- Collision Avoidance
 - Wireless Network

Token Ring

- The Token
 - Passed between devices on the network.
 - Only devices with the token can send data.
 - Token prevents network collisions.

Address Resolution Protocol (ARP)

- Resolves IP address to MAC Addresses
- Finds the hardware address of a host from a know IP address
 - And vice versa (RARP)

ARP Command: arp -a

```
Command Prompt
Microsoft Windows [Version 10.0.19042.985]
(c) Microsoft Corporation. All rights reserved.

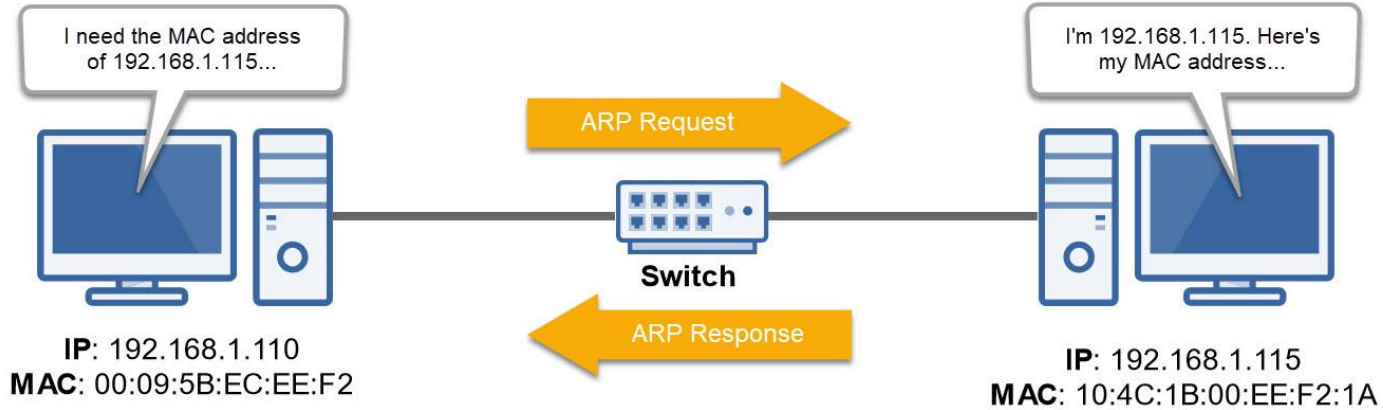
C:\Users\Alton>arp -a

Interface: 192.168.0.132 --- 0xe
Internet Address      Physical Address      Type
192.168.0.1           2c-fd-a1-a2-74-c0     dynamic
192.168.0.5           00-90-a9-db-c1-a3     dynamic
192.168.0.10          00-11-32-e2-ce-58     dynamic
192.168.0.15          00-11-32-d0-b6-9f     dynamic
192.168.0.62          10-98-c3-dc-f4-4a     dynamic
192.168.0.76          ac-ae-19-03-b3-e6     dynamic
192.168.0.186         82-07-b3-9c-ef-ab     dynamic
192.168.0.199         0c-47-c9-33-92-68     dynamic
```

```
root@kali: ~
root@kali:~# arp -a
_gateway (10.0.2.1) at 52:54:00:12:35:00 [ether] on eth0
root@kali:~#
```

```
alton — -bash — 68x7
Last login: Thu May 13 14:25:01 on console
[Altons-iMac:~ alton$ arp -a
? (10.0.2.2) at 52:54:0:12:35:2 on en0 ifscope [ethernet]
? (10.0.2.255) at ff:ff:ff:ff:ff:ff on en0 ifscope [ethernet]
? (224.0.0.251) at 1:0:5e:0:0:fb on en0 ifscope permanent [ethernet]
Altons-iMac:~ alton$
```

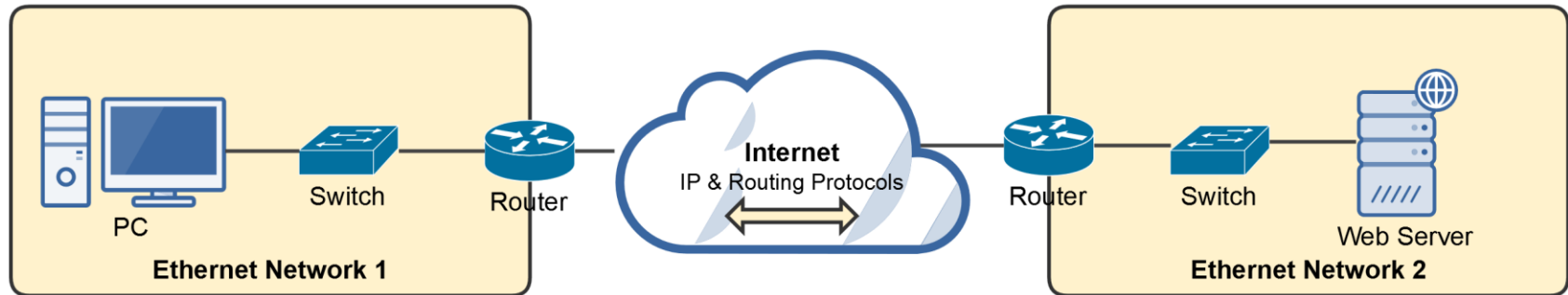
ARP Diagram



If a computer knows a device's IP address but not its MAC address, it'll send a **broadcast** message to all devices on the LAN asking which device is assigned that MAC address.

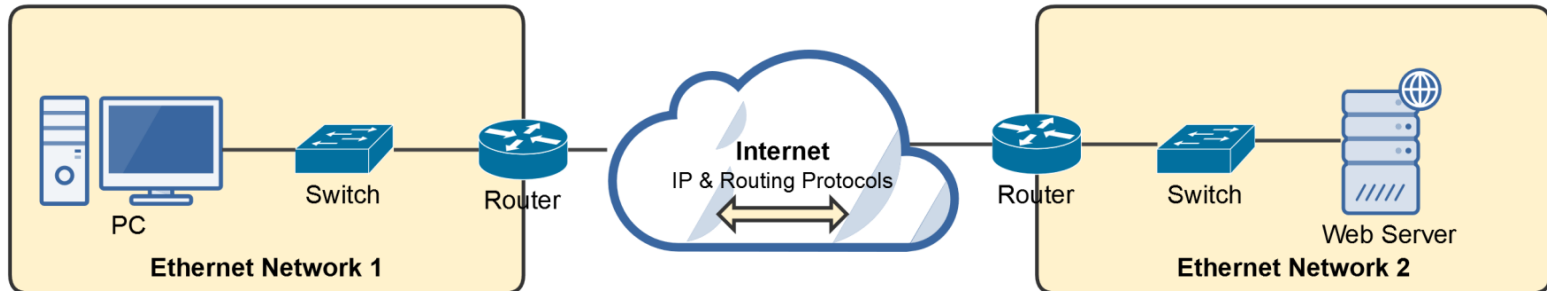
The Internet Protocol (IP)

- An OSI Layer 3 protocol that defines routing and logical addressing of packets that allow data to traverse WANs and the Internet.
- It specifies the formatting of packets and the logical addressing schema
 - **IP addresses:** IPv4 and IPv6
- Its job is to connect different OSI Layer 2 (switched) networks together.
- Provides end-to-end connectivity from one Layer 2 network to another via routers.



The Internet Protocol (IP)

- It's connectionless and, therefore, unreliable (similar to UDP).
 - No continued connection.
- Each packet sent is independent of each other packet.
 - TCP and other protocols provide a means to reassemble them properly.
 - Packets don't always follow the same path to their destination.
 - They're sent via the most efficient route.
- Doesn't provide any error recovery or sequencing functionality.
 - That's the job of other protocols.



Internet Control Message Protocol (ICMP)

- OSI Layer 3 Internet Protocol (IP) companion “error reporting” protocol within the TCP/IP suite of protocols.
- Just like IP, it’s connectionless.
- Used to generate error messages to the source IP address when network issues prevent the delivery of a packet.
- Typically used by routers to report packet delivery issues, and, most importantly, it can report errors but not correct them.
- Commonly used by IT administrators to troubleshoot network connections with command-line utilities, including ping, pathping, and traceroute.
- For IPv6, it is also used for:
 - Neighbor Solicitation and Advertisement Messages (Similar to ARP)
 - Router Solicitation and Advertisement Messages

(Some) ICMP Message Types

- **Echo Request, Echo Reply:** Tests destination accessibility and status. A host sends an *Echo Request* and listens for a corresponding *Echo Reply*. Commonly done using the **ping** command.
- **Destination Unreachable:** Sent by a router when it can't deliver an IP packet.
- **Source Quench:** Sent by a host or router if it's receiving too much data than it can handle. The message requests that the source reduces its rate of data transmission.
- **Redirect Message:** Sent by a router if it receives a packet that should have been sent to a different router. The message includes the IP address to which future packets should be sent and is used to optimize the routing.
- **Time Exceeded:** Sent by a router if a packet has reached the maximum limit of routers through which it can travel.
- **Router Advertisement, Router Solicitation (IPv6):** Allow hosts to discover the existence of routers. Routers periodically multicast their IP addresses via *Router Advertisement* messages. Hosts may also request a router IP address by broadcasting a *Router Solicitation* message, then wait for a router to reply with a *Router Advertisement*.

Understanding Protocols, Ports, and Sockets

Protocols

- Computers communicate with each other with network protocols.
- Protocols are rules governing how machines exchange data and enable effective communication.
- In an operating system (OS), a protocol runs as a process or service.

Ports

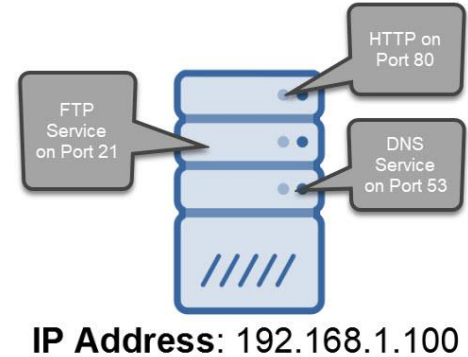
- Ports are logical constructs that bind a unique port number to a protocol process or service.

Sockets

- Sockets are a combination of an IP address and a port number, for example, 192.168.1.1:80.

Why We Need Ports and Sockets

- Computers require ports because of network application multitasking.
- Because a computer may have only one IP address, it needs ports to differentiate network protocols and services running on it.
- TCP/IP has 65,536 ports available



Port Type	Port Numbers	Description
Well Known Ports	0 – 1023	Assigned to well-known protocols.
Registered Ports	1024 – 49,151	Registered to specific protocols.
Dynamic Ports	49,152 – 65,535	Not registered and used for any purpose.

Protocols & Port Numbers

Service, Protocol, or Application	Port Number(s)	TCP or UDP
FTP (File Transfer Protocol)	20, 21	TCP
Secure FTP (SFTP)	22	TCP
SSH (Secure Shell Protocol)	22	TCP
Telnet	23	TCP
SMTP (Simple Mail Transfer Protocol)	25	TCP
DNS (Domain Name System)	53	UDP
DHCP (Dynamic Host Configuration Protocol)	67, 68	UDP
TFTP (Trivial File Transfer Protocol)	69	UDP
HTTP (Hypertext Transfer Protocol)	80	TCP
POP3 (Post Office Protocol version 3)	110	TCP

Protocols & Port Numbers

Service, Protocol, or Application	Port Number(s)	TCP or UDP
NTP (Network Time Protocol)	123	UDP
IMAP4 (Internet Message Access Protocol version 4)	143	TCP
SNMP (Simple Network Management Protocol)	161	UDP
LDAP (Lightweight Directory Access Protocol)	389	TCP
HTTPS (Hypertext Transfer Protocol Secure)	443	TCP
Server Message Block (SMB)	445	TCP
LDAPS (Lightweight Directory Access Protocol Secure)	636	TCP
RDP (Remote Desktop Protocol)	3389	TCP
ITU Telecommunication Standardization Sector A/V Recommendation (H.323)	1720	TCP
Session Initiation Protocol (SIP)	5060, 5061	TCP

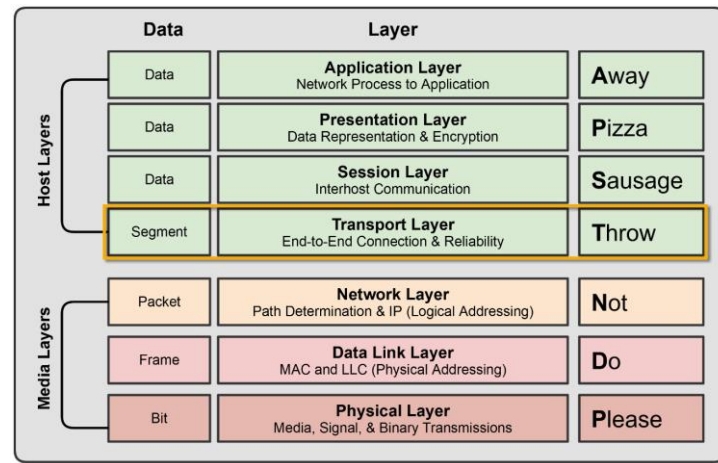
TCP vs. UDP

Transport Layer Protocols

- **TCP** (Transmission Control Protocol): Connection-Oriented
- **UDP** (User Datagram Protocol): Connectionless

TCP is the most widely used Transport Layer protocol because it is connection-oriented, which provides packet delivery reliability, i.e., guaranteed delivery.

UDP, being connectionless, is considered to be unreliable; however, it is more lightweight than TCP and often used for streaming or real-time data.

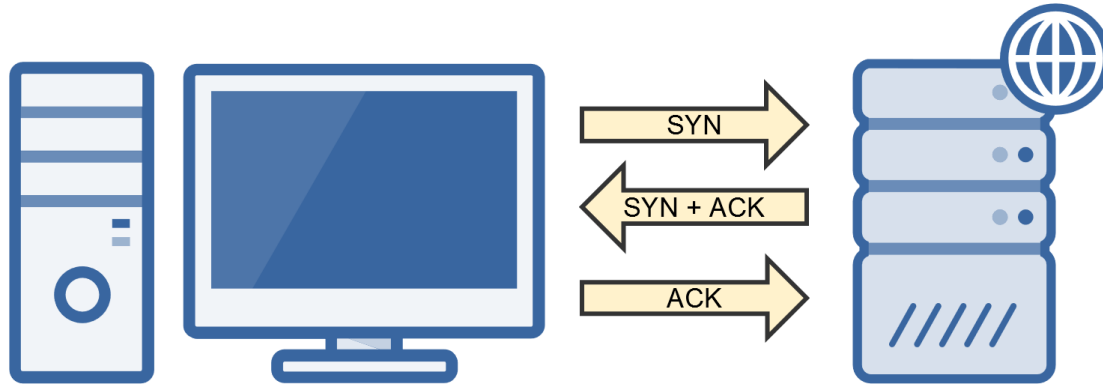


TCP Reliability

- TCP utilizes the following features to ensure reliable delivery of data.
 - **3-Way Handshake** creates a virtual connection between the source and destination before data is sent.
 - **Acknowledgment** is required before the next segment is sent.
 - **Checksum** that detects corrupted data.
 - **Sequence Numbers** that detect missing data and reassemble them in the correct order.
 - **Retransmission** that will retransmit lost or corrupt data.
- **Note:** TCP header is 20 bytes in size, whereas the UDP header is only 8 bytes.

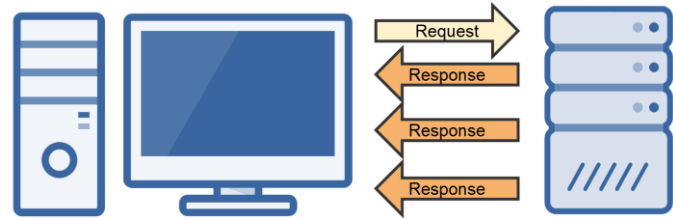
TCP Three-Way Handshake

- A connection must be established before data is transmitted, called the three-way handshake.
 - SYN → SYN / ACK → ACK
- Creates a Virtual Connection Between 2 Devices



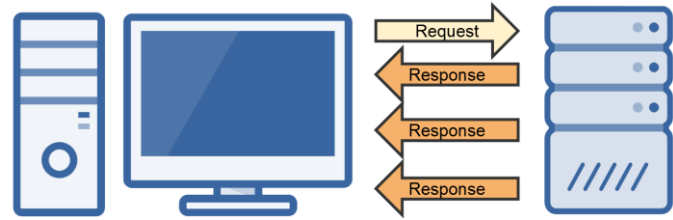
“Best Effort” UDP

- A scaled-down, economic version of TCP
 - Connectionless & Unreliable
 - No Data Retransmissions
 - “Best Effort”
- Faster than TCP
 - Smaller Header & Connectionless
- Primarily used for protocols that favor:
 - Low-Latency, i.e., Faster Speeds
 - Can Tolerate Data Loss



“Best Effort” UDP

- Example UDP Use-Cases
 - VoIP Phone Calls
 - Live Video Streams
 - Live Audio Streams
 - Online Gaming
 - Certain Network Management Protocols
 - DNS
 - DHCP
 - NTP



Application Layer Management Protocols

- Domain Name System (DNS)
- Dynamic Host Configuration Protocol (DHCP)
- Network Time Protocol (NTP)
- Simple Network Management Protocol (SNMP)
- Lightweight Directory Access Protocol (LDAP)
- LDAP Secure (LDAPS)
- Server Message Block (SMB)

Domain Name System (DNS)

Port: 53 Transport Layer Protocol: UDP

- Protocol that is used to resolve a domain name to its corresponding IP address
 - InstructorAlton.com → 162.0.232.236
- Uses TCP port 53 by default
- We'll be discussing DNS in detail in the **DNS Network Services** section of this course:
 - DNS Hierarchy
 - DNS Record Types
 - Name Resolution

Dynamic Host Configuration Protocol (DHCP)

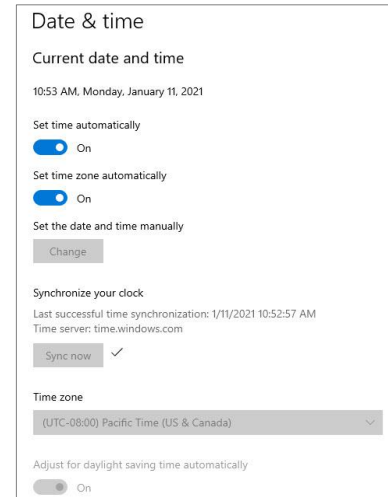
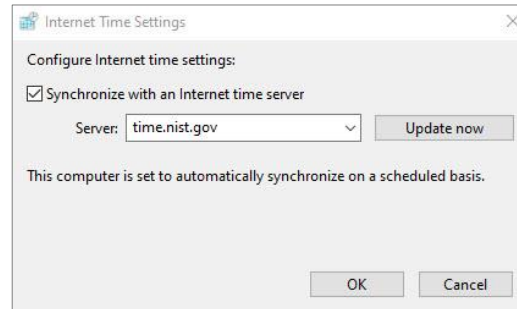
Ports: 67, 68 Transport Layer Protocol: UDP

- Protocol that automatically assigns IP address configurations to devices on a network:
 - IP Address
 - Subnet Mask
 - Default Gateway
 - DNS Server
- We'll be discussing how DHCP works in detail in the **Assigning IP Addresses** section of this course
- Uses two UDP ports 67 and 68 by default

Network Time Protocol (NTP)

Port: 123 Transport Layer Protocol: TCP

- Protocol that automatically synchronizes a system's time with a network time server.
 - Important for time-dependent network applications and protocols.
 - If a system is configured with the incorrect time, it may not be able to access network services.
 - Authentication will often fail if time isn't properly synchronized between devices.
- Uses TCP port 123 by default.



Simple Network Management Protocol (SNMP)

Port: 161 Transport Layer Protocol: TCP

- Protocol used to monitor and manage network devices
- Allows admins to monitor and manage network devices and traffic.
- Allows network devices to communicate information about their state:
 - Memory
 - CPU
 - Bandwidth
- Uses TCP port 161 by default

Lightweight Directory Access Protocol (LDAP)

Port: 389 Transport Layer Protocol: TCP

- Protocol that provides a means to access and query directory service systems:
 - Usernames, Passwords, Computer Accounts, etc.
- Typically Unix/Linux-based or Microsoft Active Directory-based
- Uses TCP 389 by default

LDAP Secure (LDAPS)

Port: 636 Transport Layer Protocol: TCP

- LDAP over SSL
- A secure version of LDAP that utilizes SSL to encrypt LDAP network traffic
- Uses TCP port 636 by default

Server Message Block (SMB)

Port: 445 **Transport Layer Protocol:** TCP

- Network and file sharing protocol commonly used in Microsoft environments
- Allows systems to share their files and printers with other systems
- Uses TCP port 445 by default

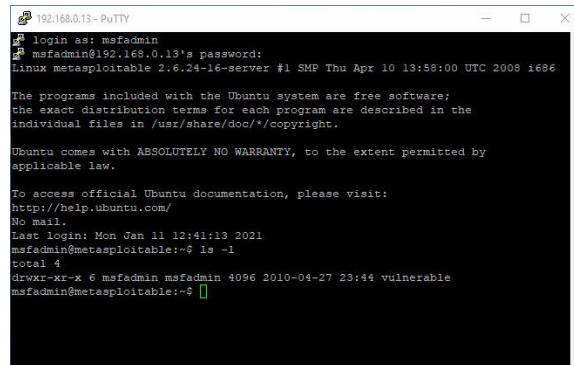
Application Layer Remote Communication Protocols

- Telnet
- Secure Shell (SSH)
- Remote Desktop Protocol (RDP)

Telnet

Port: 23 Transport Layer Protocol: TCP

- Legacy protocol used to “insecurely” connect to a remote host
 - Data is transferred in clear text, so it’s considered insecure
 - Largely replaced by SSH
- Today it’s primarily used to access managed network devices, such as routers via a serial connection
- Use TCP Port 23 by default

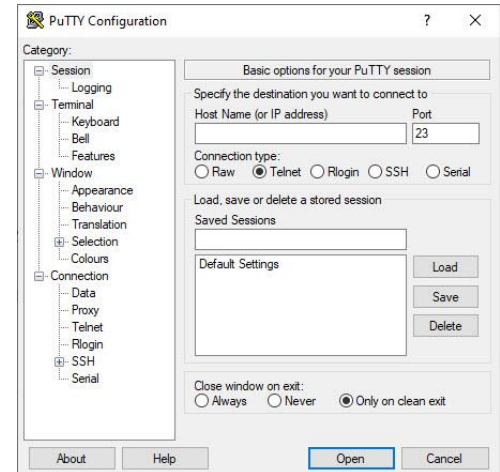


```
192.168.0.13 - PuTTY
login as: msfadmin
msfadmin@192.168.0.13's password:
Linux metasploitable 2.6.24-16-server #1 SMP Thu Apr 10 13:58:00 UTC 2008 i686

The programs included with the Ubuntu system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Ubuntu comes with ABSOLUTELY NO WARRANTY, to the extent permitted by
applicable law.

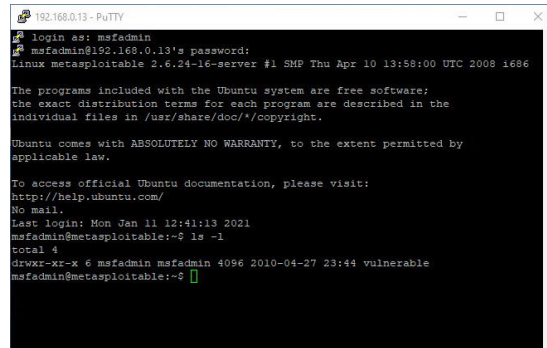
To access official Ubuntu documentation, please visit:
http://help.ubuntu.com/
No mail.
Last login: Mon Jan 11 12:41:13 2021
msfadmin@metasploitable:~$ ls -l
total 4
drwxr-xr-x 6 msfadmin msfadmin 4096 2010-04-27 23:44 vulnerable
msfadmin@metasploitable:~$
```



Secure Shell (SSH)

Port: 22 Transport Layer Protocol: TCP

- A cryptographic protocol that's used to securely connect to a remote host
 - Utilizes a terminal console
 - Typically Unix and Linux Machines, but also available on Windows and Mac OS
- Encrypts data with public key infrastructure (PKI), making it secure
 - Considered secure replacement for Telnet
- Uses TCP port 22 by default

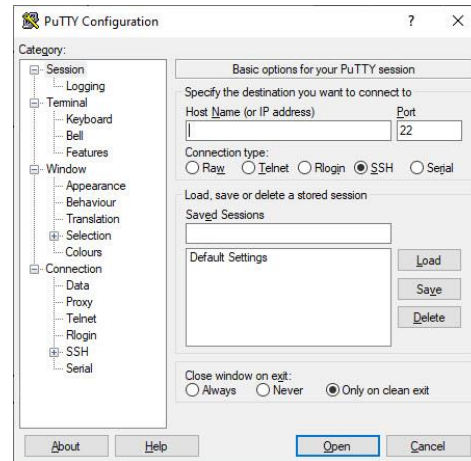


```
192.168.0.13 - PuTTY
login as: msfadmin
msfadmin@192.168.0.13's password:
Linux metasploitable 2.6.24-16-server #1 SMP Thu Apr 10 13:58:00 UTC 2008 i686

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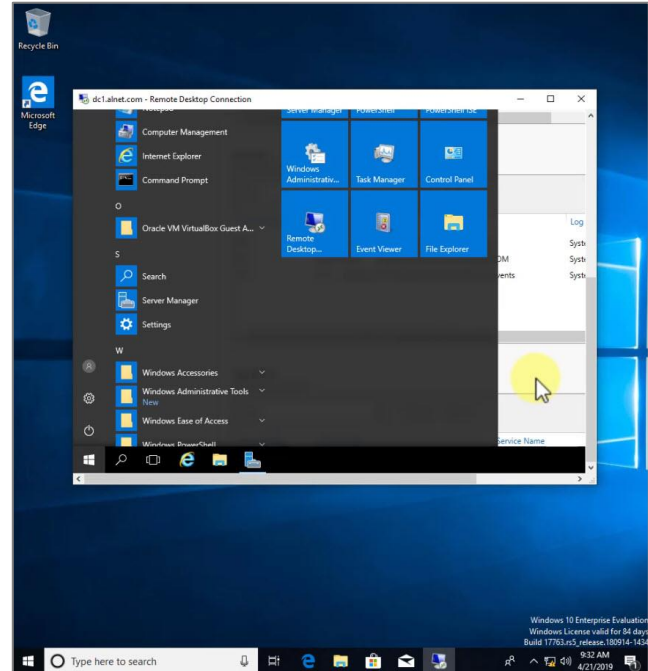
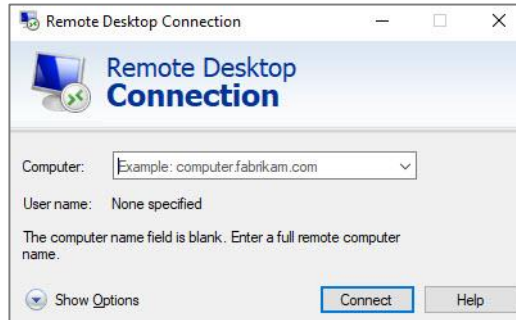
To access official Ubuntu documentation, please visit:
http://help.ubuntu.com/
No mail.
Last login: Mon Jan 11 12:41:13 2021
msfadmin@metasploitable:~$ ls -l
total 4
-rwxr-xr-x 6 msfadmin msfadmin 4096 2010-04-27 23:44 vulnerable
msfadmin@metasploitable:~$
```



Remote Desktop Protocol (RDP)

Port: 3389 Transport Layer Protocol: TCP

- A Microsoft protocol that allows users to remotely connect to, view, and control a remote computer from a Windows desktop.
- Built into the Microsoft operating system.
- Uses TCP port 3389 by default



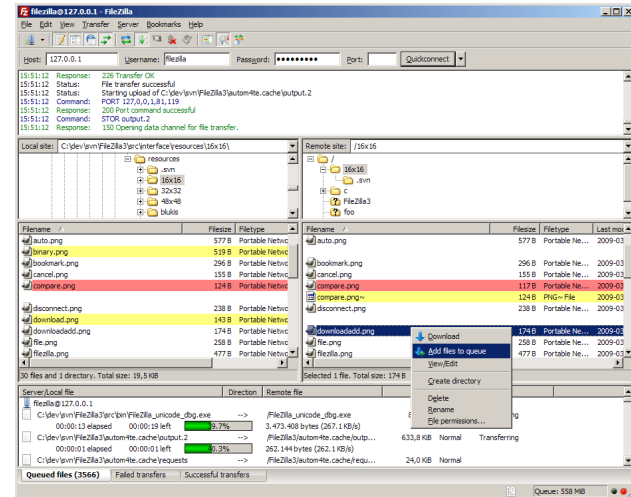
Application Layer File Transfer Protocols

- File Transfer Protocol (FTP)
- Secure File Transfer Protocol (SFTP)
- Trivial File Transfer Protocol (TFTP)

File Transfer Protocol (FTP)

Ports: 20, 21 Transport Layer Protocol: TCP

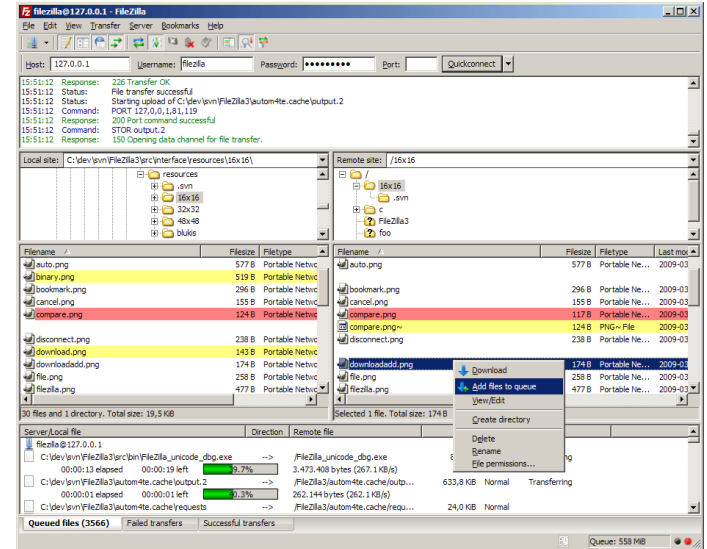
- Legacy protocol used to transfer files between systems
 - Slowly being replaced by Secure FTP (SFTP)
- Can authenticate with a username and password or utilize anonymous logins
- Data is transferred in clear text, so it's considered insecure
- Full-featured functionality:
 - View, list, add, delete, etc. files and folders
- Uses two TCP ports by default:
 - **Port 20 for Data:** Data Transfers
 - **Port 21 for Control:** Commands



Secure File Transfer Protocol (SFTP)

Port: 22 Transport Layer Protocol: TCP

- A secure cryptographic version of FTP that uses SSH to provide encryption services.
 - Provides file transfer over SSH
- Uses TCP port 22 by default (same port as SSH)



Trivial File Transfer Protocol (TFTP)

Port: 69 Transport Layer Protocol: UDP

- A bare-bones version of FTP used for simple downloads
 - Doesn't support authentication
 - Doesn't support directory navigation
- Requires that you request the exact file (and location)
- Often used to transfer software images for routers and switches during upgrades
- Utilizes UDP port 69 by default

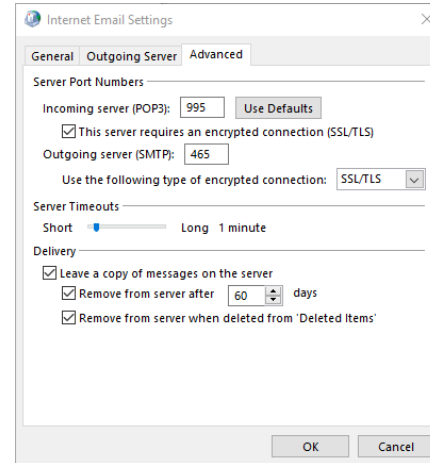
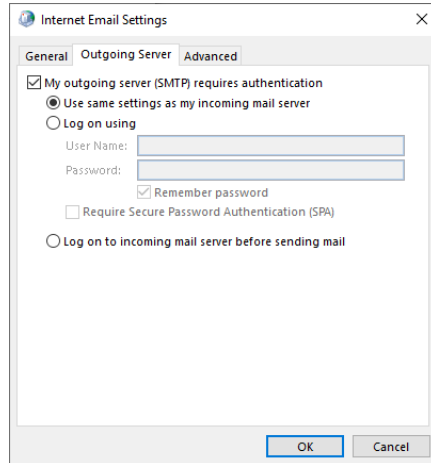
Application Layer Email Protocols

- Simple Mail Transfer Protocol (SMTP)
- Post Office Protocol Version 3 (POP3)
- Internet Message Access Protocol (IMAP)

Simple Mail Transfer Protocol (SMTP)

Port: 25 Transport Layer Protocol: TCP

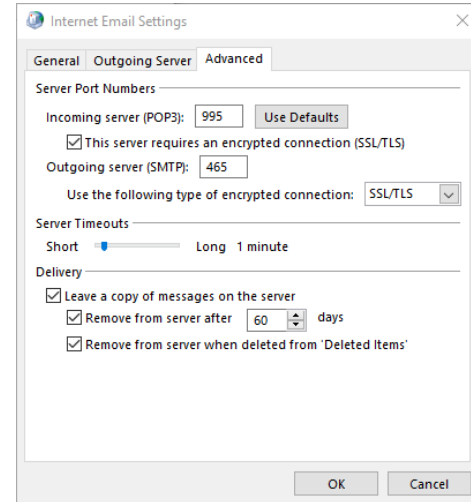
- Email protocol that is used to deliver emails from an email client (Outlook) to a destination email server
- Can be configured to use encryption (recommended) or plain text
- Uses TCP Port 25 by default



Post Office Protocol Version 3 (POP3)

Port: 110 Transport Layer Protocol: TCP

- Email protocol that is used to retrieve emails from an email server
- Can be configured to use encryption (recommended) or plain text
- Uses TCP Port 110 by default



Internet Message Access Protocol (IMAP)

Port: 143 Transport Layer Protocol: TCP

- Another email protocol that is quickly replacing POP3
- Allows users to access email on servers and either read the email on the server or download the email to the client machine
- Popular when a user accesses email from multiple different devices
- Web-based email clients, such as Gmail, use IMAP
- Uses TCP port 143 by default

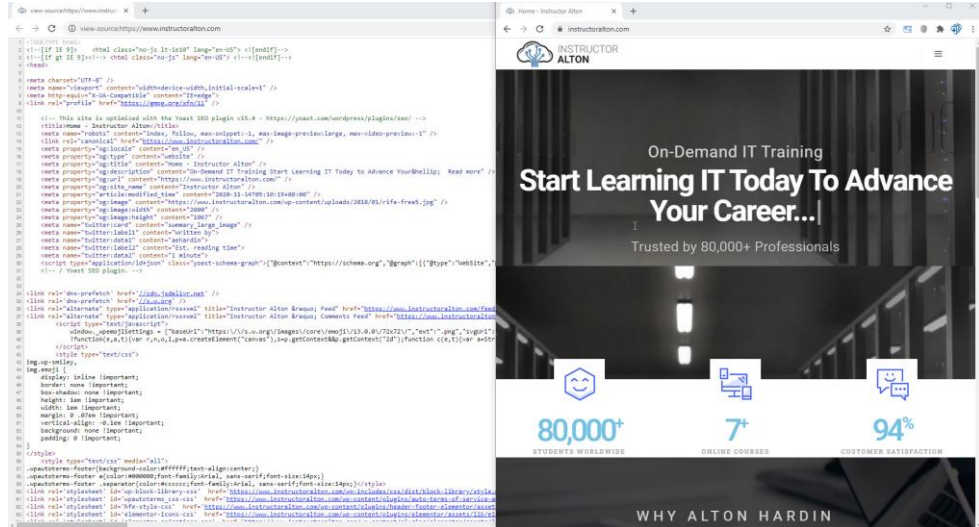
Application Layer Web Browser Protocols

- Hypertext Transfer Protocol (HTTP)
- HTTP Secure (HTTPS)

Hypertext Transfer Protocol (HTTP)

Port: 80 Transport Layer Protocol: TCP

- Protocol that provides browsing services for the World Wide Web (WWW)
 - Retrieves the content of a web page from a web server
 - Requests are made in hypertext markup language (HTML) and returned to your browser in that format
- Data is sent in plain text
- Uses TCP Port 80 by default



HTTP Secure (HTTPS)

Port: 443 Transport Layer Protocol: TCP

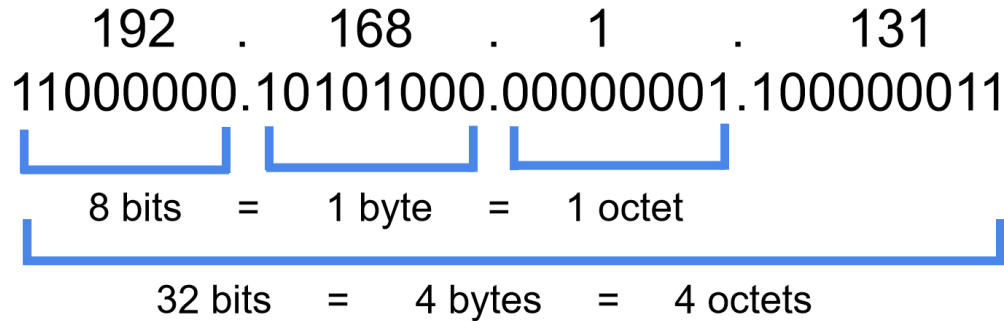
- HTTP over Secure Socket Layer (SSL) or Transport Layer Security (TLS)
- A secure version of HTTP that utilizes SSL/TLS to encrypts HTTP content
- Utilizes Public Key Infrastructure (PKI)
- Uses TCP Port 443 by default

Understanding IPv4 Addresses

- An IP Address is a **logical address** used in order to **uniquely identify** a device on an IP network.
- It's a **Network Layer** Address
- There are Two Versions:
 - IP version 4 (IPv4)
 - IP version 6 (IPv6)
- This lesson focuses on IPv4, and we'll discuss IPv6 later in the course.

IPv4 Address Anatomy

- Made up of 32 binary bits, which can be divided into a **network portion** and a **host portion** with the help of a subnet mask.
 - The 32 binary bits are broken into four octets (1 octet = 8 bits).
 - Each octet is converted to decimal and separated by a period (dot).
 - For this reason, an IP address is said to be expressed in dotted decimal format.



IPv4 Address Anatomy

192 . 168 . 1 . 131
11000000.10101000.00000001.100000011

The diagram illustrates the structure of an IPv4 address. It shows the decimal representation (192 . 168 . 1 . 131) and the binary representation (11000000.10101000.00000001.100000011). Blue brackets are used to group the bits into octets. The first three octets are each labeled as '8 bits = 1 byte = 1 octet'. A larger bracket under the entire address is labeled '32 bits = 4 bytes = 4 octets'.

8 bits = 1 byte = 1 octet

32 bits = 4 bytes = 4 octets

First Octet	Second Octet	Third Octet	Fourth Octet
192 .	168 .	1 .	131
11000000 .	10101000 .	00000001 .	10000011
8 bits	8 bits	8 bits	8 bits

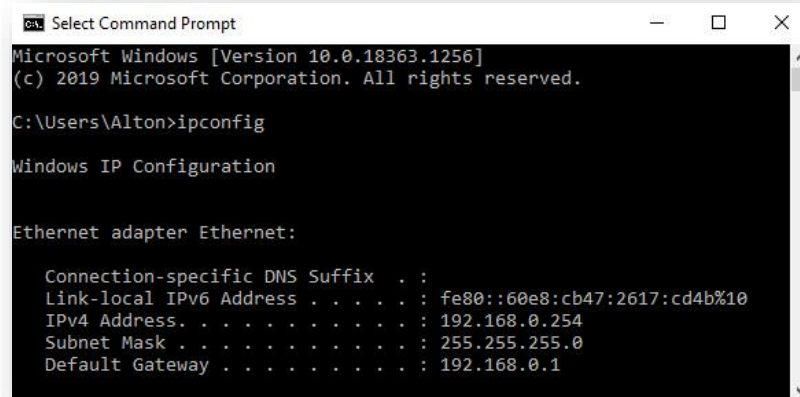
Network and Host Portion

- An IP address is broken down into two parts:
 - **Network Address**
 - Uniquely identifies each network
 - Your Street Name: 7682 **Wilshire Drive**
 - **Host Address**
 - Uniquely identifies each machine on a network
 - Your House Address: **7682** Wilshire Drive
- Network Address + Host Address = IP Address
 - **Wilshire Drive 7682**



IPv4 Address Components

- Each device on a network is assigned an IP address, subnet mask and default gateway:
 - **IP Address:** Unique logical address assigned to each device on a network.
 - **Subnet Mask:** Used by the device to determine what subnet it's on, specifically the network and host portions of the IP address.
 - **Default Gateway:** The IP address of a network's router that allows devices on the local network to communicate with other networks.



```

C:\Users\Alton>ipconfig

Windows IP Configuration

Ethernet adapter Ethernet:

    Connection-specific DNS Suffix  . : 
    Link-local IPv6 Address . . . . . : fe80::60e8:cb47:2617:cd4b%10
    IPv4 Address. . . . . : 192.168.0.254
    Subnet Mask . . . . . : 255.255.255.0
    Default Gateway . . . . . : 192.168.0.1

```

Basics of Binary Math

Lecture Goals

- Convert Binary to Decimal
- Convert Decimal to Binary

Basics of Binary Math

Why is it important?

We need to know basic binary math to perform subnetting, as well as to understand how IPv4 addresses work.

Remember This

$$128 + 64 + 32 + 16 + 8 + 4 + 2 + 1 = 255$$

What is the binary 11111111 in decimal?

	128	64	32	16	8	4	2	1										
Binary	1	1		1	1	1		1	1									
Decimal	128	+	64	+	32	+	16	+	8	+	4	+	2	+	1	=	255	Decimal

Add the number where there is a "1".
Add zero, when there is a "0".

What is the binary 10101010 in decimal?

128

64

32

16

8

4

2

1

Binary

1

0

1

0

1

0

1

0

Decimal

128

+

0

+

32

+

0

+

8

+

0

+

2

+

0

=

170 Decimal

Add the number where there is a "1".

Add zero, when there is a "0".

What is the binary 10000011 in decimal?

128

64

32

16

8

4

2

1

Binary

1

0

0

0

0

0

1

1

Decimal

128

+

0

+

0

+

0

+

0

+

0

+

2

+

1

=

131 Decimal

Add the number where there is a "1".

Add zero, when there is a "0".

What's 192 in binary?

	128	64	32	16	8	4	2	1								
Binary	1	1		0	0	0		0	0	=	11000000					
Decimal	128	+	64	+	0	+	0	+	0	+	0	+	0	=	192	Decimal

Start adding the numbers from left to right until you achieve the decimal amount you are looking for!

What's 202 in binary?

	128	64	32	16	8	4	2	1										
Binary	1	1		0	0	1	0		1	0	=	11001010						
Decimal	128	+	64	+	0	+	0	+	8	+	0	+	2	+	0	=	202	Decimal

Start adding the numbers from left to right until you achieve the decimal amount you are looking for!

What's 54 in binary?

	128	64	32	16	8	4	2	1										
Binary	0	0		1	1	0	1		1	0	=	00110110						
Decimal	0	+	0	+	32	+	16	+	0	+	4	+	2	+	0	=	54 Decimal	

Start adding the numbers from left to right until you achieve the decimal amount you are looking for!

IP Address Conversion Process

192.	168.	32.	4	Dotted Decimal
11000000.	10101000.	00100000.	00000100	Binary
1 st Octet	2 nd Octet	3 rd Octet	4 th Octet	

Whether you are given an IP address in dotted-decimal or binary format, follow the respective process above for each octet one by one until you have completed the process.

BINARY MATH WORKSHEET ANSWER KEY

CONVERSION CHART

$$128 + 64 + 32 + 16 + 8 + 4 + 2 + 1$$

1. CONVERT 11110000 TO DECIMAL

	128		64		32		16		8		4		2		1	
Binary	1		1		1		1		0		0		0		0	=
Decimal	128	+	64	+	32	+	16	+	0	+	0	+	0	+	0	= 240 Decimal

2. CONVERT 10011001 TO DECIMAL

	128		64		32		16		8		4		2		1	
Binary	1		0		0		1		1		0		0		1	=
Decimal	128	+	0	+	0	+	16	+	8	+	0	+	0	+	1	= 153 Decimal

3. CONVERT 01101011 TO DECIMAL

	128		64		32		16		8		4		2		1	
Binary	0		1		1		0		1		0		1		1	=
Decimal	0	+	64	+	32	+	0	+	8	+	0	+	2	+	1	= 107 Decimal

4. CONVERT 10110011 TO DECIMAL

	128		64		32		16		8		4		2		1	
Binary	1		0		1		1		0		0		1		1	=
Decimal	128	+	0	+	32	+	16	+	0	+	0	+	2	+	1	= 179 Decimal

5. CONVERT 240 TO BINARY

	128		64		32		16		8		4		2		1	
Binary	1		1		1		1		0		0		0		0	= 11110000 Binary
Decimal	128	+	64	+	32	+	16	+	0	+	0	+	0	+	0	=

6. CONVERT 163 TO BINARY

	128		64		32		16		8		4		2		1	
Binary	1		0		1		0		0		0		1		1	= 10100011 Binary
Decimal	128	+	0	+	32	+	0	+	0	+	0	+	2	+	1	=

7. CONVERT 94 TO BINARY

	128		64		32		16		8		4		2		1	
Binary	0		1		0		1		1		1		1		0	= 01011110 Binary
Decimal	0	+	64	+	0	+	16	+	8	+	4	+	2	+	0	=

8. CONVERT 225 TO BINARY

	128		64		32		16		8		4		2		1	
Binary	1		1		1		0		0		0		0		1	= 11100001 Binary
Decimal	128	+	64	+	32	+	0	+	0	+	0	+	0	+	1	=

9. CONVERT THE FOLLOWING IP ADDRESS FROM DECIMAL TO BINARY

192.168.98.18

- 192 = 11000000
- 168 = 10101000
- 98 = 01100010
- 18 = 00010010

Binary Format: 11000000.10101000.01100010.00010010

10. CONVERT THE FOLLOWING IP ADDRESS FROM BINARY TO DECIMAL

01000010.11010010.11000110.11000101

- 01000010 = 66
- 11010010 = 210
- 11000110 = 198
- 11000101 = 197

Dotted Decimal Format: 66.210.198.197

BINARY MATH WORKSHEET

CONVERSION CHART

128 + 64 + 32 + 16 + 8 + 4 + 2 + 1

1. CONVERT 11110000 TO DECIMAL

	128	64	32	16	8	4	2	1	
Binary									=
Decimal		+	+	+	+	+	+	+	=

2. CONVERT 10011001 TO DECIMAL

	128	64	32	16	8	4	2	1	
Binary									=
Decimal		+	+	+	+	+	+	+	=

3. CONVERT 01101011 TO DECIMAL

	128	64	32	16	8	4	2	1	
Binary									=
Decimal		+	+	+	+	+	+	+	=

4. CONVERT 10110011 TO DECIMAL

	128	64	32	16	8	4	2	1	
Binary									=
Decimal		+	+	+	+	+	+	+	=

5. CONVERT 240 TO BINARY

	128	64	32	16	8	4	2	1	
Binary									=
Decimal		+	+	+	+	+	+	+	=

6. CONVERT 163 TO BINARY

	128	64	32	16	8	4	2	1	
Binary									=
Decimal	+	+	+	+	+	+	+	+	=

7. CONVERT 94 TO BINARY

	128	64	32	16	8	4	2	1	
Binary									=
Decimal	+	+	+	+	+	+	+	+	=

8. CONVERT 225 TO BINARY

	128	64	32	16	8	4	2	1	
Binary									=
Decimal	+	+	+	+	+	+	+	+	=

9. CONVERT THE FOLLOWING IP ADDRESS FROM DECIMAL TO BINARY

192.168.98.18

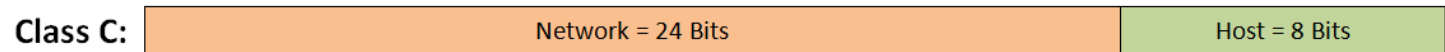
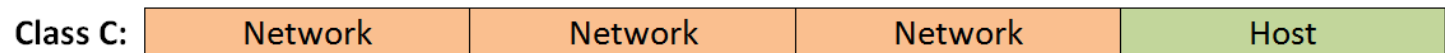
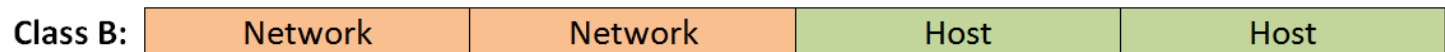
10. CONVERT THE FOLLOWING IP ADDRESS FROM BINARY TO DECIMAL

01000010.11010010.11000110.11000101

IPv4 Address Classes (Simplified)

Class	Network Bits	Host Bits	Address Range
A	8	24	1.0.0.0 – 126.255.255.255
B	16	16	128.0.0.0 – 191.255.255.255
C	24	8	192.0.0.0 – 223.255.255.255

Network and Host Bits



IPv4 Address Classes (Detailed)

Class	Leading Bits	Network Bits	Remaining Bits	Number of Networks	Hosts Per Network	Default Subnet Mask
Class A	0 (1-126)	8	24	128 (2^7)	16,777,216 (2^{24})	255.0.0.0
Class B	10 (128-191)	16	16	16,384 (2^{14})	65,536 (2^{16})	255.255.0.0
Class C	110 (192-223)	24	8	2,097,152 (2^{21})	256 (2^8)	255.255.255.0
Class D (multicast)	1110 (224-239)	Not Defined	Not Defined	Not Defined	Not Defined	Not Defined
Class E (reserved)	1111 (240-255)	Not Defined	Not Defined	Not Defined	Not Defined	Not Defined

Default Subnet Masks

- The Subnet Mask tells you which portion of the IP address identifies the network and which portion identifies the host.
- Below are default Class A, B, and C Subnet Masks.

	8 bits	8 bits	8 bits	8 bits
Class A:	Network	Host	Host	Host
IP Address	10.	0.	0.	15
Subnet Mask	11111111. 255.	00000000. 0.	00000000. 0.	00000000 0

	Network	Network	Host	Host
Class B:				
IP Address	172.	16.	0	.110
Subnet Mask	11111111. 255.	11111111. 255.	00000000. 0.	00000000 0

	Network	Network	Network	Host
Class C:				
IP Address	192.	168.	1.	50
Subnet Mask	11111111. 255.	11111111. 255.	11111111. 255.	00000000 0

Let's Practice

What class are the following IP Addresses?

- **IP Address:** 9.10.40.15
- **Subnet Mask:** 255.0.0.0

- **IP Address:** 135.240.110.100
- **Subnet Mask:** 255.255.0.0

- **IP Address:** 196.200.10.5
- **Subnet Mask:** 255.255.255.0

CIDR Notation

- **CIDR:** Classless Inter-Domain Routing
 - A methodology for subnetting
 - “Slash” Notation tells you how many bits are associated with the Subnet Mask
- A shortcut way of telling us what the Subnet Mask is:
 - /8 = 11111111.00000000.00000000.00000000
 - /8 = 255.0.0.0
- 192.168.1.0 /24 = 255.255.255.0
- 10.1.0.0 /16 = 255.255.0.0
- 196.10.10.0/25 = 255.255.255.128

Understanding the Power of 2

- We use the power of 2 in IP addressing and subnetting.
- It's important to memorize the power of 2.

$2^1 = 2$	$2^2 = 4$	$2^3 = 8$	$2^4 = 16$
$2^5 = 32$	$2^6 = 64$	$2^7 = 128$	$2^8 = 256$
$2^9 = 512$	$2^{10} = 1,024$	$2^{11} = 2,048$	$2^{12} = 4,096$

Using Power of 2 to Determine Network Hosts

	8 bits	8 bits	8 bits	8 bits
Class A:	Network = 8 Bits	Hosts = 24 Bits = $2^{24} - 2 = 16,777,214$		
Class B:	Network = 16 Bits		Hosts = 16 Bits = $2^{16} - 2 = 65,534$	
Class C:	Network = 24 Bits			Hosts = 8 Bits = $2^8 - 2 = 254$

- **Hosts Per Network** = $2^h - 2$, where h is the number of host bits available.
- We subtract two because each network includes a **network address** and **broadcast address** that are not available for use by network end devices.

Public versus Private IP Addresses

Public IP Addresses

- Original Design of Internet
- “Registered” Public IP Addresses
- Assigned by an ISP to a Business or Home
- Must be Globally Unique
 - Web Servers
 - DNS Servers
 - Routers
- By the Early 1990s, the World was Running out of Public IP Addresses
- Private IP Addresses & Network Address Translation (NAT) were Born!

Private IP Addresses

- “Unregistered” – Free for Use by Anybody!
- Designed for Use within Private Internal Networks
- Can Be Used Over and Over Again
- Cannot be Used or Routed on a Public Network
- Utilizes NAT to “Speak” to Public Networks, i.e., the Internet!

Private IP Address Ranges

Class	IP Address Range	Network ID(s) (CIDR Notation)	Number of Addresses
A	10.0.0.0 – 10.255.255.255	10.0.0.0 /8 • 1 Private Class A Network	16,777,216 IP Addresses Per Network ID
B	172.16.0.0 – 172.31.255.255	172.16.0.0 – 172.31.0.0 /16 • 16 Private Class B Networks	65,534 IP Addresses Per Network ID
C	192.168.0.0 – 192.168.255.255	192.168.0.0 – 192.168.255.0 /24 • 256 Private Class C Networks	254 IP Addresses Per Network ID

The Loopback Address

- **127.0.0.0 to 127.255.255.255** is reserved for loopback, i.e., a host's own address, also known as the localhost address.
 - **127.0.0.1** is typically configured as the default loopback address on operating systems.
- Used for diagnostics purposes to check that TCP/IP is correctly installed on a host's operating system.
 - When a process creates a packet destined to the loopback address, the operating system loops it back to itself without it ever interfacing with the NIC.
 - Data sent on the loopback is forwarded by the operating system to a virtual network interface within the operating system.
- If you can successfully ping 127.0.0.1 or any IP within the loopback range, then TCP/IP on your computer is properly working.
 - Ping 127.0.0.1
 - Ping localhost
 - Ping loopback

Why Subnet?

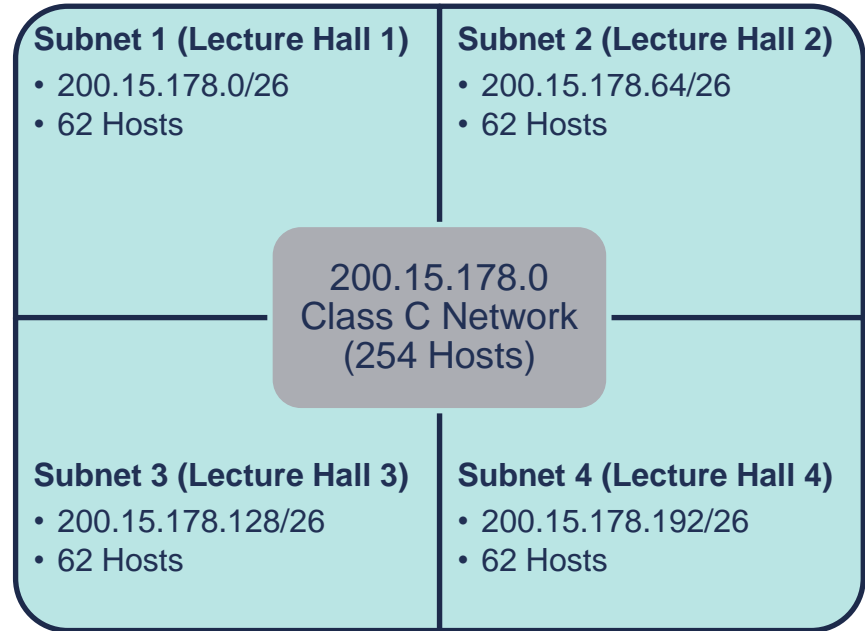
- Using default Class A, B and C subnets (called Classful IP Addressing) is inefficient:
 - Wastes unused IP Addresses (Public IP Addresses)
- Allows you to create multiple logical networks that exist within a single Class A, B, or C network.
 - Breaks up larger networks into multiple smaller sub-networks, which are called subnets
- Allows for more efficient routing via router summarization.
- Increased network security!

Fixed Length Subnetting

- We will be learning about fixed-length subnetting, known as a fixed-length subnet mask (FLSM).
- There is also variable-length subnetting (VLSM), which is beyond the scope of this beginner's course.

Class C Subnetting Example

- You're the network administrator for the Computer Science department at a university.
- You're setting up four new lecture halls that must have their own 60-person wireless network.
- You've been assigned the 200.15.178.0 Class C Network by the university, that supports 254 hosts per network by default.
- How do you break up this one Class C network into 4 smaller networks that support 60 host IP addresses per network?
- You subnet it.
- Subnetting allows your to breakup a larger network into smaller networks (subnets).



Process of Subnetting

- We borrow host bits to create more sub-networks (subnets) from a Class A, B, or C network.
- When you borrow hosts bits:
 - You create additional sub-networks, i.e., subnets
 - You also decrease the amount of host IP addresses available to use

	8 bits	8 bits	8 bits	8 bits
Class A:	Network = 8 Bits	Hosts = 24 Bits = $2^{24} - 2 = 16,777,214$		
Class B:	Network = 16 Bits		Hosts = 16 Bits = $2^{16} - 2 = 65,534$	
Class C:	Network = 24 Bits			Hosts = 8 Bits = $2^8 - 2 = 254$

How to Create Subnets

- Borrow bits from the host portion of an IP address
 - Each bit we borrow is equal to 2^1 Subnets
 - Borrow 1 Host Bit = $2^1 = 2$
 - Borrow 2 Host Bits = $2^2 = 4$
 - Borrow 3 Host Bits = $2^3 = 8$
 - Borrow 4 Host Bits = $2^4 = 16$
 - Etc.

Creating Subnets Visualized

Default Class C Network (8 Host Bits)



2 Host Bits Borrowed = 2^2 = Subnetted into 4 Subnets

1	2	3	4
---	---	---	---



3 Host Bits Borrowed = 2^3 = Subnetted into 8 Subnets

1	2	3	4	5	6	7	8
---	---	---	---	---	---	---	---

Subnetting Questions

- To Create a Subnet, Answer the Following Questions:
 - How many subnets are needed?
 - How many hosts do you need per subnet?

Class C Possible Subnets

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

Number of Subnets (2^x)

- X = number of host bits we borrow to create subnets

Block Size (2^y)

- Y = number of remaining host bits left that are used for the subnet IP addresses

Hosts per Subnet ($2^y - 2$)

- There are two addresses per network (or subnet) that we cannot use to assign to hosts on that network:
 - **Network Address:** This is the address used to uniquely identify the network (or subnet).
 - **Broadcast Address:** Address reserved for broadcast communication on the network.

Class B Possible Subnets

Binary (N.N.H.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.00000000.00000000	255.255.0.0	/16	$2^0 = 1$	$2^{16} = 65,536$	$2^{16} - 2 = 65,534$
N.N.10000000.00000000	255.255.128.0	/17	$2^1 = 2$	$2^{15} = 32,768$	$2^{15} - 2 = 32,766$
N.N.11000000.00000000	255.255.192.0	/18	$2^2 = 4$	$2^{14} = 16,384$	$2^{14} - 2 = 16,382$
N.N.11100000.00000000	255.255.224.0	/19	$2^3 = 8$	$2^{13} = 8,192$	$2^{13} - 2 = 8,190$
N.N.11110000.00000000	255.255.240.0	/20	$2^4 = 16$	$2^{12} = 4,096$	$2^{12} - 2 = 4,094$
N.N.11111000.00000000	255.255.248.0	/21	$2^5 = 32$	$2^{11} = 2,048$	$2^{11} - 2 = 2,046$
N.N.11111100.00000000	255.255.252.0	/22	$2^6 = 64$	$2^{10} = 1,024$	$2^{10} - 2 = 1,022$
N.N.11111110.00000000	255.255.254.0	/23	$2^7 = 128$	$2^9 = 512$	$2^9 - 2 = 510$
N.N.11111111.00000000	255.255.255.0	/24	$2^8 = 256$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.11111111.10000000	255.255.255.128	/25	$2^9 = 512$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.11111111.11000000	255.255.255.192	/26	$2^{10} = 1,024$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.11111111.11100000	255.255.255.224	/27	$2^{11} = 2,048$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.11111111.11110000	255.255.255.240	/28	$2^{12} = 4,096$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.11111111.11111000	255.255.255.248	/29	$2^{13} = 8,192$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.11111111.11111100	255.255.255.252	/30	$2^{14} = 16,384$	$2^2 = 4$	$2^2 - 2 = 2$

Class A Possible Subnets

Binary (N.H.H.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.00000000.00000000.00000000	255.0.0.0	/8	$2^0 = 1$	$2^{22} = 16,777,216$	$2^{22} - 2 = 16,777,214$
N.10000000.00000000.00000000	255.128.0.0	/9	$2^1 = 2$	$2^{23} = 8,388,608$	$2^{23} - 2 = 8,388,606$
N.11000000.00000000.00000000	255.192.0.0	/10	$2^2 = 4$	$2^{22} = 4,194,304$	$2^{22} - 2 = 4,194,302$
N.11100000.00000000.00000000	255.224.0.0	/11	$2^3 = 8$	$2^{21} = 2,097,152$	$2^{21} - 2 = 2,097,150$
N.11110000.00000000.00000000	255.240.0.0	/12	$2^4 = 16$	$2^{20} = 1,048,576$	$2^{20} - 2 = 1,048,574$
N.11111000.00000000.00000000	255.248.0.0	/13	$2^5 = 32$	$2^{19} = 524,288$	$2^{19} - 2 = 524,286$
N.11111100.00000000.00000000	255.252.0.0	/14	$2^6 = 64$	$2^{18} = 262,144$	$2^{18} - 2 = 262,142$
N.11111110.00000000.00000000	255.254.0.0	/15	$2^7 = 128$	$2^{17} = 131,072$	$2^{17} - 2 = 131,070$
N.11111111.00000000.00000000	255.255.0.0	/16	$2^8 = 256$	$2^{16} = 65,536$	$2^{16} - 2 = 65,534$
N.11111111.10000000.00000000	255.255.128.0	/17	$2^9 = 512$	$2^{15} = 32,768$	$2^{15} - 2 = 32,766$
N.11111111.11000000.00000000	255.255.192.0	/18	$2^{10} = 1,024$	$2^{14} = 16,384$	$2^{14} - 2 = 16,382$
N.11111111.11100000.00000000	255.255.224.0	/19	$2^{11} = 2,048$	$2^{13} = 8,192$	$2^{13} - 2 = 8,190$
N.11111111.11110000.00000000	255.255.240.0	/20	$2^{12} = 4,096$	$2^{12} = 4,096$	$2^{12} - 2 = 4,094$
N.11111111.11111000.00000000	255.255.248.0	/21	$2^{13} = 8,192$	$2^{11} = 2,048$	$2^{11} - 2 = 2,046$
N.11111111.11111100.00000000	255.255.252.0	/22	$2^{14} = 16,384$	$2^{10} = 1,024$	$2^{10} - 2 = 1,022$
N.11111111.11111110.00000000	255.255.254.0	/23	$2^{15} = 32,768$	$2^9 = 512$	$2^9 - 2 = 510$
N.11111111.11111111.00000000	255.255.255.0	/24	$2^{16} = 65,536$	$2^8 = 256$	$2^8 - 2 = 254$
N.11111111.11111111.10000000	255.255.255.128	/25	$2^{17} = 131,072$	$2^7 = 128$	$2^7 - 2 = 126$
N.11111111.11111111.11000000	255.255.255.192	/26	$2^{18} = 262,144$	$2^6 = 64$	$2^6 - 2 = 62$
N.11111111.11111111.11100000	255.255.255.224	/27	$2^{19} = 524,288$	$2^5 = 32$	$2^5 - 2 = 30$
N.11111111.11111111.11110000	255.255.255.240	/28	$2^{20} = 1,048,576$	$2^4 = 16$	$2^4 - 2 = 14$
N.11111111.11111111.11111000	255.255.255.248	/29	$2^{21} = 2,097,152$	$2^3 = 8$	$2^3 - 2 = 6$
N.11111111.11111111.11111100	255.255.255.252	/30	$2^{22} = 4,194,304$	$2^2 = 4$	$2^2 - 2 = 2$

Subnet Calculation Table (2^x)

Host Bits Borrowed	2 ^x	Number of Subnets Created
1	2 ¹	2
2	2 ²	4
3	2 ³	8
4	2 ⁴	16
5	2 ⁵	32
6	2 ⁶	64
7	2 ⁷	128
8	2 ⁸	256
9	2 ⁹	512
10	2 ¹⁰	1,024
11	2 ¹¹	2,048
12	2 ¹²	4,096
Etc....		

Subnet Hosts & Addresses Calculation Table (2^y)

Host Bits Left	2^y	Addresses per Subnet (2^y)	Hosts per Subnet ($2^y - 2$)
1	2^1	2	0
2	2^2	4	2
3	2^3	8	6
4	2^4	16	14
5	2^5	32	30
6	2^6	64	62
7	2^7	128	126
8	2^8	256	254
9	2^9	512	510
10	2^{10}	1,024	1,022
11	2^{11}	2,048	2,046
12	2^{12}	4,096	4,094

Subnetting Reference Tables

POWER OF 2'S TABLE

$$2^1 = 2$$

$$2^2 = 4$$

$$2^3 = 8$$

$$2^4 = 16$$

$$2^5 = 32$$

$$2^6 = 64$$

$$2^7 = 128$$

$$2^8 = 256$$

$$2^9 = 512$$

$$2^{10} = 1,024$$

$$2^{11} = 2,048$$

$$2^{12} = 4,096$$

$$2^{13} = 8,192$$

$$2^{14} = 16,384$$

$$2^{15} = 32,768$$

$$2^{16} = 65,536$$

DEFAULT SUBNET MASK

Class	Format	Default Subnet Mask
A	network. host.host.host	255.0.0.0
B	network.network. host.host	255.255.0.0
C	network.network.network. host	255.255.255.0

BINARY MATH TABLE

128	64	32	16	8	4	2	1
1	1	1	1	1	1	1	1

SUBNET MASK TABLE

Binary	Decimal
00000000	0
10000000	128
11000000	192
11100000	224
11110000	240
11111000	248
11111100	252

SUBNET CALCULATION TABLE (2^x)

Host Bits Borrowed	2^x	Number of Subnets Created
1	2^1	2
2	2^2	4
3	2^3	8
4	2^4	16
5	2^5	32
6	2^6	64
7	2^7	128
8	2^8	256
9	2^9	512
10	2^{10}	1,024
11	2^{11}	2,048
12	2^{12}	4,096

SUBNET HOSTS & ADDRESSES CALCULATION TABLE (2^y)

Host Bits Left	2^y	Hosts per Subnet ($2^y - 2$)	Addresses per Subnet (2^y)
1	2^1	0	2
2	2^2	2	4
3	2^3	6	8
4	2^4	14	16
5	2^5	30	32
6	2^6	62	64
7	2^7	126	128
8	2^8	254	256
9	2^9	510	512
10	2^{10}	1,022	1,024
11	2^{11}	2,046	2,048
12	2^{12}	4,094	4,096

CLASS C POSSIBLE SUBNET MASKS

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

CLASS B POSSIBLE SUBNET MASKS

Binary (N.N.H.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.00000000.00000000	255.255.0.0	/16	$2^0 = 1$	$2^{16} = 65,536$	$2^{16} - 2 = 65,534$
N.N.10000000.00000000	255.255.128.0	/17	$2^1 = 2$	$2^{15} = 32,768$	$2^{15} - 2 = 32,766$
N.N.11000000.00000000	255.255.192.0	/18	$2^2 = 4$	$2^{14} = 16,384$	$2^{14} - 2 = 16,382$
N.N.11100000.00000000	255.255.224.0	/19	$2^3 = 8$	$2^{13} = 8,192$	$2^{13} - 2 = 8,190$
N.N.11110000.00000000	255.255.240.0	/20	$2^4 = 16$	$2^{12} = 4,096$	$2^{12} - 2 = 4,094$
N.N.11111000.00000000	255.255.248.0	/21	$2^5 = 32$	$2^{11} = 2,048$	$2^{11} - 2 = 2,046$
N.N.11111100.00000000	255.255.252.0	/22	$2^6 = 64$	$2^{10} = 1,024$	$2^{10} - 2 = 1,022$
N.N.11111110.00000000	255.255.254.0	/23	$2^7 = 128$	$2^9 = 512$	$2^9 - 2 = 510$
N.N.11111111.00000000	255.255.255.0	/24	$2^8 = 256$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.11111111.10000000	255.255.255.128	/25	$2^9 = 512$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.11111111.11000000	255.255.255.192	/26	$2^{10} = 1,024$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.11111111.11100000	255.255.255.224	/27	$2^{11} = 2,048$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.11111111.11110000	255.255.255.240	/28	$2^{12} = 4,096$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.11111111.11111000	255.255.255.248	/29	$2^{13} = 8,192$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.11111111.11111100	255.255.255.252	/30	$2^{14} = 16,384$	$2^2 = 4$	$2^2 - 2 = 2$

CLASS A POSSIBLE SUBNET MASKS

Binary (N.H.H.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.00000000.00000000.00000000	255.0.0.0	/8	$2^0 = 1$	$2^{22} = 16,777,216$	$2^{22} - 2 = 16,777,214$
N.10000000.00000000.00000000	255.128.0.0	/9	$2^1 = 2$	$2^{23} = 8,388,608$	$2^{23} - 2 = 8,388,606$
N.11000000.00000000.00000000	255.192.0.0	/10	$2^2 = 4$	$2^{22} = 4,194,304$	$2^{22} - 2 = 4,194,302$
N.11100000.00000000.00000000	255.224.0.0	/11	$2^3 = 8$	$2^{21} = 2,097,152$	$2^{21} - 2 = 2,097,150$
N.11110000.00000000.00000000	255.240.0.0	/12	$2^4 = 16$	$2^{20} = 1,048,576$	$2^{20} - 2 = 1,048,574$
N.11111000.00000000.00000000	255.248.0.0	/13	$2^5 = 32$	$2^{19} = 524,288$	$2^{19} - 2 = 524,286$
N.11111100.00000000.00000000	255.252.0.0	/14	$2^6 = 64$	$2^{18} = 262,144$	$2^{18} - 2 = 262,142$
N.11111110.00000000.00000000	255.254.0.0	/15	$2^7 = 128$	$2^{17} = 131,072$	$2^{17} - 2 = 131,070$
N.11111111.00000000.00000000	255.255.0.0	/16	$2^8 = 256$	$2^{16} = 65,536$	$2^{16} - 2 = 65,534$
N.11111111.10000000.00000000	255.255.128.0	/17	$2^9 = 512$	$2^{15} = 32,768$	$2^{15} - 2 = 32,766$
N.11111111.11000000.00000000	255.255.192.0	/18	$2^{10} = 1,024$	$2^{14} = 16,384$	$2^{14} - 2 = 16,382$
N.11111111.11100000.00000000	255.255.224.0	/19	$2^{11} = 2,048$	$2^{13} = 8,192$	$2^{13} - 2 = 8,190$
N.11111111.11110000.00000000	255.255.240.0	/20	$2^{12} = 4,096$	$2^{12} = 4,096$	$2^{12} - 2 = 4,094$
N.11111111.11111000.00000000	255.255.248.0	/21	$2^{13} = 8,192$	$2^{11} = 2,048$	$2^{11} - 2 = 2,046$
N.11111111.11111100.00000000	255.255.252.0	/22	$2^{14} = 16,384$	$2^{10} = 1,024$	$2^{10} - 2 = 1,022$
N.11111111.11111110.00000000	255.255.254.0	/23	$2^{15} = 32,768$	$2^9 = 512$	$2^9 - 2 = 510$
N.11111111.11111111.00000000	255.255.255.0	/24	$2^{16} = 65,536$	$2^8 = 256$	$2^8 - 2 = 254$
N.11111111.11111111.10000000	255.255.255.128	/25	$2^{17} = 131,072$	$2^7 = 128$	$2^7 - 2 = 126$
N.11111111.11111111.11000000	255.255.255.192	/26	$2^{18} = 262,144$	$2^6 = 64$	$2^6 - 2 = 62$
N.11111111.11111111.11100000	255.255.255.224	/27	$2^{19} = 524,288$	$2^5 = 32$	$2^5 - 2 = 30$
N.11111111.11111111.11110000	255.255.255.240	/28	$2^{20} = 1,048,576$	$2^4 = 16$	$2^4 - 2 = 14$
N.11111111.11111111.11111000	255.255.255.248	/29	$2^{21} = 2,097,152$	$2^3 = 8$	$2^3 - 2 = 6$
N.11111111.11111111.11111100	255.255.255.252	/30	$2^{22} = 4,194,304$	$2^2 = 4$	$2^2 - 2 = 2$

Subnetting a Class C Network #1

Details & Requirements

You've been assigned a 192.168.1.0/24 Class C network, and you need to create two subnets from it.

How many host bit do we need to borrow?

1 host bit, $2^1 = 2$ Subnets

How many host addresses per subnet?

7 host bits left, $2^7 = 128$ Addresses / Subnet

$2^7 - 2 = 126$ Addresses / Subnet

What are the valid subnets?

192.168.1.0 and 192.168.1.128

New Subnet Mask?

11111111.11111111.11111111.10000000

255.255.255.128 or /25

Subnet	#1	#2
Network Address	192.168.1.0	192.168.1.128
First Host IP	192.168.1.1	192.168.1.129
Last Host IP	192.168.1.126	192.168.1.254
Broadcast Address	192.168.1.127	192.168.1.255

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

Visualizing Subnetting a Class C Network #1

Details & Requirements

- Network Address: 192.168.1.0
- Default Subnet Mask: 255.255.255.0
- Requires 2 Subnets

How many host bit do we need to borrow?

- 1 host bit, $2^1 = 2$ Subnets

How many addresses hosts per subnet?

- 7 host bits left, $2^7 = 128$ Addresses / Subnet
- $2^7 - 1 = 126$ Addresses / Subnet

What are the valid subnets?

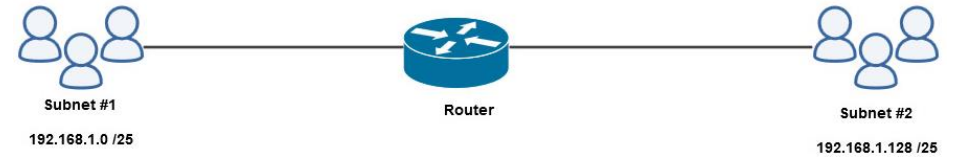
- 192.168.1.0 and 192.168.1.128

New Subnet Mask?

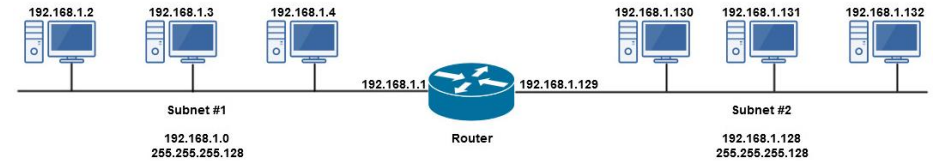
- 11111111.11111111.11111111.10000000
- 255.255.255.128 or /25

Subnet	#1	#2
Network Address	192.168.1.0	192.168.1.128
First Host IP	192.168.1.1	192.168.1.129
Last Host IP	192.168.1.126	192.168.1.254
Broadcast Address	192.168.1.127	192.168.1.255

Network Simplified View



Network Detailed View



Default Class C Network (8 Host Bits): 192.168.1.0 /24 Network

1 Host Bits Borrowed = $2^1 = 2$ Subnets

Subnet #1: 192.168.1.0 /25

Subnet #2: 192.168.1.128 /25

CLASS C POSSIBLE SUBNET MASKS

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

Subnetting a Class C Network #2

Details & Requirements

You've been assigned a 192.168.1.0/24 Class C network, and you need to create four subnets from it.

How many host bit do we need to borrow?

2 host bits, $2^2 = 4$ Subnets

How many host addresses per subnet?

6 host bits left, $2^6 = 64$ Addresses / Subnet

$2^6 - 2 = 62$ Addresses / Subnet

What are the valid subnets?

192.168.1.0, 192.168.1.64,

192.168.1.128, 192.168.1.192

New Subnet Mask?

11111111.11111111.11111111.11000000

255.255.255.192 or /26

Subnet	Network /Subnet Address	Host IP Addresses	Broadcast Address
1	192.168.1.0	1 thru 62	192.168.1.63
2	192.168.1.64	65 thru 126	192.168.1.127
3	192.168.1.128	129 thru 190	192.168.1.191
4	192.168.1.192	193 thru 254	192.168.1.255

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

Visualizing Subnetting a Class C Network #2

Details & Requirements

- Network Address: 192.168.1.0
- Default Subnet Mask: 255.255.255.0
- Requires 4 Subnets

How many host bit do we need to borrow?

- 2 host bit, $2^2 = 4$ Subnets

How many addresses hosts per subnet?

- 6 host bits left, $2^6 = 64$ Addresses / Subnet
- $2^6 - 1 = 62$ Addresses / Subnet

What are the valid subnets?

- 192.168.1.0, 192.168.1.64, 192.168.1.128, 192.168.1.192

New Subnet Mask?

- 11111111.11111111.11111111.11000000
- 255.255.255.192 or /26

Default Class C Network (8 Host Bits)

2 Host Bits Borrowed = $2^2 = 4$ Subnets

1	2	3	4

CLASS C POSSIBLE SUBNET MASKS

Binary (N.N.N.H)	Decimal	CIDR	# Subnets (2^x)	Block Size (2^y)	# Hosts ($2^y - 2$)
N.N.N.00000000	255.255.255.0	/24	$2^0 = 1$	$2^8 = 256$	$2^8 - 2 = 254$
N.N.N.10000000	255.255.255.128	/25	$2^1 = 2$	$2^7 = 128$	$2^7 - 2 = 126$
N.N.N.11000000	255.255.255.192	/26	$2^2 = 4$	$2^6 = 64$	$2^6 - 2 = 62$
N.N.N.11100000	255.255.255.224	/27	$2^3 = 8$	$2^5 = 32$	$2^5 - 2 = 30$
N.N.N.11110000	255.255.255.240	/28	$2^4 = 16$	$2^4 = 16$	$2^4 - 2 = 14$
N.N.N.11111000	255.255.255.248	/29	$2^5 = 32$	$2^3 = 8$	$2^3 - 2 = 6$
N.N.N.11111100	255.255.255.252	/30	$2^6 = 64$	$2^2 = 4$	$2^2 - 2 = 2$

Network Simplified & Detail Views

