v Hosts = end systems (last point connected to internet)
- Run network apps (YT, netflix, etc;)
Communication links
- fiber, copper, radio, satellite
- Transmission rate: bandwidth
Packet switches: Forwards packets
- Routers, switches
Interet: “network of networks”

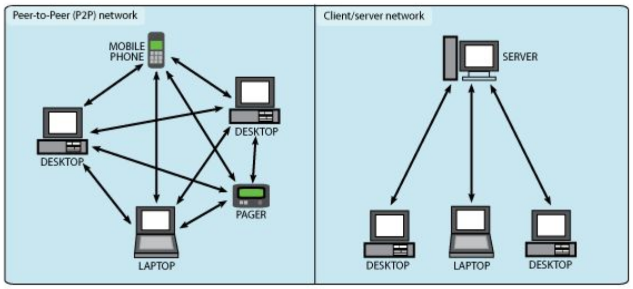
-Protocols control sending, receiving of messages and content
Ex: TCP, HTTP, IP< SKype, 802.11
End devices: laptop, desktop computer, printers, etc;
Intermediary devices: router, ln switch, firewall appearances
Network media: wireless media, LAN media, WAN media
2 ways to connect to internet:
Client server model (centralized): server that all end devices connect to, and server must stay on to keep devices
connected/allow access of media and other info to end devices.
Peer 2 Peer model: gets rid of server, decentralized. Allows end devices to connect to each other to share media and other information
Advantage of Peer 2 Peer:

- Easy to set up
- Less complexity
- Lowers cost since network devices and dedicated servers are not needed
- Can be used for simple tasks like transferring files and sharing pics

Disadvantages of Peer 2 Peer:

- No centralized administration
- Not as secure
- Not scalable
- Devices act as both client and server which can slow their performance down

Bits:
What can a network transmitter do?
Sends bits (0 and 1)
Everything that is sent across a network is represented by numbs, text, audio, video
8 bits = 1 byte
Transmitters send bits across a physical link
Data travels over many links or hops to reach a destination
Bit rate: the number of bits I can send in a second
BPS + bits per second
Capacity- Theoretical maximum bit rate based on cable type and distance
(the longer the distance, the lower the capacity)
Line rate- the actual constant bit rate for a particular link
* Assume this is fixed for class
Throughput - end-to-end bit rate achieved over a particular connection
Prefixes:
K - kilo (10^3)
M = mega (10^6)
G = giga (10^9)
T = tera (10^12)
m = milli (10^-3)
U = micro (10^-6)
n = nano (10^-9)
If talking about file size, use base of 2 with power of 10
2^10 = K
2^20 = M
2^30 = G
2^40 = T
*When doing file transfer problem, remember to multiply by 8 if in bytes, to get number in bits
Internet end to end model
Transmission Time = Data Size (in bits) / Line Rate
Client-subnet-router-subnet-router-subnet-router-subnet
Data packets travel from router to router across subnets (subnets basically link between routers)
Network Types
Body Area Networks
- Connects wearables
- Antt, bluetooth lone energy
Personal Area Networks
- Interconnect personal devices (cellphones, portable game module, pc) within 30 ft or so
Local Area Networks
- Interconnect devices within a single business or building EX: Ethernet
Metropolitan Area Networks
- Interconnect customer sites controlled by a single telecommunication carrier within a metropolitan geographic region
EX: metro ethernet within Chicago area
Wide Area Networks
- LANs separated by geographic distance are connected by a network known as a WAN
-A large network that encompasses multiple states, countries, and the world
Wi-Fi = Wireless Fidelity
4 characteristics of Network Architecture
Fault redundancy: Making sure user operations remain functional, in the case that a link fails, and that there are alternative paths to reach the desired system
Scalability: Making sure that users can join and leave the said service, and be connected with multiple other users all while performance isn’t hindered
QoS- Prioritizes apps/communication services. Usually managed by router to ensure smooth user experience w/ apps that are more data hungry such as streaming services
Security: makes sure that users on the network are protected from cyberattacks and makes sure their data is safe
Packets contain:
Source IP address
Destination IP address
Packet headers
A packet is a string of bits sent over a link containing:
- initial set of bytes called the packet headers, which contain control information about how and where to transmit the packet across the network
- the application data
Typically 1 “request” generates multiple “responses”
Maximum packet size
Packets are capped by a maximum transition unit
Maximum ethernet packet size = 1500 bytes
IP Addresses
IP routers can deliver any packet that contains an Internet Protocol Header
Within the IP header are two IP addresses corresponding to the sender and receiver of the packet
Source IP
Destination IP
Each active network connection on every device is assigned an IP address
The same way as mail is addressed to a particular address
IPv4 addresses are 32 bits long and are written in dotted decimal notation
4 values between 0-255 with dots between them
Each value represents an 8-bit value



EX: 150.21.39.52

Number Notations
Sometimes IP addresses must be examined at the bit level to understand routing and subnetting
Internet Backbone
Routers on the IB are typically densely connected by hyperspeed fiber optic links
ISPs manage one or more access lines for each customer to connect them to the backbone
Customers connect LANs to access links through an Access Networks
Routers look up each packet’s destination IP in routing table to forward packet
IP routers provide what is known as “best effort data deliver”
Means routers fone guarantee delivery -packets may drop
Not guaranteed that packets will be delivered in the same order they were sent
ISPs
Each ISP typically owns and operates many routers that are a part of the Internet Backbone
An autonomous system is a contiguous set of routers owned by a particular ISP
Each Autonomous System is assigned a unique number
No one runs the internet it is:
Decentralized, distributed, and has chaotic growth
To talk to an end device, we need its IP address which is gathered by its DNS name
SInce people remember names more easily than numbers, there are Domain Name Systems (DNS) servers on the internet that translate DNS names into IP addresses
DNS top-level domains
Top level domains (TLDs) controlled by ICANN)
A protocol defines format and order of messages sent and received among network entities and actions taken on a message transmission and receipt
Client and servers must follow a protocol which determines:
Packet format
- Permissible requests and responses
- Format of header info and data
- Packet ordering and timing
Protocol standards are documents that define protocols
For internet apps, protocol standards are called request for comments (RFCs)
Protocol layers
----Hosts
----Routers
----Links of various media
----Applications
----Protocols
----Hardware, software
Why layering?
In dealing w/ complex systems:
Explicit structure
Identification and relationship of complex pieces
Modularization eases maintenance, updating of system
Change of implementation layer’s service transparent to rest of system
EX change in airplane gate procedure doesn’t affect rest of the system
Internet Protocol Stack
5) Application: supporting network apps
FTS, SMTP, HTTP
4) Transport: Process-process data transfer
-TCP, UPP
3) Network: Routing of datagrams from source to destination
IP, routing protocols
2) Link: Data transfer between neighboring network elements
Ethernet, Wi-Fi, PPP(Point 2 Point Protocol), ARP
1) Physical: Bits “on the wire”
Programs vs process
Programs have multiple processes running in the background
What do we address?
Send message directed to a specific process ID, not a program or IP address
Uses the port number which is addressed to a certain process
Network VS transport layer example
Transport layer talks between the port numbers of the 2 devices
Network layer uses the IP address to talk over the internet (IP of each device)
The original layered protocol model was the 7-layer Open Systems Interconnect model (1977)
OSI reference model
7) Application
6) Presentation: Allows applications to interpret meaning of data
EX: encryption
5) Session: Synchronization, checkpointing, recovery of data exchange
Layers 4-1 are same as Internet Protocol Stack
Internet stack “missing” layers 5 and 6
Moved into the application layer
Removed from the internet stack because not all applications needed them
Traversing through the OSI Track
The Protocol Data Unit (PDU) grows in size due to the headers added in each layer as it travels “down the stack
The PDU reduces in size and it travels “up” the stack
Layer 2 PDU referred as a frame
Layer 3 PDU referred as a packet
Layer 4 PDU referred as a segment
Layer 5 PDU referred as a message (payload)
Process Communicating
Process: Program running within a host
Within same host, two processes communicate using inter-process communication
Processes in different host communicate by exchanging messages
Note: applications with peer-to-peer architecture typically have both client processes and server processes
Sockets
Process sends/receives messages to/from its socket
(Like a mailbox for a process)
A socket is analogous to a door
Sending process shoves the message out the door

Sending process relies on transport infrastructure on other side of door to deliver messages to a socket a receiving process

Addressing Processes

To receive messages, processes must have an identifier

Host device has unique 32-bit IP address, but cannot be used as address to send messages to processes

You need the port # of a process to deliver messages to a specific process

Identifier includes both IP address and port address associated with process on host

TCP/UDP Ports

TCP and UDP headers contain two 2-byte port numbers

Source Port

Destination Port

A port number identifies a particular software process running on a host

When a client process (like a browser window) starts up, it is assigned an unused private port number

When a server process(like a Web server) starts up, it is binded to a well-known or registered port number based on its function

Port Number Ranges

Well-known (0-1023)

Specific to certain processes (assigned by IANA) no one can use these port numbers

Registered (1024-49151)

Assigned by software vendors for new server processes

Private (49152-65535)

Assigned locally to client processes

IP Addresses

IP addressing is "hierarchical"

In classful addressing an IP address contains 3 parts:

An **IP Network** part that is used by Internet Backbone routers to deliver packets to a particular IP Network. IP Network values are assigned by IANA to guarantee uniqueness

An **IP Subnet** part that is used by Internal Routers within an IP Network to deliver packets to a particular subnet. Subnet address values are assigned by local network administration

An **IP Host** part that identifies a particular individual device on the subnet. Chosen by network admin or randomly assigned from subnet address pool by DHCP server

IPv6 increases the number of address bits by a factor of 4, from 32 bits to 128 bits

A 128 bit IPv6 address is written using up to 32 hexadecimal digits, written as 8 groups of 4 hex digits each- "coloned hex format"

* you can remove any left hand zeros present in each group

Data-Link/MAC Addresses

Every Ethernet interface has a 6-byte address stored in the interface hardware called:

Physical address

MAC (medium access control) address

Data-link address

Set as a serial number by the manufacturer

Values written in hexadecimal notation

Address information for a network connection can be found in Network details or by running "ipconfig/all"

Every Ethernet interface (NIC) has a 6-byte physical address or MAC (medium access control) address assigned and burned into the interface hardware when it is manufactured

MAC address is like a serial number.

MAC address of every Ethernet device is guaranteed to be globally unique.

Layer 2 Ethernet MAC address is a 48-bit binary value expressed as 12 hexadecimal digits.

IEEE requires vendor to follow 2 simple rules:

Must use vendor's assigned 01_11 as first 3 bytes.

All MAC addresses With the same OUI must be assigned a unique value in last 3

ARP is a broadcast protocol used to determine the MAC address corresponding to a known IP address

ARP Request packet containing an IP address is broadcast on a subnet (using the MAC all Is broadcast destination address).

ARP Reply is sent by device that recognizes its IP address in the ARP Request.

Unicast MAC Address

Sending a message to a specific device on a network

Broadcast MAC Address

Sending a message to everyone on a network

Multicast

Sending a message to a group of devices, and all devices must respond to the message

Anycast

Sending a message to a group of devices, but looking for a response from at least one device

ARP Table

IP Address/MAC Address pairs are stored in the ARP Table (also called ARP cache) by the sender so the ARP Request does not need to be re-sent.

Removing Entries from an ARP Table

ARP cache timer removes ARP entries that have not been used for a specified period of time.

Commands may also be used to manually remove all or some of the entries in the ARP table.

Two Types of Ethernets

Shared Ethernets

Computers connected via cable (no hubs) through Ethernet hubs.

Data is broadcast from single sender to all stations on LAN.

Switched Ethernets

Computers connected through Ethernet switches.

Data is forwarded by intelligent switches based on Destination MAC address

Ethernet Transmission

Shared Ethernets

Can only have one sender at a time.

CSMA/CD used to ensure single sender.

Collisions and retransmissions occur when multiple stations try to send simultaneously.

Switched Ethernets

Can have multiple senders. Collisions can be eliminated.

Data may be buffered in switches when multiple stations try to send simultaneously.

Protocols for multiple access links

2 types of "links"

point-to-point

PPP for dial-up access

point-to-point link betvæen Ethernet switch, host

broadcast (shared wire or medium)

Old-fashioned Ethernet

upstream HFC

802.11 wireless LAN

Multiple access protocols

Single shared broadcast channel

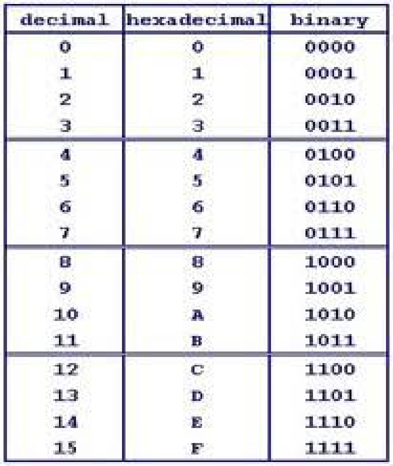
two or more simultaneous transmissions by nodes: interference

multiple access protocol

distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit

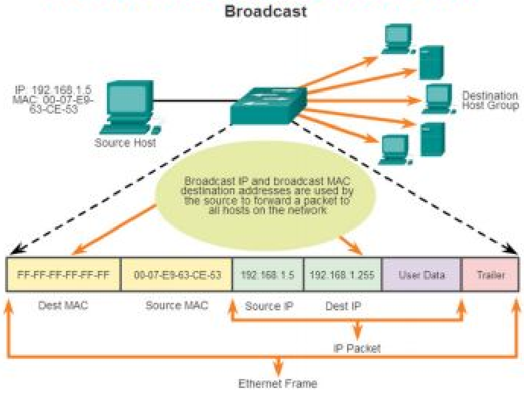
Communication about channel sharing must use the channel itself!

no out-of-band channel for coordination

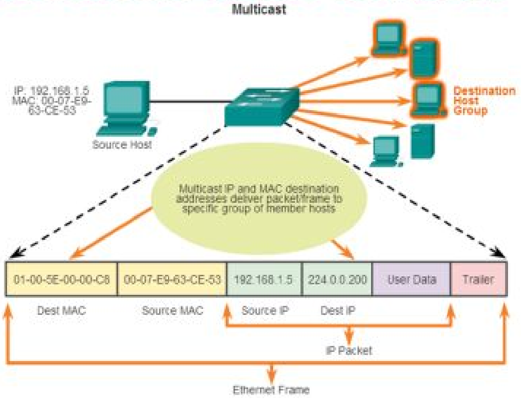


decimal	hexadecimal	binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

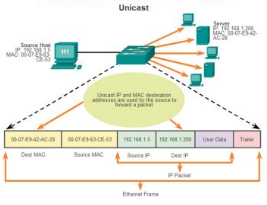
Broadcast MAC Address



Multicast MAC Address



Unicast MAC Address



MAC Protocols- Three broad classes

Channel Partitioning

- Divide channel into smaller "pieces"
  (time slots, frequency, code)
- Allocate piece-t-node for exclusive use

Random Access

- Channel not divided, allows collisions
- "Recover" from collisions

Taking Turns

- Nodes take turns, but nodes with more data to send can take longer turns

CSMA (Carrier Sense Multiple Access)

- Listen before you transmit
- If channel is idle: transmit entire frame
- If channel is busy: defer transmission

CSMA Collisions

- Propagation delay means that two noes may not hear each other's transmission
- Collisions: entire packet transmission time wasted
  - Distance and propagation delay play a role in determining collision probability

CSMA with Collision Detections

- On shared ethernets, only 1 station can transmit at any one time
- CSMA/CD protocol used to resolve contention if multiple stations want to transmit at same time
- Not needed in switched ethernets in which the central switch stores data if multiple stations send at same time

CSMA/CA

- 802.11 LANs use CSMA with Collision Avoidance (CA)
- When an 802.11 station wants to transmit:
  - Wait until the frequency band is idle (CSMA). Wait a random time to avoid collisions (CA)
  - If still idle, (optionally) send Request-to-send msg to AP, wait for Clear-to-send msg from the AP for reserved time on channel
  - Transmit data frame and start ACK timer
  - Access point sends back ACK frame
  - Sender retransmits data if no ACK within timeout

Wi-Fi LANs

- IEEE 802.11 committee has created multiple standards for transmitting wireless data within shared frequency bands
  - 802.11a, 802.11b, 802.11g, 802.11n, 902.11ac
- Configurations
  - Infrastructure- access points act as hubs for all WiDi devices that join a common SSID
  - Ad-hoc- A group of WiFI devices can talk without an AP (SSID = Service Set Identifier)

Service Set Identifier (SSID)

- The SSID is a name (up to 32 characters) for a BSS or ESS
- A **Basic Service Set** (BSS) is an 802.11 Access Point and associated stations. The AP uses its 48-bit MAC address as the BSS identifier
- An **Extended Service Set** (ESS) consists of multiple APs on same Ethernet LAN that all use the same SSID and same security credentials

Frequencies Used

- Devices connect to a wireless LAN using 2.4 gHz or 5 gHz frequency bands
- A "Hertz" is the term for a unit of frequency, as defined by the international system of units
- Lower frequencies (2.4 GHz) can travel **farther**, can pass through most objects, and carry lower data rates
- Higher frequencies (5.0 GHz) can carry **higher data rates**, but cannot travel as far and are blocked by more types of materials (walls,etc)

802.11 Frequency Channels

2.4 GHz band (802.11 b/g/n)

- There are up to 14 frequency channels, 22 MHz each- but each channel overlaps with up to 2 channels on each side.
- There are only 3 non-overlapping channels (1, 6, 11).
- Overlapping channels = interference = decreased data rates

5 GHz band (802.11 a/n)

- In the US there are 12 non-overlapping frequency channels of 20 MHz each

Mixed Mode Operations

- In an organization with different kinds of devices, access points must operate in mixed-mode, supporting old and new devices simultaneously
- But mixed-mode operation decreases 802.11n client throughput by about 30%!

MIMO for improving Mixed-operation

- Employ dual-antenna units that use separate antennas at 2.4 GHz (for old 802.11g clients) and at 5.0 GHz (for new 802.11n clients)

Adaptive Coding

- All Wi-Fi LAN Access Points utilize adaptive coding, meaning transmission speeds can change based on network conditions
- APs are continuously evaluating signal quality (power levels, signal interference, noise levels, etc) and adjusting their data rate based on conditions
- For example an 802.11n AP that normally sends at 72.2 Mbps may down-shift to 65 Mbps, 57 Mbps, 29 Mbps, or even lower speeds (down to 7 Mbps) if signal interference occurs

Wi-Fi = Shared Network

802.11 LANs are shared networks, meaning:

- Only one device can send at a time
- As more devices are added to LAN, throughputs of each device gets slower

Two Types of Ethernets

Shared Ethernets

- Computers connected via coaxial cable or through Ethernet hubs
- Data is broadcasted from single sender to all stations on LAN

Switched Ethernets

- Computers connected through ethernet switched
- Data is forwarded by intelligent switched based on Destination MAC address

Switched Ethernet Data Delivery

- Forwarding Table in switch contains, for each LAN device
  - The MAC Address of that device
  - The switch port that connects out to that device
- Incoming data packets are then simply sent out the switch port associated with the destination address in the packet

Two Switch Modes

Store-and-Forward Mode

+ No erroneous frames are forwarded

- Must wait until each frame is completely buffered before starting to re-transmit
  EX 2 complete frame transmission times required to go through 1 switch

Cut-Through Mode

+ Minimizes delay in switch
+ Used in high performance networks (trading)

- Switch may forward erroneous frames

Half Duplex Ethernet

-Like a walkie talkie where one person at a time can talk and receive messages without interference

Full Duplex Ethernet

- Full-Duplex Ethernet allows a workstation to send and receive data simultaneously
- Requirements
  - Must have a full-duplex Ethernet interface
  - Must be connected to ethernet switch

Switch Operations

- Data frame arrives on switch interface (port) x:
- If destination address = FF:FF:FF:FF:FF:FF (broadcast) then the frame is re-transmitted out all ports except port x
- Else switch looks up destination address in forwarding table and finds associated port = y
- If x not equal to y then send frame out port y
- Else if x = y, drop the frame
- If there is no entry for destination address in Forwarding Table, then forward frame out all ports except port x (that is, broadcast the frame)

Building Forwarding Table

Switch Learning

- For each arriving data frame, switch examines source address and adds/updates its entry in forwarding table containing: Source address (6 byte format), Port that this frame arrived on, and Frame arrival time\

Timing out Table Entries

Table Entry Removal

- If the source address of an arriving frame is already in the Forwarding Table, switch will simply update the Update time to the current time.
- Any entry not updated within a specific timeout period (typically 5 mins) is erased from the Forwarding Table

Allowing Multiple Paths

- Only one active data path can exist between any pair of LAN switches (o.w. Address learning gets messed up)
- However, we want multiple paths for backup in case of transmission line failure
- Activating the *Spanning Tree Protocol* allows loops to exist in the network

Virtual LANs

- If we connect many switches together, we can get scalability problems
- **Problem:** Broadcasts can start to consume a lot of bandwidth since each broadcast fram gets copied to every device on every switch
- **Problem:** We may not want broadcasts sent everywhere due to security concerns

Solutions?

- A network can be split by a network manager into several Virtual LANs (VLANs)
- Each VLAN is it's own broadcast domain

VLAN Implementation

- Sets of switch ports can be grouped into Virtual LANs by an admin
- Broadcast frame sent by any station are only set out to other ports on the same VLAN
- It works as if each VLAN is a separate switch

VLAN Advantages

- Less broadcast traffic = better performance, better security
- Network manager can control which resources each VLAN device "sees" when it broadcasts
- Different priorities may be assigned to different VLAN IDs, giving multiple levels of service
- Each VLAN is a separate IP subnet

Overview of VLANs

- A VLAN is a logical partition of a layer 2 network
- Multiple partitions can be created, allowing for multiple VLANs to co-exist
- Each VLAN is a broadcast domain, usually with its own IP network
- VLANs are mutually isolated and packets can only pass between then via a router
- The partitioning of the layer 2 network takes place inside a layer 2 device, usually via a switch
- The hosts grouped within a VLAN are unaware of the VLANs existence

Additional Header Bytes IEEE 802.1Q sub-headers

- Optional 802.1Q subheader adds 2 bytes between Ethernet and IP headers
  - Priority (3 bits)
  - Virtual LAN (13 bits)
- This subheader can be used by switches and servers to mark Ethernet frames with VLAN and Priority information

Ethernet Frame Priorities

- With 3 priority bits, an Ethernet frame can be assigned to any one of 8 (ex 2^3) priority classes:
  Priority 7: Network-critical traffic, such as routing table update messages
  Priority 5, 6: Delay-sensitive traffic, such as interactive video or voice
  Priority 4: Business-critical traffic, such as streaming data, SAP data, transaction processing
  Priority 2-3: Less critical business data
  Priority 0-1: Best-effort traffic, such as non-essential e-mails and file transfers
- Switches use these bits to prioritize data frame transfer through the switch

IPv4 Header

- IPv4 adds 20 bytes of *IPv4 Header* to every data packet
- These 20 bytes include all information required by IP routers to direct this packet to its destination

IPv4 Header Fields

- **Version:** IP protocol version. Value = "4" for IPv4 header
- **IP Header Length:** Length of IP header in 32-bit words
- **Type of Service:** Indicates whether this packet should be low or high priority
- **Total Length:** Length of IP packet in bytes
- **Identification / Fragment Offset:** used to identify and reassemble **fragments** that are formed when routers break IP packets into smaller packets
- **Time to Live:** Max number of routers this IP packet may pass through. If exceeded, packet will be discarded
- **Protocol:** Identifies the protocol carried inside the ***next header*** after this IPv4 header-typically TCP or UDP
- **Header Checksum:** Allows error checking of IP packets
- **Source Address:** 4 byte IPv4 source address for the packet
- **Destination Address:** 4-byte IPv4 destination address for this packet

Dynamic Host Configuration Protocol (DHCP)

- Network admin can set static or dynamic address
- For dynamic, device will broadcast to the DHCP server
- DHCP server will return the following values required to sent IPv4 data
  - IP Address
  - Subnet Mask
  - Default gateway address
  - DNS server address
  -Lease access time

DHCP Server

- DHCP server maintains pool of free IP addresses for each subnet and allocates with a *lease time*
- Device must renew IP address before lease time is up or the DHCP will reclaim it

What's a Router?

- A router is a device with multiple network interfaces
  - Ethernet interfaces connect the router to ethernet switches
  - Serial interfaces connect routers to other router over point-to-point links
- Each interface has its own IP address and subnet mask
- Each interface connects to an *IP Subnet* of devices
  - For us subnet = Ethernet LAn or a point-to-point link

A Router's Job

Simply, forward packets from one IP subnet to another IP subnet

- It receives packets on one interface
- It looks up the packet's IP destination address in routing table
- It ***retransmits*** the packet out another interface to get it closer to its destination

Types of Routers

Wireless Home Routers

- Combine a Wi-Fi access point, an Ethernet switch and a simple access router into a single box for home networking and Internet access across a DSL or Cable Modem connection

Enterprise Routers

- Interconnect Ethernets within a business organization

Access Routers

- Used to connect home or business LANs to an Internet access link to an Internet Service Provider (ISP)

Backbone Routers

- transport packets across the Internet backbone

What's a Subnet?

- A subnet is a group of devices that can all send packets to each other *without* going through a router
- An Ethernet LAN is an example of a subnet
- PCs that can send packets to each other through any combination of Ethernet hubs and switches are members of the same subnet
- Every device in a subnet is allocated an IP address from a group of addresses called an **IP Subnet**

What's a Routing Table?

- Each router stores a routing table that tells it how to forward packets to different IP address destinations

Routing Table

This routing table is somewhat like the Forwarding Table in an Ethernet switch **except**

- Forwards to IP subnets rather than Ethernet addresses
    - Each IP subnet is a group of IP addresses
    - Note that the routers are more scalable than switches, since each routing table entry is for an entire subnet of devices, while each switch forwarding table entry is for one individual device
- Routing tables can have a default route. If a packet destination doesn't match any other routes in the table, it is forwarded over the default route
- *How do we keep addresses current?*
- Neighboring router periodically exchange Router Table Update messages to keep their tables up-to-date

What's in a Routing Table?

Each entry in a routing table contains the following

- Destination IP Subnet - This identifies a group of IP addresses

- Outgoing Interface - The router interface the packet should be sent out to forward it towards the destination IP subnet

- Next Hop - The IP address of the next router this packet needs to go through, if any

Router forwarding operation: For each arriving packet

- Find the destination IP Subnet in the routing table that contains the IP destination address in the packet header
- Send packet out the corresponding Outgoing Interface to the Next Hop router

Keeping Router Tables Up-to-Date

How is a routing table set up and maintained?

- Initially, a network administrator specifies an IP address and subnet mask for each router interface
    - This creates routing table entries for directly connected subnets
- In static routing, the network administrator manually enters routes for remote subnets into the routing table
- In dynamic routing, the router exchanges Routing Protocol messages with all neighbor routers
    -Each router creates and updates remote subnet routes in its routing table based on information in Routing Protocol messages

IP vs. MAC Addresses

IP addresses are global

- The IP address of a device can be used by any other device on the entire Internet to communicate with it
- IP addresses are easily discoverable via DNS lookup, hyperlinks or scanning

MAC addresses are local to their subnet

- The MAC address or a computer or server is only known to other devices on the same IP subnet (EX the same LAN)
- MAC addresses never cross routers- there is no way to discover the MAC address of a device in a different subnet

How a PC sends an IP packet

When a device wants to send an IP packet, it must first determine whether the Destination IP is on the same subnet as the sending PC or on a different subnet

- If the destination is on the same subnet, then the PC adds an Ethernet header with Destination PC's MAC address in the Ethernet Destination field
- If the destination is on a different IP subnet, then the PC adds an Ethernet header with the MAC address of the default gateway in the Ethernet Destination field.

MAC Header Swapping

When forwarding a packet, a router will:

1. Remove the MAC header of arriving packets
2. Determine the outgoing interface from Routing Table
3. Create a new MAC header for outgoing packet that has MAC source and destination addresses for next subnet

- The MAC header is either Ethernet (for Ethernet interfaces) or PPP header (for point-to-point interface)
- Thus, the TCP and IP headers stay unchanged end-to-end, but the layer 2 header changes at each router (hop) and local MAC addresses are never seen in packets outside the local subnet

How does the router know all these MAC addresses?

- Sends ARP request packets to learn them and stores them in a router ARP Table

How's the Routing Table used?

For each arriving packet, the router will:

1. Remove the MAC header from the arriving packet
2. Look up the destination IP address from the packet in the Routing Table to determine both Interface and Next Hop (if present)
3. Create a new MAC header of the appropriate type (either Ethernet or PPP) of the selected interface
4. If there is a Next Hop value then
    - If Ethernet interface, look in ARP Table to find MAC Address corresponding to Next Hop and put that into Destination Field of the new MAC header
5. If there is no Next Hop
    - Look in ARP Table to find MAC address corresponding to Dest IP in packet and put that into Destination Field of the new MAC header

IP Address Subnets

An IP Address subnet is a group of IP addresses

- The size of the subnet (number of IP addresses) must be a power of 2
- All IP addresses within a subnet must be identical in the first n bits
    - Value 'n' is called the Prefix Length, written "/n"
    - Size of the subnet it 2^(32-n)
- First n bits of IP address are Routing Prefix Bits
- Last (32-n) bits of IP address are Host Bits
- The first IP in a subnet is called the **Network Address.** All Host bits in the Network Address must be 0

A Device Subnet

- A device subnet is a set of devices that can communicate with each other without going through a router
    An Ethernet LAN is an example of a device subnet
- All devices in Subnet must be allocated IP addresses that are from the same IP address subnet
- Each interface on a router connects to a different subnet
- Thus, a router forwards packets from one subnet to another

Subnet Notation

IP Subnets are written as:

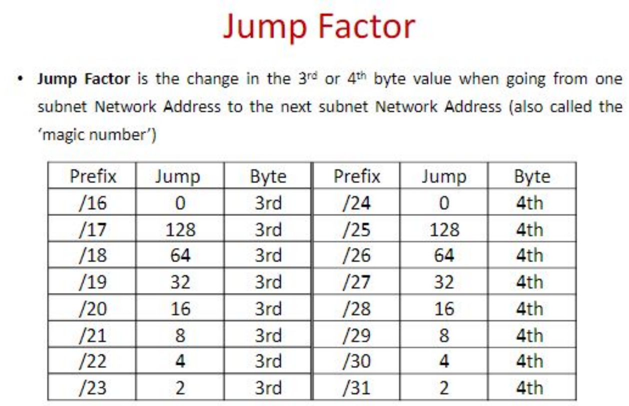
<Network Address>/<prefix length>

- This is called a Subnet ID
- This refers to the full group of addresses
- Example: 130.88.55.0/24 refers to a group of 256 IP addresses

Assignable Host Addresses

In any subnet, there are **2 IP addresses** that cannot be assigned to any device:

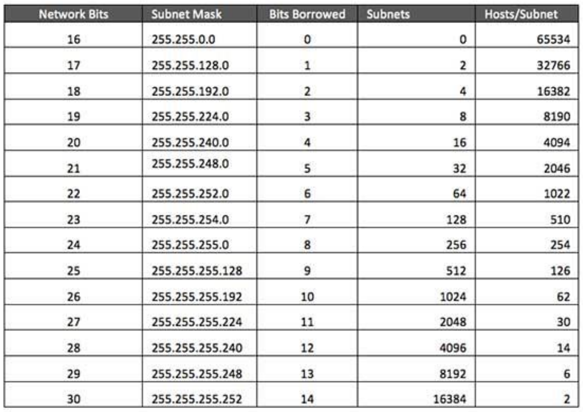
- The **first address** in the subnet (host bits are all 0s) is the Network Address and cannot be assigned to any device
- The **last address** in the subnet (host bits are all 1s) is the Subnet Broadcast Address and cannot be assigned to any device
- So the maximum number of assignable host addresses (also called valid host addresses) is **2 less than the subnet size**



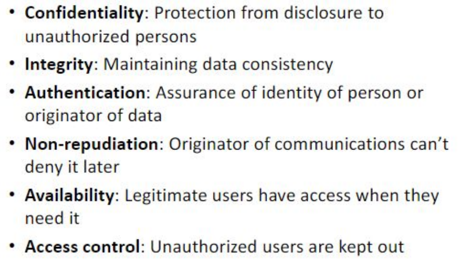
Jump Factor

- **Jump Factor** is the change in the 3rd or 4th byte value when going from one subnet Network Address to the next subnet Network Address (also called the 'magic number')

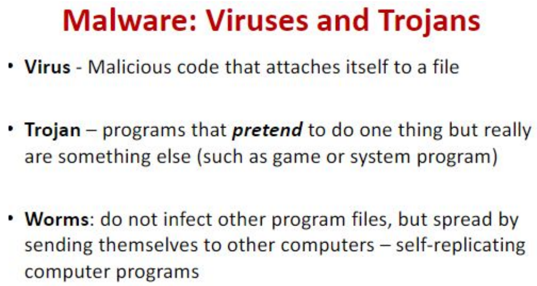
Prefix	Jump	Byte	Prefix	Jump	Byte
/16	0	3rd	/24	0	4th
/17	128	3rd	/25	128	4th
/18	64	3rd	/26	64	4th
/19	32	3rd	/27	32	4th
/20	16	3rd	/28	16	4th
/21	8	3rd	/29	8	4th
/22	4	3rd	/30	4	4th
/23	2	3rd	/31	2	4th



Network Bits	Subnet Mask	Bits Borrowed	Subnets	Hosts/Subnet
16	255.255.0.0	0	0	65534
17	255.255.128.0	1	2	32766
18	255.255.192.0	2	4	16382
19	255.255.224.0	3	8	8190
20	255.255.240.0	4	16	4094
21	255.255.248.0	5	32	2046
22	255.255.252.0	6	64	1022
23	255.255.254.0	7	128	510
24	255.255.255.0	8	256	254
25	255.255.255.128	9	512	126
26	255.255.255.192	10	1024	62
27	255.255.255.224	11	2048	30
28	255.255.255.240	12	4096	14
29	255.255.255.248	13	8192	6
30	255.255.255.252	14	16384	2

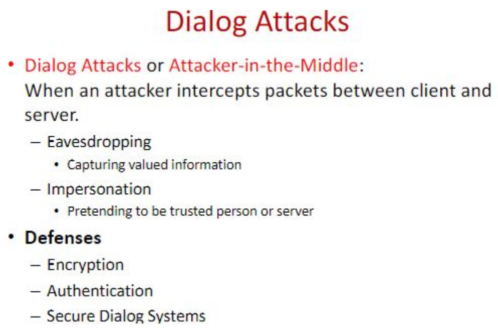


- **Confidentiality**: Protection from disclosure to unauthorized persons
- **Integrity**: Maintaining data consistency
- **Authentication**: Assurance of identity of person or originator of data
- **Non-repudiation**: Originator of communications can't deny it later
- **Availability**: Legitimate users have access when they need it
- **Access control**: Unauthorized users are kept out



Malware: Viruses and Trojans

- **Virus** - Malicious code that attaches itself to a file
- **Trojan** – programs that ***pretend*** to do one thing but really are something else (such as game or system program)
- **Worms**: do not infect other program files, but spread by sending themselves to other computers – self-replicating computer programs

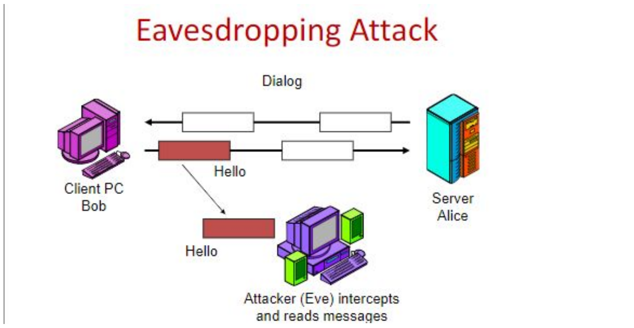


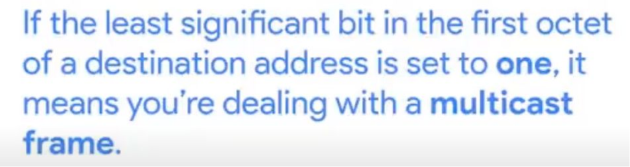
Dialog Attacks

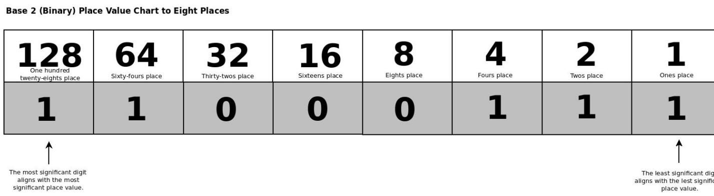
- Dialog Attacks or Attacker-in-the-Middle:
  When an attacker intercepts packets between client and server.
  - Eavesdropping
    - Capturing valued information
  - Impersonation
    - Pretending to be trusted person or server
- **Defenses**
  - Encryption
  - Authentication
  - Secure Dialog Systems

Subnet Masks

- Example: Prefix length = **/20**
  - Subnet Mask (binary) = 11111111 11111111 11110000 00000000
  - Subnet Mask (dotted decimal) = 255.255.240.0
  - Each IP address contains 20 prefix bits and 12 host bits.
  - This subnet contains 2^{12} = 4096 IP addresses


Eavesdropping Attack


If the least significant bit in the first octet of a destination address is set to **one**, it means you're dealing with a **multicast frame.**

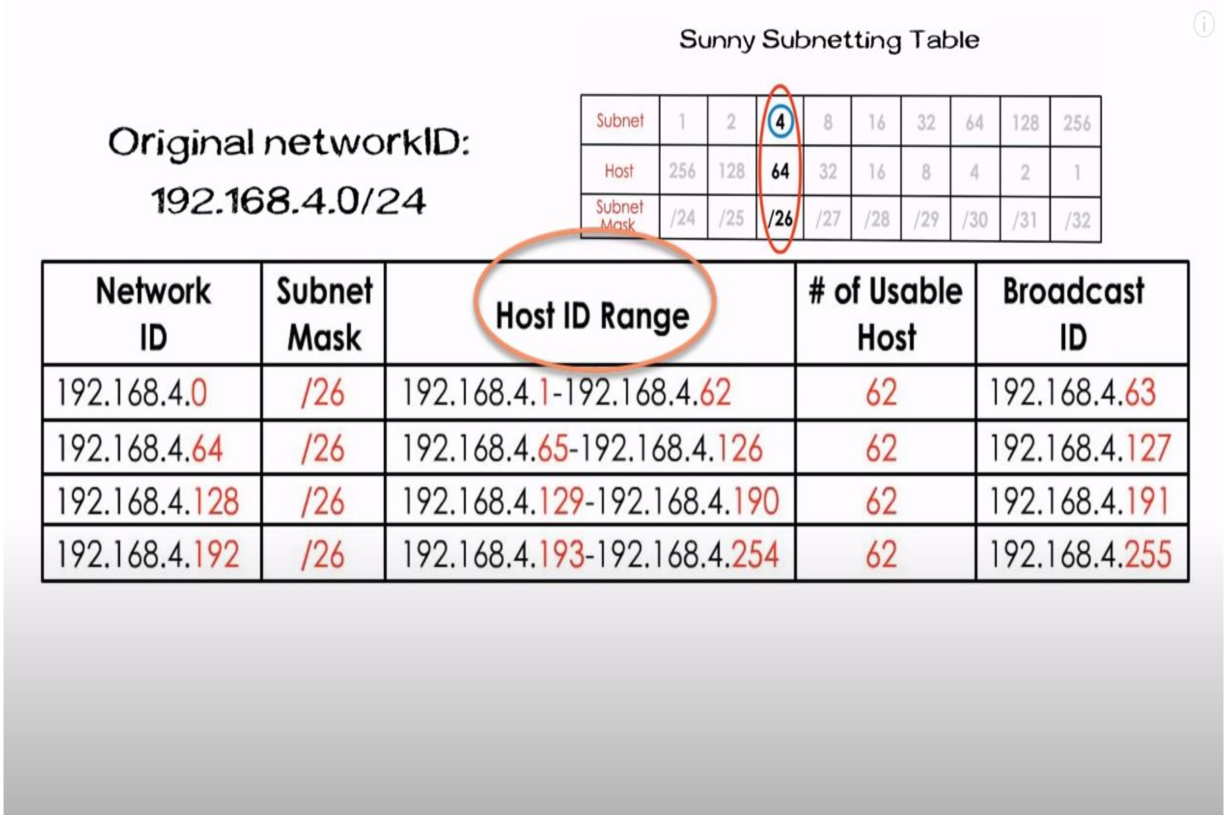

Base 2 (Binary) Place Value Chart to Eight Places

128 One hundred twenty-eights place	64 Sixty-fours place	32 Thirty-twos place	16 Sixteens place	8 Eights place	4 Fours place	2 Twos place	1 Ones place
1	1	0	0	0	1	1	1

The most significant digit aligns with the most significant place value.

The least significant dig aligns with the lest signific place value.

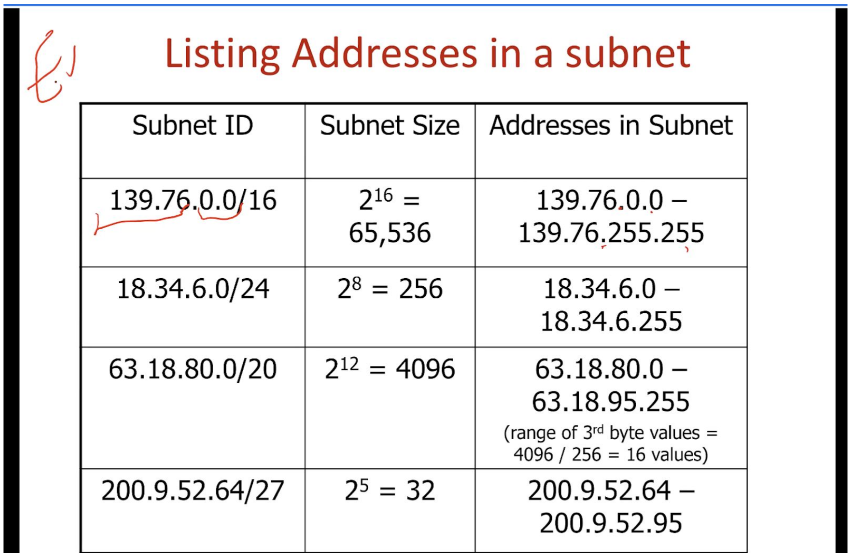
8 bits per slot in IP address ->
00000000.00000000.00000000.00000000
(ex: 140.192.18.0 ->
10001100.11000000.00010010.00000000)


Sunny Subnetting Table

Subnet	1	2	4	8	16	32	64	128	256
Host	256	128	64	32	16	8	4	2	1
Subnet Mask	/24	/25	/26	/27	/28	/29	/30	/31	/32

Original networkID:
192.168.4.0/24

Network ID	Subnet Mask	Host ID Range	# of Usable Host	Broadcast ID
192.168.4.0	/26	192.168.4.1-192.168.4.62	62	192.168.4.63
192.168.4.64	/26	192.168.4.65-192.168.4.126	62	192.168.4.127
192.168.4.128	/26	192.168.4.129-192.168.4.190	62	192.168.4.191
192.168.4.192	/26	192.168.4.193-192.168.4.254	62	192.168.4.255



Listing Addresses in a subnet

Subnet ID	Subnet Size	Addresses in Subnet
139.76.0.0/16	2^{16} = 65,536	139.76.0.0 – 139.76.255.255
18.34.6.0/24	2^{8} = 256	18.34.6.0 – 18.34.6.255
63.18.80.0/20	2^{12} = 4096	63.18.80.0 – 63.18.95.255 (range of 3rd byte values = 4096 / 256 = 16 values)
200.9.52.64/27	2^{5} = 32	200.9.52.64 – 200.9.52.95