SECURITY IN COMPUTING, FIFTH EDITION

Chapter 6: Networks

Objectives for Chapter 6

- Networking basics
- Network threats and vulnerabilities
- WiFi security
- Denial-of-service attacks
- Network encryption concepts and tools
- Types of firewalls and what they do
- Intrusion detection and prevention systems
- Security information and event management tools

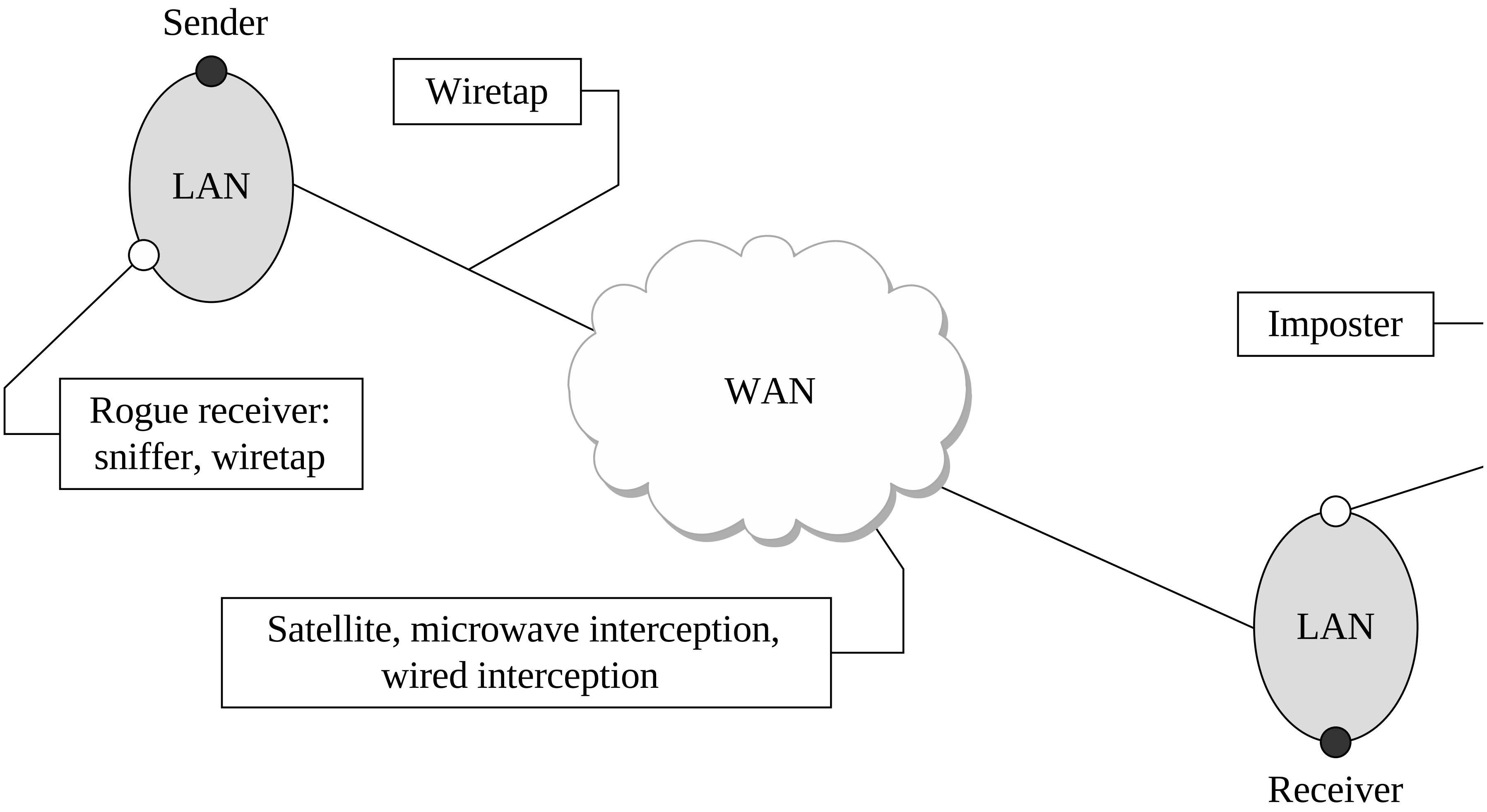
Network Transmission Media

- Cable
- Optical fiber
- Microwave
- WiFi
- Satellite communication

Communication Media Vulnerability

- Each transmission media has different physical properties
  - Those properties will influence their susceptibility to different kinds of attack
- There are different touch points where attackers can take advantage of communication media:
  - Wiretaps
  - sniffers and rogue receivers
  - Interception
  - impersonation

Communication Media Vulnerability



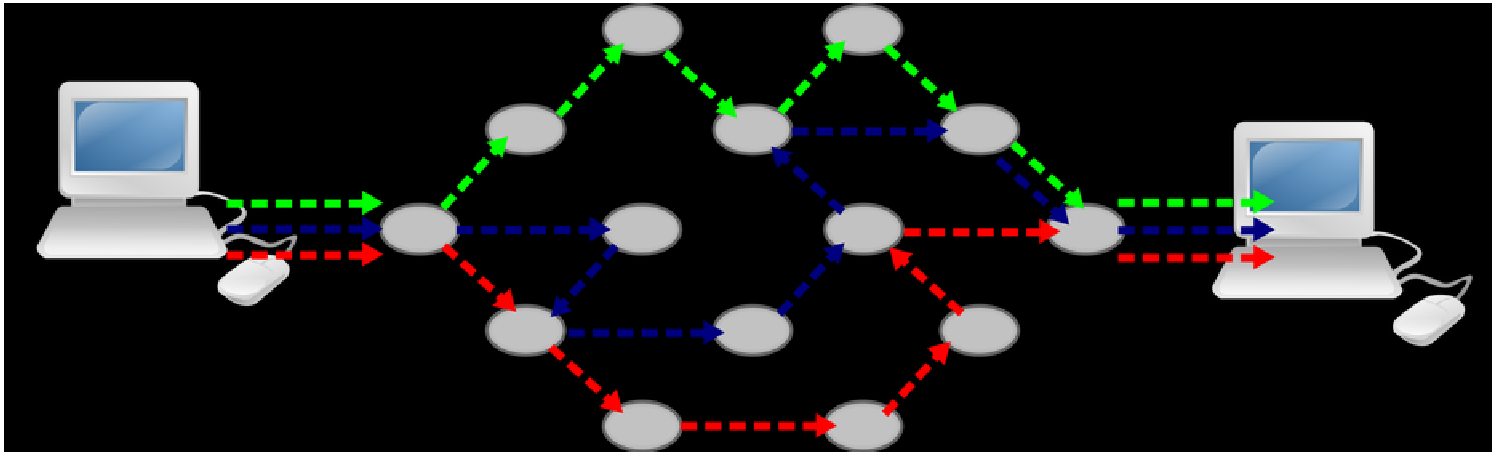
Communication Media Pros/Cons

Medium	**Strengths**	**Weaknesses**
Wire	• Widely used • Inexpensive to buy, install, maintain	• Susceptible to emanation • Susceptible to physical wiretapping
Optical fiber	• Immune to emanation • Difficult to wiretap	• Potentially exposed at connection points
Microwave	• Strong signal, not seriously affected by weather	• Exposed to interception along path of transmission • Requires line of sight location • Signal must be repeated approximately every 30 miles (50 kilometers)
Wireless (radio, WiFi)	• Widely available • Built into many computers	• Signal degrades over distance; suitable for short range • Signal interceptable in circular pattern around transmitter
Satellite	• Strong, fast signal	• Delay due to distance signal travels up and down • Signal exposed over wide area at receiving end

Computer Networks

https://nizamtaher.wordpress.com/topics/topic-1-introduction-of-computer-network/

Circuit and Packet Switching



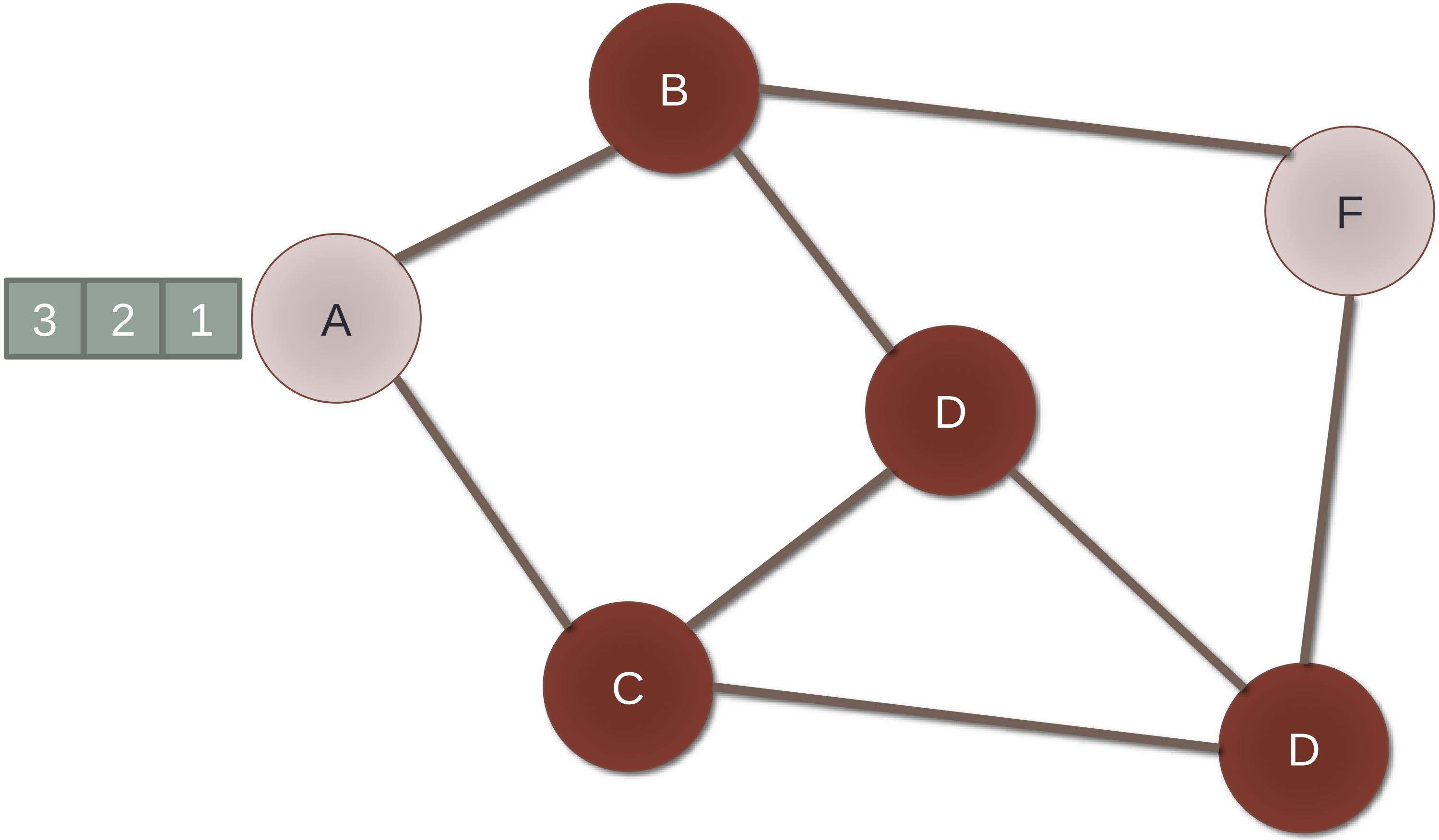
http://www.apposite-tech.com/blog/uncategorized/packet-switching-vs-circuit-switching/

Circuit and Packet Switching

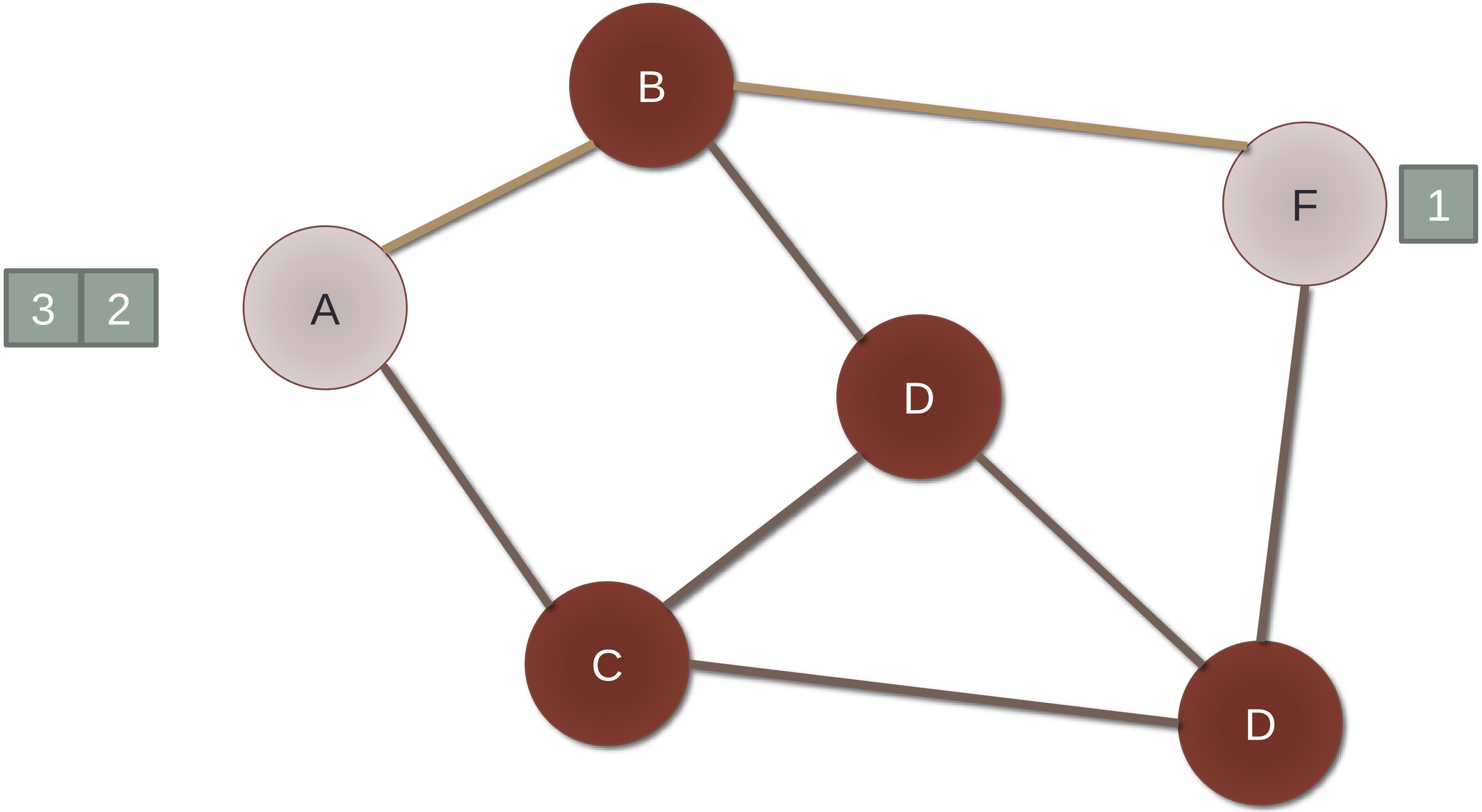
- Circuit switching
  - Legacy phone network
  - Single route through sequence of hardware devices established when two nodes start communication
  - Data sent along route
  - Route maintained until communication ends

- Packet switching
  - Internet
  - Data split into packets
  - Packets transported independently through network
  - Each packet handled on a best efforts basis
  - Packets may follow different routes

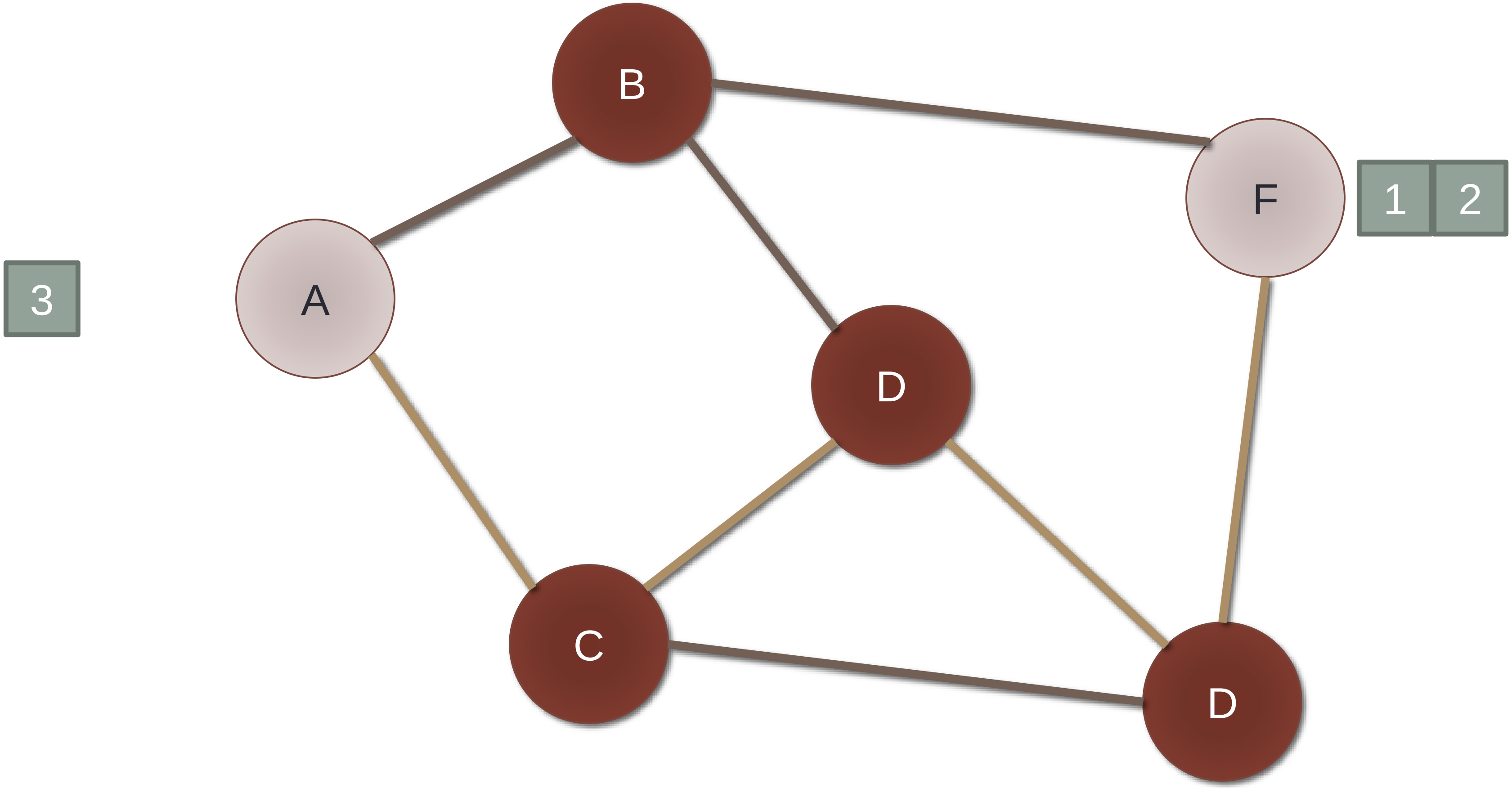
Packet Switching



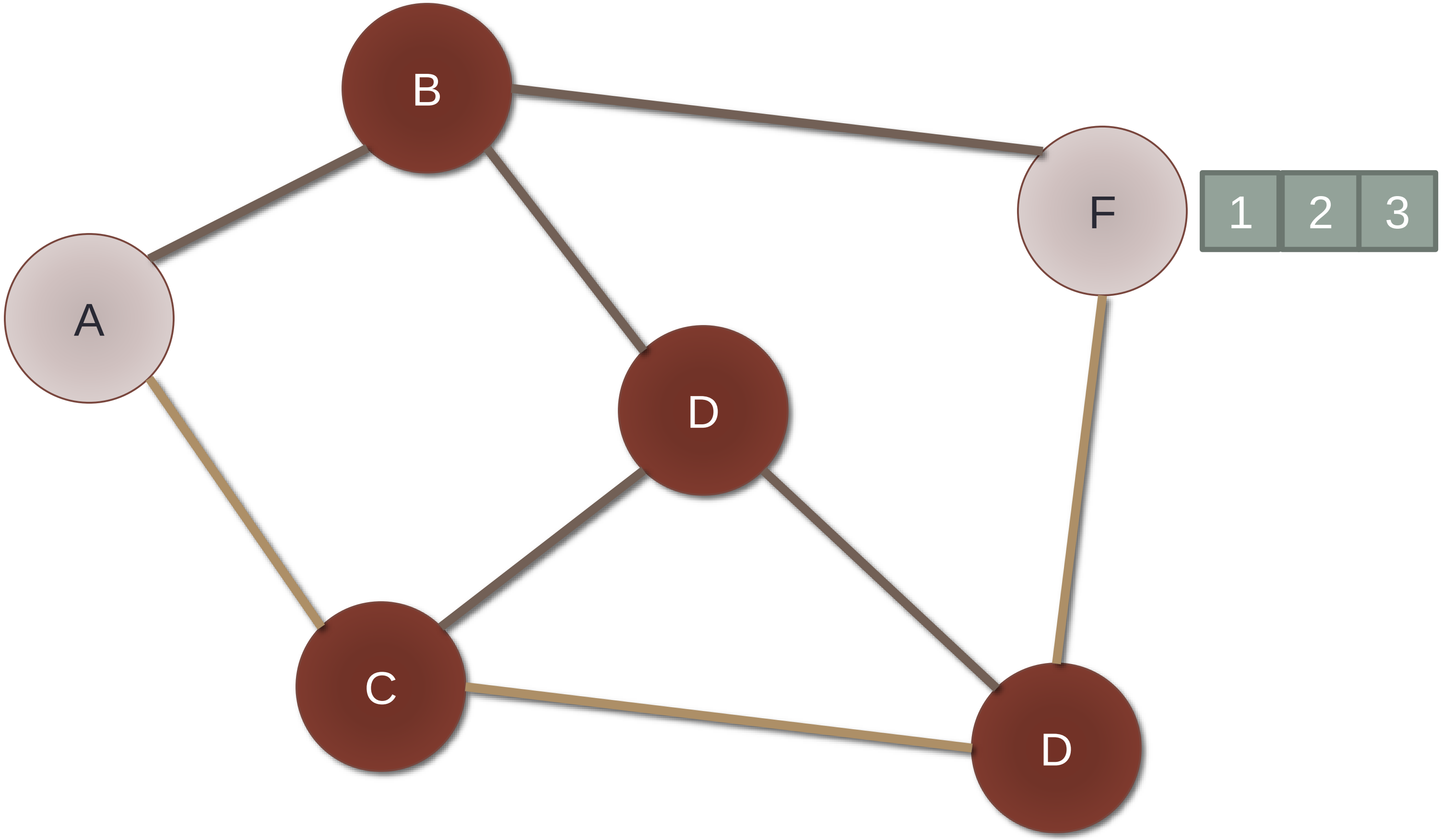
Packet Switching



Packet Switching



Packet Switching



Protocols

- A protocol defines the rules for communication between computers
- Protocols are broadly classified as connectionless and connection oriented
- Connectionless protocol
  - Sends data out as soon as there is enough data to be transmitted
  - E.g., user datagram protocol (UDP)
- Connection-oriented protocol
  - Provides a reliable connection stream between two nodes
  - Consists of set up, transmission, and tear down phases
  - Creates virtual circuit-switched network
  - E.g., transmission control protocol (TCP)

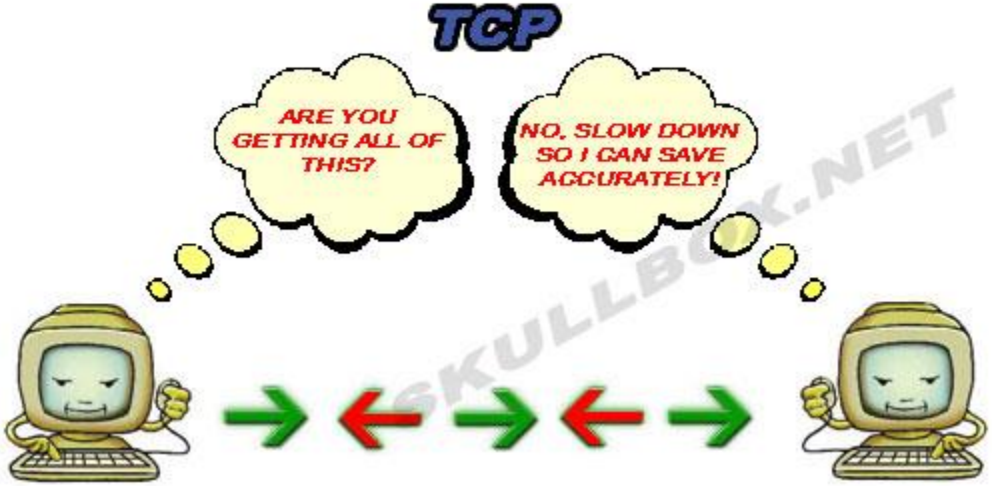
http://www.hinditechy.com/what-is-protocol-in-networking-hindi/

Connectionless protocol

UDP
ARE YOU GETTING ALL OF THIS?
WHO CARES JUST SEND IT FASTER!
SKULLBOX.NET

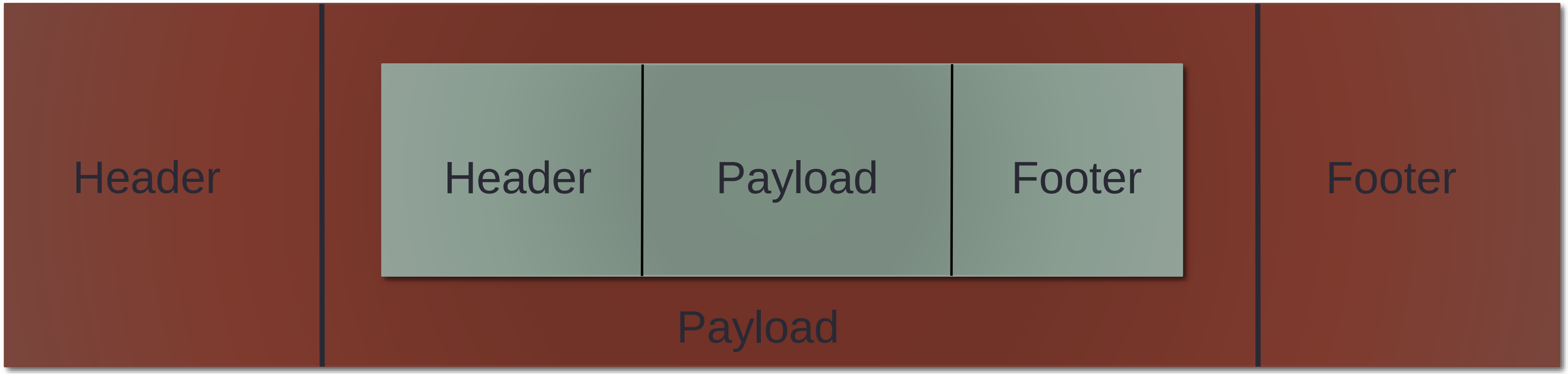
https://www.b4x.com/android/forum/threads/question-about-two-way-communication-using-udp.17316/

Connection-oriented protocol


TCP
ARE YOU GETTING ALL OF THIS?
NO, SLOW DOWN SO I CAN SAVE ACCURATELY!
SKULLBOX.NET

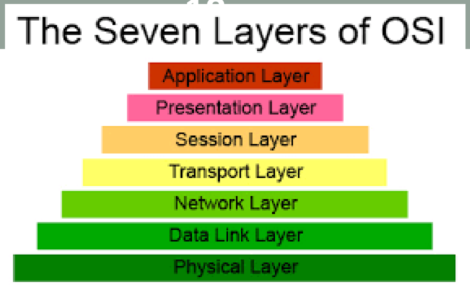
Encapsulation

- A packet typically consists of
  - Control information for addressing the packet: header and footer
  - Data: payload
- A network protocol N1 can use the services of another network protocol N2
  - A packet p1 of N1 is encapsulated into a packet p2 of N2
  - The payload of p2 is p1
  - The control information of p2 is derived from that of p1



https://www.facebook.com/utplacentaencapsulation/

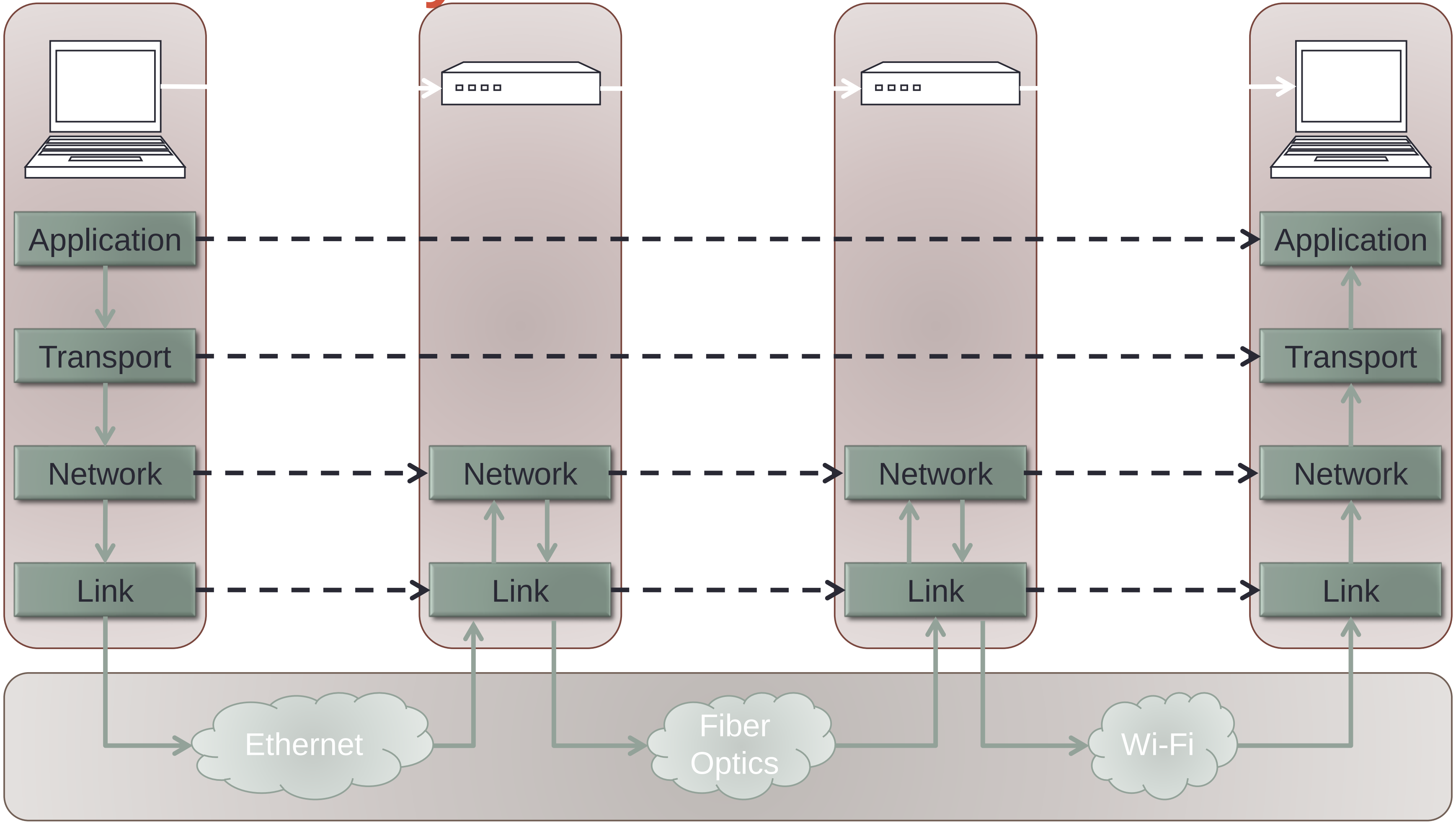
Network Layers



- Network models typically use a stack of layers
  - Higher layers use the services of lower layers via encapsulation
  - A layer can be implemented in hardware or software
  - The bottommost layer must be in hardware
- A network device may implement several layers
- A communication channel between two nodes is established for each layer
  - Actual channel at the bottom layer
  - Virtual channel at higher layers

https://techiemaster.wordpress.com/2016/08/15/osi-layer/

Internet Layers

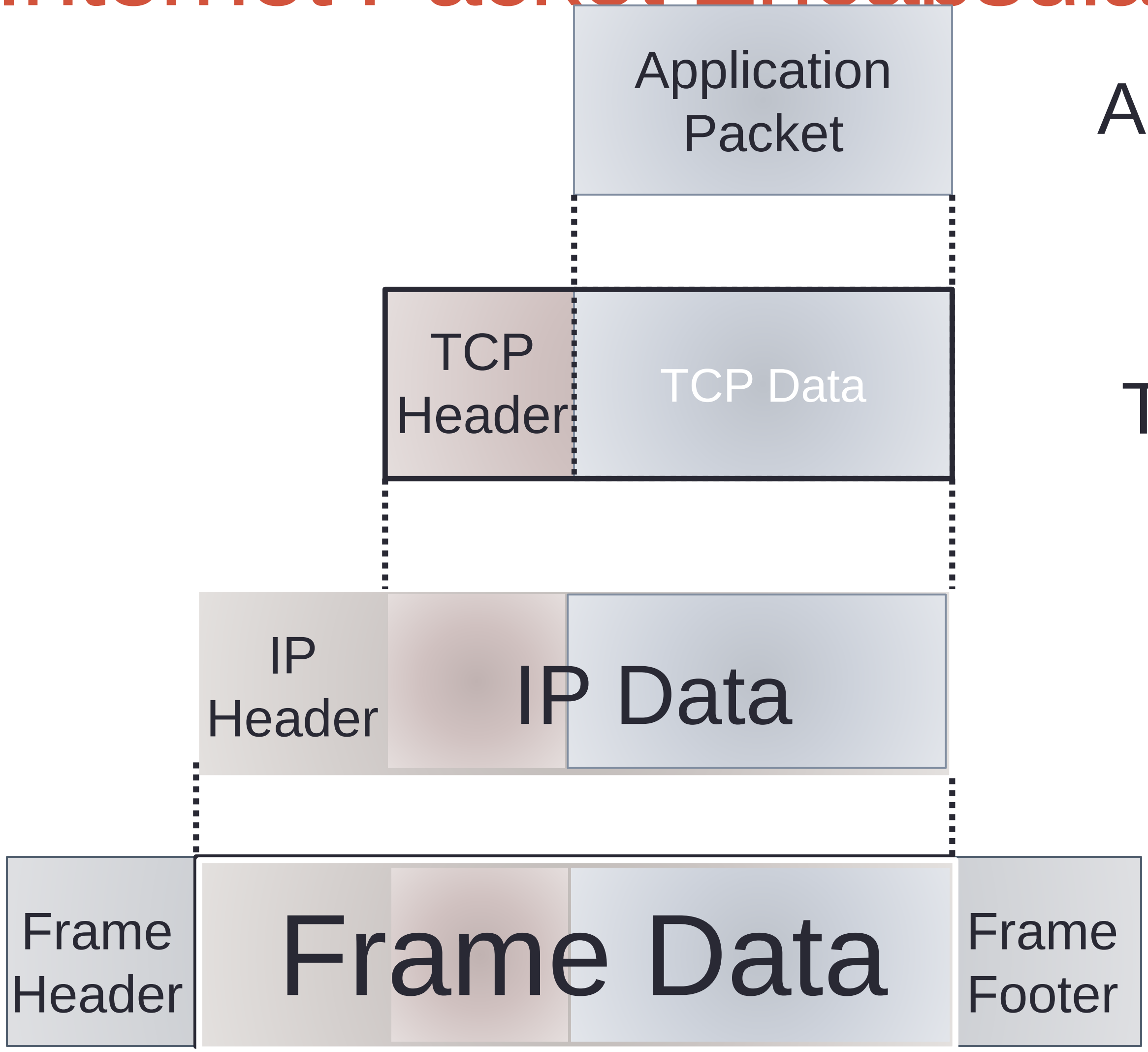


Physical Layer

Intermediate Layers

- Link layer
  - Local area network: Ethernet, WiFi, optical fiber
  - 48-bit media access control (MAC) addresses
  - Packets called frames
- Network layer
  - Internet-wide communication
  - Best efforts
  - 32-bit internet protocol (IP) addresses in IPv4
  - 128-bit IP addresses in IPv6
- Transport layer
  - 16-bit addresses (ports) for classes of applications
  - Connection-oriented transmission layer protocol (TCP)
  - Connectionless user datagram protocol (UDP)

Internet Packet Encapsulation



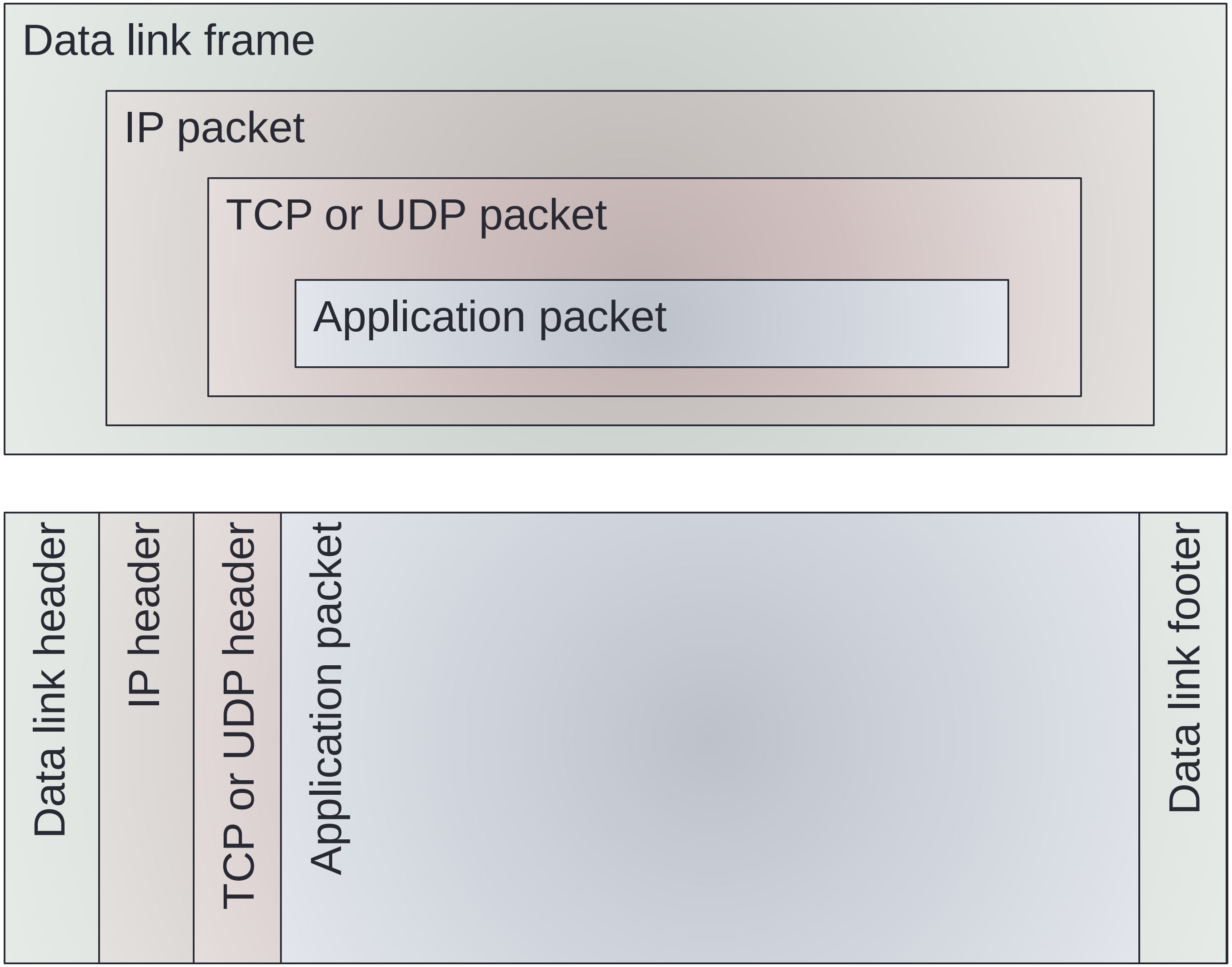
Application Layer

Transport Layer

Network Layer

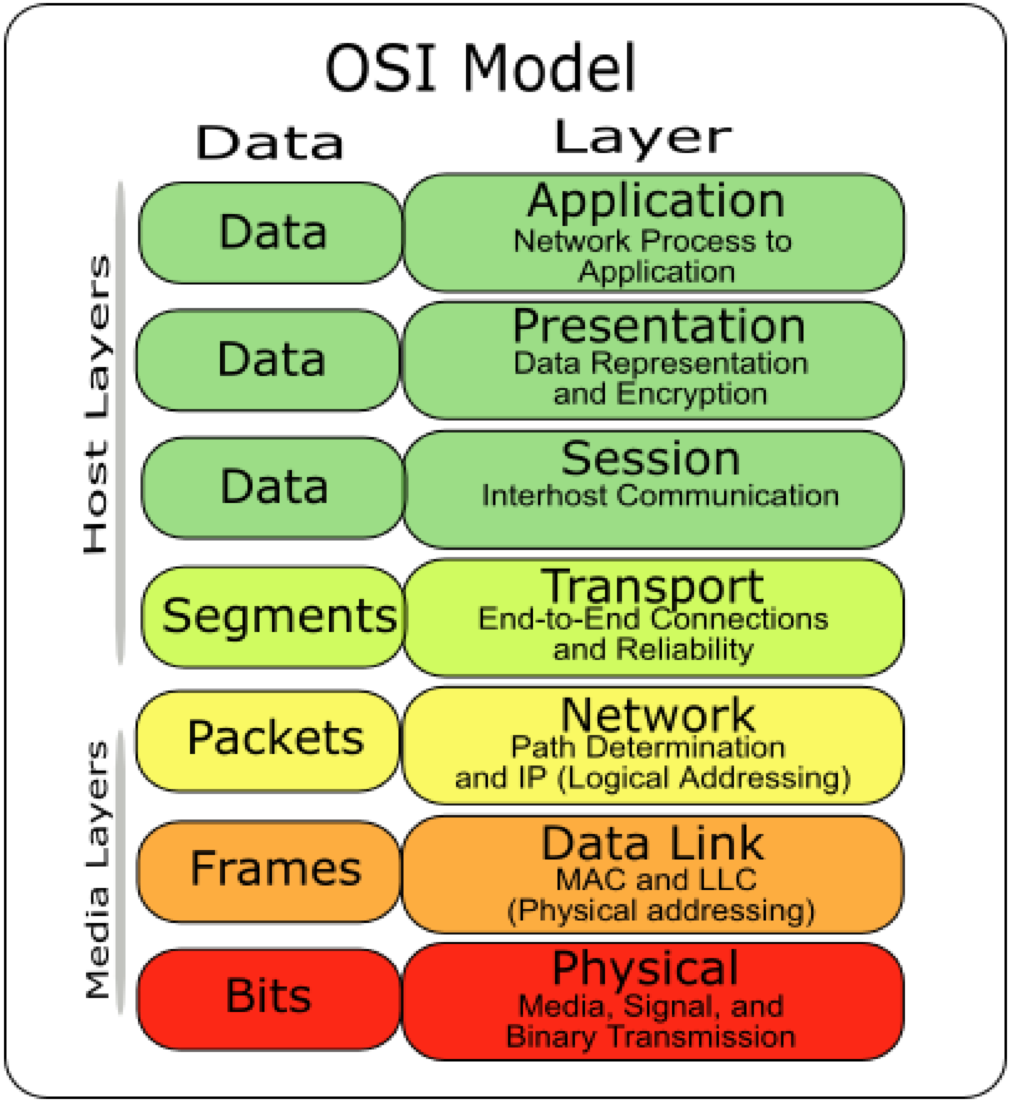
Link Layer

Internet Packet Encapsulation

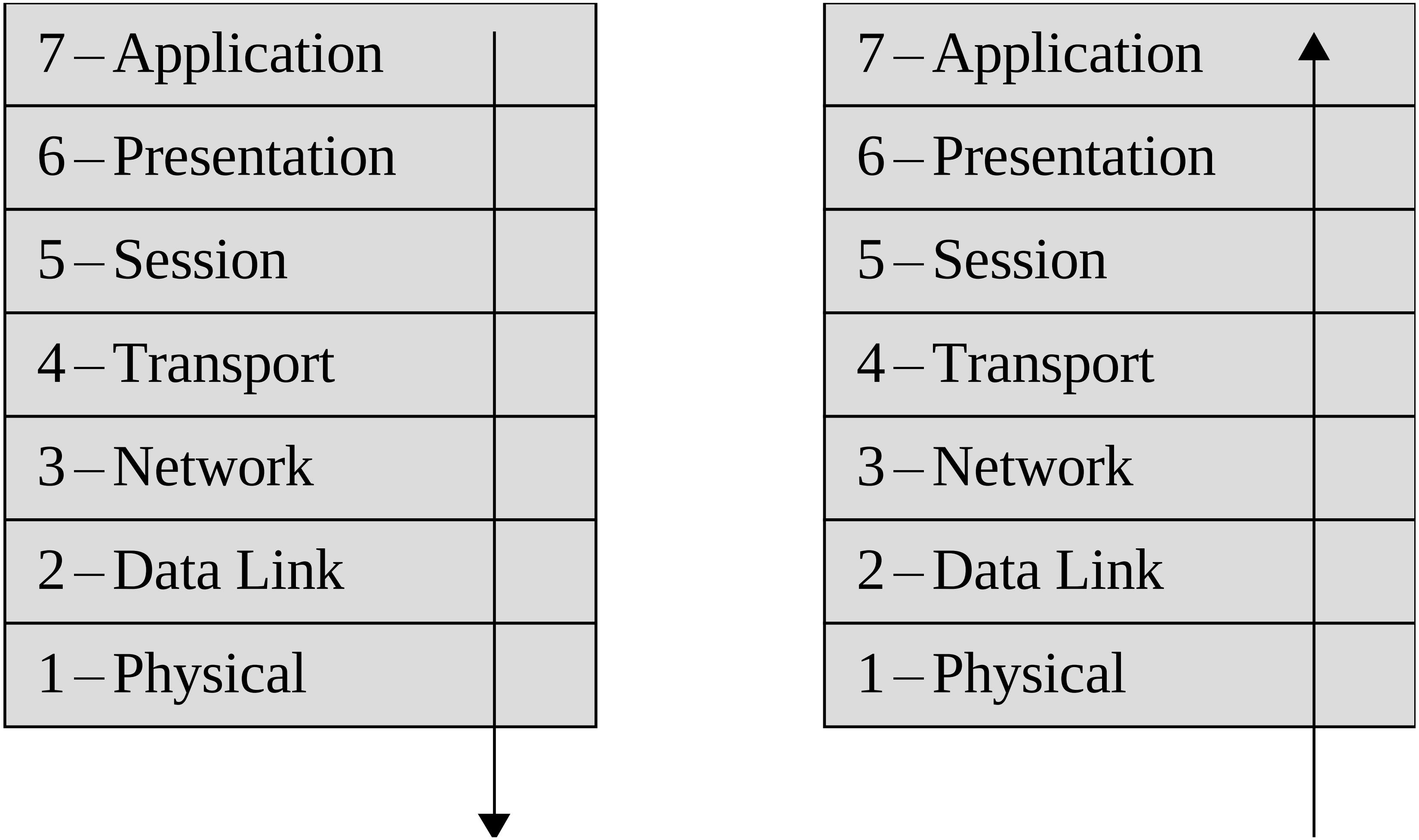


The OSI Model

- The OSI (Open System Interconnect) Reference Model is a network model consisting of seven layers
- Created in 1983, OSI is promoted by the International Standard Organization (ISO)


OSI Model
Data
Layer
Host Layers
Media Layers
Data
Application
Network Process to Application
Data
Presentation
Data Representation and Encryption
Data
Session
Interhost Communication
Segments
Transport
End-to-End Connections and Reliability
Packets
Network
Path Determination and IP (Logical Addressing)
Frames
Data Link
MAC and LLC (Physical addressing)
Bits
Physical
Media, Signal, and Binary Transmission

The OSI Model



7 – Application
6 – Presentation
5 – Session
4 – Transport
3 – Network
2 – Data Link
1 – Physical

7 – Application
6 – Presentation
5 – Session
4 – Transport
3 – Network
2 – Data Link
1 – Physical

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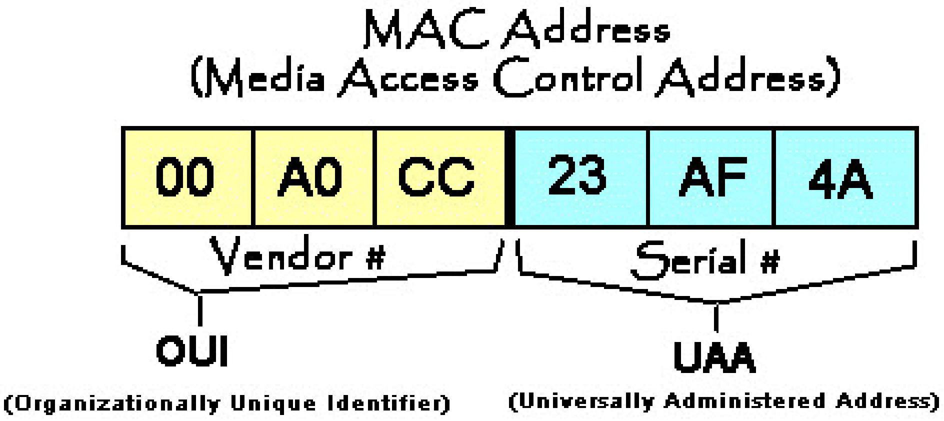
Network Interfaces

- Network interface: device connecting a computer to a network
  - Ethernet card
  - WiFi adapter
- A computer may have multiple network interfaces
- Packets transmitted between network interfaces
- Most local area networks, (including Ethernet and WiFi) broadcast frames
- In regular mode, each network interface gets the frames intended for it
- Traffic sniffing can be accomplished by configuring the network interface to read all frames (promiscuous mode)

MAC Addresses

- Most network interfaces come with a predefined MAC address
- A MAC address is a 48-bit number usually represented in hex
  - E.g., 00-1A-92-D4-BF-86
- The first three octets of any MAC address are IEEE-assigned Organizationally Unique Identifiers
  - E.g., Cisco 00-1A-A1, D-Link 00-1B-11, ASUSTek 00-1A-92
- The next three can be assigned by organizations as they please, with uniqueness being the only constraint
- Organizations can utilize MAC addresses to identify computers on their network
- MAC address can be reconfigured by network interface driver software

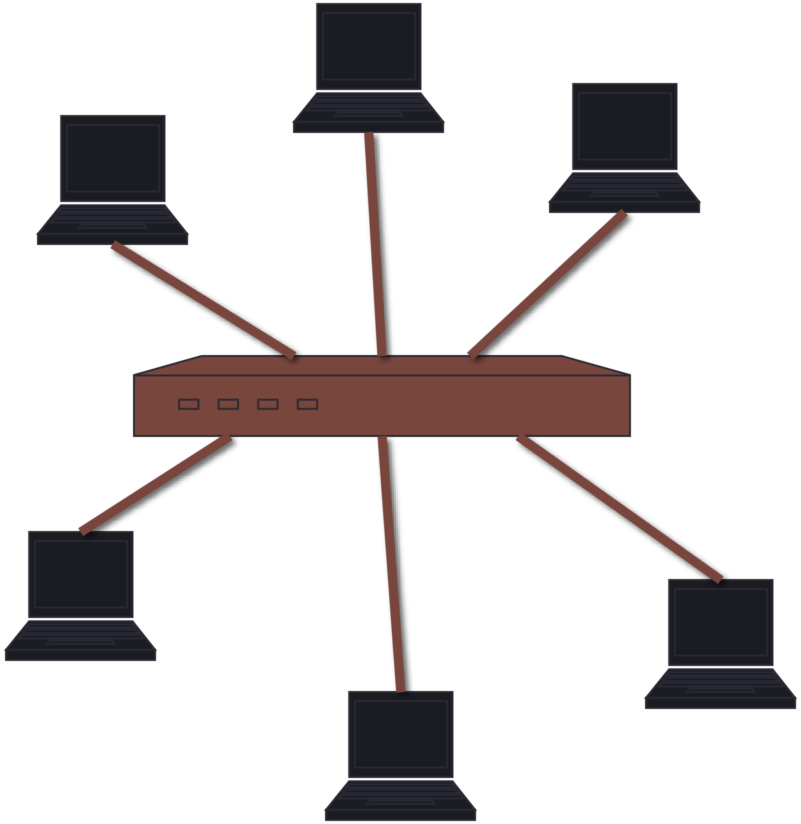
MAC Address


MAC Address
(Media Access Control Address)
00
A0
CC
23
AF
4A
Vendor #
Serial #
OUI
(Organizationally Unique Identifier)
UAA
(Universally Administered Address)

http://www.thewindowsclub.com/change-mac-address-in-windows

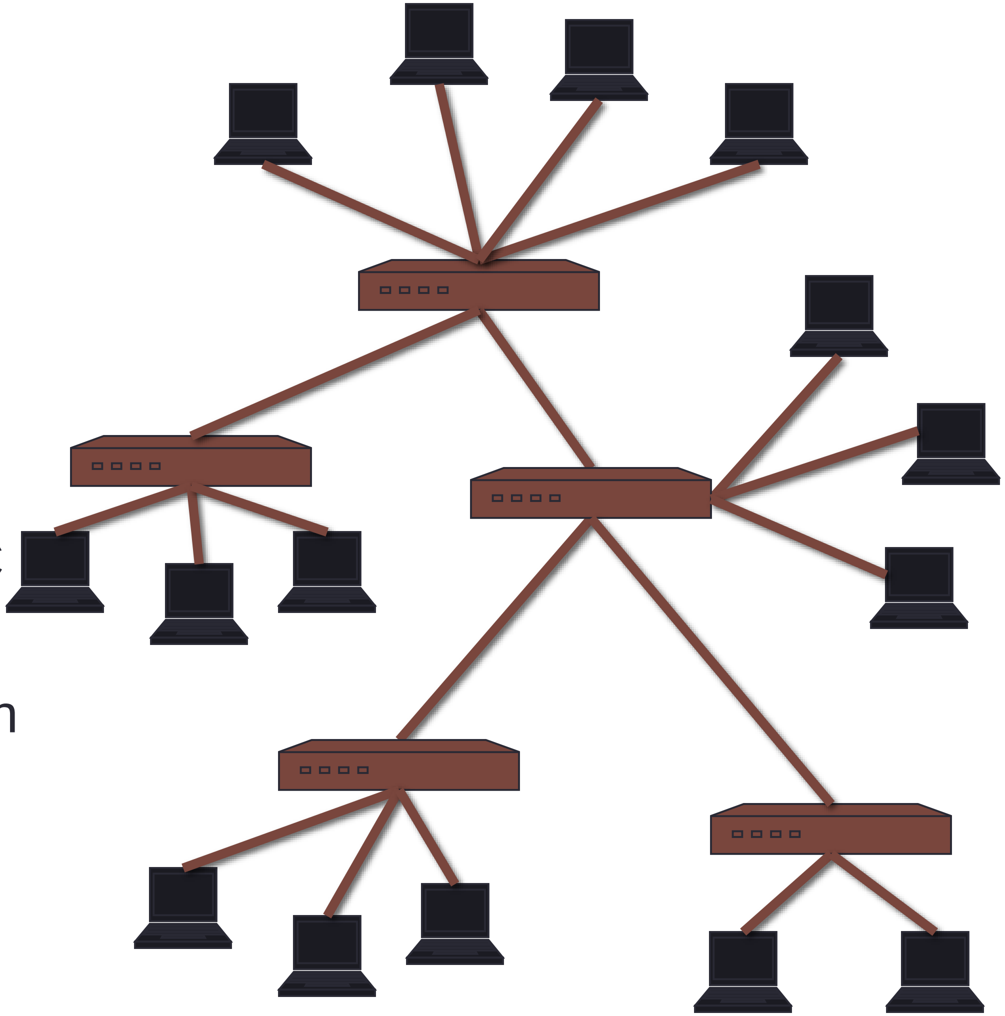
Switch

- A switch is a common network device
  - Operates at the link layer
  - Has multiple ports, each connected to a computer
- Operation of a switch
  - Learn the MAC address of each computer connected to it
  - Forward frames only to the destination computer



Combining Switches

- Switches can be arranged into a tree
- Each port learns the MAC addresses of the machines in the segment (subtree) connected to it
- Fragments to unknown MAC addresses are broadcast
- Frames to MAC addresses in the same segment as the sender are ignored



MAC Address Filtering

- A switch can be configured to provide service only to machines with specific MAC addresses
- Allowed MAC addresses need to be registered with a network administrator
- A MAC spoofing attack impersonates another machine
  - Find out MAC address of target machine
  - Reconfigure MAC address of rogue machine
  - Turn off or unplug target machine
- Countermeasures
  - Block port of switch when machine is turned off or unplugged
  - Disable duplicate MAC addresses

Viewing and Changing MAC Addresses

- Viewing the MAC addresses of the interfaces of a machine
  - Linux: ifconfig
  - Windows: ipconfig /all
- Changing a MAC address in Linux
  - Stop the networking service: /etc/init.d/network stop
  - Change the MAC address: ifconfig eth0 hw ether <MAC-address>
  - Start the networking service: /etc/init.d/network start
- Changing a MAC address in Windows
  - Open the Network Connections applet
  - Access the properties for the network interface
  - Click “Configure …”
  - In the advanced tab, change the network address to the desired value
- Changing a MAC address requires administrator privileges

ARP

- The address resolution protocol (ARP) connects the network layer to the data layer by converting IP addresses to MAC addresses
- ARP works by broadcasting requests and caching responses for future use
- The protocol begins with a computer broadcasting a message of the form

  who has <IP address1> tell <IP address2>
- When the machine with <IP address1> or an ARP server receives this message, its broadcasts the response

  <IP address1> is <MAC address>
- The requestor’s IP address <IP address2> is contained in the link header
- The Linux and Windows command arp - a displays the ARP table

```
Internet Address      Physical Address      Type
128.148.31.1          00-00-0c-07-ac-00     dynamic
128.148.31.15         00-0c-76-b2-d7-1d     dynamic
128.148.31.71         00-0c-76-b2-d0-d2     dynamic
128.148.31.75         00-0c-76-b2-d7-1d     dynamic
128.148.31.102        00-22-0c-a3-e4-00     dynamic
128.148.31.137        00-1d-92-b6-f1-a9     dynamic
```

ARP Spoofing

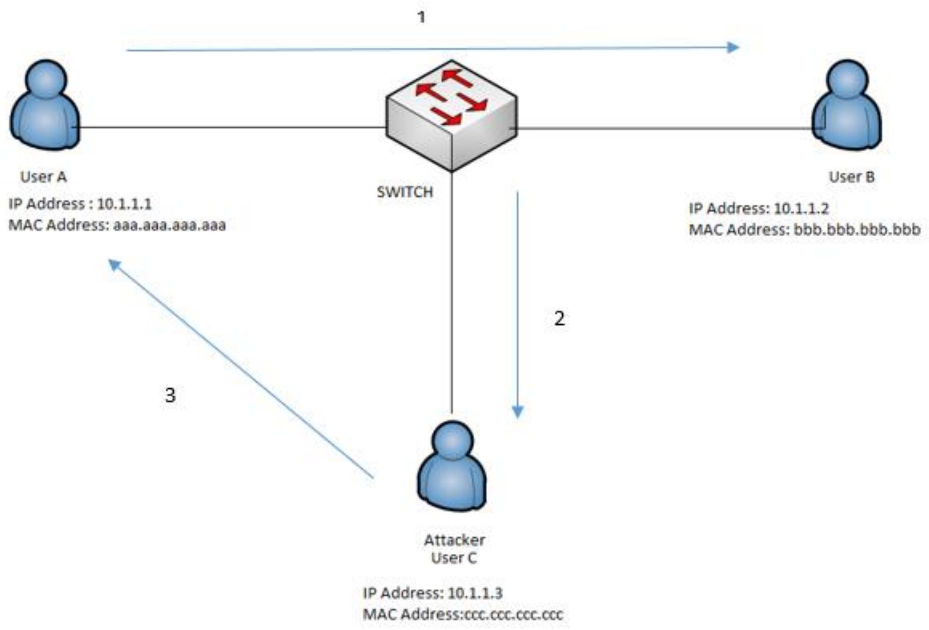
- The ARP table is updated whenever an ARP response is received
- Requests are not tracked
- ARP announcements are not authenticated
- Machines trust each other
- A rogue machine can spoof other machines

ARP Poisoning (ARP Spoofing)

- According to the standard, almost all ARP implementations are stateless
- An arp cache updates every time that it receives an arp reply… even if it did not send any arp request!
- It is possible to “poison” an arp cache by sending gratuitous arp replies
- Using static entries solves the problem but it is almost impossible to manage!

ARP Poisoning (ARP Spoofing)

- Attacker tries to map the MAC address with the IP address of a victim
- Once the MAC address is mapped, the attacker intercepts the data
- By using ARP spoofing attack, the attacker can steal or delete the data



https://www.safaribooksonline.com/library/view/ccna-security-210-260/9781787128873/5628067a-4601-4a57-a221-c08d777dc39c.x

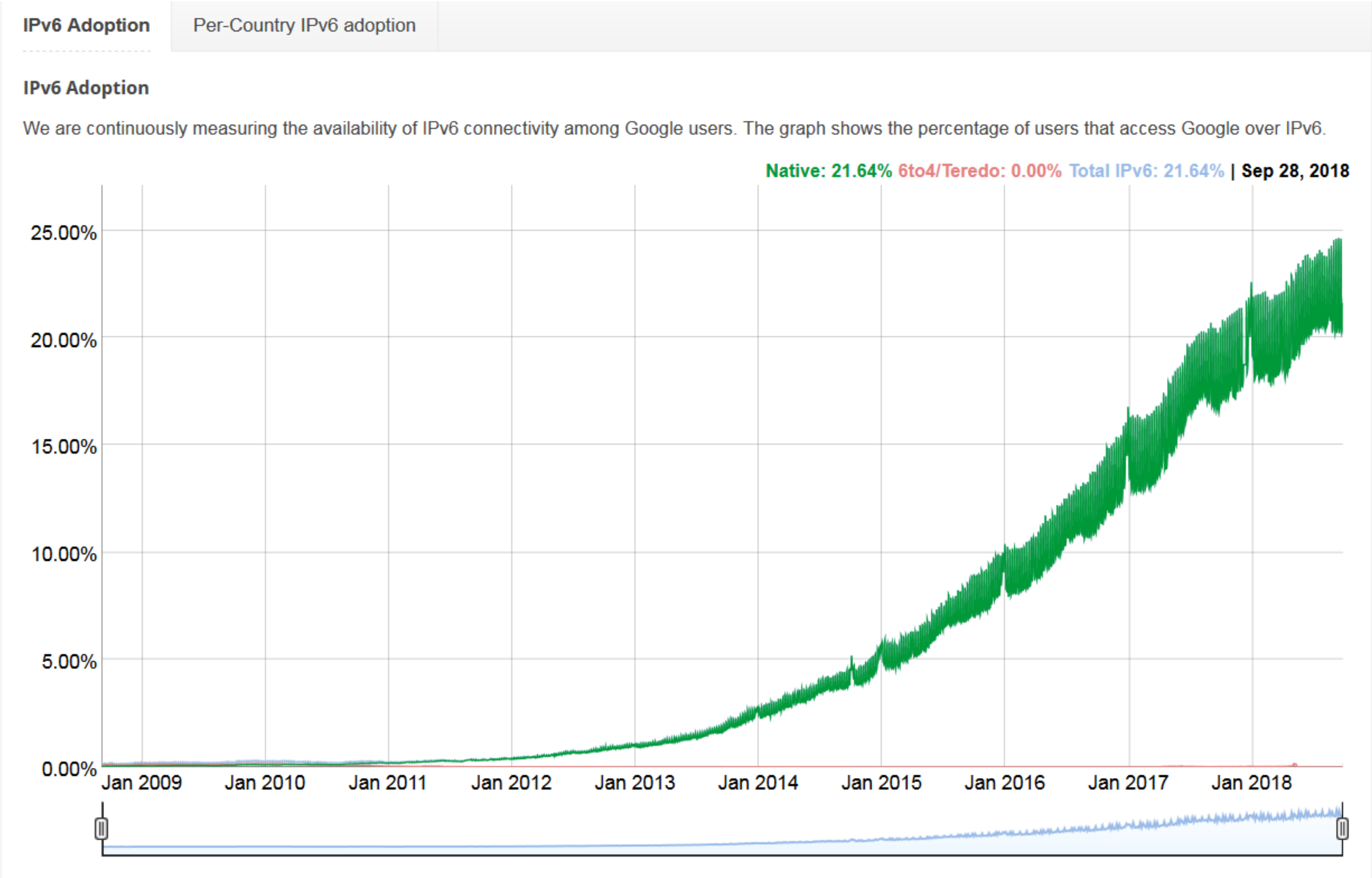
ARP Poisoning Defenses

- Use ARP spoofing detection and prevention software
  - certifies or cross-checks ARP responses
  - AntiARP (Windows), ArpStar(Linux), etc.
- Using VPNs (Virtual Private Networks)
  - Uses an encrypted tunnel for data transmission
  - Data that goes through it is encrypted

ARP Spoofing

- ARP Implemented in IPv4, which still routes most Internet traffic today In Internet Protocol Version 6 (IPv6) networks, the functionality of ARP is provided by the Neighbor Discovery Protocol (NDP)
    - Less vulnerable to spoofing
    - uses the Secure Neighbor Discovery (SEND) Protocol. Cryptographically generated addresses ensure that the claimed source of an NDP message is the owner of the claimed address
    - However, IPv6 deployment is still ongoing

IPv6 adoption



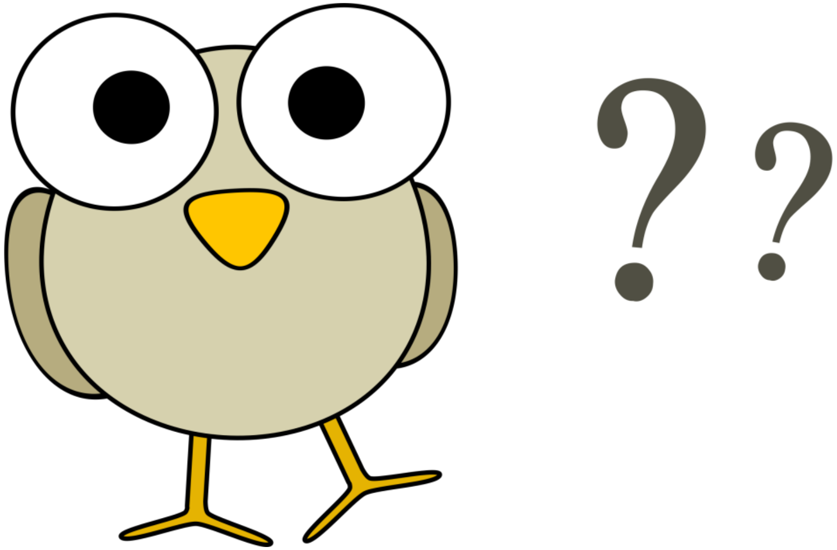
IPv6 Adoption

We are continuously measuring the availability of IPv6 connectivity among Google users. The graph shows the percentage of users that access Google over IPv6.

Native: 21.64% 6to4/Teredo: 0.00% Total IPv6: 21.64% | **Sep 28, 2018**

https://www.google.com/intl/en/ipv6/statistics.html

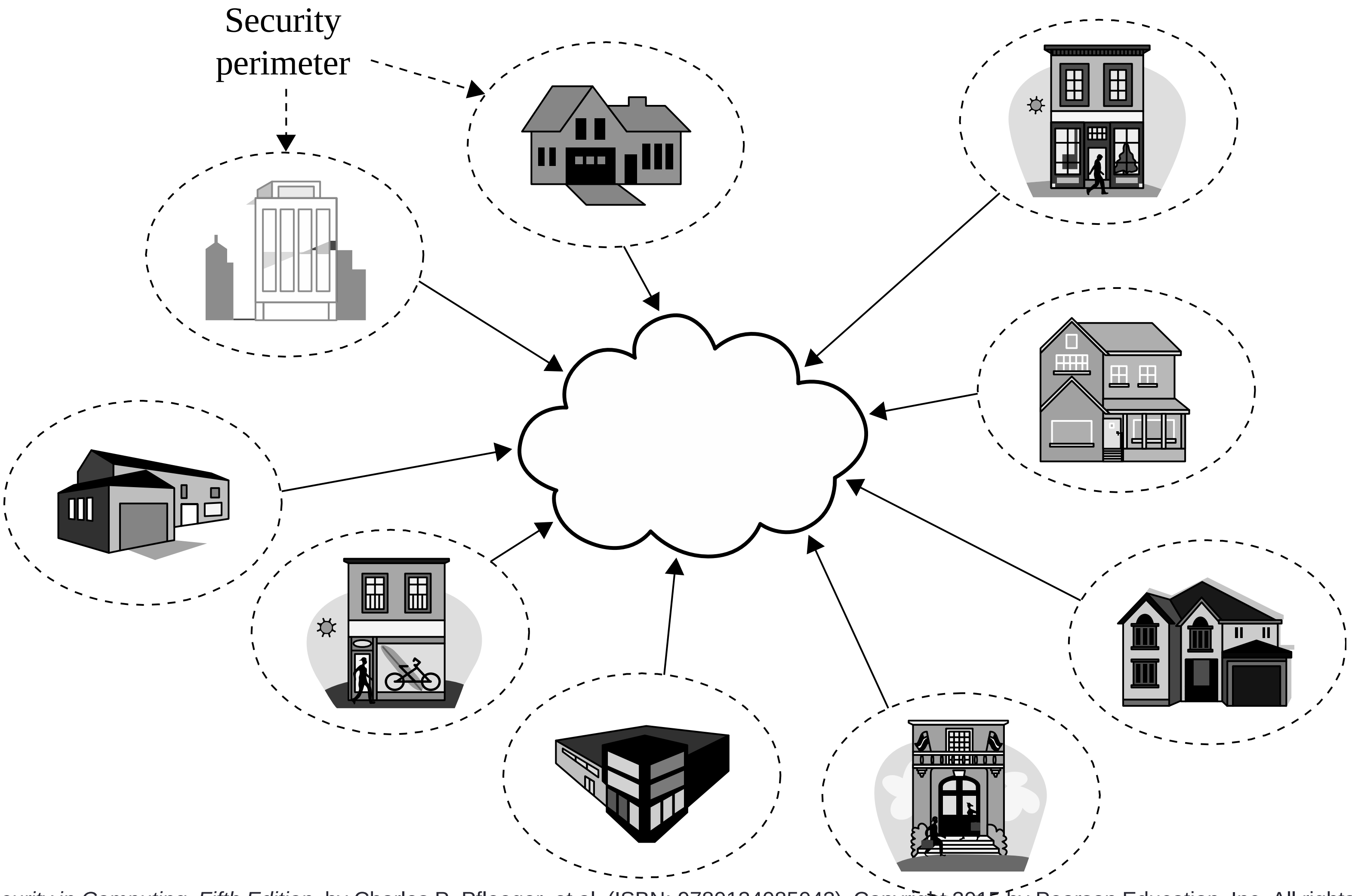
- Questions?



Threats to Network Communications

- *Interception*, or unauthorized viewing
- *Modification*, or unauthorized change
- *Fabrication*, or unauthorized creation
- *Interruption*, or preventing authorized access

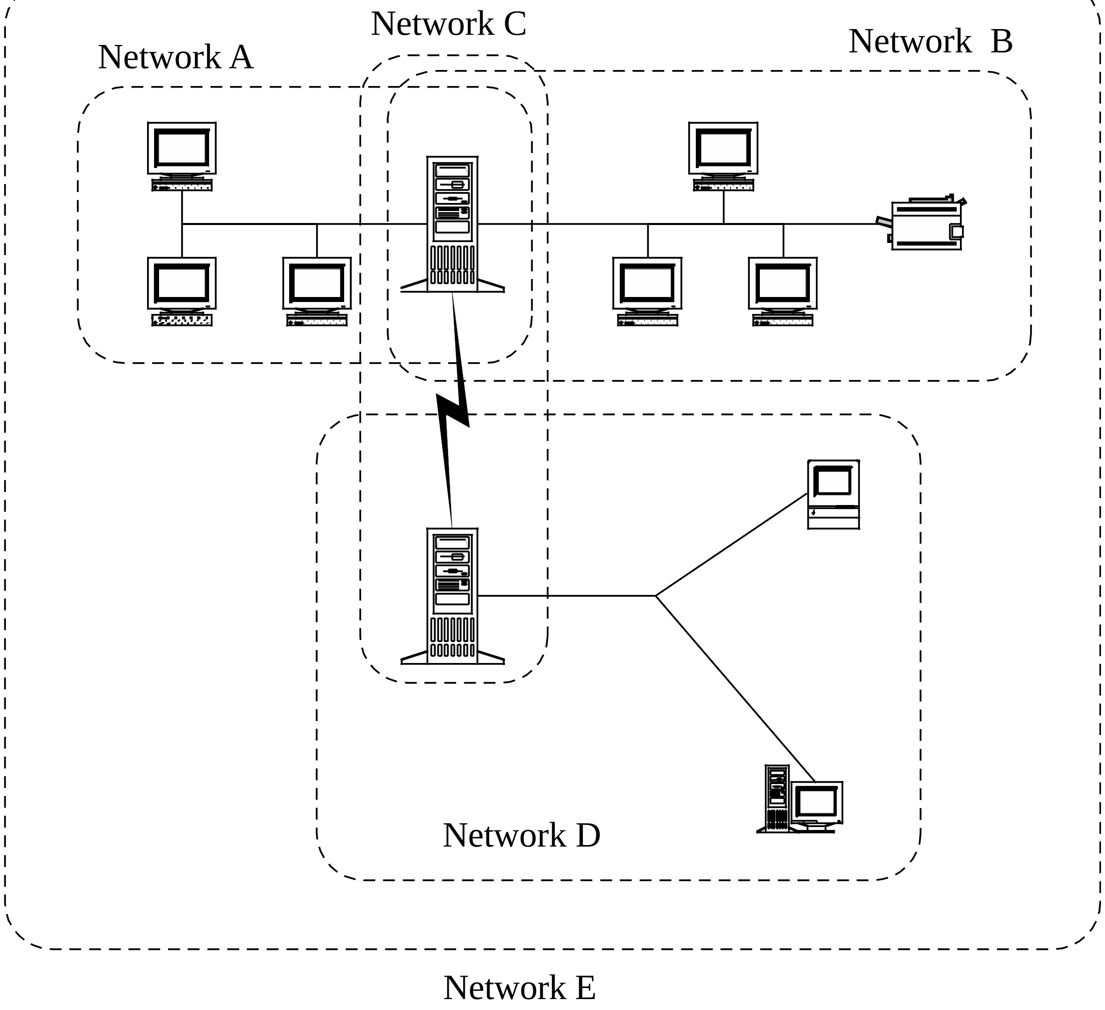
Security Perimeters



What Makes a Network Vulnerable to Interception?

- Anonymity
  - An attacker can attempt many attacks, anonymously, from thousands of miles away
- Many points of attack
  - Large networks mean many points of potential entry
- Sharing
  - Networked systems open up potential access to more users than do single computers
- System complexity
  - One system is very complex and hard to protect; networks of many different systems, with disparate OSs, vulnerabilities, and purposes are that much more complex
- Unknown perimeter
  - Networks, especially large ones, change all the time, so it can be hard to tell which systems belong and are behaving, and impossible to tell which systems bridge networks
- Unknown path
  - There may be many paths, including untrustworthy ones, from one host to another

Unknown Perimeter



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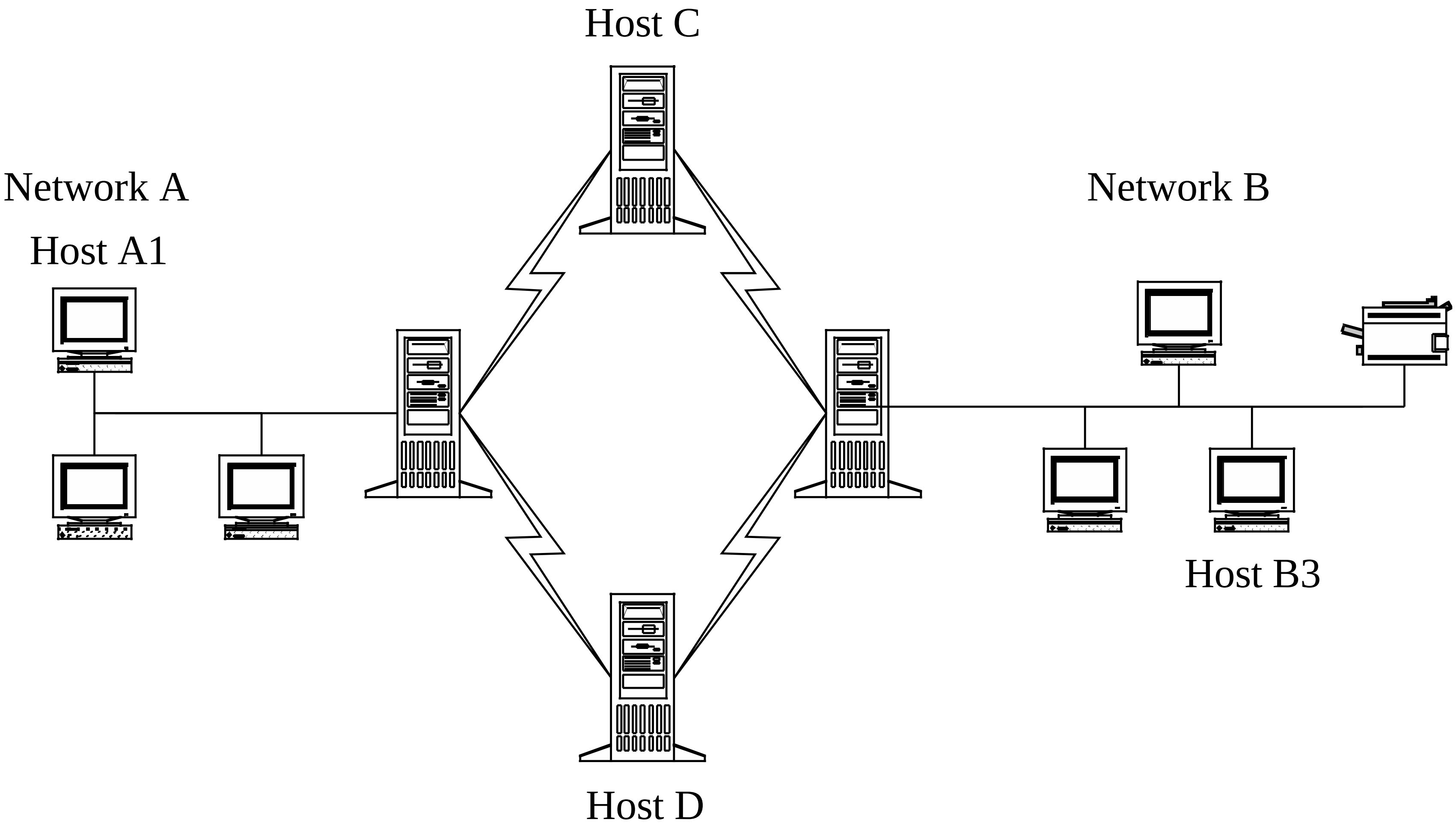
Unknown Path



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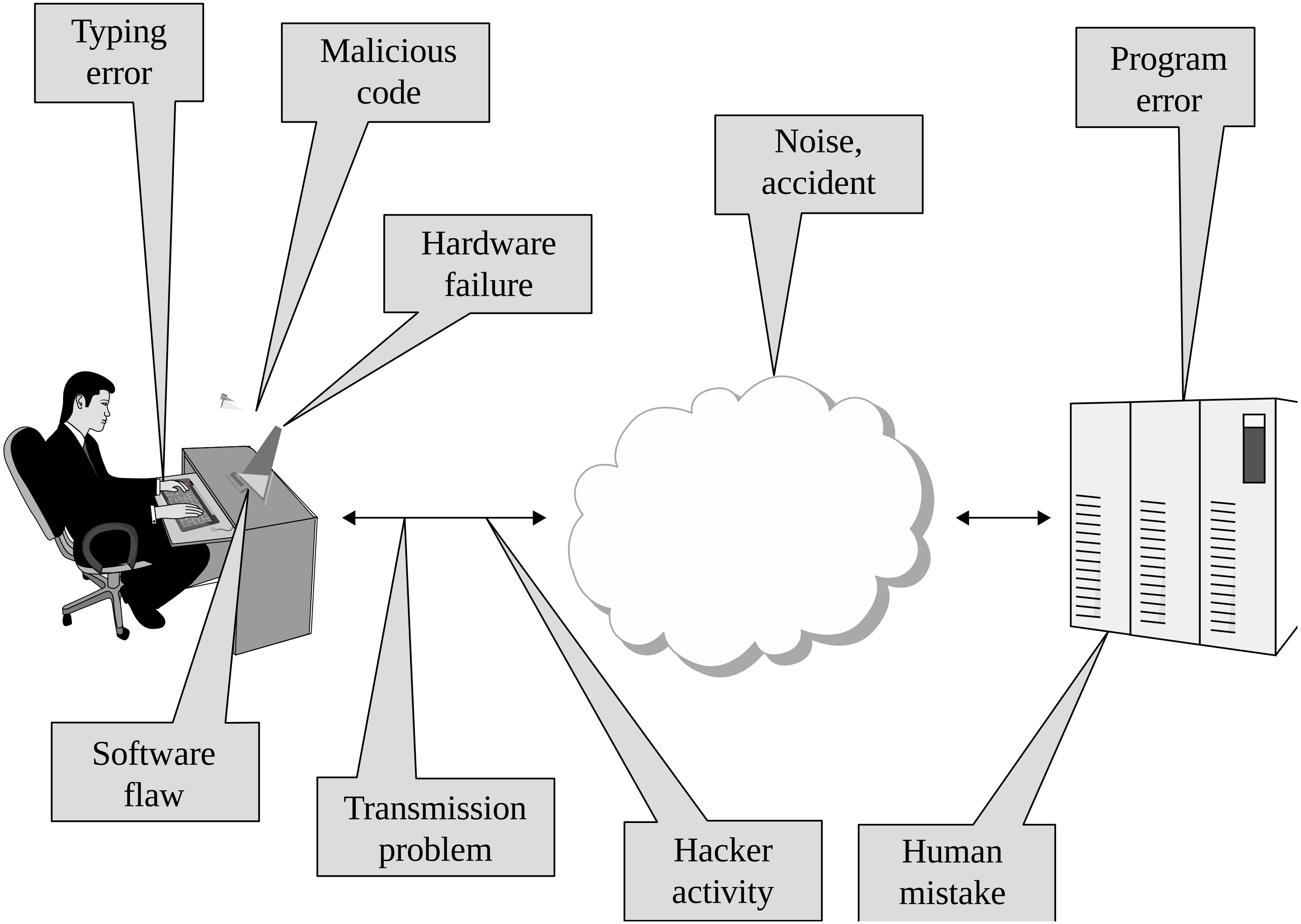
Modification and Fabrication

- Data corruption
  - May be intentional or unintentional, malicious or nonmalicious, directed or random
- Sequencing
  - Permuting the order of data, such as packets arriving in sequence
- Substitution
  - Replacement of one piece of a data stream with another
- Insertion
  - A form of substitution in which data values are inserted into a stream
- Replay
  - Legitimate data are intercepted and reused

Sources of Data Corruption



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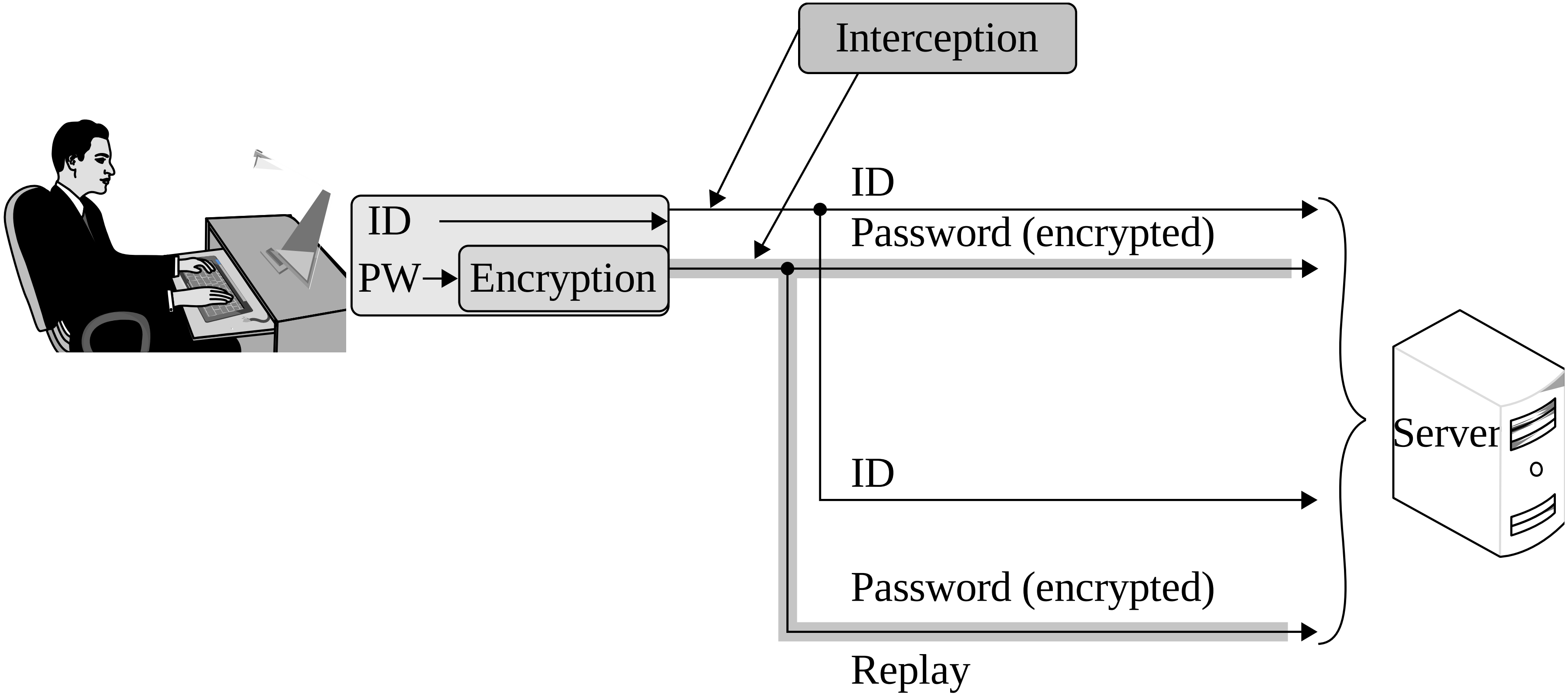
Simple Replay Attack



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Interruption: Loss of Service

- Routing
  - Internet routing protocols are complicated, and one misconfiguration can poison the data of many routers
- Excessive demand
  - Network capacity is finite and can be exhausted; an attacker can generate enough demand to overwhelm a critical part of a network
- Component failure
  - Component failures tend to be sporadic and unpredictable, and will cause loss of service if not planned for

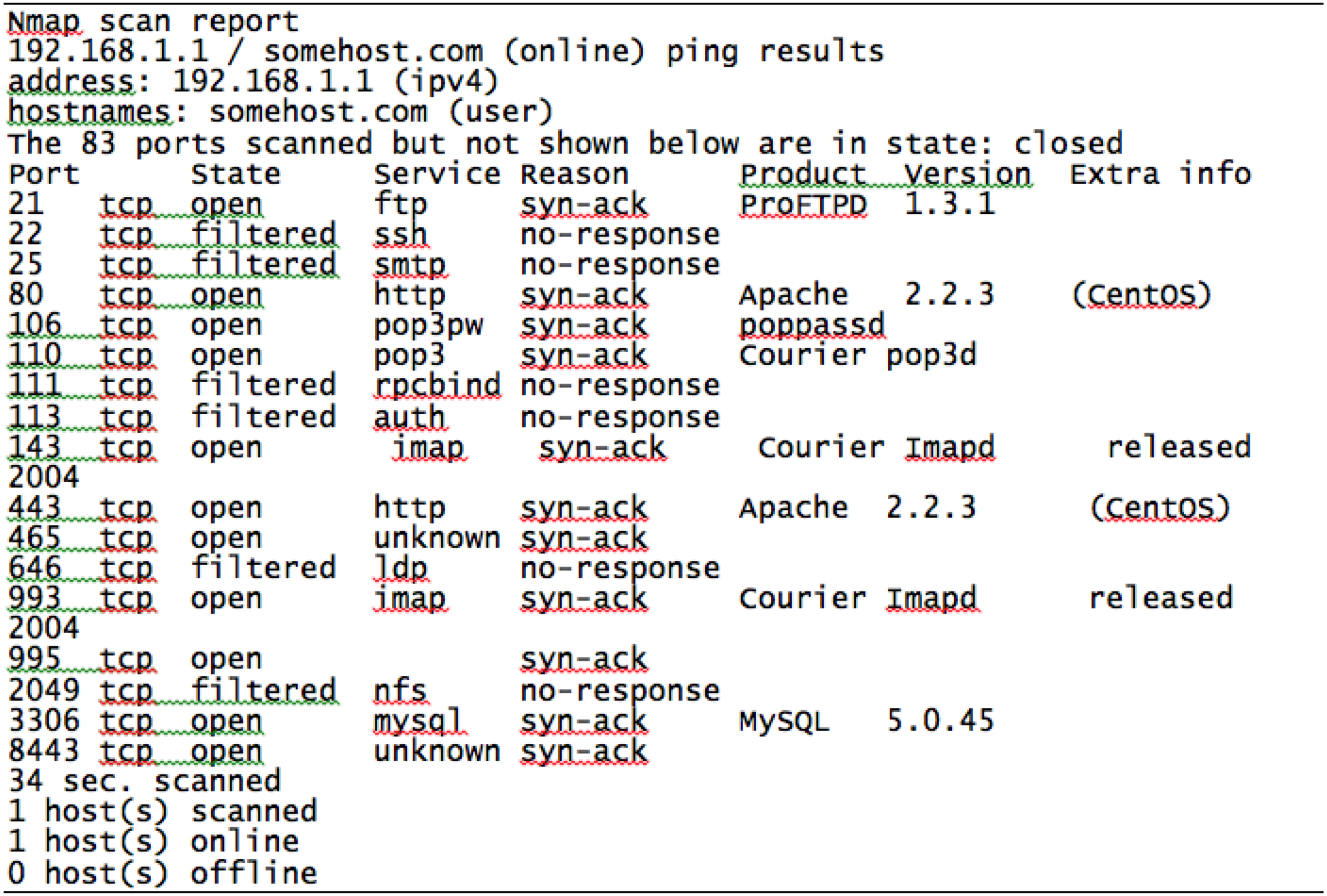
Port Scanner

- an application designed to probe a server or host for open ports.
- May be used by:
  - Administrators, to verify security policies of their networks
  - Attackers, to identify network services running on a host and exploit vulnerabilities

Port Scan

- A process that sends client requests to a range of server port addresses on a host
  - with the goal of finding an active port;
  - not a nefarious process in and of itself.
- Port scan can be used to determine services available on a remote machine
- The majority of uses of a port scan are not attacks

Port Scanning



```
Nmap scan report
192.168.1.1 / somehost.com (online) ping results
address: 192.168.1.1 (ipv4)
hostnames: somehost.com (user)
The 83 ports scanned but not shown below are in state: closed
Port       State     Service Reason      Product  Version  Extra info
21    tcp  open      ftp     syn-ack     ProFTPD  1.3.1
22    tcp  filtered  ssh     no-response
25    tcp  filtered  smtp    no-response
80    tcp  open      http    syn-ack     Apache   2.2.3    (CentOS)
106   tcp  open      pop3pw  syn-ack     poppassd
110   tcp  open      pop3    syn-ack     Courier pop3d
111   tcp  filtered  rpcbind no-response
113   tcp  filtered  auth    no-response
143   tcp  open       imap    syn-ack     Courier Imapd      released
2004
443   tcp  open      http    syn-ack     Apache  2.2.3      (CentOS)
465   tcp  open      unknown syn-ack
646   tcp  filtered  ldp     no-response
993   tcp  open      imap    syn-ack     Courier Imapd      released
2004
995   tcp  open              syn-ack
2049 tcp   filtered  nfs     no-response
3306 tcp   open      mysql   syn-ack     MySQL   5.0.45
8443 tcp   open      unknown syn-ack
34 sec. scanned
1 host(s) scanned
1 host(s) online
0 host(s) offline
```

Vulnerabilities in Wireless Networks

- Confidentiality
- Integrity
- Availability
- Unauthorized WiFi access
- WiFi protocol weaknesses
    - Picking up the beacon
    - SSID in all frames
    - Association issues

Failed Countermeasure: WEP

- Wired equivalent privacy, or WEP, was designed at the same time as the original 802.11 WiFi standards as the mechanism for securing those communications
- Weaknesses in WEP were first identified in 2001, four years after release
- More weaknesses were discovered over the course of years, until any WEP-encrypted communication could be cracked in a matter of minutes

How WEP Works

- Client and access point (AP) have a pre-shared key
- AP sends a random number to the client, which the client then encrypts using the key and returns to the AP
- The AP decrypts the number using the key and checks that it's the same number to authenticate the client
- Once the client is authenticated, the AP and client communicate using messages encrypted with the key

WEP Weaknesses

- Weak encryption key
  - WEP allows to be either 64- or 128-bit, but 24 of those bits are reserved for initialization vectors (IV), thus reducing effective key size to 40 or 140 bits
  - Keys were either alphanumeric or hex phrases that users typed in and were therefore vulnerable to dictionary attacks
- Static key
  - Since the key was just a value the user typed in at the client and AP, and since users rarely changed those keys, one key would be used for many months of communications
- Weak encryption process
  - A 40-bit key can be brute forced easily. Flaws that were eventually discovered in the RC4 encryption algorithm WEP uses made the 104-bit keys easy to crack as well

WEP Weaknesses (cont.)

- Weak encryption algorithm
  - WEP used RC4 in a strange way (always a bad sign), which resulted in a flaw that allowed attackers to decrypt large portions of any WEP communication
- IV collisions
  - There were only 16 million possible values of IV, which, in practice, is not that many to cycle through for cracking. Also, they were not as randomly selected as they should have been, with some values being much more common than others
- Faulty integrity check
  - WEP messages included a checksum to identify transmission errors but did not use one that could address malicious modification
- No authentication
  - Any client that knows the AP's SSID and MAC address is assumed to be legitimate

WPA (WiFi Protected Access)

- WPA was designed in 2003 as a replacement for WEP and was quickly followed in 2004 by WPA2, the algorithm that remains the standard today
- Non-static encryption key
  - WPA uses a hierarchy of keys: New keys are generated for confidentiality and integrity of each session, and the encryption key is automatically changed on each packet
  - This way, the keys that are most important are used in very few places and indirect ways, protecting them from disclosure
- Authentication
  - WPA allows authentication by password, token, or certificate

WPA (cont.)

- Strong encryption
  - WPA adds support for AES, a much more reliably strong encryption algorithm
- Integrity protection
  - WPA includes a 64-bit cryptographic integrity check
- Session initiation
  - WPA sessions begin with authentication and a four-way handshake that results in separate keys for encryption and integrity on both ends
- While there are some attacks against WPA, they are either of very limited effectiveness or require weak passwords

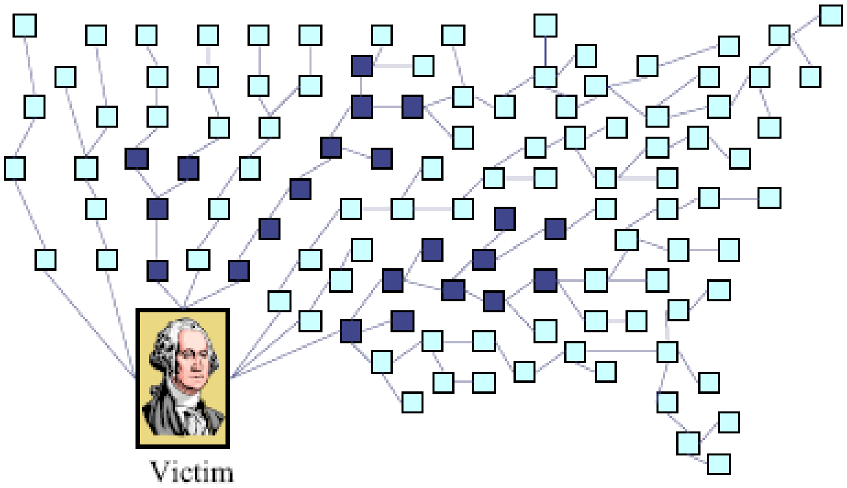
Denial of Service (DoS)

- DoS attacks are attempts to defeat a system’s availability
- Volumetric attacks
- Application-based attacks
- May result in disabled communications
- Hardware or software failure

Denial of Service (DOS) Attack

- Send large number of packets to host providing service
  - Slows down or crashes host
  - Often executed by botnet
- Attack propagation
  - Starts at zombies
  - Travels through tree of internet routers rooted
  - Ends at victim
- IP source spoofing
  - Hides attacker
  - Scatters return traffic from victim

Source:
M.T. Goodrich, Probabalistic Packet Marking for Large-Scale IP Traceback, IEEE/ACM Transactions on Networking 16:1, 2008.



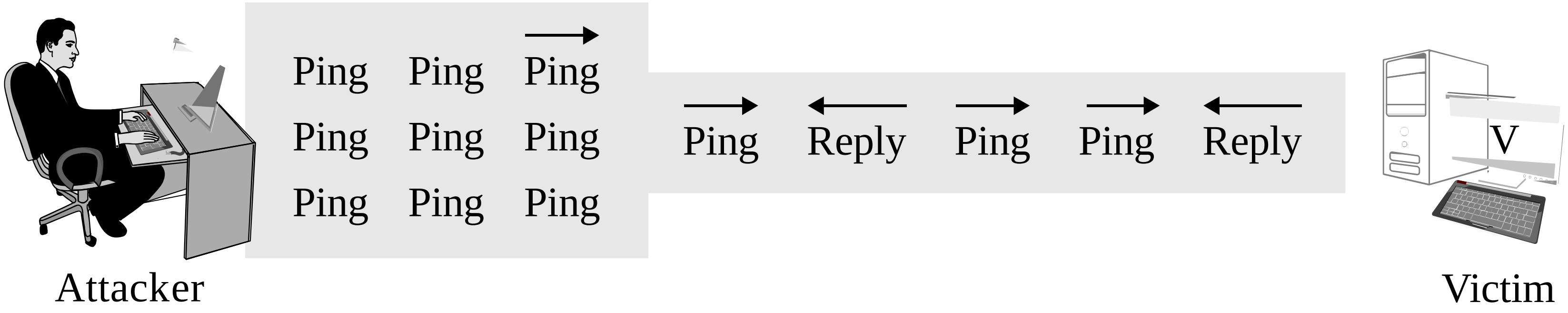
DOS Attacks - Examples

- SYN(PING) flood
- Smurf Attack
- Teardrop attack
- DNS Spoofing
- Session hijacking

SYN (PING) Flood

- Typically DOS attack, though can be combined with other attack such as TCP hijacking
- Rely on sending TCP connection requests faster than the server can process them
- Attacker creates a large number of packets with spoofed source addresses and setting the SYN flag on these
- The server responds with a SYN/ACK for which it never gets a response (waits for about 3 minutes each)
- Eventually the server stops accepting connection requests, thus triggering a denial of service.
- Can be solved in multiple ways
- One of the common way to do this is to use SYN cookies

DoS Attack: Ping Flood



Ping Ping Ping

Ping Ping Ping

Ping Ping Ping

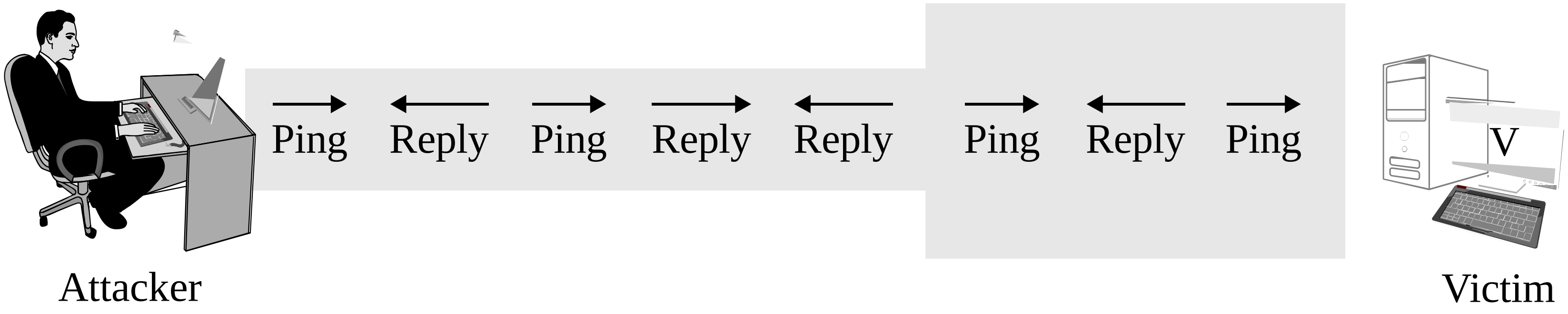
Ping Reply Ping Ping Reply

V

Attacker

Victim

(a) Attacker has greater bandwidth



Ping Reply Ping Reply Reply Ping Reply Ping

V

Attacker

Victim

(b) Victim has greater bandwidth

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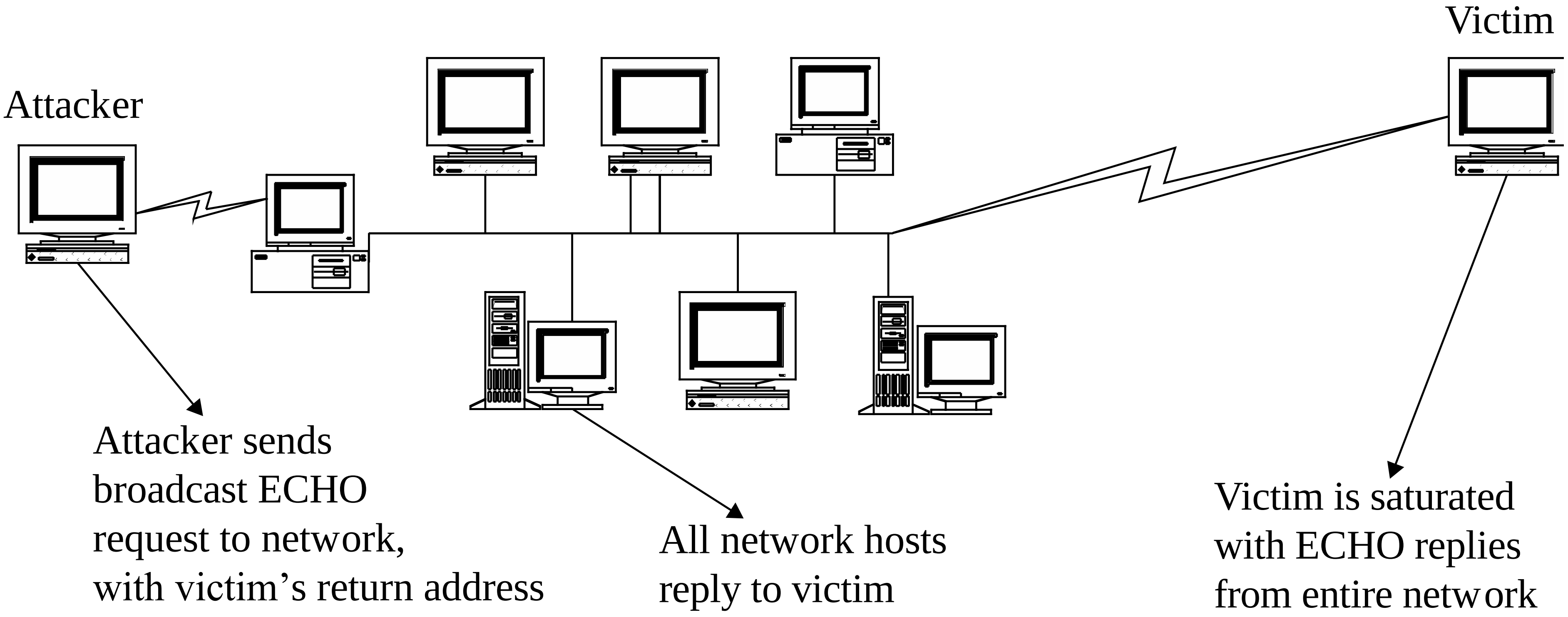
Smurf Attack

- Ping a broadcast address using a spoofed source address
- A distributed denial-of-service attack
  - Multiple systems flood the bandwidth or resources of a targeted system
- Most devices on a network will respond to this by sending a reply to the source IP address
- If the number of machines on the network that respond to these packets is very large => victim's computer will be flooded with traffic

DoS Attack: Smurf Attack



Attacker

Victim

Attacker sends
broadcast ECHO
request to network,
with victim’s return address

All network hosts
reply to victim

Victim is saturated
with ECHO replies
from entire network

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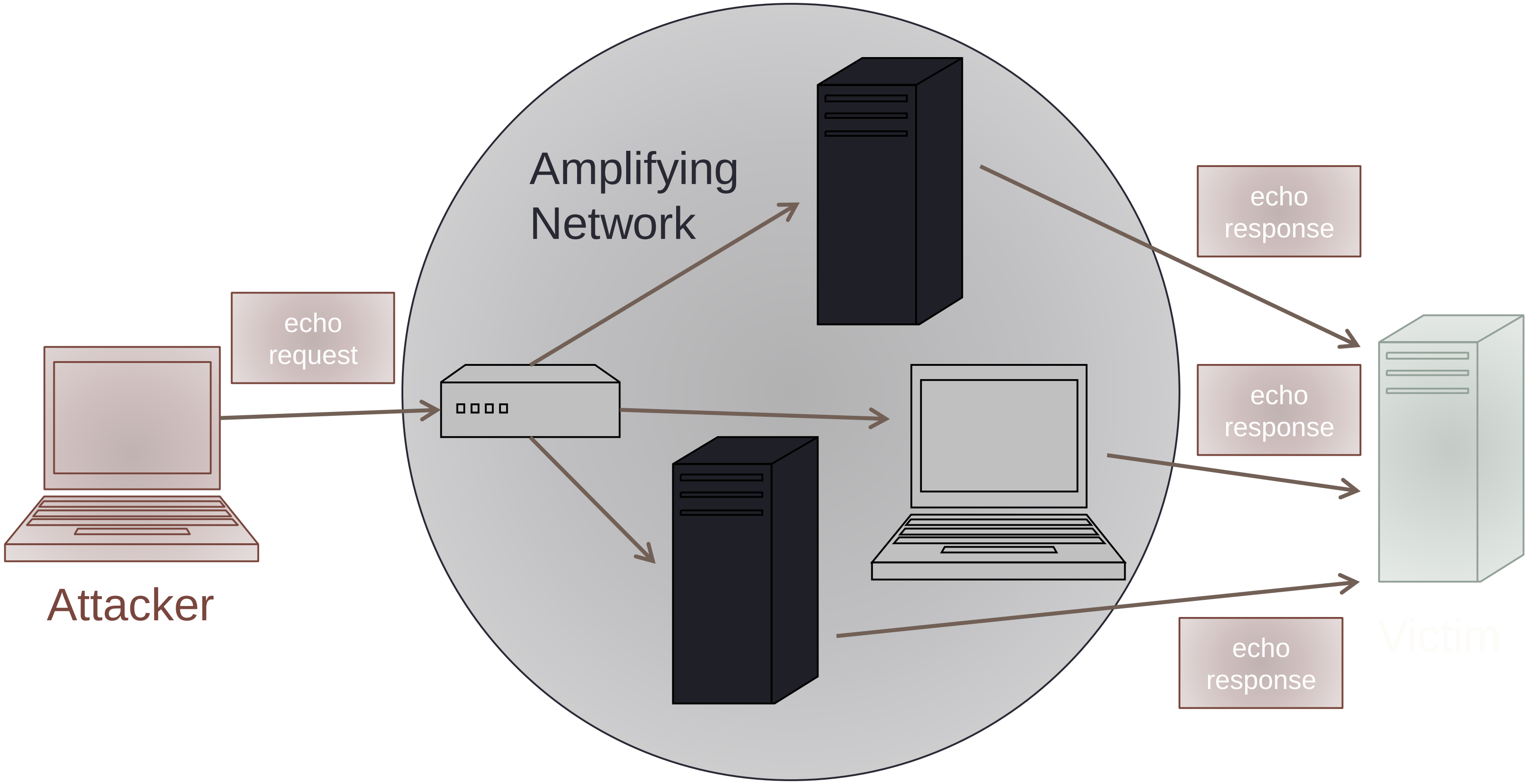
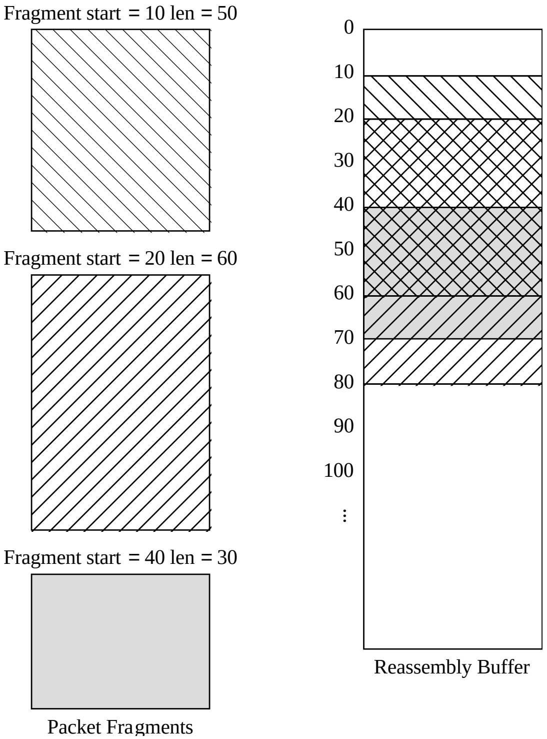
Smurf Attack



DoS Attack: Teardrop Attack

- The attacker sends packets that cannot possibly be reassembled (conflicting reassembly instructions)
- In extreme cases, this can cause the entire OS to lock up.


Fragment start = 10 len = 50
Fragment start = 20 len = 60
Fragment start = 40 len = 30
Packet Fragments
0
10
20
30
40
50
60
70
80
90
100
⋮
Reassembly Buffer

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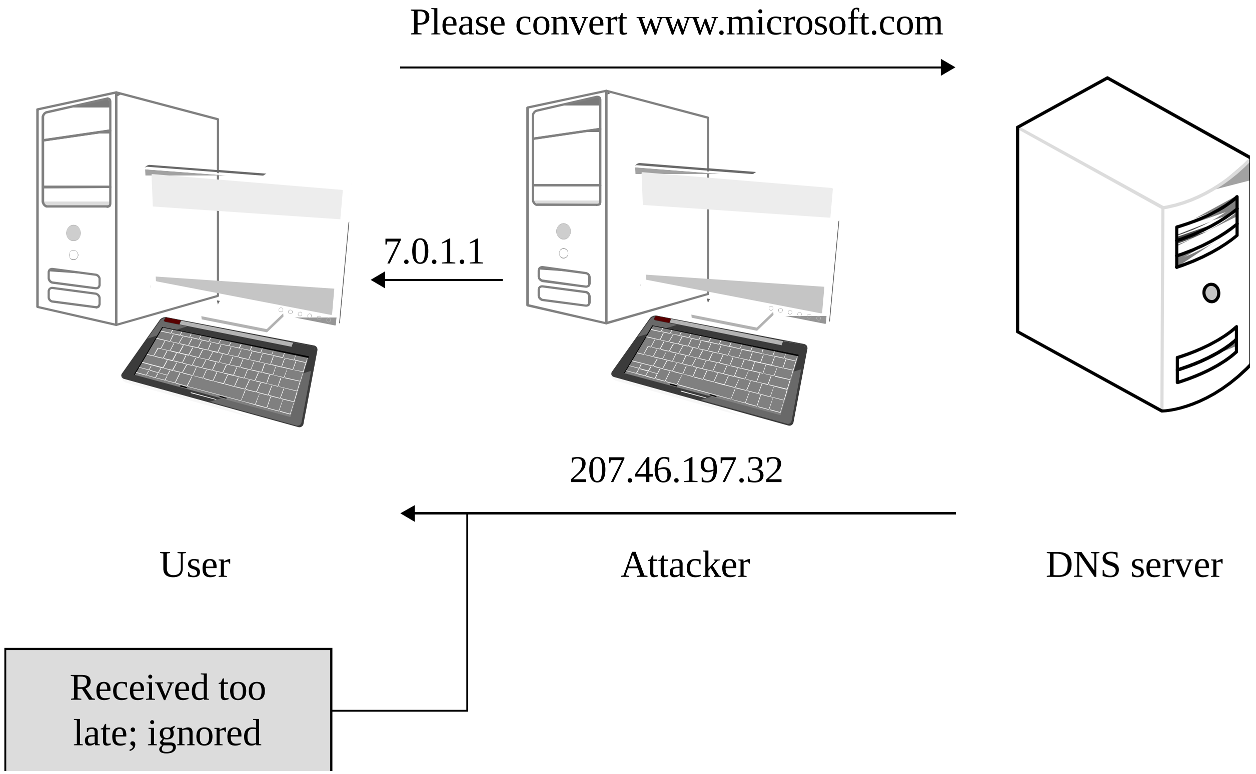
DoS Attack: DNS Spoofing

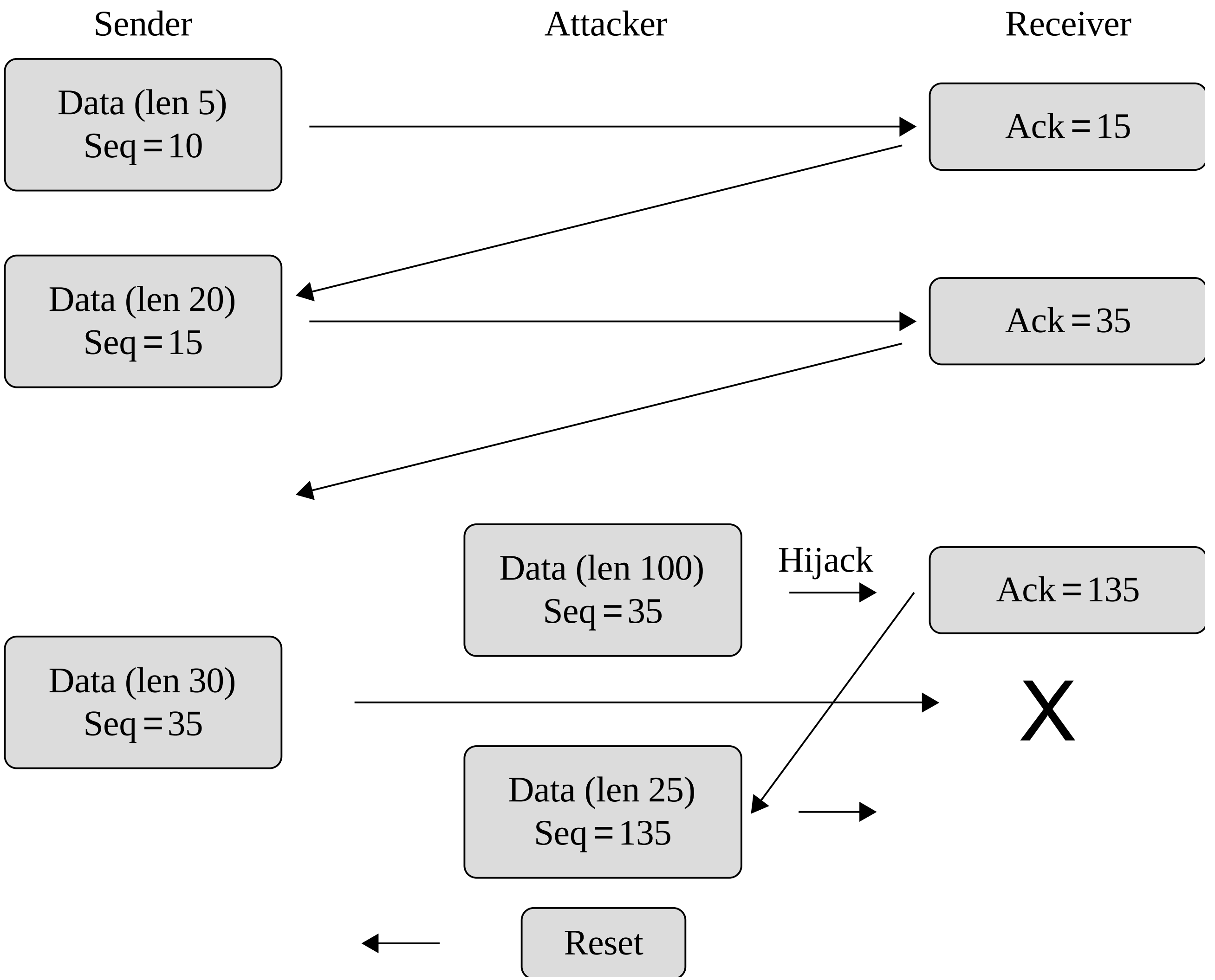
- The attacker acts as the DNS server in order to redirect the user to malicious sites



DoS Attack: Session Hijacking

- An attacker is able to synchronize with a receiver while breaking synchronization with the sender and resetting sender’s connection.
- The attacker continues the TCP session while the sender thinks the connection just broke off

DoS Attack: Session Hijacking



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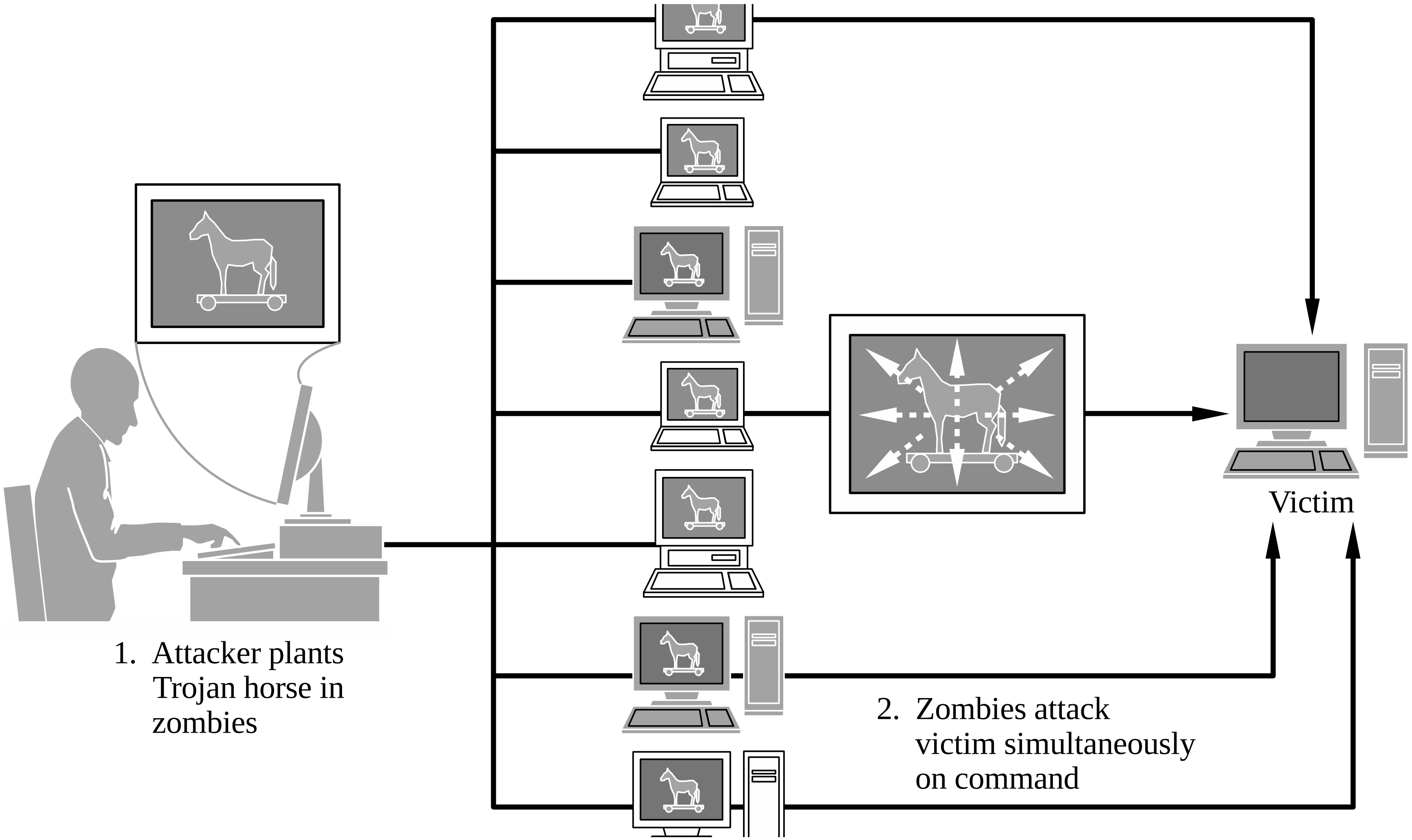
Distributed Denial of Service (DDoS)

- Conscript an army of compromised machines
  - to attack a victim
- Choose a victim
- Have the whole army unleash a DoS attack at once

- DDoS much more effective than traditional DoS attacks
  - employing a multiplied version of the same methods.

Distributed Denial of Service (DDoS)


Victim
1. Attacker plants Trojan horse in zombies
2. Zombies attack victim simultaneously on command

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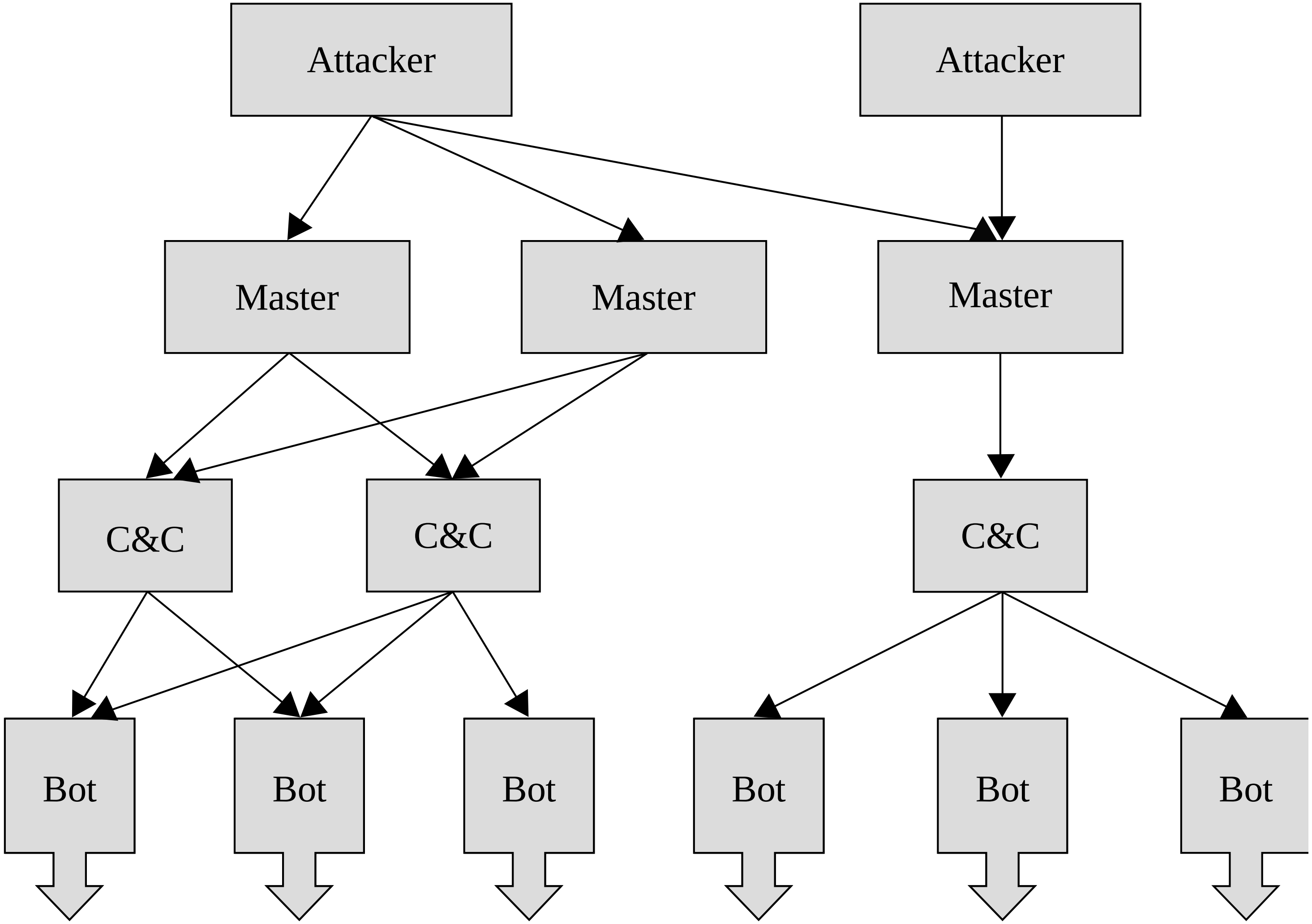
Botnets

- Botnets are networks of machines running malicious code under remote control.
- They often go undetected because they do little harm to the machines they run on.
- Botnets are often used to execute DDoS attacks.

Botnets

- Botnet command and control (C&C):
  - The attacker is separated from the bots by multiple layers
    - making the attacker difficult to trace.
  - Multiple redundant systems are built in
    - if one master or C&C node is taken down, the bots can continue to connect to the botnet.

Botnets



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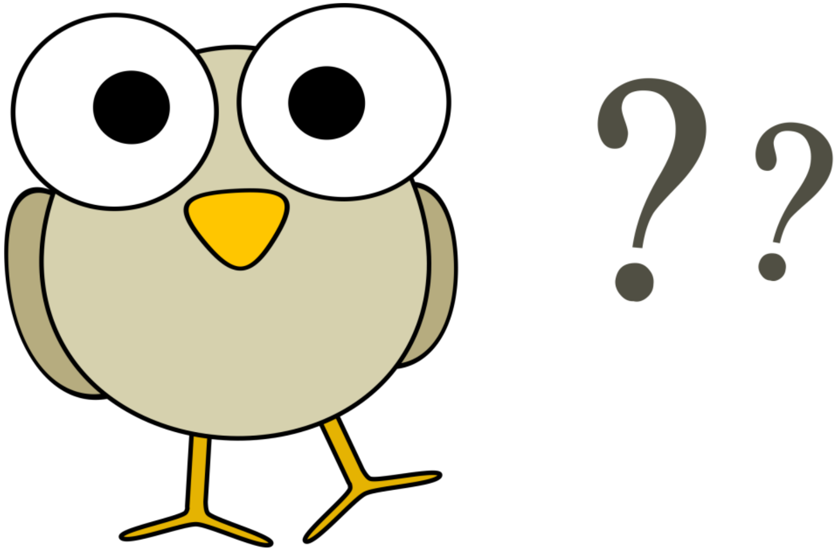
- Questions?



COMPUTER SECURITY QUIZ

- Increased Traffic is due to a spike in network traffic from several sources. Assuming this is malicious, what is the MOST likely explanation?
  - A. A smurf attack
  - B. A flood guard attack
  - C. A denial-of-service (DoS) attack
  - D. distributed denial-of-service (DDoS) attack

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- A SYN flood is an example of what type of attack?
  - A. Malicious code
  - B. Denial-of-service
  - C. Man-in-the-middle
  - D. Spoofing

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  - D. Spoofing

- An attacker simply listens for all traffic being transmitted across a network, in the hope of viewing something such as a user ID and password combination. This is known as:
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  - B. Denial-of-service
  - C. Man-in-the-middle
  - D. Sniffing

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  - [✓ D. Sniffing]

Questions?