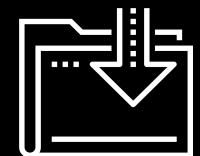




Following Data Through Layers 2, 3, and 4

Cybersecurity
Networking 101, Day 3



Class Objectives

By the end of today's class, you will be able to:



Define enumeration as a set of methods used by security professionals and attackers to determine network vulnerabilities.



Use Wireshark to capture and analyze ARP activity, including ARP spoofing.



Use ping and fping to determine if hosts are reachable.



Use traceroute to troubleshoot networking communication issues between two devices.



Define and distinguish between TCP and UDP.



Analyze TCP traffic in Wireshark.



Analyze SYN Scans to determine the availability of ports on a network.



Attackers will often try to gain unauthorized access into a network. It's the job of security professionals to secure networks by identifying vulnerabilities.



Real World Hacking Example

- An attacker may discover that a server with payroll data accidentally has open port 22, for SSH.
- This lets the attacker gain unauthorized access to the network, allowing the attacker to steal or alter important data, e.g., social security numbers or salary information.
- It is the security professional's job to determine which unauthorized ports are open, and then close them, thus protecting the integrity of the company.



Enumeration



Both attackers and security pros will use the method of **enumeration** to gather data from a specific network in order to gain access to that network.

Enumeration

Enumeration can yield the following information:

Physical addresses of devices within a network.

The IPs and ports that are being used or are accessible.

Network and network security devices being used.

Moving Through the Layers

Today, we'll move through three important OSI layers and their corresponding tools and protocols:

The Layer 2: Data Link protocol **ARP**,
used to transfer network traffic within a local network.

Layer 2: Data Link

The Layer 3: Network utilities **ping** and **traceroute**, used by network and security professionals to diagnose network issues.

Layer 3: Network

The Layer 4: Transport protocols TCP and UDP, and
how TCP establishes a connection with a three-way handshake.

Layer 4: Transport

Media Access Control (MAC)

When data travels from a WAN to a LAN, it still needs to find its final destination *within* the LAN.

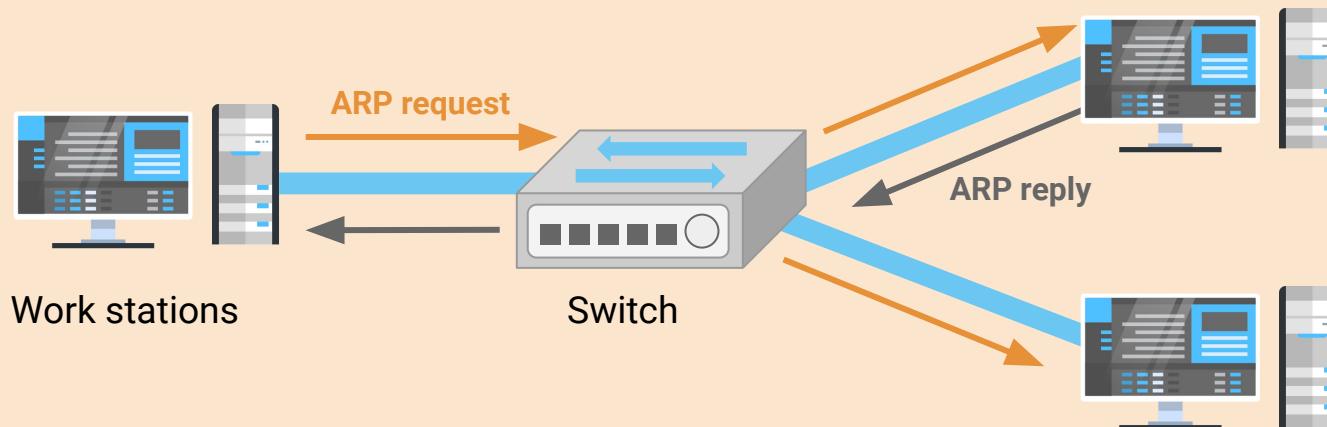
Data is routed via switches to a physical machine address, known as a **Media Access Control (MAC)** address:

A sequence of numbers such as 00:0c:29:0f:71:a3 that identifies the destination computer's unique hardware number.



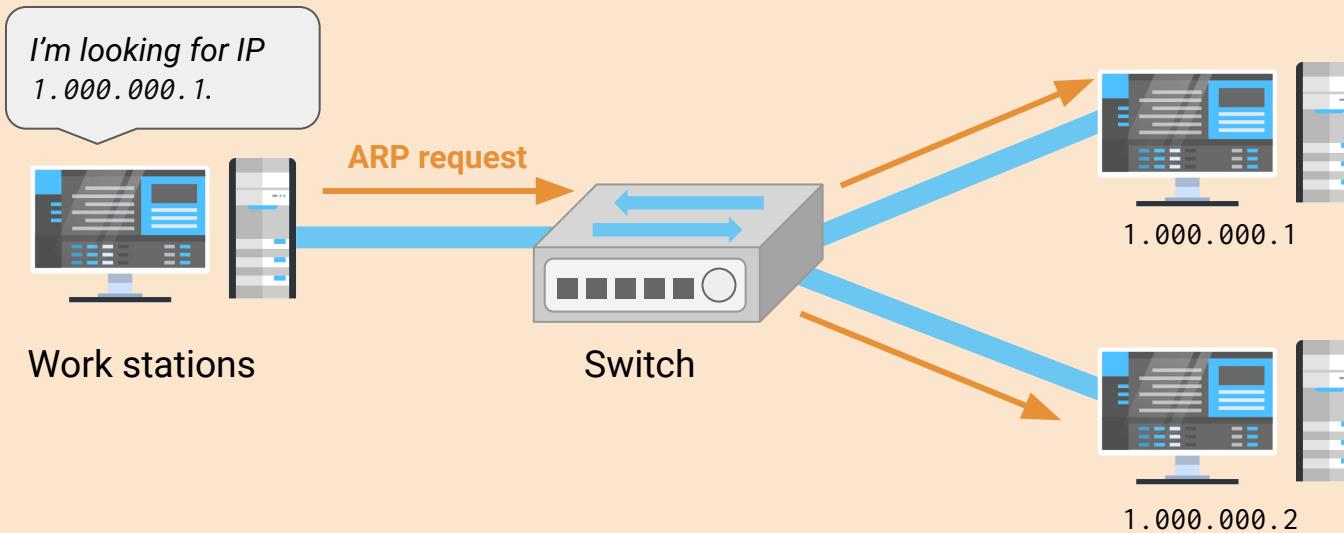
Now Entering Layer 2: Data Link

To ensure data gets from LAN to machine, the Address Resolution Protocol (ARP) maps this known address to an IP address within the LAN.



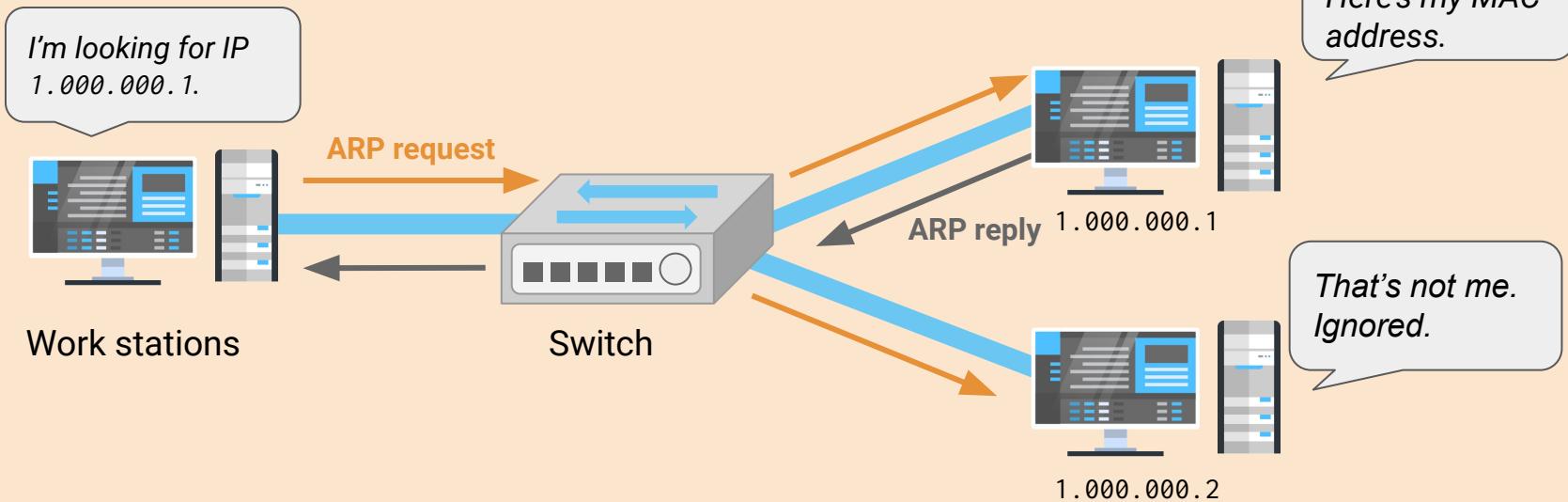
Now Entering Layer 2: Data Link

Request: The network device transmitting the data broadcasts an ARP request to all devices in its network to find the physical address matching the IP address.



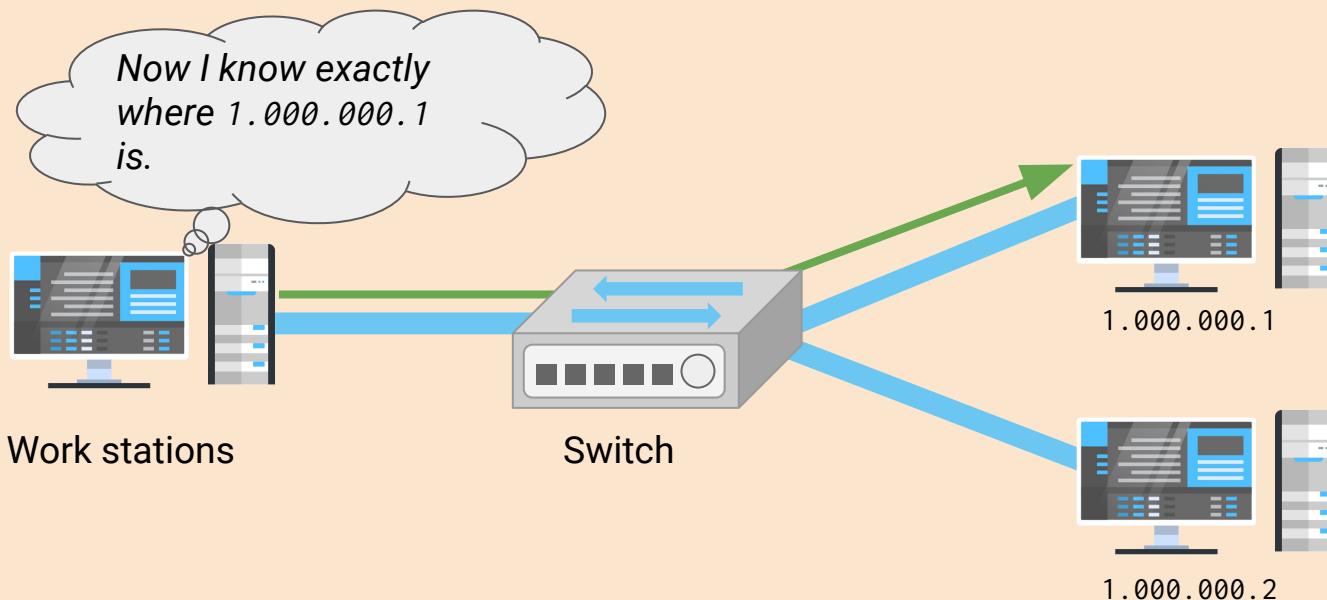
Now Entering Layer 2: Data Link

Reply: The device owning that IP address recognizes their IP in the ARP request and sends an ARP reply with their MAC address so the network knows where to route the data.



Now Entering Layer 2: Data Link

The mapping of the MAC address to the IP address is added into the ARP cache. The next time data comes in for this specific destination, it won't need to broadcast an ARP request. The network has the record in its cache, and can automatically route the data.



ARP Cache Timeout

Entries added to the ARP cache are called **dynamic** ARP entries, meaning they can be changed with future ARP replies.



Dynamic ARP entries will only stay in the ARP cache for a limited period of time known as the **ARP cache timeout**.



When the ARP cache timeout expires, the record is removed from the ARP cache and any future requests for the host require a new ARP request.

ARP and Wireshark Setup

Wireshark lets us analyze ARP requests and responses. In the next demo, we will:



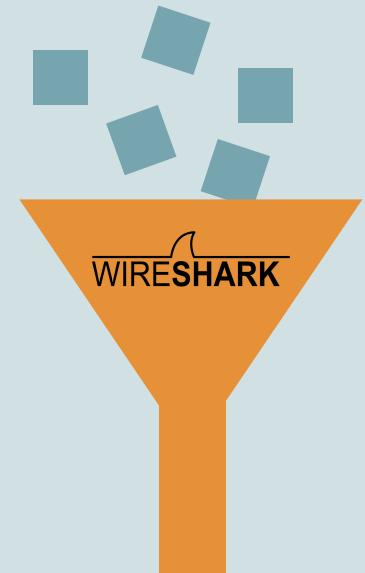
Filter for all ARP packets in a .pcap file.



This filter will show us the request from the source host, which will include a MAC address, associated with a specific IP address, that the data needs to be transmitted to.



If the request can be successfully answered, we'll see a response from the owner of the IP address, containing the device's MAC address.





Instructor Demonstration ARP and Wireshark Setup

ARP and Security

If an attacker has access to a LAN, they can intercept traffic on its way to the correct destination (“the good host”).

ARP Spoofing

- The attacker can send a spoof ARP message to the LAN, directing all traffic intended for the good host to the attacker's MAC address.
- After the attacker sends the spoof ARP message, all traffic originally destined for the good host is intercepted by the attacker's device with the malicious MAC address.

No.	Time	Source Port	Source	Destination	Protocol	Length	Info
298	9.417131		00:0c:29:1d:b3:b1	00:50:56:c0:00:08	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
299	9.417178		00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.200 is at 00:0c:29:1d:b3:b1
300	9.417211		00:0c:29:1d:b3:b1	00:0c:29:0f:71:a3	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
•	301	9.417243	00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.254 is at 00:0c:29:1d:b3:b1
302	9.417276		00:0c:29:1d:b3:b1	00:50:56:f9:f5:54	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
304	11.017553		00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.1 is at 00:0c:29:1d:b3:b1

> Frame 302: 42 bytes on wire (336 bits), 42 bytes captured (336 bits)
> Ethernet II, Src: 00:0c:29:1d:b3:b1, Dst: 00:50:56:f9:f5:54
▼ [Duplicate IP address detected for 192.168.47.2 (00:0c:29:1d:b3:b1) - also in use by 00:50:56:fd:2f:16 (frame 301)]
 > [Frame showing earlier use of IP address: 301]
 > [Expert Info (Warning/Sequence): Duplicate IP address configured (192.168.47.2)]
 [Seconds since earlier frame seen: 0]
> Address Resolution Protocol (reply)

ARP Spoofing

- The good host is 192.168.47.2; the correct MAC address is 00:50:56:fd:2f:16.
- The attacker's MAC address is 00:0c:29:1d:b3:b1. A spoof ARP message directs traffic intended for the good MAC address to the attacker's MAC address.
- The spoof ARP message can be understood as: 192.168.47.2 is at 00:0c:29:1d:b3:b1.

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

arp

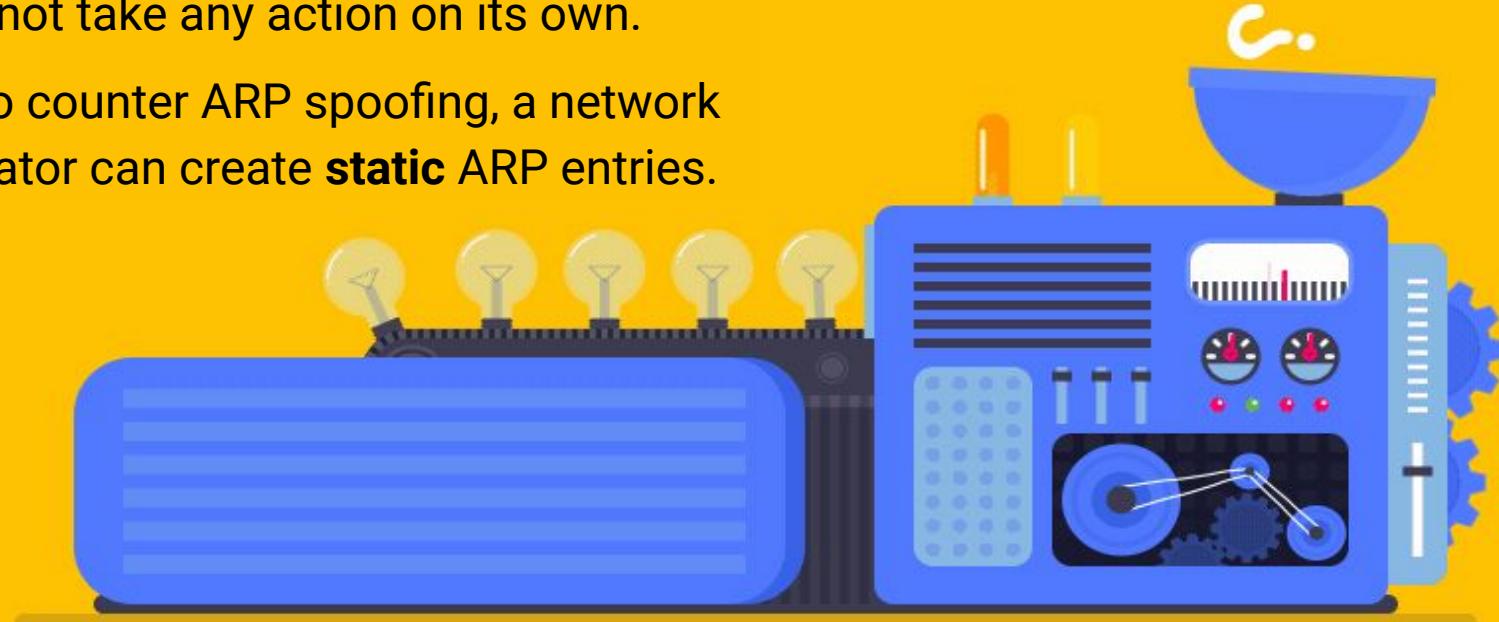
No.	Time	Source Port	Source	Destination	Protocol	Length	Info
298	9.417131		00:0c:29:1d:b3:b1	00:50:56:c0:00:08	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
299	9.417178		00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.200 is at 00:0c:29:1d:b3:b1
300	9.417211		00:0c:29:1d:b3:b1	00:0c:29:0f:71:a3	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
301	9.417243		00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.254 is at 00:0c:29:1d:b3:b1
302	9.417276		00:0c:29:1d:b3:b1	00:50:56:f9:f5:54	ARP	42	192.168.47.2 is at 00:0c:29:1d:b3:b1
304	11.017553		00:0c:29:1d:b3:b1	00:50:56:fd:2f:16	ARP	42	192.168.47.1 is at 00:0c:29:1d:b3:b1

> Frame 302: 42 bytes on wire (336 bits), 42 bytes captured (336 bits)
> Ethernet II, Src: 00:0c:29:1d:b3:b1, Dst: 00:50:56:f9:f5:54
▼ [Duplicate IP address detected for 192.168.47.2 (00:0c:29:1d:b3:b1) - also in use by 00:50:56:fd:2f:16 (frame 301)]
 └ [Frame showing earlier use of IP address: 301]
 > [Expert Info (Warning/Sequence): Duplicate IP address configured (192.168.47.2)]
 [Seconds since earlier frame seen: 0]
> Address Resolution Protocol (reply)

But There's a Solution!

Wireshark can detect and alert multiple MAC addresses associated with a single IP address, but it will not take any action on its own.

Instead, to counter ARP spoofing, a network administrator can create **static** ARP entries.



Static ARP Entries



Static ARP entries create permanent IP-to-MAC-address mappings in the ARP cache.



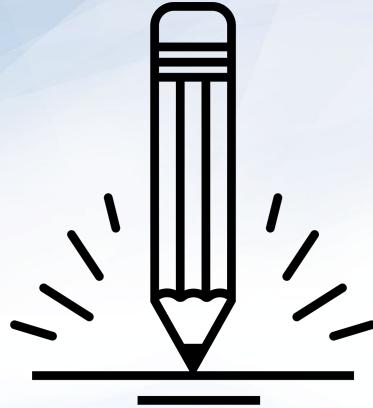
Unlike the dynamic ARP entries, these cannot be changed.



All IP-to-MAC address mappings of all hosts on a network must be known ahead of time.



It's time-consuming to enter each IP-to-MAC mapping in the ARP cache, and these need to be continuously maintained as hosts get added or changed.



Activity: Analyzing ARP Activity

In this activity, you will play the role of a security analyst at Acme Corp.

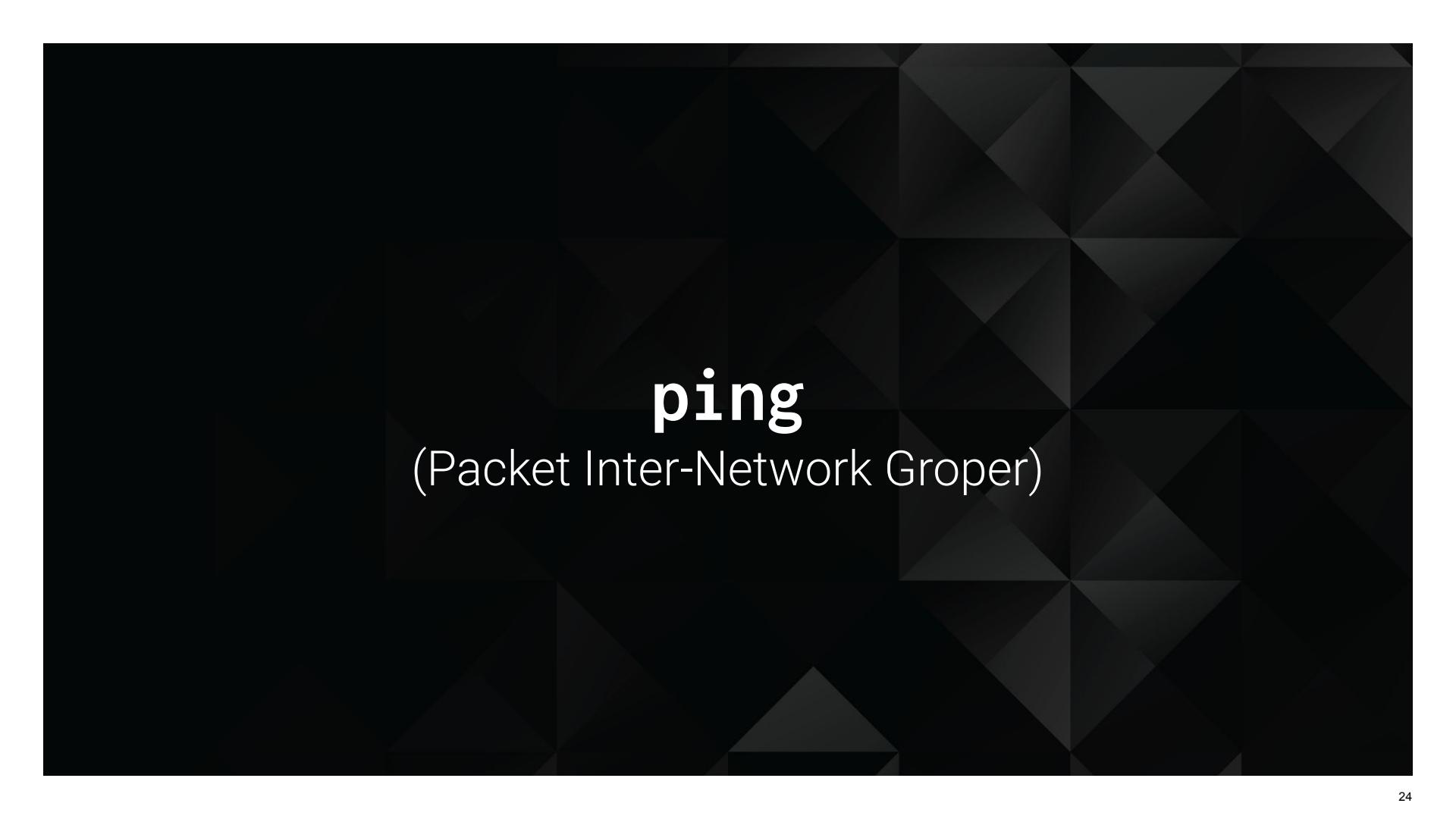
Your task is to analyze ARP activity from a CompuCom packet capture to determine if any vulnerabilities exist.

Suggested Time:
15 minutes





Time's Up! Let's Review.



ping
(Packet Inter-Network Groper)

When enumerating, it's important to check if an external host is reachable.



ping Example

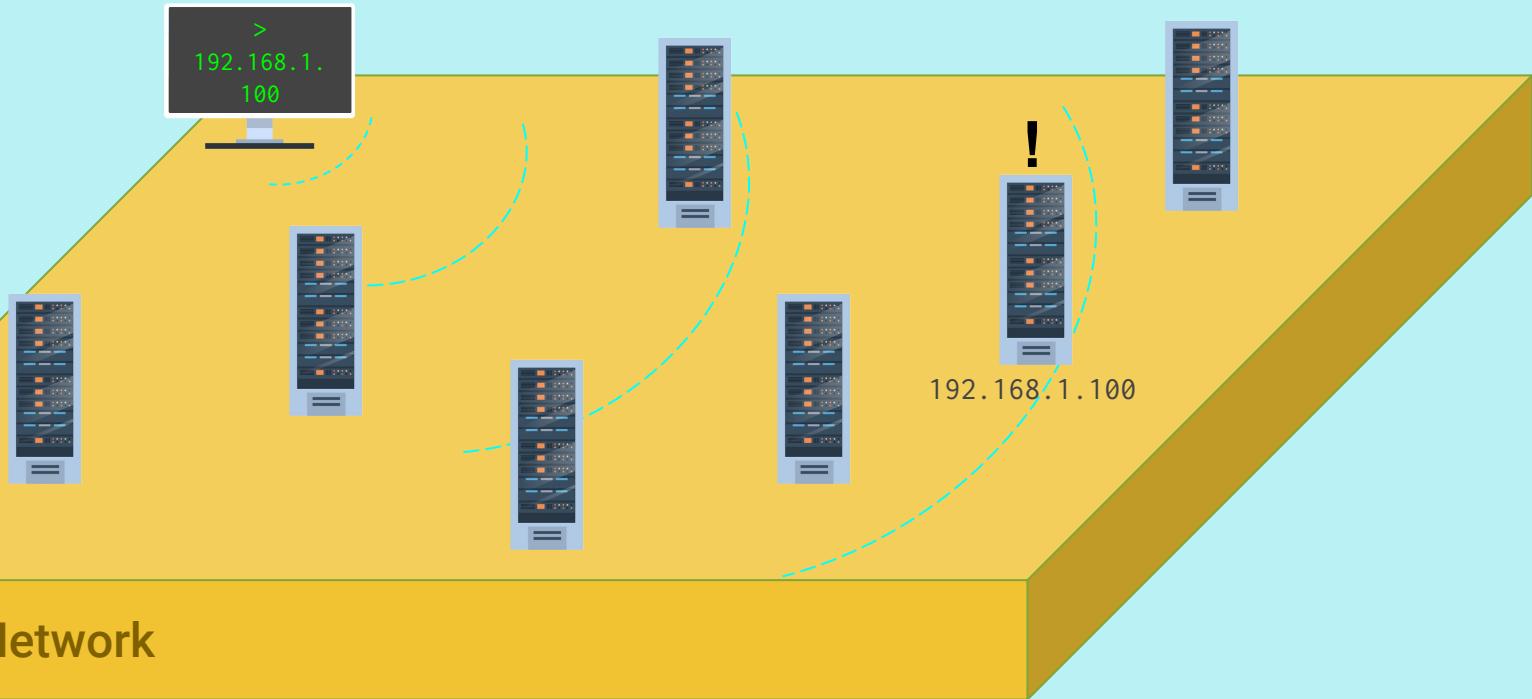
Company X wants to make sure their new intranet is accessible from their offices in the United States and Japan. The intranet is used for daily employee tasks and to access employee contact information. So availability of the intranet is critical for all employees.

- To test the accessibility to the intranet, Company X might have employees from the United States and Japan each send a ping request from their location to validate the intranet is available and accessible from each location.



Now Entering Layer 3: Network Layer

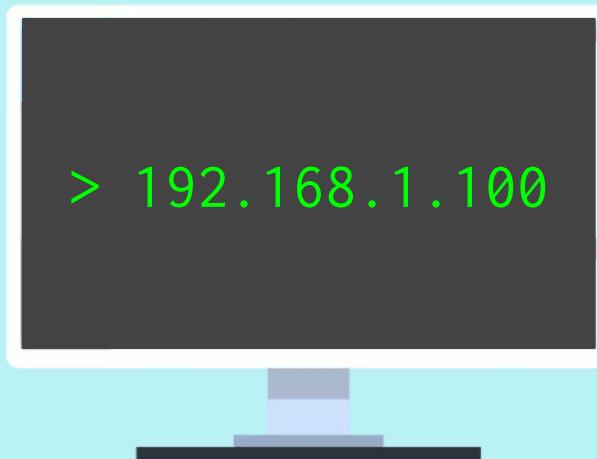
ping (Packet Inter-Network Groper) is a utility used to determine if a host is operating and accepting requests.



Internet Control Message Protocol

When we ping a host, it sends an **Internet Control Message Protocol (ICMP)** echo request to a specific IP address and waits on a reply.

- ICMP is a protocol that network devices use to send error messages and operational information about whether a requested service or host can be reached.



192.168.1.100

ping Demo Scenario

In the following demonstration, we'll use ping on the command line with the following scenario:

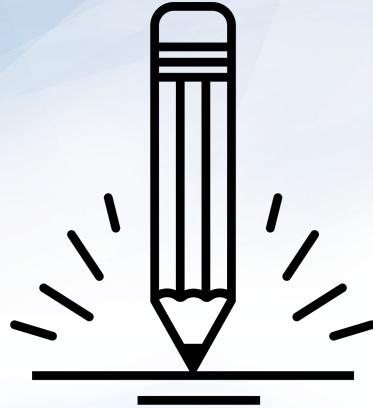
- We are a restaurant looking to purchase commercial beverages online.

We need to check if Pepsi.com is working and accepting requests.





Instructor Demonstration
ping



Activity: Enumerating with ping

In this activity, you will continue to play the role of a security analyst at Acme Corp.

You must use `ping` to determine which of CompuCom's host IP addresses are accepting connections.

Suggested Time:
15 minutes





Time's Up! Let's Review.



Countdown timer

15:00

(with alarm)

Break



Introduction to traceroute

traceroute Demo

In the previous demonstration, we discovered that
redbull.com was not accepting requests.

Now we'll find out why.

A large, blue, rounded rectangular button with the word "Submit" centered in white text.

Submit

While ping indicates if a host is up or down, security professionals will often need more info to determine *why*.

Company X's employees were able to successfully ping their intranet from the United States office, but unable to ping the exact same address from the Japan office.

- More information is needed to understand why the intranet is not accessible from Japan.
- Company X can better understand the issue by finding out where in the request the failure occurred.



Routing and Redirections

When data travels from a source to a destination, it typically doesn't follow a straight path.



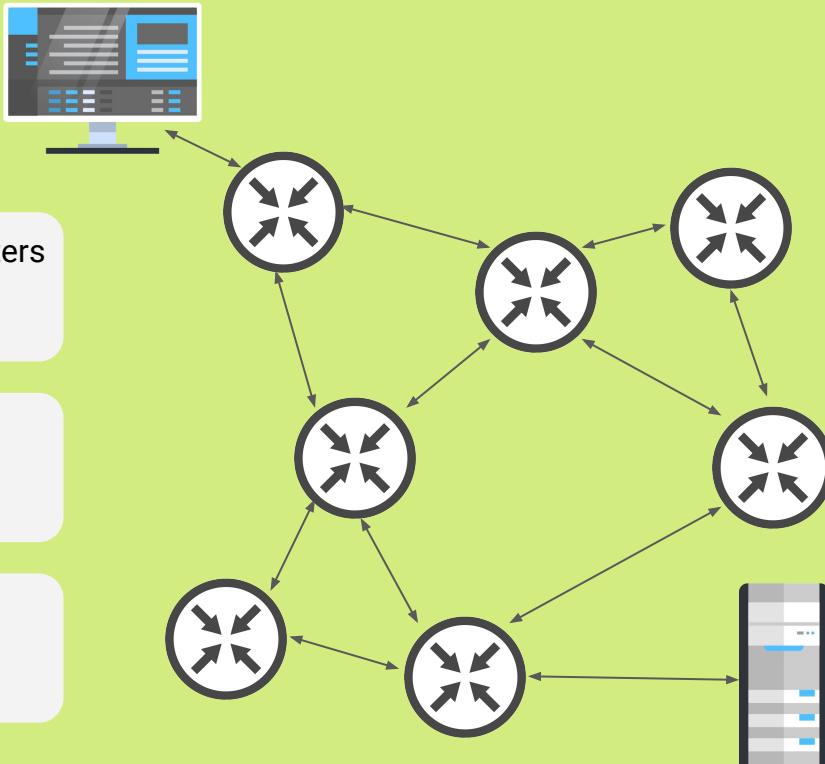
Data is often redirected by many routers. Routers connect different networks so their hosts can communicate.



Redirection of data transmissions are called **hops**.



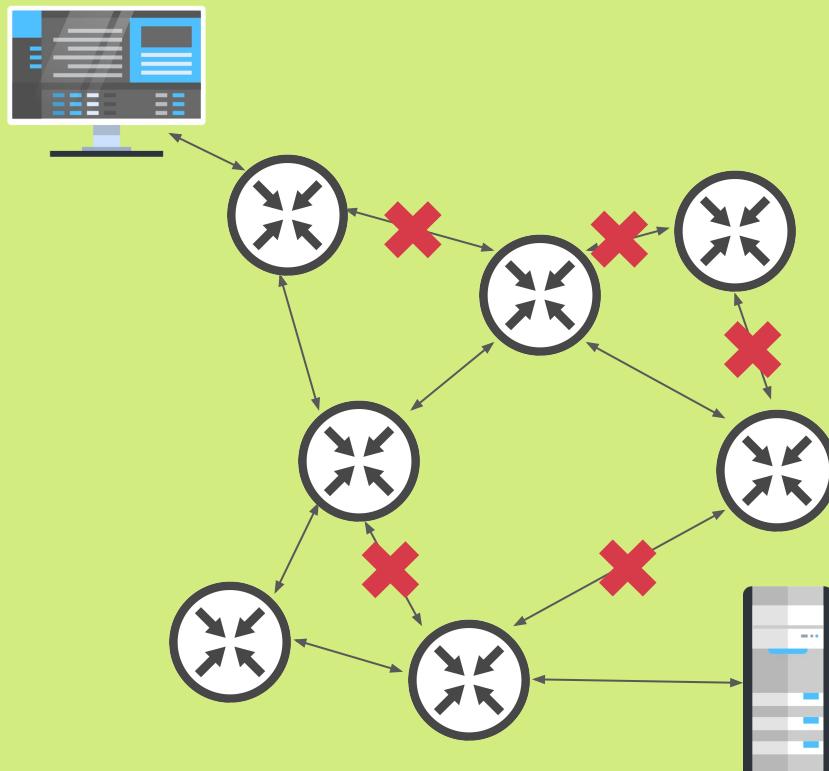
Optimal routing paths are determined based on the "shortest path," which is influenced by network topology.

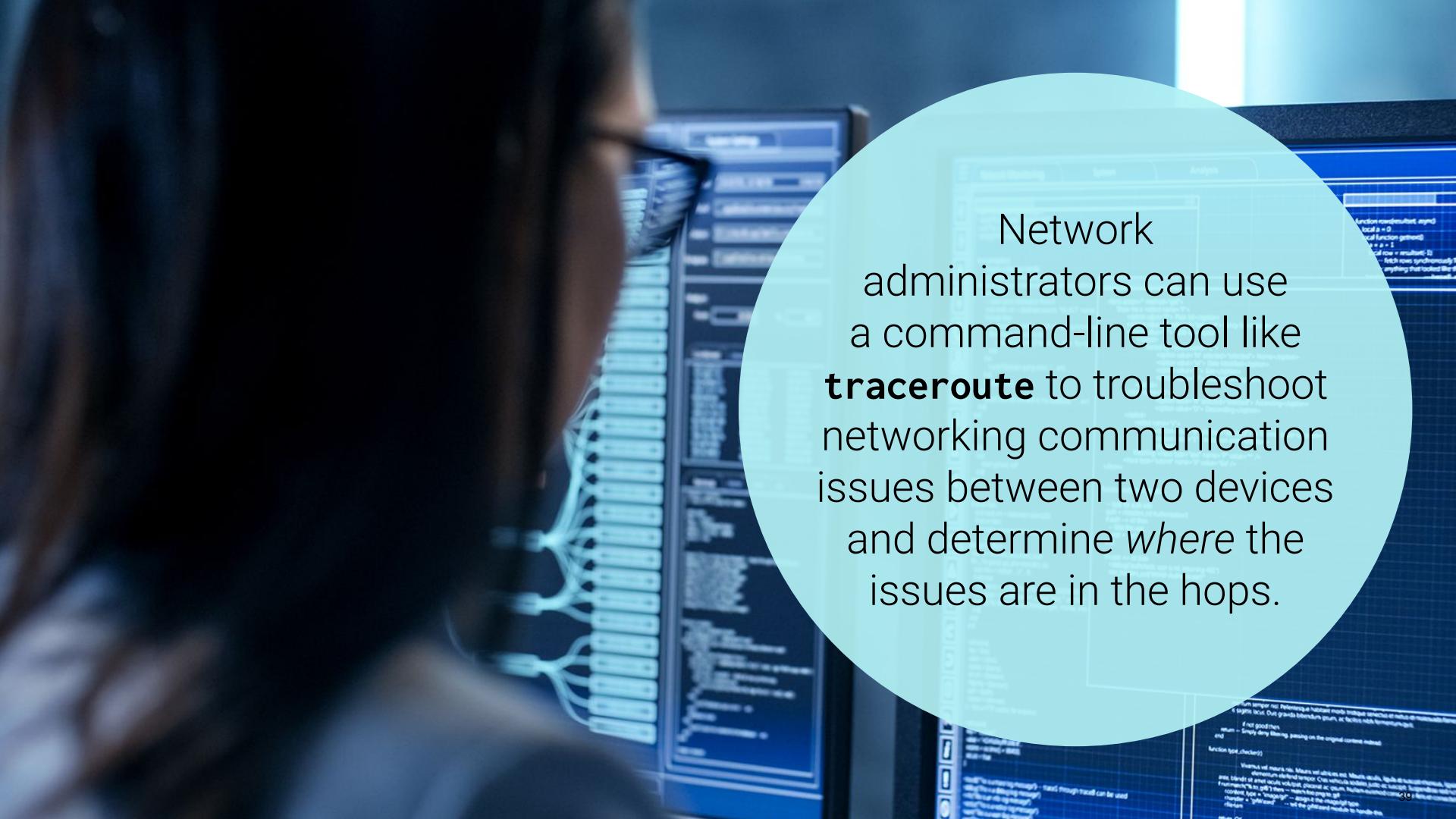


Routing and Redirections

Despite using the “shortest path,” communication between two devices can sometimes **fail**, leaving network administrators unsure where a communication problem is located.

Subpar connectivity and latency problems are often due to packets being dropped along their routing paths.

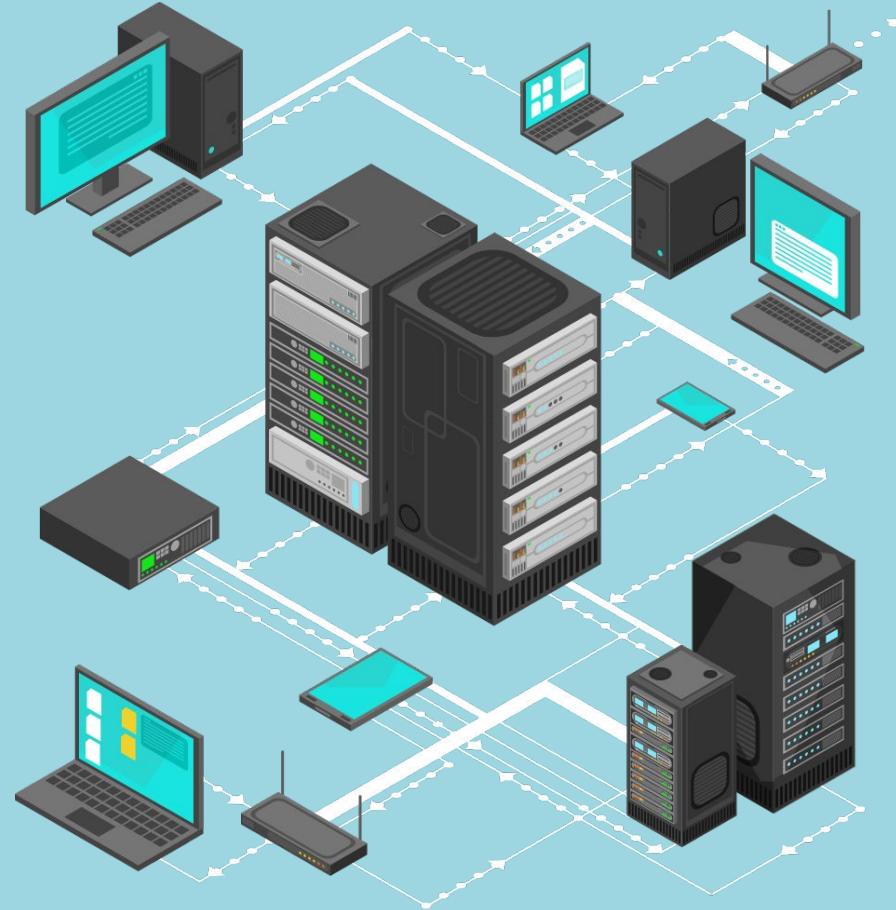


A person wearing glasses is shown from the side, looking at several computer monitors. The screens display various pieces of software, including what appears to be a terminal window showing command-line code and a network monitoring tool showing a complex network topology with many nodes and connections.

Network administrators can use a command-line tool like **traceroute** to troubleshoot networking communication issues between two devices and determine where the issues are in the hops.

Introduction to traceroute

- traceroute shows the route taken between two systems across a network.
- It lists all routers (hops) the connection must pass through to get to the destination.
- Network administrators can use traceroute to identify precisely where connectivity problems occur.



traceroute Uses

In addition to troubleshooting connectivity issues, traceroute can be used to:



Display how systems are connected, or map the network.



Generate baseline profiles of the network.



Diagnose subpar network performance issues.

ICMP and Time to Live (TTL)

Like ping, traceroute also utilizes the ICMP protocol. It also shows the time taken to travel across each of these hops, from source to destination.

The ICMP header contains a field called **Time to Live (TTL)**:

01

TTL is an indicator of how long a data packet can exist in a network.

02

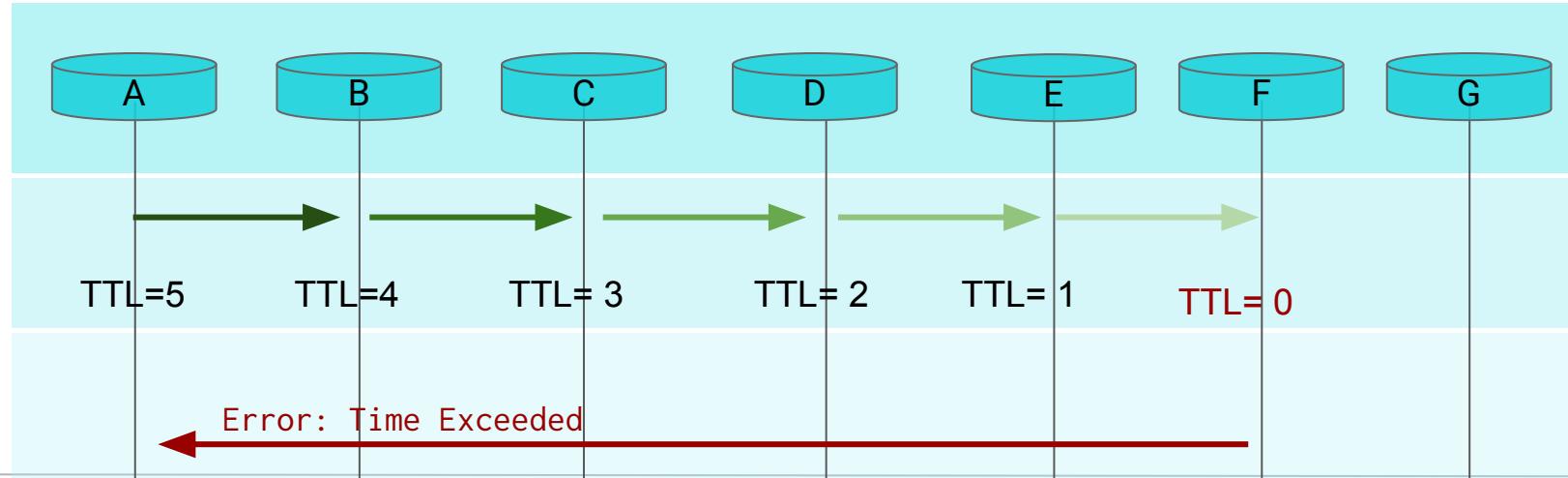
TTL is utilized as a decrementing hop counter.

Every router that forwards the packet decrements (reduces) the TTL value by one.

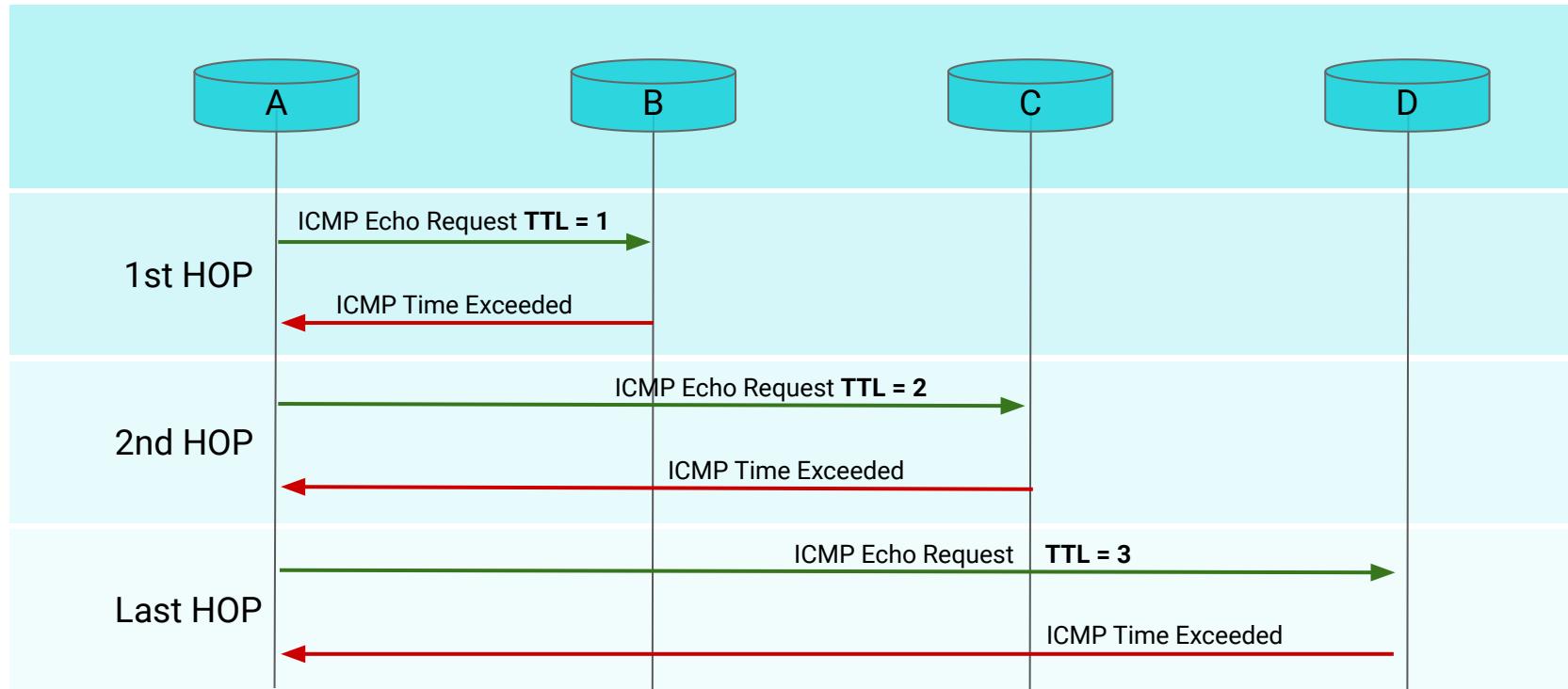
Time to Live (TTL)

If the starting TTL value of a data packet is **five**, and the data travels across **two** routers, the TTL will drop to **three**.

- When the TTL count reaches zero, it sends a "time exceeded" error message back to the source address.
- This prevents data from being stuck in an infinite loop if it's unable to be delivered to the destination.



User Datagram Protocol (UDP)

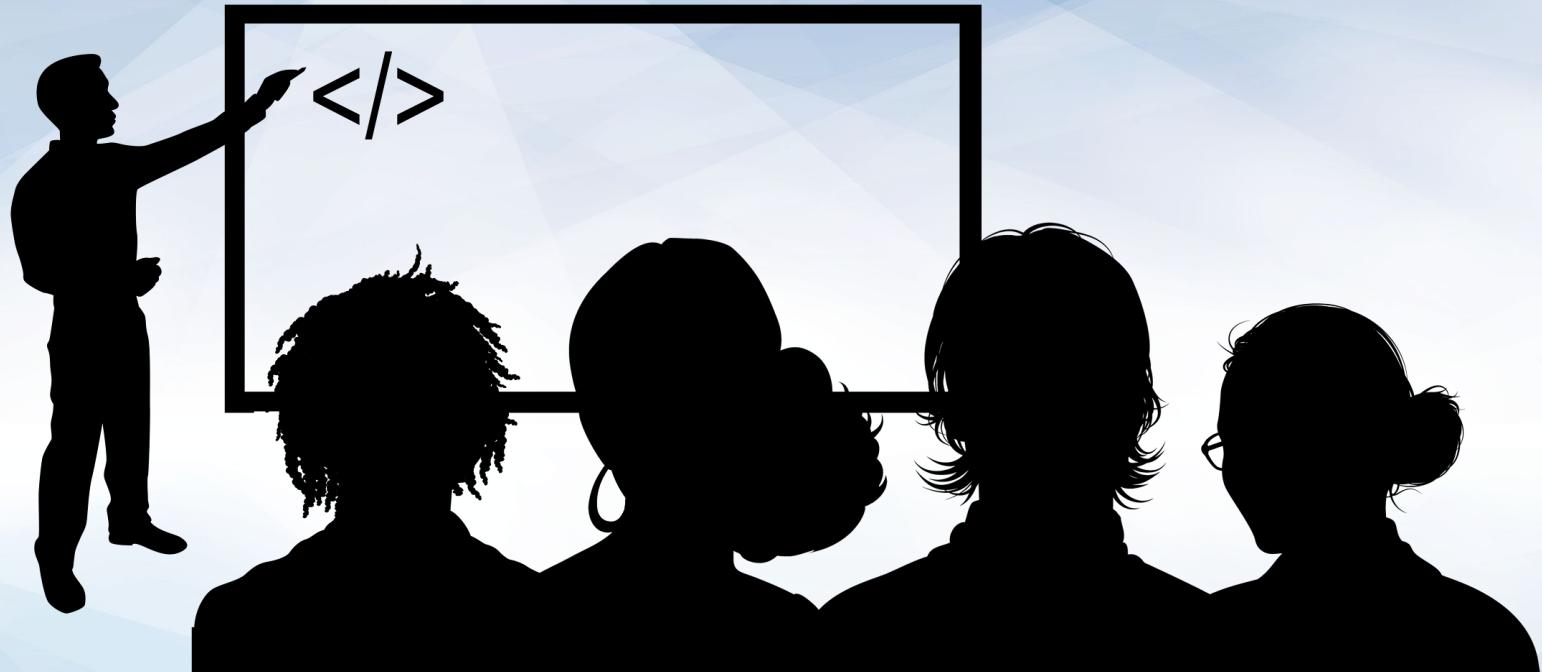


Traceroute Demo

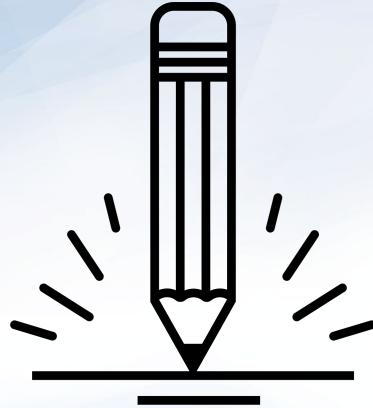
Now we'll use traceroute on the command line to further investigate why **redbull.com** isn't responding.

A large blue rectangular button with rounded corners and a thin white border. The word "Submit" is centered in the middle of the button in a white, sans-serif font.

Submit



Instructor Demonstration traceroute



[Optional] Activity: Enumerating with traceroute

In this activity, you will continue to play the role of a security analyst at Acme Corp.

You've been tasked with further analyzing the IPs rejected in the last activity to determine where in their path the connection is being dropped.

Suggested Time:
Complete if class falls on a Saturday



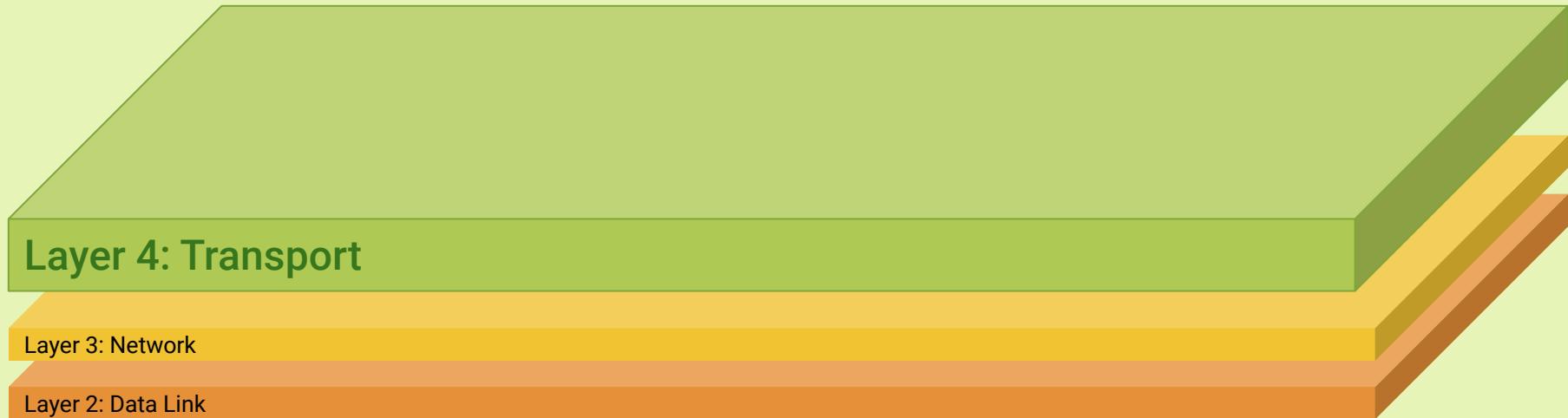


Time's Up! Let's Review.

Checkpoint

So far, we've studied the ARP protocol on Layer 2 and the ping and traceroute utilities from Layer 3.

Now, we'll move onto Layer 4 protocols **TCP** and **UDP**.



Layer 4: Transport Refresher

The Transport layer is responsible for end-to-end communication over a network.

The data from the above layers is broken into smaller packets and transported to the destination.



The recipient reassembles these packets into a complete message.

TCP (Transmission Control Protocol)

TCP (Transmission Control Protocol) is one of the most widely used protocols for data transmission.



It is a “connection-oriented” protocol, meaning the server must acknowledge it has received the request from the client.



If the recipient doesn't acknowledge the request, the sender assumes the request has not been received and will attempt to resend.

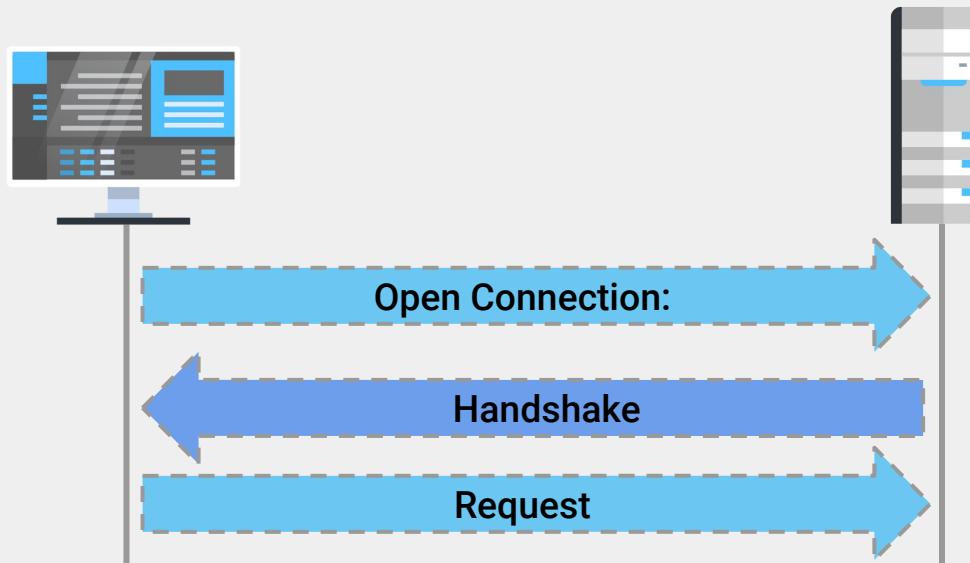


This connection-oriented acknowledgment is known as the **TCP Handshake**.

TCP in the Real World

TCP also ensures that all data is transmitted without errors, in the correct order.

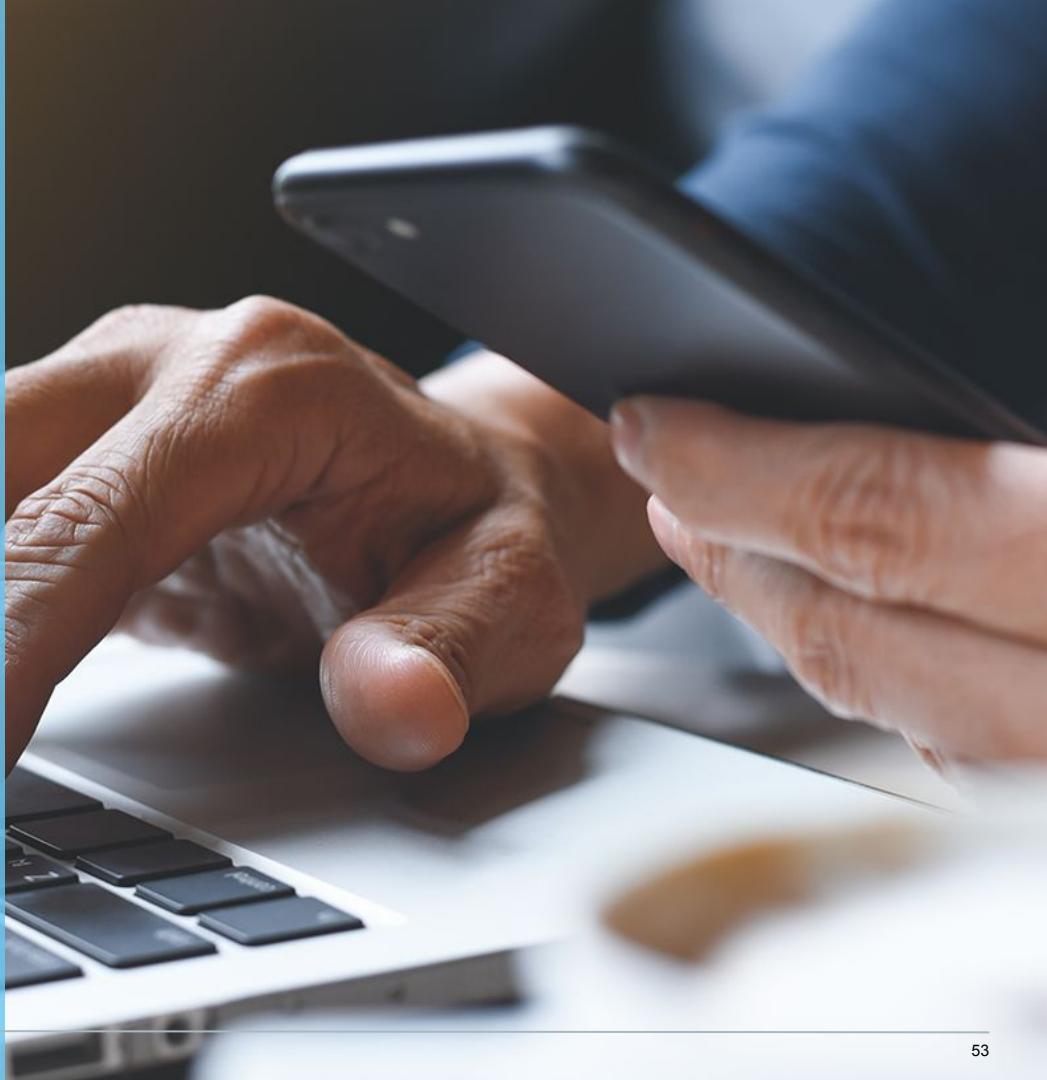
TCP is used with familiar protocols such as HTTP, HTTPS, FTP, SSH, and SMTP.



TCP in the Real World

For example: We want to check our transaction history on an online banking website.

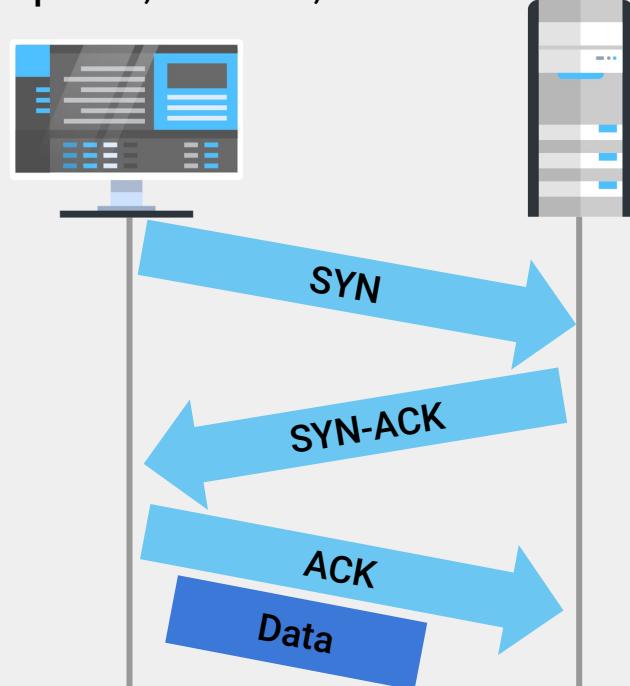
- We would use HTTPS, a protocol that runs over TCP. It ensures that all the requested data from our banking transaction history has been transmitted from the bank's web server.
- Banking customers need to trust the integrity of the data they are viewing. It's critical that banking data is complete and error free.



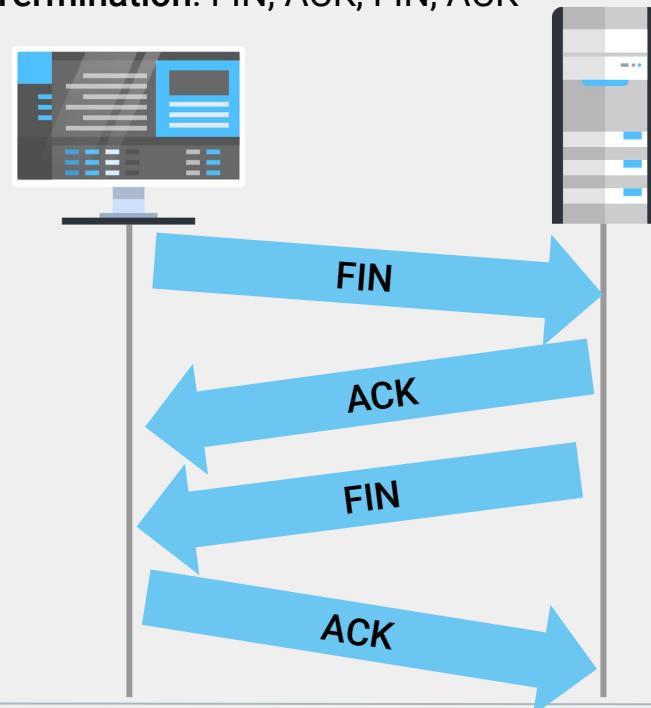
Three-Way Handshake

The TCP three-way handshake is the process that lets both sides know data has been transmitted completely.

Setup: SYN, SYN-ACK, ACK



Termination: FIN, ACK, FIN, ACK



Three-Way Handshake: Step by Step

01

SYN (*synchronize*): From client to server. Client sends a SYN data packet to the server to determine if it is ready to open a connection.

02

SYN/ACK (*synchronize/acknowledge*): From server to client. The server acknowledges or confirms receipt of the SYN packet.

03

ACK (*acknowledge*): From client to server. Client confirms receipt of the SYN/ACK packet.

04

Once the handshake is successfully completed, the data transmission can begin.

Four-Way-Termination: Step by Step

01

FIN (*finish*): From client to server. The client sends a FIN data packet to the server to close the connection.

02

ACK: From server to client. The server acknowledges receipt of the FIN packet.

03

FIN: From server to client. After the server terminates the connection, it sends a FIN packet.

04

ACK: From client to server. The client acknowledges it has received the server's FIN packet. The TCP termination process is complete.

TCP Downsides

TCP also has disadvantages.

Retransmissions (when the server resends packets because the client does not acknowledge receipt) and the ordering of packets can cause delays during data transmissions.

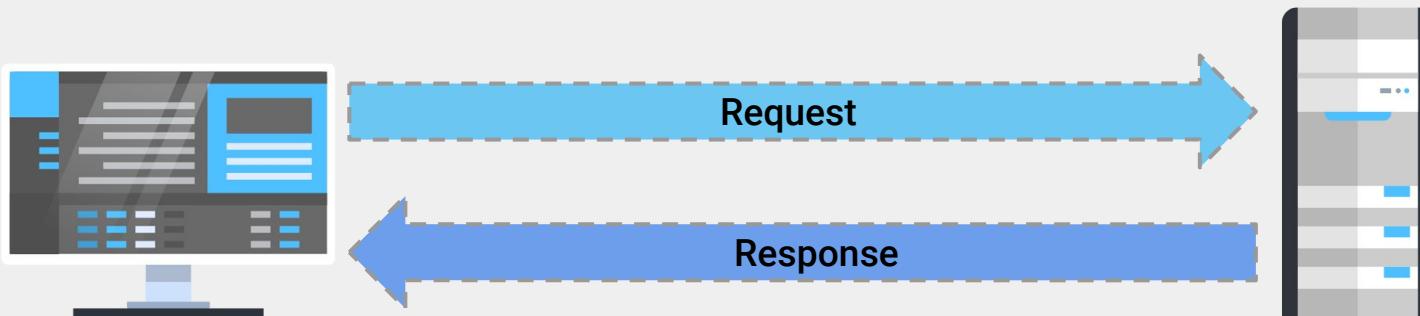
- In cases when every single packet of data does not need to be transmitted, TCP is not used. For example, streaming live video.



User Datagram Protocol (UDP)

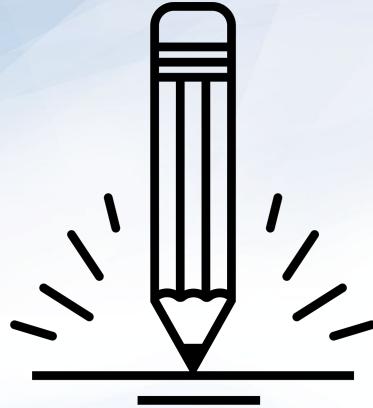
For situations when it's not necessary for all data to reach the destination, there is the **User Datagram Protocol (UDP)**.

- UDP is better for reducing latency versus transmitting all data.
- UDP is a **connectionless** protocol—it doesn't require a handshake to transmit data.
- UDP simply sends off the packets. Its attitude is: *"If all the packets are received, great. If not, that's okay too."*





Instructor Demonstration
TCP



Activity: Analyzing TCP Traffic

In this activity, you will continue to play the role of a security analyst at Acme Corp.

Your task is to analyze a new employee's TCP traffic to determine what they're working on during their first week.

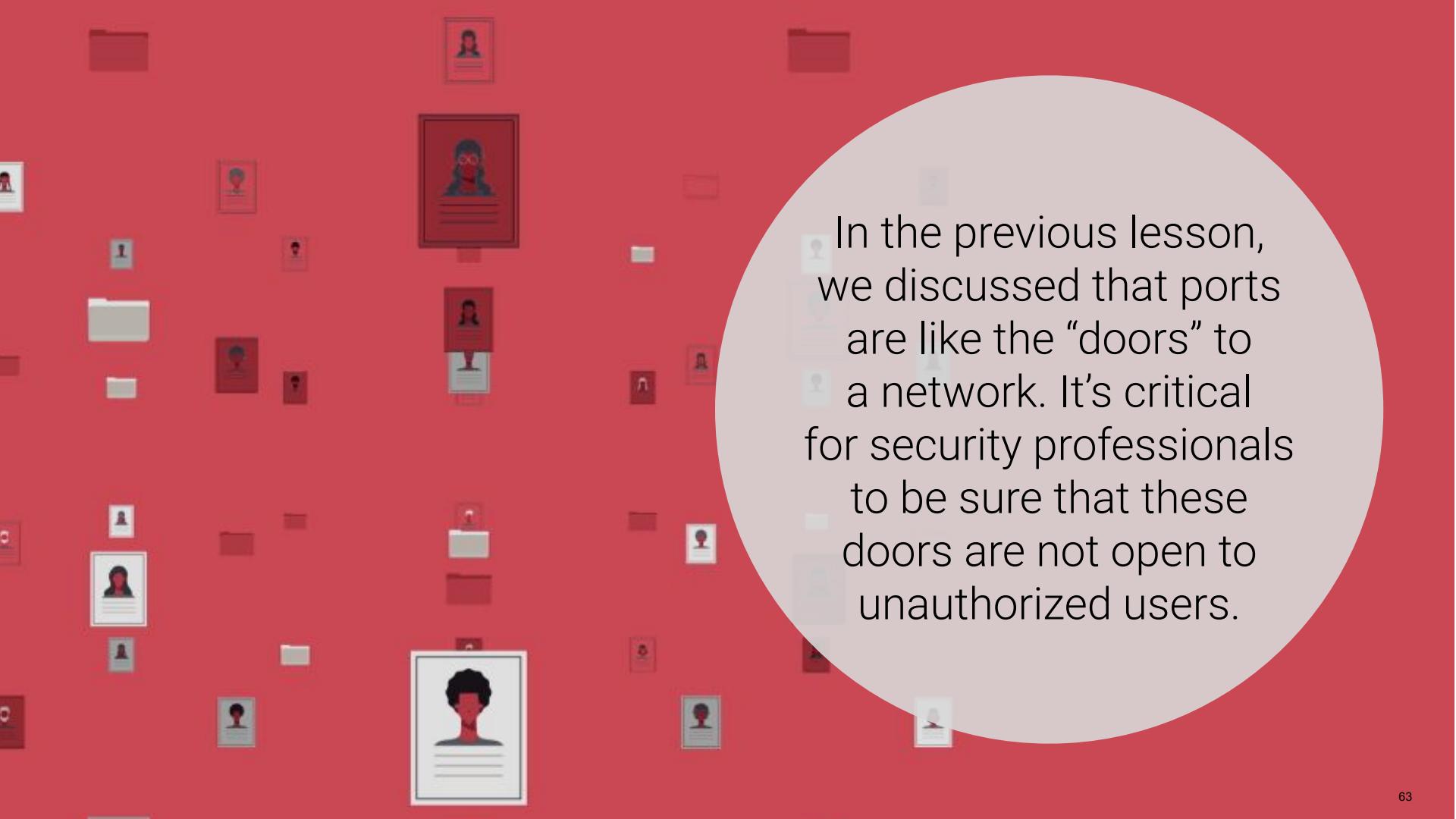
Suggested Time:
15 Minutes





Time's Up! Let's Review.

Introduction to SYN Scan



In the previous lesson, we discussed that ports are like the “doors” to a network. It’s critical for security professionals to be sure that these doors are not open to unauthorized users.

Ports

Consider the following scenario:

- Company X recently set up a new network in its London office. A security administrator needs to ensure the only ports open on the machines are 80 (HTTP) and 443 HTTPS, since incoming and outgoing web traffic is allowed for their employees.
- If ports other than HTTP and HTTPS are open, there's a risk an attacker could access the network and view confidential info, or impact the availability of the network.



We can check for open ports on a network by sending a SYN request to every port on that network. If we receive a SYN/ACK response, we know the port is **open**.

Introduction to SYN Scan

This enumeration process of sending SYN requests to many ports on a network is called a SYN Scan.



A SYN Scan is typically run by a software program that automates the sending of the SYN requests.



If a server responds with a SYN/ACK response, the client will not complete the three-way handshake with an ACK response.



The purpose of the SYN Scan is to determine the states of the ports on a network.

Port States

There are three main port states: **open**, **closed**, and **filtered**.

01

Open means the port is accepting connections.

02

Closed means it is not accepting connections.

03

Filtered means it may be open, but a firewall or another network device is likely blocking it.



We can use Wireshark to display request and response conversations in order to determine if ports are open, closed or filtered.

SYN Scan Demo

In the upcoming demonstration:



As security analysts at Company X, we have to analyze the ports from the machine recently set up in London.

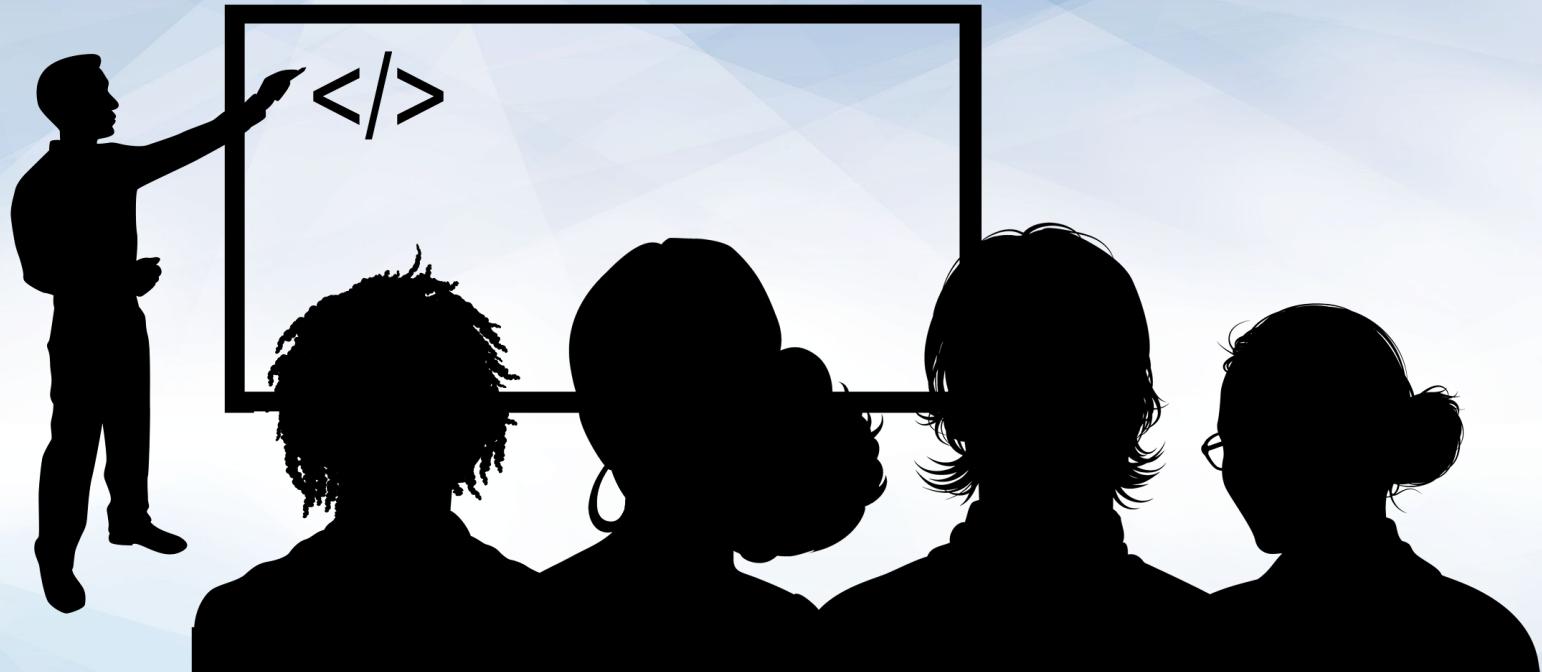


Company X is concerned that the networking team left ports open, putting the company at risk of unauthorized access.



The security manager ran a SYN Scan against the machine. We'll analyze the results to see which open ports put the company at risk.





Instructor Demonstration
SYN Scan

SYN Scan Demo Summary



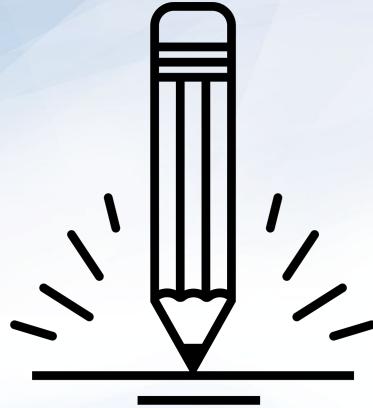
All of the SYN requests going from port to port was expected. We knew a SYN Scan was run by the security manager.



If a SYN SCAN wasn't planned, it is unusual network activity that should be looked into.



If a security professional saw this activity, they'd consider using a firewall to block the source IP from scanning the network. An attacker can use the same SYN Scan process for malicious reasons.



Activity: Analyzing a SYN Scan

CompuCom has hired you to do a security assessment of their network.

You will analyze a packet capture of a SYN Scan CompuCom ran against one of its hosts. You must determine what ports are open, closed, and filtered.

Suggested Time:
12 Minutes





Time's Up! Let's Review.