



# Module 2 - Networking

Session 2 - Layer 2, Data Link

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YOUR GATEWAY TO CYBERSECURITY SKILLS AND CAREERS

Welcome to Cyber Aces, Module 2! A firm understanding of network fundamentals is essential to being able to secure a network or attack one. This section provides a broad overview of networking, covering the fundamental concepts needed to understand computer attacks and defenses from a network perspective.

# SANS CYBER ACES ONLINE TUTORIALS

YOUR GATEWAY TO CYBERSECURITY SKILLS AND CAREERS

## 1. Introduction to Operating Systems

- 01. Linux
- 02. Windows

## 2. Networking

## 3. System Administration

- 01. Bash
- 02. PowerShell
- 03. Python

This training material was originally developed to help students, teachers, and mentors prepare for the Cyber Aces Online Competition. This module focuses on the basics of networking. This session is part of Module 2, Networking.

The three modules of Cyber Aces Online are Operating Systems, Networking, and System Administration.

For more information about the Cyber Aces program, please visit the Cyber Aces website at <https://CyberAces.org/>.

## Module 2 - Networking

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- Layer 1 - Physical
- Layer 2 - Data Link
- Layer 3 - Network
  - Addressing & Masking
  - Routing
  - Communication
- Layer 4 - Transport
- Layer 5 - Session
- Layer 6 - Presentation
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- Intra-Layer Communications

In this section, you'll learn about the Data Link Layer. We'll cover devices that operate at this layer, such as network switches, and ARP, an important networking protocol operating at this layer.



## Data Link Layer



Transfers data between adjacent network nodes

Detect errors in the Physical Layer

Only traverses a single network (i.e., not routed)

A MAC address is a unique 6 byte identifier that is hard-coded in most networking cards

- Represented as six hex octets: 00:11:22:33:44:55
- First 3 bytes are the OUI, which identifies the manufacturer
- Can be spoofed

Data travels in "frames" across a network segment

- Each frame has a source and destination MAC address

Common devices include network switches, network bridges, and wireless access points

Now that we can physically connect our computers and transmit single bits of data, we need a way to organize those bits (1's and 0's) and identify the sender and receiver. That is where the data link layer comes in. The IEEE established the 802 standard, which gave us the MAC address. The MAC address is a 6 byte (each byte is 8 bits) address that is hard coded on most networking cards in computer systems and network devices. MAC addresses are generally represented as six hexadecimal (base 16) octets, such as "00:11:22:33:44:55". (Hexadecimal is a base 16 numbering system, where each digit represents a decimal number between 0 and 15 (A=10,B=11,C=12,D=13,E=14,F=15).) The first three octets are called the OUI (Organizationally Unique Identifier), and identify the company that manufactured the network device. Since the first 3 octets represent the manufacturer, you may sometimes see MAC addresses of the form "Dell\_33:44:55", where "Dell" is the manufacturer associated with the first 3 octets. Although MAC addresses are hard-coded in network cards, it is possible for them to be spoofed in software. Therefore, it is not safe to rely exclusively on MAC addresses as a means of secure identification.

Leveraging the 802 standard, we have built standards such as Ethernet 802.3 and Wireless 802.11. A message, consisting of a collection of bits with a source MAC address and destination MAC address destined for a given system, is often referred to as a FRAME. Network switches and wireless access points operate at this layer, exchanging frames. Frames are only transmitted within a single network, and are not routed between different networks (routing occurs at Layer 3). Therefore, your MAC address is not sent across the Internet. Common Data Link Layer devices include network switches, network bridges, and wireless access points.



## Network Switch



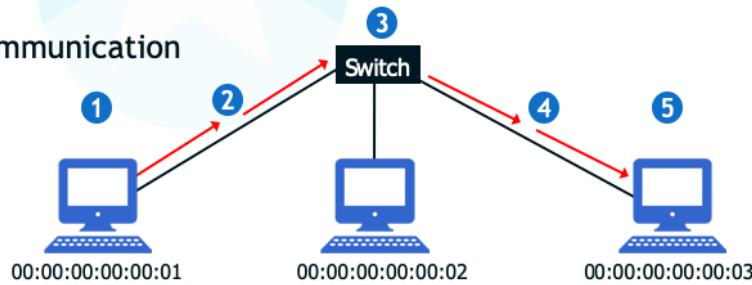
Switches keep track of which devices are connected to which ports

- They watch traffic for MAC addresses and keep track

Switches use this information to decide which port to send packets to

A Hub would forward to all ports, operating at layer 1

- No intelligence
- Simply repeats communication



Switches track MAC addresses to make decisions about where to send Ethernet frames. They monitor traffic to determine which ports hosts are reachable through, and store a mapping of MAC addresses to switch port in the CAM (Content Addressable Memory) table. Using this information, switches only send packets to the necessary port, instead of to all ports (the way a hub would). This makes switches more efficient than hubs, since they reduce the amount of traffic each node must filter through. This efficiency helps with Carrier Sense Multiple Access/Collision Detection, as there will be less traffic on the local wires, and therefore less chance of a collision.

In the diagram above, imagine that a frame is being sent from 00:00:00:00:01 to 00:00:00:00:03. In Step 1, the frame is transmitted from the source computer through a network cable, and arrives at the switch. In Step 2, the switch consults its CAM table to determine which of its ports 00:00:00:00:03 is connected to, and then transmits the frame from the appropriate port, though the network cable to the destination (3). Other systems connected to the switch, such as 00:00:00:00:02, never see the frame.

Note that if a switch does not yet know which port a given host is attached to, or if the CAM table is full, it will send the frame to all ports.



## ARP



Computers need a way to map IP addresses (Layer 3) to MAC addresses (Layer 2) in order to communicate on the same physical network

Devices on the same network use ARP (Address Resolution Protocol) to determine the MAC address associated with a given IP address

One system broadcasts an ARP request to all other systems asking who has a given IP address

The system with that IP address answers with its MAC address

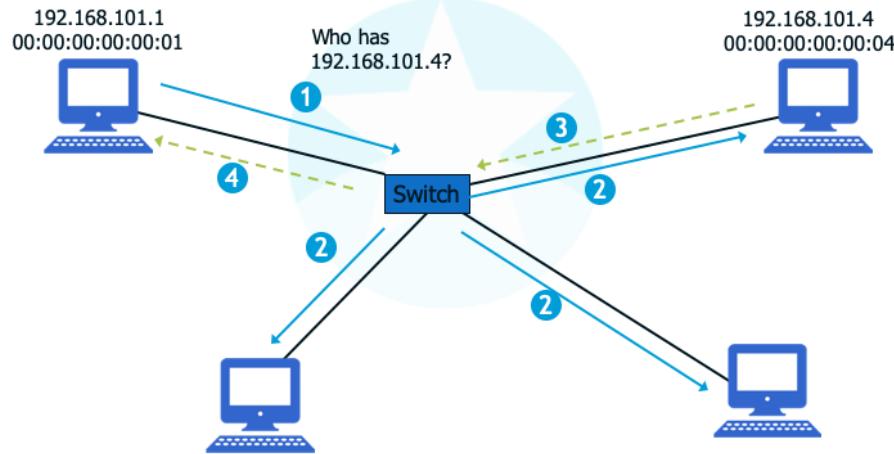
Both systems store each other's MAC addresses in their local ARP cache so they don't have to ask again for a while

Address Resolution Protocol, or "ARP", is a Layer 2 protocol that enables the communications between Layer 2 and Layer 3 by maintaining a mapping of IP Addresses to MAC addresses and vice versa. When a system needs to know another system's MAC address, it sends a broadcast message to all systems on the network asking who has a given IP address (i.e., "Who has 192.168.23.42?"). The system with that IP address will then answer with its MAC address (i.e., "192.168.23.42 is at 00:01:02:03:04:05"). Both systems will then store the IP address to MAC address mapping in their local ARP cache.



## ARP Example

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Let's say that the computer at 192.168.101.1 would like to communicate with 192.168.101.4. Since they are on the same local network, 192.168.101.1 will need 192.168.101.4's MAC address. In step 1, it sends an ARP request to the entire network asking who has the IP address 192.168.101.4. In step 2, the switch sends the request to every port, and every computer on the network receives it. In step 3, the computer with the IP address 192.168.101.4 answers with an ARP reply, which gets sent to the original computer (step 4). Note that all of the other computers on the network simply ignore the ARP request.



## Other Uses of ARP



### ARP Probe

- An ARP message sent by a computer when it obtains a new IP address, to ensure it isn't already in use

### Gratuitous ARP

- An ARP reply that is sent without a corresponding request
- Many OS's send an ARP announcement when they boot or change IP addresses
- Most systems will accept a gratuitous ARP reply and update their ARP cache
- Can also be used maliciously

### ARP Spoofing

- Can be used to pretend to be another system on the network

An ARP probe is a special ARP packet used to help prevent IP address conflicts. Before a system begins using a new IP address, it will send an ARP probe to the network asking if anyone is already using the IP address. If there is no response, then the IP address should be safe to use.

Gratuitous ARP messages are generally ARP replies that are sent without having received an ARP request. They are legitimately used by many operating systems to announce a system's new IP address after a reboot or IP address change, allowing other systems on the network to update their ARP caches right away. Otherwise, if a system had an outdated entry in its ARP cache, it may disrupt the ability to communicate with that host. Most systems will happily accept an unsolicited ARP reply and use it to update its ARP cache. Therefore, it can also be used maliciously, such as for ARP spoofing. ARP spoofing is used to pretend to be another system on the network by sending a gratuitous ARP reply with the desired IP address and the attacker's MAC address. This causes other systems on the network to believe the attacker's system has the desired IP address.



## Review



True/False: Your MAC address will be recorded in the logs of an Internet web server you access.

True/False: The first three octets of a MAC address identify the manufacturer.

True/False: A MAC address is hard-coded and cannot be spoofed.

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## Answers



Your MAC address will be recorded in the logs of an Internet web server you access.

- FALSE
- ARP traffic is not routed beyond the local network

The first three octets of a MAC address identify the manufacturer.

- TRUE
- The first three octets are called the OUI (Organizationally Unique Identifier)

A MAC address is hard-coded and cannot be spoofed.

- FALSE
- MAC addresses can be spoofed at the software level

Your MAC address will be recorded in the logs of an Internet web server you access.

False, ARP traffic is not routed beyond the local network

The first three octets of a MAC address identify the manufacturer.

True, the first three octets are called the OUI (Organizationally Unique Identifier)

A MAC address is hard-coded and cannot be spoofed.

False, MAC addresses can be spoofed at the software level

# ARP Exercise - Windows

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Take a look at your ARP cache:

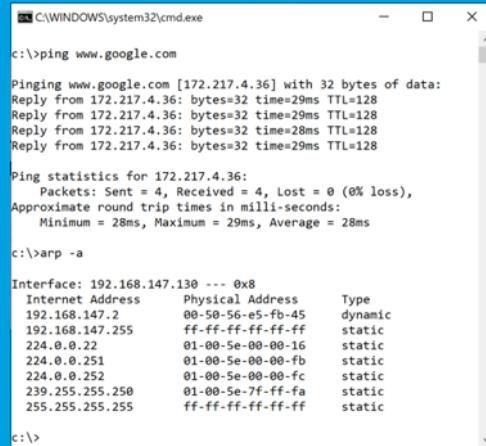
- Open a "Command Prompt"
- Ping Google by typing "ping www.google.com", then press enter
- Type "arp -a" and press enter

You should see an entry for your machine's default gateway

- Since Layer 2 is not routed, the frame has to be sent to the default gateway, which then forwards it on to the next network

You should also see the broadcast address (all F's)

Multicast addresses (01:00:5e)



The screenshot shows a Windows Command Prompt window with the following content:

```
c:\>ping www.google.com

Pinging www.google.com [172.217.4.36] with 32 bytes of data:
Reply from 172.217.4.36: bytes=32 time=29ms TTL=128
Reply from 172.217.4.36: bytes=32 time=29ms TTL=128
Reply from 172.217.4.36: bytes=32 time=28ms TTL=128
Reply from 172.217.4.36: bytes=32 time=29ms TTL=128

Ping statistics for 172.217.4.36:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 28ms, Maximum = 29ms, Average = 28ms

c:\>arp -a

Interface: 192.168.147.130 --- 0x8
  Internet Address      Physical Address      Type
  192.168.147.2          00-50-56-e5-fb-45  dynamic
  192.168.147.255        ff-ff-ff-ff-ff-ff  static
  224.0.0.22              01-00-5e-00-00-16  static
  224.0.0.251             01-00-5e-00-00-fb  static
  224.0.0.252             01-00-5e-00-00-fc  static
  239.255.255.250         01-00-5e-7f-ff-fa  static
  255.255.255.255         ff-ff-ff-ff-ff-ff  static
```

As a quick exercise, try viewing your computer's ARP cache after pinging a server. First, open a "Command Prompt" or "Terminal" window, then ping Google by running the following command:

```
C:\> ping google.com
```

Then, to view your ARP cache, run:

```
C:\> arp -a
```

You should see an entry for your machine's default gateway (run `ipconfig` to confirm)! Note that since Layer 2 traffic is not routed between networks, you won't see an ARP entry for Google's IP address. Instead, you see your default gateway's IP and MAC addresses because your computer has to communicate through the default gateway to reach Google.

The "arp" command also has a "-d" option, which allows you to delete an entry from the ARP cache. For example, to remove the ARP entry for 192.168.198.2 above, you would run:

```
C:\> arp -d 192.168.198.2
```



# ARP Exercise - Linux



The "arp" command will display the addresses in much the same way as Windows

Follow the same steps as you did on Windows

- Ping (the Linux ping command will run forever, use Ctrl+C to stop)
- Run the arp command

For help on the arp command run "man arp"

```
liveuser@localhost:~$ ping -c 2 www.google.com
PING www.google.com (172.217.6.4) 56(84) bytes of data.
64 bytes from ord38s01-in-f4.1e100.net (172.217.6.4): icmp_seq=1 ttl=128 time=30.1 ms
64 bytes from ord38s01-in-f4.1e100.net (172.217.6.4): icmp_seq=2 ttl=128 time=32.0 ms

--- www.google.com ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1002ms
rtt min/avg/max/mdev = 30.109/31.066/32.024/0.973 ms
[liveuser@localhost ~]$ arp
Address           HWtype  HWaddress          Flags Mask   Iface
192.168.231.254  ether    00:50:56:f0:49:e2  C      ens33
gateway          ether    00:50:56:eb:1a:ea  C      ens33
[liveuser@localhost ~]$
```

The "arp" command in Linux operates much in the same was as it does in Windows.

First, ping [www.google.com](http://www.google.com). The ping command in Linux will run forever, so press Ctrl+C or use the count option (-c) to specify the number of ICMP packets to send.

```
[liveuser@localhost ~]$ ping -c 2 www.google.com
PING www.google.com (172.217.6.4) 56(84) bytes of data.
64 bytes from 172.217.6.4: icmp_seq=1 ttl=128 time=30.1 ms
64 bytes from 172.217.6.4: icmp_seq=2 ttl=128 time=32.0 ms

--- www.google.com ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1002ms
rtt min/avg/max/mdev = 30.109/31.066/32.024/0.973 ms
```

Next, run the arp command to see the MAC address of your default gateway.

```
[liveuser@localhost ~]$ arp
Address           HWtype  HWaddress          Flags Mask   Iface
192.168.1.254  ether    00:50:56:f0:49:32  C      ens33
gateway          ether    00:50:56:eb:1a:ea  C      ens33
[liveuser@localhost ~]$
```



## Tutorial Complete!

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This concludes Module 2 - Networking Layer 2

- We've learned the Data Link layer and how communication occurs at this layer

In the next module, we'll learn about Layer 3, the Network Layer

This concludes the discussion about Layer 2, the Data Link Layer.

In the next tutorial we'll discuss the next layer in the OSI model, the Network Layer.

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In the next session we will begin our discussion on the Layer 3, the Network Layer.