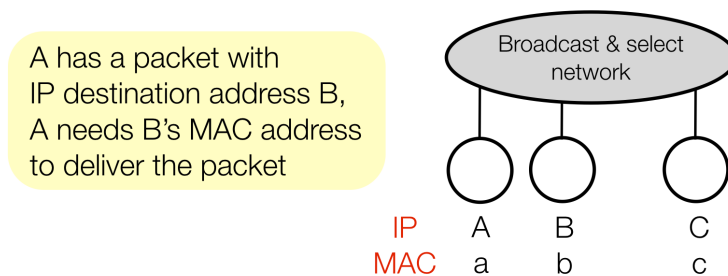


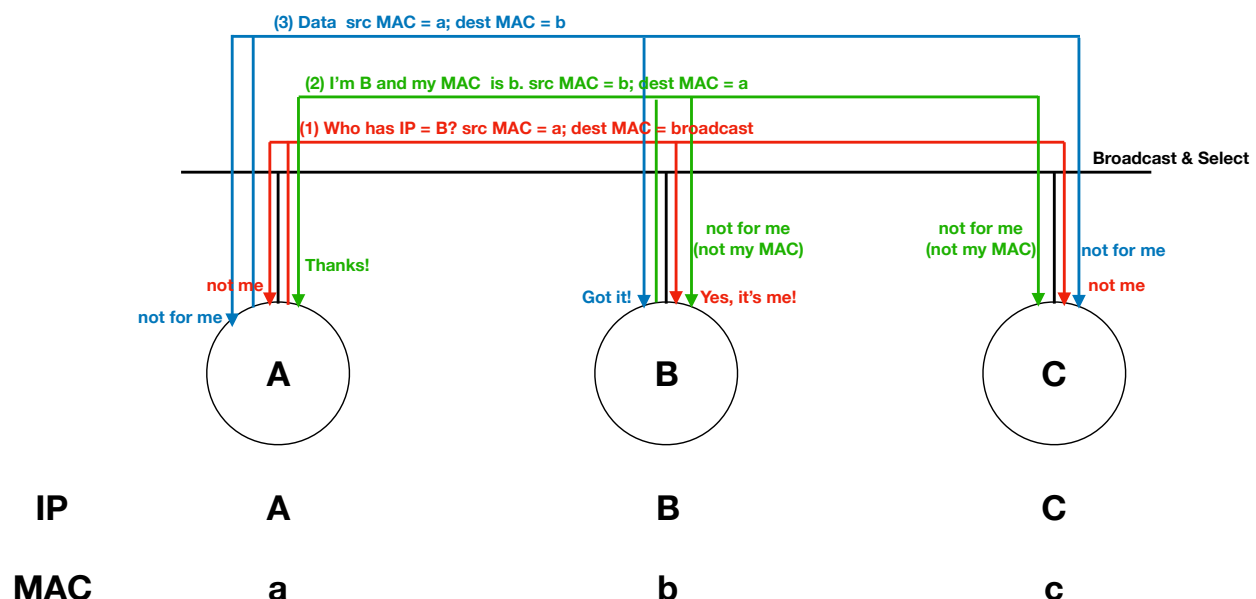
Networking Fundamentals (I)

Address Resolution

- Packet transmission in a L2 broadcast & selected network is based on the MAC address. Suppose you are on d122-01 and want to send a message to your friend on d122-05. You know the hostname d122-05, which can be mapped to its IP address. But **how can d122-01 tell the MAC address of d122-05?**
- When d122-01 transmits a packet, it will consult its arp table first.
 - What is the arp table?
 - It's a table maps MAC addresses to IP addresses, maintained by the computer.
 - How do you check the arp table of your computer?
 - Use command line `arp -a`
- If the IP address exists in the table, then packet is sent to another machine in on the same subnet. Otherwise, the system will use **ARP** - **Address Resolution Protocol**.
 - How does ARP work?
 - Suppose a L2 network with three nodes shown in the figure below. A wants to send a packet to B. A knows B's IP but has no idea about its MAC address.



- The way ARP works is demonstrated in the figure below.



- The broadcast MAC address is a reserved MAC address, FF-FF-FF-FF-FF-FF. When using broadcast MAC address, every node in the L2 network is the destination for that packet.
- After knowing the MAC address of B, A will update its arp table including the record for B into the table.
 - Suppose d122-05 was not in d122-01's arp table initially. After you ping d122-05 from d122-01 and check d122-01's arp table again, you will find the entry for d122-05 in the updated arp table.
- Please note that if the destination IP is not in the updated arp table, the packet will be sent to the router, the default gateway. For example, if you ping google.com. Google is not on Colby network. Your laptop therefore needs the MAC address of the next hop, usually the default gateway, rather than the Google's MAC address, as ARP is local.
- Example, run `arp -a`, ping google.com, meanwhile capturing ARP in Wireshark (Wireshark filter arp). The sniffer would show Who has ...? ... is at ...
- Also note that, hosts A, B, and C are connected to a L2 network via a Hub. A hub is simply a repeater. Once an interface on a hub receive a packet, the packet will be broadcasted to the all the interfaces on the hub, so all hosts connect to this hub will receive a copy of the packet. Nowadays, switches are often used in L2 networks. Each switches will maintain a switch table mapping MAC addresses of the hosts connected to it with its interfaces. If a host sends a packet to another host in the L2 network, the switch will inspects its switching table for the interface that connects to the destination host and forward the packet to that interface only rather than broadcast, unless the dest MAC of the packet is a broadcast address. In this way, L2 networks are securer and more efficient.
- ARP is IPv4-specific.

Subnetting

- When a packet arrives at L2 network, it can be delivered via MAC address using ARP table, but **how does the network decide whether an IP address belongs to a L2 network?**
- Nodes on a local network (and only those) have IP addresses within a specific range.
- For example, Colby has its own IP address ranges. All nodes connect to Colby network has IP addresses within that range.
- In computer networks, the way to specify a range of consecutive IP addresses is via **IP Prefix**.

IP Prefix

- An IP prefix consists of a **subnet id** and a **prefix length (N)**
- For example, the prefix for Colby network is **137.146.0.0/16**, the **subnet id** is **137.146.0.0** and the **prefix length** is **16**.
- An **IP address belongs to a range** specified by a prefix **if the leftmost N bits of the IP address are the same as those in the subnet id**
- E.g., IP address 137.146.183.19 belongs to the range 137.146.0.0/16, as the first 16 bits of the IP address are the same as those in the subnet id.

Subnet Mask

- Another way to specify **prefix length**.
- It is a 32 bit, IP address-like string. The **leftmost N bits** of the string are **1s**, and the remaining bits are 0s.
 - E.g., the subnet mask represents the prefix length /16 is
 - 1111 1111.1111 1111.0000 0000. 0000 0000 (in binary)
 - 255.255.0.0 (in decimal, **a typical representation**)
 - ff.ff.00.00 (in hexadecimal)
- Prefix length and subnet mask (netmask) are equivalent for all practical purposes:
 - E.g., **137.146.183.0 with net mask 255.255.255.0** is equivalent to **137.146.183.0/24**
 - But, subnet mask is easier for computers to conduct bit operations such as AND to decide whether a IP address belongs to the range or not.
- You will need to know subnet mask when you configure the network on some OS (e.g., Ubuntu).

Example for IP Address Calculations

- Given IP address **192.168.152.30** and prefix length **26**, answer the following questions.
 - Subnet ID: **192.168.152.0**
 - First host: **192.168.152.1**
 - Broadcast address: **192.168.152.63**
 - Last host: **192.168.152.62**
 - Subnet mask: **255.255.255.192**
- Subnet mask: the **leftmost 26 bits are 1s, and the rest bits are 0s**, which is 11111111.11111111.11111111.11 000000. In decimal, it's **255.255.255.192**.

- Subnet ID

```

11000000.10101000.10011000.00 011110
AND 11111111.11111111.11111111.11 000000
-----
11000000.10101000.10011000.00 000000 -> 192.168.152.0

```

- Range represented by 192.168.152.0/26: start with 192.168.152.00 000000, end with 192.168.152.00 111111, which is 192.168.152.0 ~ 192.168.152.63
- **First host**: the first address in the range that can be assigned to a host, which is subnet ID + 1. In this question, it's 192.168.152.1
- **Broadcast address**: the maximum address in the range, usually reserved for broadcasting in the subnet specified by the range. The maximum address in this range 192.168.152.0/26 is 11000000.10101000.10011000.00 111111 (the rightmost 32-26 = 6 bits are all 1s, and the rest bits remain the same as what they were in subnet ID). In decimal, the broadcast address is 192.168.152.63.
- **Last host**: the last address in the range that can be assigned to a host, which is broadcast address - 1. In this question, it's 192.168.152.62

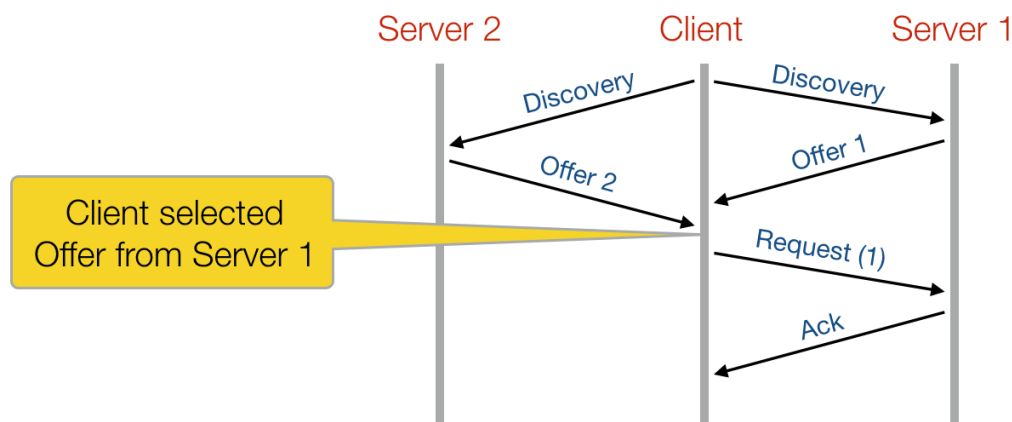
Exercise: Design a small network

- Give the network 192.168.10.0/24, you are expected to plan the addresses for four subnets, each supporting approximately 50 devices. What prefix length should you use? What are the four prefixes? What is the address range of each?
 - Step 1: How many host addresses does each subnet need?
 - Each needs at least 50 usable host addresses. If we have h host bits (32-prefix length), the total number of addresses is 2^h . Two addresses are reserved: network address and broadcast address. So, usable host addresses are $2^h - 2$. We need $2^h - 2 \geq 50$. So, $h = 6$.
 - Step 2: Determine the prefix length
 - $32 - 6 = 26$
 - Step 3: Check how many /26 subnets fit inside a /24
 - The original network is 192.168.10.0/24. We are extending the prefix from /24 to /26. That means we borrowed $26 - 24 = 2$ bits for subnetting. Two bits give $2^2 = 4$ subnets, which is exactly what we need.
 - Step 4: Determine the prefixes.
 - A /26 leaves 6 host bits, so each subnet contains $2^6 = 64$ total addresses. So the subnet boundaries increase by 64. The four subnet prefixes are 192.168.10.0/26, 192.168.10.64/26, 192.168.10.128/26, and 192.168.10.192/26.
 - Step 5: Find the usable host address range.
 - For 192.168.10.0/26
 - Network address: 192.168.10.0
 - First host: 192.168.10.1
 - Last host: 192.168.10.62
 - Broadcast: 192.168.10.63
 - For 192.168.10.64/26
 - Network address: 192.168.10.64

- First host: 192.168.10.65
- Last host: 192.168.10.126
- Broadcast: 192.168.10.127
- For 192.168.10.128/26
 - Network address: 192.168.10.128
 - First host: 192.168.10.129
 - Last host: 192.168.10.190
 - Broadcast: 192.168.10.191
- For 192.168.10.192/26
 - Network address: 192.168.10.192
 - First host: 192.168.10.193
 - Last host: 192.168.10.254
 - Broadcast: 192.168.10.255

DHCP

- We know that when a computer joins into a subnet, it will be assigned a new IP address in the address range of that subnet without any human intervention. How does the network assign an IP address to a newly joined computer automatically?
- **Dynamic Host Configuration Protocol** (a major IPv4 mechanism)
 - **application layer** protocol
 - plug-and-play or **zero-configuration** protocol, alleviate the workload of administrator
 - to obtain IP address and other configuration params (e.g., how long you can use the IP)
 - one or more DHCP servers on the same subnet (to reduce congestions and improve reliability)
 - utilizes IP broadcast (255.255.255.255) and UDP
 - **Four steps** to acquire an IP address:
 - **Discovery**: find a DHCP server
 - **Offer**: proposed IP address and IP address lease time (several hours or days)
 - **Request**: choose from one of the offers, echo back the configuration parameters
 - **Ack**: confirm the request parameters



Disclaimer: Notes adapted from the textbook and online resources.