Virtual vs. Physical Networks

- MAC is the part of the underlying network
  - MAC is used on the LAN

- What is the addressing mechanism in WAN?
  - WAN is interconnections of man many LANS

- Networking addressing is required
  - Making the network of networks to appear seamless

- For Internet we use IP addressing

TCP/IP Stack
Ethernet Addressing

- MAC address is 48 bits:
  - 24 bits (OUI – Organizationally unique Identifier)
  - 24 bit hardware address – burned in the ROM
### Ethernet Addressing

These MAC addresses are found via:

Enter MAC: [Enter] Submit Query

Here are the results of your search through the public section of the IEEE Standards OUI database report for **002170**:

<table>
<thead>
<tr>
<th>Address</th>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-21-70</td>
<td>(hex) Dell Inc</td>
<td>Dell Inc One Dell Way, MS RR5-45 Round Rock Texas 78682 UNITED STATES</td>
</tr>
<tr>
<td>002170</td>
<td>(base 16)</td>
<td></td>
</tr>
</tbody>
</table>
Network Layer Architecture

- Layer 3 of the seven-layer
- Provides services to upper layer (Primitives and parameter)
- The Network Layer is responsible for routing packets delivery
  - Note the Data Link Layer is responsible for Media Access Control, Flow Control and Error Checking
- Connection model: connectionless communication
  - No setup path is required
  - The recipient does not have to send an acknowledgement
- Provides unique host addressing
Network Layer Examples

- IPv4/IPv6, Internet Protocol
- DVMRP, Distance Vector Multicast Routing Protocol
- ICMP, Internet Control Message Protocol
- IGMP, Internet Group Multicast Protocol
- PIM-SM, Protocol Independent Multicast Sparse Mode
- PIM-DM, Protocol Independent Multicast Dense Mode
- IPsec, Internet Protocol Security
- IPX, Internetwork Packet Exchange
- RIP, Routing Information Protocol
- DDP, Datagram Delivery Protocol
- BGP, Border Gateway Protocol
Internet Protocol

- We focus on IP
- IP was the connectionless datagram service
- Originally introduced by Vint Cerf and Bob Kahn in 1974 to be interfaced with TCP
  - The first major version of IP is known as Internet Protocol Version 4 (IPv4) – dominant
  - Internet Protocol Version 6 (IPv6) is the successive version
- Main responsibility: addressing hosts and routing datagrams (packets) from a source host to the destination host across one or more IP networks
  - Addresses identify hosts
  - Provides a logical location service
Internet Protocol

- IP Design Issues
  - Interconnection
  - Routing
    - Static or Dynamic
  - Looping and lifetime
  - Fragmentation
  - Error Control
  - Flow Control
  - IP Header and Addressing
IP Encapsulation in Frames

- The IP datagram contains **data** and **IP address**
- The IP datagram is encapsulated in a frame with physical address
- The header changes as the frame goes from one network domain to the next

![Diagram of IP encapsulation in frames]

<table>
<thead>
<tr>
<th>IP Datagram</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Address</td>
<td>IP Address</td>
</tr>
</tbody>
</table>
IP: Connectionless Internetworking

- Advantages
  - Flexibility and robust
  - No unnecessary overhead

- Unreliable
  - Not guaranteed delivery (no ACK is required)
  - Not guaranteed order of delivery
    - Packets can take different routes
  - Reliability is responsibility of next layer up (e.g. TCP)
IP Routing

- End systems and routers maintain routing tables
  - Indicate next router to which datagram should be sent
  - Static
    - May contain alternative routes
  - Dynamic
    - Flexible response to congestion and errors

- Source routing
  - Source specifies route as sequential list of routers to be followed
IP Datagram Lifetime

- Datagrams could loop indefinitely
  - Consumes resources
  - Transport protocol may need upper bound on datagram life

- Datagram marked with lifetime
  - Time To Live field in IP
  - Once lifetime expires, datagram discarded (not forwarded)
  - Hop count
    - Decrement time to live on passing through a router
  - Time count
    - Need to know how long since last router
IP Packet TTL

- TTL (time-to-live) refers to the number of router hops the IP packet is allowed before it must be discarded.
  - Each router that receives a packet subtracts one from the count in the TTL field.
  - When the count reaches zero, the router detecting it discards the packet and sends an Internet Control Message Protocol (ICMP) message back to the originating host.
IP Flow Control and Error Control

- Error Control
  - FCS (frame Check Sequence)
  - CRC
  - Congestion errors / lifetime expiration
  - Error notification may not possible – error in address!

- Flow Control
  - ICMP (change the sending rate)
  - Node-to-node backoff
IP Services and Versions

- Part of TCP/IP
  - Used by the Internet
- Specifies interface with higher layer
  - e.g. TCP
- Specifies network protocol format and mechanisms
- IPv4
  - Addresses are 32 bits wide
  - Its header is 20 bytes at minimum
  - Uses *dotted-decimal* notation (e.g. 43.23.43.56) – using octets
- IPv6
  - Provides large address domain; addresses are 128 bits wide
  - Multiple separate headers are supported
  - Offers roaming features
  - Handles audio and video; providing high quality paths
  - Supports unicast, multicast, anycast
IPv4 Addressing
Internet Addressing

- Over half million networks are connected to the Internet – 5 billion users by 2015!
- Network numbers are managed by ICANN (Internet Corporation for Assigned Names and Numbers) - http://www.icann.org/
  - Delegates part of address assignments to regional authorities called registrars
    - Registrars are authorized by ICANN to assign blocks of addresses
    - IP address blocks are given to ISPs and companies
    - ISPs distribute individual addresses to users and organizations
- IP addresses are based on dotted decimal notation: 192.41.7.32 (Octets from 0 to 255 – 8 bits)
  - IP address 0.0.0.0 refer to machine’s own network when it is being booted (This host)
  - 255.255.255.255 broadcast on the LAN
  - 127.x.y.z reserved for loopback testing
IP Addressing – IPv4

- A network IP address is divided into Netid and Hostid
- Also called Prefix and Suffix.
- IP Address classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Leading bits</th>
<th>Network Address (Netid)</th>
<th>Host Address (Hostid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>0</td>
<td>7 bit (125)*</td>
<td>24 bit (16,777,216)</td>
</tr>
<tr>
<td>Class B</td>
<td>10</td>
<td>14 bit (16,382)</td>
<td>16 bit (65,534)</td>
</tr>
<tr>
<td>Class C</td>
<td>110</td>
<td>21 bit (2,096,150)</td>
<td>8 bit (254)</td>
</tr>
<tr>
<td>Class D (multicast)</td>
<td>1110</td>
<td>Multicast Address</td>
<td></td>
</tr>
<tr>
<td>Class E (reserved)</td>
<td>1111</td>
<td>Reserved (not assigned)</td>
<td></td>
</tr>
</tbody>
</table>

- Some values are reserved (e.g., all zero, all one)!
- Leading bits refer to most significant bits
IP Addressing Classification

### First Octet

- **Class A**: 0 - 127
  - **Network Address**: 8 bits (0NNNNNNN)
  - **Host Address**: 24 bits (HHHHHHHH HHHHHHHH HHHHHHHH)

- **Class B**: 128 - 191
  - **Network Address**: 16 bits (10NNNNNNNN)
  - **Host Address**: 16 bits (HHHHHHHH HHHHHHHH)

- **Class C**: 192 - 233
  - **Network Address**: 24 bits (110NNNNNNNNNNNNNN)
  - **Host Address**: 8 bits (HHHHHHHH)

#### Network Address

- **Network**: 0 - 127
- **Host Address**: 0 - 255

#### Host Address

- **Network**: 0 - 255
- **Host Address**: 0 - 255

---

### Middle

- **Class D**: 240 - 255
  - **Multicast Address**:
    - 32 bits
    - 1110MMMM MMMMMMMM MMMMMMMM MMMMMMMM

- **Class E**: 240 - 255
  - **Reserved for Internet research**
    - 32 bits
    - 1111XXXX XXXXXXXX XXXXXXXX XXXXXXXX

#### Network Address

- **Network**: 0 - 127
- **Host Address**: 0 - 255

#### Host Address

- **Network**: 0 - 255
- **Host Address**: 0 - 255

---

### Last Octet

- **Class B**: 128 - 191
  - **Network Address**: 16 bits (10NNNNNNNN)
  - **Host Address**: 16 bits (HHHHHHHH HHHHHHHH)

- **Class C**: 192 - 233
  - **Network Address**: 24 bits (110NNNNNNNNNNNNNN)
  - **Host Address**: 8 bits (HHHHHHHH)

- **Class D**: 240 - 255
  - **Multicast Address**:
    - 32 bits
    - 1110MMMM MMMMMMMM MMMMMMMM MMMMMMMM

- **Class E**: 240 - 255
  - **Reserved for Internet research**
    - 32 bits
    - 1111XXXX XXXXXXXX XXXXXXXX XXXXXXXX
Example of IP Addressing

Q1: Determine the network address for the following IP addresses:

1- 84.42.58.11 (84 = 54 Hex = 0101 0100)
   → Netid=84.0.0.0
   → Class A
   → Hostid=0.42.58.11
2- 144.54.67.5 (144 = 90 Hex = 1001 0000)
   → Netid=144.54.0.0
   → Class B
   → Hostid=0.0.67.5

Q2: What type of IP address classification will a large organization with 1000 individual users in 150 dispersed buildings use? → Class B
Reserved Addresses

- Some addresses are reserved
- Loopback 127.0.0.1 commonly used for Loopback
  - When Loopback address is used packet do not penetrate to the network (used to check the network card)
- If HostID is all-one \( \rightarrow \) packets are broadcasted to all the hosts on the network
  - Hardware must support broadcast delivery otherwise software must send single messages to each host
- In case of BSC (BSD – Berkeley Software Distribution [http://www.bsd.org/](http://www.bsd.org/)) when HostID is all-zero \( \rightarrow \) packets are broadcasted to all hosts on the network
  - BSD one of the original Unix Distributions
  - Implemented TCP/IP
  - Many are still using it
Subnets and Subnet Masks

- Each LAN assigned *subnet* number
- Host portion of address partitioned into *subnet number* and *host number*
- Local routers route within the subnet
- **Subnet mask** indicates which bits are subnet number and which are host number
  - Ones indicate NetID
  - Zeros indicate Hosts
- Insulate overall internet from growth of network numbers and routing complexity
Routing Using Subnets

LAN X
- Net ID/Subnet ID: 192.228.17.32
- Subnet number: 1
- R1
  - IP Address: 192.228.17.33
  - Host number: 1
- A
  - IP Address: 192.228.17.57
  - Host number: 25

LAN Y
- Net ID/Subnet ID: 192.228.17.64
- Subnet number: 2
- C
  - IP Address: 192.228.17.65
  - Host number: 1
- R2

LAN Z
- Net ID/Subnet ID: 192.228.17.96
- Subnet number: 3
- D
  - IP Address: 192.228.17.97
  - Host number: 1
Masking

57d = 11000000111001

IP Address of B: 192.228.17.57 00 1 10 01
IP Address of A: 192.228.17.33 00 0 00 01
IP Address of X: 192.228.17.32 00 0 00 00

Subnet mask: 255.255.255.224

Note: if we AND IP Address of B & Subnet Mask
We will have:
00 11 10 01 AND
11 10 00 00 =
00 10 00 00 ← 32 The packet belongs to subnet 32 (Accept)
Packet check: 00 1 10 01 → 25 is the host number

192 → 1100 0000, hence, Class C network (8-bit host/subnet)!
Subnet Mask Example

- Given IP Address of LAN X: 192.228.17.32 and its MASK is defined as 255.255.255.224, will 192.228.17.58 be a valid address on the LAN?
  - If so, what will be its Host Number?
Classes and Subnets…

- Classful routing is not very efficient
- Having IP address classes creates issues
  - Addresses can be under utilized (Class A)
  - Addresses can be over utilized (Class C)
  - Management of addresses may be difficult
  - Organizations can grow!

**Example:** Site 1: 12 Hosts / Site 29 Hosts
  - We use 128.211.0.0 → C Class; Dedicated 256-2=254 users!
  - But only few are used

- Alternatives
  - Subnets addressing
  - Classless addressing

- **Classless Inter Domain Routing (CIDR)**
  - Allocate remaining IP addresses in variable-sized block; no regard to class!
  - Use 32-bit mask!
  - Uses a single routing table
Classless vs. Classfull

- **Class C**
  - 24 bits of prefix
  - 0 1 2
  - 1 1 0
  - x
  - 24
  - 31

- **Dedicated to each site**
  - 26 bits of prefix
  - 0 0
  - 0 1
  - 1 0
  - 1 1

- (a) Class C
- (b) Dedicated to each site
More about subnets….

- Routers can be connected to multiple LANs
- LANS are divided into subnets each identified by a subnet mask: 255.255.252.0 (... 1111 1100 0000 0000) → 32-bit-10-bit=22-bit to identify the subnet!
  - **Mask**: netID + SubnetID or /22 (subnet mask is 22 bit long) – **we mask or “hide” the first 22 bits**
  - Subnets are **not visible** outside the network

- **Example**: Assume subnet mask is **255.255.252.0/22**
  - Subnet 1: 130.50.4.0
  - Subnet 2: 130.50.8.0
  - Subnet 3: 130.50.12.0
  - Assume a packet’s destination is **130.50.15.6** → which subnet does it belong to?
  - Mask: ... **1111 11|00 0000 0000**
  - Adrs: ... **0000 11|11 0000 0110**
  - ... **0000 11|00 0000 0000**
  - Hence: the packet must go to Subnet 3 (130.50.12.xx)

**Do problems**

Represents the NetId part in the mask
## CIDR Notation

- **Example 1:**
  - Calculate the mask for 192.168.100.0/24
  
  255.255.255.0

- **Example 2:**
  - Assuming a host (connection) has an address of 172.16.45.0
  - With mask value of 255.255.254.0
  - What will be the network address?

  9 bits are for HostID
  
  45→ 00 10 11 01
  00 10 11 0 → 22 → NetId: 192.16.22.0

  172→ 1010 1100 → B

### CIDR Table

<table>
<thead>
<tr>
<th>Length (CIDR)</th>
<th>Address Mask</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>/0</td>
<td>0.0.0.0</td>
<td>All 0s (equivalent to no mask)</td>
</tr>
<tr>
<td>/1</td>
<td>128.0.0.0</td>
<td>Original Class A mask</td>
</tr>
<tr>
<td>/2</td>
<td>192.0.0.0</td>
<td>Original Class B mask</td>
</tr>
<tr>
<td>/3</td>
<td>224.0.0.0</td>
<td>Original Class C mask</td>
</tr>
<tr>
<td>/4</td>
<td>240.0.0.0</td>
<td></td>
</tr>
<tr>
<td>/5</td>
<td>248.0.0.0</td>
<td></td>
</tr>
<tr>
<td>/6</td>
<td>252.0.0.0</td>
<td></td>
</tr>
<tr>
<td>/7</td>
<td>254.0.0.0</td>
<td></td>
</tr>
<tr>
<td>/8</td>
<td>255.0.0.0</td>
<td></td>
</tr>
<tr>
<td>/9</td>
<td>255.128.0.0</td>
<td></td>
</tr>
<tr>
<td>/10</td>
<td>255.192.0.0</td>
<td></td>
</tr>
<tr>
<td>/11</td>
<td>255.224.0.0</td>
<td></td>
</tr>
<tr>
<td>/12</td>
<td>255.240.0.0</td>
<td></td>
</tr>
<tr>
<td>/13</td>
<td>255.248.0.0</td>
<td></td>
</tr>
<tr>
<td>/14</td>
<td>255.252.0.0</td>
<td></td>
</tr>
<tr>
<td>/15</td>
<td>255.254.0.0</td>
<td></td>
</tr>
<tr>
<td>/16</td>
<td>255.255.0.0</td>
<td></td>
</tr>
<tr>
<td>/17</td>
<td>255.255.128.0</td>
<td></td>
</tr>
<tr>
<td>/18</td>
<td>255.255.192.0</td>
<td></td>
</tr>
<tr>
<td>/19</td>
<td>255.255.224.0</td>
<td></td>
</tr>
<tr>
<td>/20</td>
<td>255.255.240.0</td>
<td></td>
</tr>
<tr>
<td>/21</td>
<td>255.255.248.0</td>
<td></td>
</tr>
<tr>
<td>/22</td>
<td>255.255.252.0</td>
<td></td>
</tr>
<tr>
<td>/23</td>
<td>255.255.254.0</td>
<td></td>
</tr>
<tr>
<td>/24</td>
<td>255.255.255.0</td>
<td></td>
</tr>
<tr>
<td>/25</td>
<td>255.255.255.128.0</td>
<td>All 1s (host specific mask)</td>
</tr>
<tr>
<td>/26</td>
<td>255.255.255.192.0</td>
<td></td>
</tr>
<tr>
<td>/27</td>
<td>255.255.255.224.0</td>
<td></td>
</tr>
<tr>
<td>/28</td>
<td>255.255.255.240.0</td>
<td></td>
</tr>
<tr>
<td>/29</td>
<td>255.255.255.248.0</td>
<td></td>
</tr>
<tr>
<td>/30</td>
<td>255.255.255.252.0</td>
<td></td>
</tr>
<tr>
<td>/31</td>
<td>255.255.255.254.0</td>
<td></td>
</tr>
<tr>
<td>/32</td>
<td>255.255.255.255.0</td>
<td></td>
</tr>
</tbody>
</table>
Reserved Addresses

- 10.0.0./8
- 169.254.0.0/16
- 172.16.0.0/12
- 192.168.0.0/16
Classless Routing - Example

What happens if a packet has an address of 194.24.17.4? Where does it go?

O: ....1111 0000 0000 0000 AND
   ....0001 0001 0000 0100 →
→ .... ....0001 0000 0000 0000 (194.24.16.0) → Oxford

How do you represent class B using CIDR?

16-bit NetID + 16-bit HostID → /16
Routing Decisions by the Router

- If \((\text{Mask [i] } \& \ D) == \text{Destination [i]}\) → Forward next hop

Assume R2 receives packet with destination 192.4.10.3!

<table>
<thead>
<tr>
<th>Destination</th>
<th>Mask</th>
<th>Next Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.0.0.0</td>
<td>255.0.0.0</td>
<td>40.0.0.7</td>
</tr>
<tr>
<td>40.0.0.0</td>
<td>255.0.0.0</td>
<td>deliver direct</td>
</tr>
<tr>
<td>128.1.0.0</td>
<td>255.255.0.0</td>
<td>deliver direct</td>
</tr>
<tr>
<td>192.4.10.0</td>
<td>255.255.255.0</td>
<td>128.1.0.9</td>
</tr>
</tbody>
</table>

Each port has a diff. address

Write a program!
Router IP Address / Connections

- IP addresses refer to connections
- The suffixes for each router can be the same for ease of remembering

![Diagram of network connections](image)

**Ethernet 131.108.0.0/16**

- 131.108.99.5
- 223.240.129.2

**Wi-Fi Net 223.240.129.0/24**

- 223.240.129.17
- 78.0.0.17

**WAN 78.0.0.0/8**
Note:
Route 2 uses the same suffix (suffix in this case is the last byte)
Router 1 Uses different suffix
Questions:
- Can you reach 78.0.1.17?
- Router 1 passes a packet with destination address 131.108.255.255; where does it go?
- If BSD is used what will be the broadcast address 131.108.0.0
Practice Problems:

Provide the following parameter values for each of the network classes A, B, and C. Be sure to consider any special or reserved addresses in your calculations.

a. Number of bits in network portion of address
b. Number of bits in host portion of address
c. Number of distinct networks allowed
d. Number of distinct hosts per network allowed
e. Integer range of first octet

What percentage of the total IP address space does each of the network classes represent?

What is the difference between the subnet mask for a Class A address with 16 bits for the subnet ID and a class B address with 8 bits for the subnet ID? Is the subnet mask 255.255.0.255 valid for a Class A address?

Given a network address of 192.168.100.0 and a subnet mask of 255.255.255.192,

a. How many subnets are created?
b. How many hosts are there per subnet?
References

- Tanenbaum
- Tomasi Text Book
- Comer Text book