Internet Layer and IP

TCP/IP Model

- HTTP, SSH, SMTP,...
- TCP or UDP
- IPv4 or IPv6
- Ethernet, 802.11, ...

Application
Transport
Internet
Host-to-Network

Application communications
End-to-end communications
Communications not local, need to route across devices
Directly connected devices

- Host-to-network communicates between directly connected devices
  - Communications within a Local Area Network (LAN)
  - Therefore communications are one hop (one link) oriented

- *What if the destination is located in a different LAN (multiple hops)*?
Internet Layer

- Concerned with getting packets from the source to the destination
- In contrast, the host-to-network layer
  - Moves frames from one end of the wire to another
  - Assume everyone is locally connected
- Internet layer deals with end-to-end transmission
  - Routing packets (or datagrams) from one computer to another until destination is reached

Network Layer Issues

- Routing
  - Given different paths, which should be taken?
  - Should every packet take the same route?
- Congestion control
  - Prevent a link (router) from becoming overwhelmed
- Internetworking
  - Interconnect different networks at the network level
Internet Operation Overview

- Network layer takes data streams and breaks into datagrams
  - Datagram can be up to 64KB each, average is 1500 bytes
- Each datagram is transmitted through the Internet
  - Possibly fragmented
- Pieces arrive at destination, reassembled into original datagram
- Datagram is passed to the transport layer

IP Protocol Packets

- Packet consists of a header part and data part
- Header consists of: 20 byte fixed part and an optional part

<table>
<thead>
<tr>
<th>Field</th>
<th>Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version</td>
<td>8</td>
</tr>
<tr>
<td>IHL</td>
<td>8</td>
</tr>
<tr>
<td>Type of service</td>
<td>8</td>
</tr>
<tr>
<td>Total length</td>
<td>16</td>
</tr>
<tr>
<td>Identification</td>
<td>16</td>
</tr>
<tr>
<td>Time to live</td>
<td>8</td>
</tr>
<tr>
<td>Protocol</td>
<td>8</td>
</tr>
<tr>
<td>Source address</td>
<td></td>
</tr>
<tr>
<td>Destination address</td>
<td></td>
</tr>
<tr>
<td>Options</td>
<td></td>
</tr>
</tbody>
</table>
IP Fragmentation and Reassembly

- Different network technologies have different packet sizes
  - Every network has a **Maximum Transmission Unit** (MTU)
  - If the datagram is larger than the MTU, then it is fragmented

- “Every internet module must be able to forward a datagram of 68 octets without further fragmentation... Every internet destination must be able to receive a datagram of 576 octets either in one piece or in fragments to be reassembled.” - [RFC791]

 IPv4 Addresses

Every host or router (actually interface) has a unique IP address

- IP addresses are 32 bits long (IP version 4) and are used in the source and destination fields of the IP datagram

- *Dotted-decimal notation* is used to represent each address, each byte is represented via a decimal number
  - 193.32.216.9 ⇒ [11000001 00100000 11011000 00001001]

- Addresses are hierarchical and encode two numbers, **network** and **host**
IP Network Example

Consider one router and seven hosts (one address per interface)

- Three hosts at bottom have similar addresses, 223.1.1.x
  - The leftmost 24 bits they share is the network portion
  - Remaining 8 bits is the host portion

  How many hosts can connect to the 223.1.1.x network?

- Hosts of 223.1.1.x form a network, interconnected via a LAN
  - The network address is 223.1.1.0/24
  - The /24 is also called the network mask or network prefix
    ∗ Indicates the 24 leftmost bits define the network address
  - Any additional host that would attach to this network must have a unique address of the form 223.1.1.x

- The remaining networks have a similar structure
Multiple IP Networks

IP definition of a *network* is not restricted to Ethernet segments

- Consider three routers interconnected via point-to-point links

![Diagram showing three routers R1, R2, and R3 connected via point-to-point links.]

- Each router has three interfaces
  - One for each point-to-point link
  - One for the broadcast link to the hosts

- What are the *networks* in the diagram
  - Three networks interconnecting hosts,
    - 223.1.1.0/24, 223.1.2.0/24, and 223.1.3.0/24
  - Three additional networks that interconnect routers
    * 223.1.7.0/24 connects R1 ⇔ R2
    * 223.1.8.0/24 connects R2 ⇔ R3
    * 223.1.9.0/24 connects R3 ⇔ R1

- How do we determine what is a network
  - Detach each interface from host or router
  - Resulting *islands* are the networks
IPv4 Address Classes

The original Internet architecture defined 5 different IP address classes

- This is also know as **classful addressing**
- Classes differ on how bits are divided (network versus host)

<table>
<thead>
<tr>
<th>Class</th>
<th>Network</th>
<th>Host</th>
<th>Range of host addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td></td>
<td>1.0.0.0 to 127.255.255</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td></td>
<td>128.0.0.0 to 191.255.255</td>
</tr>
<tr>
<td>C</td>
<td>110</td>
<td></td>
<td>192.0.0.0 to 223.255.255</td>
</tr>
<tr>
<td>D</td>
<td>1110</td>
<td>Multicast address</td>
<td>224.0.0.0 to 239.255.255</td>
</tr>
<tr>
<td>E</td>
<td>11110</td>
<td>Reserved for future use</td>
<td>240.0.0.0 to 247.255.255</td>
</tr>
</tbody>
</table>

- This creates 3 different classes of networks (A, B, and C)

- For example, consider class A addresses

  - First bit is zero, identifies class A
  - Next 7 bits identify the network
  - Last 24 bits identify the host (interface) in the class A network

- In comparison, class B has

  What class is **223.1.1.0/24**? As a company, would you prefer an A, B, or C address?
### IP Addresses with Special Meanings

<table>
<thead>
<tr>
<th>Network</th>
<th>Host</th>
<th>Broadcast on the local network</th>
<th>Broadcast on a distant network</th>
<th>Loopback</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0.0.0</td>
<td>0 0 ... 0 0</td>
<td>This host</td>
<td>A host on this network</td>
<td></td>
</tr>
<tr>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
<td>127 (Anything)</td>
<td>(Anything)</td>
<td></td>
</tr>
</tbody>
</table>

- 0.0.0.0 only used by a host when booting
- All zeroes for the network number, refers to the local network
  - If 223.1.1.0/24 is the network and I am 223.1.1.52, locally I can be reached using 0.0.0.52
- Address of all ones is the broadcast address for the local network

*What is the dotted-decimal address?*

- Address with the proper network number, and all ones for the host number allows host to broadcast to a different network
  - If 223.1.1.0/24 is a distant network, then 223.1.1.255 broadcasts to all hosts at the network
  
  *This and ping can can be used as a network attack, how?*

- 127.x.y.z is reserved for loop-back testing
  - Packet is never placed on the network, processed locally
  
  *Given a class A address, how many hosts can be connected to the network?*
IP Addresses and Routing

- We have introduced IP addresses and the concept of a network
  - IP addresses are 32 bits long, and can be divided into classes
  - Each class divides address into network and host portion

```
+----------------+------------------+
<table>
<thead>
<tr>
<th>Class</th>
<th>32 Bits</th>
<th>Range of host addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>1.0.0.0 to 127.255.255.255</td>
</tr>
<tr>
<td>B</td>
<td>Network Host</td>
<td>128.0.0.0 to 191.255.255.255</td>
</tr>
<tr>
<td>C</td>
<td>Network Host</td>
<td>192.0.0.0 to 223.255.255.255</td>
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</tr>
</tbody>
</table>
```

- All hosts in one network have the same network portion, different host portion; therefore, the addresses are hierarchical

Why is it important to identify the class of an address?

Routing Tables

How does a source host send a datagram to a destination host?

- The IP layer maintains a routing table in memory
  - Remember, routing tables are next hop oriented
  - Multiple hop paths are not recorded
- Each entry in the routing table has the following information\(^a\)
  1. Destination address, either host or network address
  2. IP address of the next-hop router
  3. Flags specifying if next hop is host or network
  4. Identification of the interface the datagram should be passed to (e.g. multiple Ethernet cards attached)

\(^a\)Abbreviated list of items, more later.
• In the diagram, each interface (Ethernet card) is labeled (in red)

• For example, the router has 3 interfaces (eth0, eth1, and eth2)
  – Each interface must be uniquely identified, since it attaches a unique network

• An abbreviated routing table for host A would be

<table>
<thead>
<tr>
<th>Destination</th>
<th>Next Hop</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>223.1.1.0/24</td>
<td>eth0</td>
<td>eth0</td>
</tr>
<tr>
<td>223.1.2.0/24</td>
<td>223.1.1.4</td>
<td>eth0</td>
</tr>
<tr>
<td>223.1.3.0/24</td>
<td>223.1.1.4</td>
<td>eth0</td>
</tr>
</tbody>
</table>

  – First entry indicates 223.1.1.0/24 is the local network
  – The second and third entries indicate datagrams for destinations on network 223.1.2.0/24 or 223.1.3.0/24 must be sent to 223.1.1.4
  – eth0 is the Ethernet interface (only one card on A)

Each network is represented with one entry, how many would be required if each host had a separate entry?
An abbreviated routing table for the router would be

<table>
<thead>
<tr>
<th>Destination</th>
<th>Next Hop</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>223.1.1.0/24</td>
<td></td>
<td>eth0</td>
</tr>
<tr>
<td>223.1.2.0/24</td>
<td></td>
<td>eth1</td>
</tr>
<tr>
<td>223.1.3.0/24</td>
<td></td>
<td>eth2</td>
</tr>
</tbody>
</table>

- First entry indicates 223.1.1.0/24 is local on eth0
- Second entry indicates 223.1.2.0/24 is local on eth1
- Third entry indicates 223.1.3.0/24 is local on eth2

**IP Routing Steps**

- IP routing performs the following actions
  1. Search routing table for complete destination address, if found send packet to the next-hop entry
  2. Search routing table for an entry that matches the destination network number, if found send packet to the next-hop entry
     - Must take into account possible subnet mask
  3. Search for default entry, if found send to next-hop router
- IP search order is, host address → host network → default
- If all the steps fail, then the datagram is not deliverable
Routing Example: A → B

Assume A (223.1.1.1) sends datagram to B (223.1.1.3)

- There is no host entry for 223.1.1.3
- There is a network entry for 223.1.1.0/24
- A link layer frame (containing the datagram) is created and addressed to the link layer address of 223.1.1.3

*We are at layer 3, how do we get a layer 2 address?*

- Ethernet frame is sent and received by host B

Routing Example: A → E

Assume A (223.1.1.1) sends datagram to E (223.1.2.2)

- Host A finds entry for 223.1.2.0/24 network
  - Requires sending packet to 223.1.1.4
- Host A creates and sends link-layer frame (containing datagram) addressed to the link-layer address of 223.1.1.4
  - Therefore, the next-hop entry is used for the link-layer address
  - IP destination address remains unchanged
• Router 223.1.1.4 receives frame and removes datagram
  – Destination address is 223.1.2.2
  – Router is allowed to forward datagrams

• Router finds entry for 223.1.2.0/24 network
  – This is directly connected via eth1
  – Datagram will be forwarded

• Router creates and sends link-layer frame (containing datagram) addressed to the link-layer address of 223.1.2.2 on eth1

• Frame received by host E, datagram removed and processed

• N.B. operation of host and router are equivalent, except routers are allowed to forward datagrams
Another Routing Example

Assume 140.1.1.1 sends a datagram to 152.24.25.5

140.1.1.1 sends a datagram to 152.24.25.5.