Network layer: Overview

- Network layer functions
- IP
- Routing and forwarding

Network layer functions

- Transport packet from sending to receiving hosts
- Network layer protocols in every host, router

Three important functions:
- Path determination: route taken by packets from source to dest. Routing algorithms
- Switching: move packets from router’s input to appropriate router output
IP addressing

- **IP address:** 32-bit identifier for host, router *interface*

- **Interface:** connection between host, router and physical link
  - Routers typically have multiple interfaces
  - Host may have multiple interfaces
  - IP addresses associated with interface, not host, router

```
223.1.1.1  = 11011111 00000001 00000001 00000001
```

IP addressing (2)

- **IP address:**
  - Network part (high order bits)
  - Host part (low order bits)

- **What's a network?**
  (from IP address perspective)
  - Device interfaces with same network part of IP address
  - Can physically reach each other without intervening router

Network consisting of 3 IP networks (for IP addresses starting with 223, first 24 bits are network address)
IP addressing (3)

How to find the networks?
- Detach each interface from router, host
- Create “islands” of isolated networks

Interconnected system consisting of six networks

IP networks: Subnets

- Sub divide address space
  - Network part
  - Host address
- Address format: a.b.c.d/x, where x is # bits in subnet portion of address

```
subnet part  host part
11001000 00010111 00010000 00000000
200.23.16.0/24
```
Fixed subnetting (classful)

<table>
<thead>
<tr>
<th>Class</th>
<th>Network</th>
<th>Host</th>
<th>Address Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>host</td>
<td>1.0.0.0 to 127.255.255.255</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>network</td>
<td>128.0.0.0 to 191.255.255.255</td>
</tr>
<tr>
<td>C</td>
<td>110</td>
<td>network</td>
<td>192.0.0.0 to 239.255.255.255</td>
</tr>
<tr>
<td>D</td>
<td>1110</td>
<td>multicast address</td>
<td>240.0.0.0 to 247.255.255.255</td>
</tr>
</tbody>
</table>

Address management

- Problem: we are running out of networks
- Solution
  - Subnetting
  - CIDR (Classless Inter Domain Routing)
CIDR

- Classless InterDomain Routing
- Class A is too large, Class C is too small
- Everyone has a Class B address!!!

- Solution: sites are given contiguous blocks of class-C addresses (256 addresses each) and a mask or parts of former class A/B networks.

CIDR: Classless InterDomain Routing

- Subnet portion of address of arbitrary length
- Address format: a.b.c.d/x, where x is # bits in subnet portion of address

```
11001000  00010111 00010000  00000000

200.23.16.0/23
```
Hierarchical address structure

- Recall: CIDR
  - 128.119.48.12/18 = \(10000000\ 01110111\ 00110000\ 00001100\)
  - High order bits form the **prefix**
  - Once inside the network, can **subnet**: divide remaining bits
  - Subnet example:

    - 129.128.0.0/10
    - 129.128.0.0/12
    - 129.160.0.0/12
    - 129.176.0.0/14
    - 129.176.0.0/14
    - 129.184.0.0/14

    ![Diagram](Note: Picture shows prefix masks, not interface addrs!)

- **Forwarding decision: longest prefix match**

Forwarding vs. Routing

- **Forwarding**: the process of moving packets from input to output
  - The forwarding table
  - Information in the packet

- **Routing**: process by which the forwarding table is built and maintained
  - One or more routing protocols
  - Procedures (algorithms) to convert routing info to forwarding table.
  (Much more later ...)
Forwarding with CIDR

- Packet should be sent towards the interface with the longest matching prefix

Advertised addresses

<table>
<thead>
<tr>
<th>Network</th>
<th>Mask</th>
<th>Next-Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>134.96.252.0/24</td>
<td>A</td>
<td>134.96.252.200</td>
</tr>
<tr>
<td>134.96.0.0/16</td>
<td>C</td>
<td>134.96.254.2</td>
</tr>
<tr>
<td>134.96.240.0/20</td>
<td>B</td>
<td>134.96.239.200</td>
</tr>
<tr>
<td>134.96.252.192/28</td>
<td>B</td>
<td>134.97.239.200</td>
</tr>
<tr>
<td>134.96.252.128/28</td>
<td>A</td>
<td>134.96.252.191</td>
</tr>
</tbody>
</table>
**IPv4 datagram format**

- **IP protocol version number**
- **Header length (bytes)**
- "**Type**" of data
- **Max number remaining hops** (decremented at each router)
- **Upper layer protocol to deliver payload to**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version</td>
<td>32 bits</td>
</tr>
<tr>
<td>Protocol</td>
<td>16-bit identifier</td>
</tr>
<tr>
<td>Type of service</td>
<td>16-bit identifier</td>
</tr>
<tr>
<td>Data length</td>
<td>16-bit identifier</td>
</tr>
<tr>
<td>Time to live</td>
<td>16-bit identifier</td>
</tr>
<tr>
<td>Upper layer checksum</td>
<td>32 bit source IP address</td>
</tr>
<tr>
<td>Internet checksum</td>
<td>32 bit destination IP address</td>
</tr>
<tr>
<td>Options (if any)</td>
<td>E.g. timestamp, record route taken, specify list of routers to visit.</td>
</tr>
<tr>
<td>Data</td>
<td>(variable length, typically a TCP or UDP segment)</td>
</tr>
</tbody>
</table>

**Total datagram length (bytes)**

**For fragmentation/reassembly**

**ICMP: Internet Control Message Protocol**

- **Used by hosts, routers, gateways to communication network-level information**
  - Error reporting: unreachable host, network, port, protocol
  - Echo request/reply (used by ping)
- **Network-layer "above" IP:**
  - ICMP msgs carried in IP datagrams
- **ICMP message:** type, code plus first 8 bytes of IP datagram causing error

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>echo reply (ping)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>dest network unreachable</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>dest host unreachable</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>dest protocol unreachable</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>dest port unreachable</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>dest network unknown</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>dest host unknown</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>source quench (congestion control – not used)</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>echo request (ping)</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>route advertisement</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>router discovery</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>TTL expired</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>bad IP header</td>
</tr>
</tbody>
</table>
Network layer: Summary

- Network layer functions
- IP
- Routing and forwarding