The IP Internet Protocol

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The Network Layer: Routing & Addressing

Outline

- Network layer services
- Routing algorithms
  - Least cost path computation algorithms
- Hierarchical routing
  - Connecting networks of networks
- IP Internet Protocol
  - Addressing
  - IPv6
- Routing on the Internet
  - Intra-domain routing
  - Inter-domain routing
- Router architecture
The Internet Network layer
Host and router network layer functions

- **Routing protocols**
  - RIP, OSPF, BGP

**Transport layer:** TCP, UDP

**Network layer**

**Link layer**

**Physical layer**

The Internet Network layer
IP datagram format

- **IP datagrams**
  - The protocol data units at the IP network layer

- (Not to be confused with UDP datagrams)
  - The protocol data units at the UDP transport layer are also called datagrams

**IP datagram format**

- 32-bit source IP address
- 32-bit destination IP address
- Options (if any)
- Data (variable length, typically a TCP segment or UDP datagram)
IP Addressing

Introduction

- IP address: 32-bit identifier for host or router interface
- Interface: connection between host or router and a physical link
  - Routers typically have multiple interfaces
  - Host may have multiple interfaces (typically not)
  - IP addresses are associated with an interface, not the host or router

```
223.1.1.1
223.1.1.2
223.1.1.3
223.1.1.4
223.1.2.1
223.1.2.2
223.1.2.9
223.1.2.10
223.1.3.1
223.1.3.2
223.1.3.27
```
IP Addressing
Host address v. Network addresses

- A network is the set of hosts reachable without having to traverse a router
  - Detach each interface from router or host
  - Create “islands” of isolated networks

![Network Diagram with IP addresses]

Note: single point-to-point link is an (IP) network

IP Addressing
UNC campus topology (2016)

- Internet connections
- Med School
- The rest of campus!
- Resnet
- Wireless Interconnection Points
- ITS Machine Rooms
- Computer Science
### IP Addressing

#### Class-based addressing

- **Class A addresses**
  - 128 networks
  - 65,536 to $2^{24}$ hosts
- **Class B addresses**
  - 16,384 networks
  - 256 to 65,536 hosts
- **Class C addresses**
  - $2^{21}$ networks
  - Less than 256 hosts
- **Class D addresses**
  - 28-bit multicast addresses
  - No origin or network information is encoded

#### Classless Inter Domain Routing (CIDR)

- **Class-based addressing**
  - Inefficient use of address space, address space exhaustion
  - e.g., class B network allocated enough addresses for 64K hosts, even if only 300 hosts in that network
- **Classless addressing**
  - Network portion of address has an arbitrary length
  - Address format: a.b.c.d/x, where x is the number of bits in network portion of address; called the network mask
  - Used only in routing tables, not IP datagram source/destination

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Here is a sample diagram and some text content related to IP addressing and classless addressing. The content includes details about the different classes of IP addresses and their characteristics, as well as an explanation of Classless Inter Domain Routing (CIDR). The diagram illustrates the structure of IP addresses and how they are represented in routing tables.
IP addresses
How are IP addresses assigned?

◆ The network address is assigned by the ISP
  » Hosts portion only; all hosts share the same network portion
◆ Host address
  » Static assignment:
    ❖ Configuration parameter (manually) set during system installation
  » Dynamic assignment at boot/wake-up time
    ❖ DHCP: Dynamic Host Configuration Protocol:
      » Host broadcasts a "DHCP discover" message
      » DHCP server responds with a "DHCP offer" message
      » Host requests IP address: "DHCP request" message
      » DHCP server sends address: "DHCP ack" message

ISP's block
Organization 0
Organization 1
Organization 2
Organization 7

ISP's block from ICANN (Internet Corporation for Assigned Names and Numbers)
» ICANN allocates IP address blocks, manages DNS, (used to assign domain names), resolves disputes
◆ ISPs subdivide their block among their customers
Routing IP Datagrams

**Example**

All routing is based on the IP destination address field in the IP header.

IP destination address (and data fields) never change!

- Delivery to intermediate hops involves link-layer addresses.

### Routing table in A

<table>
<thead>
<tr>
<th>Dest. Net</th>
<th>next router</th>
<th>Nhops</th>
</tr>
</thead>
<tbody>
<tr>
<td>223.1.1/24</td>
<td>223.1.1.4</td>
<td>2</td>
</tr>
<tr>
<td>*(default)</td>
<td>223.1.1.4</td>
<td>2</td>
</tr>
</tbody>
</table>

### Delivery to intermediate hops

- The IP layer on A looks up the network address of B...
- And determines that B is on the same network as A (223.1.1)
- A's link layer sends the IP datagram directly to B inside link-layer frame.
- B and A are assumed to be connected to the same physical network.

**Routing to a local destination**

An application on A generates an IP datagram addressed to B.

The IP layer on A looks up the network address of B...

And determines that B is on the same network as A (223.1.1).
Routing IP Datagrams
Routing to a remote destination

◆ Host A generates an IP datagram addressed to E
  » The IP layer on A looks up network address of E (223.1.2)
  » A determines that E is NOT on same network as A
  » A's routing table shows router 223.1.1.4 as the default for all networks

◆ A's link layer sends IP datagram to router inside link-layer frame
Routing IP Datagrams

NetMasks

<quintet.cs.unc.edu>$ ifconfig
eth0   Link encap:Ethernet  HWaddr 00:06:5B:F3:34:7F
       inet addr:152.2.128.80  Bcast:152.2.255.255  Mask:255.255.0.0
       inet6 addr: fe80::206:5bff:feff:347f/64 Scope:Link
       UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
       RX packets:59314376 errors:0 dropped:0 overruns:0 frame:0
       TX packets:7659872 errors:0 dropped:0 overruns:0 carrier:0
       collisions:0 txqueuelen:1000
       RX bytes:401871884 (383.2 MiB)  TX bytes:2309337676 (2.1 GiB)
       Interrupt:193

Hierarchical addressing

Route aggregation

- Hierarchical addressing allows efficient specification of routing information by gateway routers

4 billion possible Internet addresses!
Hierarchical addressing

Specific routes

Q: If Organization 1 moves to ISPsRUs, how will Internet core routers choose a route to Organization 1?
   A: Use "longest prefix match" on network part of IP destination address

Longest Prefix Matching

<table>
<thead>
<tr>
<th>Destination Address Range</th>
<th>Port/Interface</th>
<th>Prefix To Match</th>
<th>Port/Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001000.00010111.00010000.00000000</td>
<td>0</td>
<td>11001000.00010111.00010000</td>
<td>0</td>
</tr>
<tr>
<td>11001000.00010111.00010111.11111111</td>
<td>1</td>
<td>11001000.00010111.00010111</td>
<td>1</td>
</tr>
<tr>
<td>11001000.00010111.00010111.11111111</td>
<td>2</td>
<td>11001000.00010111.00010111</td>
<td>2</td>
</tr>
<tr>
<td>11001000.00010111.00010111.11111111</td>
<td>3</td>
<td>otherwise</td>
<td>3</td>
</tr>
</tbody>
</table>

Examples (given destination IP address, forward to which interface?)

- Destination Address: 11001000.00010111.00010111.01001001
  - Port/Interface: ??

- Destination Address: 11001000.00010111.00010100.10101001
  - Port/Interface: ??

- Destination Address: 11001000.00010111.00010100.10101010
  - Port/Interface: ??
Datagram Routing and Transmission
IP datagram encapsulation (Ethernet)

- Sending interface adapter encapsulates IP datagram (or other network layer protocol packet) in an *Ethernet frame*.
IP Datagrams
Fragmentation & Reassembly

- Network links have a maximum frame size
  - Called the **maximum transmission unit (MTU)**
  - Different link types, different MTUs
- Large IP datagrams must be “fragmented” to link MTU sizes
  - One IP datagram becomes several IP datagrams as it transits networks
  - “Fragments” reassembled only at the final destination
- All fragments carry the same IP identification number
  - All fragments (except the last) have the fragment bit set

IP Fragmentation and Reassembly
Ethernet MTU example

- Consider a 3,980 byte message sent in an FDDI frame
- The message generates 3 fragments when it transits an Ethernet
  - How much application data is in each fragment?