Internetworking

■ Motivation
  ● Heterogeneity
  ● Scale

■ IP is the glue that connects heterogeneous networks giving the illusion of a homogenous one.

■ Salient Features
  ● Best Effort Service Model
  ● Global Addressing Scheme
IP Internet

- Concatenation of Networks

- Protocol Stack
Service Model

- Connectionless (datagram-based)
- Best-effort delivery (unreliable service)
  - packets are lost
  - packets are delivered out of order
  - duplicate copies of a packet are delivered
  - packets can be delayed for a long time
- Datagram format
Fragmentation and Reassembly

- Each network has some MTU

- Strategy
  - fragment when necessary
    - If (MTU < Datagram_size) fragment
  - try to avoid fragmentation at source host
  - re-fragmentation is possible
  - fragments are self-contained datagrams
  - use CS-PDU (not cells) for ATM
  - delay reassembly until destination host
  - do not recover from lost fragments
Example
Global IP Addresses

■ Properties
 ● globally unique
 ● hierarchical: network + host

■ Dot Notation
 ● 10.3.2.4
 ● 128.96.33.81
 ● 192.12.69.77
Datagram Forwarding

Strategy
- every datagram contains destination's address
- if directly connected to destination network, then forward to host
- if not directly connected to destination network, then forward to some router
- forwarding table maps network number into next hop
- each host has a default router
- each router maintains a forwarding table

Example (R2)

<table>
<thead>
<tr>
<th>Network Number</th>
<th>Next Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R3</td>
</tr>
<tr>
<td>2</td>
<td>R1</td>
</tr>
<tr>
<td>3</td>
<td>interface 1</td>
</tr>
<tr>
<td>4</td>
<td>interface 0</td>
</tr>
</tbody>
</table>
Address Translation

- Map IP addresses into physical addresses

Techniques

- encode physical address in host part of IP address
  - Problem: Limited by number of bits in the host part of the IP address
- table-based mapping between IP addresses and link layer addresses
Address Resolution Protocol (ARP)

- Maps IP addresses to Ethernet Addresses
- ARP responses are cached
ARP Details

Request Format
- HardwareType: type of physical network (e.g., Ethernet)
- ProtocolType: type of higher layer protocol (e.g., IP)
- HLEN & PLEN: length of physical and protocol addresses
- Operation: request or response
- Source/Target-Physical/Protocol addresses

Usage Notes
- table entries timeout in about 10 minutes
- update table with source when you are the target
- update table if already have an entry
- do not refresh table entries upon reference
ARP Packet Format

<table>
<thead>
<tr>
<th>0</th>
<th>8</th>
<th>16</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware type = 1</td>
<td>ProtocolType = 0x0800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HLen = 48</td>
<td>PLen = 32</td>
<td>Operation</td>
<td></td>
</tr>
<tr>
<td>SourceHardwareAddr (bytes 0 – 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SourceHardwareAddr (bytes 4 – 5)</td>
<td>SourceProtocolAddr (bytes 0 – 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SourceProtocolAddr (bytes 2 – 3)</td>
<td>TargetHardwareAddr (bytes 0 – 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TargetHardwareAddr (bytes 2 – 5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TargetProtocolAddr (bytes 0 – 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Internet Control Message Protocol (ICMP)

- Echo (ping)
- Redirect (from router to source host)
- Destination unreachable (protocol, port, or host)
- TTL exceeded (so datagrams don’t cycle forever)
- Checksum failed
- Reassembly failed
- Cannot fragment