Internetworking

Outline
- 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
- Design decisions
  - fragment when necessary (MTU < Datagram)
  - 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

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Example

```
<table>
<thead>
<tr>
<th>H1</th>
<th>K2</th>
<th>K3</th>
<th>K4</th>
<th>H8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETH</td>
<td>IP (1400)</td>
<td>FDDI</td>
<td>IP (1400)</td>
<td>PPP</td>
</tr>
<tr>
<td>PPP</td>
<td>IP (376)</td>
<td>PPP</td>
<td>IP (512)</td>
<td></td>
</tr>
<tr>
<td>ETH</td>
<td>IP (512)</td>
<td>ETH</td>
<td>IP (376)</td>
<td>ETH</td>
</tr>
</tbody>
</table>
```

- Ident = x
- Offset = 0
- Start of header 0
- Rest of header 1400 bytes
- Ident = x
- Offset = 512
- Start of header 1
- Rest of header 512 bytes
- Ident = x
- Offset = 1024
- Start of header 0
- Rest of header 376 bytes

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Global Addresses

- Properties
  - globally unique
  - hierarchical: network + host

- Dot Notation
  - 10.3.2.4
  - 128.96.33.81
  - 192.12.69.77

```
<table>
<thead>
<tr>
<th>Network</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>21</td>
<td>8</td>
</tr>
</tbody>
</table>
```
Datagram Forwarding

• Strategy
  – every datagram contains destination’s address
  – if connected to destination network, then forward to host
  – if not directly connected, 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
  – destination host
  – next hop router

• Techniques
  – encode physical address in host part of IP address
  – table-based

• ARP
  – table of IP to physical address bindings
  – broadcast request if IP address not in table
  – target machine responds with its physical address
  – table entries are discarded if not refreshed

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

• 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

```
0  8  16  31
<table>
<thead>
<tr>
<th>Hardware type = 1</th>
<th>Protocol Type = 0x0800</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLen = 48</td>
<td>PLen = 32</td>
</tr>
<tr>
<td>Operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Source Hardware Addr (bytes 0 – 3)</td>
<td></td>
</tr>
<tr>
<td>Source Protocol Addr (bytes 4 – 5)</td>
<td></td>
</tr>
<tr>
<td>Source Protocol Addr (bytes 2 – 3)</td>
<td></td>
</tr>
<tr>
<td>Target Hardware Addr (bytes 0 – 3)</td>
<td></td>
</tr>
<tr>
<td>Target Protocol Addr (bytes 0 – 1)</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