**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

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**IP Internet**

- **Concatenation of Networks**

- **Protocol Stack**

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**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**

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**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

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**Example**

- **Global IP Addresses**
  - **Properties**
    - Globally unique
    - Hierarchical: network + host
  - **Dot Notation**
    - 10.3.2.4
    - 128.96.33.81
    - 192.12.69.77

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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**

<table>
<thead>
<tr>
<th>ARP Query</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet: 0A:03:21:60:09:FA</td>
</tr>
<tr>
<td>IP: 130.245.20.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ARP Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet: 0A:03:23:65:09:FB</td>
</tr>
<tr>
<td>IP: 130.245.20.2</td>
</tr>
</tbody>
</table>

**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>Hardware type</th>
<th>Protocol Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0x0800</td>
</tr>
<tr>
<td>HLen</td>
<td>PLen</td>
</tr>
<tr>
<td>48</td>
<td>32</td>
</tr>
<tr>
<td>Operation</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**