PART VI

INTERNET PROTOCOL:
CONNECTIONLESS DATAGRAM DELIVERY
Internet Protocol

• One of two major protocols in TCP/IP suite
• Major goals
  – Hide heterogeneity
  – Provide the illusion of a single large network
  – Virtualize access
The Concept

*IP allows a user to think of an internet as a single virtual network that interconnects all hosts, and through which communication is possible; its underlying architecture is both hidden and irrelevant.*
Internet Services And Architecture Of Protocol Software

- Design has proved especially robust
IP Characteristics

- Provides connectionless packet delivery service
- Defines three important items
  - Internet addressing scheme
  - Format of packets for the (virtual) Internet
  - Packet forwarding
Internet Packet

- Analogous to physical network packet
- Known as *IP datagram*
IP Datagram Layout

- Header contains
  - Source Internet address
  - Destination Internet address
  - Datagram type field
- Payload contains data being carried
## Datagram Header Format

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Addresses In The Header

- SOURCE is the address of original source
- DESTINATION is the address of ultimate destination
IP Versions

- Version field in header defines version of datagram
- Internet currently uses version 4 of IP, IPv4
- Preceding figure is the IPv4 datagram format
- IPv6 discussed later in the course
Datagram Encapsulation

- Datagram *encapsulated* in network frame
- Network hardware treats datagram as data
- Frame type field identifies contents as datagram
  - Set by sending computer
  - Tested by receiving computer
Datagram Encapsulation For Ethernet

- Ethernet header contains Ethernet hardware addresses
- Ethernet type field set to 0x0800
## Ethernet Frame Format

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<tr>
<th>Destination Hardware Address</th>
<th>Source Hardware Address</th>
<th>Frame Type</th>
<th>Frame Data</th>
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<td>6 Bytes</td>
<td>2 Bytes</td>
<td>46 - 1500 Bytes</td>
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- Header format fixed (Destination, Source, Type fields)
- Frame data size can vary from packet to packet
  - Maximum 1500 octets
  - Minimum 46 octets
Datagram Encapsulated In Ethernet Frame

- 20-octet IP header follows Ethernet header
- IP source: 128.10.2.3 (800a0203)
- IP destination: 128.10.2.8 (800a0208)
- IP type: 01 (ICMP)
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<th><strong>Frame Type</strong></th>
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**Header Checksum:**

- Source: 10001011 10111011 11101011 11010101 10100011 00000000
- Destination: 10111011 11001111 00000100 01111111 10101100 00101011

**Fragment Offset:**

- Source: 00010100 10001101
- Destination: 00010100 10001101

**Source IP Address (Decimal):**

- Source: 210 146 142 57
- Destination: 73 22 117 2

**Payload Data:**

- Source: 11010110 00011011 10111110 11001000 00110011
- Destination: 01001001 00010110 01110101 00000010
<table>
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<tr>
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<th>Source Hardware Address</th>
<th>Frame Type</th>
<th>Frame Data</th>
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| 00 | 72 | CA | 0C | 33 | 6A | BC | EA | F7 | 21 | 21 | 09 | 7F | 7A | C1 | 2B |
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<td>D1 1A 9D 41 79 BD</td>
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<tr>
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</tr>
<tr>
<td>Vers &amp; Len</td>
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<tr>
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<td>Total Length</td>
<td>00 72</td>
</tr>
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<tr>
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<tr>
<td>Fragment Offset</td>
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<tr>
<td>TTL</td>
<td>BC</td>
</tr>
<tr>
<td>Type</td>
<td>EA</td>
</tr>
<tr>
<td>Header Checksum</td>
<td>F7 21</td>
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| Source IP Address            | 21 09 7F 7A |
| Class                        | A            |
| Network                      | 21           |
| Host                         | 09 7F 7A     |
| Source IP Address (Decimal)  | 33 9 127 122 |
| Destination IP Address       | C1 2B 02 5D  |
| Class                        | C            |
| Network                      | C1 2B 02     |
| Host                         | 5D           |

| Destination IP Address (Decimal) | 193 43 2 93 |

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<th>Payload Data</th>
<th>7E 7D 37 33 97</th>
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<td></td>
<td>01111110 01111101 00110111 00110011 10010111</td>
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<td>Destination Hardware Address</td>
<td>Source Hardware Address</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>6 Bytes</td>
<td>6 Bytes</td>
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<td>3</td>
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<td>Type Of Service</td>
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<td>12</td>
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<td>16</td>
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</tr>
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<td>IP Options (May Be Omitted)</td>
<td>Padding</td>
<td></td>
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<td>20</td>
<td>IP Payload Data</td>
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```
87 36 8F 42 77 95 83 1A AB 39 16 D9 08 00 45 EE
00 72 B3 45 4A 9A E0 E0 BC 20 39 16 85 EA DE 78
12 02 B3 86 BE AA B7 06 0C 15 71 87 B1 85 28 59
F9 68 E9 13 C5 B7 76 2C A9 B4 C9 78 1C 42 39 AE
8C 54 EB E7 DA BB 05 CF F4 BA FD 5B 1C 42 4A 8D
61 FD 13 4F 2B 02 36 99 30 67 43 28 C1 98 C7 03
F1 80 ED 5F 1F 31 05 04 E6 41 70 E5 26 47 4A 19
A6 1C CD DA 14 5C CA AD D2 72 CB 71 42 93 08 01
```
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<th>Destination Hardware Address</th>
<th>87  36  8F  42  77  95</th>
<th>10000111 00110110 10001111 01000010 01110111 10010101</th>
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<td>Source Hardware Address</td>
<td>83  1A  AB  39  16  D9</td>
<td>10000011 00011010 10101011 00111001 00010110 11011001</td>
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<tr>
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<td>08  00</td>
<td>00001000 00000000</td>
</tr>
<tr>
<td>Vers &amp; Len</td>
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<td>01000101</td>
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<tr>
<td>Type Of Service</td>
<td>EE</td>
<td>11101110</td>
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<td>Total Length</td>
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<td>00000000 01110010</td>
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<tr>
<td>Identi</td>
<td>B3  45</td>
<td>10110011 01000101</td>
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<tr>
<td>Flags &amp; Fragment Offset</td>
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<td>01001010 10011010</td>
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<tr>
<td>Flags</td>
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<tr>
<td>Fragment Offset</td>
<td>0A  9A</td>
<td>00001010 10011010</td>
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<td>Destination IP Address</td>
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<td>Class</td>
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<td>Destination IP Address</td>
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<td>(Decimal)</td>
<td>222 120 18 2</td>
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<td>Payload Data</td>
<td>B3  86  BE  AA  B7</td>
<td>10110011 10000110 10111110 10101010 10110111</td>
</tr>
</tbody>
</table>
Standards For Encapsulation

- TCP/IP protocols define encapsulation for each possible type of network hardware
  - Ethernet
  - Frame Relay
  - Others
A Potential Problem

- A datagram can contain up to 65535 total octets (including header)
- Network hardware limits maximum size of frame (e.g., Ethernet limited to 1500 octets)
  - Known as the network *Maximum Transmission Unit (MTU)*
- Question: how is encapsulation handled if datagram exceeds network MTU?
Possible Ways To Accommodate Networks With Differing MTUs

- Force datagram to be less than smallest possible MTU
  - Inefficient
  - Cannot know minimum MTU
- Hide the network MTU and accommodate arbitrary datagram size
Accommodating Large Datagrams

• Cannot send large datagram in single frame
• Solution
  – Divide datagram into pieces
  – Send each piece in a frame
  – Called *datagram fragmentation*
Illustration Of When Fragmentation Needed

- Hosts A and B send datagrams of up to 1500 octets
- Router $R_1$ fragments large datagrams from Host A before sending over Net 2
- Router $R_2$ fragments large datagrams from Host B before sending over Net 2
Datagram Fragmentation

- Performed by routers
- Divides datagram into several, smaller datagrams called fragments
- Fragment uses same header format as datagram
- Each fragment forwarded independently
Illustration Of Fragmentation

<table>
<thead>
<tr>
<th>Header</th>
<th>data₁</th>
<th>data₂</th>
<th>data₃</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>600 bytes</td>
<td>600 bytes</td>
<td>200 bytes</td>
</tr>
</tbody>
</table>

fragment #1 (offset of 0)
fragment #2 (offset of 600)
fragment #3 (offset of 1200)

- Offset specifies where data belongs in original datagram
- Offset actually stored as multiples of 8 octets
- MORE FRAGMENTS bit turned off in header of fragment #3
Fragmenting A Fragment

• Fragment can be further fragmented

• Occurs when fragment reaches an even-smaller MTU

• Discussion: which fields of the datagram header are used, and what is the algorithm?
Reassembly

- Ultimate destination puts fragments back together
  - Key concept!
  - Needed in a connectionless Internet
- Known as reassembly
- No need to reassemble subfragments first
- Timer used to ensure all fragments arrive
  - Timer started when first fragment arrives
  - If timer expires, entire datagram discarded
Time To Live

- TTL field of datagram header decremented at each hop (i.e., each router)
- If TTL reaches zero, datagram discarded
- Prevents datagrams from looping indefinitely (in case forwarding error introduces loop)
- IETF recommends initial value of 255 (max)
Checksum Field In Datagram Header

- 16-bit 1’s complement checksum
- Over IP header only!
- Recomputed at each hop
IP Options

- Seldom used
- Primarily for debugging
- Only *some* options copied into fragments
- Are variable length
- Note: padding needed because header length measured in 32-bit multiples
- Option starts with option code octet
IP Semantics

- IP uses best-effort delivery
  - Makes an attempt to deliver
  - Does not guarantee delivery
- In the Internet, routers become overrun or change routes, meaning that:
  - Datagrams can be lost
  - Datagrams can be duplicated
  - Datagrams can arrive out of order or scrambled
- Motivation: allow IP to operate over the widest possible variety of physical networks
Summary

- Internet Protocol provides basic connectionless delivery service for the Internet
- IP defines *IP datagram* to be the format of packets on the Internet
- Datagram header
  - Has fixed fields
  - Specifies source, destination, and type
  - Allows options
- Datagram encapsulated in network frame for transmission
Summary
(continued)

- Fragmentation
  - Needed when datagram larger than MTU
  - Usually performed by routers
  - Divides datagram into fragments

- Reassembly
  - Performed by ultimate destination
  - If some fragment(s) do not arrive, datagram discarded

- To accommodate all possible network hardware, IP does not require reliability (best-effort semantics)