Module 4

(Lecture – 2)

(Network Layer: Router architecture; Internet Protocol (IP) - Forwarding and Addressing in the Internet; Routing algorithms - Link-state routing, Distance vector routing, Hierarchical routing; Routing in the Internet - RIP, OSPF, BGP; Broadcast & multicast routing; ICMP; Next Generation IP - IPv6)

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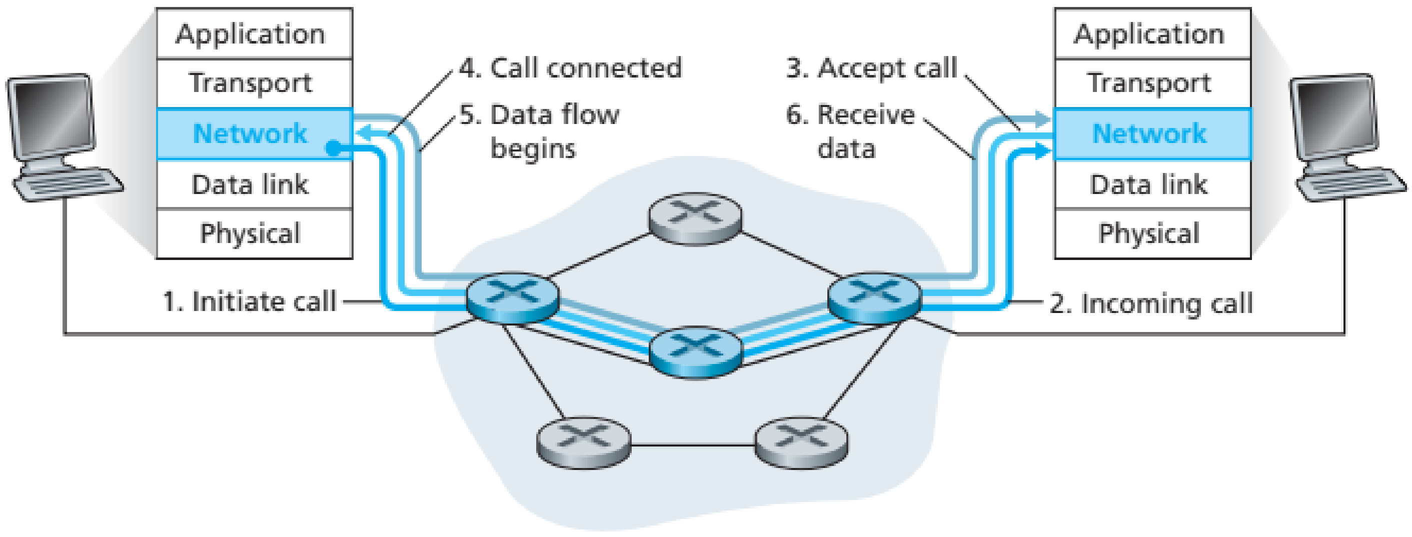
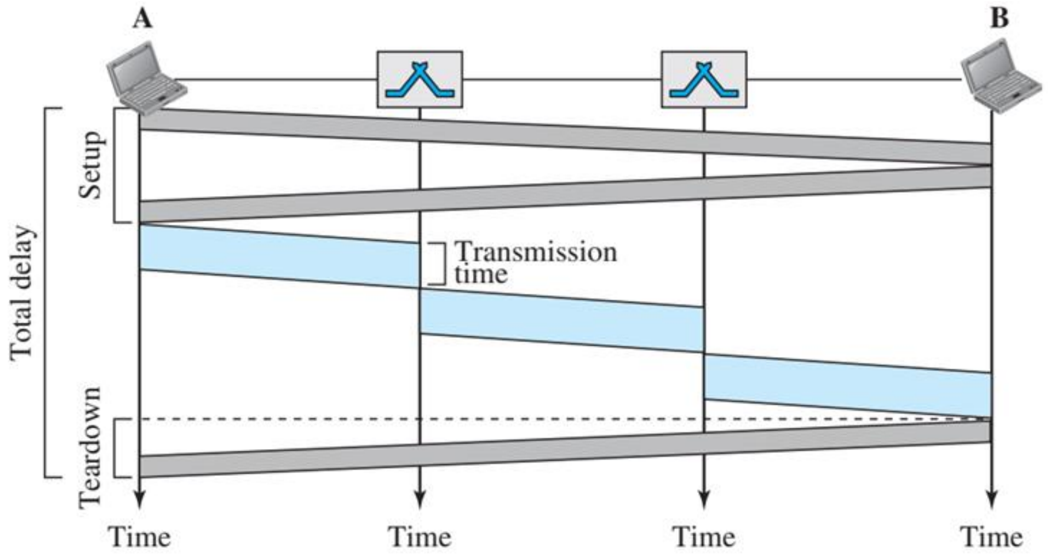
Virtual Circuit Network

- Routers need to maintain connection-state information for each ongoing connections
  - Signaling messages
  - Connection established: add new entry
  - Connection released: remove the entry
- Three phases in a VC:
  - Setup
  - Data transfer
  - Tear down
- Higher efficiency, less delay



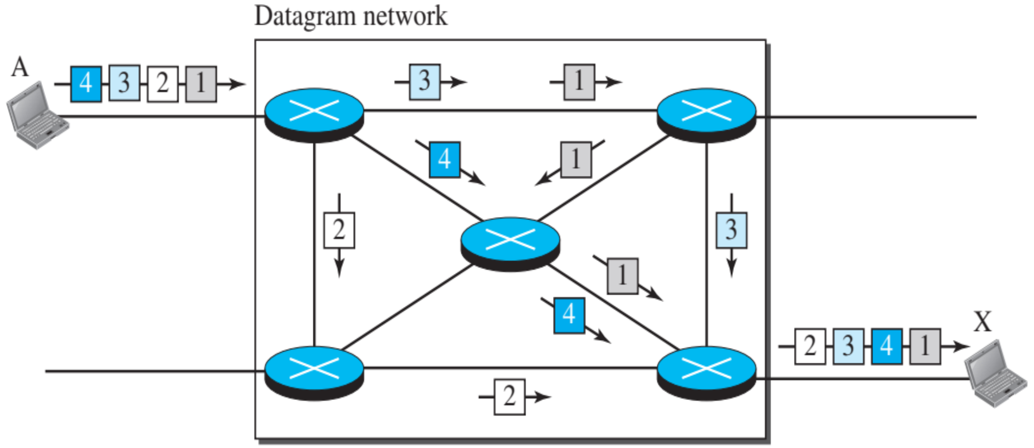
Virtual Circuit Setup



Delay in Virtual-Circuit Networks

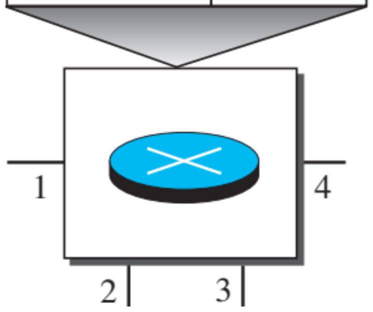
Datagram Network

- Connection-less network
- Each packet (called datagram) is independent of all other packets
- Packets belonging to the same message may travel along different paths
- Challenges
  - Out-of-order
  - Variable packet arrival time
  - Packet loss
- Higher delay

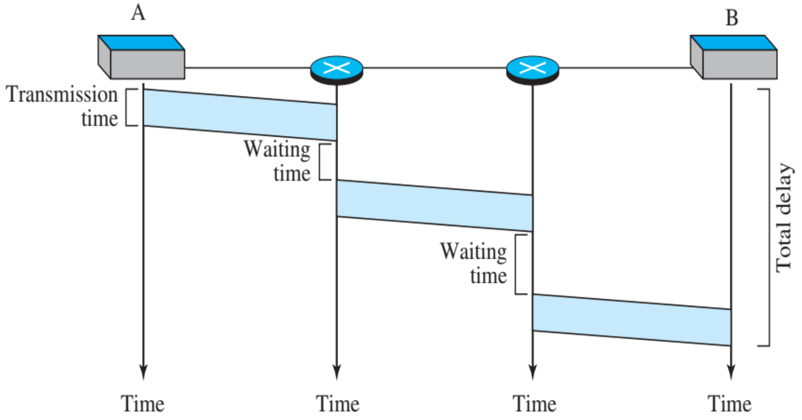


Datagram Network

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



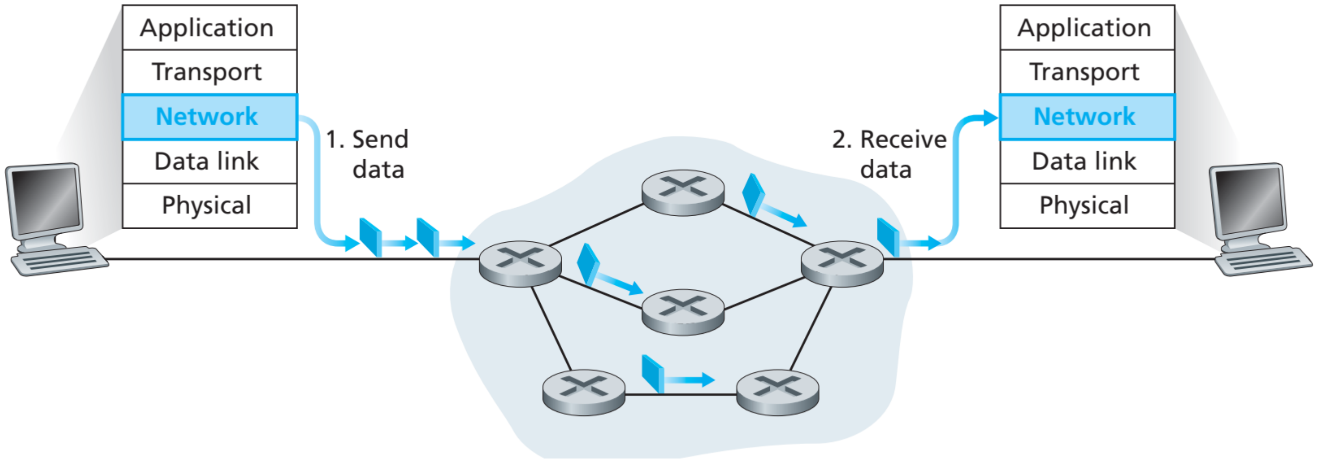
Forwarding Table



Delay in Datagram Network

Datagram Network

- End system – while sending a packet (datagram)
  - Stamps destination address
  - Pops it into the network
  - No VC setup
- Packet: passes through a series of routers
- Router
  - Do not maintain VC state information
  - Reads the destination address
  - Looks up its forwarding table
  - Determines output link interface
  - Uses longest prefix matching rule to match addresses with the entries in the table



Datagram Network

- Routers – maintain forwarding state information
- Use routing algorithms to update forwarding tables at regular intervals (one to five minutes)

Datagram Network – Router's Lookup Operation

- Longest Prefix Matching Rule

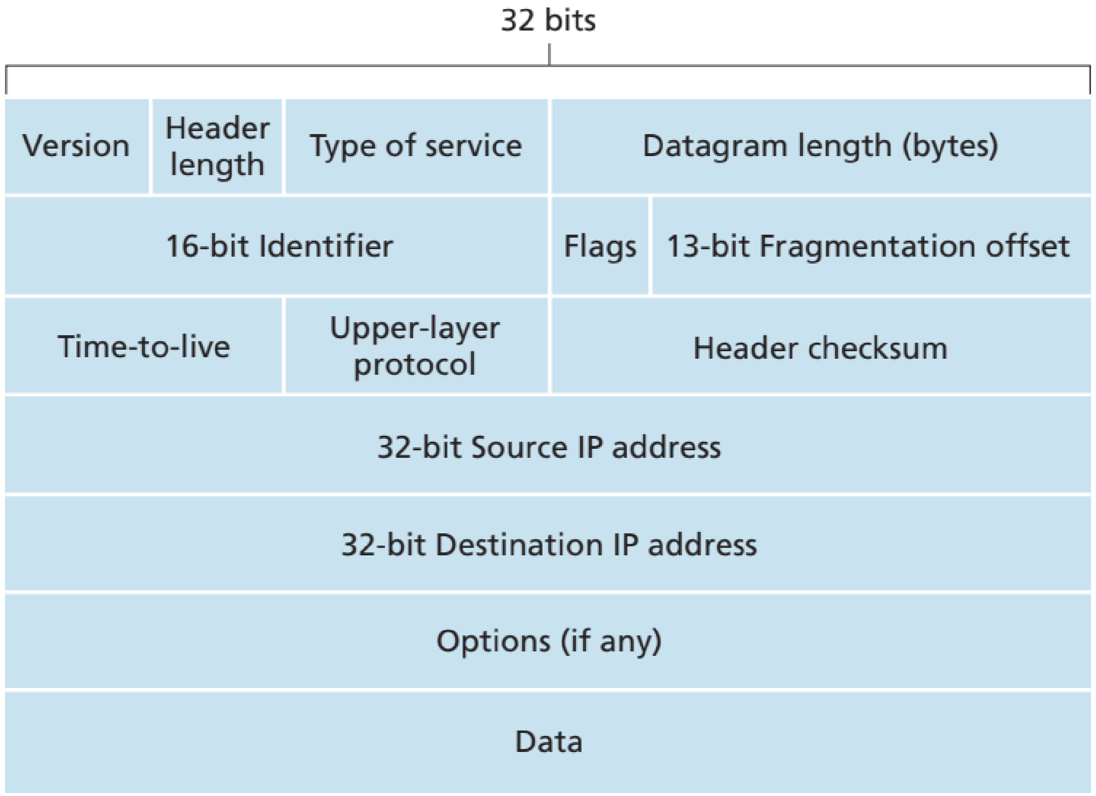
Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

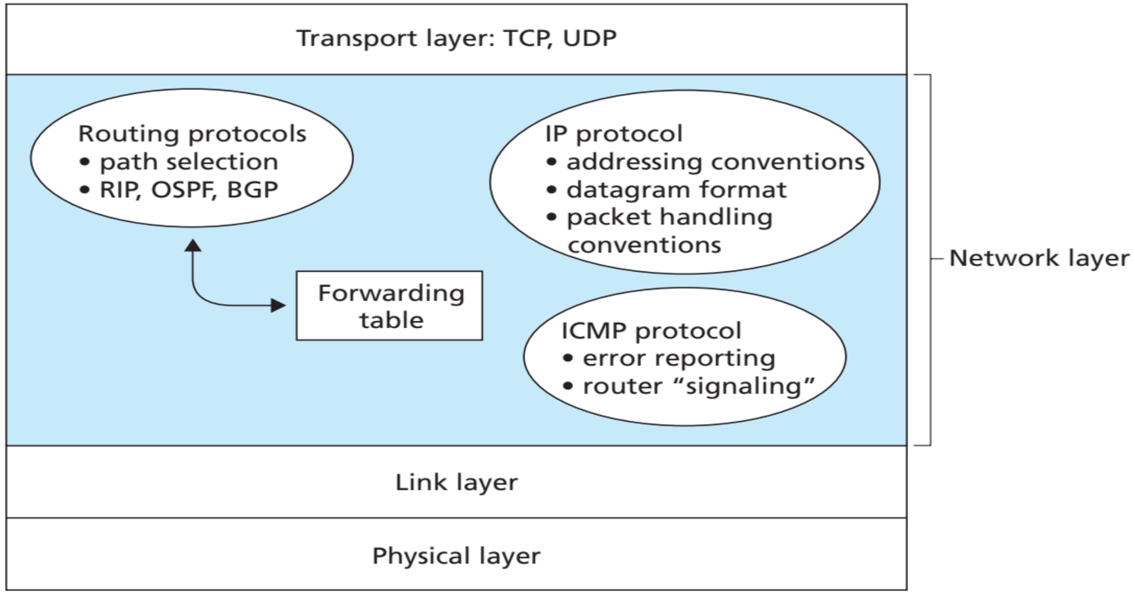
- Router matches a prefix of the packet's destination address with the entries in the table
- If there is match, the router forwards the packet to a link associated with the match
- When there are multiple matches, the router uses the longest prefix matching rule
  - Example: the first 24 bits of the address 11001000 00010111 00011000 10101010 match the second entry in the table, and the first 21 bits of the address match the third entry in the table.

Datagram Format

- Components of the Internet's network layer
  - IP protocol: logical addressing
  - Routing protocols: determines a path the datagram follows – compute forwarding/routing tables
  - ICMP protocol: error reporting in datagrams



IPv4 Datagram Format

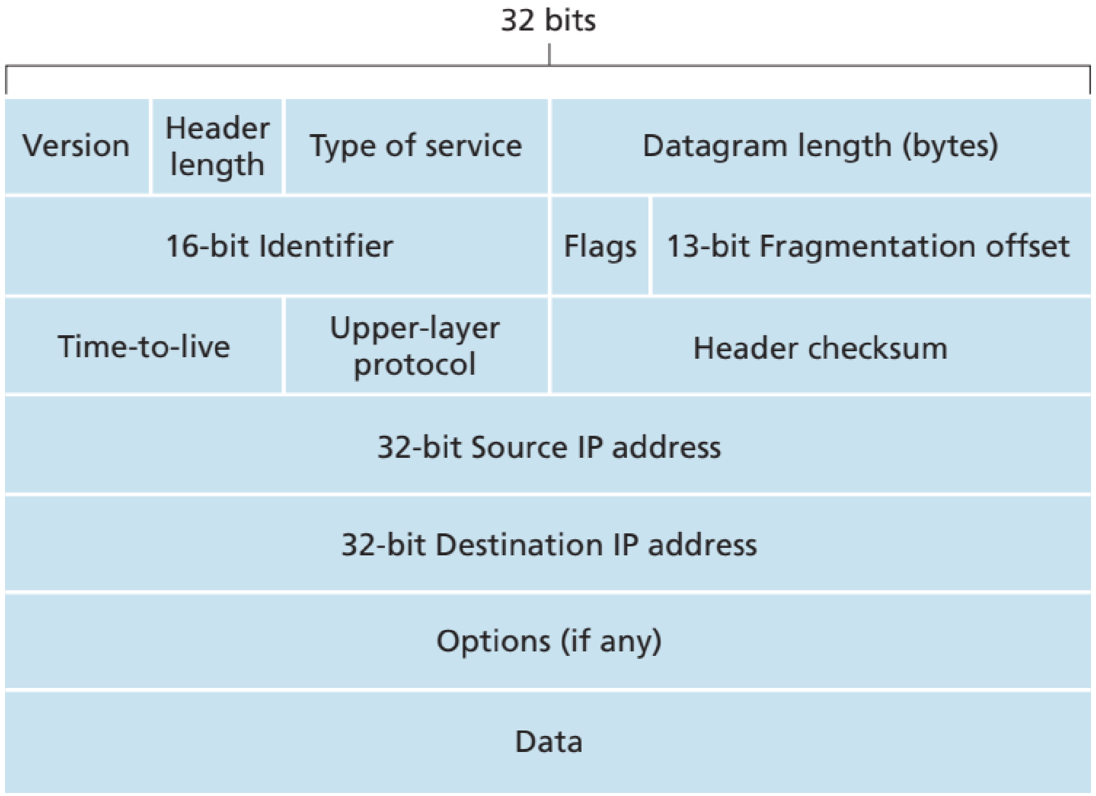


Internet's Network Layer

- Version number (4-bits): IP protocol version – IPv4/IPv6 – enables router to interpret the remainder of the datagram
- Header length (4-bits): marks the beginning of the actual data in the datagram (typical header size: 20 bytes)
- Type of service (8-bits): distinguishes different types of IP datagrams (e.g., datagrams requiring low delay, high throughput, or reliability)

Datagram Format

- Datagram length (16-bits): total length of the datagram - theoretical maximum size 65,535 byte – in practice usual length is 1,500 bytes
- Identifier, flags, fragmentation offset: helps in fragmentation of the datagram
- Time-to-live (8-bits): decremented by one each time the datagram is processed by a router – dropped if the TTL = 0
- Protocol (8-bits): specific transport-layer protocol (TCP/6; UDP/17) to which the data portion of IP datagram should be delivered
- Header checksum (16-bits): Internet checksum is computed by taking each 2 bytes in the header as a number – summing them using 1s complement arithmetic - store the result in this field – router recomputes checksum to detect bit errors

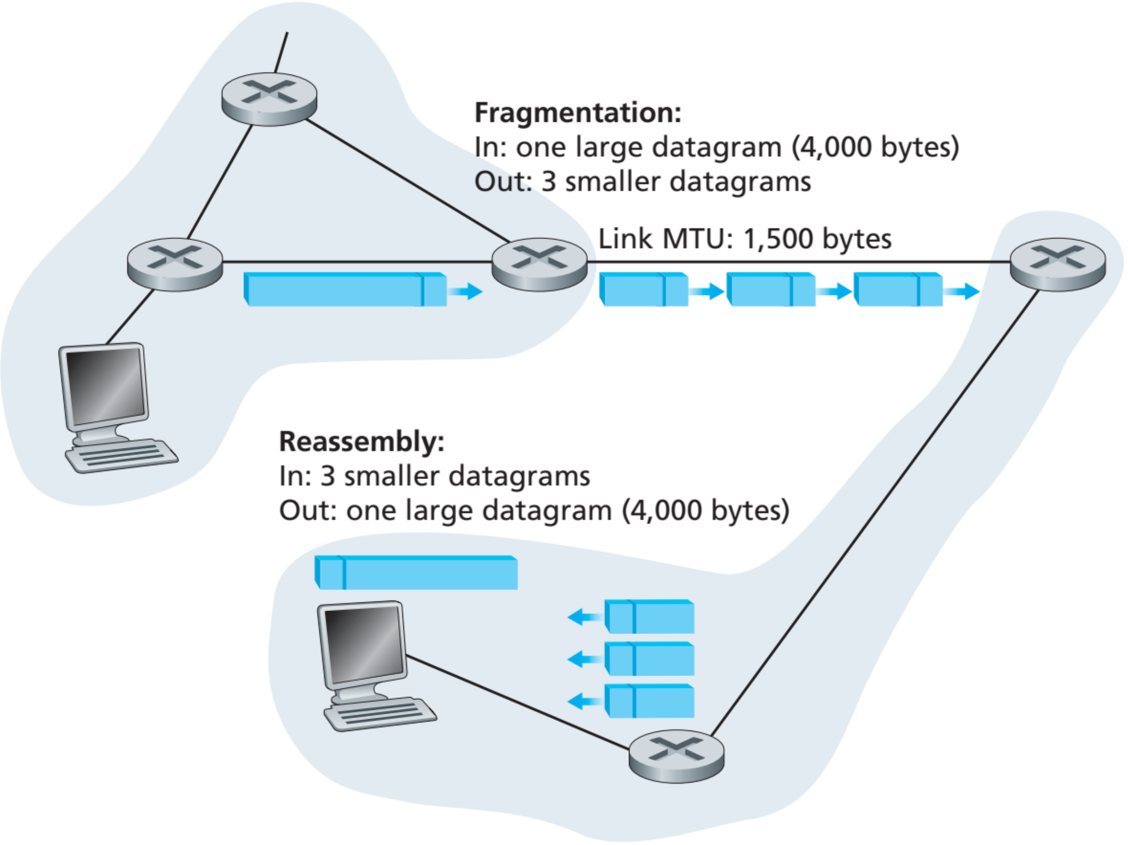


IPv4 Datagram Format

- Source & Destination IP Addresses
- Options: allow an IP header to be extended
- Data (payload): contains the transport-layer segment (TCP or UDP) to be delivered, ICMP messages, etc.
- Size of each nonfragmented IP datagram carrying TCP segment: 20 bytes header (without options) + 20 bytes of TCP header + application-layer message

IP Datagram Fragmentation

- Link-layer protocols: carry variable length network-layer packets
- Ethernet frame: 1500 bytes (max); wide-area links' frame: 576 bytes (max)
- Maximum transmission unit (MTU): maximum amount of data that a link-layer frame can carry
  - MTU: places a hard limit on the length of an IP datagram
- Major challenge: multiple links interconnected by the router can use different link-layer protocols – different MTUs – need to satisfy the MTU constraint
- Fragmentation at the router:
  - Split data at the IP datagram into two or more smaller IP datagrams as per the MTU of the outgoing link (fragments)
  - Encapsulate each of these smaller IP datagrams in separate link-layer frames



IP Fragmentation and Assembly