Internet Protocol (IP)

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- Internetworking
- IP Address format
- IP data forwarding
- Fragmentation and reassembly

Ref: Chapters 13, 14, 16, and 17 of Comer's Computer Networks and Internets

Internetworking

- Internetwork = Collection of networks
  Connected via routers

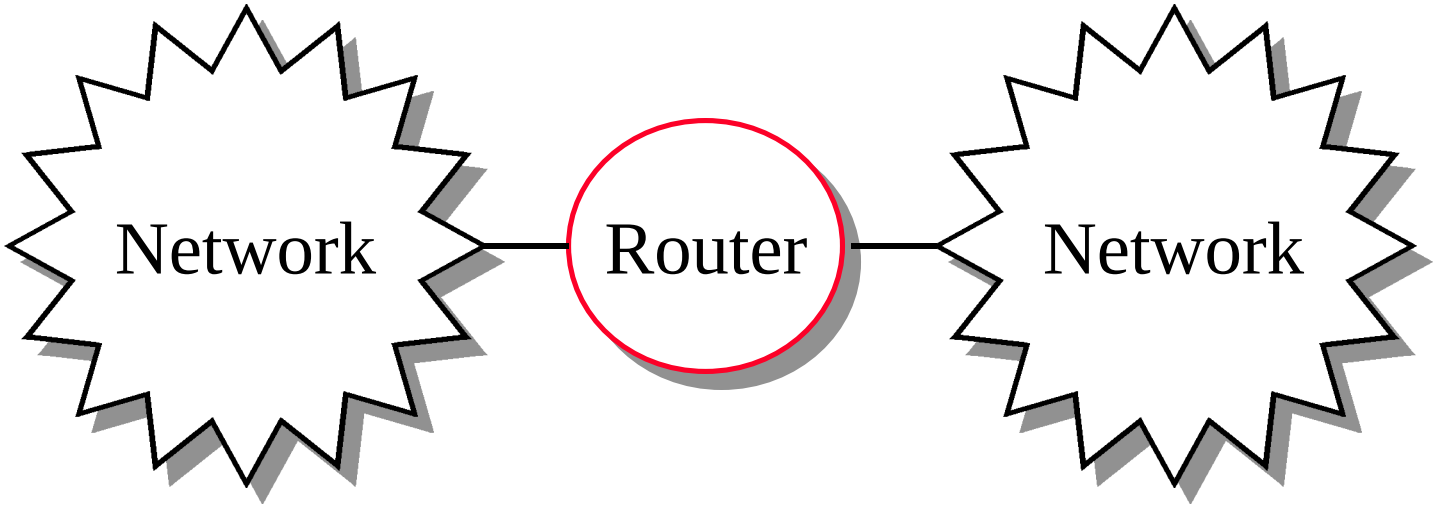


Fig 13.1

Internet = Virtual Network

- Any computer can talk to any other computer

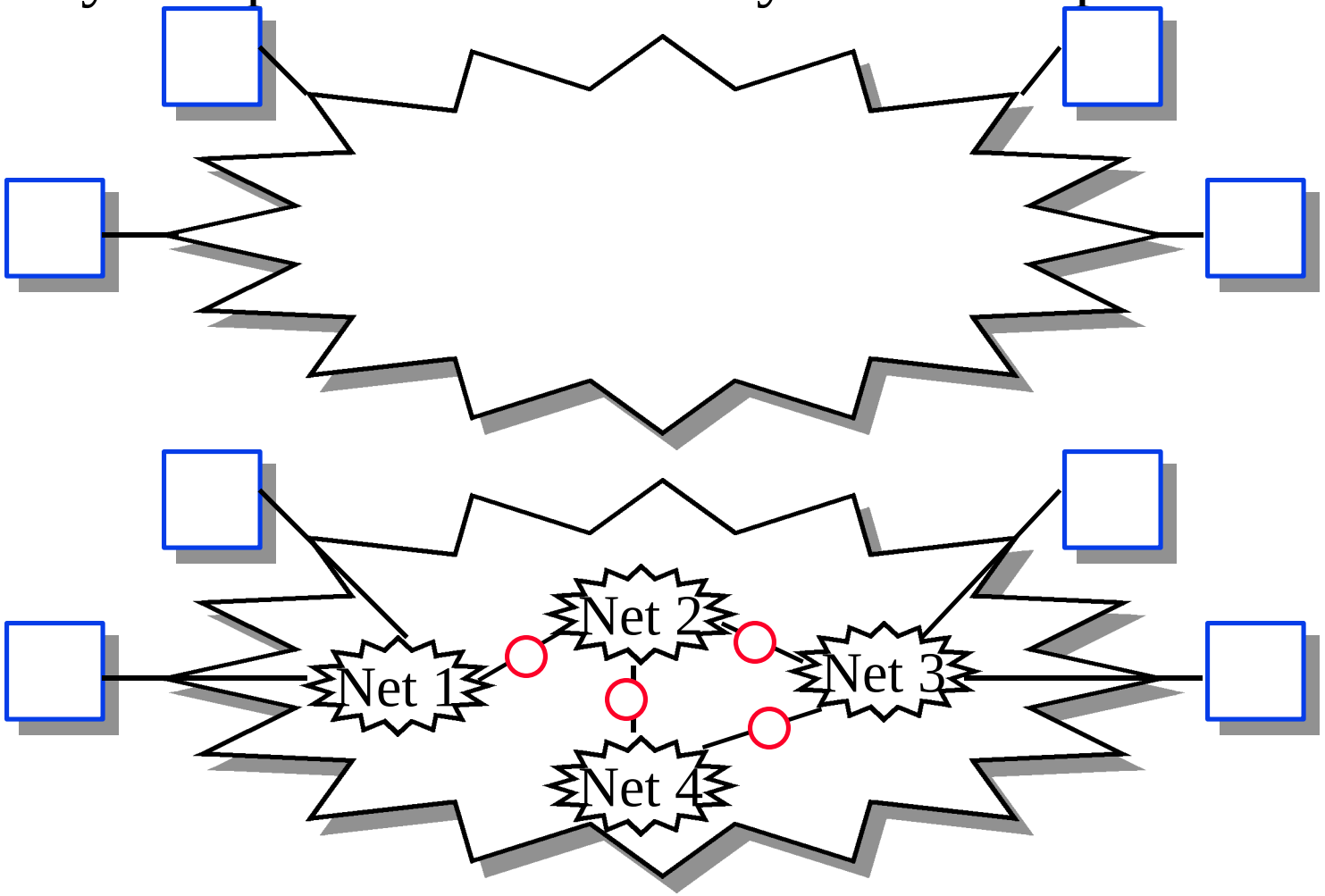
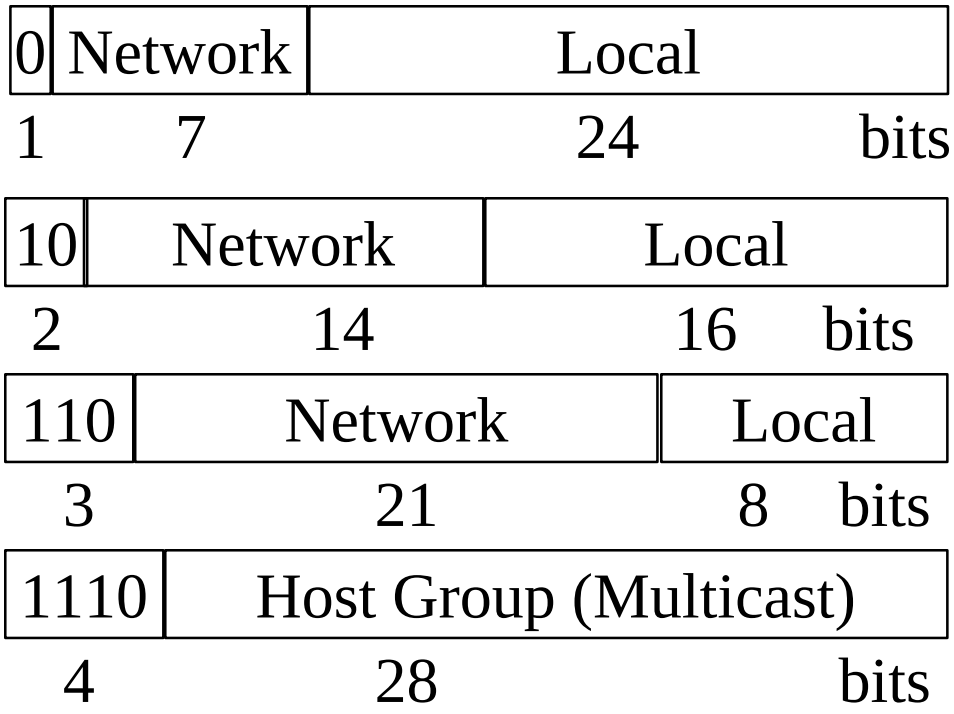


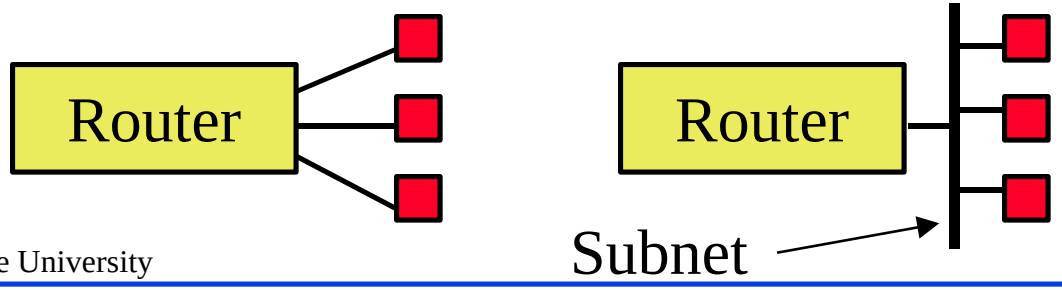
Fig 13.3

IP Address

- Class A: (1+3 bytes)
- Class B: (2+2 bytes)
- Class C: (3+1 bytes)
- Class D:



- Local = Subnet + Host (Variable length)



Computing The Class of an Address

First 4 bits	Index	Class
0000	0	A
0001	1	A
0010	2	A
0011	3	A
0100	4	A
0101	5	A
0110	6	A
0111	7	A
1000	8	B
1001	9	B
1010	10	B
1011	11	B
1100	12	C
1101	13	C
1110	14	D
1111	15	E

Classes and Dotted Decimal Notation

- Binary: 11000000 00000101 00110000 00000011
  Hex Colon: C0:05:30:03
  Dotted Decimal: 192.5.48.3

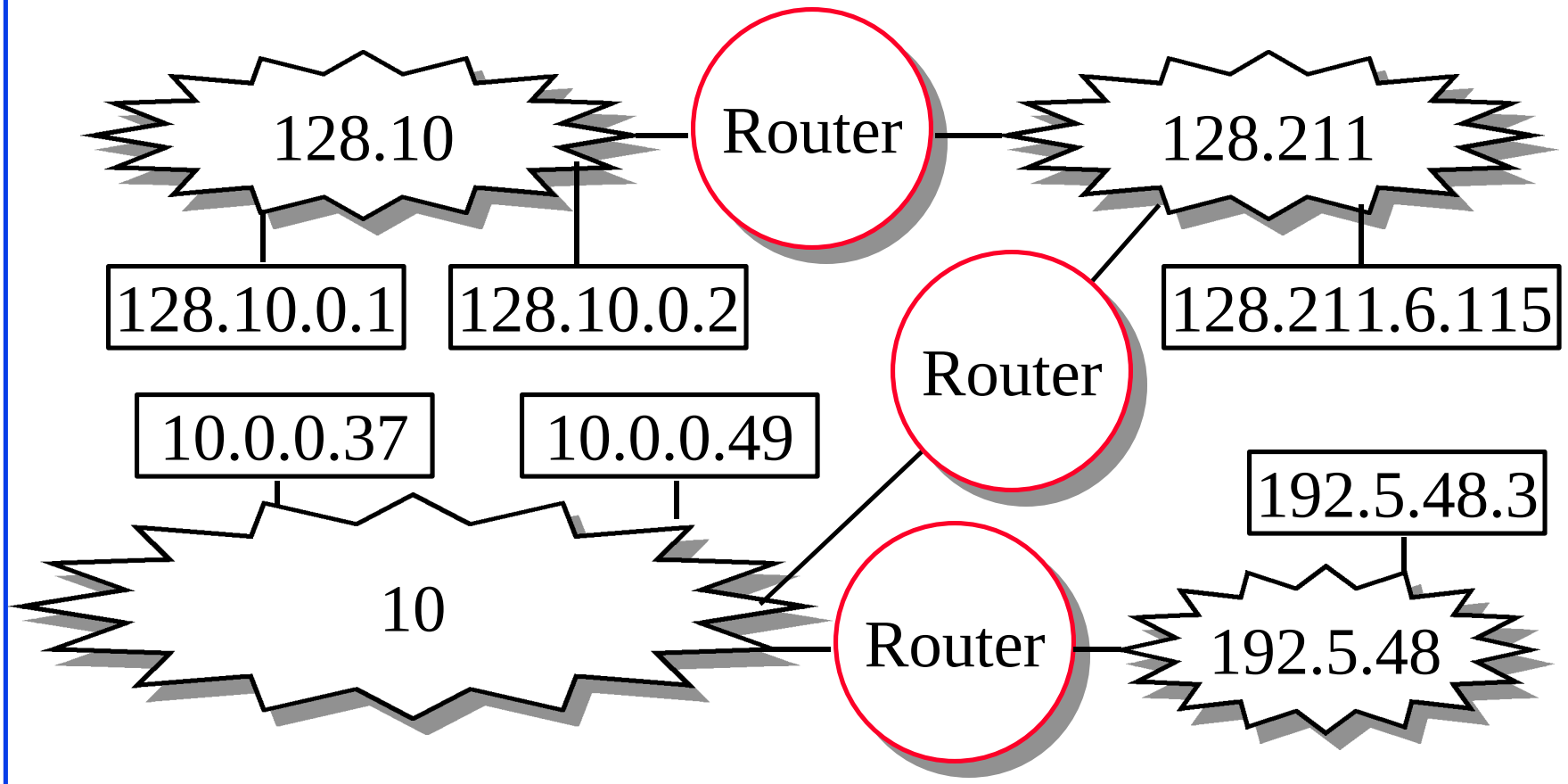
Class	Range
A	0 through 127
B	128 through 191
C	192 through 223
D	224 through 239
E	240 through 255

Division of the Address Space

Class	Bits in Prefix	Max # of Nets	Bits in Suffix	Max # of Hosts per Net
A	7	128	24	16,777,216
B	14	16,384	16	65,536
C	21	2,097,152	8	256

- Not all possible addresses can be used.

An Addressing Example

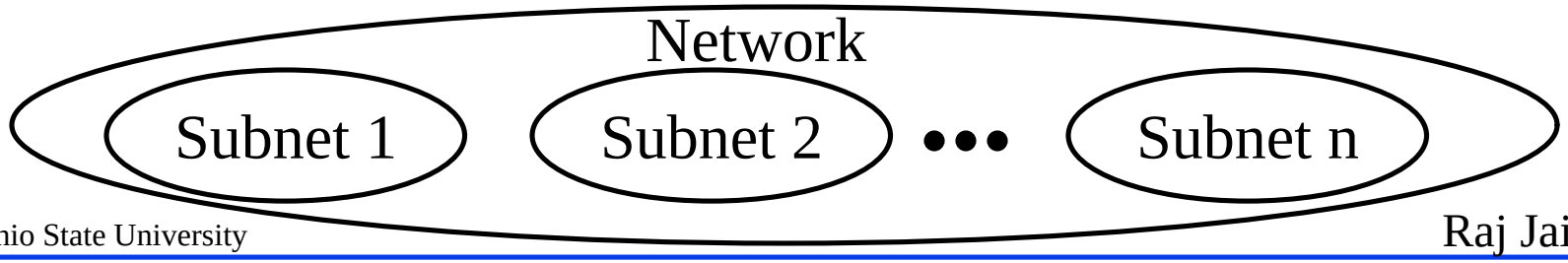


- All hosts on a network have the same network prefix

Subnetting

- With classes, the network part is 1-byte, 2-byte, or 3-byte long. You need class B address space just for 257 addresses.
- Any number of bits can be treated as one "subnetwork"
- Example: First 23 bits = subnet

  Address: 10010100 10101000 00010000 11110001
  Mask: 11111111 11111111 11111110 00000000
  .AND. 10010100 10101000 00010000 00000000



Supernetting

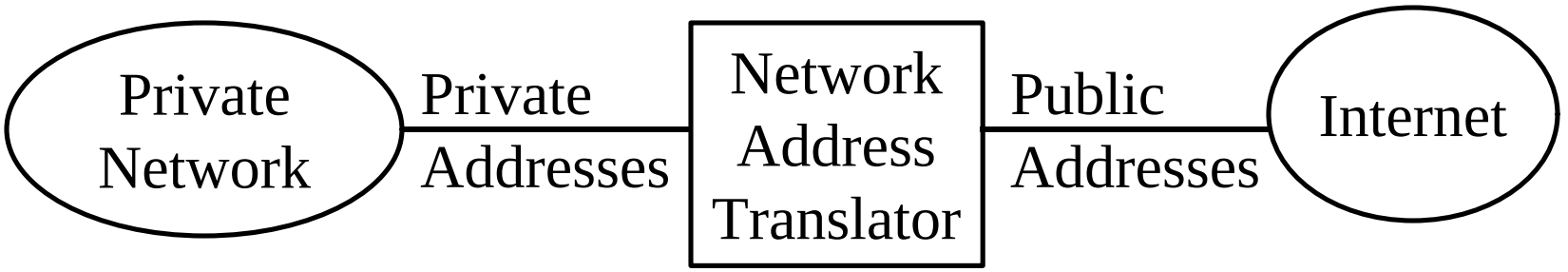
- Subnetting = subset of a network
- Supernet = superset of networks
  = Σ Class C addresses
- Example:
  Class C 1:11010100 10101000 00010000
  Class C 2:11010100 10101000 00010001
  Supernet: 11010100 10101000 0001000
- First 23 bits = subnet
  Address: 11010100 10101000 00010001 11110001
  Mask: 11111111 11111111 11111110 00000000
  .AND. 10010100 10101000 00010000 00000000

Special IP Addresses

- All-0 host suffix ⇒ Network Address
- All-0s ⇒ This computer
  (In some old networks: 0.0.0.0 = broadcast. Not used.)
- All-0s network ⇒ This network.
  E.g., 0.0.0.2 = Host 2 on this network
- All-1 host suffix ⇒ All hosts on the destination net (directed broadcast),
  All-0 host suffix ⇒ Berkeley directed broadcast address
- All-1s ⇒ All hosts on this net (limited broadcast)
  ⇒ Subnet number cannot be all 1
- 127.*.*.* ⇒ Looback through IP layer

Private Addresses

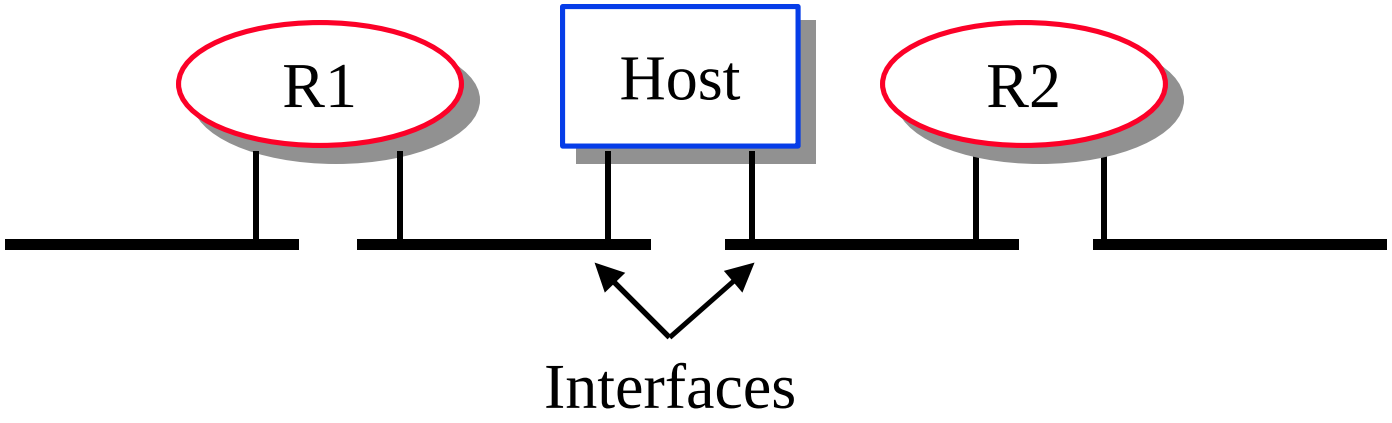
- Any organization can use these inside their network Can't go on the internet. [RFC 1918]
- 10.0.0.0 - 10.255.255.255 (10/8 prefix)
- 172.16.0.0 - 172.31.255.255 (172.16/12 prefix)
- 192.168.0.0 - 192.168.255.255 (192.168/16 prefix)



Classless Interdomain Routing (CIDR)

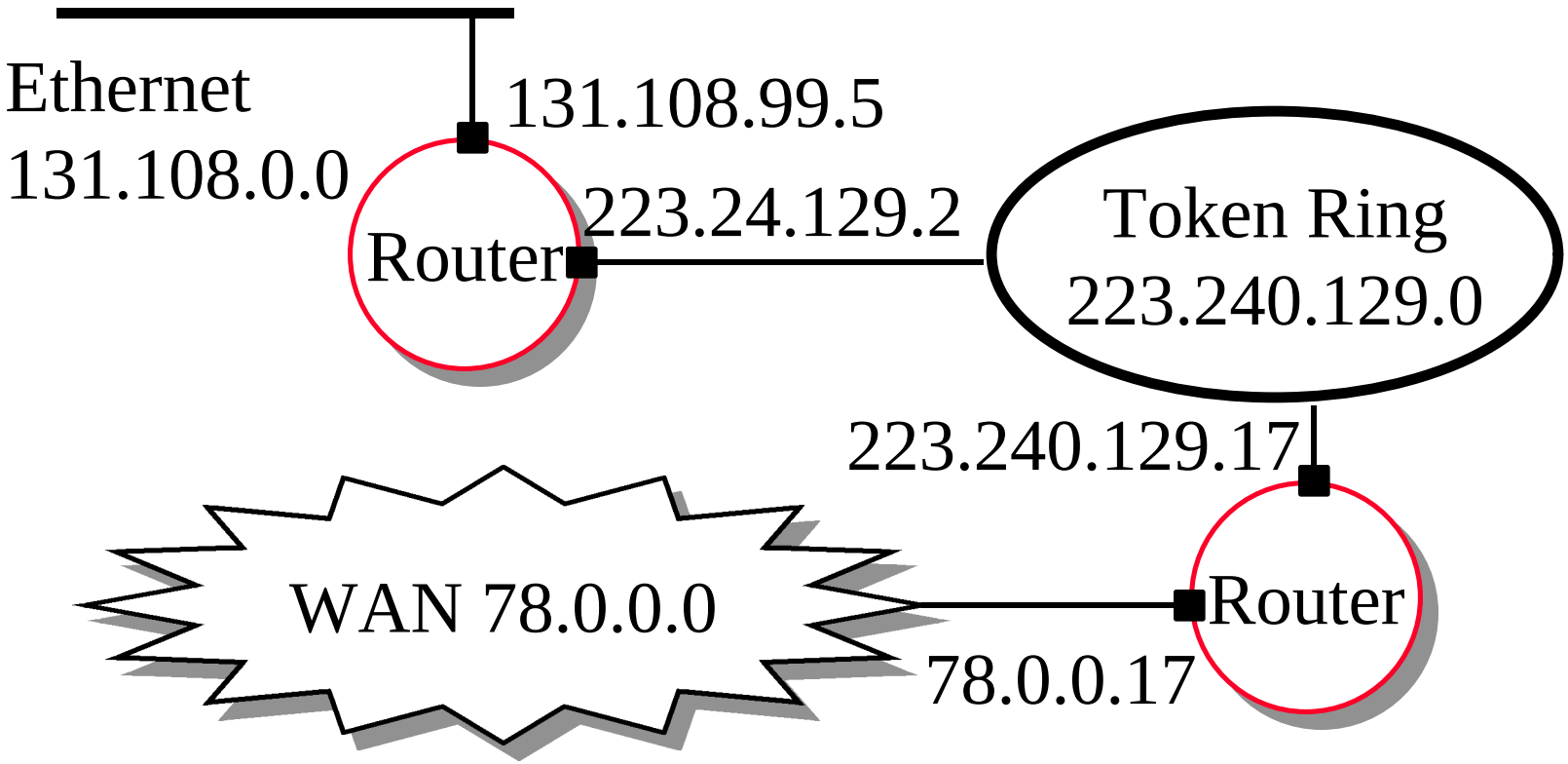
- Pronounced “Cider”
- Classless ⇒ Forget classes.
  Use Addresses and prefix lengths [RFC1517-1520]
- All routing table entries have prefix lengths
  Example: 164.107.61.0/26

Multi-Homed Hosts



- Each interface has an address.
  Two or more interfaces ⇒ Multi-homed hosts
- Multihoming is for reliability or performance

Routers and the IP Addressing Principle



- Routers have two or more addresses. One for each interface.

IP Features

- Connectionless service
- Variable size datagrams
- Best-effort delivery: Delay, out-of-order, corruption, and loss possible. Higher layers should handle these.
- Handles only data forwarding
  Uses routing tables prepared by other protocols, e.g.,
  Open Shortest Path First (OSPF),
  Routing Information Protocol (RIP)
- Provides only "Send" and "Delivery" services
  Error and control messages generated by
  Internet Control Message Protocol (ICMP)

Forwarding an IP Datagram

- Delivers datagrams to destination network (subnet)
- Routers maintain a "routing table" of "next hops"
- Next Hop field does not appear in the datagram

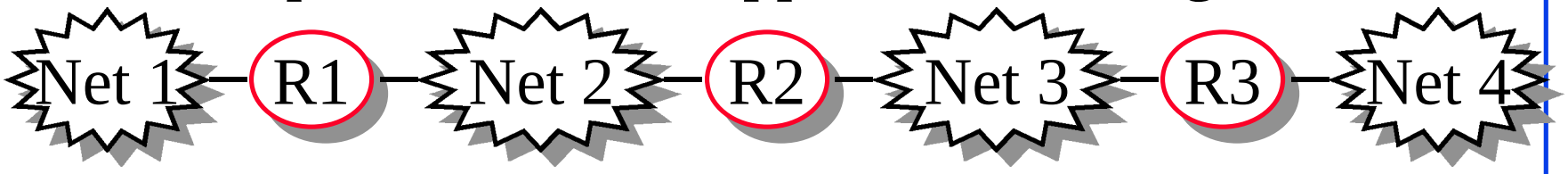


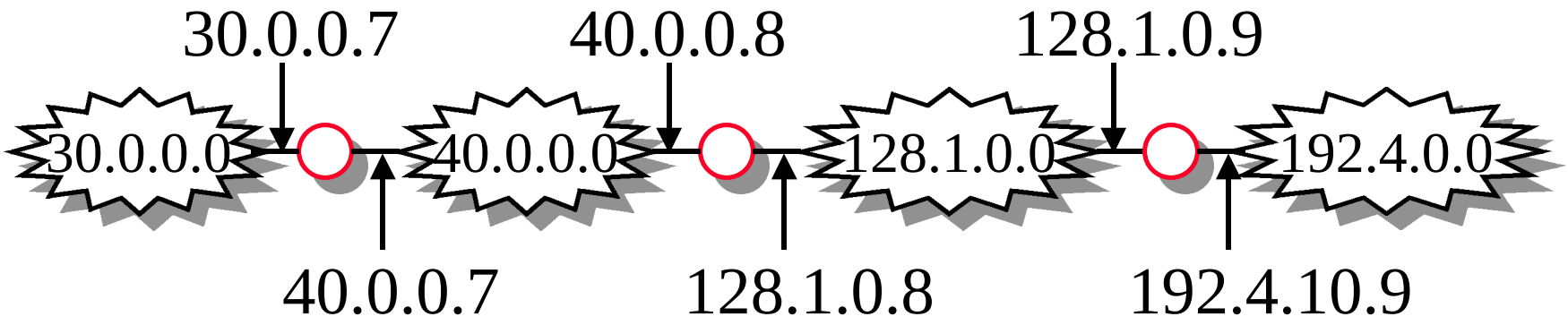
Table at R2:

Destination	Next Hop
Net 1	Forward to R1
Net 2	Deliver Direct
Net 3	Deliver Direct
Net 4	Forward to R3

Fig 16.2

IP Addresses and Routing Table Entries

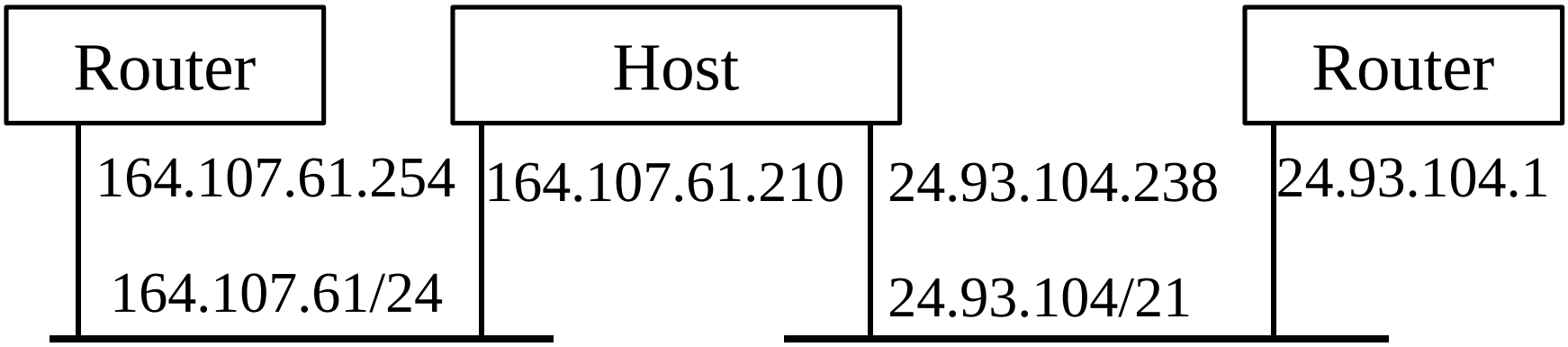
- IF ((Mask[i] & Destination Addr) = = Destination[i])
  Forward to NextHop[i]



Destination	Mask	Next Hop
30.0.0.0	255.0.0.0	40.0.0.7
40.0.0.0	255.0.0.0	Deliver direct
128.1.0.0	255.255.0.0	Deliver direct
192.4.10.0	255.255.255.0	128.1.0.9

Fig 16.3

Sample Routing Table



Network-Address	Netmask	Gateway-Address	Interface	Metric
0.0.0.0	0.0.0.0	24.93.104.1	24.93.107.238	1
24.93.104.0	255.255.248.0	24.93.107.238	24.93.107.238	1
24.93.107.238	255.255.255.255	127.0.0.1	127.0.0.1	1
24.255.255.255	255.255.255.255	24.93.107.238	24.93.107.238	1
127.0.0.0	255.0.0.0	127.0.0.1	127.0.0.1	1
128.146.0.0	255.255.0.0	164.107.61.254	164.107.61.210	1
164.107.61.0	255.255.255.0	164.107.61.210	164.107.61.210	1
164.107.61.210	255.255.255.255	127.0.0.1	127.0.0.1	1
164.107.255.255	255.255.255.255	164.107.61.210	164.107.61.210	1
224.0.0.0	224.0.0.0	24.93.107.238	24.93.107.238	1
224.0.0.0	224.0.0.0	164.107.61.210	164.107.61.210	1
255.255.255.255	255.255.255.255	164.107.61.210	164.107.61.210	1

IP Datagram Format

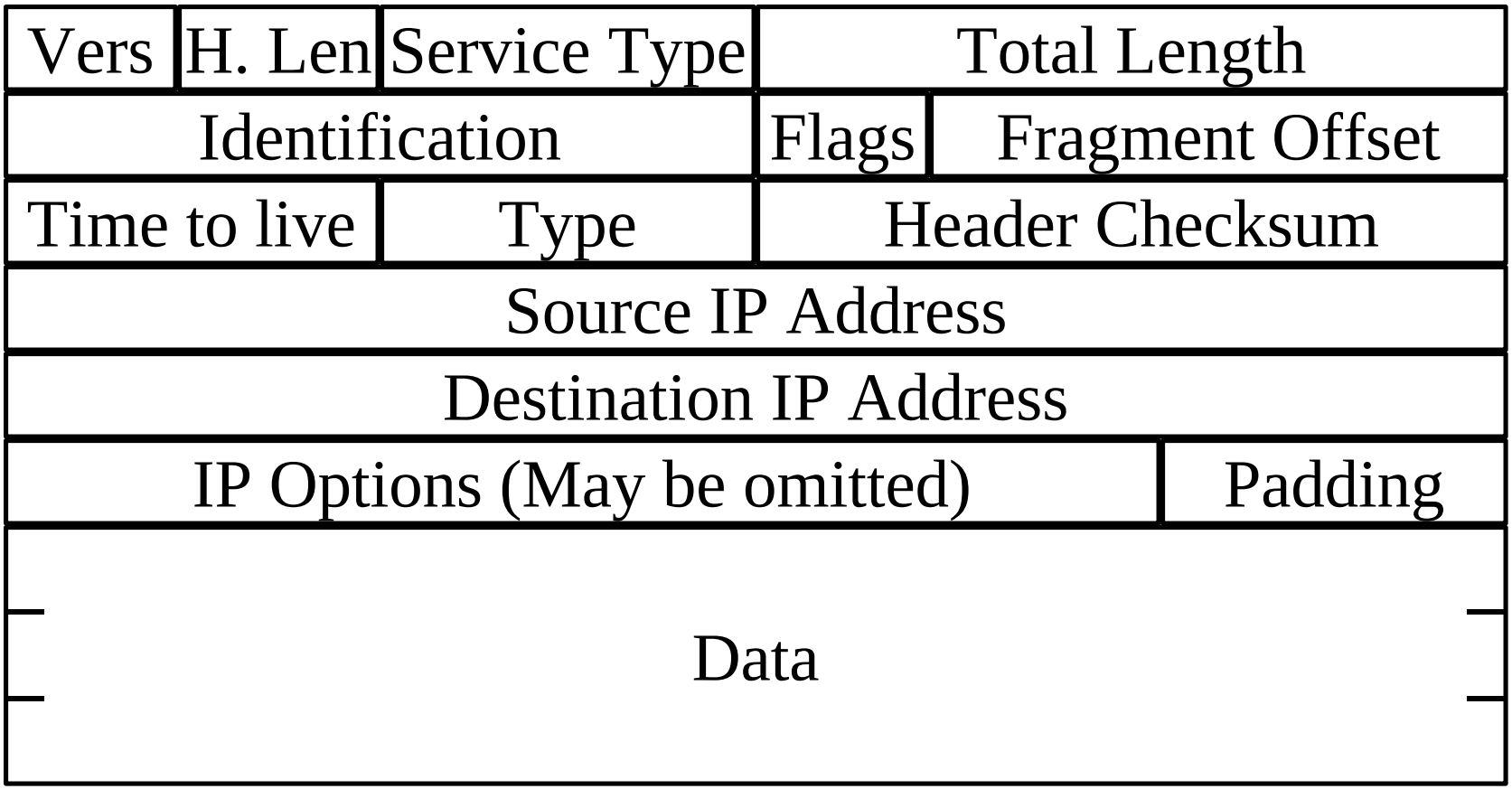


Fig 16.4

IP Header Format

- Version (4 bits)
- Internet header length (4 bits): in 32-bit words.
  Min header is 5 words or 20 bytes.
- Type of service (8 bits): Reliability, precedence, delay, and throughput
- Total length (16 bits): header + data in bytes
  Total must be less than 64 kB.
- Identifier (16 bits): Helps uniquely identify the datagram during its life for a given source, destination address

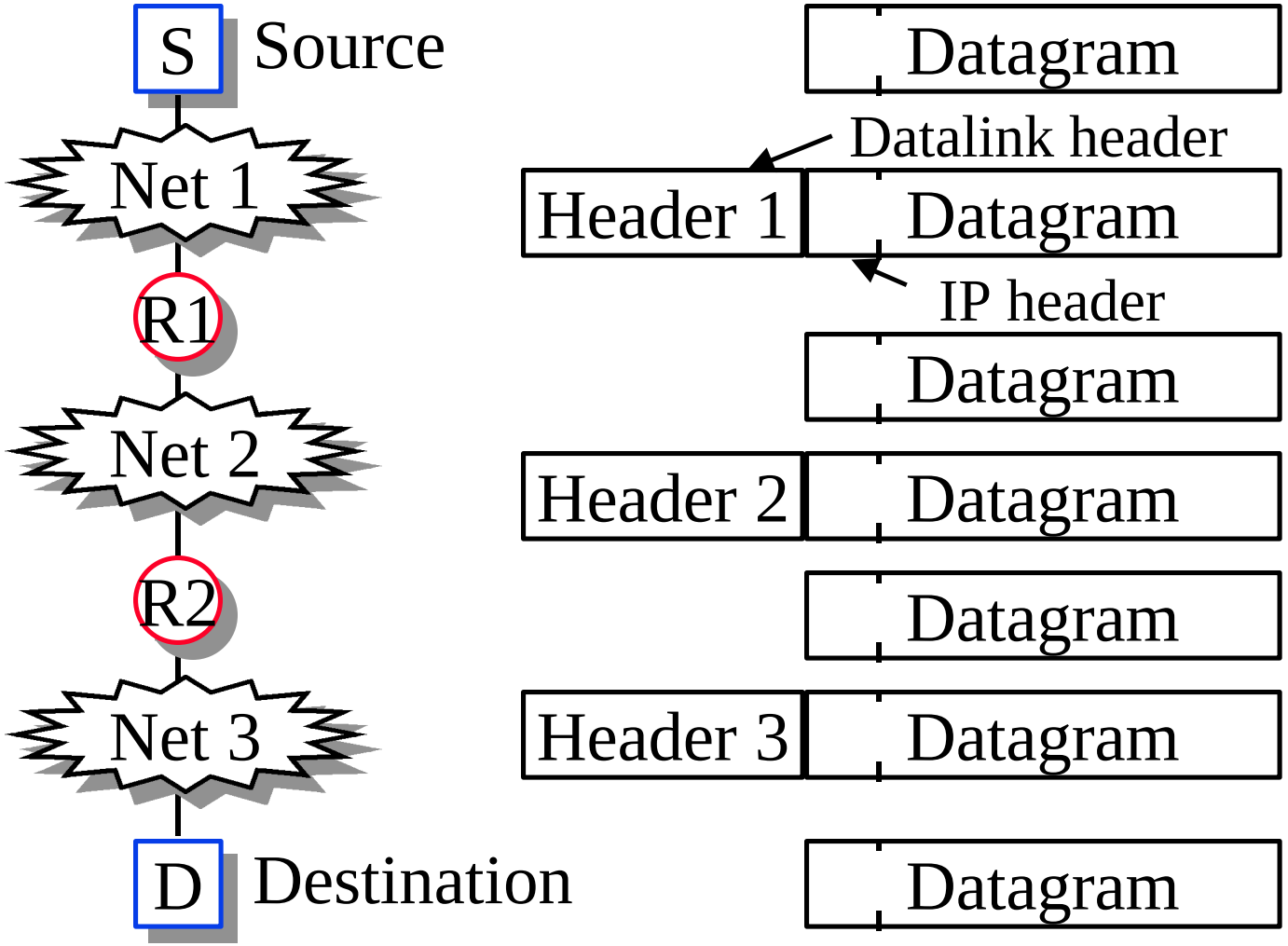
IP Header (Cont)

- Flags (3 bits): More flag - used for fragmentation
  No-fragmentation
  Reserved
- Fragment offset (13 bits): In units of 8 bytes
- Time to live (8 bits): Specified in router hops
- Protocol (8 bits): Next level protocol to receive the data
- Header checksum (16 bits): 1's complement sum of all 16-bit words in the header

IP Header (Cont)

- Source Address (32 bits): Original source.
  Does not change along the path.
- Destination Address (32 bits): Final destination.
  Does not change along the path.
- Options (variable): Security, source route, record route, stream id (used for voice) for reserved resources, timestamp recording
- Padding (variable):
  Makes header length a multiple of 4
- Data (variable): Data + header $\leq$ 65,535 bytes

Transmission Across An Internet



- Datalink header changes at every hop

Fig 17.2

Maximum Transmission Unit

- Each subnet has a maximum frame size
  Ethernet: 1518 bytes
  FDDI: 4500 bytes
  Token Ring: 2 to 4 kB
- Transmission Unit = IP datagram (data + header)
- Each subnet has a maximum IP datagram length: MTU

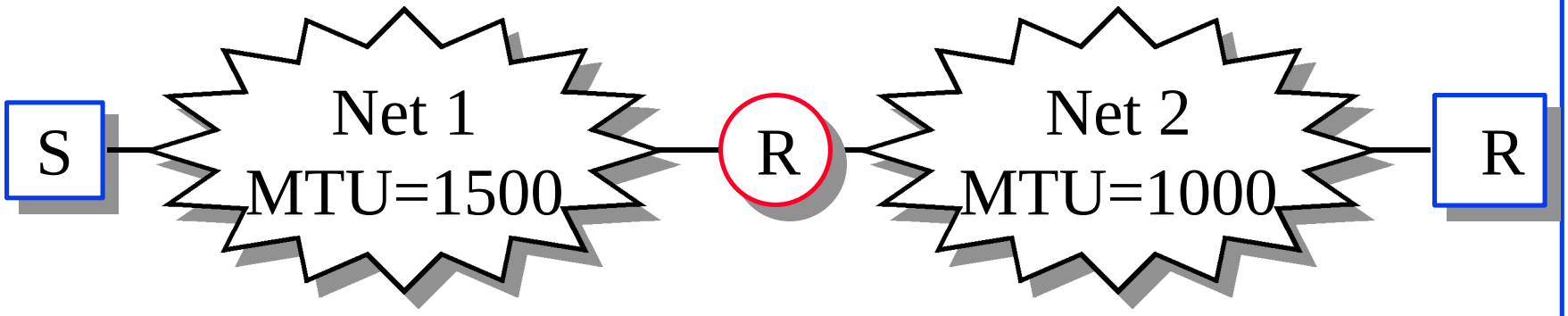


Fig 17.3

IP Protocol Numbers

Decimal	Key word	Protocol
0		Reserved
1	ICMP	Internet Control Message Protocol
2	IGMP	Internet Group Management Protocol
4	ST	Stream Protocol
5	TCP	Transmission Control Protocol
8	EGP	Exterior Gateway Protocol
9	IGP	Interior Gateway Protocol
17	UDP	User Datagram Protocol

IP Forwarding Process

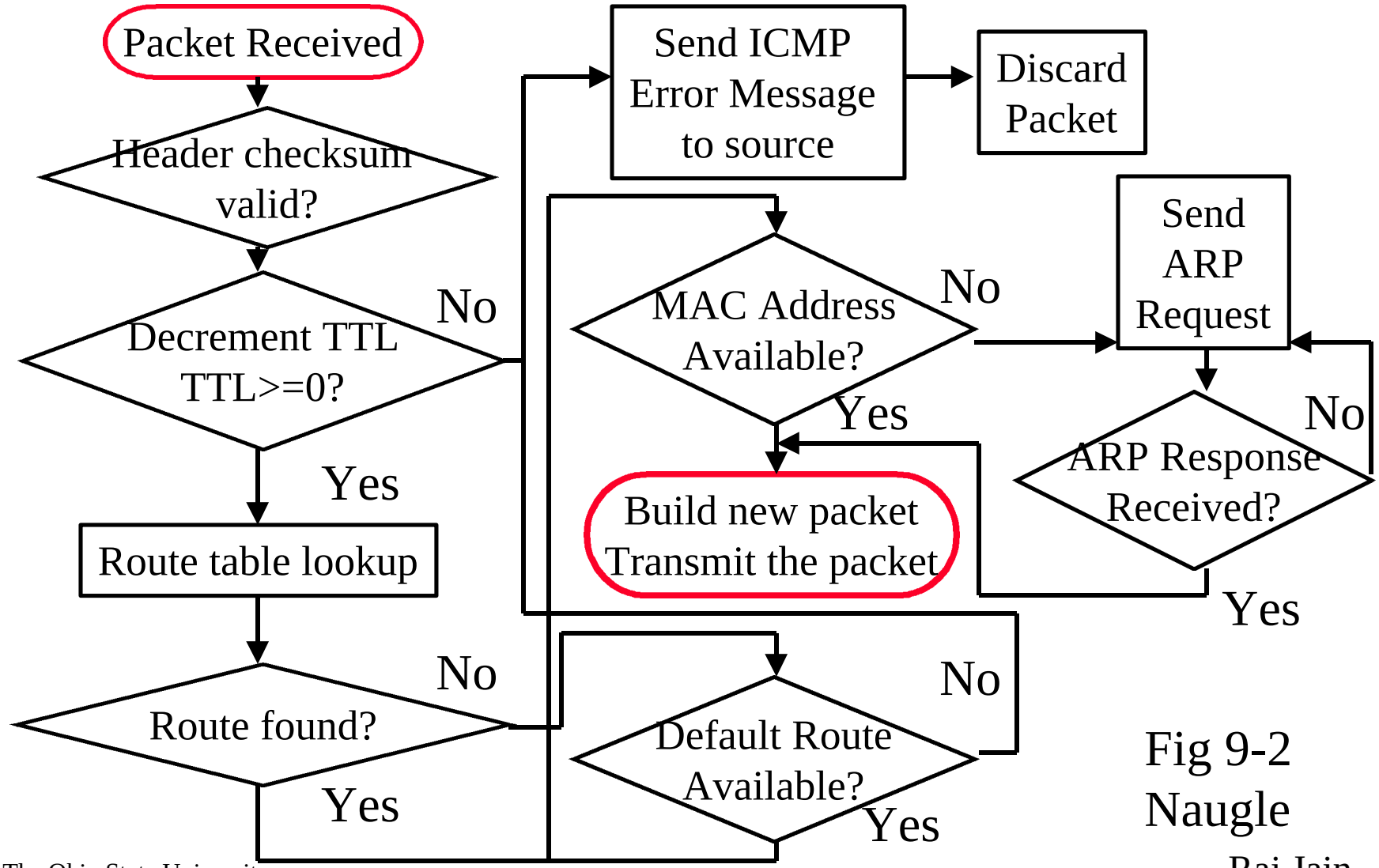


Fig 9-2
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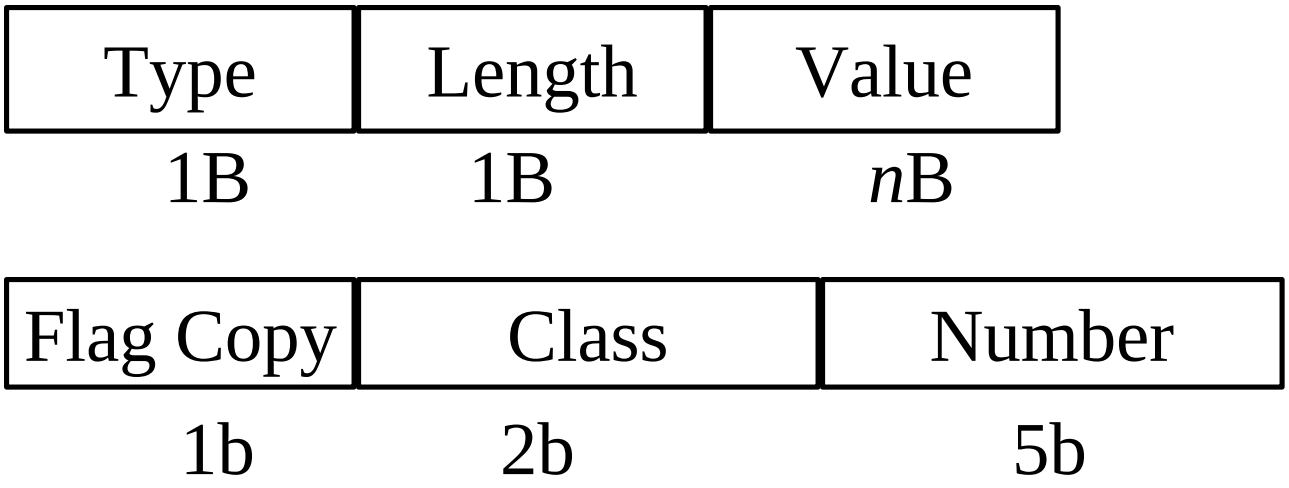
IP Options Coding

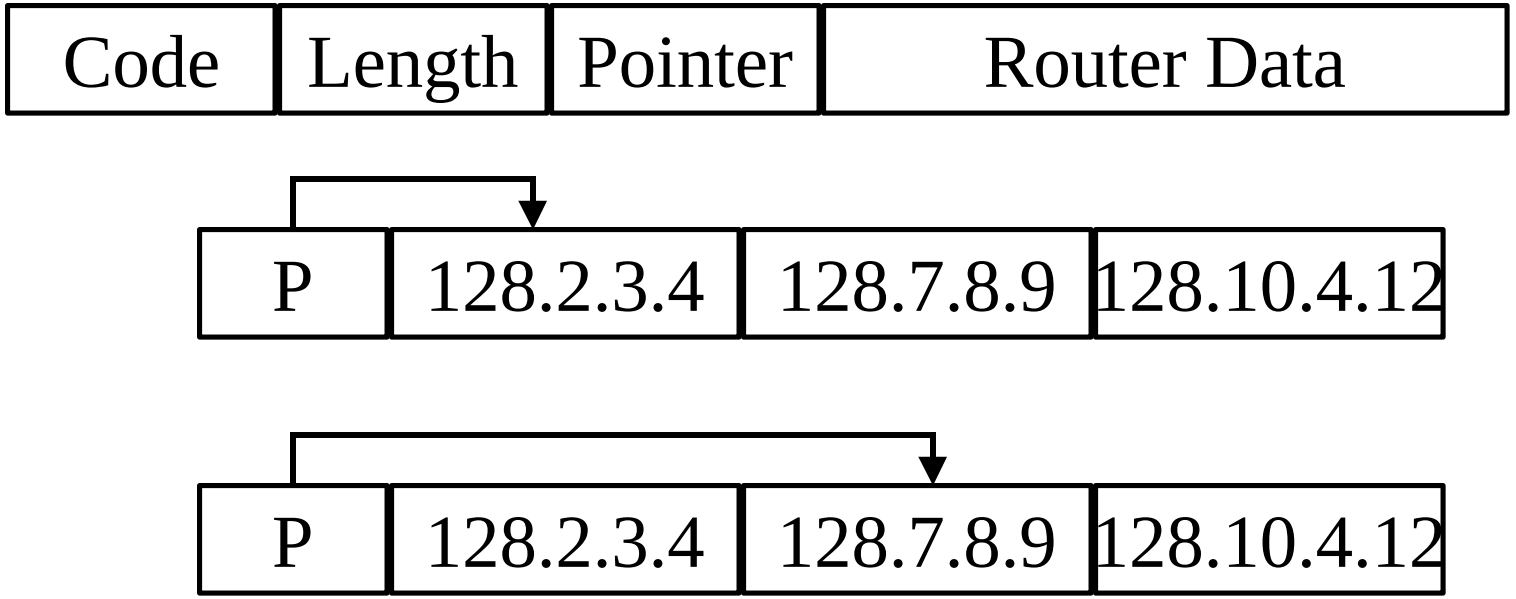


- Flag Copy: 0 = Copy the option only into the first fragment of a fragmented datagram
  1 = Copy into all fragments
- Class: 0 =User or control, 1=Reserved, 2=Diagnostics, 3=reserved

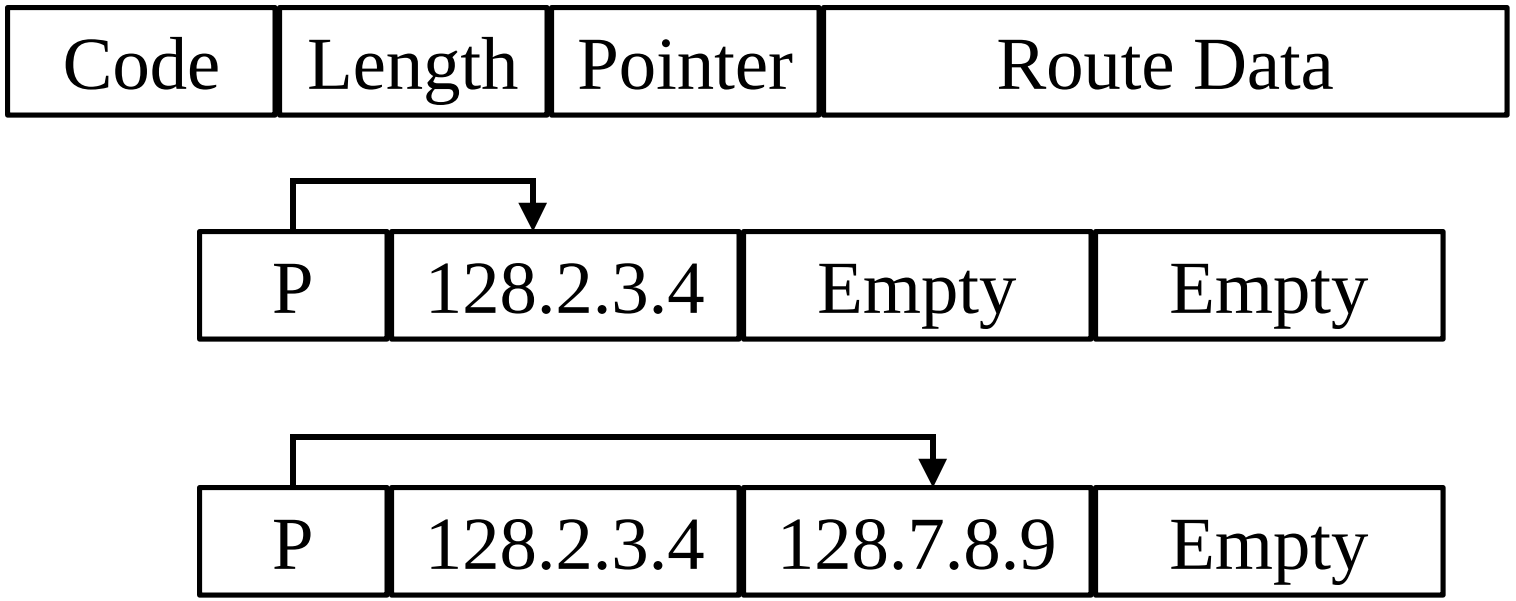
IP Options

Class	Number	Length	Description
0	0	0	End of Options
0	1	0	No Op
0	2	11	Security
0	3	Var	Loose Source Routing
0	7	Var	Record Route
0	8	4	Stream ID (obsolete)
0	9	Var	Strict Source Routing
2	4	Var	Internet Time-Stamp

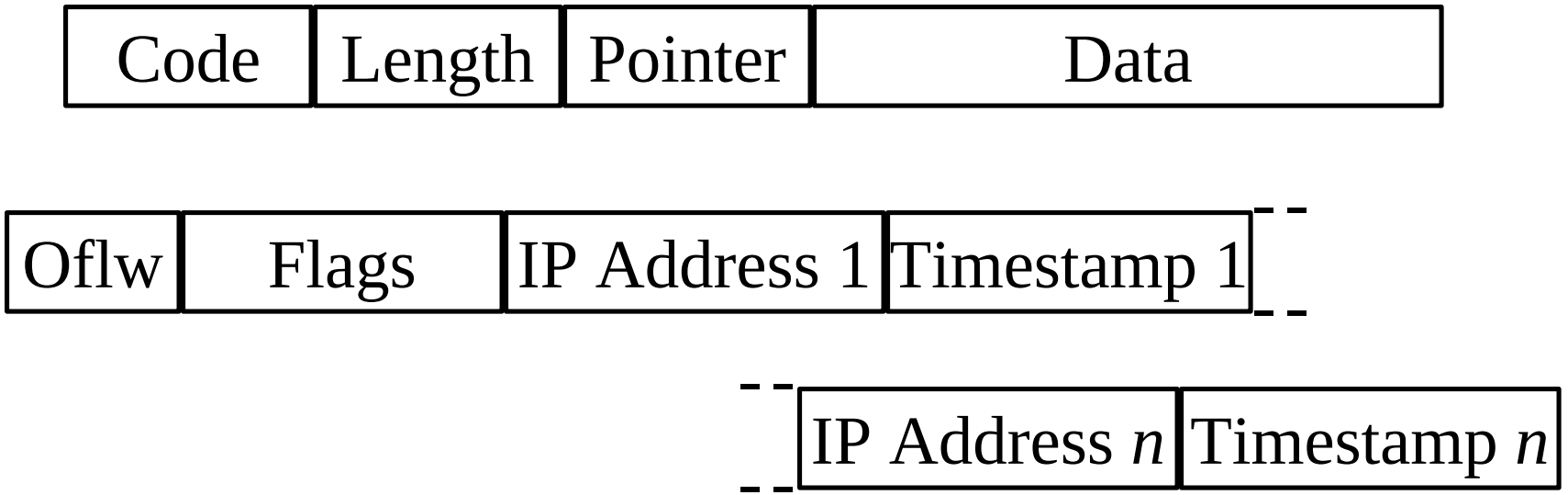
IP Source Routing



Route Recording



Timestamp Option



Fragmentation

- Datagrams larger than MTU are fragmented
- Original header is copied to each fragment and then modified (fragment flag, fragment offset, length,...)

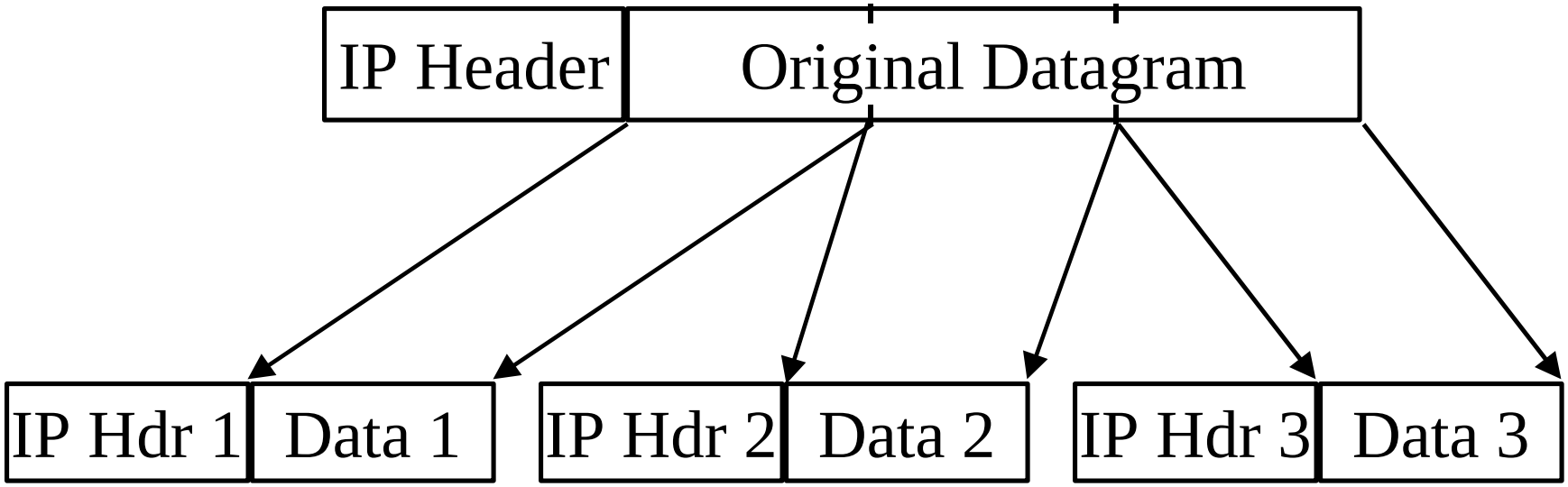
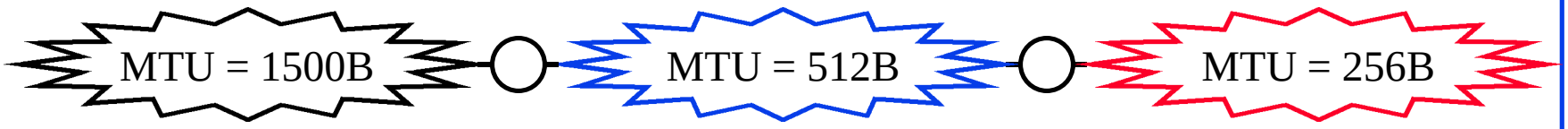


Fig 17.4

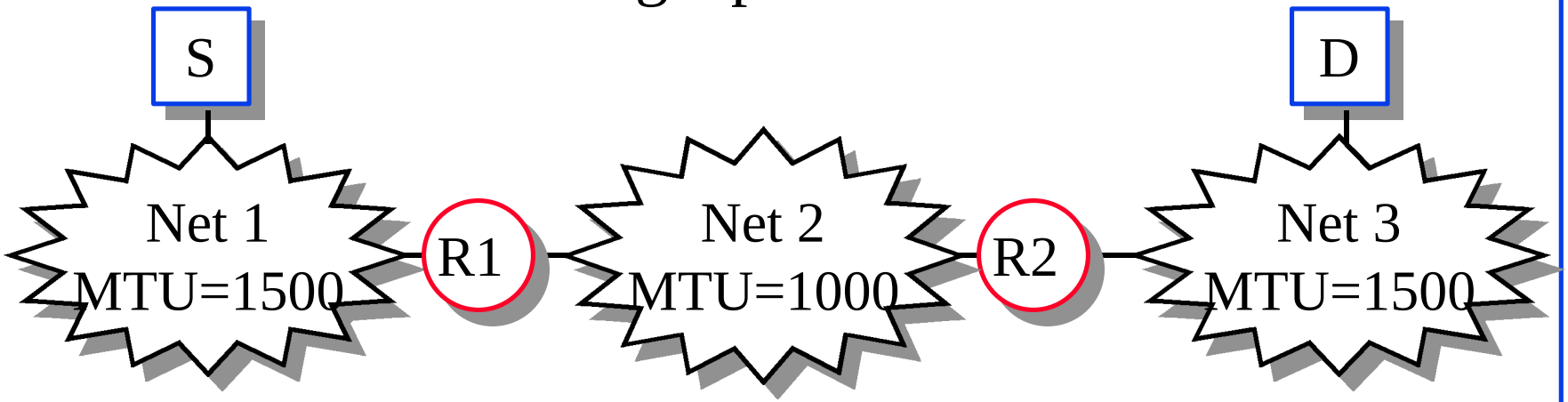
Fragmentation



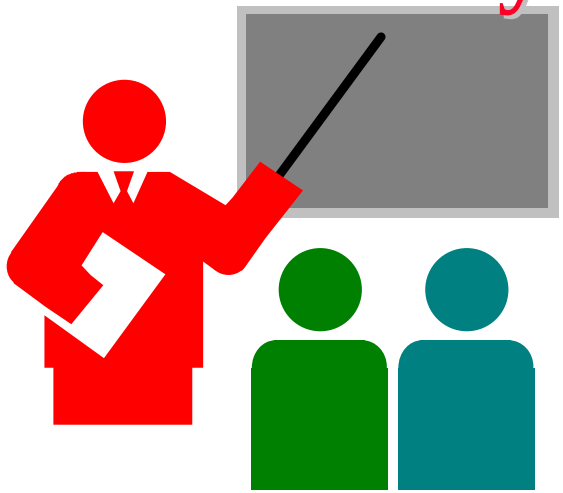
MTU = 1500B	MTU = 512B	MTU = 256B
ID = 12345, More = 1 Offset = 160W, Len = 1500B	ID = 12345, More = 1 Offset = 0W, Len = 512B	ID = 12345, More = 1 Offset = 0W, Len = 256B
		ID = 12345, More = 1 Offset = 32W, Len = 256B
	ID = 12345, More = 1 Offset = 64W, Len = 512B	ID = 12345, More = 1 Offset = 64W, Len = 256B
		ID = 12345, More = 1 Offset = 96W, Len = 256B
	ID = 12345, More = 1 Offset = 128W, Len = 476B	ID = 12345, More = 1 Offset = 128W, Len = 256B
		ID = 12345, More = 1 Offset = 160W, Len = 220B

Reassembly

- Reassembly only at the final destination
- Partial datagrams are discarded after a timeout
- Fragments can be further fragmented along the path. Subfragments have a format similar to fragments. It is not possible to tell how many times fragmented.
- Minimum MTU along a path ⇒ Path MTU



Summary



- IPv4 uses 32-bit addresses organized as network prefix and host suffix.
- Four classes of networks: A, B, C, D
- Routers determine next hop using routing tables
- IP provides connectionless unreliable service