

# Internet Protocol (IP)

Raj Jain

The Ohio State University

Columbus, OH 43210

Jain@CIS.Ohio-State.Edu

<http://www.cis.ohio-state.edu/~jain/>

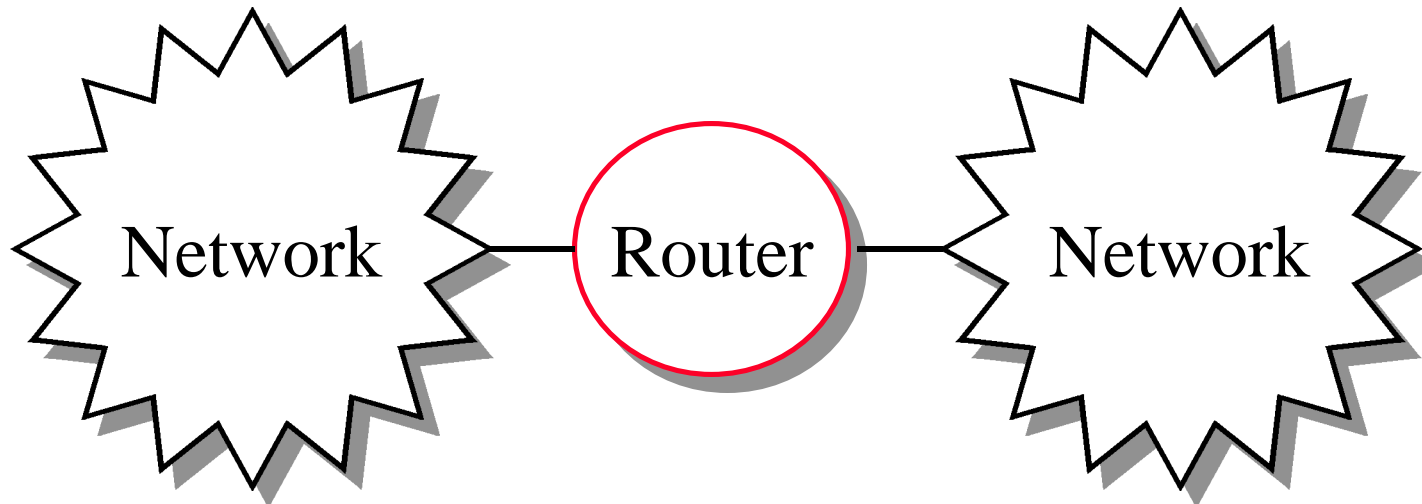


- ❑ Internetworking
- ❑ IP Address format
- ❑ IP data forwarding
- ❑ Fragmentation and reassembly

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

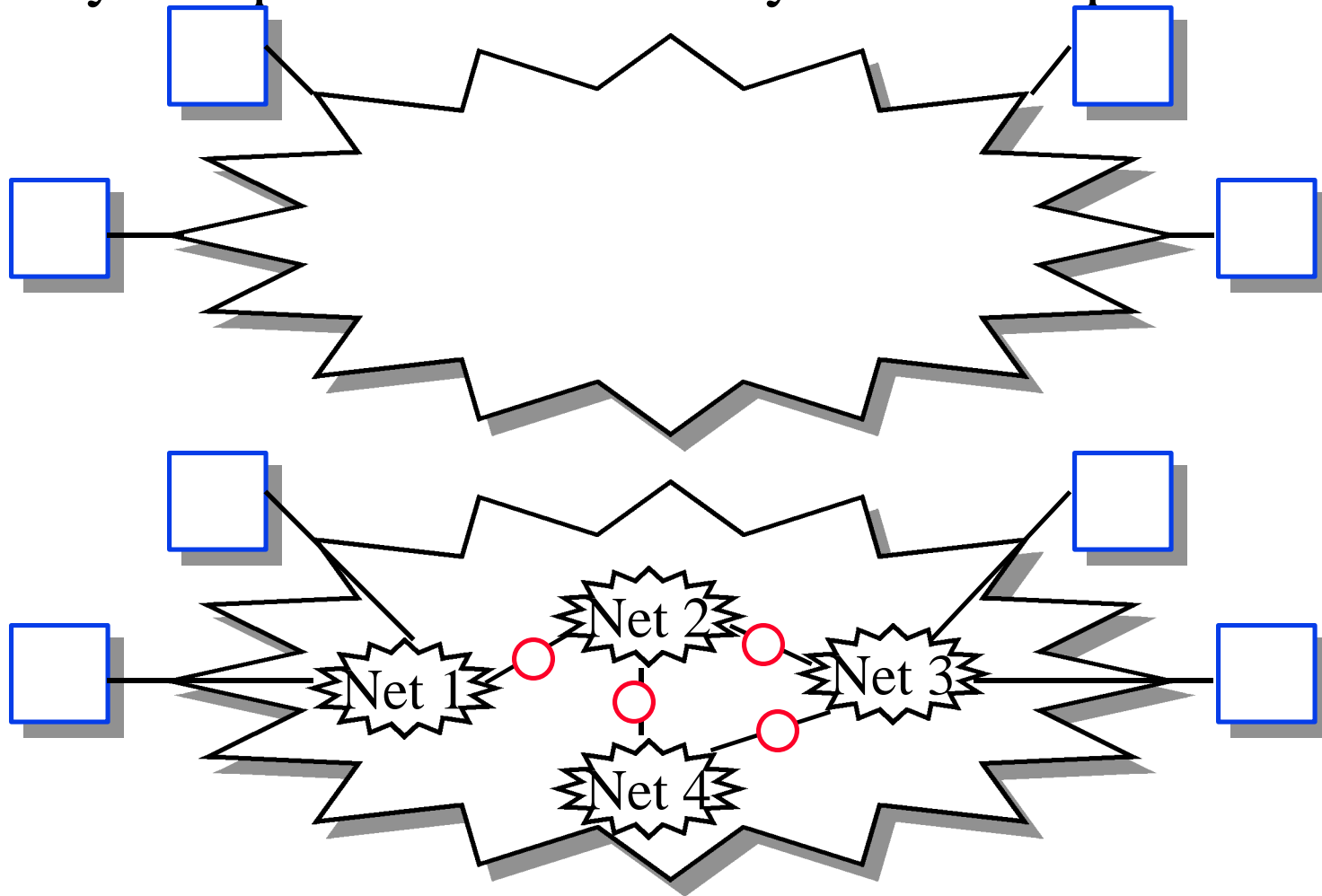
# Internetworking

- Internetwork = Collection of networks  
Connected via routers



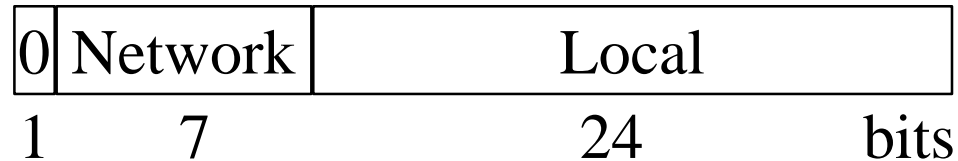
# Internet = Virtual Network

- Any computer can talk to any other computer

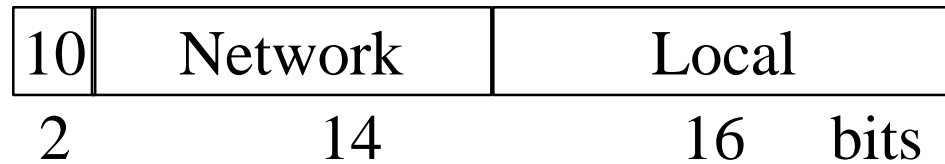


# IP Address

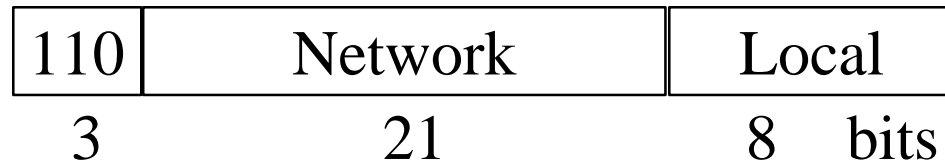
- Class A:  
(1+3 bytes)



- Class B:  
(2+2 bytes)



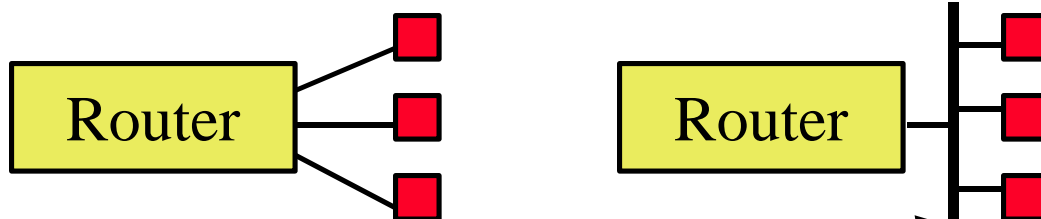
- Class C:  
(3+1 bytes)



- 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

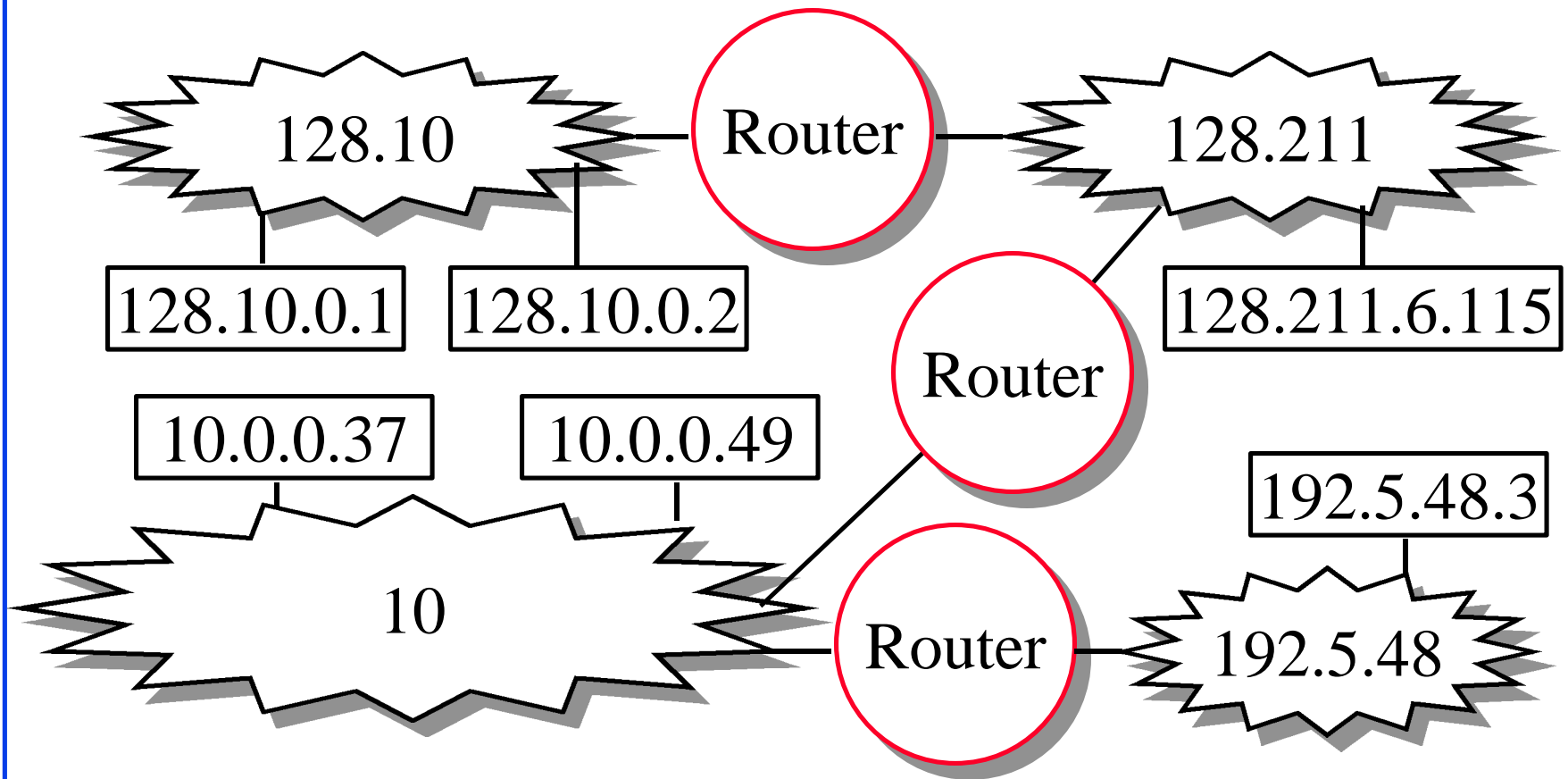
## Division of the Address Space

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

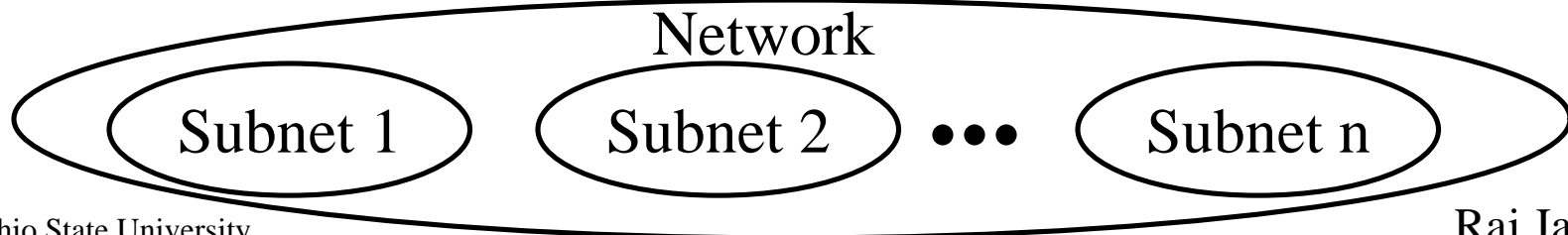
# Subnetting

- ❑ 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  
=  $\Sigma$  Class C addresses

❑ Example:

Class C 1: 11010100 10101000 00010000

Class C 2: 11010100 10101000 00010001

Supernet: 11010100 10101000 00010000

❑ First 23 bits = subnet

Address: 11010100 10101000 00010001 11110001

Mask: 11111111 11111111 11111110 00000000

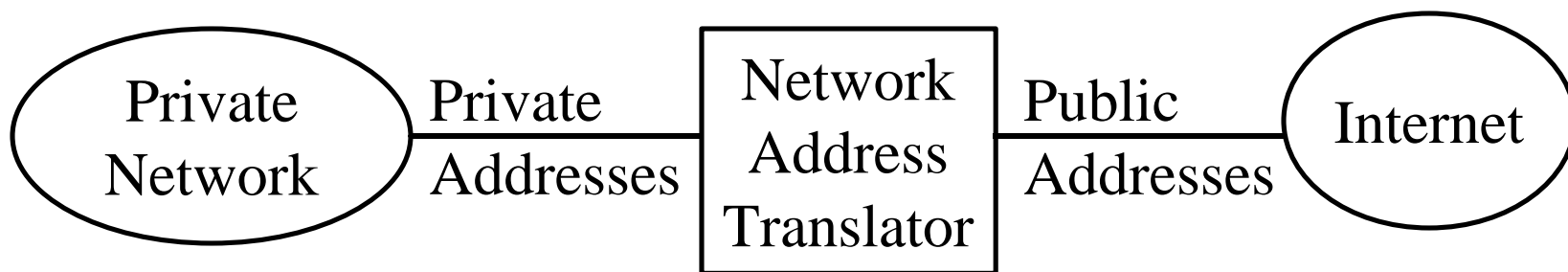
.AND. 10010100 10101000 00010000 00000000

# Special IP Addresses

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

# Private Addresses

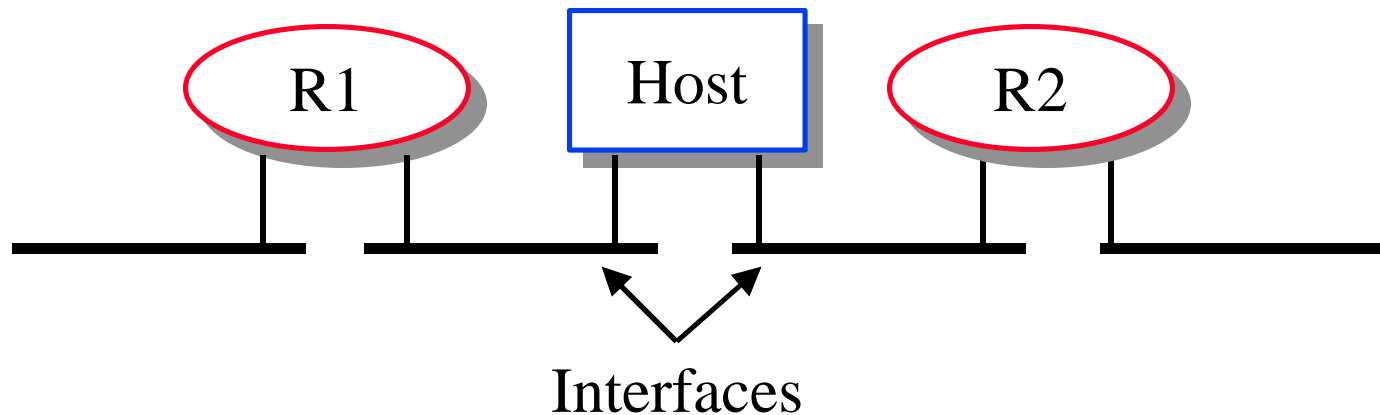
- ❑ Any organization can use these inside their network  
Can't go on the internet. [RFC 1918]
- ❑ 10.0.0.0 - 10.255.255.255 (10/8 prefix)
- ❑ 172.16.0.0 - 172.31.255.255 (172.16/12 prefix)
- ❑ 192.168.0.0 - 192.168.255.255 (192.168/16 prefix)



# Classless Interdomain Routing (CIDR)

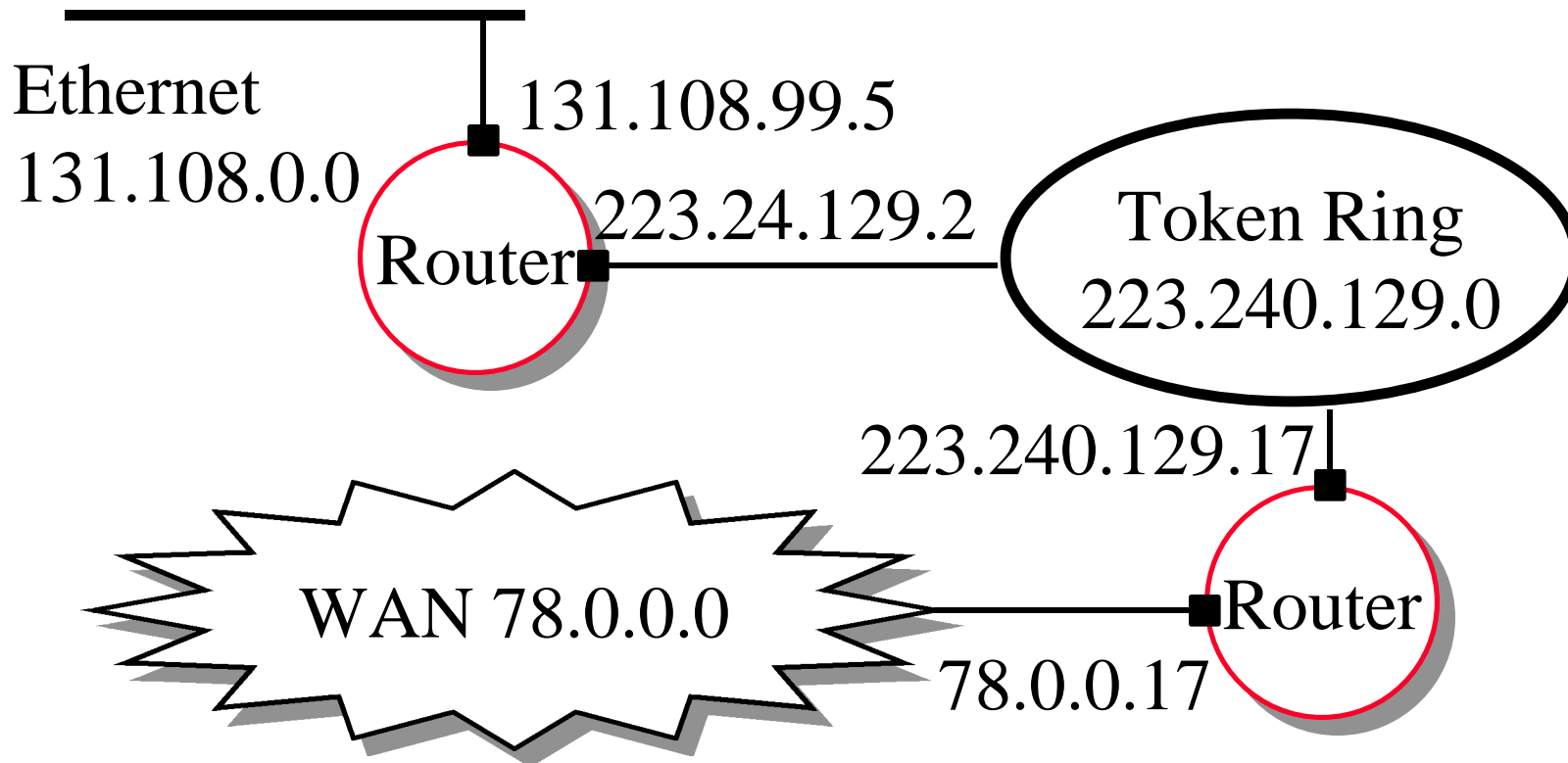
- ❑ Pronounced “Cider”
- ❑ Classless  $\Rightarrow$  Forget classes.  
Use Addresses and prefix lengths [RFC1517-1520]
- ❑ All routing table entries have prefix lengths  
Example: 164.107.61.0/26

# Multi-Homed Hosts



- ❑ Each interface has an address.  
Two or more interfaces  $\Rightarrow$  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

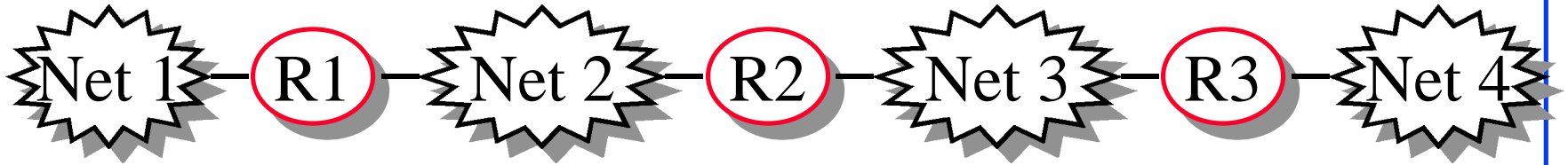


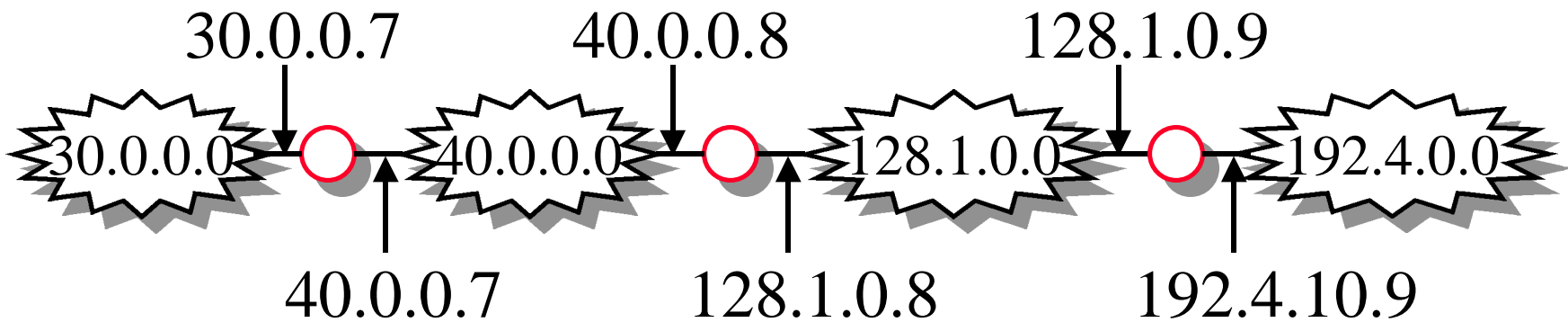
Table at R2:

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

Fig 16.2

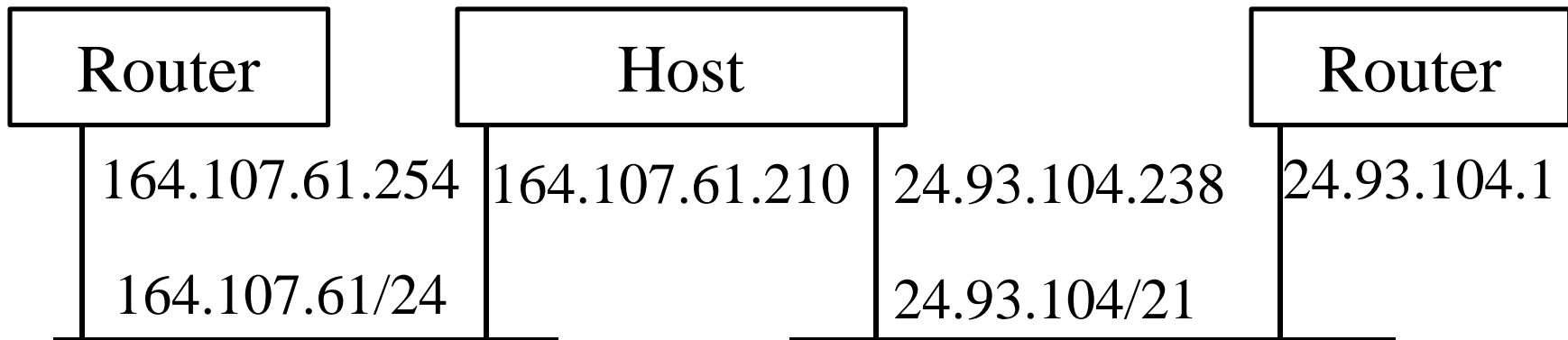
# IP Addresses and Routing Table Entries

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



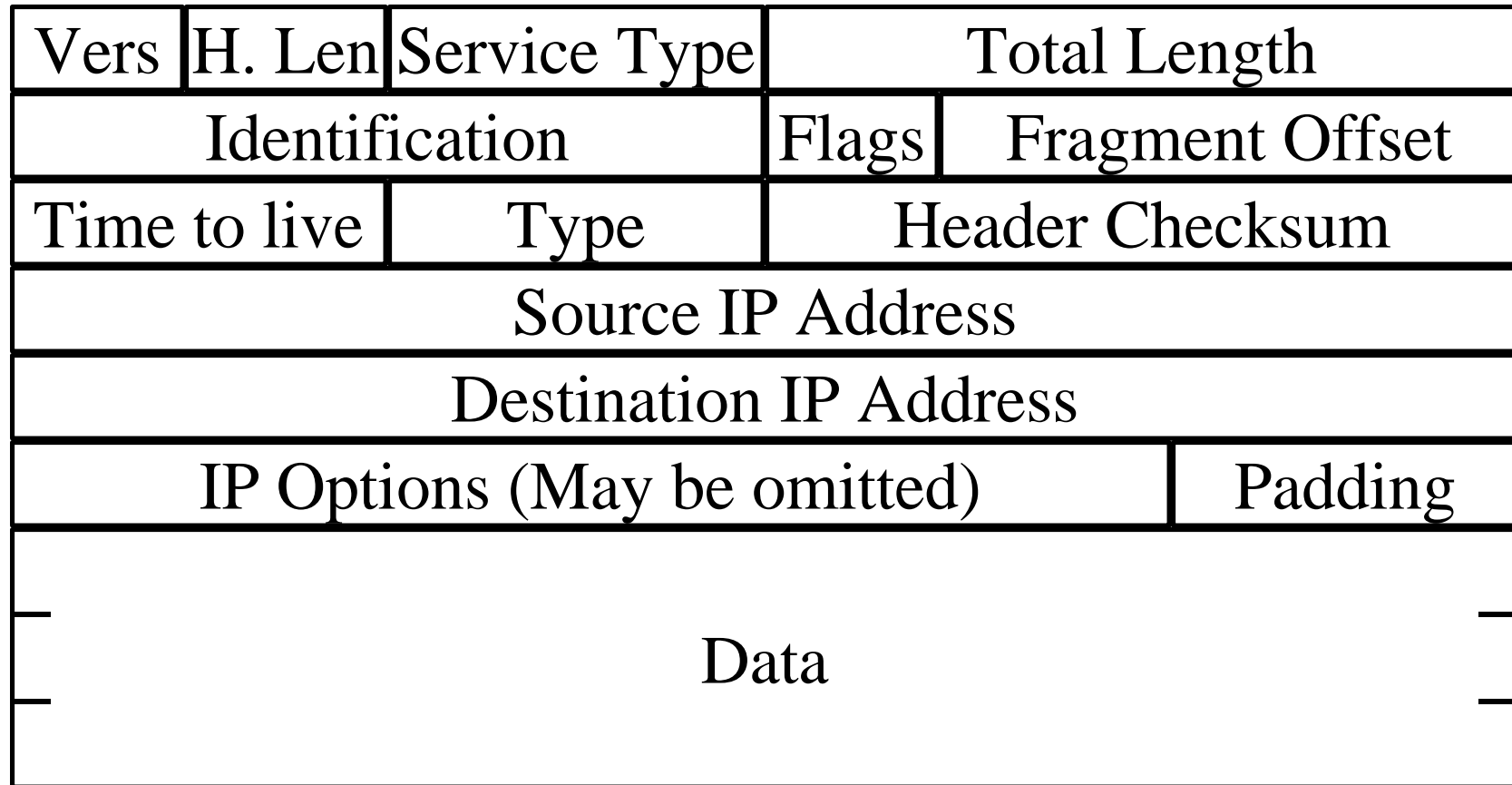
Destination	Mask	Next Hop
30.0.0.0	255.0.0.0	40.0.0.7
40.0.0.0	255.0.0.0	Deliver direct
128.1.0.0	255.255.0.0	Deliver direct
192.4.10.0	255.255.255.0	128.1.0.9

# 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



# 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)

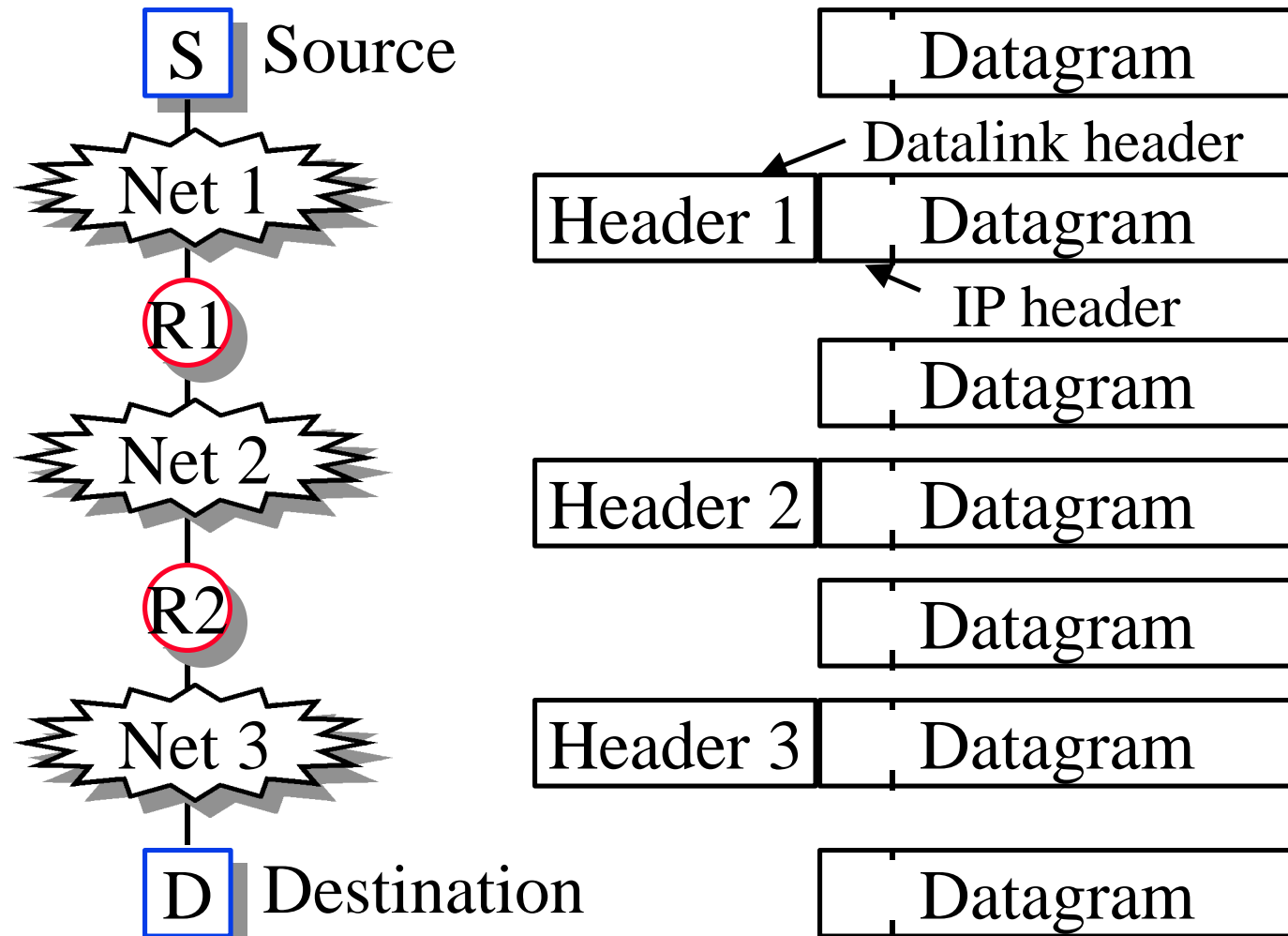
- ❑ Flags (3 bits):
  - More flag - used for fragmentation
  - No-fragmentation
  - Reserved
- ❑ Fragment offset (13 bits): In units of 8 bytes
- ❑ Time to live (8 bits): Specified in router hops
- ❑ Protocol (8 bits): Next level protocol to receive the data
- ❑ Header checksum (16 bits): 1's complement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

# 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

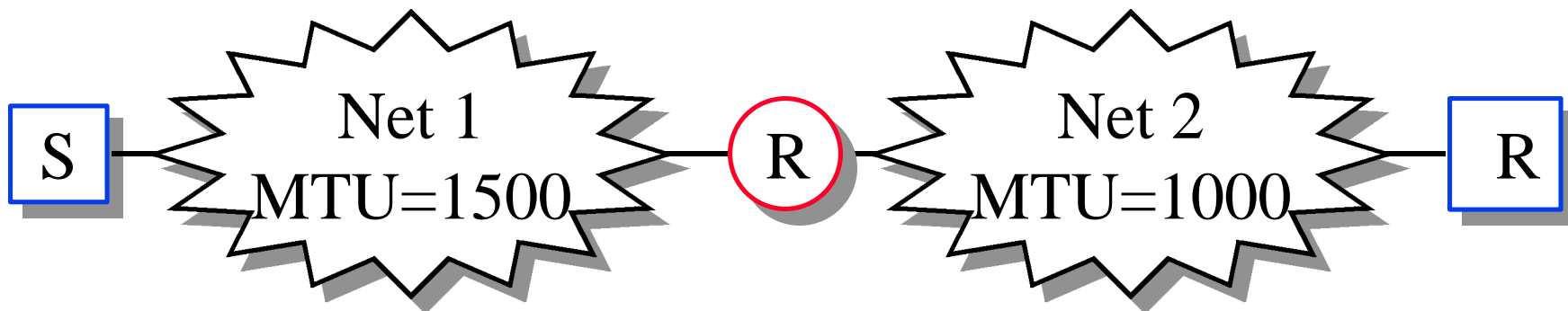


Fig 17.3

# 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

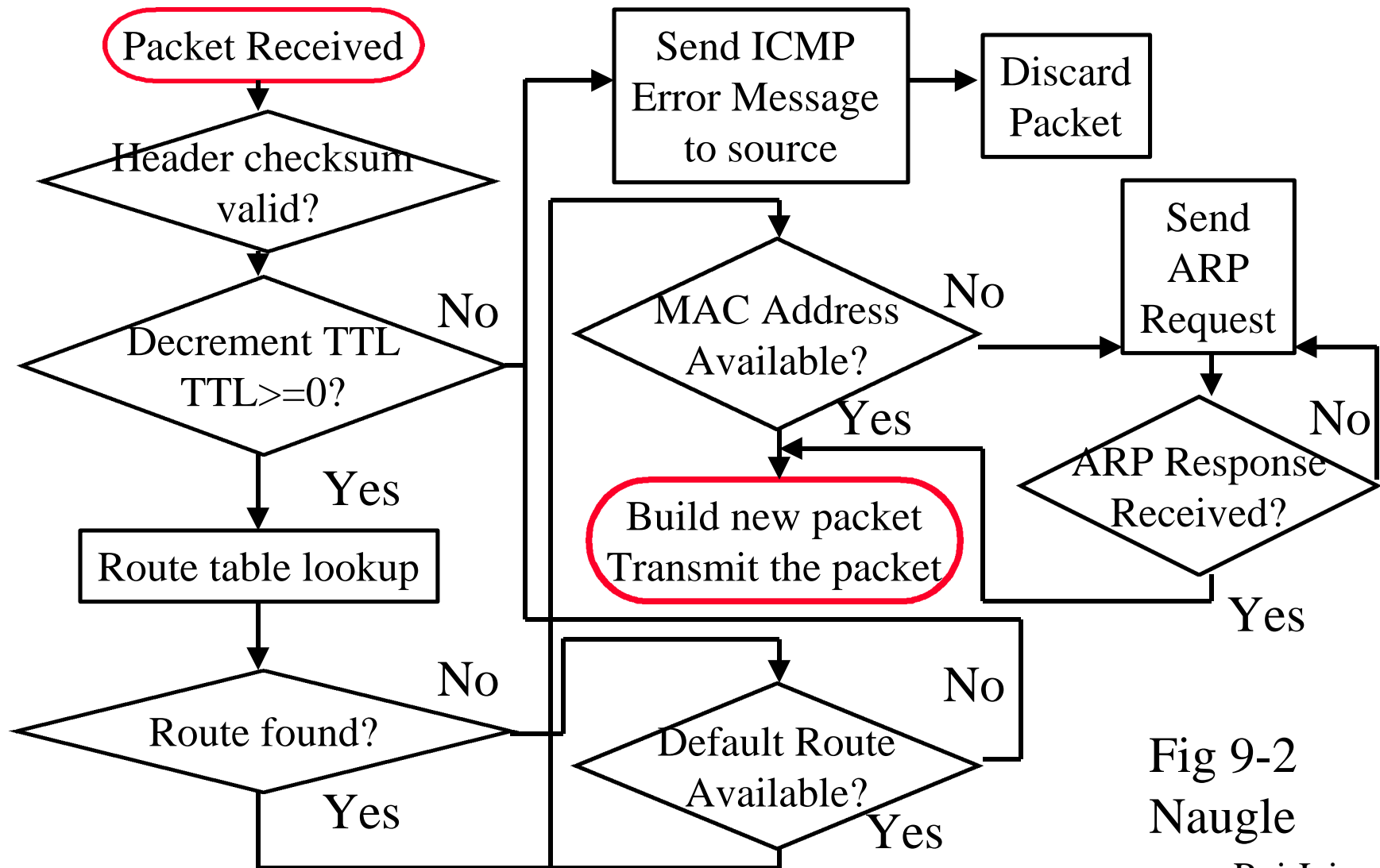


Fig 9-2  
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Raj Jain

# IP Options Coding

Type	Length	Value
1B	1B	$n$ B

Flag Copy	Class	Number
1b	2b	5b

- ❑ 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

Code	Length	Pointer	Router Data
------	--------	---------	-------------

P	128.2.3.4	128.7.8.9	128.10.4.12
---	-----------	-----------	-------------




P	128.2.3.4	128.7.8.9	128.10.4.12
---	-----------	-----------	-------------




# Route Recording

Code	Length	Pointer	Route Data
------	--------	---------	------------

P	128.2.3.4	Empty	Empty
---	-----------	-------	-------

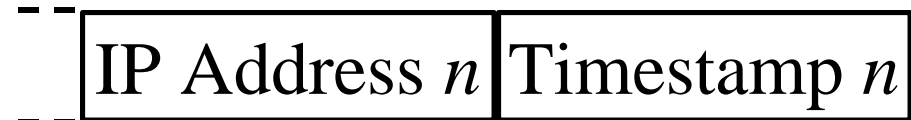


P	128.2.3.4	128.7.8.9	Empty
---	-----------	-----------	-------



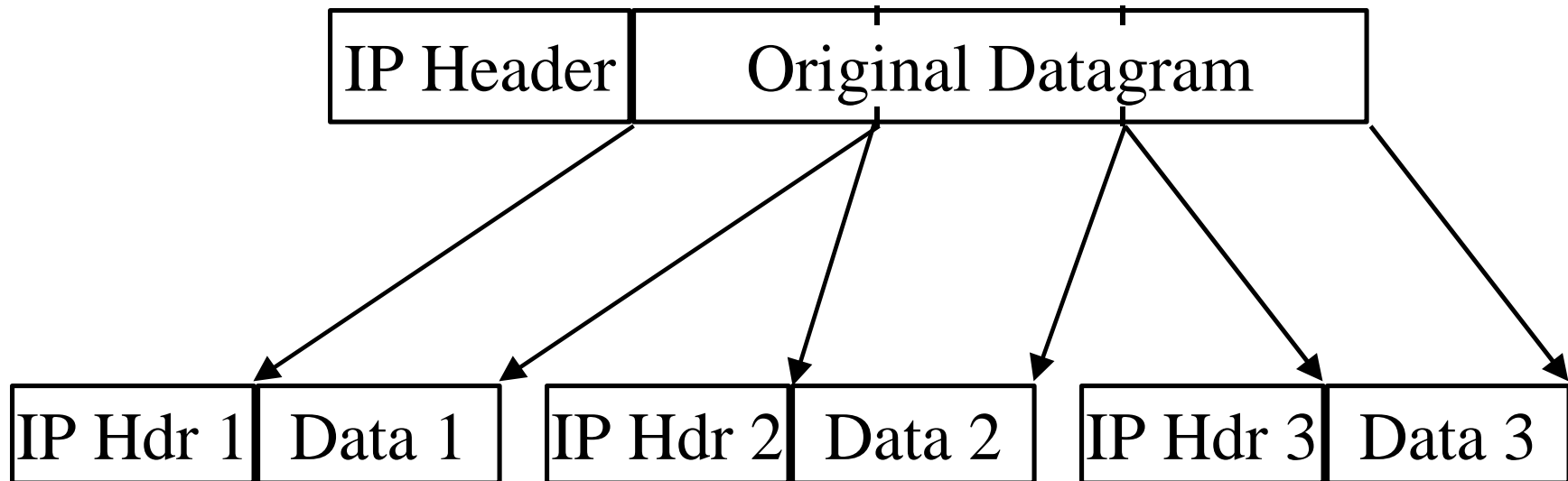


# Timestamp Option

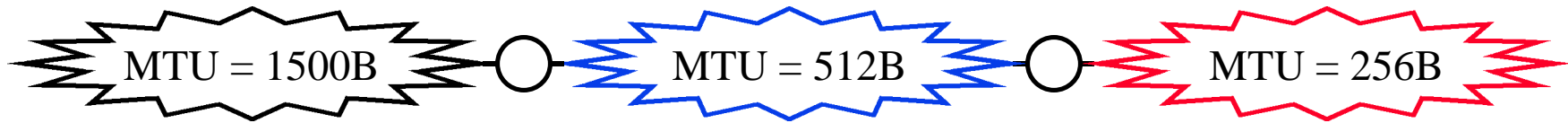


# Fragmentation

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



# Fragmentation



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

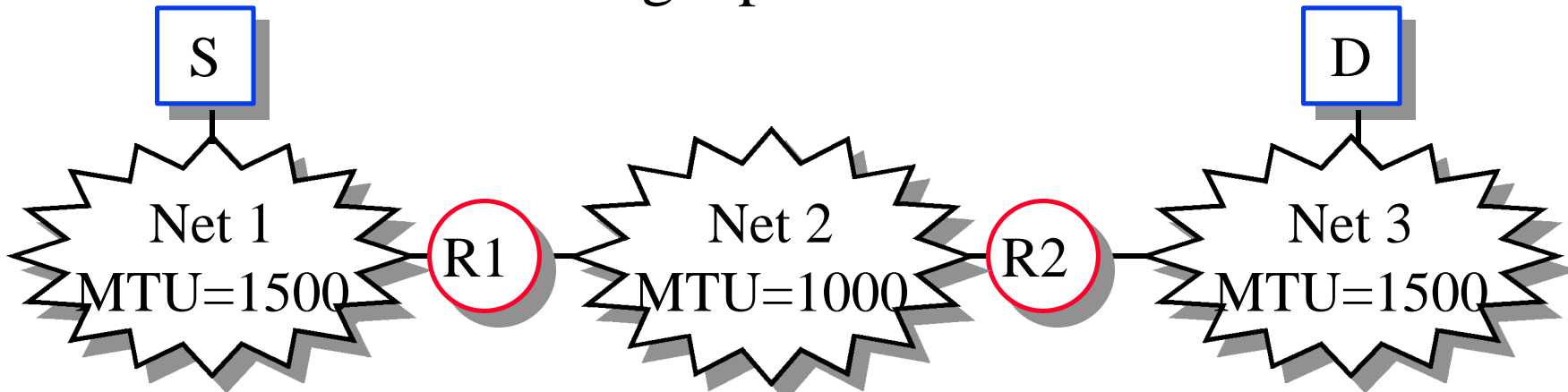
ID = 12345, More = 1  
Offset = 128W, Len = 476B

ID = 12345, More = 1  
Offset = 128W, Len = 256B

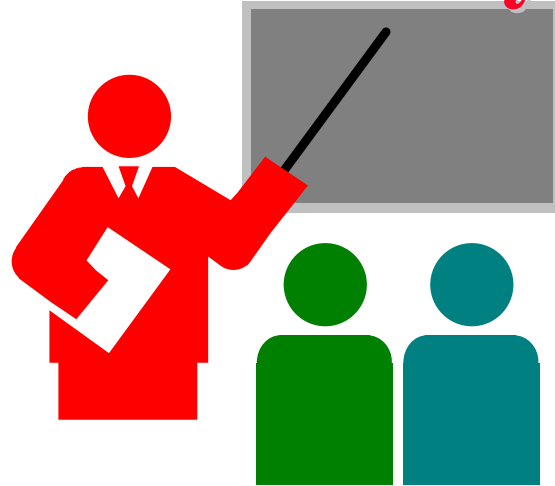
ID = 12345, More = 1  
Offset = 160W, Len = 220B

# 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  $\Rightarrow$  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