

PART VI

**INTERNET PROTOCOL:
CONNECTIONLESS DATAGRAM
DELIVERY**

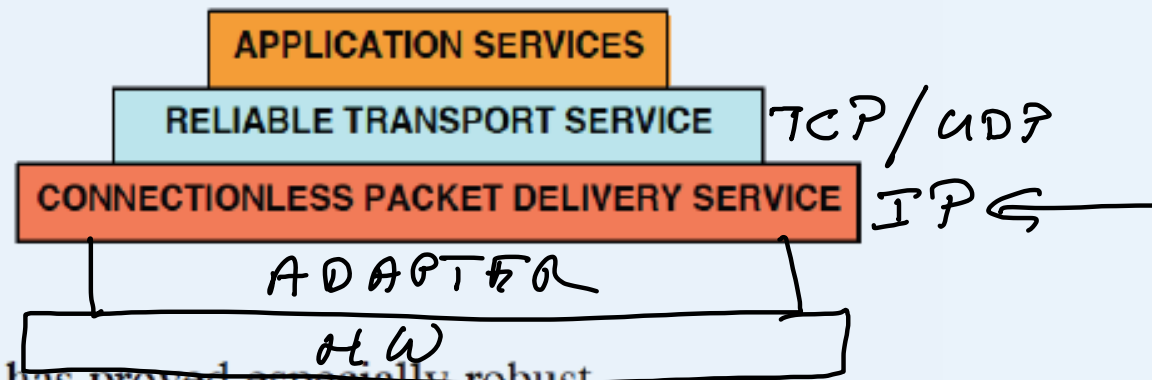
Internet Protocol

- 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*

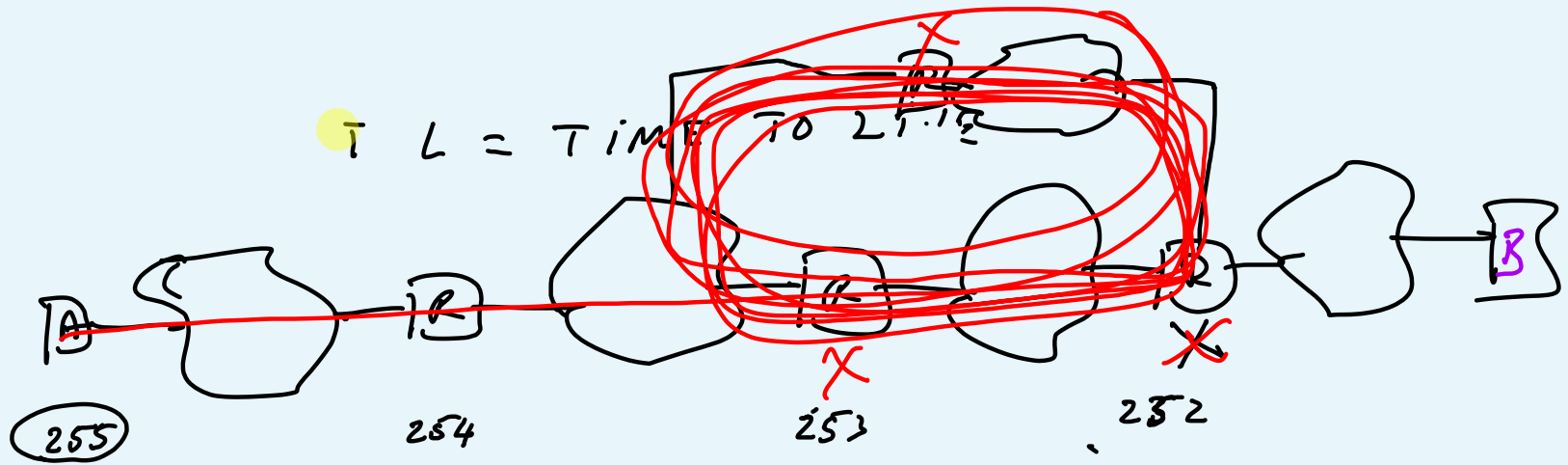
IP Datagram Layout



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

Datagram Header Format

Byte	0				1				2				3																			
bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	Version				Header Length				Type Of Service				Total Length																			
4	Identification								Flags				Fragment Offset																			
8	TTL				Type				Header Checksum				TOTAL																			
12	Source IP Address																															
16	Destination IP Address																															
																																
20	IP Payload Data																															



$$\begin{array}{r}
 1011 \quad 0110 \xrightarrow{\text{1's comp}} 0100 \quad 1001 \\
 0111 \quad 1001 \longrightarrow 1000 \quad 0110 \\
 1101 \quad 1001 \longrightarrow \boxed{1100 \quad 1111} \\
 0010 \quad 0110 \\
 \boxed{1111 \quad 0101}
 \end{array}$$

$$\begin{array}{r}
 \overset{1}{1} \overset{1}{1} \overset{1}{0} \overset{1}{1} \cdot \overset{1}{0} \overset{1}{0} \overset{1}{1} \overset{1}{0} \xrightarrow{\text{1's com}} 0010 \quad 1101 \\
 0010 \quad 1110 \\
 \boxed{0000 \quad 0000}
 \end{array}$$

$$\begin{array}{r}
 0010 \quad 1101 \\
 + 0000 \quad 0001 \\
 \hline
 \boxed{0010 \quad 1110}
 \end{array}$$

Addresses In The Header

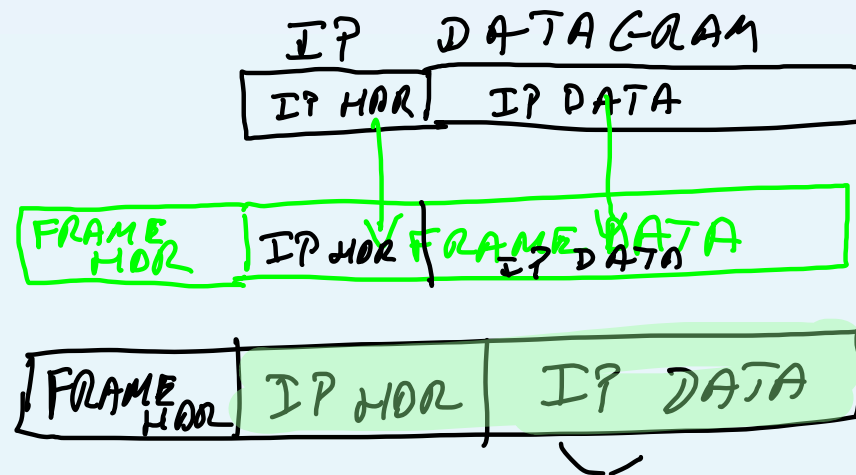
- SOURCE is the address of original source
- DESTINATION is the address of ultimate destination

IP Versions

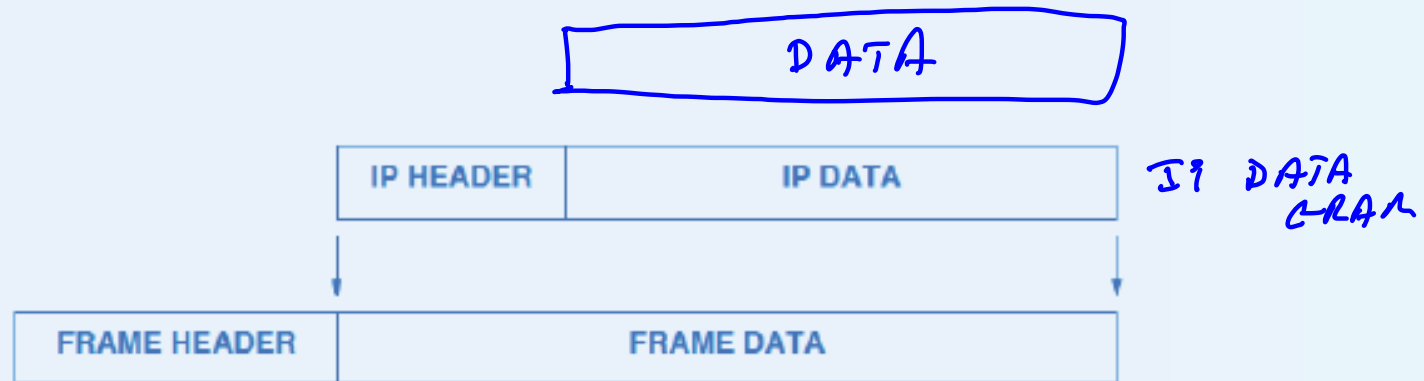
- Version field in header defines version of datagram
- Internet currently uses version 4 of IP, IPv4
- Preceding figure is the IPv4 datagram format
- IPv6 discussed later in the course

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



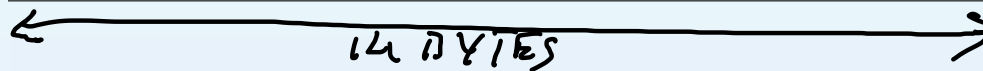
Datagram Encapsulation For Ethernet



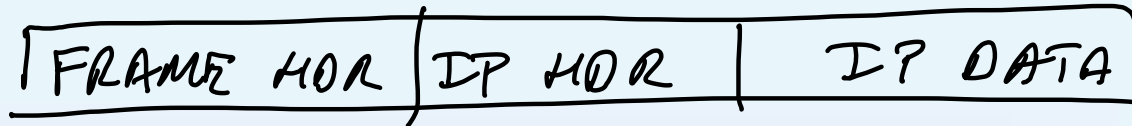
- Ethernet header contains Ethernet hardware addresses
- Ethernet type field set to 0x0800

Ethernet Frame Format

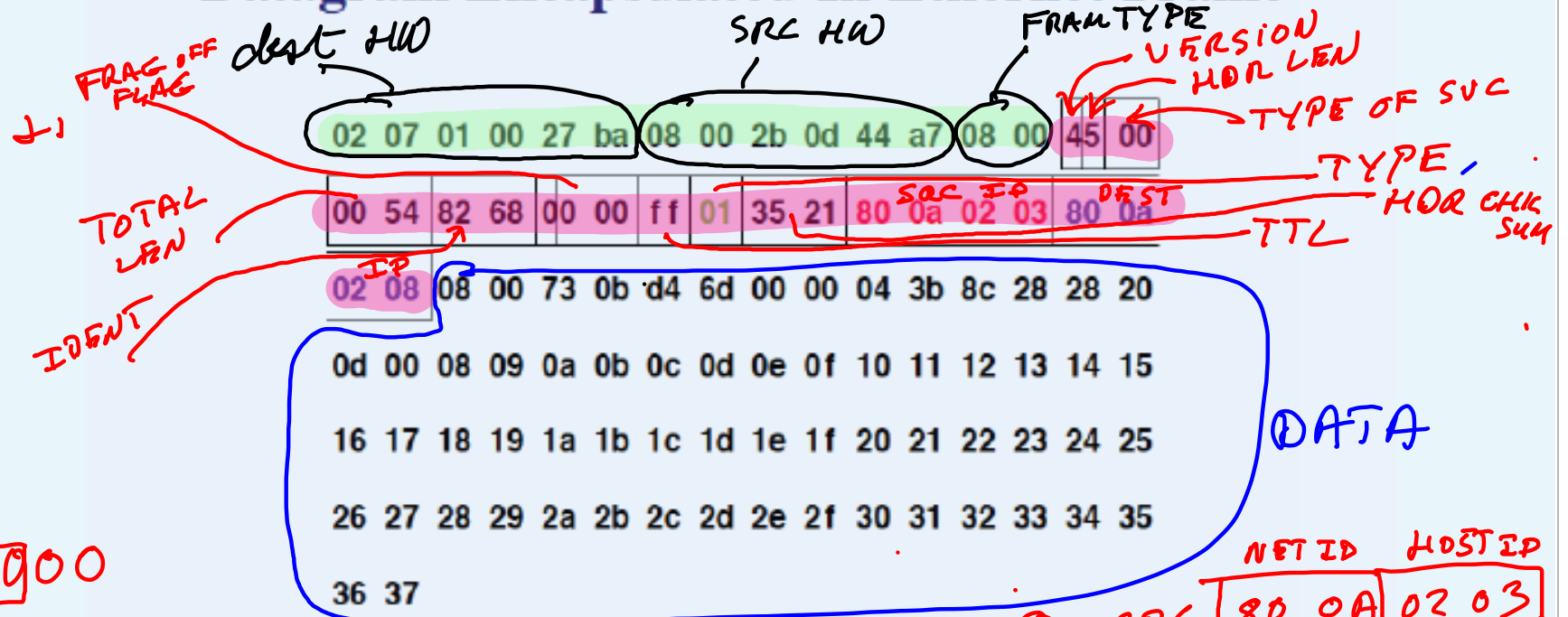
Destination Hardware Address	Source Hardware Address	Frame Type	Frame Data
6 Bytes	6 Bytes	2 Bytes	46 - 1500 Bytes



- 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)

(B)
(B)

	NET ID	HOST IP
SRC	80 0A	02 03
DEST	80 0A	02 08

Destination Hardware Address	Source Hardware Address	Frame Type	Frame Data
6 Bytes	6 Bytes	2 Bytes	46 - 1500 Bytes

FRAME

Byte	0							1							2							3										
bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	Version			Header Length				Type Of Service							Total Length																	
4	Identification											Flags		Fragment Offset																		
8	TTL				Type				Header Checksum																							
12	Source IP Address																															
16	Destination IP Address																															
Optional	IP Options (May Be Omitted)														Padding																	
20	IP Payload Data																															

IP

8B	BD	EB	D5	A3	00	9E	CF	04	7F	AC	2B	08	00	49	11
00	72	FC	53	14	8D	47	36	9A	84	D2	92	8E	39	49	16
75	02	D6	1B	BE	C8	33	02	C7	DF	1A	12	AF	D3	91	AF
BE	91	3D	25	0D	6E	4F	5E	61	0A	E5	42	F0	6C	B1	0E
4C	E7	57	89	4E	9D	C7	2D	7E	74	A8	AF	FE	7B	1A	FF
1E	1B	45	4A	3D	5B	5E	7A	95	8E	31	C4	83	3E	A8	47
E0	A1	95	35	99	33	07	2D	D6	7F	3F	E5	E8	5C	20	9D
80	25	CC	B1	EF	7F	69	44	B6	AC	A4	EE	03	88	5C	B0

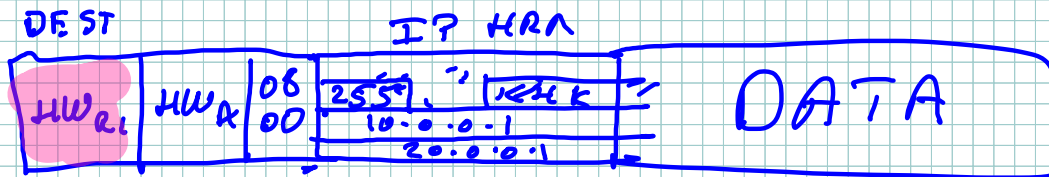
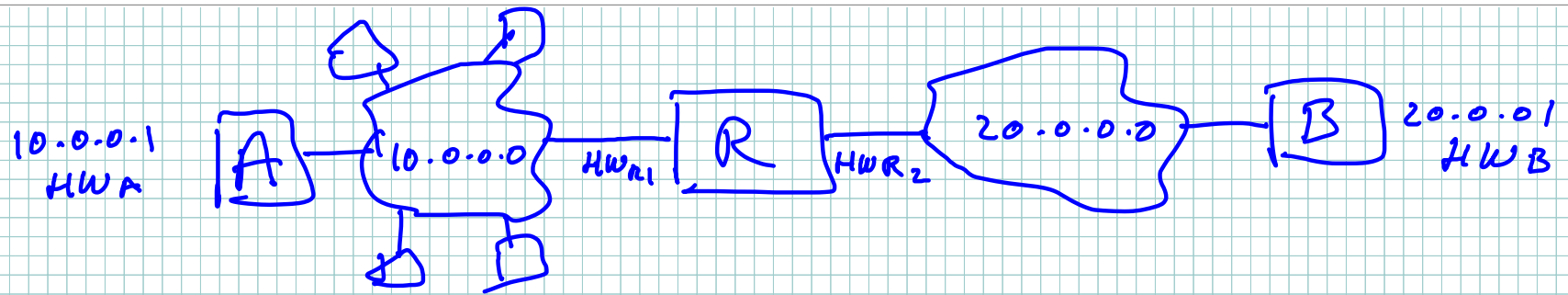
VER 4
 HDR LEN 5
 TYPE OF SVC 11
 TOTAL LEN 0072
 IDENT FC53
 OFFSET 1480
 FLAGS 000
 TTL 47
 TYPE 36
 CHKSM 9A84

DEST HW 8B BD EB D5 A3 00
 SRC HW 9E CF 04 7F AC 2B
 FRAME TYPE 08 00 ← IP

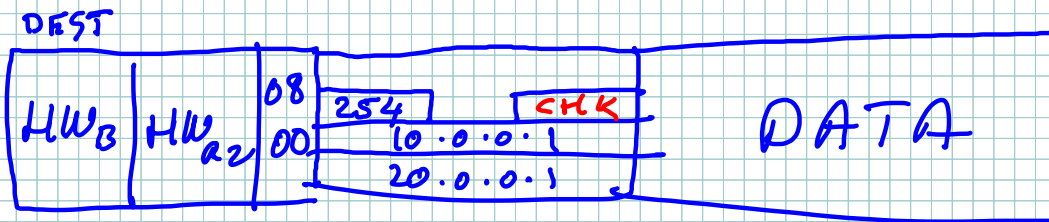
1 4 8 D
 0001 0100 1000 1101
 FCAGS

(C) SRC IP D2 12 8E 39
 (A) DST IP 49 16 75 02
 DATA D6 1B BE C8 33

02 1101
 49 0100



FROM A
TO R



FROM R
TO B

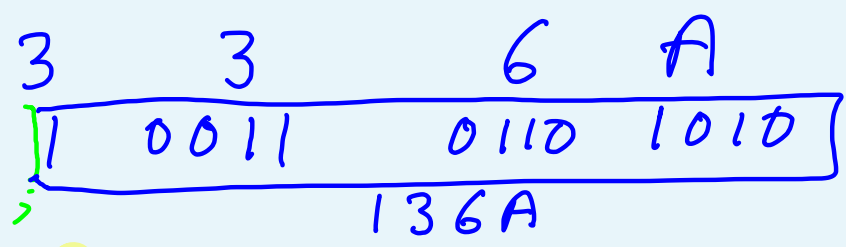
Destination Hardware Address	8B BD EB D5 A3 00	10001011	10111101	11101011	11010101	10100011	00000000
Source Hardware Address	9E CF 04 7F AC 2B	10011110	11001111	00000100	01111111	10101100	00101011
Frame Type	08 00	00001000	00000000				
Vers & Len	45	01000101					
Type Of Service	11	00010001					
Total Length	00 72	00000000	01110010				
Ident	FC 53	11111100	01010011				
Flags & Fragment Offset	14 8D	00010100	10001101				
Flags							
Fragment Offset	14 8D	00010100	10001101				
TTL	47	01000111					
Type	36	00110110					
Header Checksum	9A 84	10011010	10000100				
Source IP Address	D2 92 8E 39	11010010	10010010	10001110	00111001		
Class	C						
Network	D2 92 8E	11010010	10010010	10001110			
Host	39	00111001					
Source IP Address (Decimal)	210 146 142 57						
Destination IP Address	49 16 75 02	01001001	00010110	01110101	00000010		
Class	A						
Network	49	01001001					
Host	16 75 02	00010110	01110101	00000010			
Destination IP Address (Decimal)	73 22 117 2						
Payload Data	D6 1B BE C8 33	11010110	00011011	10111110	11001000	00110011	

Destination Hardware Address	Source Hardware Address	Frame Type	Frame Data
6 Bytes	6 Bytes	2 Bytes	46 - 1500 Bytes

Byte	0							1							2							3										
bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	Version			Header Length				Type Of Service							Total Length																	
4	Identification														Flags		Fragment Offset															
8	TTL							Type							Header Checksum																	
12	Source IP Address														Destination IP Address																	
16	Destination IP Address														IP Options (May Be Omitted)							Padding										
Optional	IP Options (May Be Omitted)														IP Payload Data																	
20	IP Payload Data														IP Payload Data																	

FLAGS 001
OFFSET 136A

4B	A8	A0	4E	76	1B	D1	1A	9D	41	79	BD	08	00	45	61
00	72	CA	0C	33	6A	BC	EA	F7	21	21	09	7F	7A	C1	2B
02	5D	7E	7D	37	33	97	91	CA	7A	0C	5A	AE	A0	A7	8A
CF	56	07	DC	79	35	EA	BD	DE	11	6E	12	77	81	D8	33
88	73	1E	75	02	70	20	7B	2C	96	61	DE	E2	27	75	29
19	52	9A	87	C4	CA	1A	96	1C	72	0C	BF	A8	2F	84	A3
BF	C7	CC	A4	6E	37	99	13	44	48	C5	D8	39	22	94	72
95	13	D5	DD	91	F7	A7	EF	E0	AB	30	7F	8E	54	7B	B4



21 = 0010 0001
C1 = 1100 1010

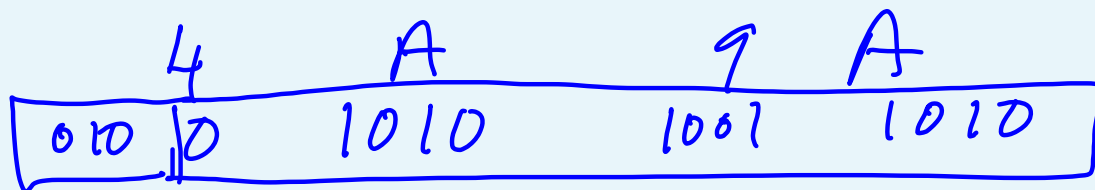
Destination Hardware Address	4B A8 A0 4E 76 1B	01001011 10101000 10100000 01001110 01110110 00011011
Source Hardware Address	D1 1A 9D 41 79 BD	11010001 00011010 10011101 01000001 01111001 10111101
Frame Type	08 00	00001000 00000000
Vers & Len	45	01000101
Type Of Service	61	01100001
Total Length	00 72	00000000 01110010
Ident	CA 0C	11001010 00001100
Flags & Fragment Offset	33 6A	00110011 01101010
Flags	More Fragments	
Fragment Offset	13 6A	00010011 01101010
TTL	BC	10111100
Type	EA	11101010
Header Checksum	F7 21	11110111 00100001
Source IP Address	21 09 7F 7A	00100001 00001001 01111111 01111010
Class	A	
Network	21	00100001
Host	09 7F 7A	00001001 01111111 01111010
Source IP Address (Decimal)	33 9 127 122	
Destination IP Address	C1 2B 02 5D	11000001 00101011 00000010 01011101
Class	C	
Network	C1 2B 02	11000001 00101011 00000010
Host	5D	01011101
Destination IP Address (Decimal)	193 43 2 93	
Payload Data	7E 7D 37 33 97	01111110 01111101 00110111 00110011 10010111

Destination Hardware Address	Source Hardware Address	Frame Type	Frame Data
6 Bytes	6 Bytes	2 Bytes	46 - 1500 Bytes

Byte	0							1							2							3										
bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	Version			Header Length				Type Of Service							Total Length																	
4	Identification														Flags		Fragment Offset															
8	TTL							Type							Header Checksum																	
12	Source IP Address																															
16	Destination IP Address																															
Optional	IP Options (May Be Omitted)																												Padding			
20	IP Payload Data																															

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
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																																
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																																																																
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																																																																																																

FLAGS
 010
 OFFSETS
 0A9A



Destination Hardware Address	87 36 8F 42 77 95	10001111 00110110 10001111 01000010 01110111 10010101
Source Hardware Address	83 1A AB 39 16 D9	10000011 00011010 10101011 00111001 00010110 11011001
Frame Type	08 00	00001000 00000000
Vers & Len	45	01000101
Type Of Service	EE	11101110
Total Length	00 72	00000000 01110010
Ident	B3 45	10110011 01000101
Flags & Fragment Offset	4A 9A	01001010 10011010
Flags	Don't Fragment	
Fragment Offset	0A 9A	00001010 10011010
TTL	E0	11100000
Type	E0	11100000
Header Checksum	BC 20	10111100 00100000
Source IP Address	39 16 85 EA	00111001 00010110 10000101 11101010
Class	A	
Network	39	00111001
Host	16 85 EA	00010110 10000101 11101010
Source IP Address (Decimal)	57 22 133 234	
Destination IP Address	DE 78 12 02	11011110 01111000 00010010 00000010
Class	C	
Network	DE 78 12	11011110 01111000 00010010
Host	02	00000010
Destination IP Address (Decimal)	222 120 18 2	
Payload Data	B3 86 BE AA B7	10110011 10000110 10111110 10101010 10110111

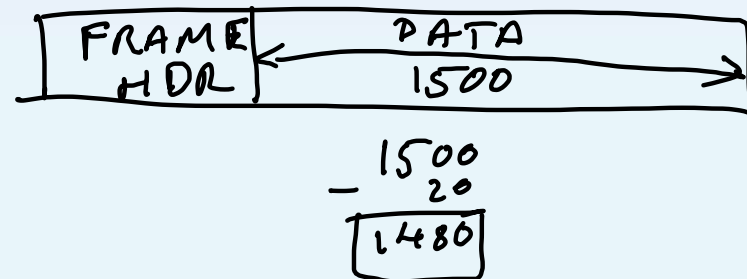
Standards For Encapsulation

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

A Potential Problem

64k

- A datagram can contain up to 65535 total octets (including header)
65,535
- 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?

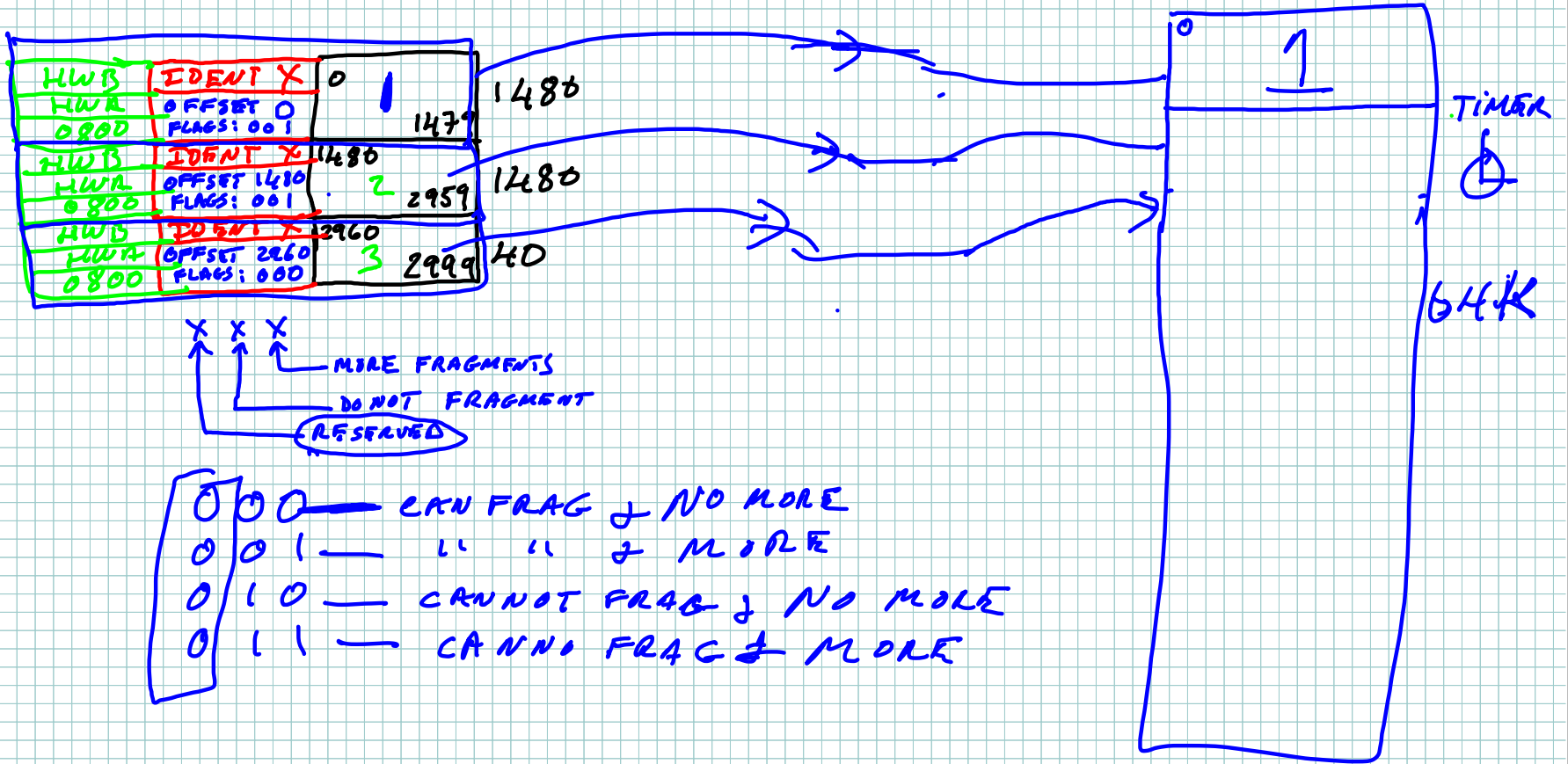
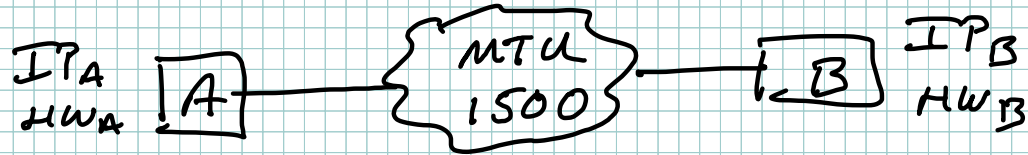


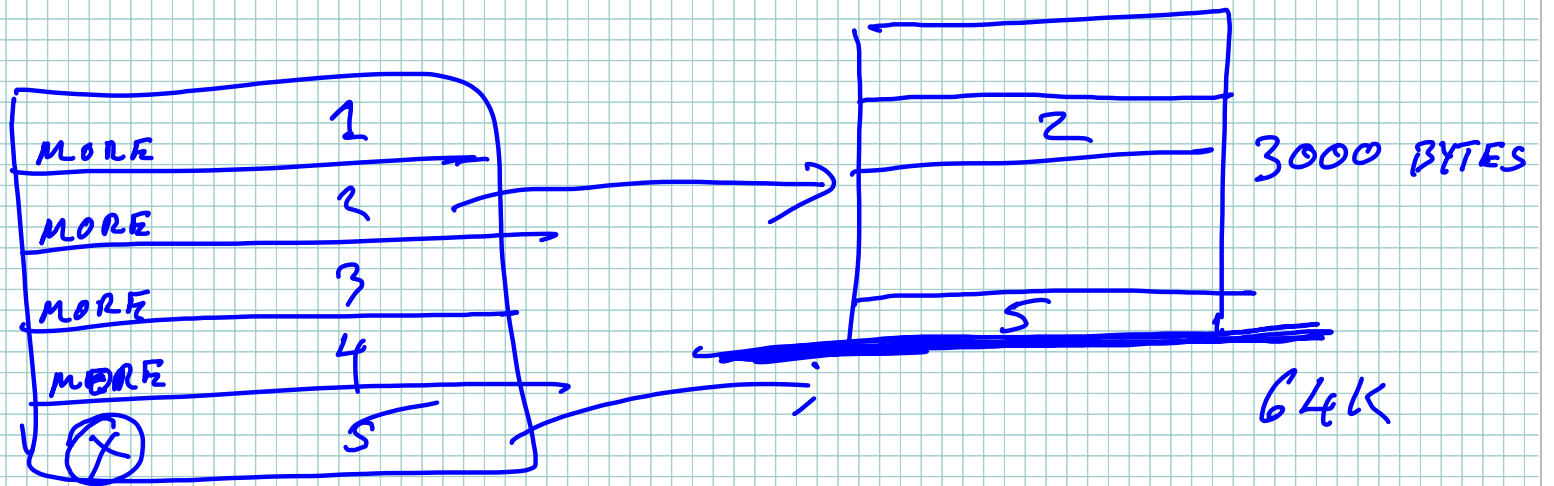
Possible Ways To Accommodate Networks With Differing MTUs

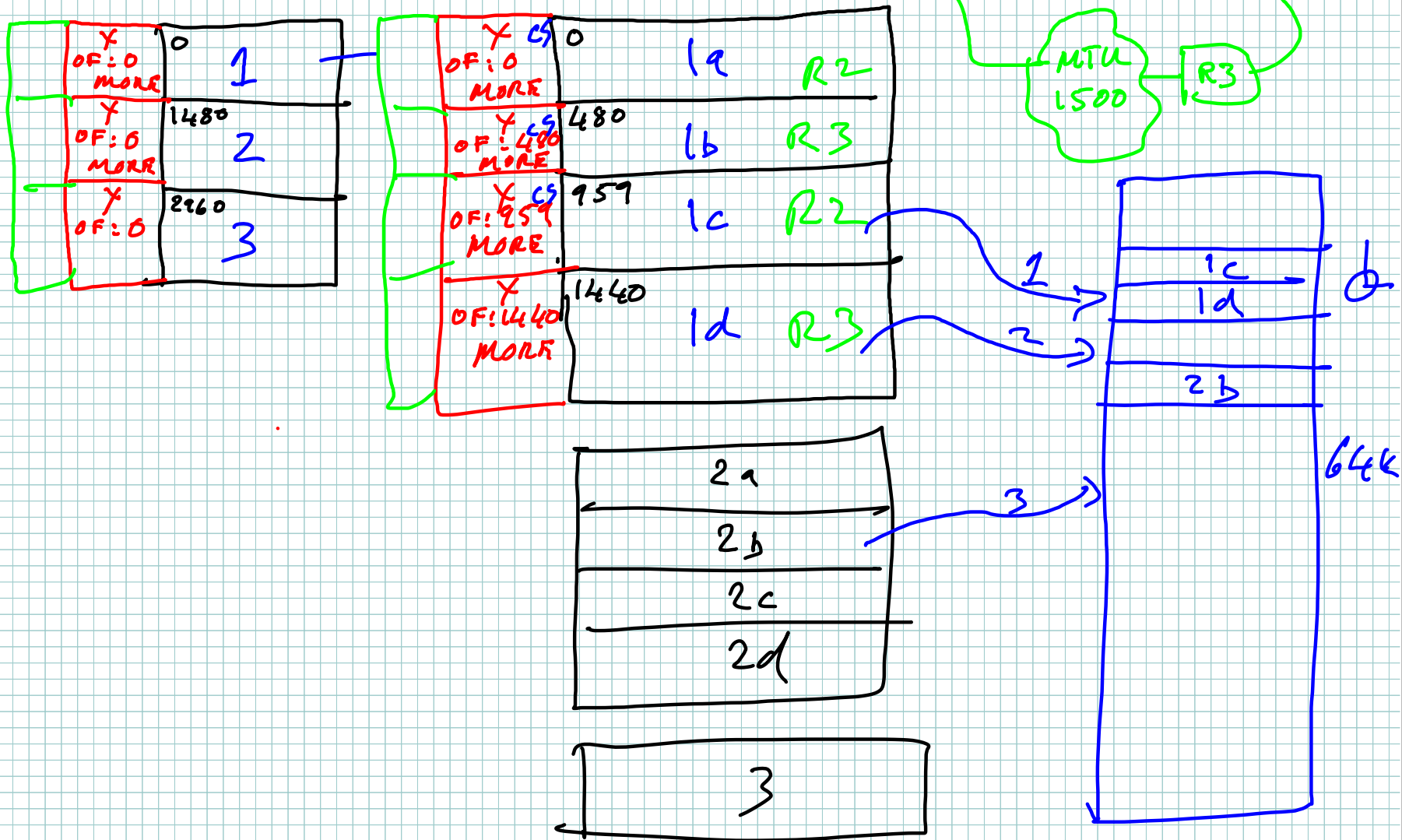
- Force datagram to be less than smallest possible MTU
 - Inefficient
 - Cannot know minimum MTU
- Hide the network MTU and accommodate arbitrary datagram size

Accommodating Large Datagrams

- Cannot send large datagram in single frame
- Solution
 - Divide datagram into pieces
 - Send each piece in a frame
 - Called *datagram fragmentation*







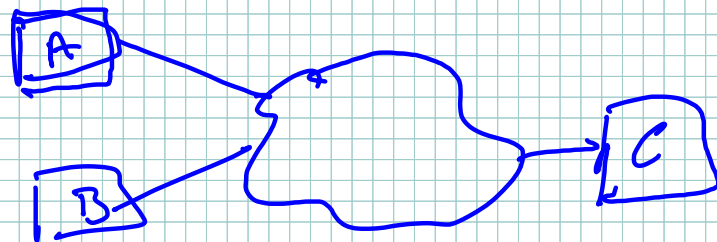
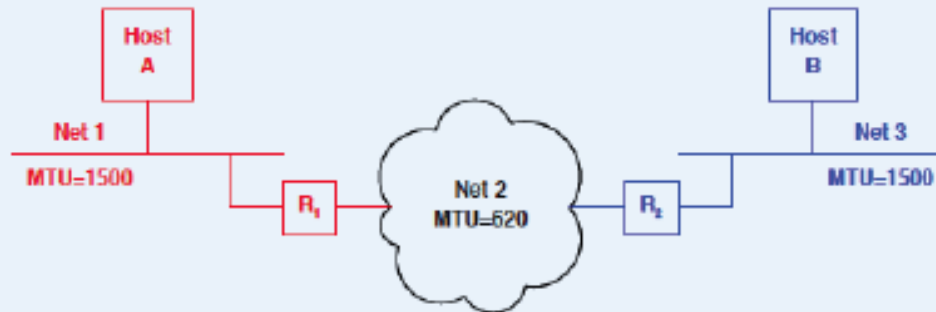


Illustration Of When Fragmentation Needed

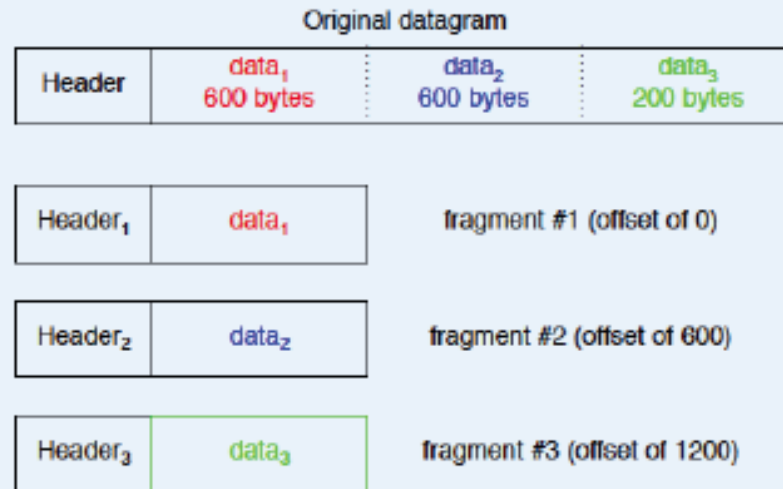


- Hosts A and B send datagrams of up to 1500 octets
- Router R₁ fragments large datagrams from Host A before sending over Net 2
- Router R₂ fragments large datagrams from Host B before sending over Net 2

Datagram Fragmentation

- Performed by routers ↓ *SOURCE*
- Divides datagram into several, smaller datagrams called fragments
- Fragment uses same header format as datagram
- Each fragment forwarded independently

Illustration Of Fragmentation



- 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)