CSC465 – Computer Networks
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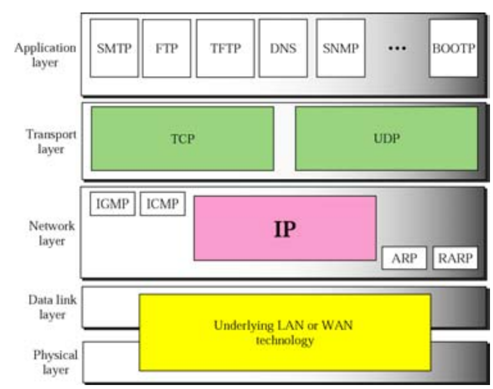
Chapter 8

Internet Protocol (IP)

CONTENTS

- **DATAGRAM**
- **FRAGMENTATION**
- **OPTIONS**
- **CHECKSUM**
- **IP PACKAGE**

Position of IP in TCP/IP protocol suite



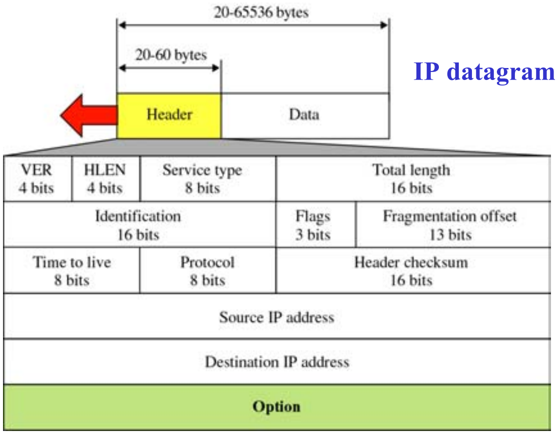
IP

- Unreliable
- Connectionless
- Datagrams can follow different paths
- Can arrive out of order or be lost

8.1

DATAGRAM

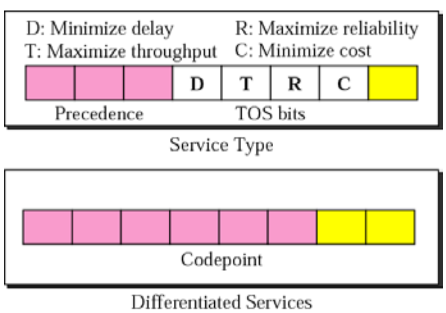
IP datagram



IP

- Version (VER): defines IP version 4-bits = 4
- Header length (HLEN): datagram header
  - In 4-byte words; range is 5 to 15 (5 if no options)
- Differentiated Services (8-bit field)
  - Old interpretation is “Service Type”
  - First 3-bits Precedence: not used
  - Bit 4: D - Minimize delays
  - Bit 5: T – Maximize throughput
  - Bit 6: R – Maximize reliability
  - Bit 7: C – Minimize cost
  - Bit 8: Not used

Service Type or Differentiated Services



Some Default Types of Service

Protocol	**TOS Bits**	**Description**
ICMP	0000	Normal
SNMP	0010	Maximize Reliability
FTP (Data)	0100	Maximize Throughput
FTP (Command)	1000	Minimize delay
DNS (UDP query)	1000	Minimize delay
DNS (TCP query)	0000	Normal
Telnet	1000	Minimize delay
Interior Gateway	0010	Maximize reliability

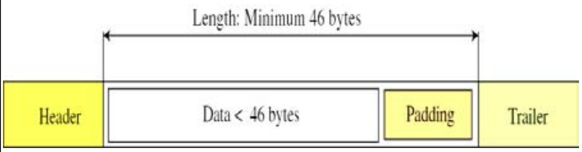
Codepoint Values

Category	**Codepoint**	**Assigning Authority**
1	XXXXX0	Internet
2	XXXX11	Local
3	XXXX01	Temp/Experimental

Total Length

- 16-bit value with length of header plus data
- IP Datagram limited to 64K bytes
  - Some networks can’t encapsulate a 64K datagram into their frames
  - Datagram must be fragmented
- Length field not normally needed
  - Ethernet frame holds data sizes 46 to 1500 bytes
  - If IP datagram is < 46 bytes padding will be added to meet minimum requirement of DL layer
  - Receiving IP layer needs to know breakdown

Encapsulation of a small datagram in an Ethernet frame

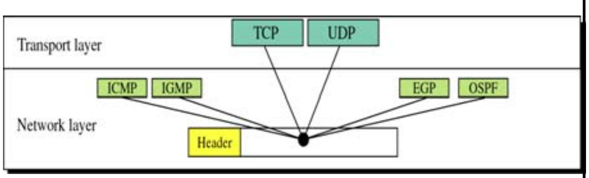


Time to Live

- Constrains "lifetime" of packet
- Stops "run-a-way" packets due to corrupt router tables
  - Protects network resources
  - Avoids confusing TCP
- Field decremented by routers
- Can limit packet journey
  - Set to one to keep traffic on LAN

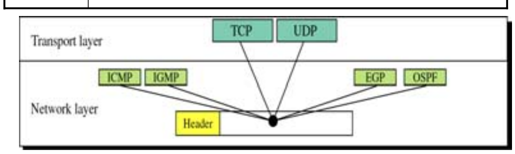
Protocol

- 8-bits
- Defines higher-level protocol using IP layer
- Field specifies final destination protocol for delivery
- Helps in the IP demultiplexing process



Higher-level Protocol Field Values

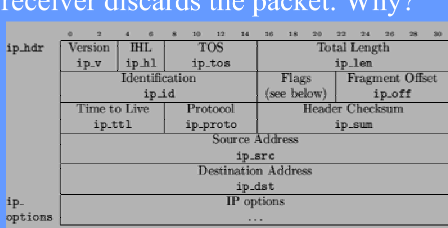
Value	Protocol
1	ICMP
2	IGMP
6	TCP
17	UDP
89	Open Shortest-Path First (OSPF) Routing



Example 1

An IP packet has arrived with the first 8 bits as: 01000010.

The receiver discards the packet. Why?



An IP packet has arrived with the first 8 bits as shown:

← 01000010

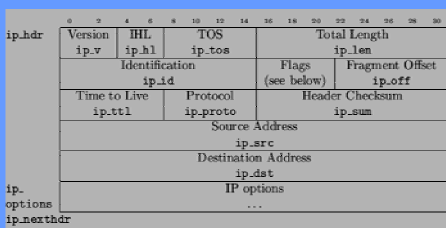
The receiver discards the packet. Why?

There is an error in this packet. The 4 left-most bits (0100) show the version, which is correct.

The next 4 bits (0010) show the header length, which means (2×4 byte words = 8 bytes), which is wrong. The minimum number of bytes in the header must be 20. The packet has been corrupted in transmission.

Example 2

In an IP packet, the value of HLEN is 1000 in binary. How many bytes of options are being carried by this packet?



Solution

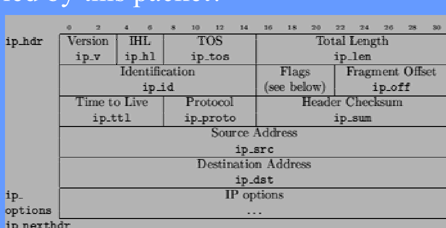
In an IP packet, the value of HLEN is 1000 in binary. How many bytes of options are being carried by this packet?

The HLEN value is 8, which means the total number of bytes in the header is 8 × 4 byte words or 32 bytes.

The first 20 bytes are the main header, the next 12 bytes are the options.

Example 3

In an IP packet, the value of HLEN is 5_{16} and the value of the total length field is 0028_{16}. How many bytes of data are being carried by this packet?



Solution

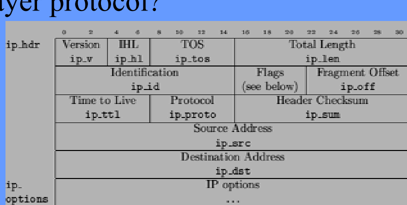
In an IP packet, the value of HLEN is 5_{16} and the value of the total length field is 0028_{16}. How many bytes of data are being carried by this packet?

The HLEN value is 5, which means the total number of bytes in the header is 5 × 4 or 20 bytes (no options). The total length is 40 bytes, which means the packet is carrying 20 bytes of data (40–20).

Example 4: An IP packet arrives with the first few hexadecimal digits as shown below:

← 45000028000100000102..................

How many hops can this packet travel before being dropped? The data belongs to what upper layer protocol?



An IP packet has arrived with the first few hexadecimal digits as shown below:

← 45000028000100000102..................

How many hops can this packet travel before being dropped? The data belong to what upper layer protocol?

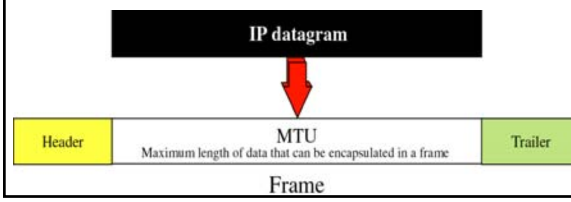
To find the time-to-live field, we should skip 8 bytes (16 hexadecimal digits). The time-to-live field is the ninth byte, which is 01. This means the packet can travel only one hop. The protocol field is the next byte (02), which means that the upper layer protocol is IGMP.

8.2

FRAGMENTATION

Fragmentation

- Datagram travels through different networks
- Router decapsulates frame, and encapsulates
- Format & Size of frame depends on network
- Each DL layer specifies maximum frame size (Maximum Transfer Unit)



MTUs for Different Networks

Protocols	MTU
HyperChannel	65,536
Token Ring (16 Mbps)	17,914
Token Ring (4 Mbps)	4,464
Fiber Distributed Data Interface	4,352
Ethernet	1,500
X.25	576
PPP	296

IP Fragmentation

- IP Should be independent of physical network
- IP Maximum Transfer Unit (MTU) = 64K bytes
- Transmission most efficient with DLs with 64K MTUs
- For networks with smaller MTUs, IP packet must be fragmented
- Each fragment has own header (with most fields)
- Fragmented packet may again be fragmented if it encounters a network with a still smaller MTU

IP Fragmentation (con't)

- IP packet can be fragmented by any host or any router encountered along the path of travel
- Reassembly of the datagram is performed at the destination (each datagram is independent)
  - Only place we can expect that all IP packets will eventually arrive
- Each fragment need most of header fields
  - Option field may be copied also
- Host or router that fragments must change flags, fragmentation offset and total length (& checksum); rest of fields copied

Fragmentation Fields

- Identification
  - IP Addresses, ID $\rightarrow$ Datagram
  - All datagram fragments retain datagram ID
  - Counter maintained to ensure uniqueness
  - ID used to reassemble datagram from fragments

Flag Field

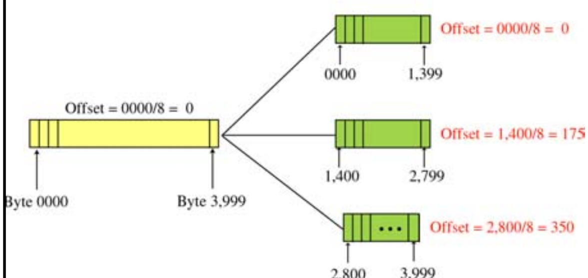
D: Do not fragment
M: More fragments

- If "Do Not Fragment" bit set, machines are instructed to drop packet if MTU too large:
  - ICMP error message sent to host
- More Fragments:
  - Indicates that the fragment is not the last

Fragmentation Offset

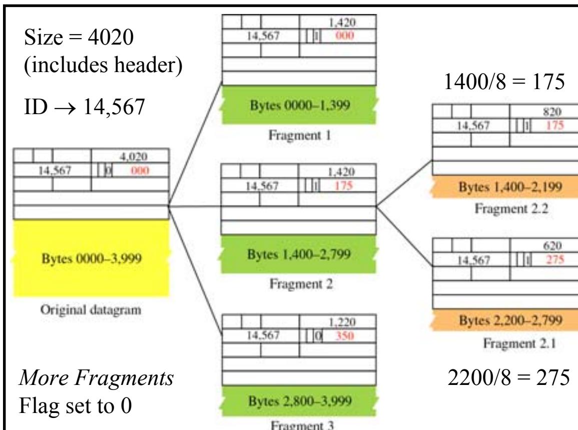
- 13-bit field shows relative position of fragment w.r.t. entire datagram
- Offset of data in original datagram measured in units of 8-bytes
- 13-bits → 8192 * 8 = 65,536 (Max MTU size)
- Forces routers and hosts that fragment to choose the size of each fragment so that the first byte number is divisible by 8

Fragmentation Example



Size = 4020
(includes header)

ID → 14,567



1400/8 = 175

2200/8 = 275

More Fragments
Flag set to 0

Reassembly Strategy

1. The 1st fragment has an offset field value of 0
2. Divide the length of this fragment by 8. The 2nd fragment has an offset value equal to that result.
3. Divide the total length of the 1st & 2nd fragments by 8. The 3rd fragment has an offset value equal to that result.
4. Continue the process; last fragment has a more bit value of zero

Example 5

A packet has arrived with an *M* bit value of 0. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

Solution

A packet has arrived with an *M* bit value of 0. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

If the *M* bit is 0, it means that there are no more fragments; the fragment is the last one. However, we cannot say if the original packet was fragmented or not. A non-fragmented packet is considered the last fragment.

Example 6

A packet has arrived with an *M* bit value of 1. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

A packet has arrived with an *M* bit value of 1. Is this the first fragment, the last fragment, or a middle fragment? Do we know if the packet was fragmented?

If the *M* bit is 1, it means that there is at least one more fragment. This fragment can be the first one or a middle one, but not the last one. We don't know if it is the first one or a middle one; we need more information (the value of the fragmentation offset). However, we can definitely say the original packet has been fragmented because the *M* bit value is 1.

Example 7

A packet has arrived with an *M* bit value of 1 and a fragmentation offset value of zero. Is this the first fragment, the last fragment, or a middle fragment?

Solution

A packet has arrived with an *M* bit value of 1 and a fragmentation offset value of zero. Is this the first fragment, the last fragment, or a middle fragment?

Because the *M* bit is 1, it is either the first fragment or a middle one. Because the offset value is 0, it is the first fragment.

Example 8

A packet has arrived in which the offset value is 100. What is the number of the first byte? Do we know the number of the last byte?

Solution

A packet has arrived in which the offset value is 100. What is the number of the first byte? Do we know the number of the last byte?

To find the number of the first byte, we multiply the offset value by 8. This means that the first byte number is 800. We cannot determine the number of the last byte unless we know the length of the data.

Example 9

A packet has arrived in which the offset value is 100, the value of HLEN is 5 and the value of the total length field is 100. What is the number of the first byte and the last byte?

Solution

A packet has arrived in which the offset value is 100, the value of HLEN is 5 and the value of the total length field is 100. What is the number of the first byte and the last byte?

The first byte number is $100 \times 8 = 800$. The total length is 100 bytes and the header length is 20 bytes (5×4), which means that there are 80 bytes in this datagram. If the first byte number is 800, the last byte number must be 879.

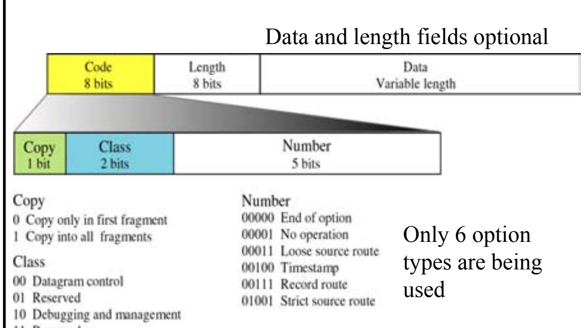
8.3

OPTIONS

Options

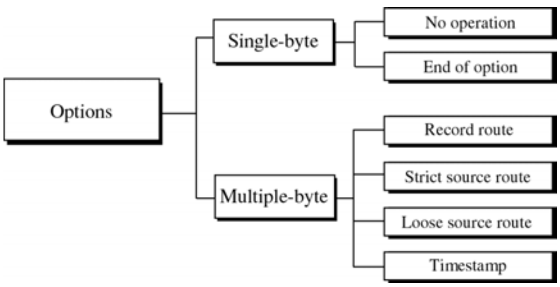
- IP Datagram Header comprised of two parts:
- Fixed: 20 bytes (previously discussed)
- Variable: comprises "options" (max 40 bytes)
- Options used for network testing and debugging
- Options not required to appear in IP packet but *option processing* mandatory in all IP implementations

Option Format



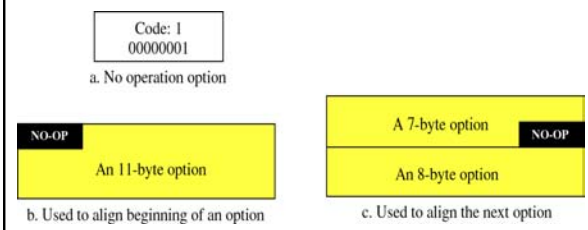
Only 6 option types are being used

Categories of options

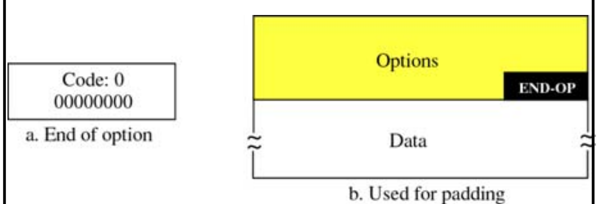


- Multi-byte options require length and data fields

No operation option



End of option option

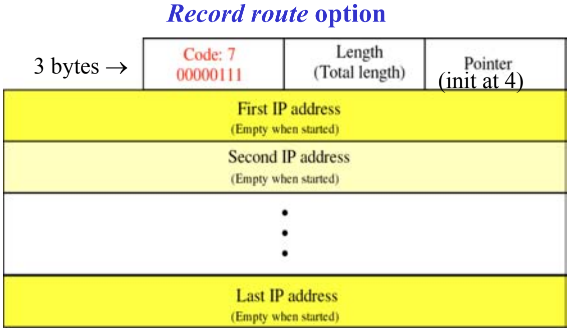


- Only one End-of-Option (EoO) can be used
- EoO must be used as last field of IP Option field
- After EoO, packet receiver expects payload data

Record Route Option

- Records the internet routers that handle the datagram
- Can store at most 9 router's IP addresses
  - 40 byte options – (9 * 4-bytes) – Code (1 byte) – Length (1 byte) – Pointer (1 byte) = 1
- If (Pointer > Length) then Options area is full & no further changes are made
- Otherwise, router inserts its *outgoing* IP address
- Each routers increments pointer field by 4 (bytes) to point to next free entry for IP address (to prepare for next router's address)

Record route option



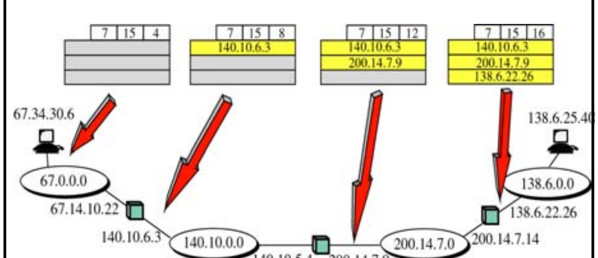
9 IP addr maximum (9 * 4-byte addr = 36 bytes) + 3 = 39

40 byte maximum for Options field

Record route concept

Length field includes code, length and data

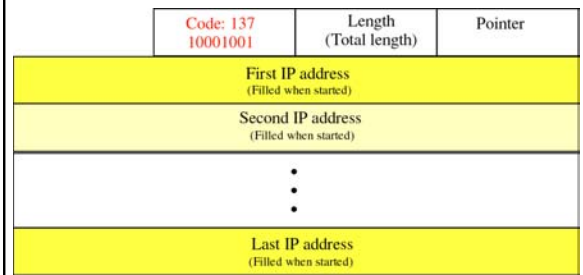
Code is 7; Ptr increments



Strict Source Route

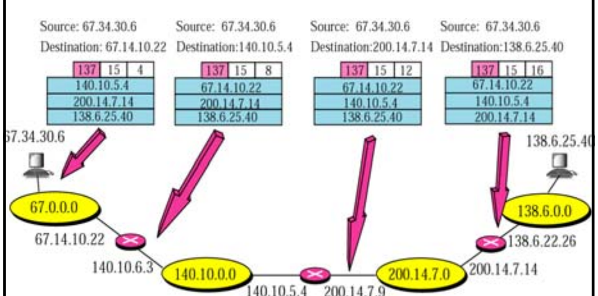
- Used to specify a predetermined route through the Internet
- Useful to specify a preferred route based on type of service, e.g., min delay, max throughput
- All routers specified must be visited
- If packet received by router not in list, packet dropped and error generated
- If packet reaches destination without visiting all routers, packet dropped and error generated

Strict source route option



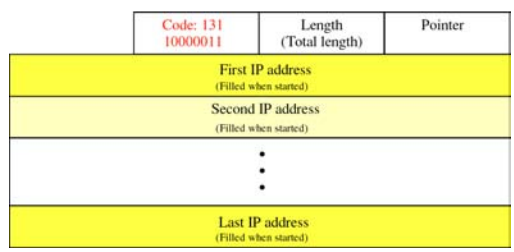
Strict source route concept

Incoming router IP addressed used in datagram



Loose Source Route

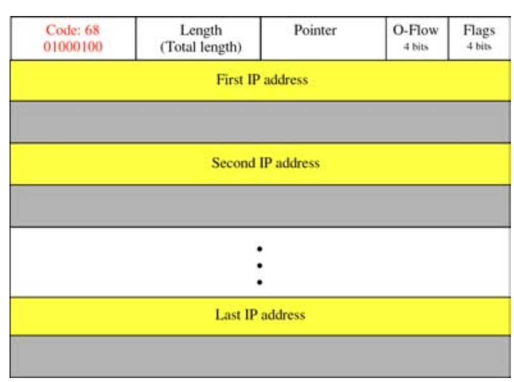
- Similar to Strict Source Routing
- Datagram can visit routers not in option list



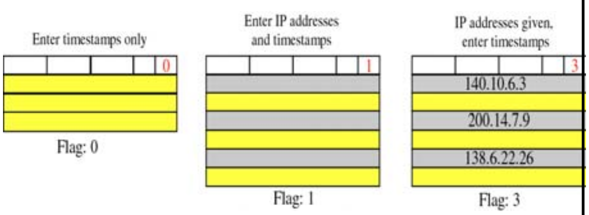
Timestamp

- Used to record the time that the datagram was processed by the router
- Helps users and managers track the behavior of Internet routers
- Determine time required for datagram to travel from one router to the next
- Amount is estimate since no router’s clocks cannot be guaranteed to be in sync

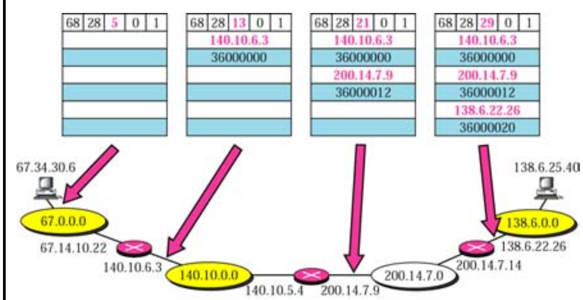
Timestamp option



Use of flag in timestamp



Timestamp concept



Example 10

Which of the six options must be copied to each fragment?

- No operation
- End of option
- Record route
- Strict source route
- Loose source route
- Timestamp

Solution

Which of the six options must be copied to each fragment?

We look at the first (left-most) bit of the code for each option.

No operation: Code is **0**0000001; no copy.
End of option: Code is **0**0000000; no copy.
Record route: Code is **0**0000111; no copy.
Strict source route: Code is **1**0001001; copied.
Loose source route: Code is **1**0000011; copied.
Timestamp: Code is **0**1000100; no copy.

Example 11

Which of the six options are used for datagram control and which are used for debugging and management?

Solution

We look at the second and third (left-most) bits of the code.

No operation: Code is 0**00**00001; control.
End of option: Code is 0**00**00000; control.
Record route: Code is 0**00**00111; control.
Strict source route: Code is 1**00**01001; control.
Loose source route: Code is 1**00**00011; control.
Timestamp: Code is 0**10**00100; debugging

8.4

CHECKSUM

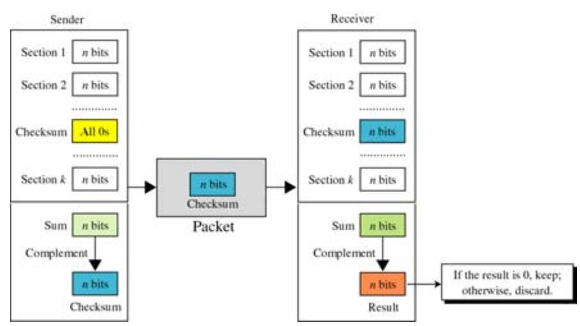
Checksum

- Error **detection** mechanism
- Protects against packet corruption during transmission
- Used by most TCP/IP Protocols
- Checksum calculated at sender; sent with packet
- Receiver repeats the same calculation

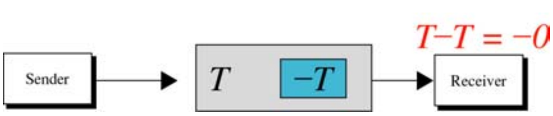
To create the checksum the sender does the following:

1. *The packet is divided into k sections, each of n bits.*
2. *All sections are added together using one's complement arithmetic.*
3. *The final result is complemented to make the checksum.*

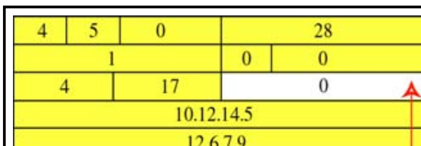
Checksum concept



Checksum in one's complement arithmetic

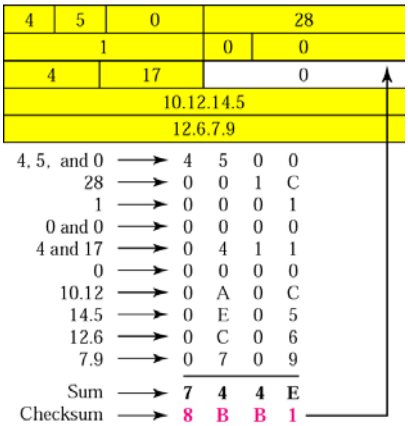


Example of checksum calculation in binary



4, 5, and 0	01000101	00000000
28	00000000	00011100
1	00000000	00000001
0 and 0	00000000	00000000
4 and 17	00000100	00010001
0	00000000	00000000
10.12	00001010	00001100
14.5	00001110	00000101
12.6	00001100	00000110
7.9	00000111	00001001
Sum	01110100	01001110
Checksum	10001011	10110001

Example of checksum calculation in hexadecimal



Checksum on Header

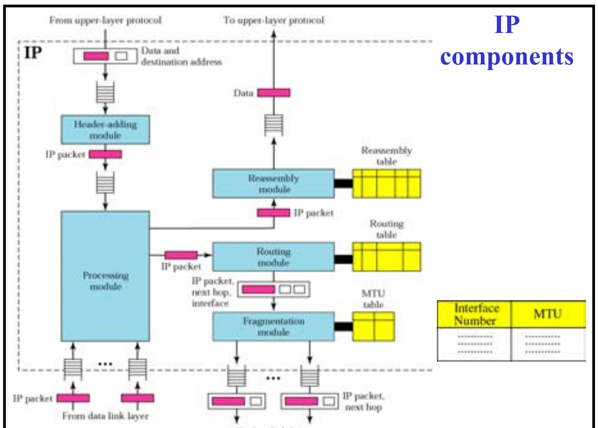
- Only applied to IP header
- Higher-level protocols have own error detection
- Checksum recomputed at each router
- Faster to only compute checksum on the (smaller) header data

Check Appendix C for a detailed description of checksum calculation and the handling of carries.

8.5

IP PACKAGE

IP components



Reassembly table