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Inspiring Excellence

Network Layer: IPv4 Functions

Lecture 8 | CSE421 – Computer Networks

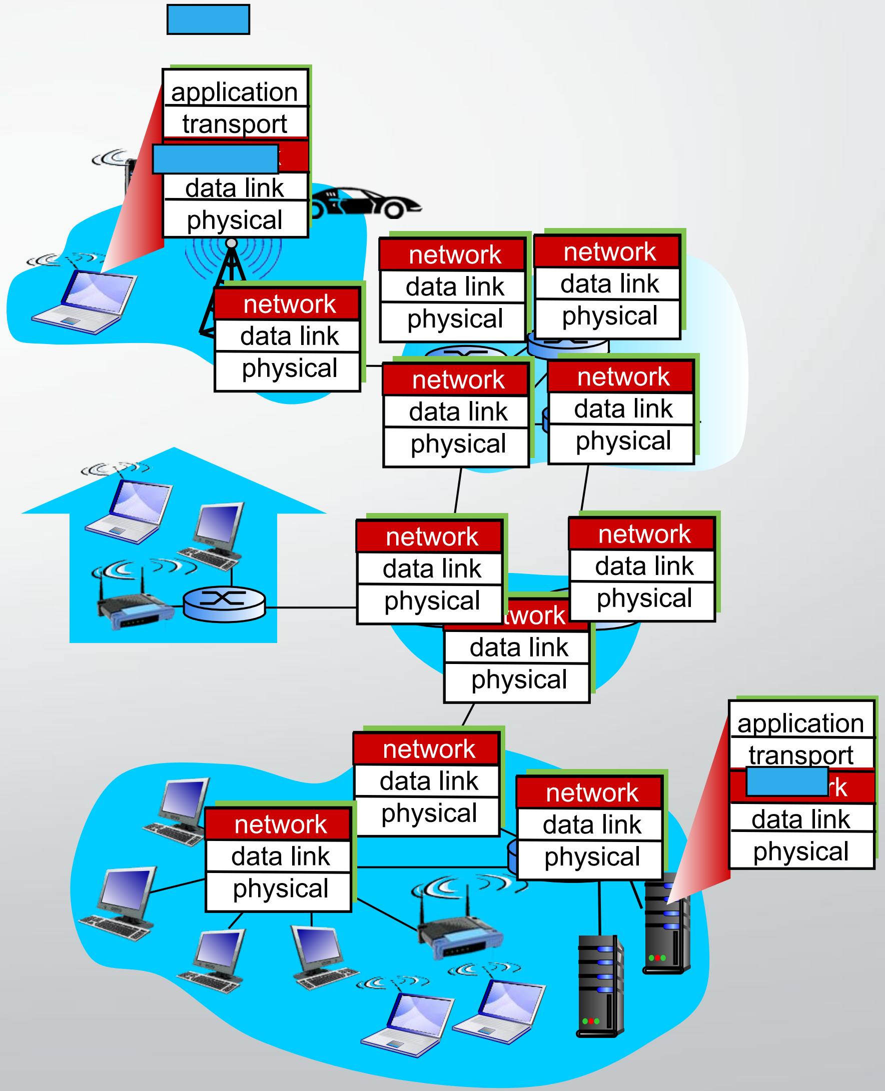
Department of Computer Science and Engineering
School of Data & Science

Objectives

- Short overview of the Network Layer
- Packet Switching: Virtual Circuits & Datagram Networks
- IPv4 Packet Format
- IP Fragmentation & Reassembly
- ICMP
  - Ping
  - Traceroute

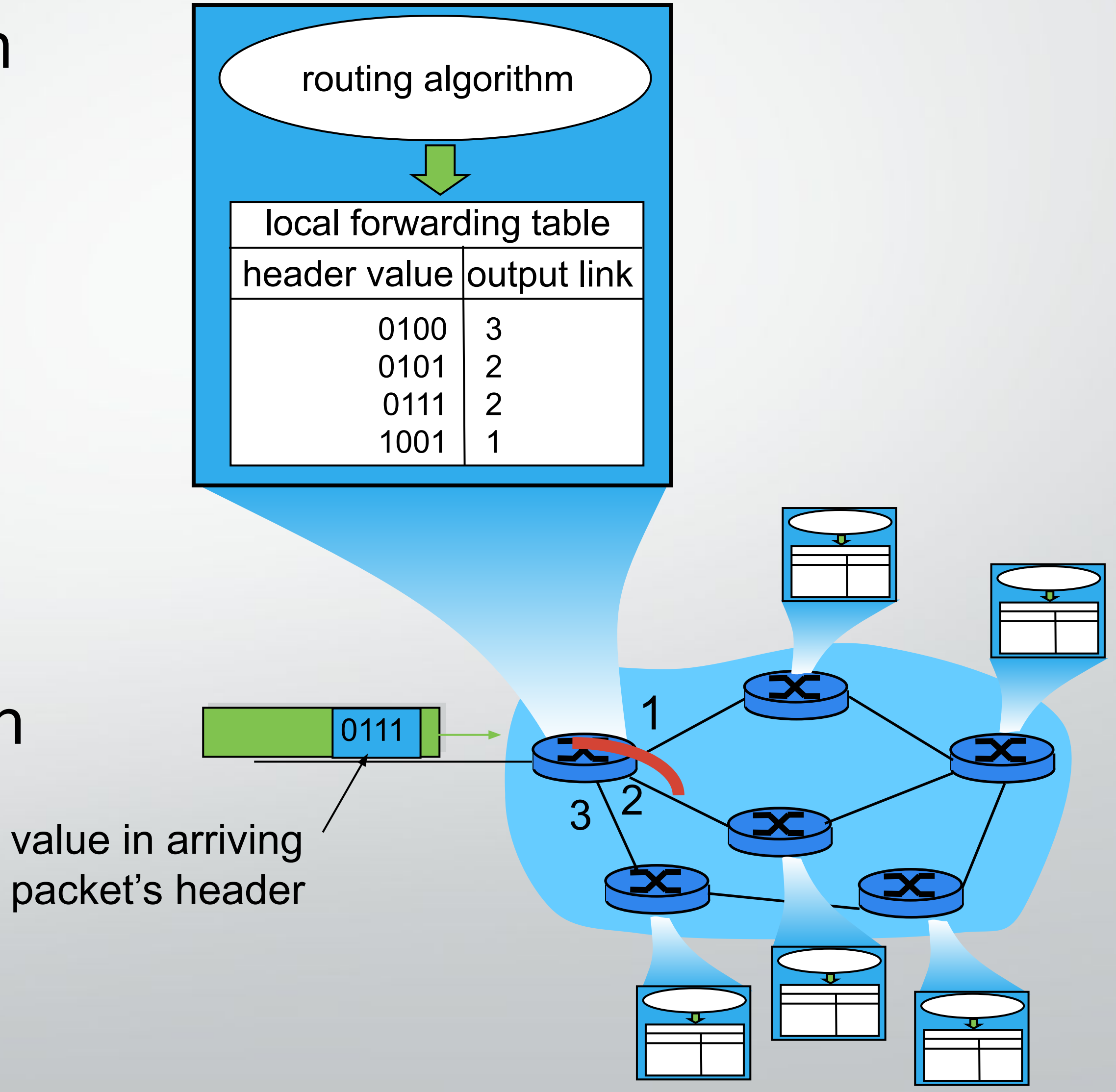
The Network Layer

- Encapsulates data into **packets** on the sending side.
- Network Layer protocols operates on **hosts** and **routers**.
- **Routers** inspect IP header fields for forwarding.
- Delivers segments to the **transport layer** on the receiving side.



Functions of Network Layer

- **Routing:** determine route taken by packets from source to destination
    - The algorithms that calculate the paths are referred to as routing algorithms.
    - Analogy: process of planning trip from source to destination
- **Forwarding:** move packets from router's input to appropriate router output
    - Analogy: process of getting through a single interchange



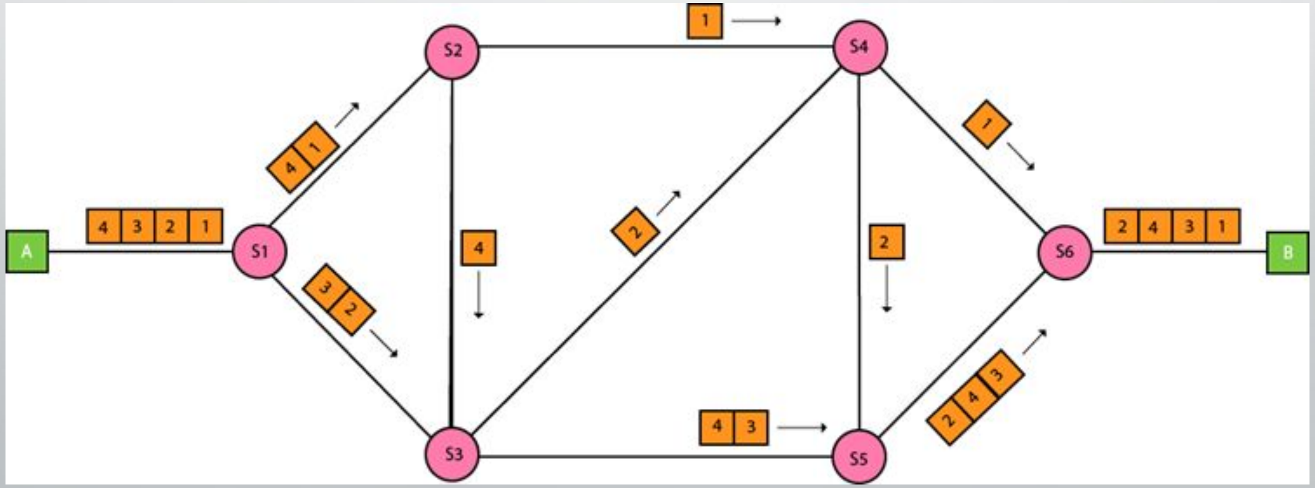
local forwarding table	
header value	output link
0100	3
0101	2
0111	2
1001	1

value in arriving packet's header

Packet Switching

Packet Switching

- Part of Network layer
- Packet Switching is a method of transferring data across a network by breaking it into smaller packets.
- Two type of networks based on packet switching
  - **Datagram Networks**
  - **Virtual Circuit Networks**



Datagram networks

- **No Call Setup**:

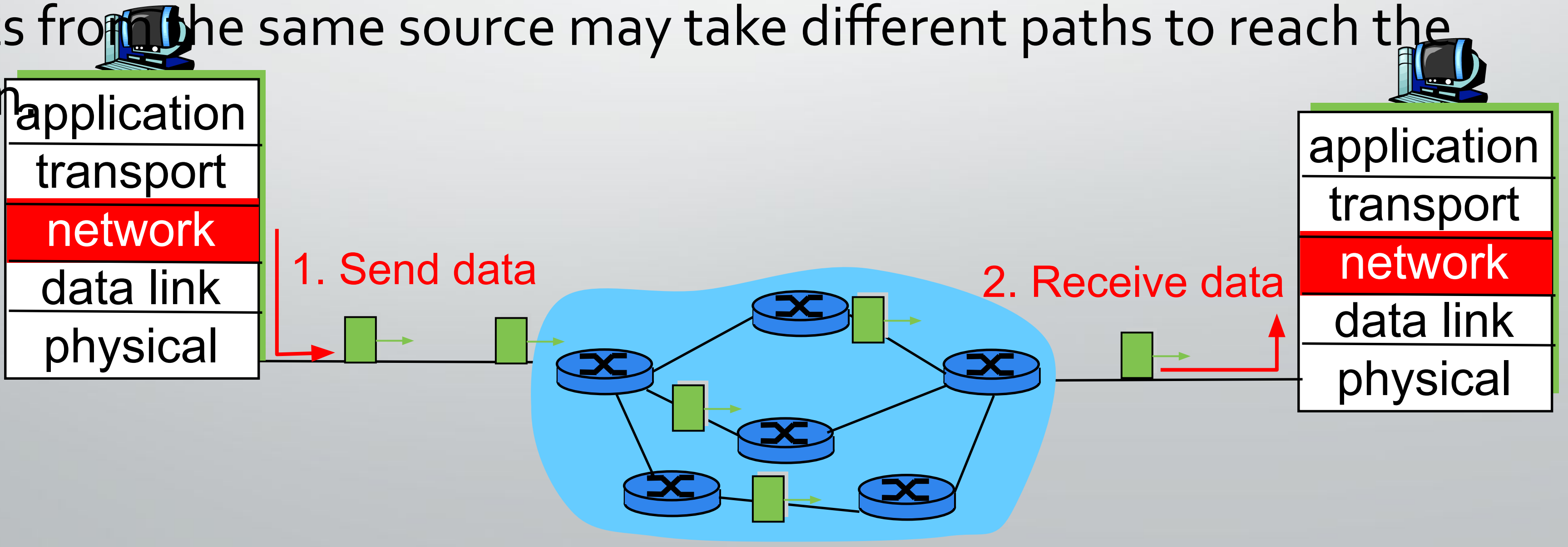
  Devices can send data immediately without establishing a connection.

- **Stateless Routers**:

  Routers forward packets independently based on their destination IP address.

- **Packet Forwarding**:

  Packets from the same source may take different paths to reach the destination.



Virtual Circuits: Signaling Protocols

- **Call Setup:**

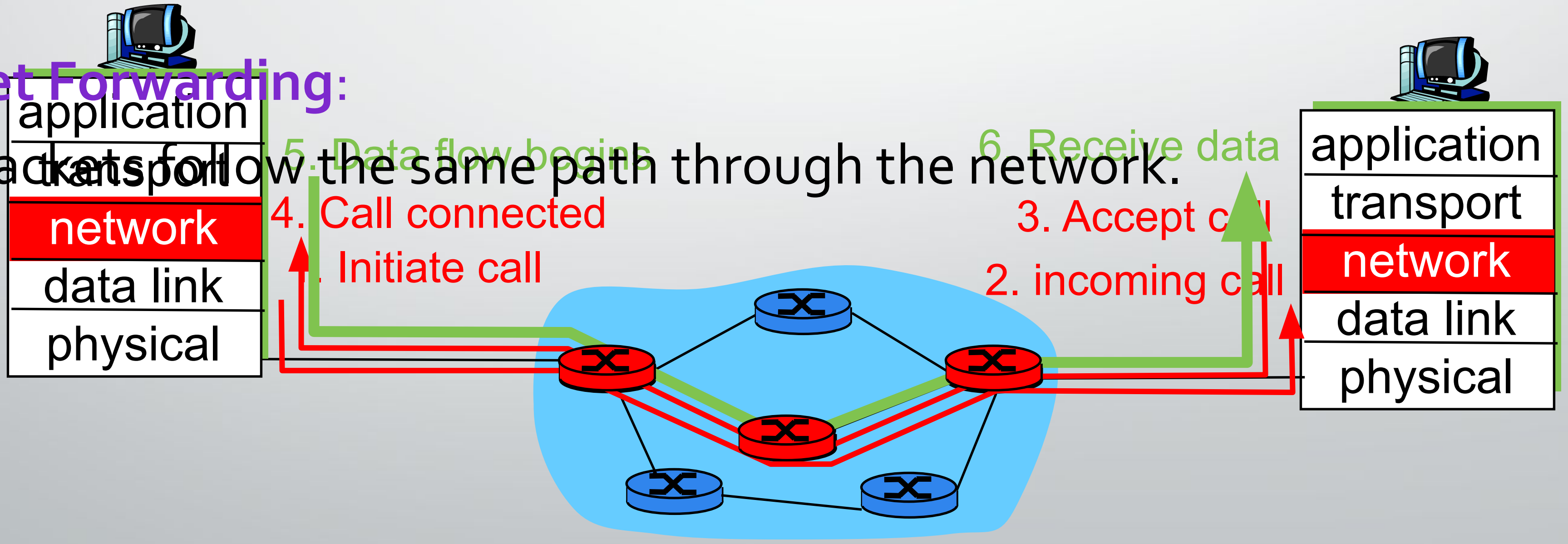
  A connection (virtual circuit) is established between sender and receiver before data transfer.

- **Stateful Routers:**

  Routers maintain information about active connections (virtual circuits).

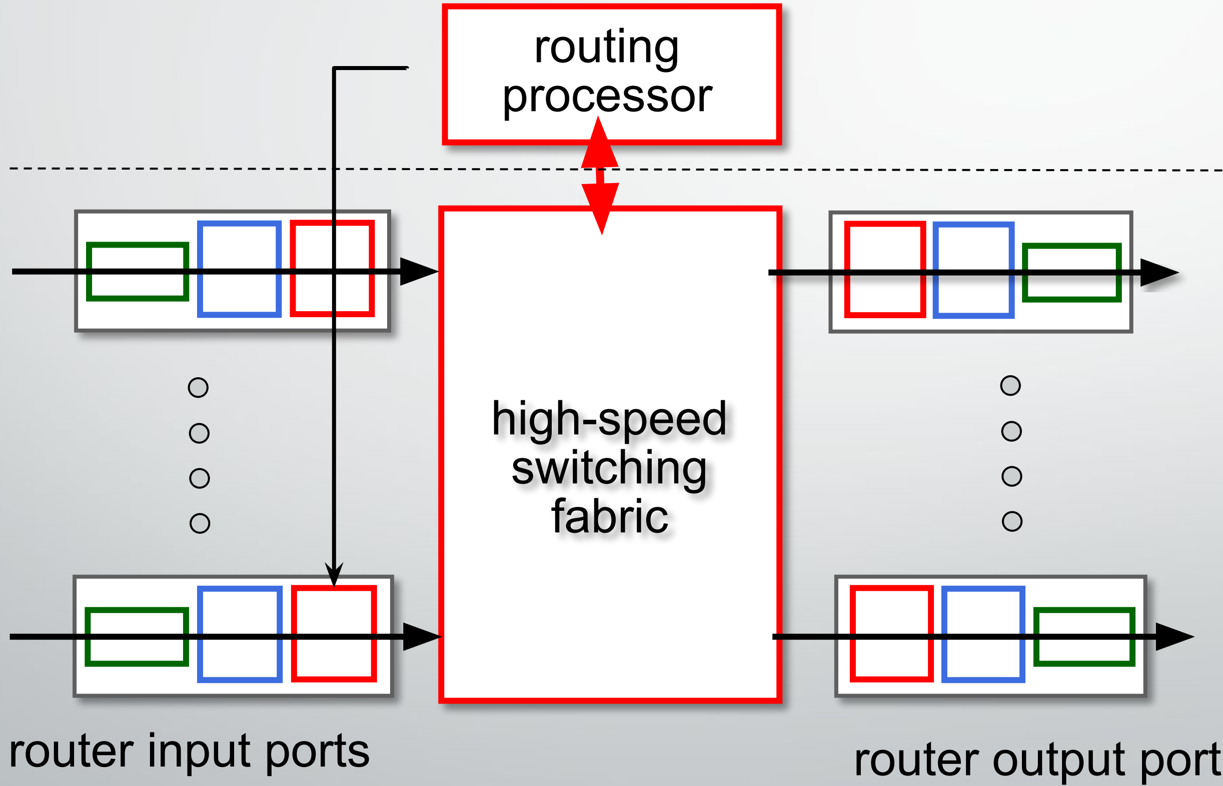
- **Packet Forwarding:**

  All packets follow the same path through the network.



Router architecture overview

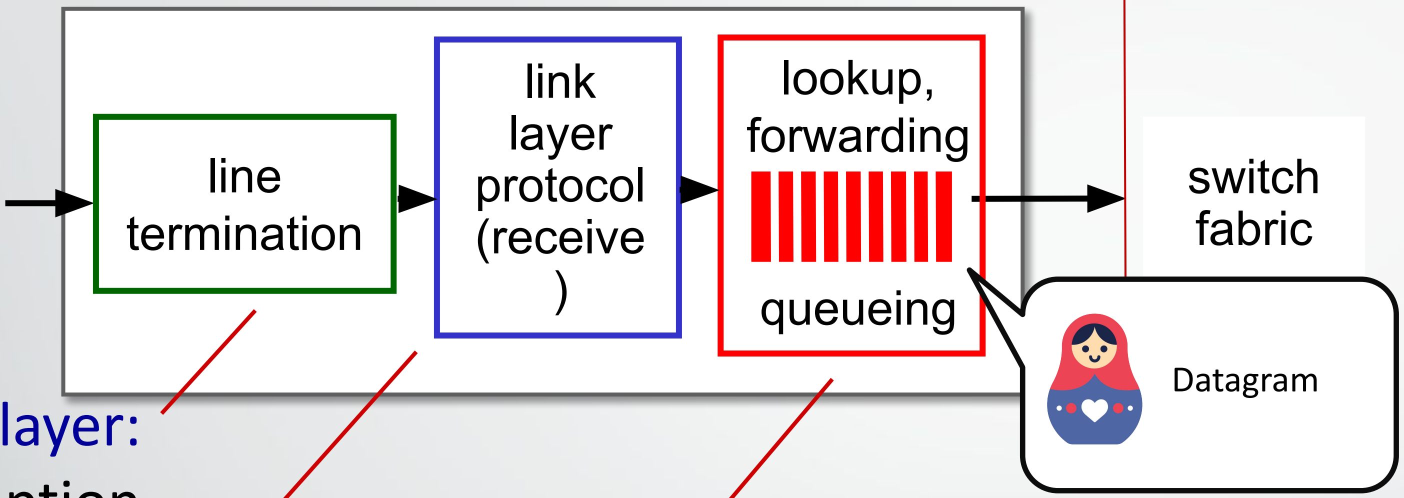
high-level view of generic router architecture:



routing, management
control plane (software)
operates in millisecond
time frame

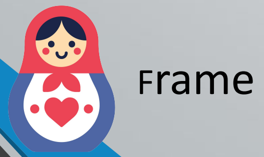
forwarding data plane
(hardware) operates
in nanosecond
timeframe

Input port functions



physical layer:
bit-level reception

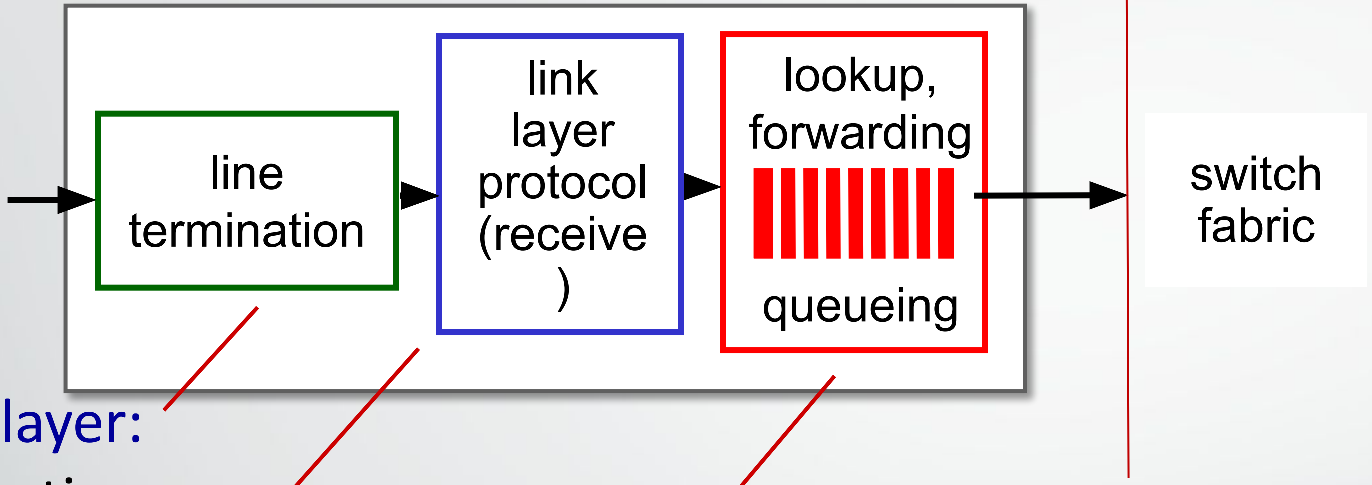
link layer:
e.g., Ethernet
(chapter 6)



decentralized switching*:*

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- goal: complete input port processing at 'line speed'
- input port queuing: if datagrams arrive faster than forwarding rate into switch fabric

Input port functions



physical layer:
bit-level reception

link layer:
e.g., Ethernet
(chapter 6)

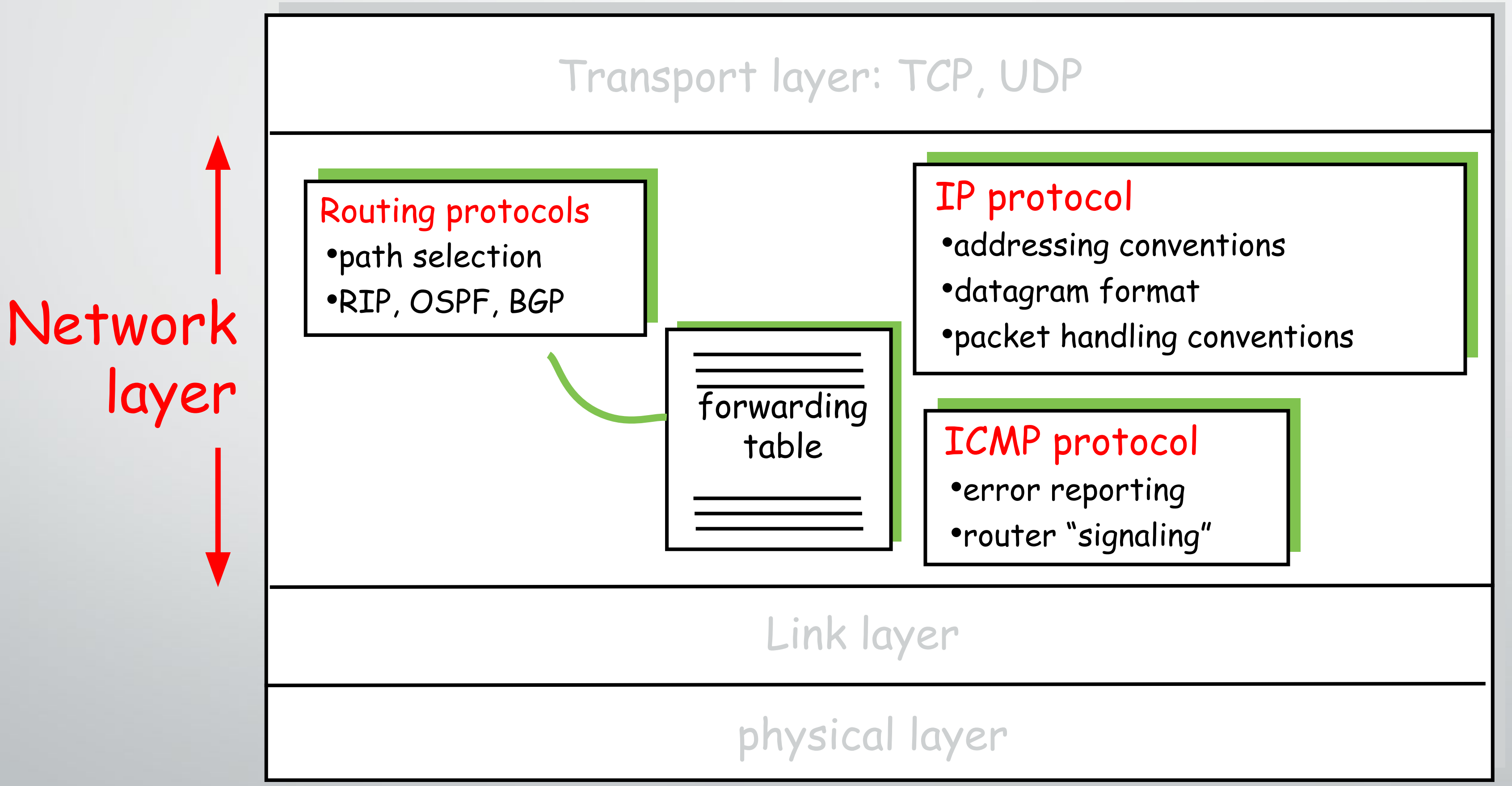
decentralized switching*:*

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- destination-based forwarding: forward based only on destination IP address (traditional)
- generalized forwarding: forward based on any set of header field values

Internet Protocol
IPv4

Internet Network Layer

- Host, router network layer functions:



Transport layer: TCP, UDP

Network layer

Routing protocols
- path selection
- RIP, OSPF, BGP

forwarding table

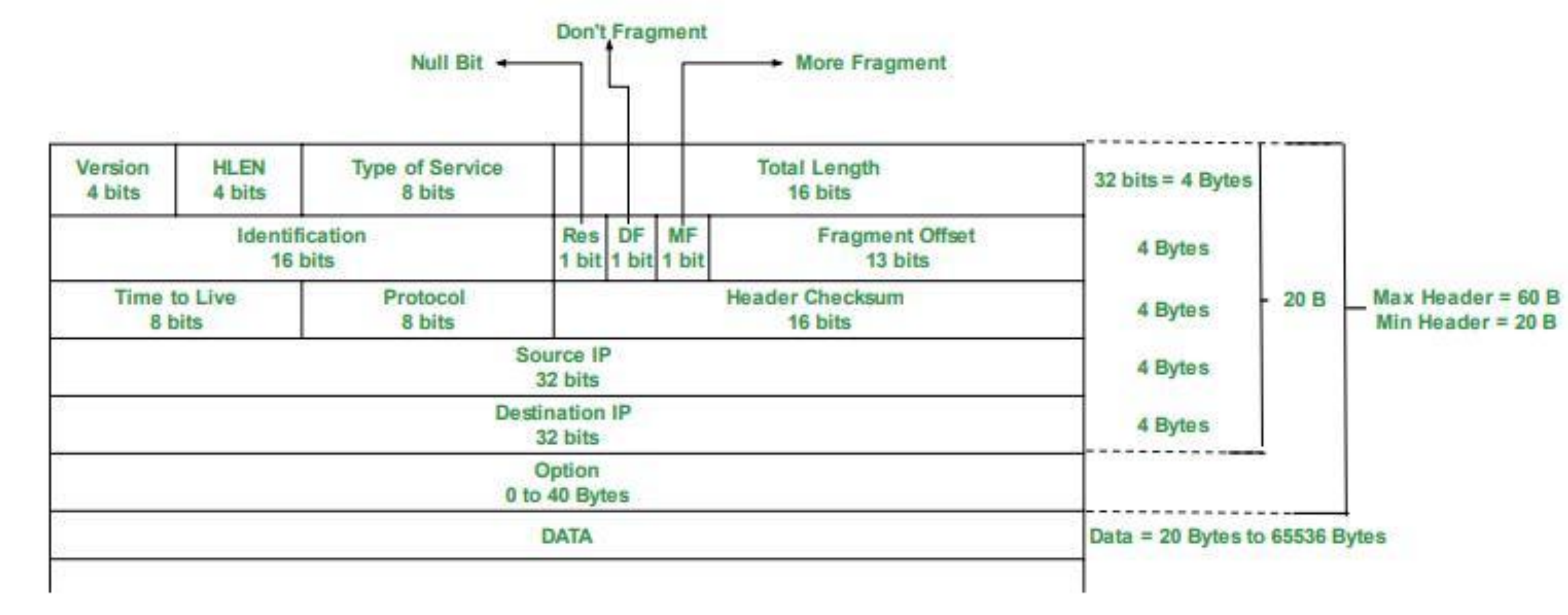
IP protocol
- addressing conventions
- datagram format
- packet handling conventions

ICMP protocol
- error reporting
- router "signaling"

Link layer

physical layer

IPv4 Datagram Format



Don't Fragment

Null Bit

More Fragment

Version 4 bits	HLEN 4 bits	Type of Service 8 bits	Total Length 16 bits			32 bits = 4 Bytes
Identification 16 bits			Res 1 bit	DF 1 bit	MF 1 bit	Fragment Offset 13 bits
Time to Live 8 bits	Protocol 8 bits	Header Checksum 16 bits				4 Bytes
Source IP 32 bits						4 Bytes
Destination IP 32 bits						4 Bytes
Option 0 to 40 Bytes						
DATA						Data = 20 Bytes to 65536 Bytes

Identification row: 4 Bytes

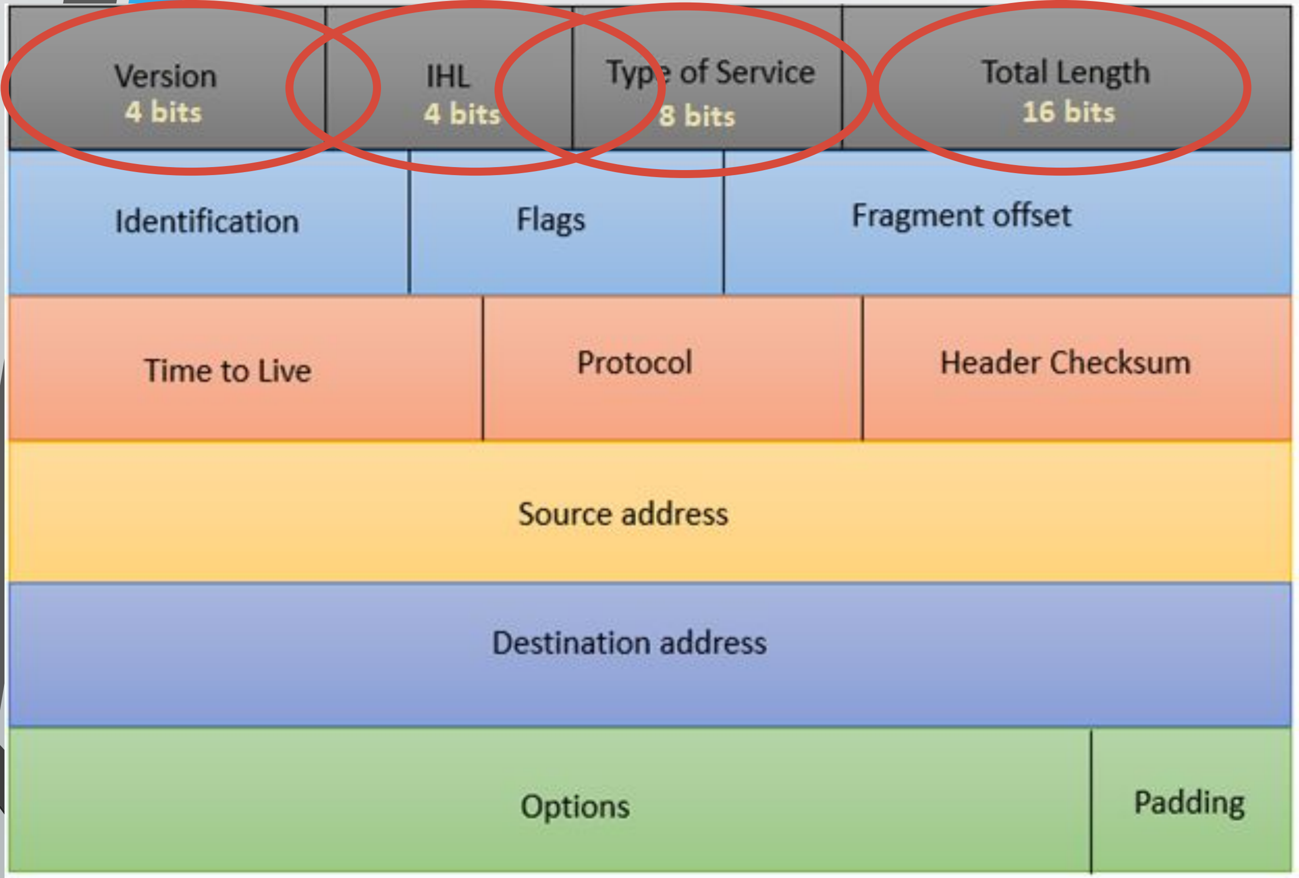
20 B

Max Header = 60 B
Min Header = 20 B

The size of an IP datagram:

- The **minimum** size is **20 bytes** (if you have no data)
- The **maximum** size is **65,535 bytes**

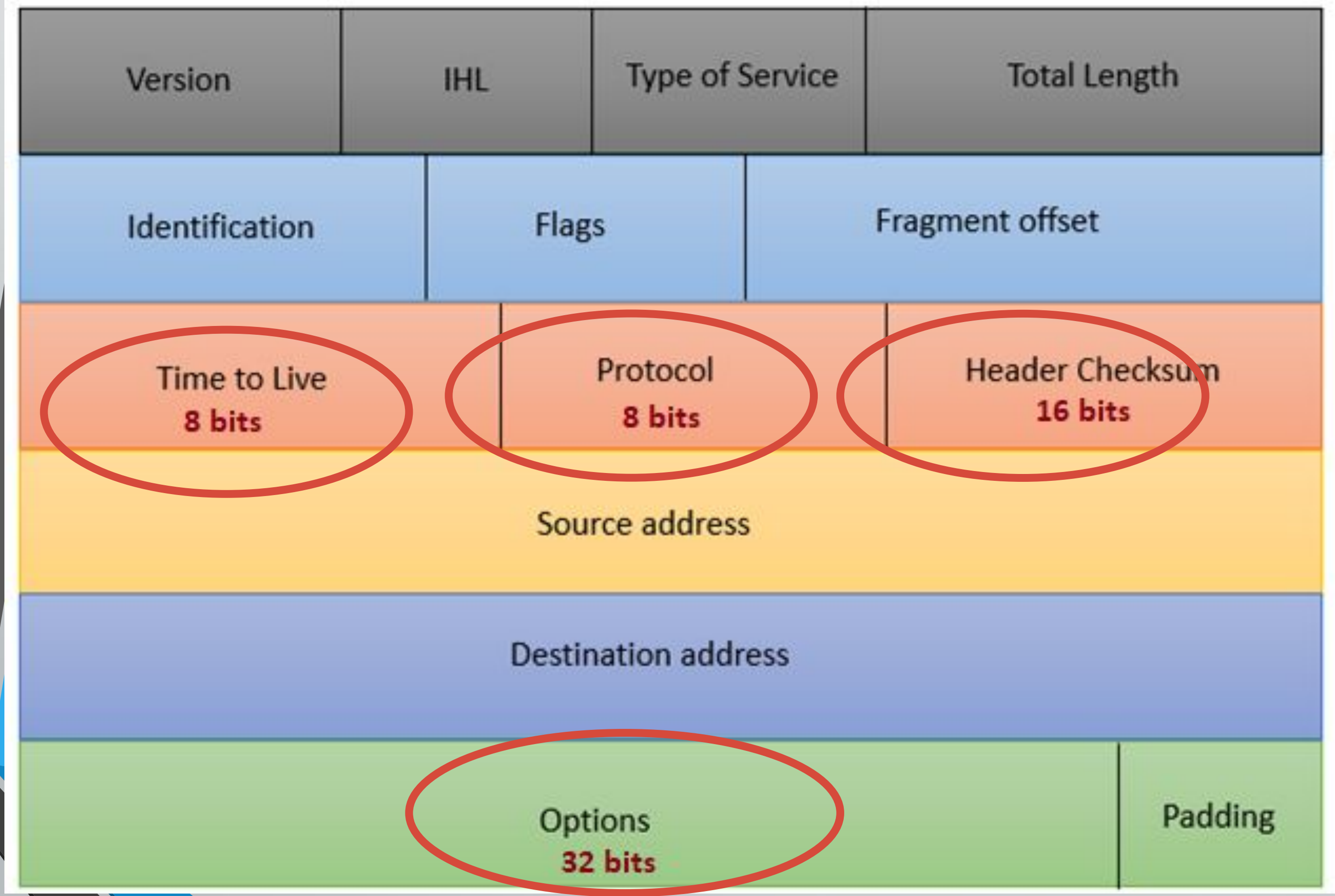
IPv4 Datagram Header Format



Version 4 bits	IHL 4 bits	Type of Service 8 bits	Total Length 16 bits
Identification	Flags	Fragment offset	
Time to Live	Protocol	Header Checksum	
Source address			
Destination address			
Options	Padding		

- **Version:** value of which IP version is being used. For IPv4 the value will be 4 here.
- **Internet Header Length**: value of the header length, min 20 bytes, max 60 bytes. Shown in 4 byte word. **So min value 5, max 15.**
- **Type of Service**: for QoS (Quality of Service). To mark the packet to give special treatment or priority.
- **Total Length:** value of the entire size of the IP packet (header and data) in bytes.

IPv4 Datagram Header Format

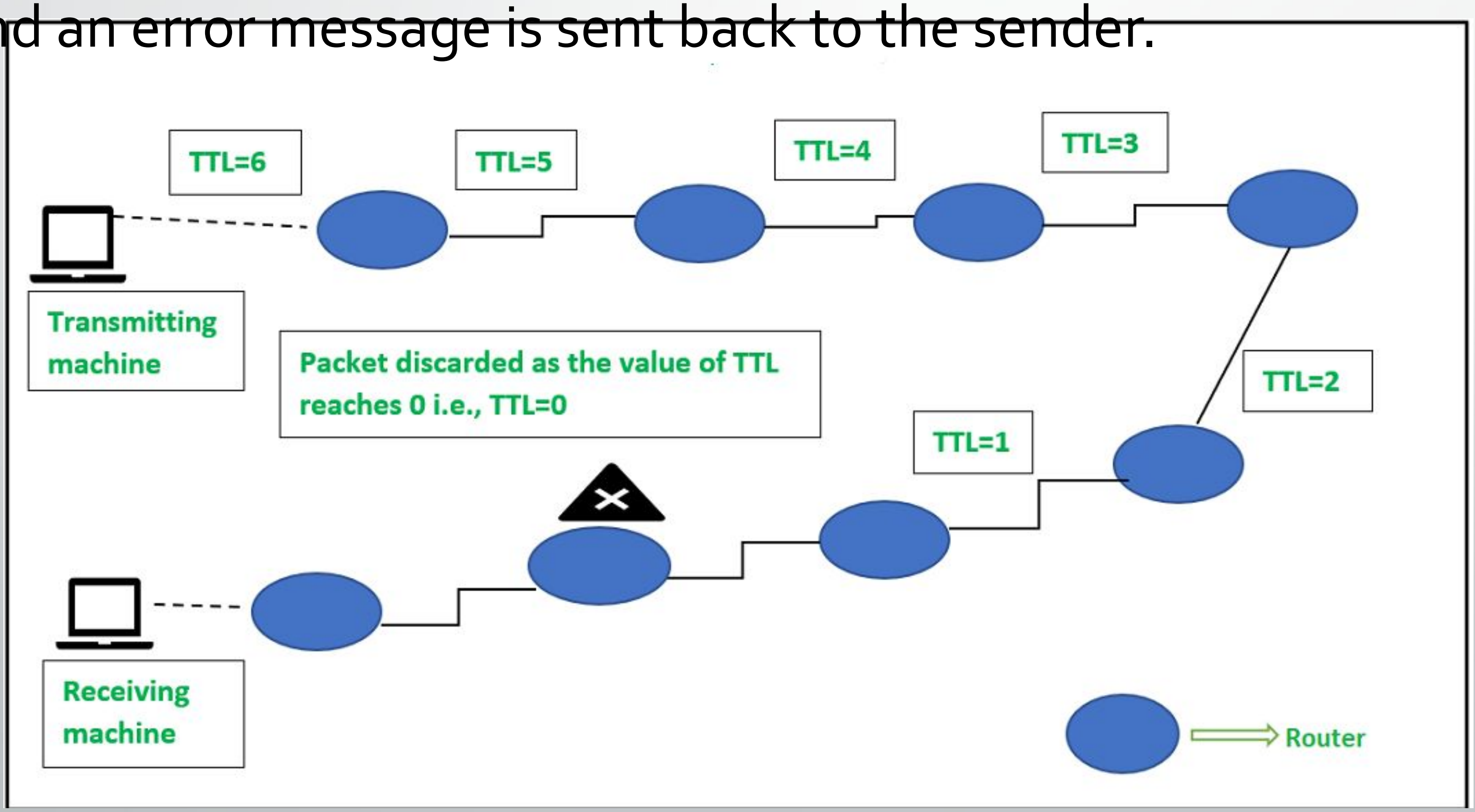


Version	IHL	Type of Service	Total Length
Identification	Flags	Fragment offset	
Time to Live 8 bits	Protocol 8 bits	Header Checksum 16 bits	
Source address			
Destination address			
Options 32 bits	Padding		

- **Time to Live:** maximum number of **hops** (routers) a packet can travel
- **Protocol:** value tells us which upper layer protocol is present, for example **TCP** has value **6** and **UDP** has value **17**.
- **Header Checksum**: to check if there are any errors in the header.
- **Options:** value of any extra information

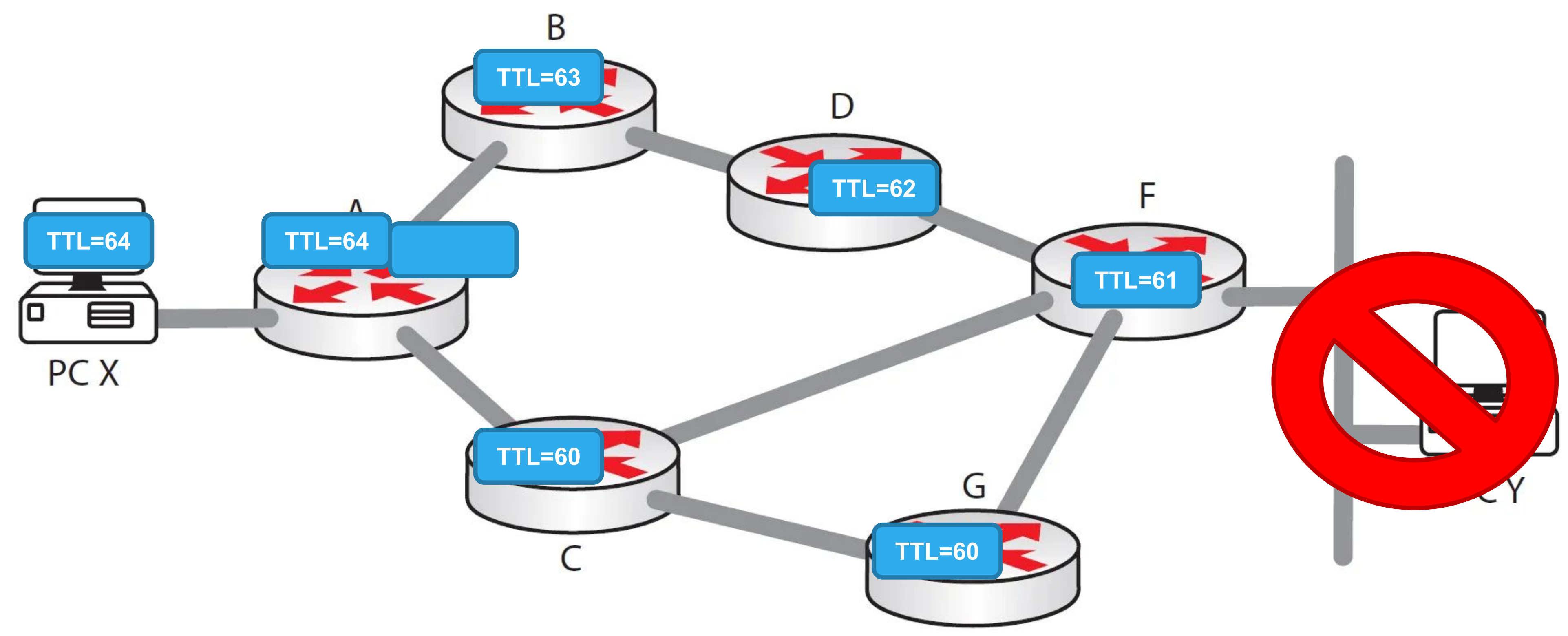
Time to Live - TTL

- Maximum number of **hops** (routers) a packet can before being discarded.
- At each hop, the TTL is decreased by **1**.
- When the TTL reaches **0**, the packet is dropped.
- And an error message is sent back to the sender.

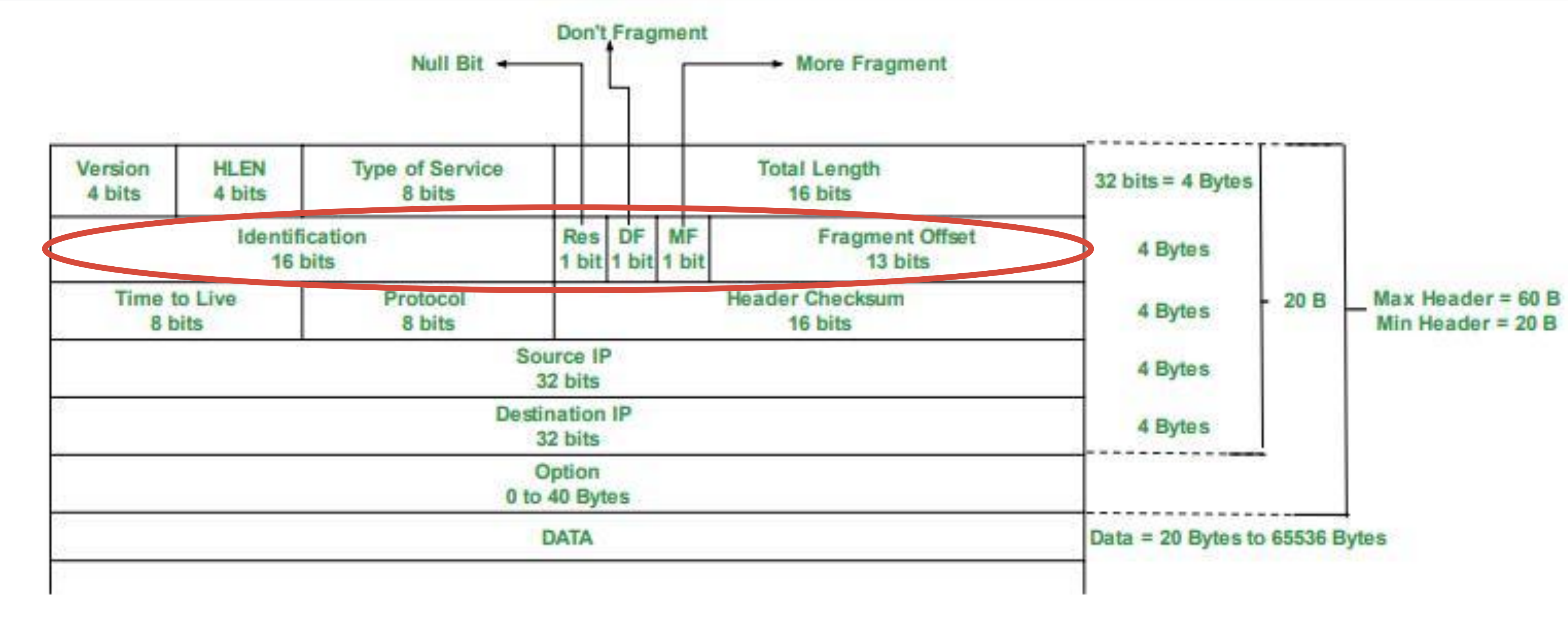


Time to Live - TTL

- **Not** just the "value of hops"
- It's a mechanism to prevent packets from **looping endlessly** in the network.
- Ensure finite packet lifetimes.



IPv4 Datagram Format



Don't Fragment

Null Bit

More Fragment

Version 4 bits	HLEN 4 bits	Type of Service 8 bits	Total Length 16 bits			
Identification 16 bits			Res 1 bit	DF 1 bit	MF 1 bit	Fragment Offset 13 bits
Time to Live 8 bits		Protocol 8 bits	Header Checksum 16 bits			
Source IP 32 bits						
Destination IP 32 bits						
Option 0 to 40 Bytes						
DATA						

32 bits = 4 Bytes

4 Bytes

4 Bytes

4 Bytes

4 Bytes

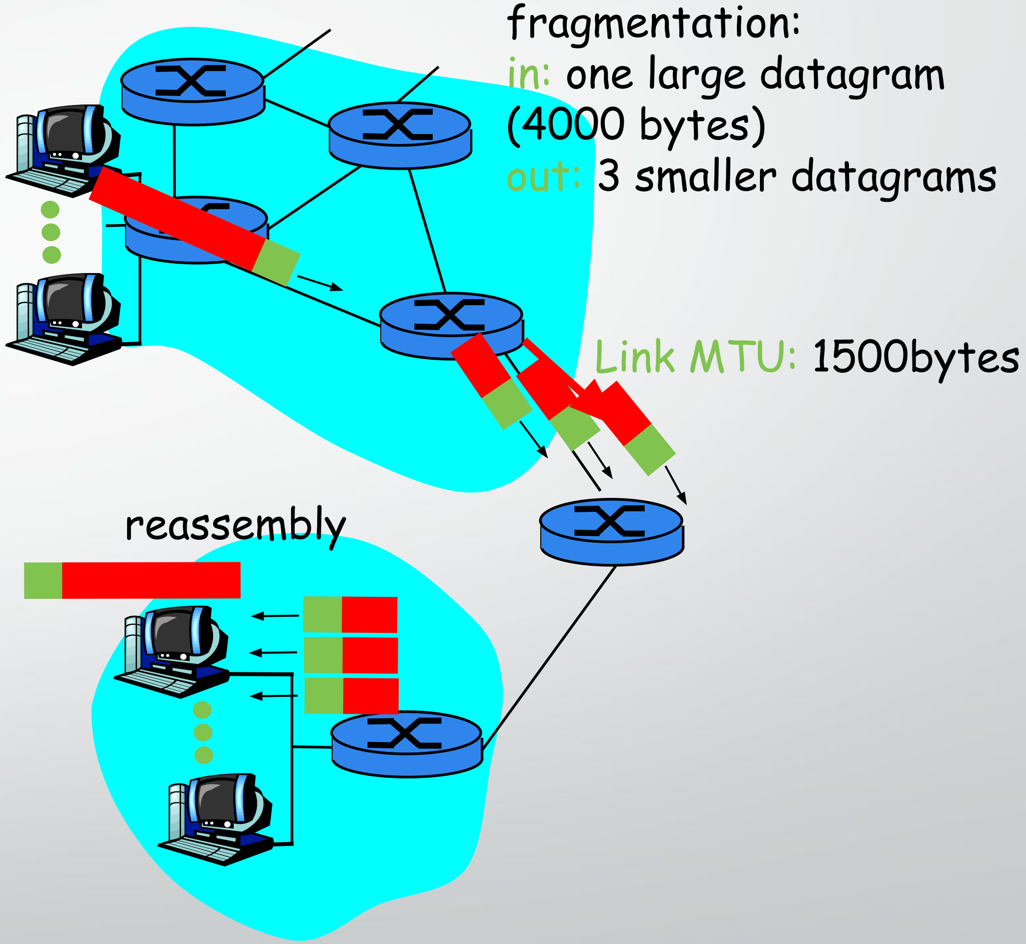
20 B

Max Header = 60 B
Min Header = 20 B

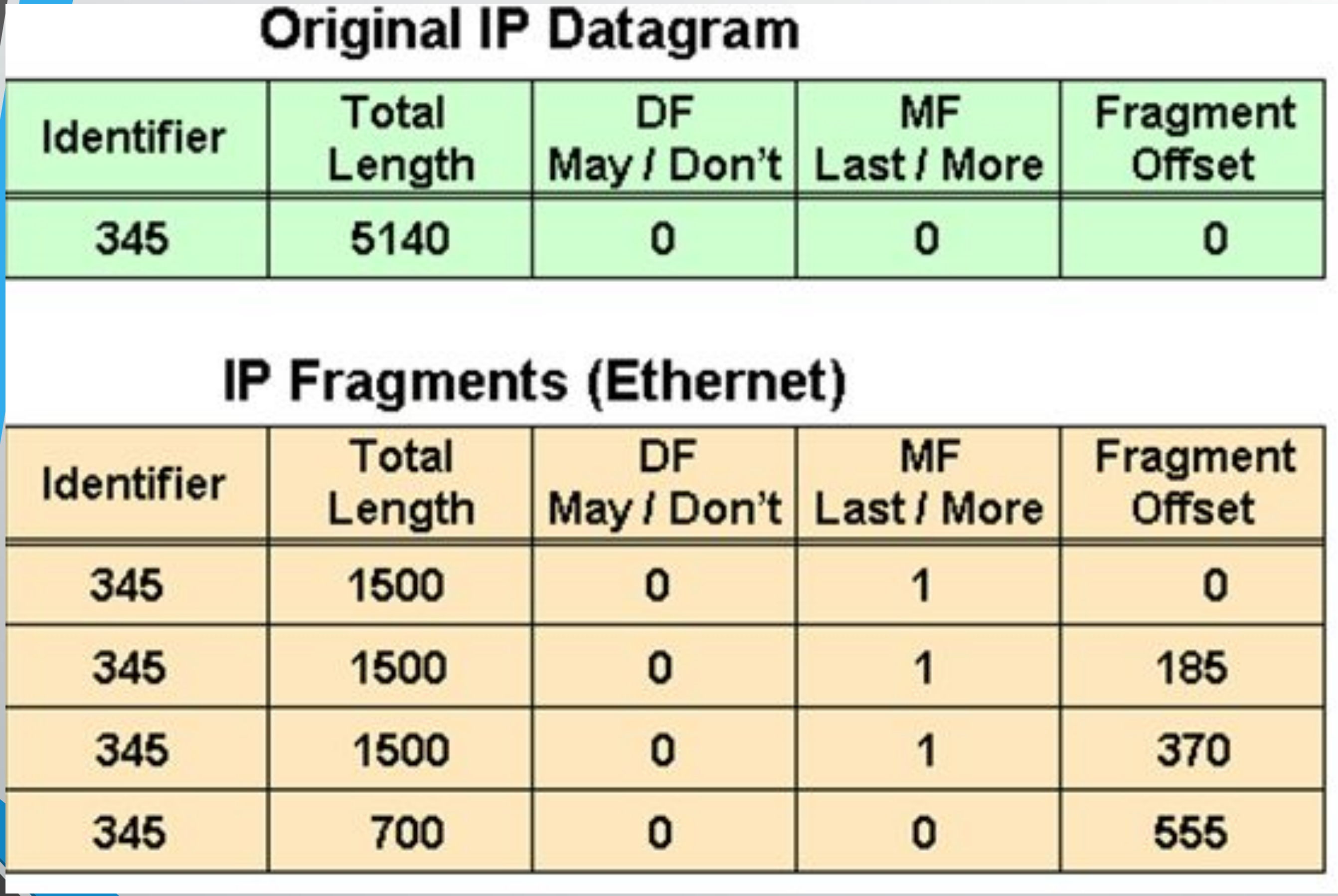
Data = 20 Bytes to 65536 Bytes

IP Fragmentation & Reassembly

- Network links have **MTU**
  - Maximum transmission unit or maximum transfer size
  - Different link types have different MTUs



IP Fragmentation & Reassembly



Original IP Datagram

Identifier	Total Length	DF May / Don't	MF Last / More	Fragment Offset
345	5140	0	0	0

IP Fragments (Ethernet)

Identifier	Total Length	DF May / Don't	MF Last / More	Fragment Offset
345	1500	0	1	0
345	1500	0	1	185
345	1500	0	1	370
345	700	0	0	555

MTU=20(H)+1480(D)

5140=20(H)+5120(D)

5120-1480=3640 (1st)

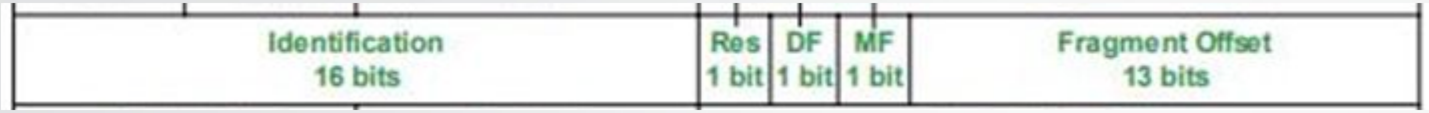
3640-1480=2160 (2nd)

2160-1480=680 (3rd)

680+20=700

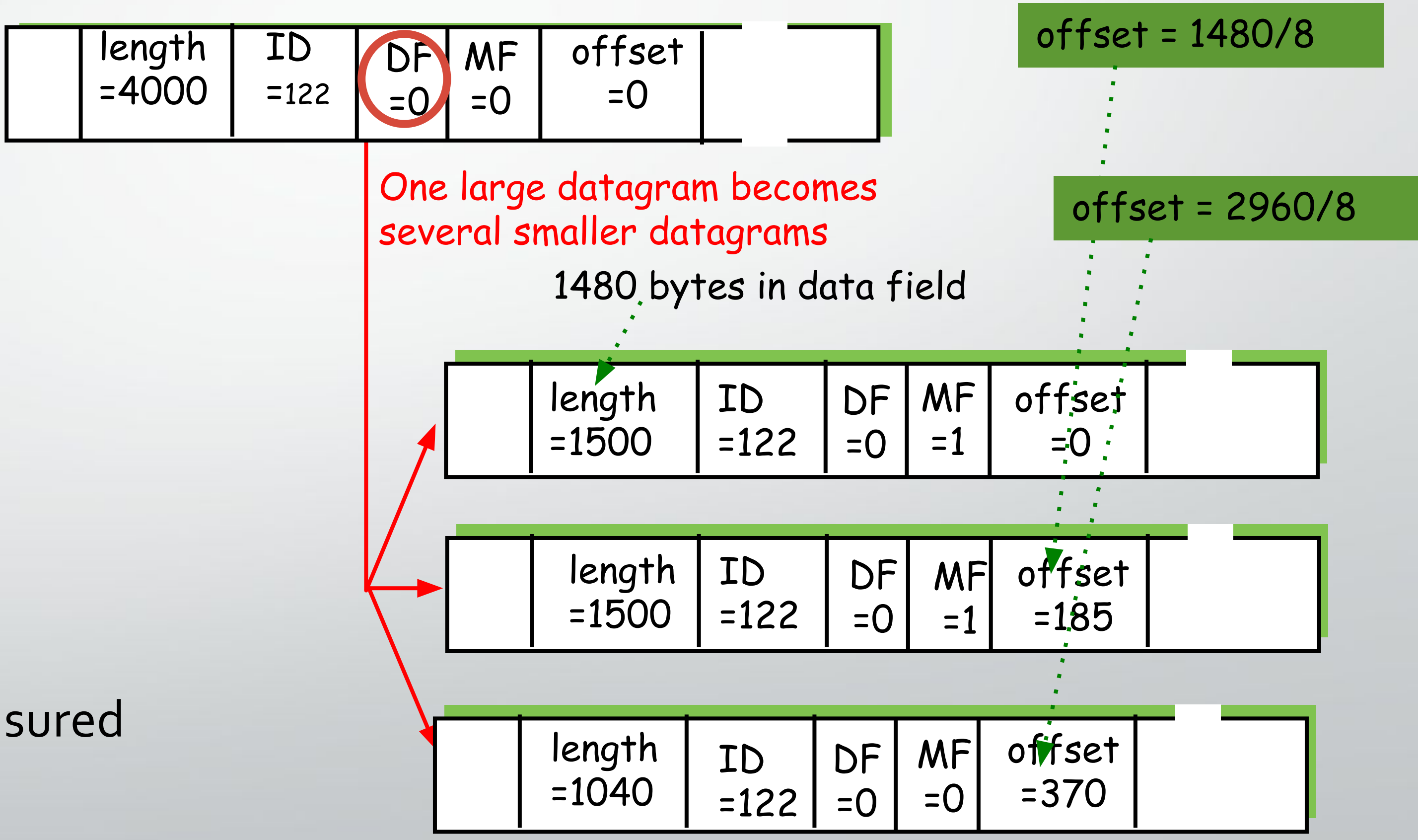
Data Bytes	Fragment Offset
0 -1479	0/8=0
1480-2959	1480/8=185
2960-4439	2960/8=370
4440-5119	4440/8=555

IP Fragmentation & Reassembly



Identification 16 bits	Res 1 bit	DF 1 bit	MF 1 bit	Fragment Offset 13 bits

- Example:
  - 4000 Bytes of datagram
  - MTU = 1500 Bytes
- **DF – Don't Fragment Bit**
  - Value 0 or 1
- **Fragment Offset**
  - The value of the offset is measured in units of 8 bytes.



	length =4000	ID =122	DF =0	MF =0	offset =0	

One large datagram becomes several smaller datagrams

1480 bytes in data field

offset = 1480/8

offset = 2960/8

	length =1500	ID =122	DF =0	MF =1	offset =0	
	length =1500	ID =122	DF =0	MF =1	offset =185	
	length =1040	ID =122	DF =0	MF =0	offset =370	

ICMP

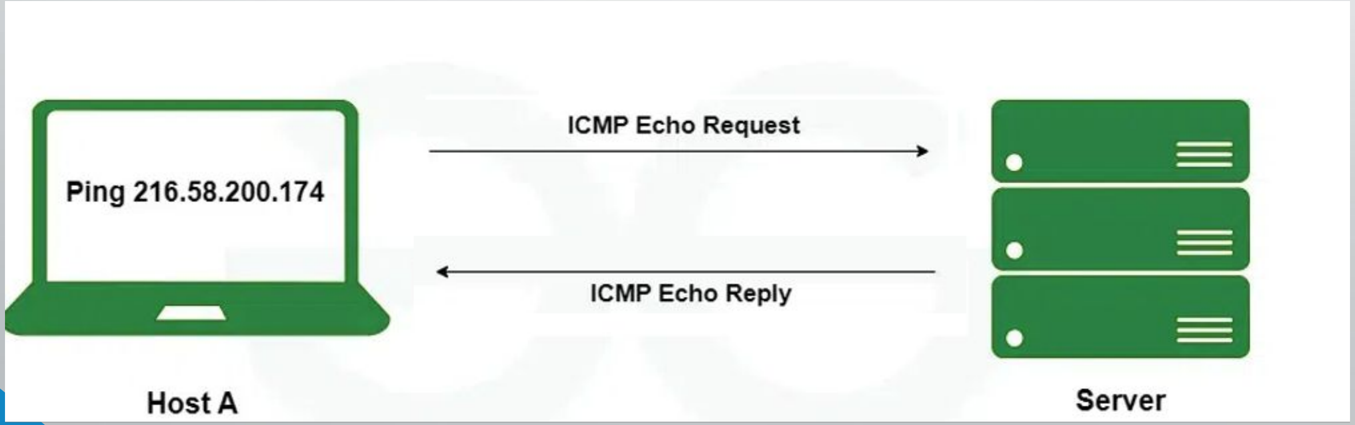
ICMP

- **Internet Control Message Protocol**
  - Helps manage and troubleshoot IP networks.
- **Functions**:
  - Reports errors in communication between devices.
  - Checks if a remote host is reachable.
  - Monitors network congestion.
- **Key Point**:
  - ICMP doesn’t send actual user data—it only provides network status updates.
  - Mainly used by the operating systems in IP network management and administration.

- **Example of ICMP in practice**
  - **Ping**
  - **T**

Ping

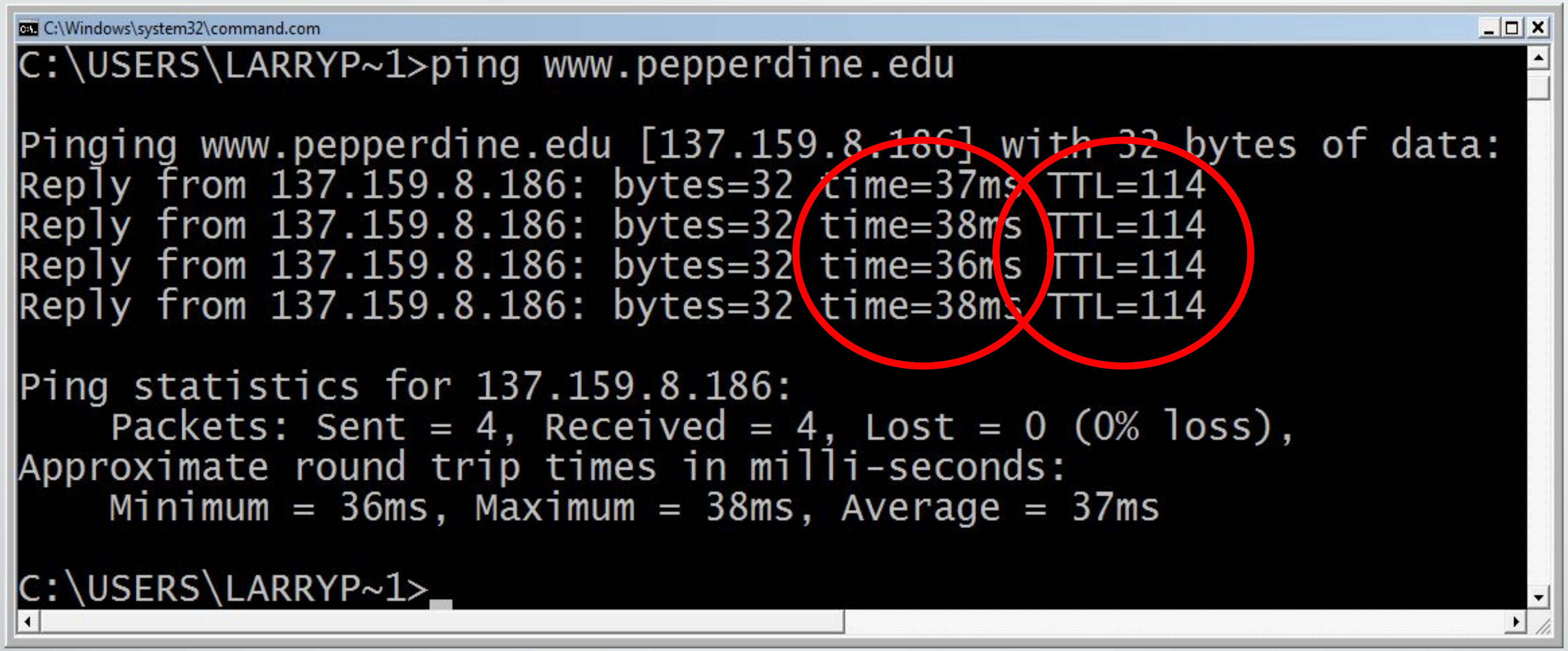
- **PING** stands for Packet Internet Groper and is a network utility tool.
  - **Purpose**: Checks if a device is reachable and measures the time it takes for data to travel (round-trip time).
  - **Mechanism**: Sends ICMP Echo Request packets to a target and waits for Echo Reply packets.
  - **Results**: Displays the number of packets sent, received, lost, and the time taken for the round-trip.



- Commands:

  ping 216.58.200.174

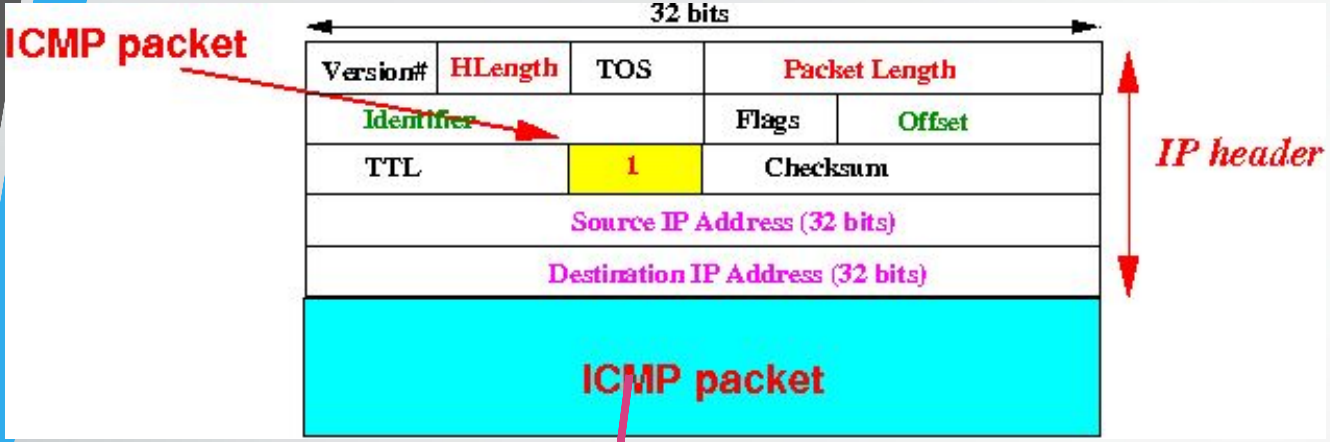
Ping



```
C:\USERS\LARRYP~1>ping www.pepperdine.edu

Pinging www.pepperdine.edu [137.159.8.186] with 32 bytes of data:
Reply from 137.159.8.186: bytes=32 time=37ms TTL=114
Reply from 137.159.8.186: bytes=32 time=38ms TTL=114
Reply from 137.159.8.186: bytes=32 time=36ms TTL=114
Reply from 137.159.8.186: bytes=32 time=38ms TTL=114

Ping statistics for 137.159.8.186:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 36ms, Maximum = 38ms, Average = 37ms

C:\USERS\LARRYP~1>_
```

- **Questions :**
- Why 4 replies?
- What the time refer to?

ICMP Packet Format

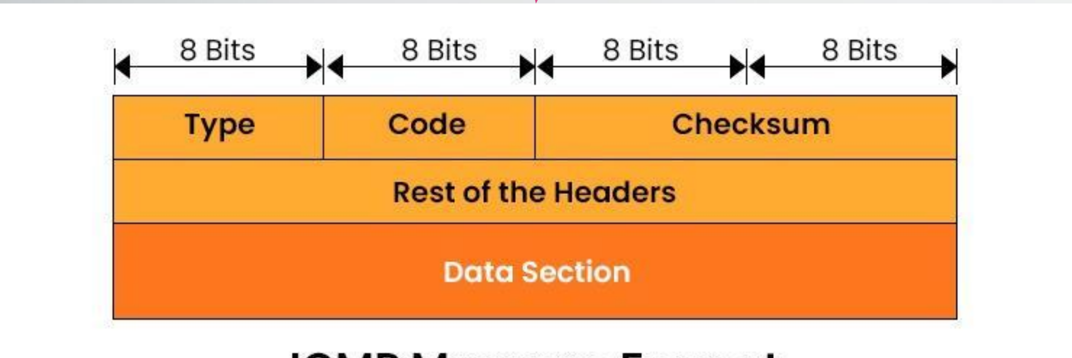

32 bits

ICMP packet

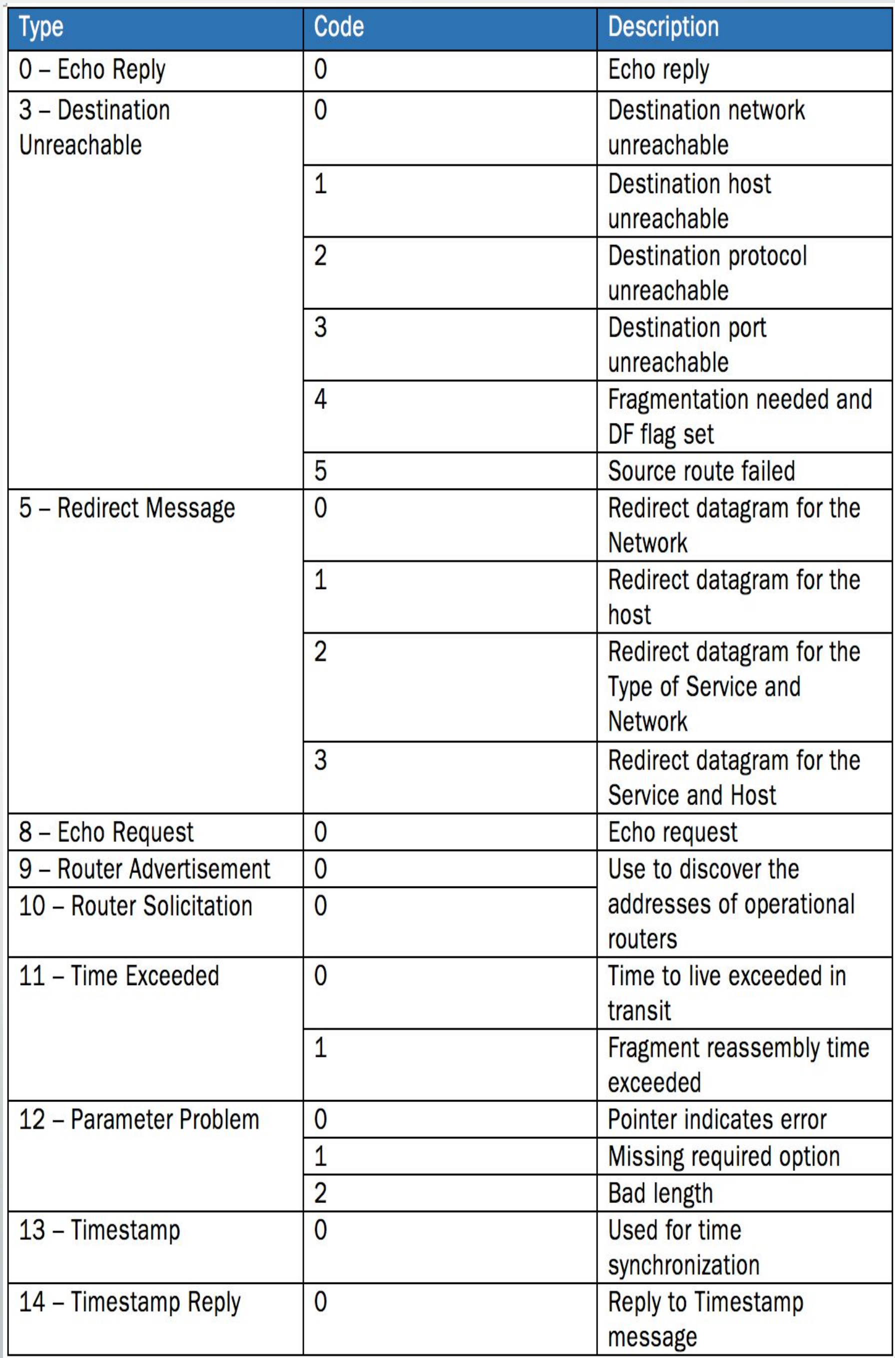
Version#	HLength	TOS	Packet Length
Identifier		Flags	Offset
TTL	1	Checksum	
Source IP Address (32 bits)			
Destination IP Address (32 bits)			

IP header

ICMP packet

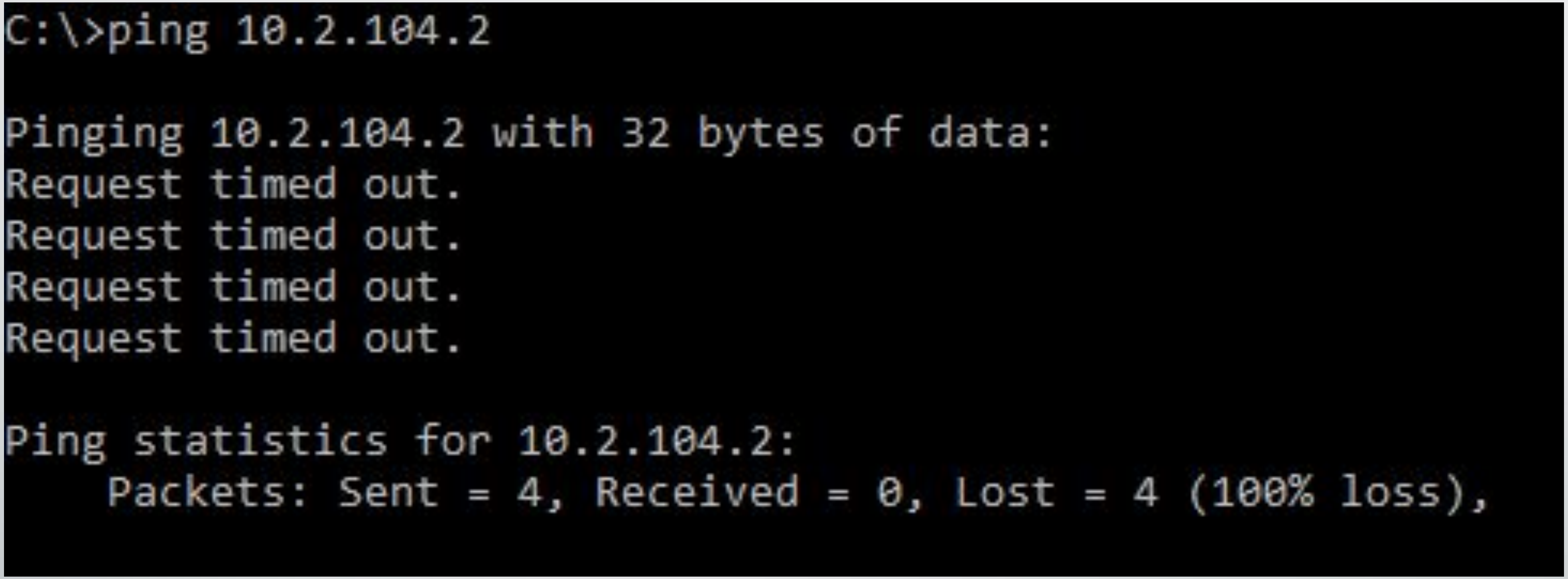


ICMP Message Format



Type	Code	Description
0 – Echo Reply	0	Echo reply
3 – Destination Unreachable	0	Destination network unreachable
	1	Destination host unreachable
	2	Destination protocol unreachable
	3	Destination port unreachable
	4	Fragmentation needed and DF flag set
	5	Source route failed
5 – Redirect Message	0	Redirect datagram for the Network
	1	Redirect datagram for the host
	2	Redirect datagram for the Type of Service and Network
	3	Redirect datagram for the Service and Host
8 – Echo Request	0	Echo request
9 – Router Advertisement	0	Use to discover the addresses of operational routers
10 – Router Solicitation	0	
11 – Time Exceeded	0	Time to live exceeded in transit
	1	Fragment reassembly time exceeded
12 – Parameter Problem	0	Pointer indicates error
	1	Missing required option
	2	Bad length
13 – Timestamp	0	Used for time synchronization
14 – Timestamp Reply	0	Reply to Timestamp message

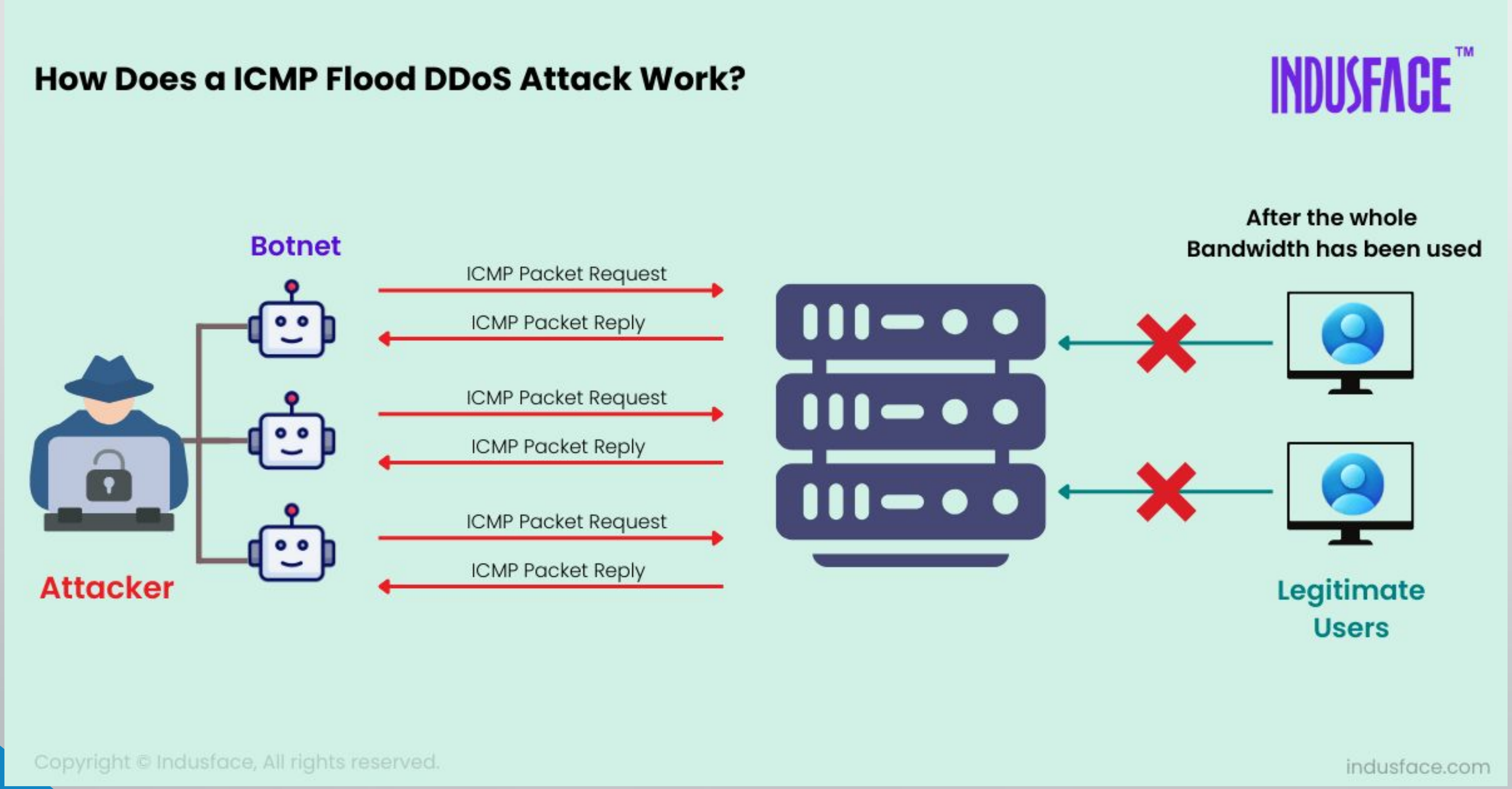
Unsuccessful Ping



```
C:\>ping 10.2.104.2

Pinging 10.2.104.2 with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 10.2.104.2:
    Packets: Sent = 4, Received = 0, Lost = 4 (100% loss),
```

Ping Attacks

- **ICMP DDOS attack – Zombie Attack:**

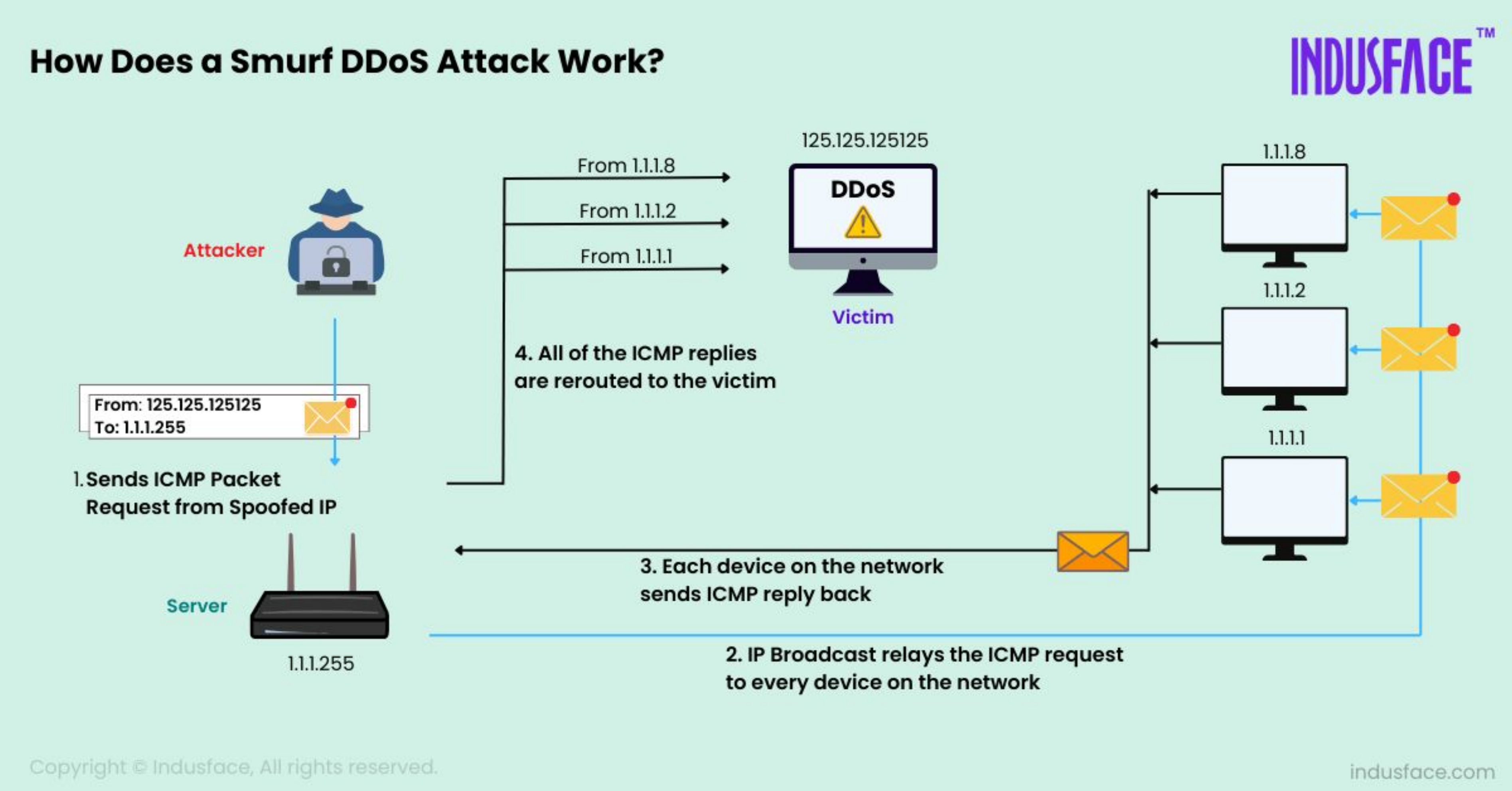


How Does a ICMP Flood DDoS Attack Work?

indusface.com

Ping Attacks

- **ICMP DDOS attack – Packet magnification (or ICMP Smurf):**


How Does a Smurf DDoS Attack Work?
INDUSFACE™
Attacker
From: 125.125.125125
To: 1.1.1.255
1. Sends ICMP Packet Request from Spoofed IP
Server
1.1.1.255
From 1.1.1.8
From 1.1.1.2
From 1.1.1.1
125.125.125125
DDoS
Victim
4. All of the ICMP replies are rerouted to the victim
1.1.1.8
1.1.1.2
1.1.1.1
3. Each device on the network sends ICMP reply back
2. IP Broadcast relays the ICMP request to every device on the network
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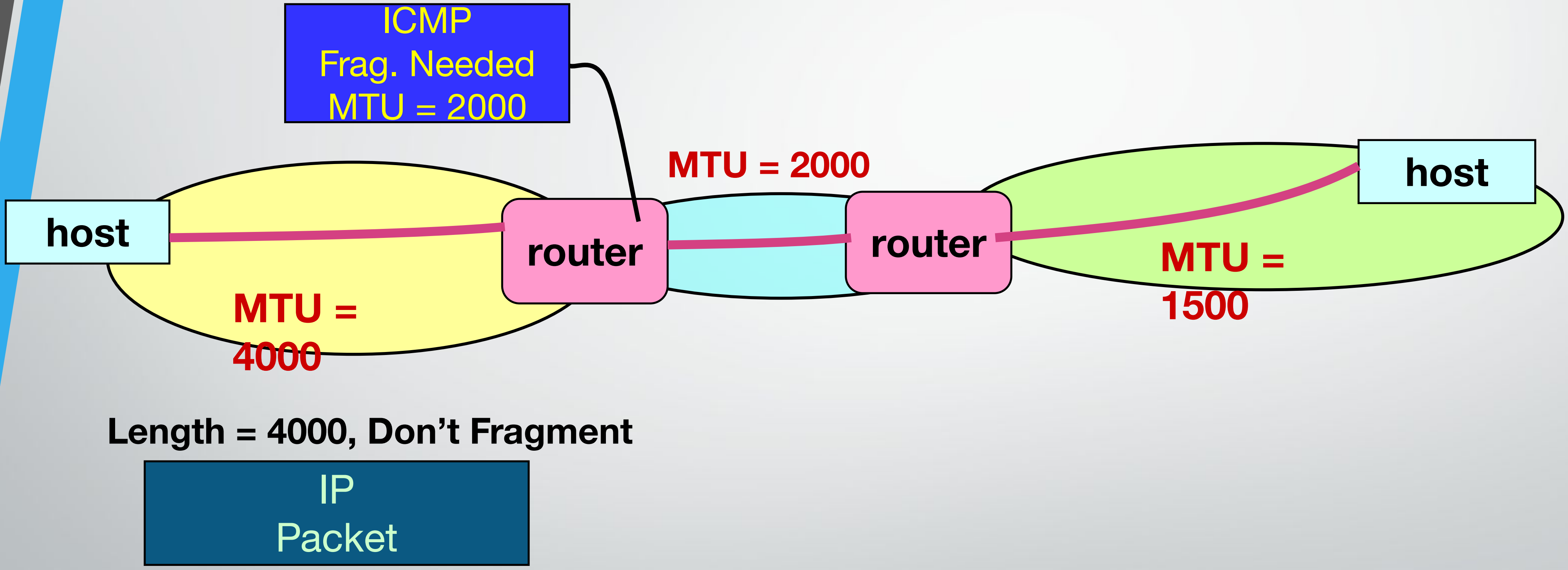
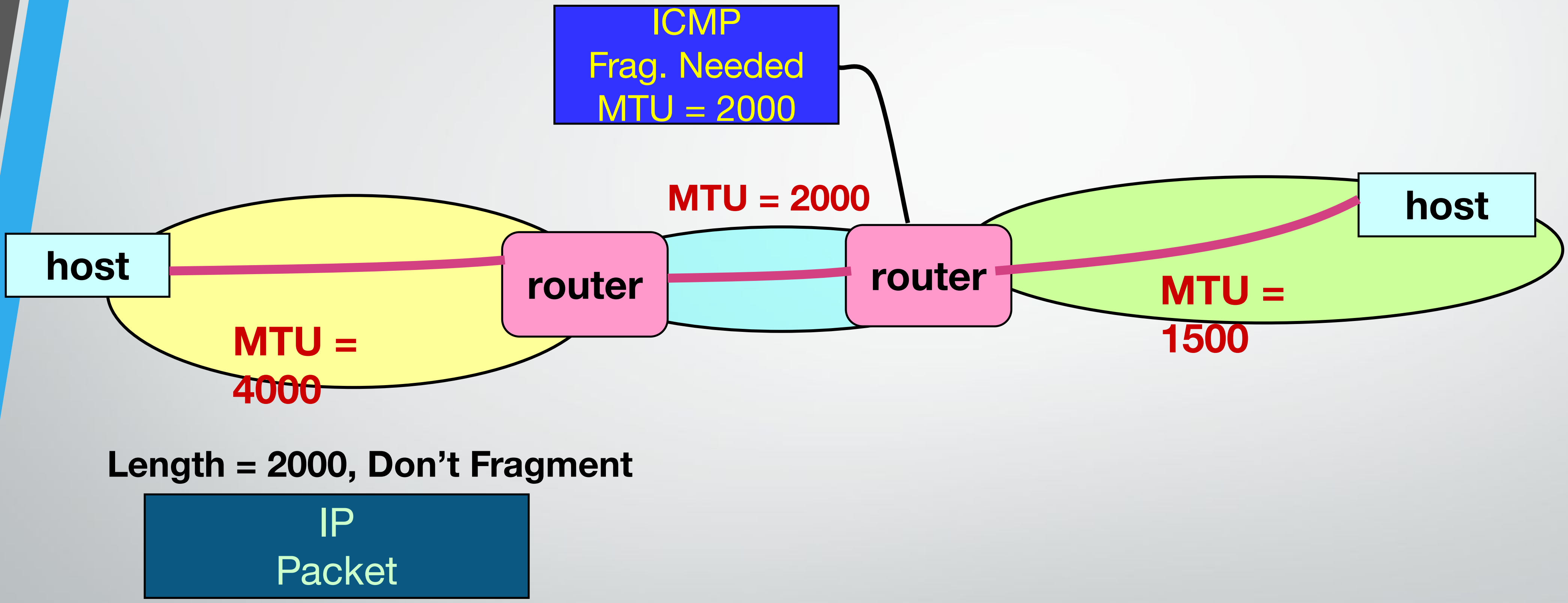
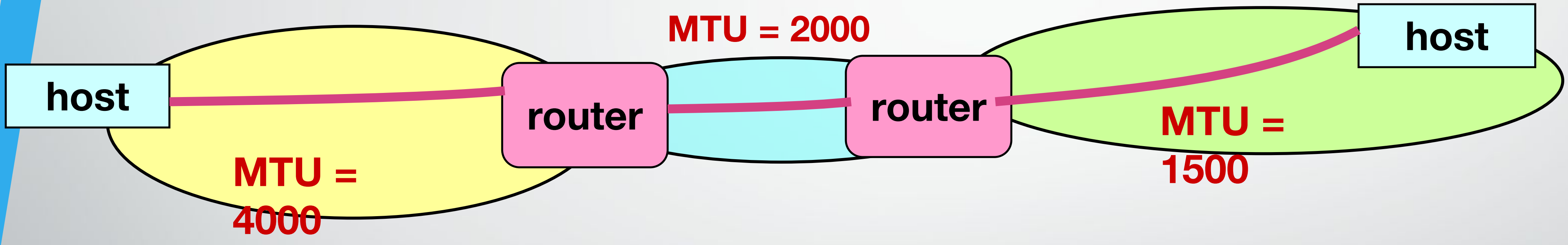
IP MTU Discovery with ICMP

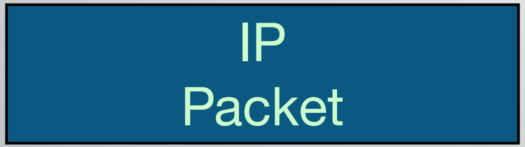


IP MTU Discovery with ICMP



IP MTU Discovery with ICMP





- When successful, no reply at IP level

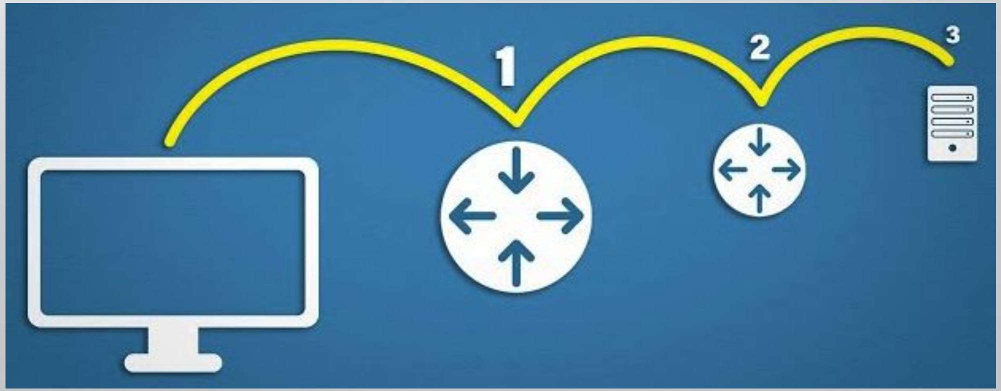
“No news is good news”

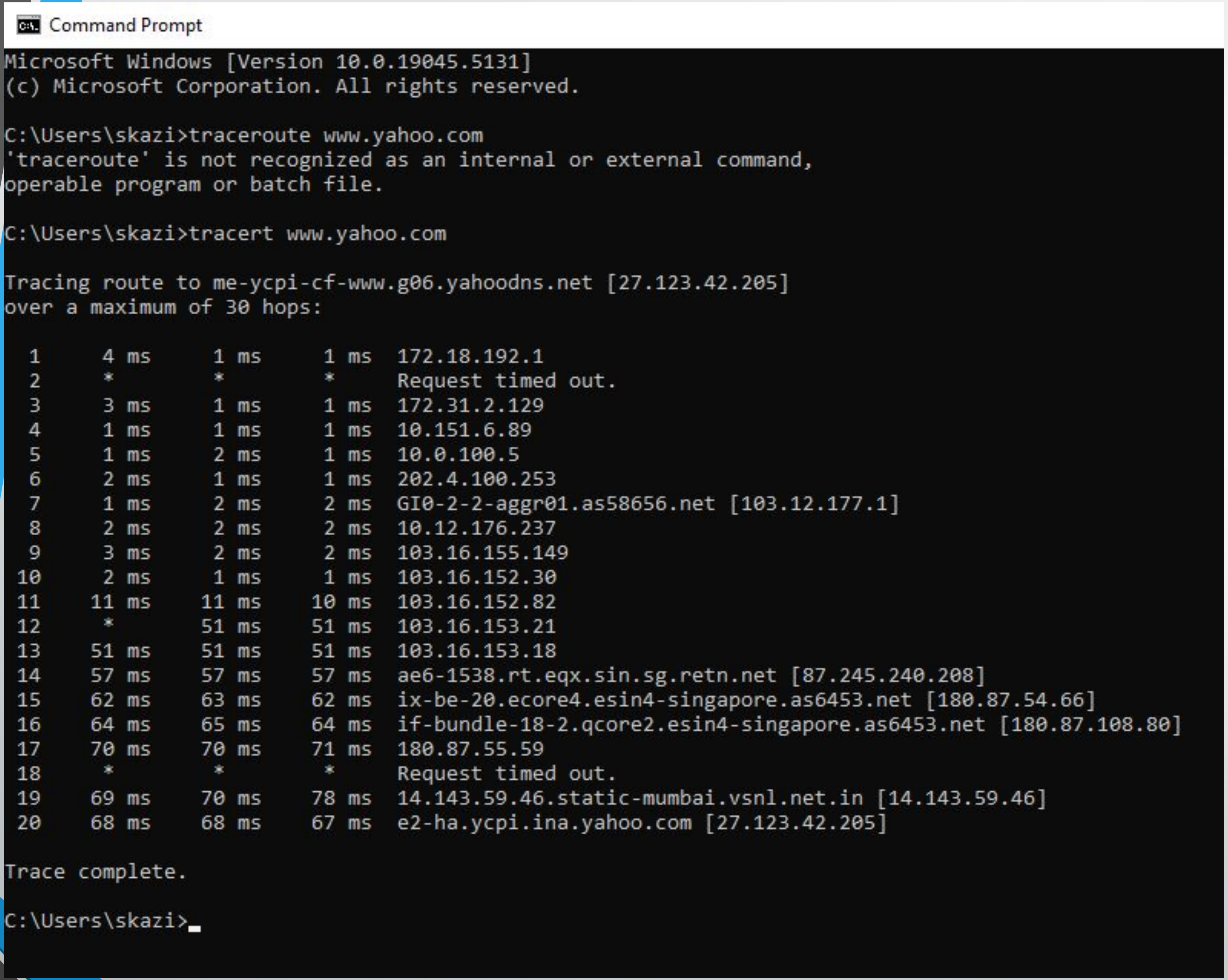
Higher level protocol might have some form of acknowledgement

Traceroute

- A network diagnostic tool used to trace the path that data packets take from your computer to a target server or IP address.
  - **Purpose**: Identifies the routers or hops data passes through to reach its destination mostly for troubleshooting
  - **Mechanism**: Uses ICMP or UDP packets with incrementing TTL (Time-to-Live) values to get "Time Exceeded" responses from each hop.
  - **Results**: Displays the IP address, hostname (if resolvable), and latency for each hop.

- Commands:
  - Unix: **traceroute**
  - Cisco IOS: **traceroute (trace)**
  - DOS: **tracert**





```
Microsoft Windows [Version 10.0.19045.5131]
(c) Microsoft Corporation. All rights reserved.

C:\Users\skazi>traceroute www.yahoo.com
'traceroute' is not recognized as an internal or external command,
operable program or batch file.

C:\Users\skazi>tracert www.yahoo.com

Tracing route to me-ycpi-cf-www.g06.yahoodns.net [27.123.42.205]
over a maximum of 30 hops:

  1     4 ms     1 ms     1 ms  172.18.192.1
  2     *        *        *     Request timed out.
  3     3 ms     1 ms     1 ms  172.31.2.129
  4     1 ms     1 ms     1 ms  10.151.6.89
  5     1 ms     2 ms     1 ms  10.0.100.5
  6     2 ms     1 ms     1 ms  202.4.100.253
  7     1 ms     2 ms     2 ms  GI0-2-2-aggr01.as58656.net [103.12.177.1]
  8     2 ms     2 ms     2 ms  10.12.176.237
  9     3 ms     2 ms     2 ms  103.16.155.149
 10     2 ms     1 ms     1 ms  103.16.152.30
 11    11 ms    11 ms    10 ms  103.16.152.82
 12     *       51 ms    51 ms  103.16.153.21
 13    51 ms    51 ms    51 ms  103.16.153.18
 14    57 ms    57 ms    57 ms  ae6-1538.rt.eqx.sin.sg.retn.net [87.245.240.208]
 15    62 ms    63 ms    62 ms  ix-be-20.ecore4.esin4-singapore.as6453.net [180.87.54.66]
 16    64 ms    65 ms    64 ms  if-bundle-18-2.qcore2.esin4-singapore.as6453.net [180.87.108.80]
 17    70 ms    70 ms    71 ms  180.87.55.59
 18     *        *        *     Request timed out.
 19    69 ms    70 ms    78 ms  14.143.59.46.static-mumbai.vsnl.net.in [14.143.59.46]
 20    68 ms    68 ms    67 ms  e2-ha.ycpi.ina.yahoo.com [27.123.42.205]

Trace complete.

C:\Users\skazi>_
```

Using Tracert

Hop 1: Our local router or gateway (private IP address).

Hops 2–5: Internal routing within Bracu ISP's private network (non-public IPs).

Hop 6: First public IP, ISP's gateway to the internet.

Hops 7–9: Routing through regional and backbone ISPs.

Hops 10–13: Routing through Singapore (a major internet hub).

Hops 14–19: Routing through Indian networks, ending in Mumbai.

Hop 20: Final destination—Yahoo's server, located in India, near Mumbai.

Traceroute: Another example

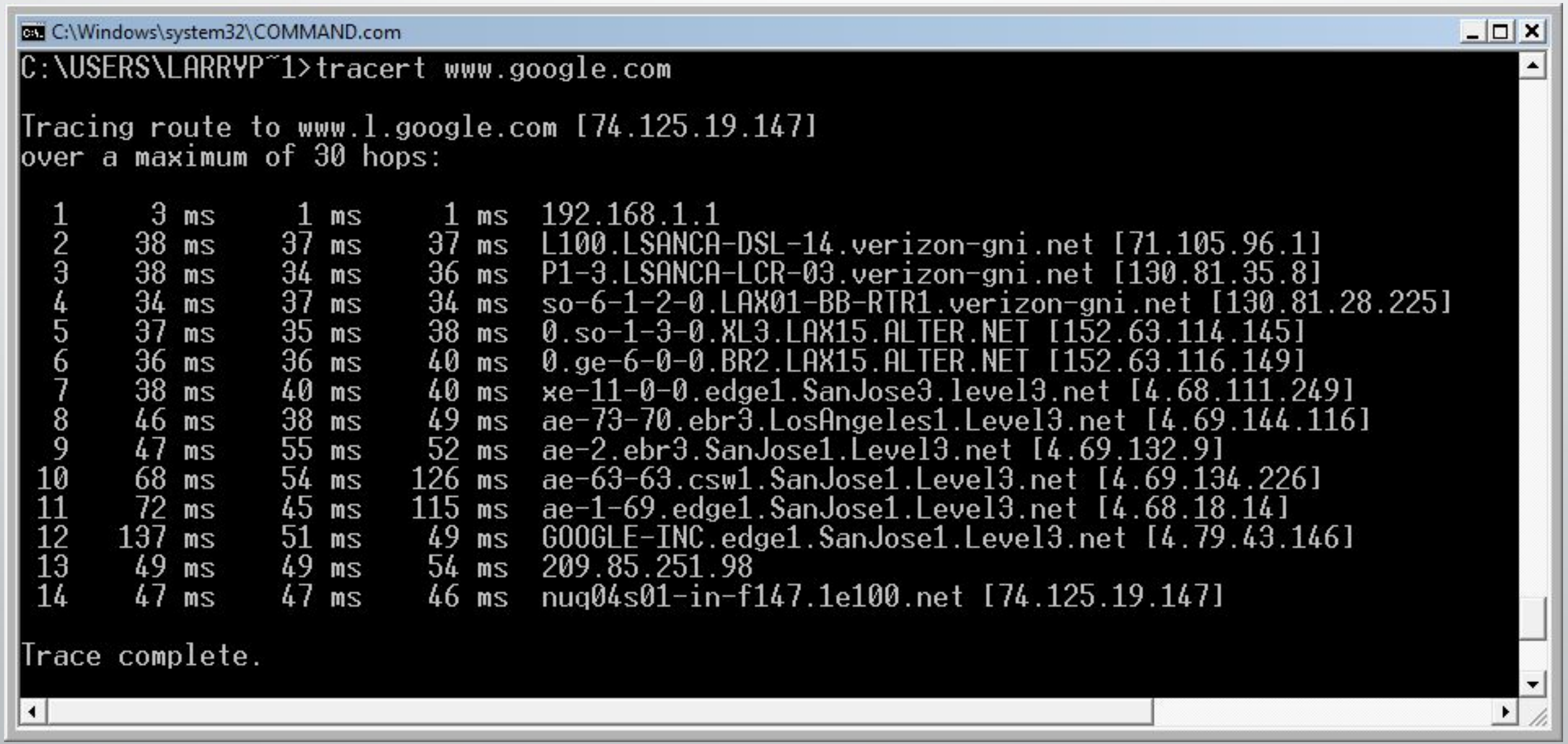
Hop 1: User LAN router

Hops 2-4: Verizon network (a backbone ISP)

Hops 5-6: Alternet (a backbone ISP)

Hops 7-11: Level 3 (a backbone ISP)

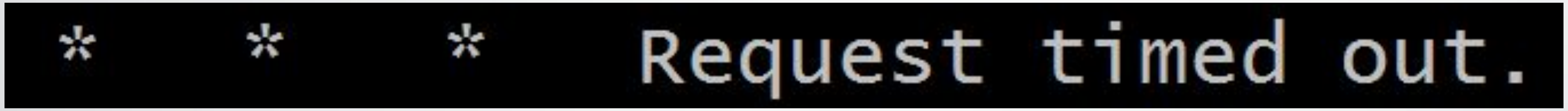
Hops 12-14: the Google LAN



```
C:\USERS\LARRYP~1>tracert www.google.com

Tracing route to www.l.google.com [74.125.19.147]
over a maximum of 30 hops:

  1     3 ms     1 ms     1 ms  192.168.1.1
  2    38 ms    37 ms    37 ms  L100.LSANCA-DSL-14.verizon-gni.net [71.105.96.1]
  3    38 ms    34 ms    36 ms  P1-3.LSANCA-LCR-03.verizon-gni.net [130.81.35.8]
  4    34 ms    37 ms    34 ms  so-6-1-2-0.LAX01-BB-RTR1.verizon-gni.net [130.81.28.225]
  5    37 ms    35 ms    38 ms  0.so-1-3-0.XL3.LAX15.ALTER.NET [152.63.114.145]
  6    36 ms    36 ms    40 ms  0.ge-6-0-0.BR2.LAX15.ALTER.NET [152.63.116.149]
  7    38 ms    40 ms    40 ms  xe-11-0-0.edge1.SanJose3.level3.net [4.68.111.249]
  8    46 ms    38 ms    49 ms  ae-73-70.ebr3.LosAngeles1.Level3.net [4.69.144.116]
  9    47 ms    55 ms    52 ms  ae-2.ebr3.SanJose1.Level3.net [4.69.132.9]
 10    68 ms    54 ms   126 ms  ae-63-63.csw1.SanJose1.Level3.net [4.69.134.226]
 11    72 ms    45 ms   115 ms  ae-1-69.edge1.SanJose1.Level3.net [4.68.18.14]
 12   137 ms    51 ms    49 ms  GOOGLE-INC.edge1.SanJose1.Level3.net [4.79.43.146]
 13    49 ms    49 ms    54 ms  209.85.251.98
 14    47 ms    47 ms    46 ms  nuq04s01-in-f147.1e100.net [74.125.19.147]

Trace complete.
```

Traceroute: Request Timed Out

This message indicates that the router security settings keep it from revealing its identity or the router and connection are slow.



```
  *        *        *     Request timed out.
```

The End