Intro to Computer Networking

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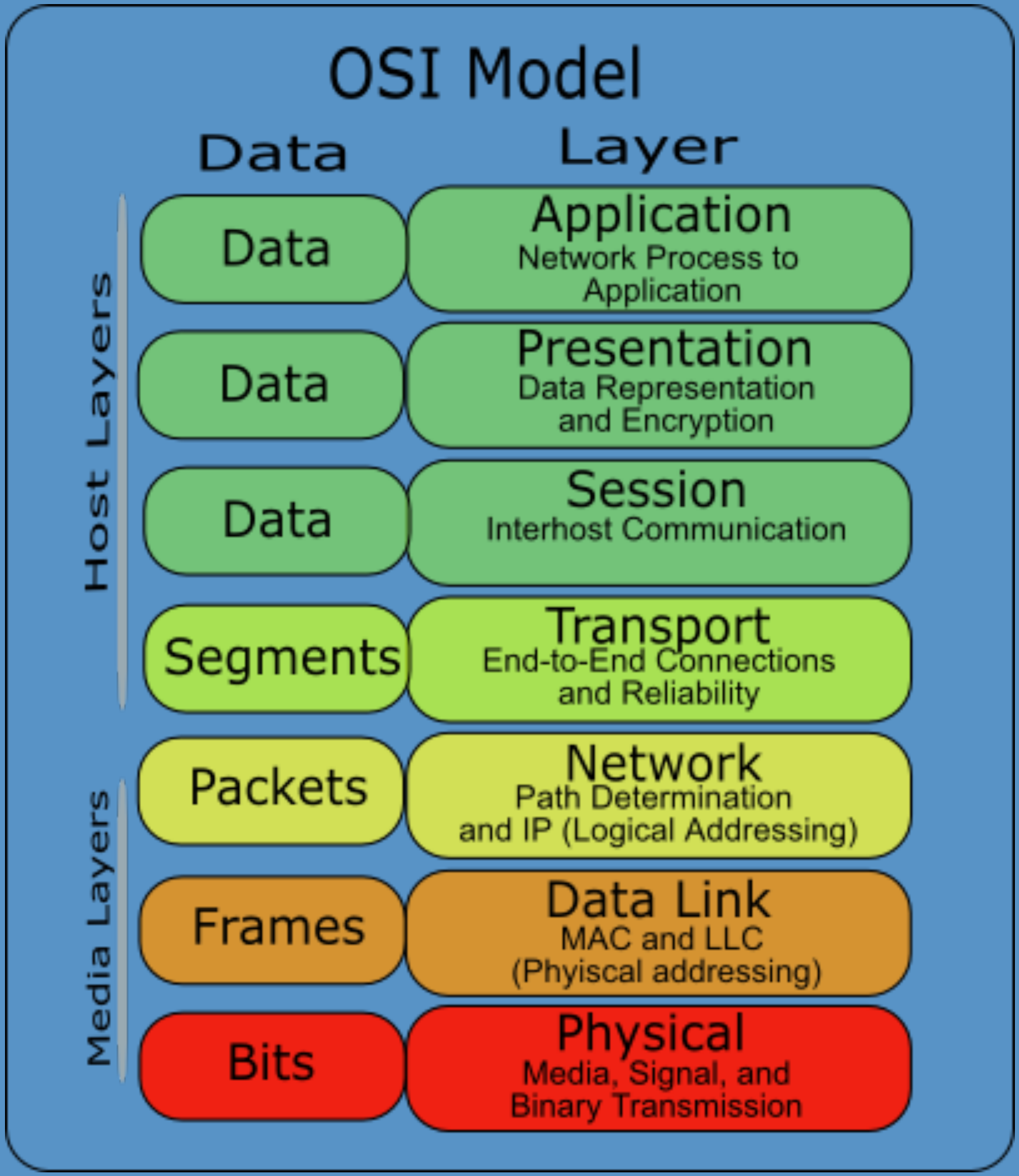
Networking

- *an infrastructure allowing computers to exchange data*
- At some point, computers were siloed devices, limited to word processing, local audio/image processing, games, etc. People did not collaborate via machines.

OSI Model

- a conceptual model that standardizes the functions of a telecommunication or computing system without regard of their underlying internal structure and technology
- goal: the ***interoperability*** of diverse communication systems with standard protocols
- A layer serves the layer above it and is served by the layer below it
- The original version of this model defined seven layers

OSI Model



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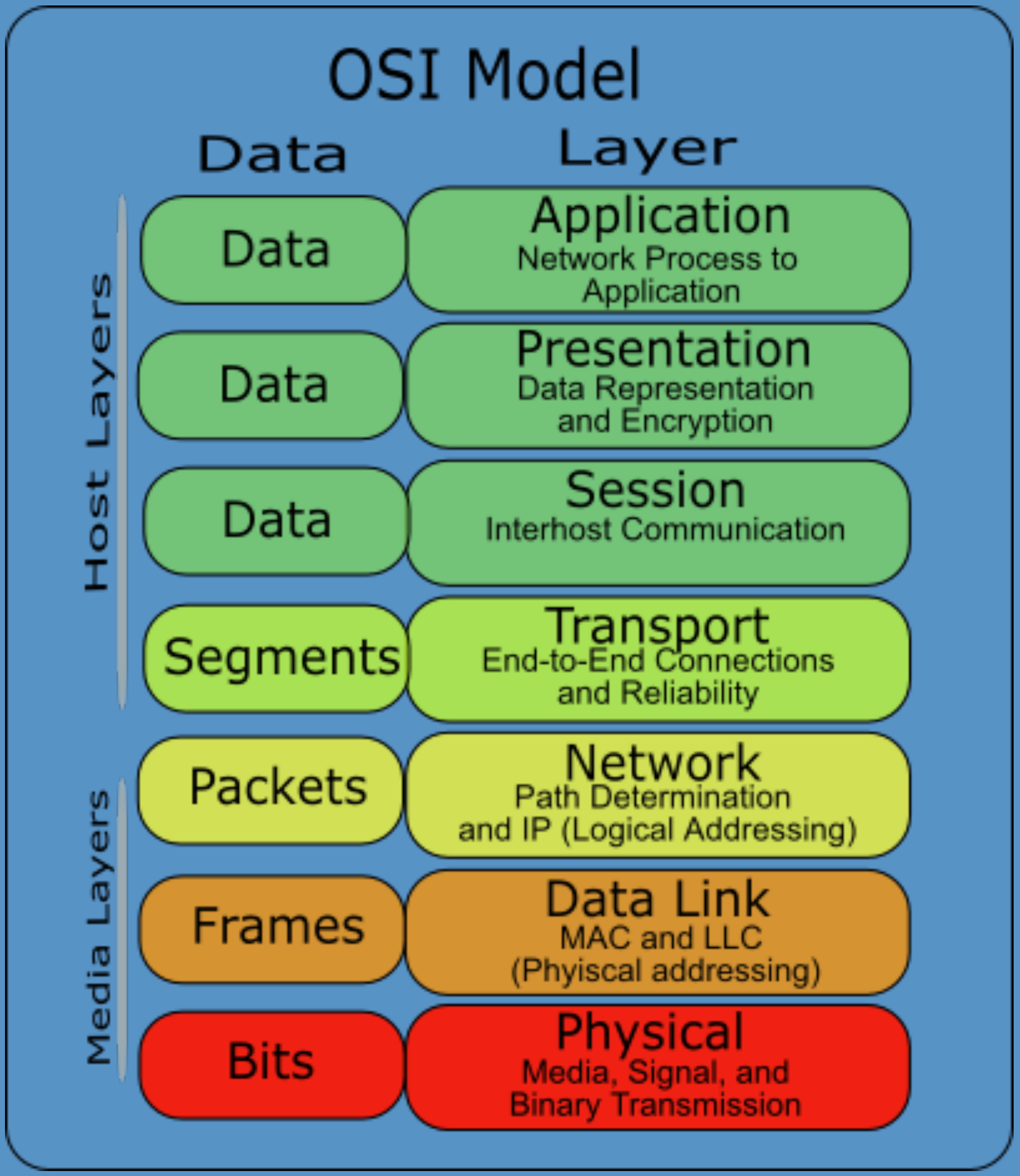
Path Determination and IP (Logical Addressing)
Frames
Data Link
MAC and LLC (Phyiscal addressing)
Bits
Physical
Media, Signal, and Binary Transmission

OSI Model

App 1

↓



OSI Model

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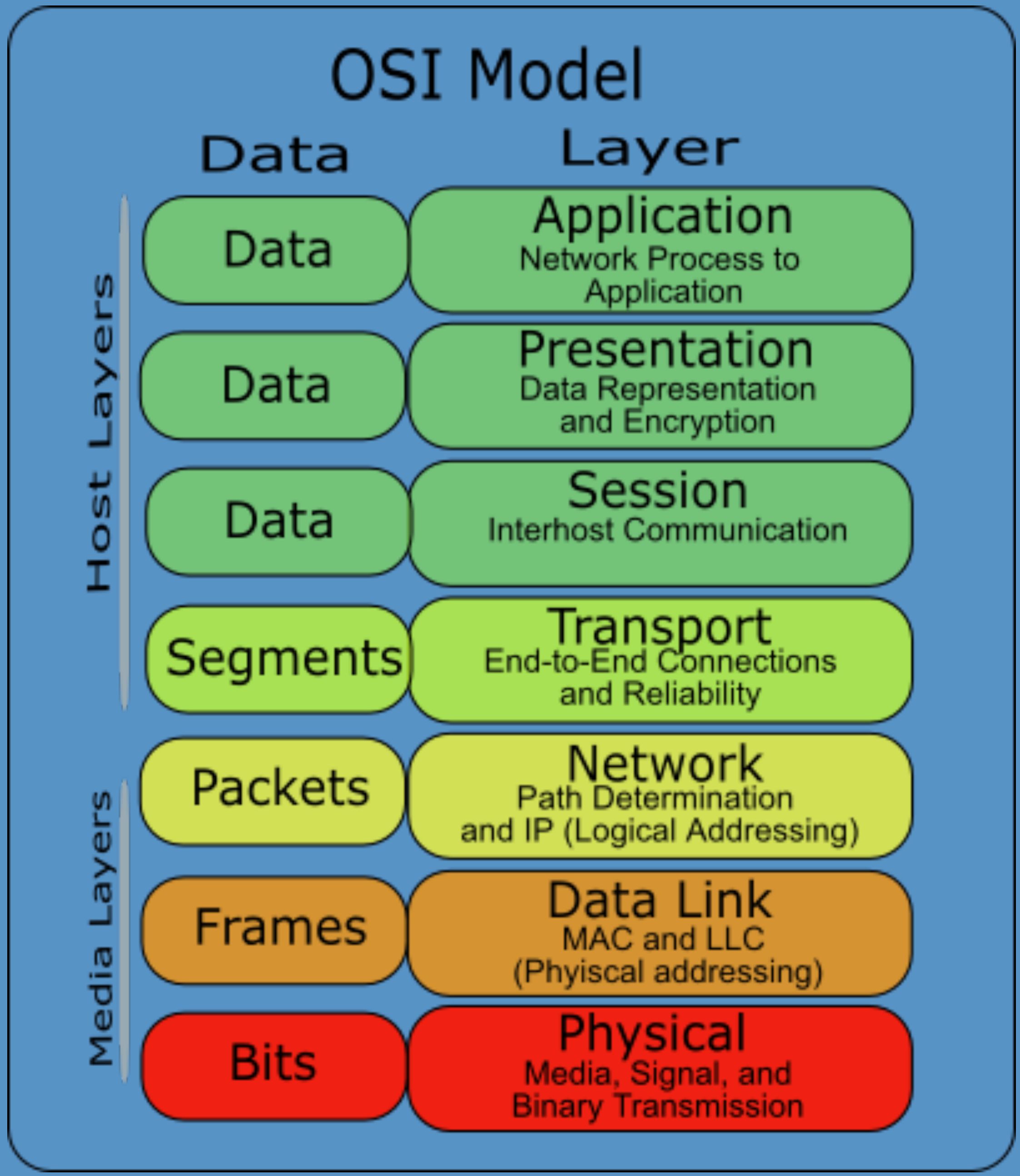

OSI Model

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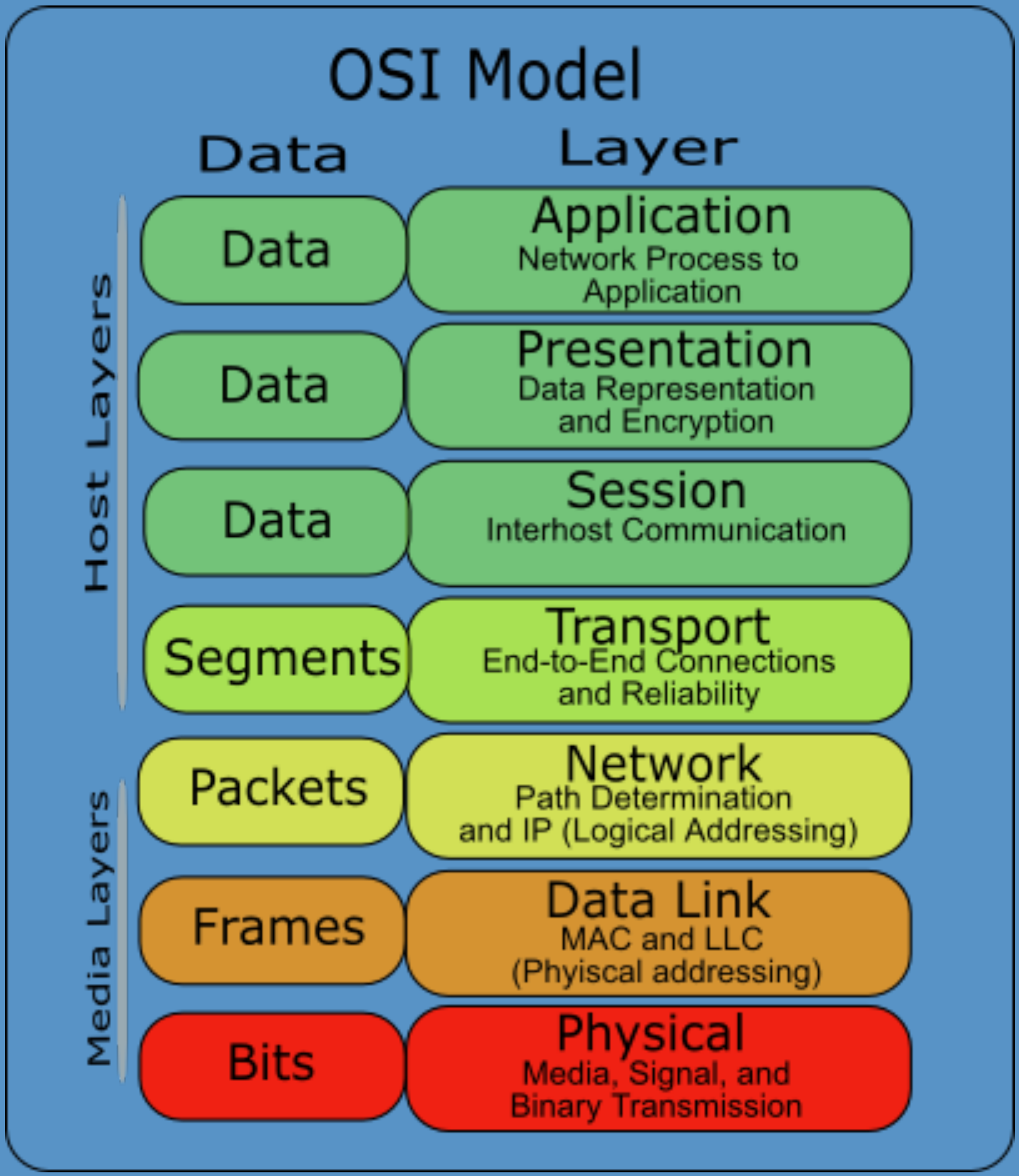
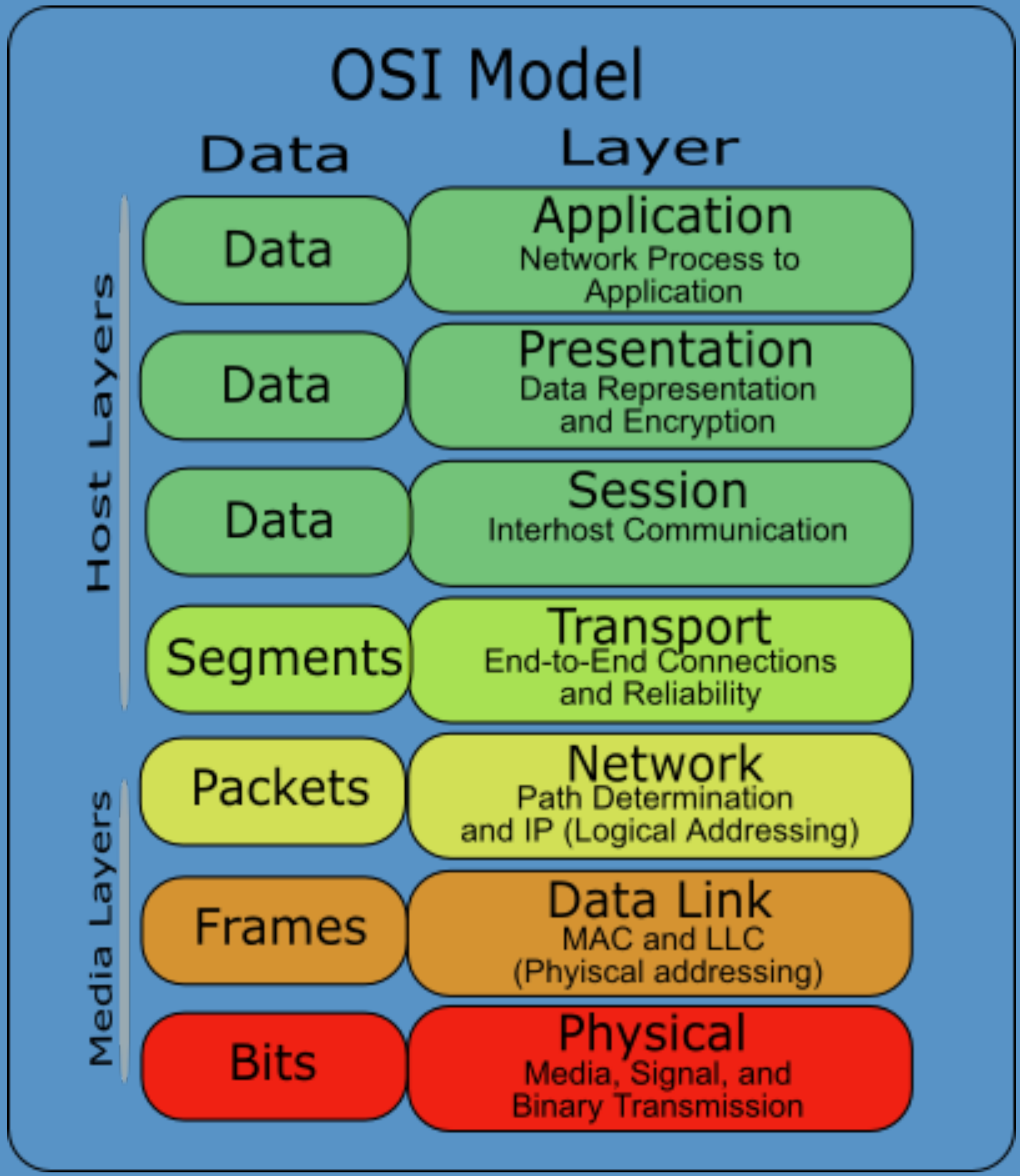


App 2

OSI Model

App 1

App 2



Layer 1

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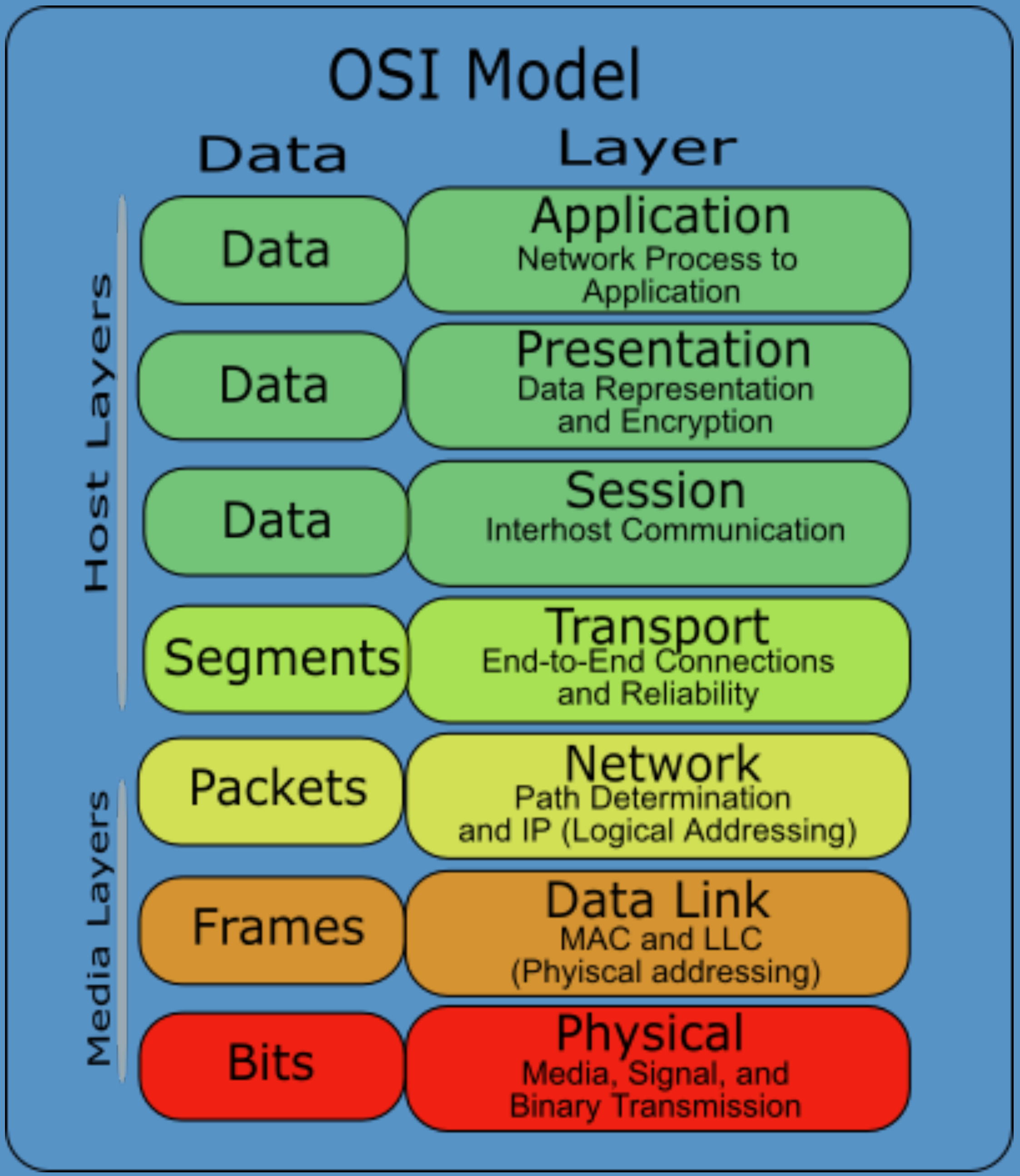
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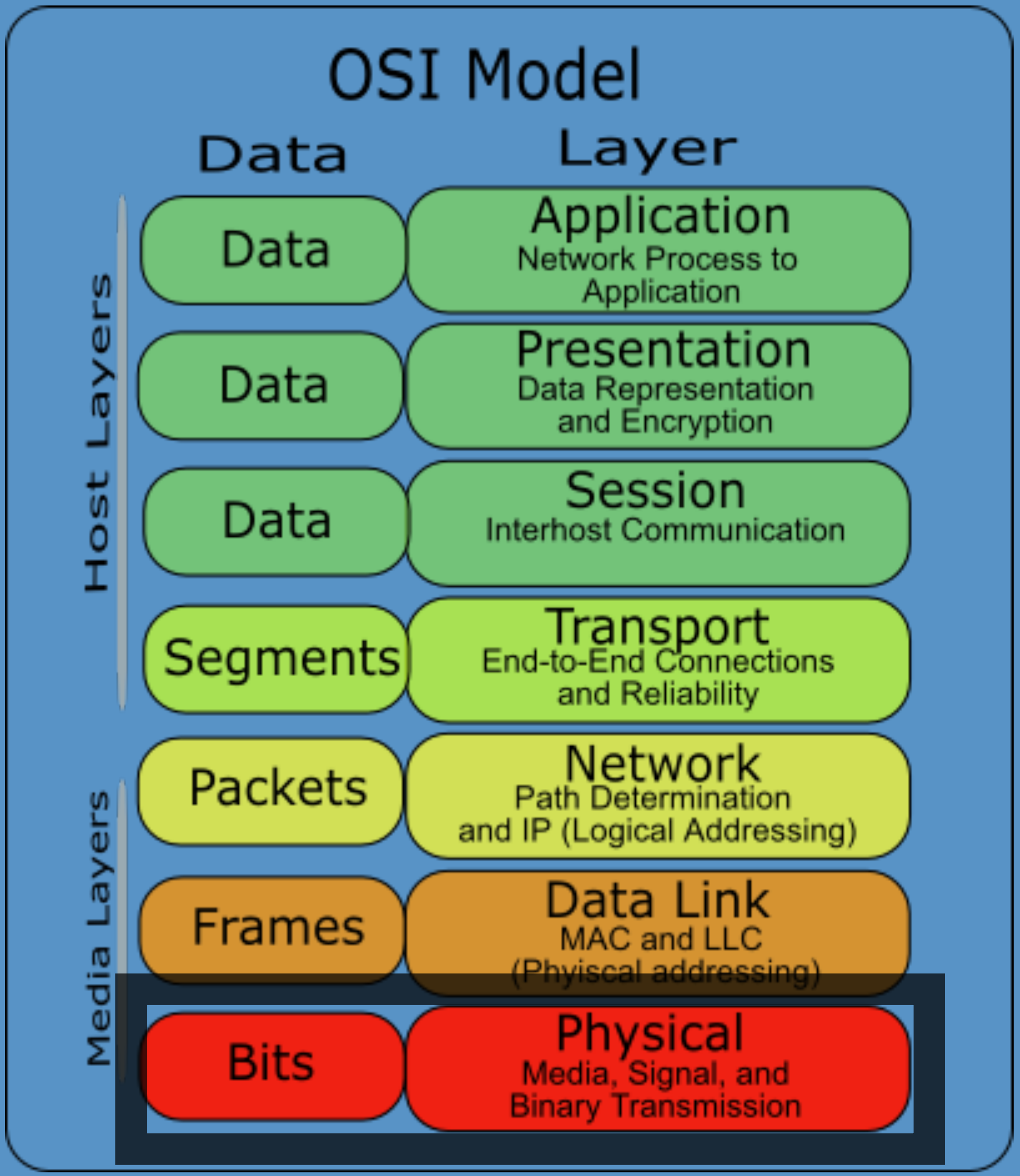
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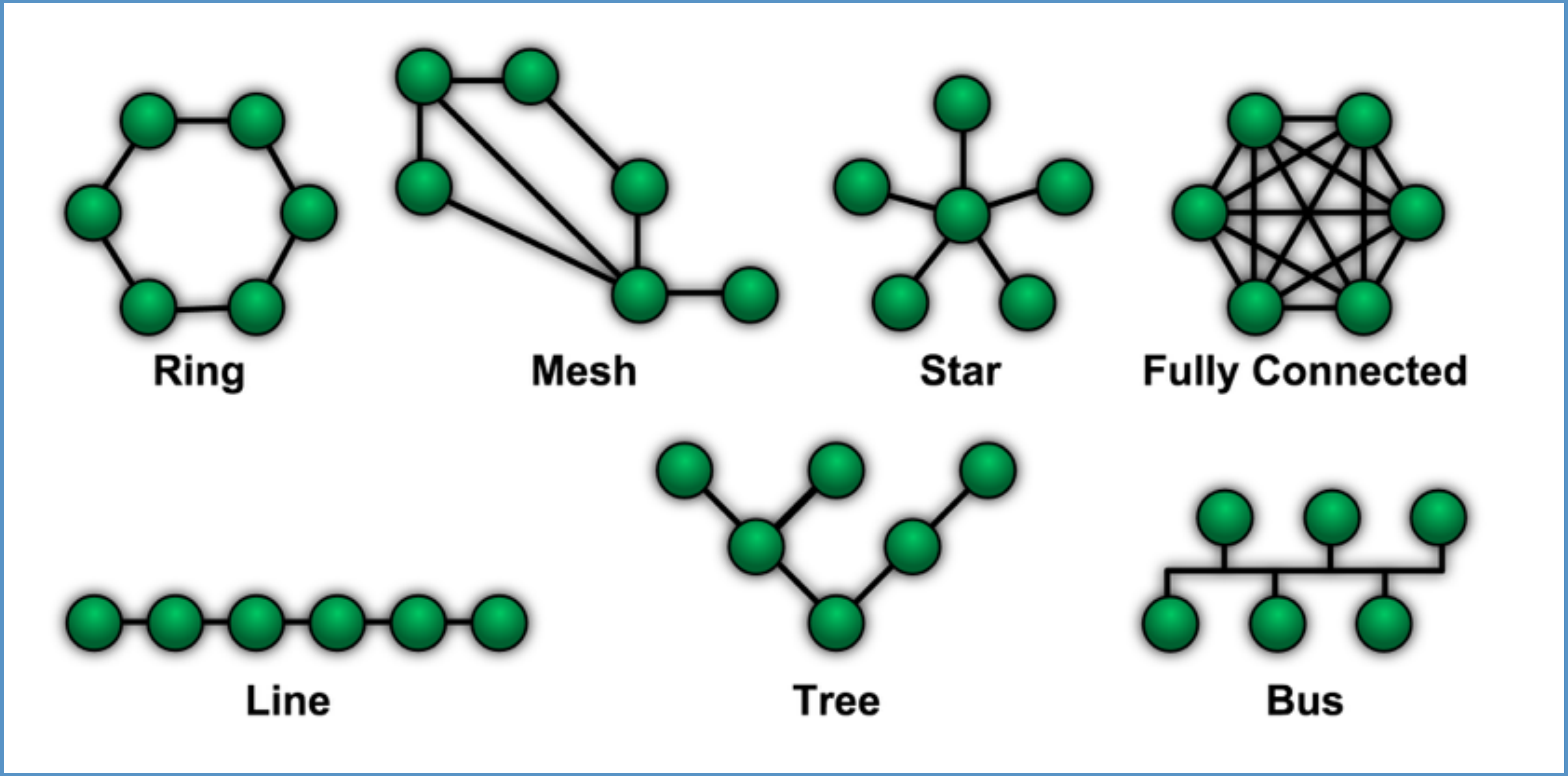
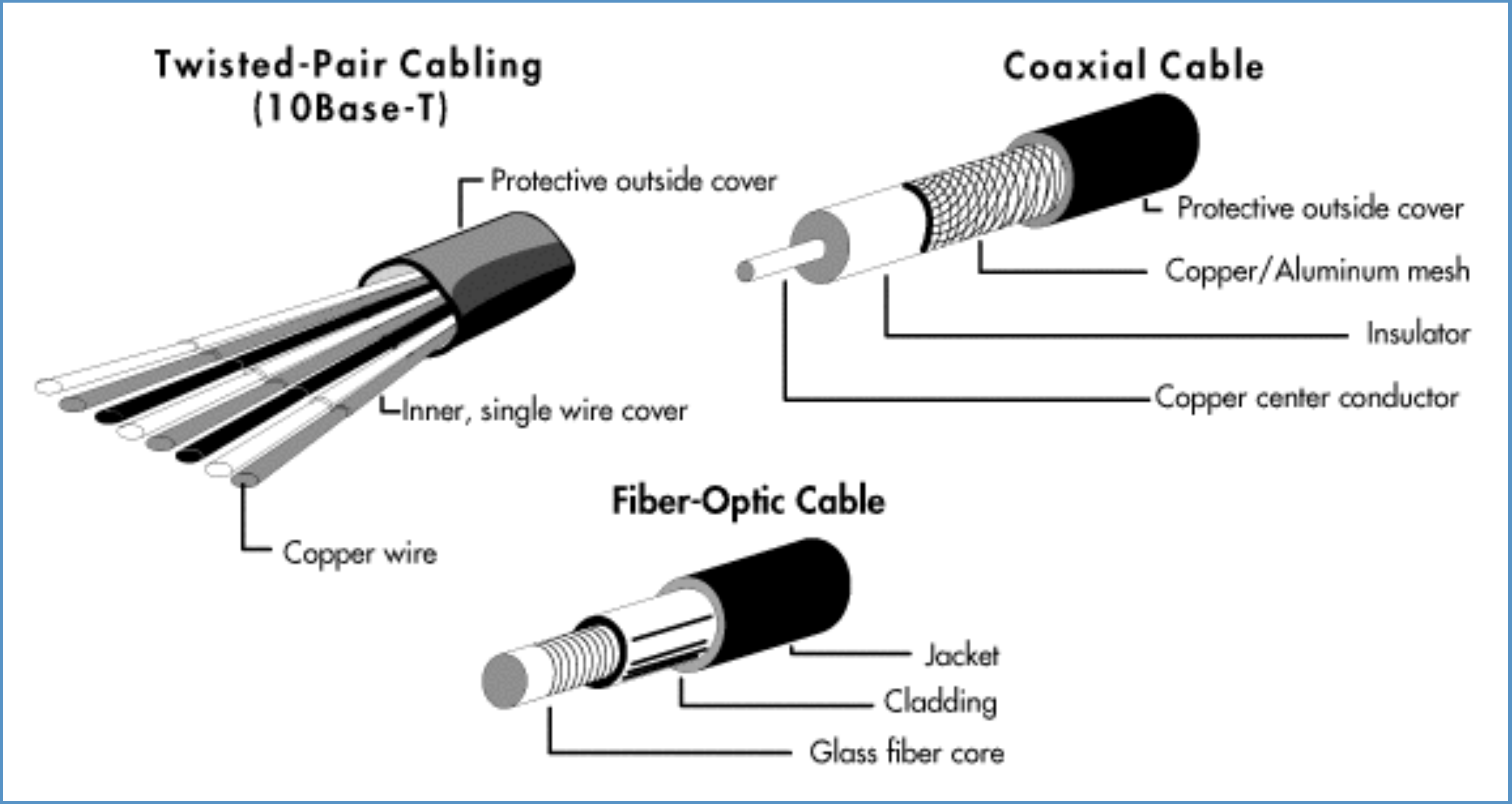
Layer 1: Physical Layer

- defines the means of transmitting raw bits rather than logical data packets over a physical link connecting network nodes
- defines the relationship between a device and a physical transmission medium (e.g., a copper or fiber optical cable, radio frequency)
- defines the transmission mode: simplex, half duplex, full duplex
- defines the network topology: bus, mesh, ring
- Transmission media: air, coaxial cable, category 5E cable, USB cable, fiber cable

Network Topology



Transmission Media



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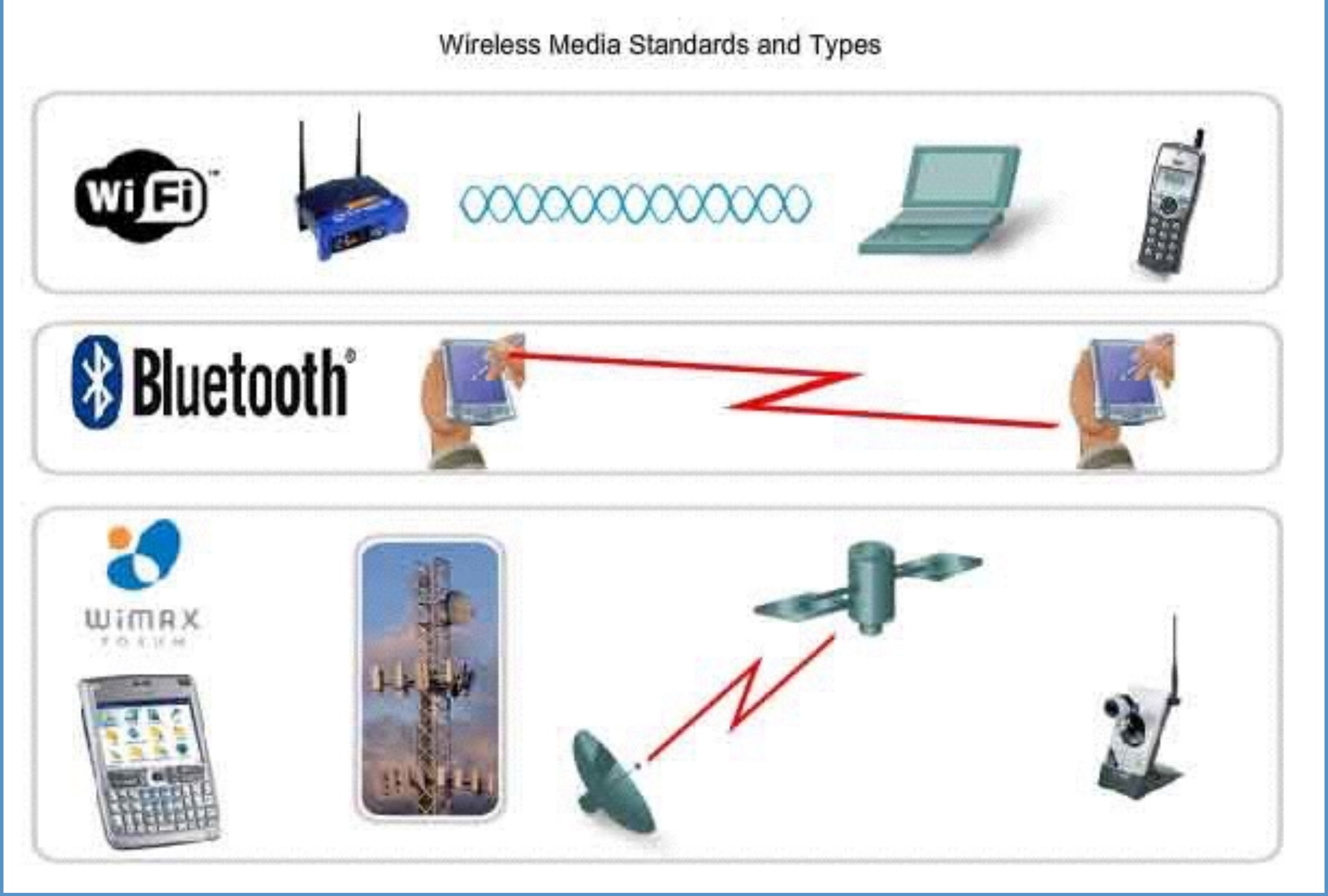
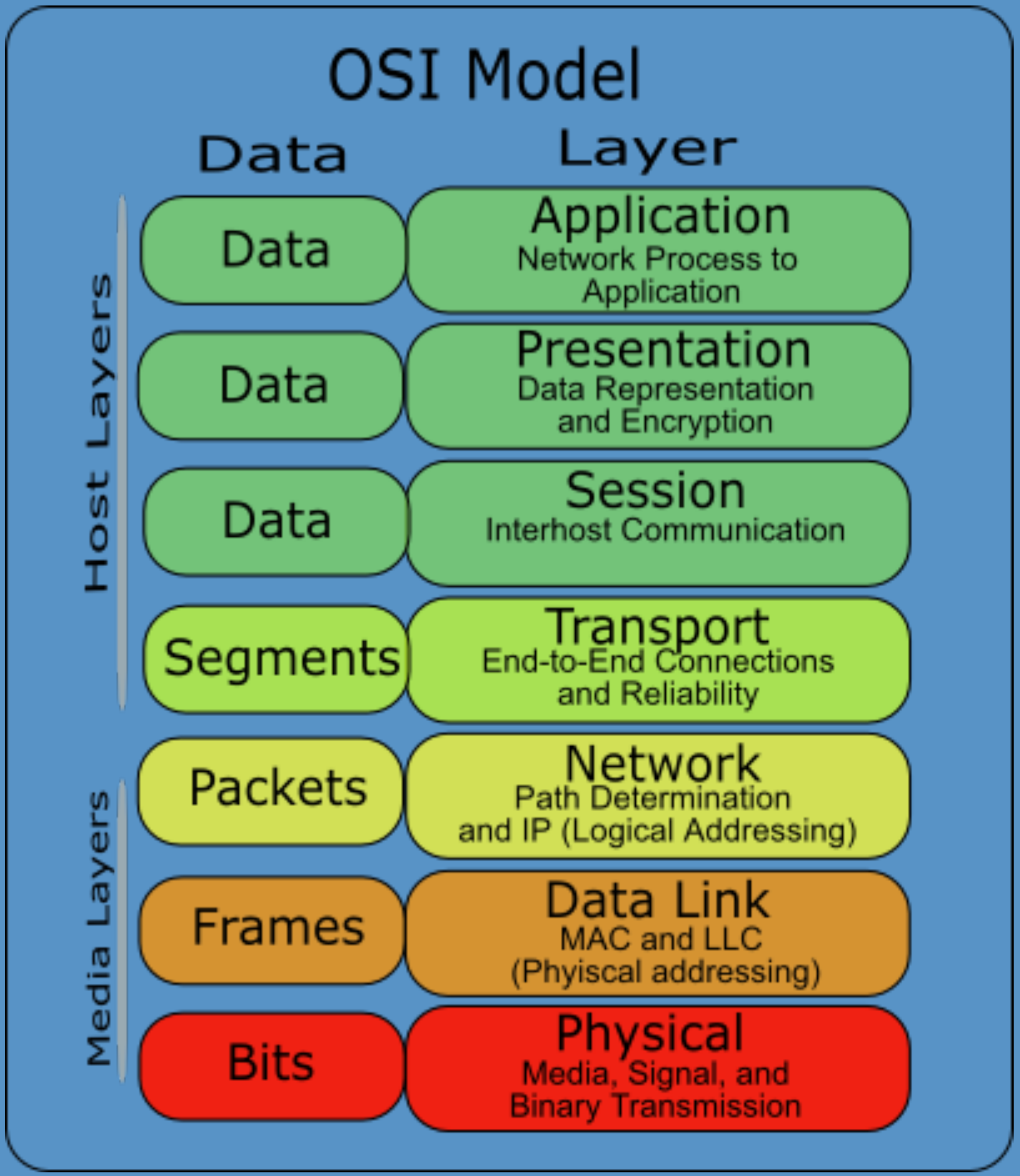


Layer 1: Examples

- Digital Subscriber Line (DSL)
- Integrated Services Digital Network (ISDN)
- Infrared Data Association (scanners)
- Universal Serial Bus (USB)
- Bluetooth
- Ethernet

Layer 2

Layer 2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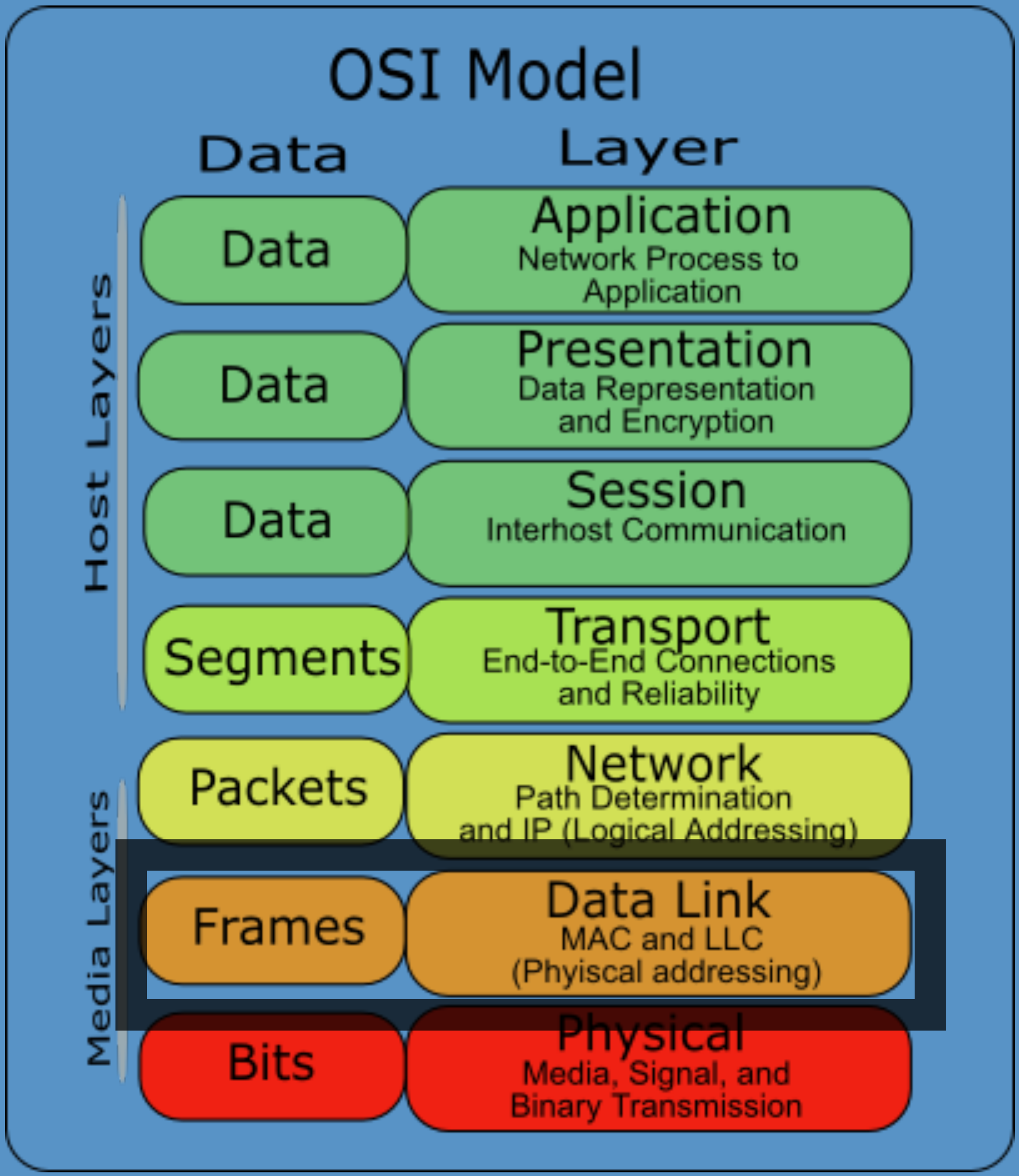

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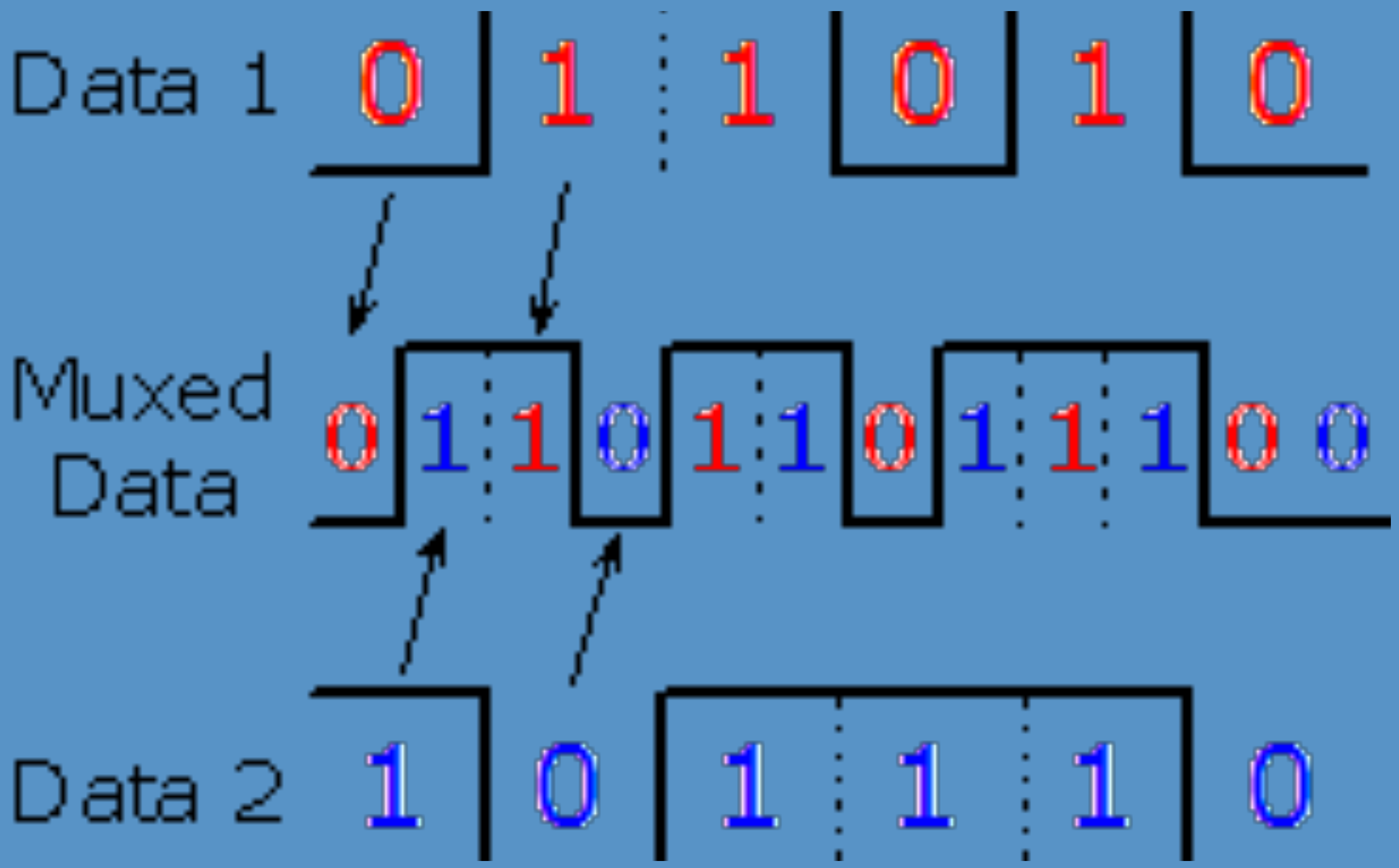
Media Layers

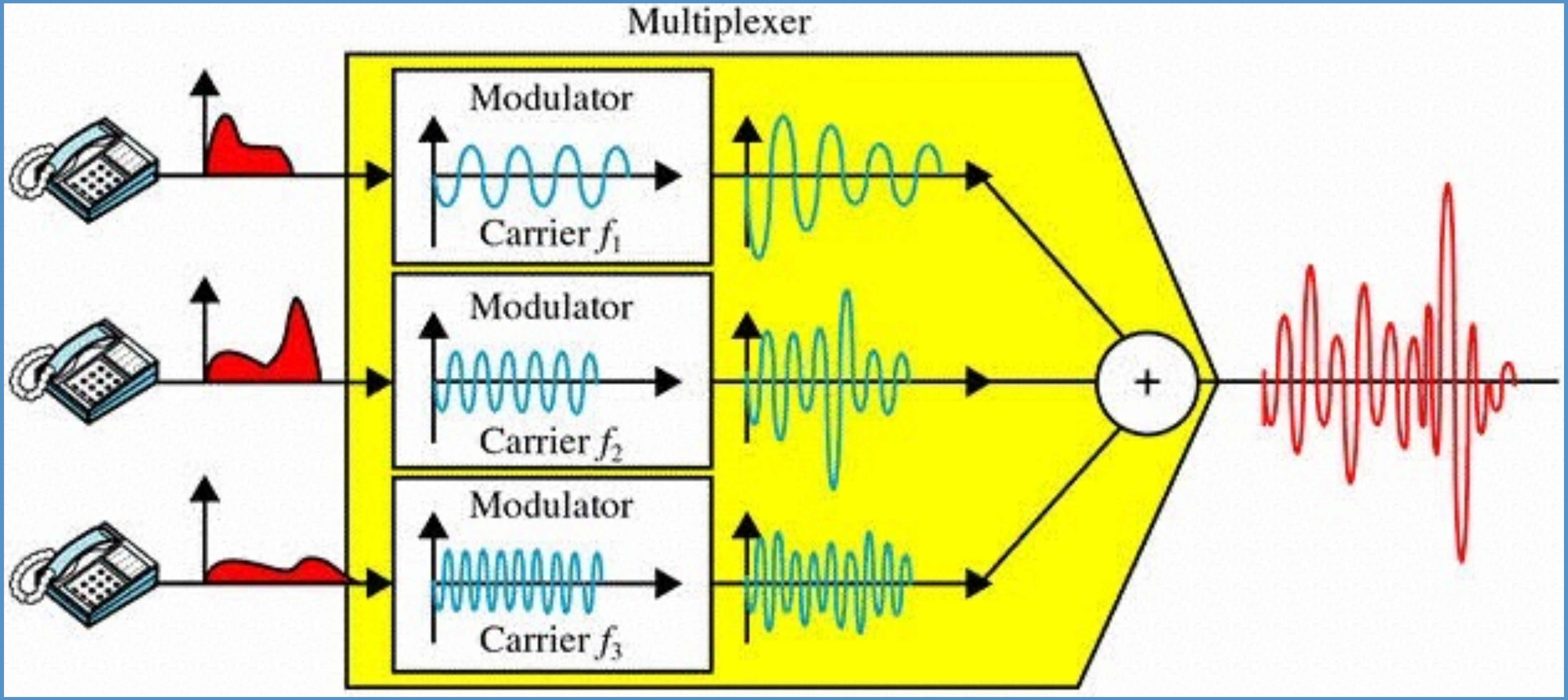
Layer 2: Link Layer

- provides node-to-node transfer of “frames”
- defines the protocol to establish and terminate a connection between two physically connected devices and the protocol for flow control between them
- detects and possibly corrects errors that may occur in the physical layer
- aka the Media Access Control (MAC) layer

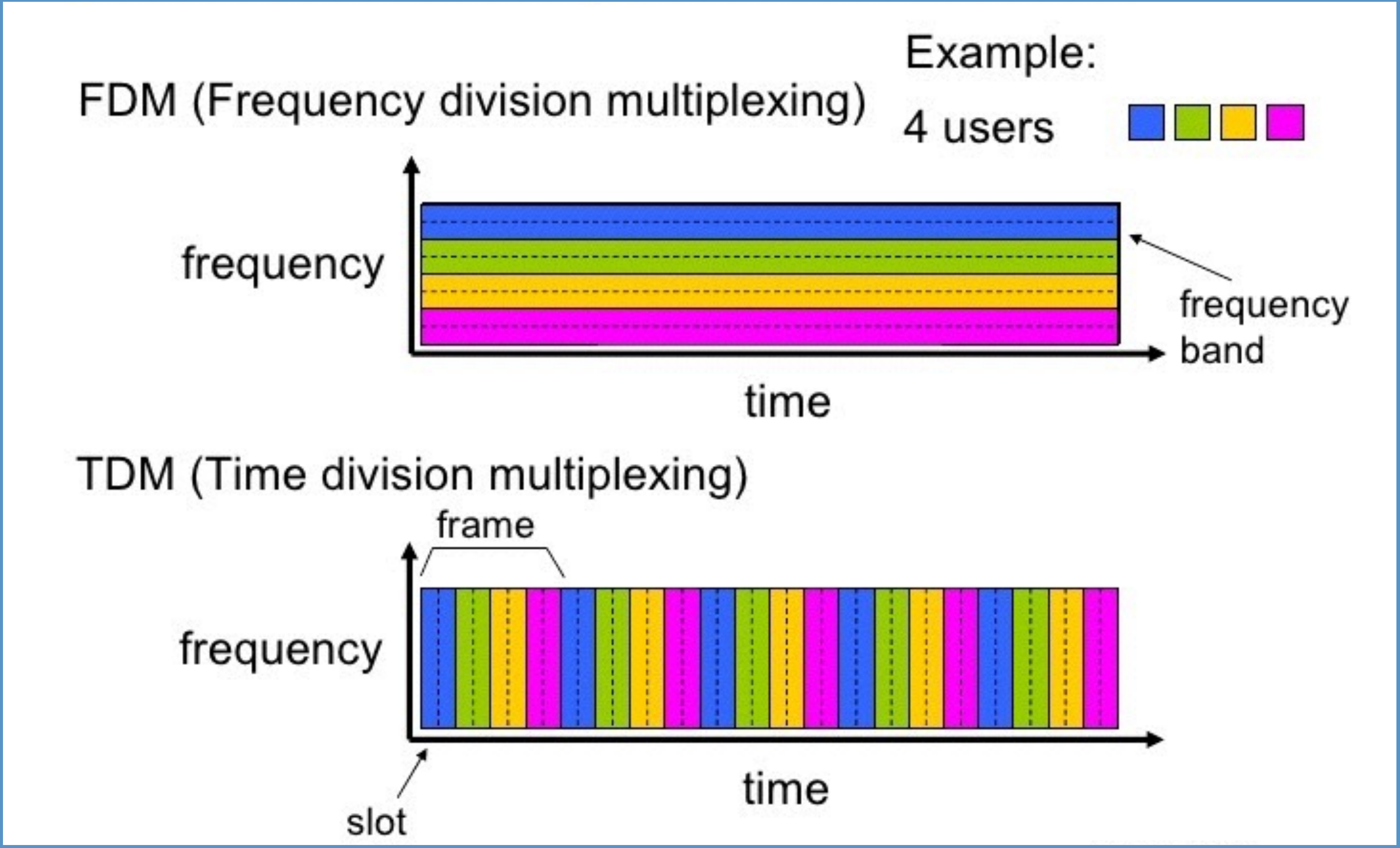
Time Division



Frequency Division



Time vs Frequency DM



Error Detection: Parity Bit

7 bits of data	(count of 1 bits)	8 bits including parity	
		even	odd
0000000	0	0000000**0**	0000000**1**
1010001	3	1010001**1**	1010001**0**
1101001	4	1101001**0**	1101001**1**
1111111	7	1111111**1**	1111111**0**

Error Detection: Parity Bit

Type of bit parity	Successful transmission scenario
Even parity	A wants to transmit: 1001 A computes parity bit value: 1+0+0+1 (mod 2) = 0 A adds parity bit and sends: 10010 B receives: 10010 B computes parity: 1+0+0+1+0 (mod 2) = 0 B reports correct transmission after observing expected even result.

Error Detection: Parity Bit

Type of bit parity error	Failed transmission scenario
Even parity Error in the second bit	A wants to transmit: 1001 A computes parity bit value: 1^0^0^1 = 0 A adds parity bit and sends: 10010 **...TRANSMISSION ERROR...** B receives: 1**1**010 B computes overall parity: 1^1^0^1^0 = 1 B reports incorrect transmission after observing unexpected odd result.

Error Detection: Parity Bit

Type of bit parity error	Failed transmission scenario
Even parity Two corrupted bits	A wants to transmit: 1001 A computes even parity value: 1^0^0^1 = 0 A sends: 10010 **...TRANSMISSION ERROR...** B receives: 1**1**01**1** B computes overall parity: 1^1^0^1^1 = 0 B reports correct transmission though actually incorrect.

Error Correction: (3,1) Repetition

Triplet received	Interpreted as
000	0 (error free)
001	0
010	0
100	0
111	1 (error free)
110	1
101	1
011	1

Layer 2: MAC Address

- Each Network Interface Controller (NIC) has its own 6-byte MAC address which physically identifies itself
- Although intended to be a permanent and globally unique identification, it is possible to change the MAC address on most modern hardware
- Changing MAC addresses is necessary in network virtualization
- It can also be used in the process of exploiting security vulnerabilities. This is called MAC spoofing.
- According to Edward Snowden, the NSA has a system that tracks the movements of everyone in a city by monitoring the MAC addresses of their electronic devices. As a result of users being trackable by their devices' MAC addresses.

Layer 2: MAC Address

via 'ifconfig'

```
~ ifconfig
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
        options=3<RXCSUM,TXCSUM>
        inet6 ::1 prefixlen 128
        inet 127.0.0.1 netmask 0xff000000
        inet6 fe80::1%lo0 prefixlen 64 scopeid 0x1
        nd6 options=1<PERFORMNUD>
gif0: flags=8010<POINTOPOINT,MULTICAST> mtu 1280
stf0: flags=0<> mtu 1280
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether a4:5e:60:e9:a7:85
        inet6 fe80::a65e:60ff:fee9:a785%en0 prefixlen 64 scopeid 0x4
        inet 172.19.131.92 netmask 0xffffff00 broadcast 172.19.131.255
        nd6 options=1<PERFORMNUD>
        media: autoselect
        status: active
en1: flags=8963<UP,BROADCAST,SMART,RUNNING,PROMISC,SIMPLEX,MULTICAST> mtu 1500
        options=60<TSO4,TSO6>
```

Layer 2: Exercise

- The following bit sequence was sent over an unreliable channel using a (3,1) repetition sequence:

```
001 111 000 000 000 100 101 111

000 000 110 111 000 111 001 010

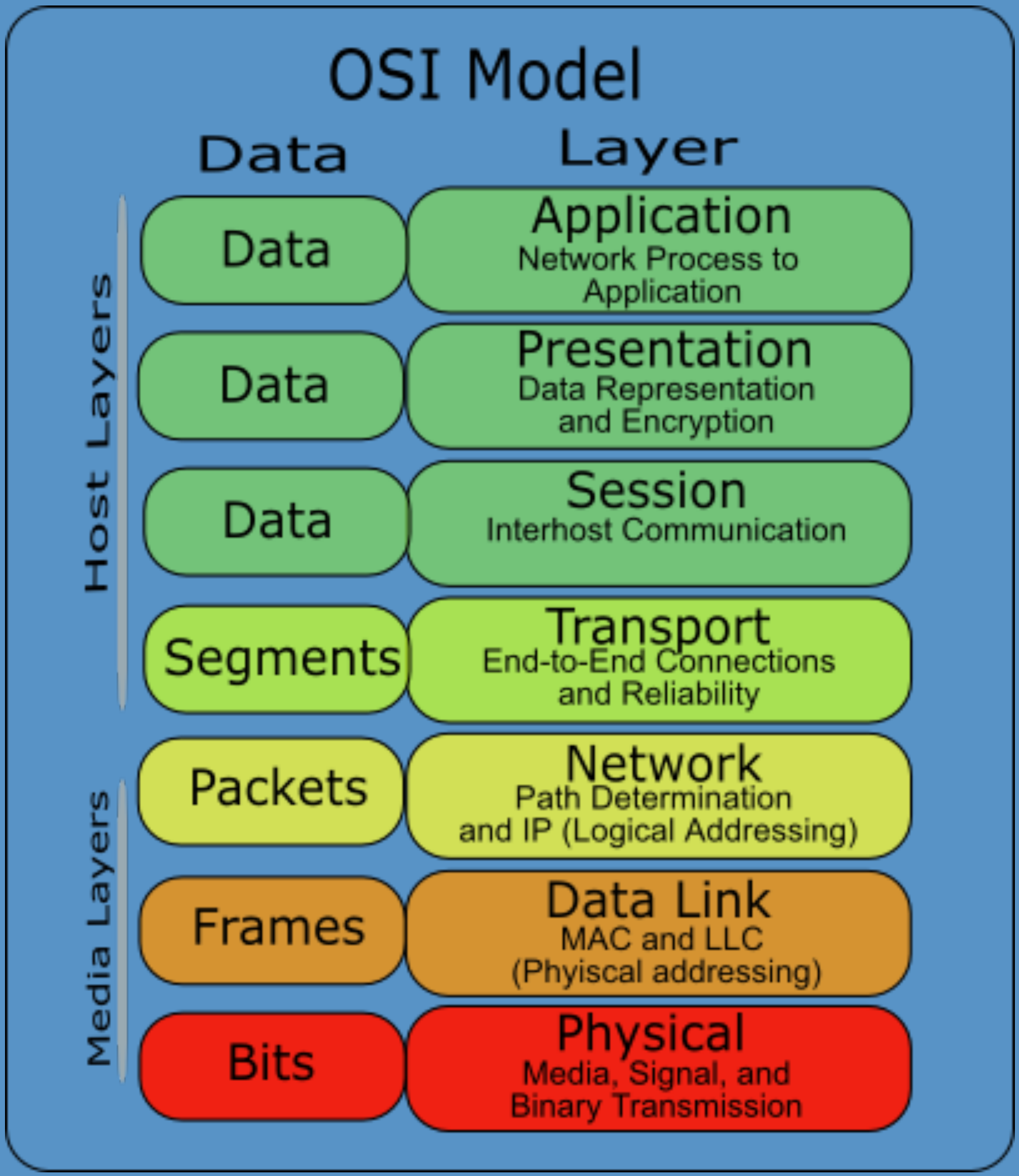
000 111 000 011 000 000 100 111
```

Recover the transmitted bit sequence and convert using ASCII:

http://www.binaryhexconverter.com/binary-to-ascii-text-converter

Layer 3

Layer 3



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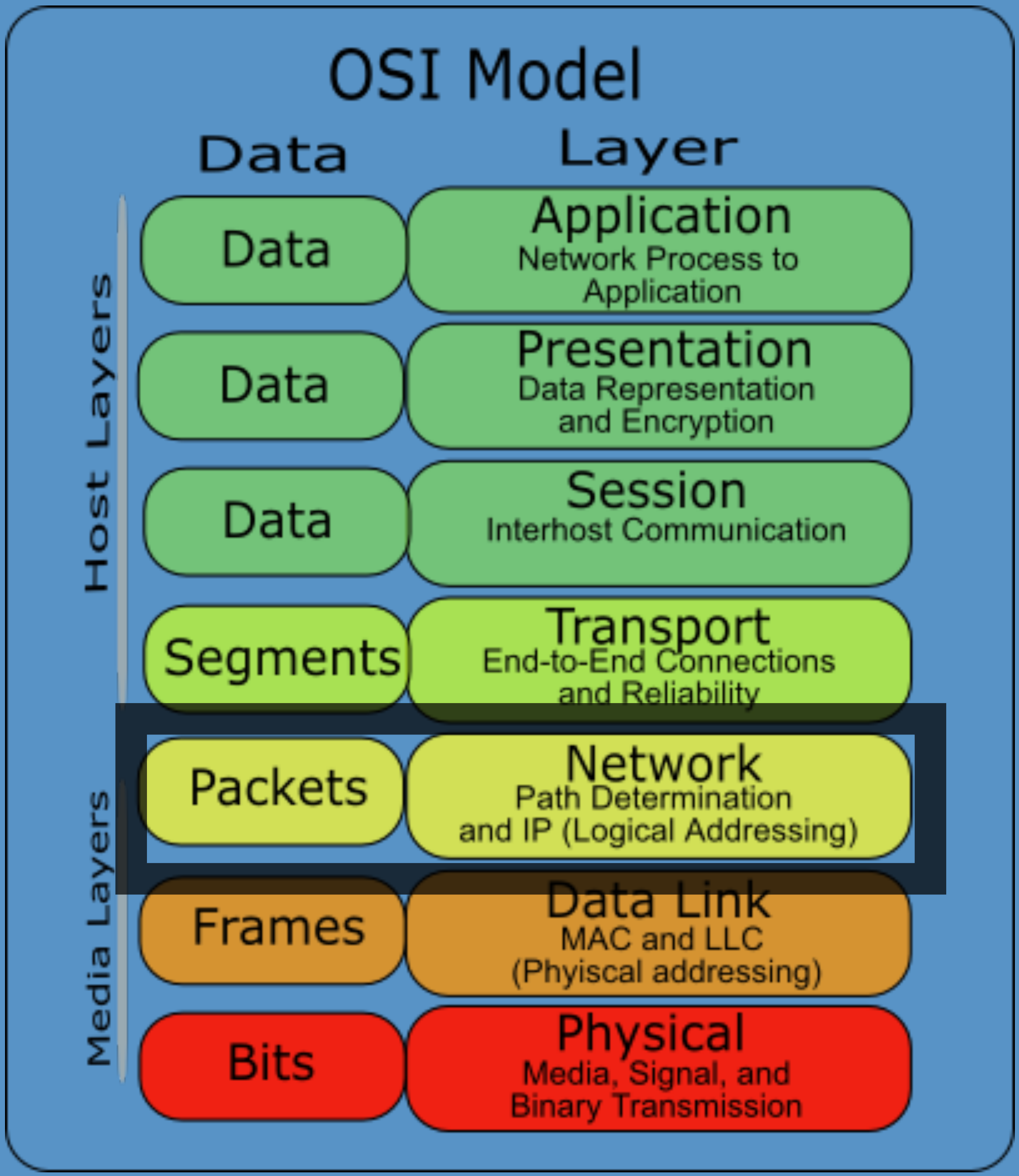

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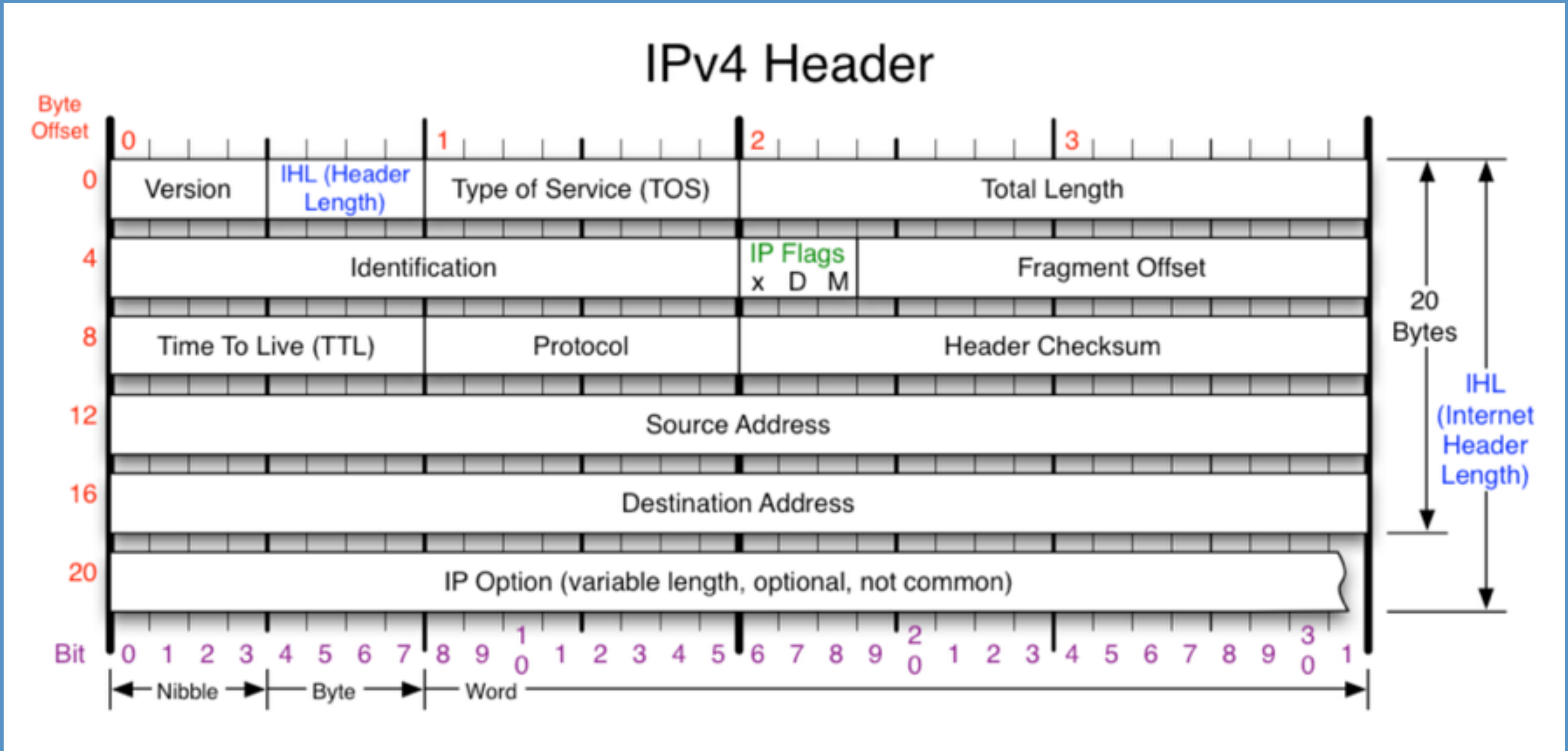
Layer 3: Network Layer

- Enables the routing of “packets” from one system to system
- IP Addresses (IPv4, IPv6)
- “Best Effort” but not guaranteed
- IPv4 uses 32-bit (4-byte) addresses (2^{32} = 4,294,967,296)

Layer 3: Network Layer



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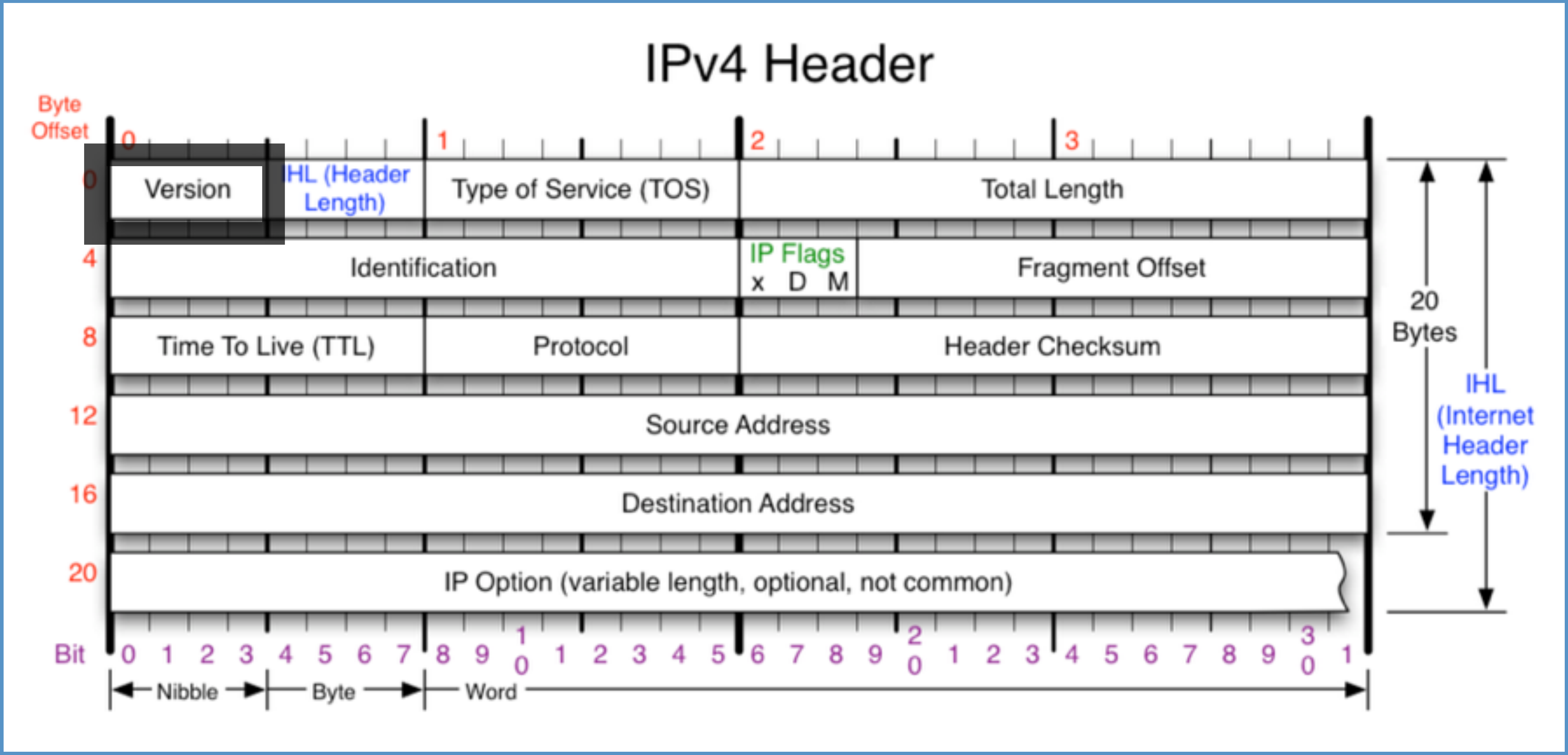
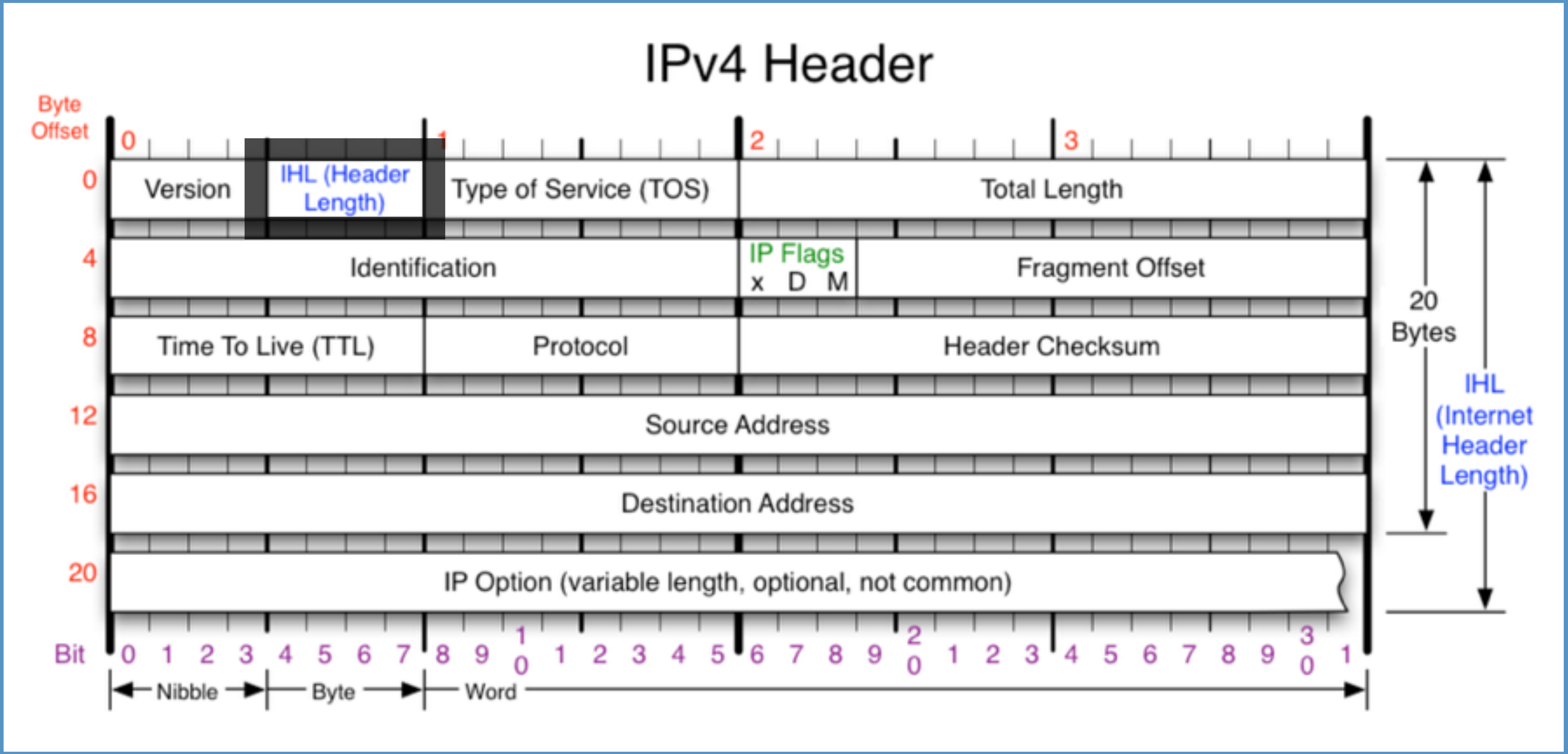


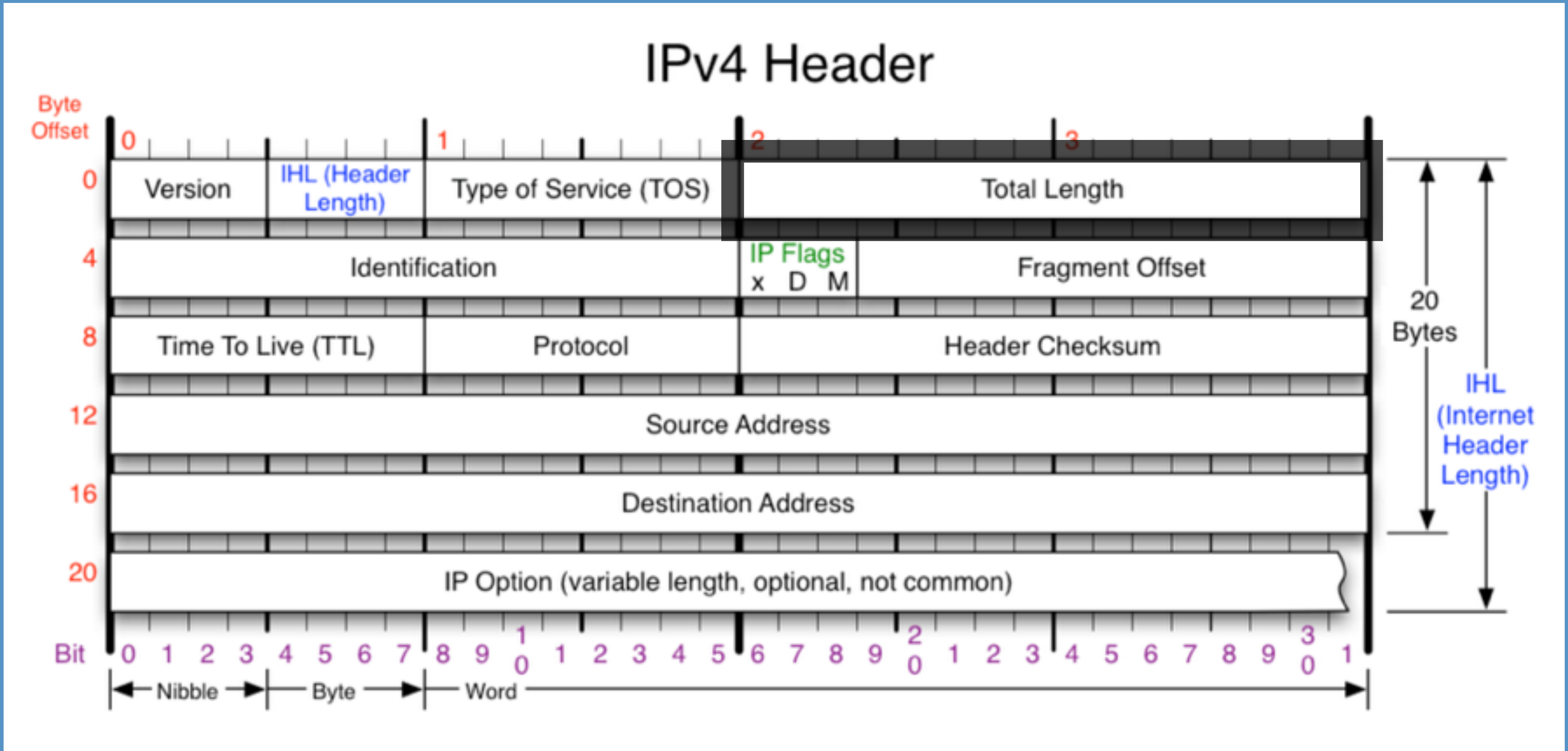
Version: 4 (IPv4) or 6 (IPv6)

Layer 3: Network Layer



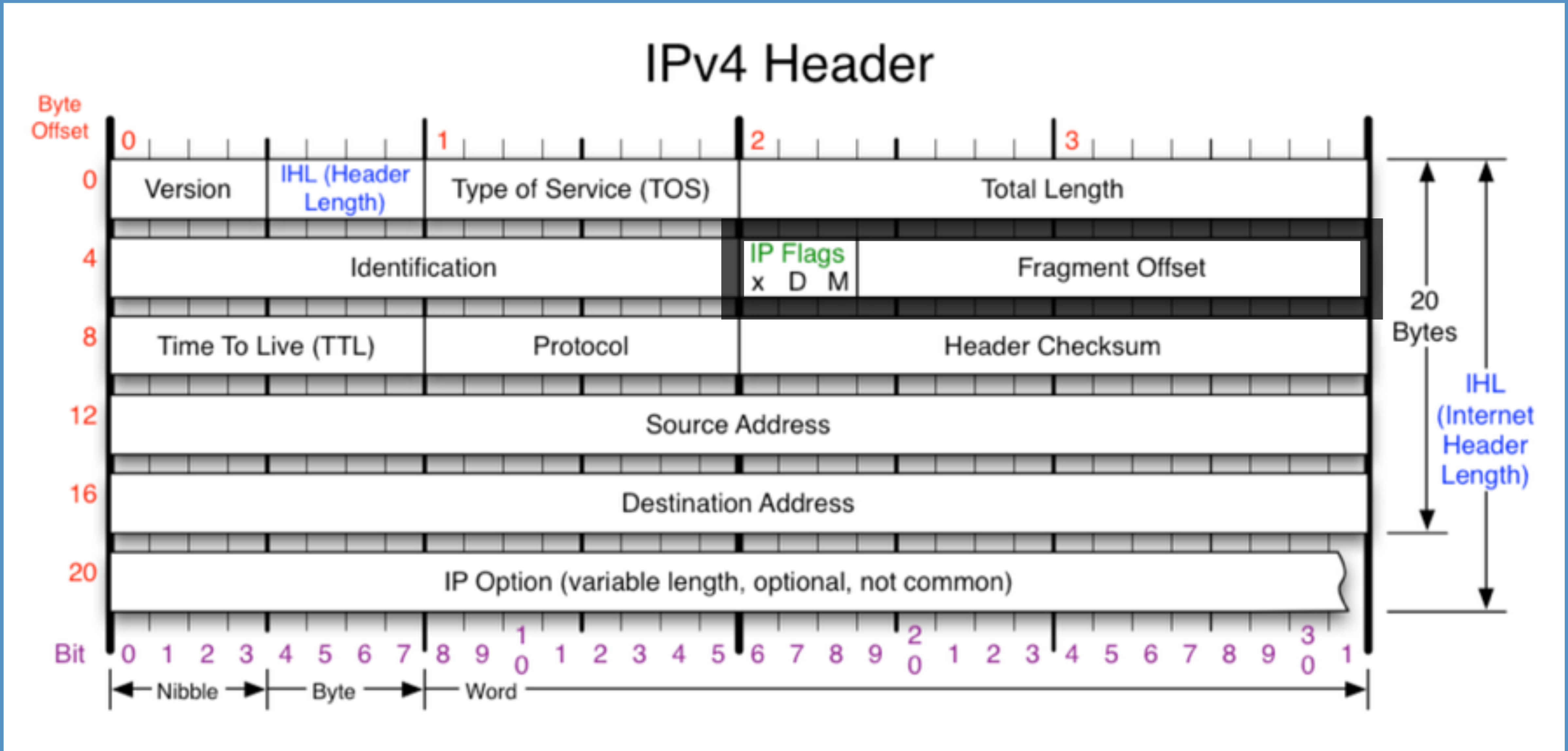
Internet Header Length: # of 32-bit *words* in header

Layer 3: Network Layer



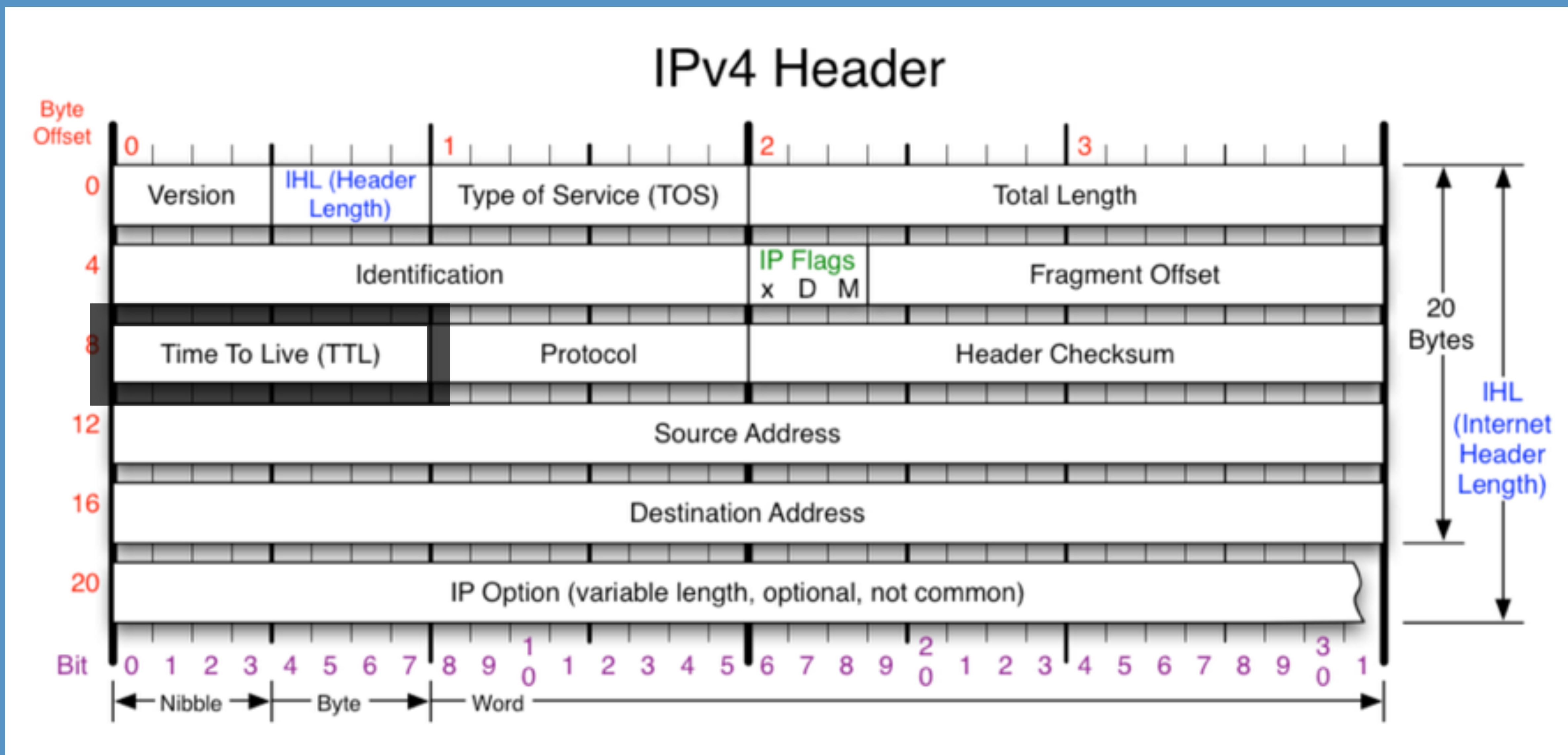
Total Length: entire packet size, *in bytes*

Layer 3: Network Layer



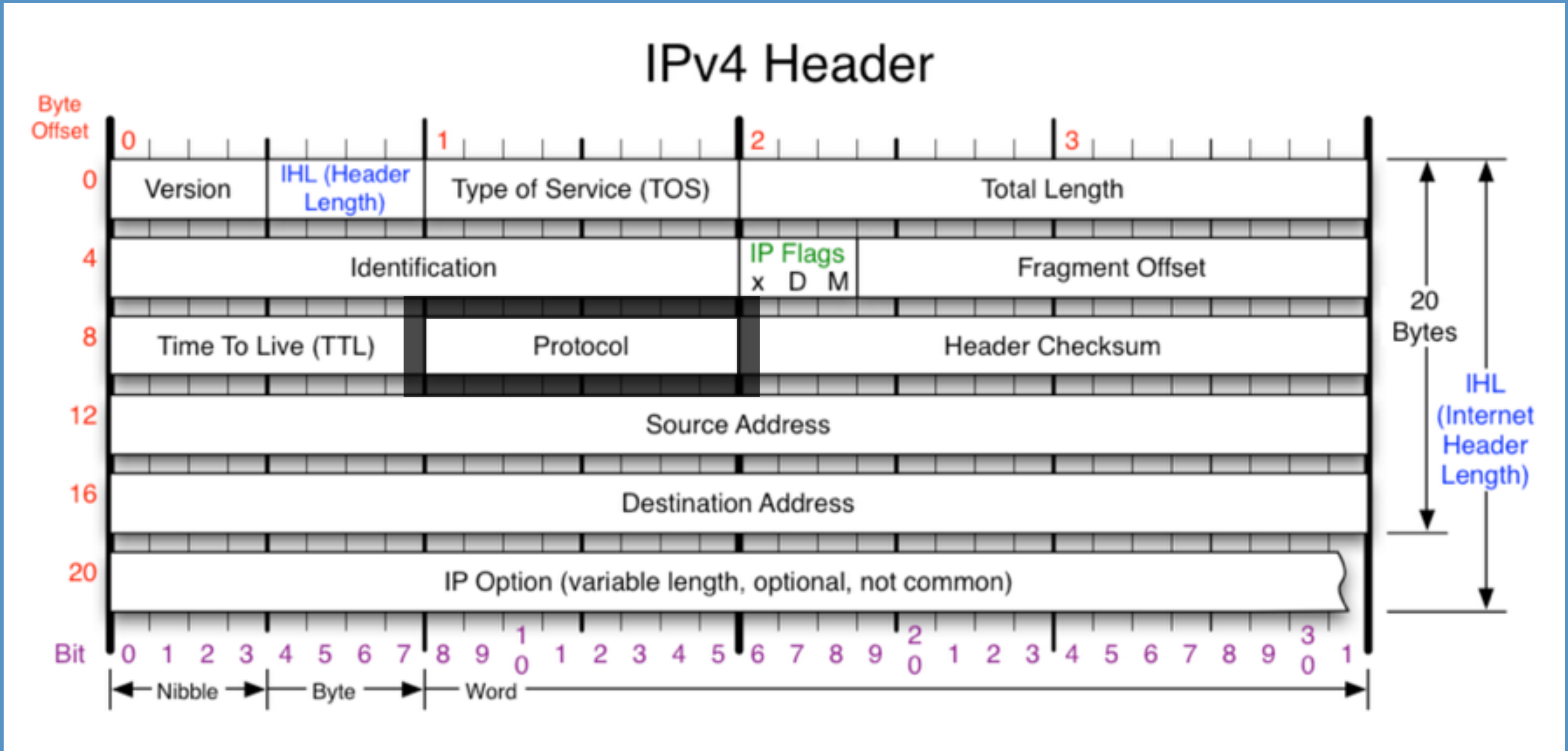
Fragmentation: *more on this*

Layer 3: Network Layer



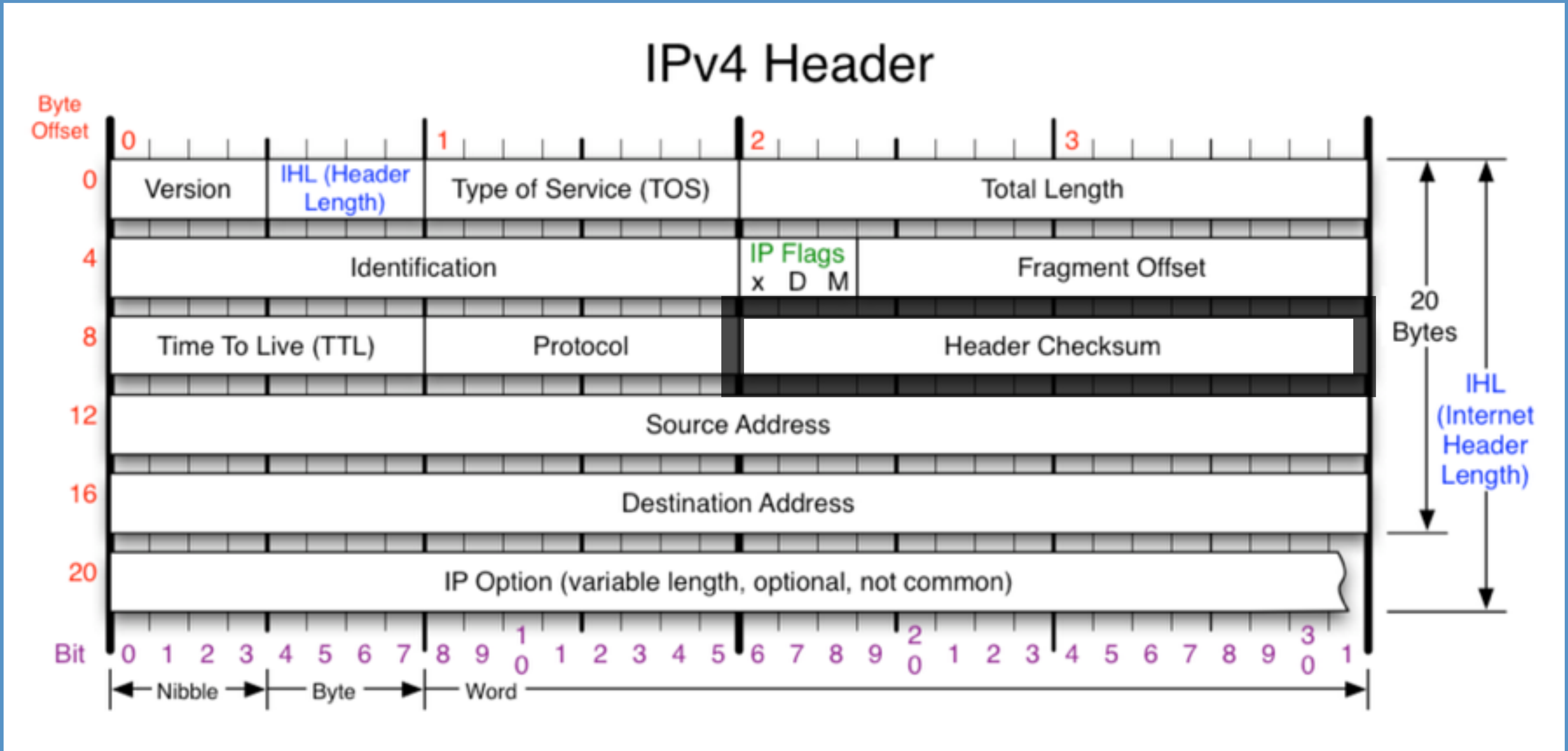
Time to Live: every hop on network decrements by 1

Layer 3: Network Layer



Protocol: defines the next layer in the ISO model…

Layer 3: Network Layer



Checksum: only for *header*, upper layer handles *data*

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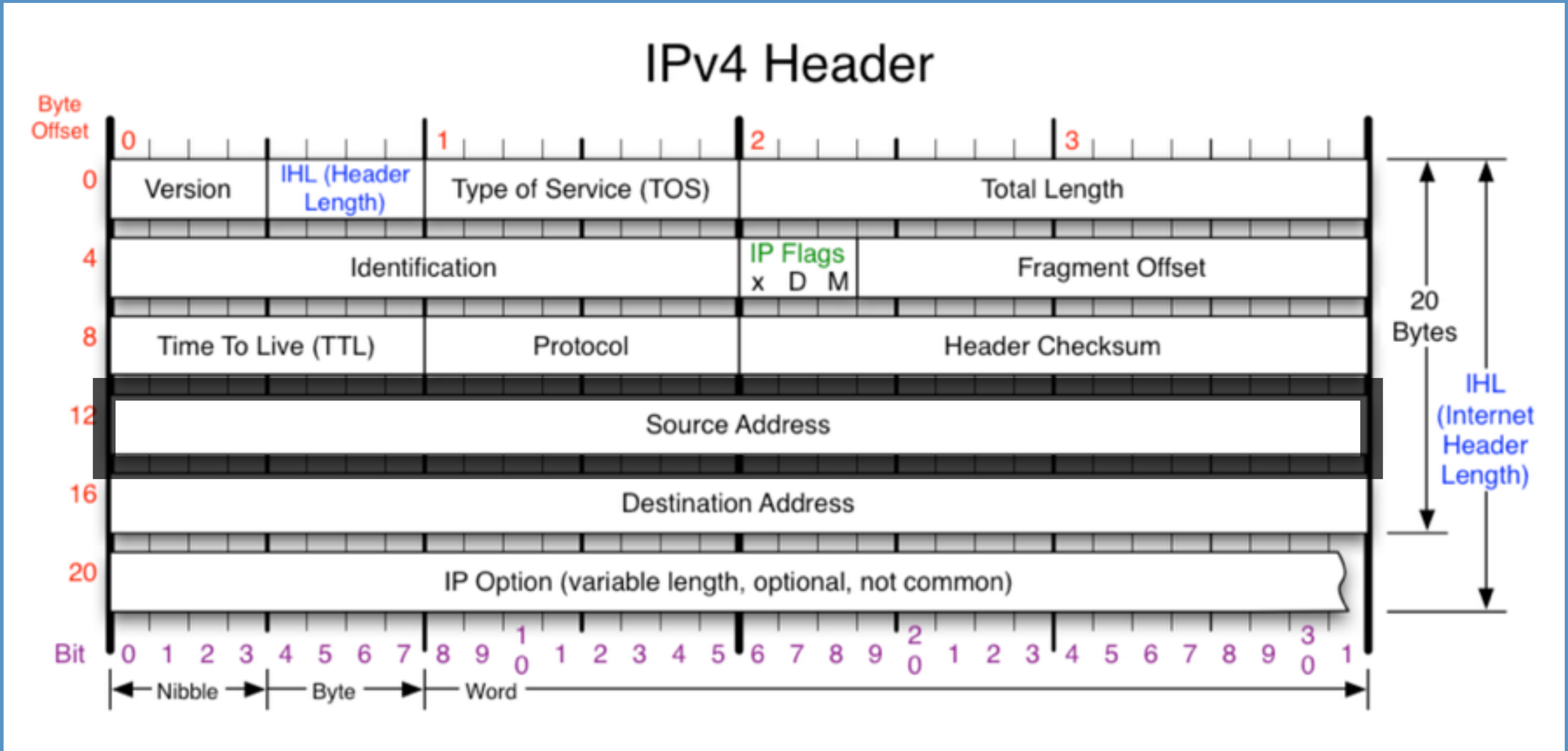

Source: IP address of sender (may change)

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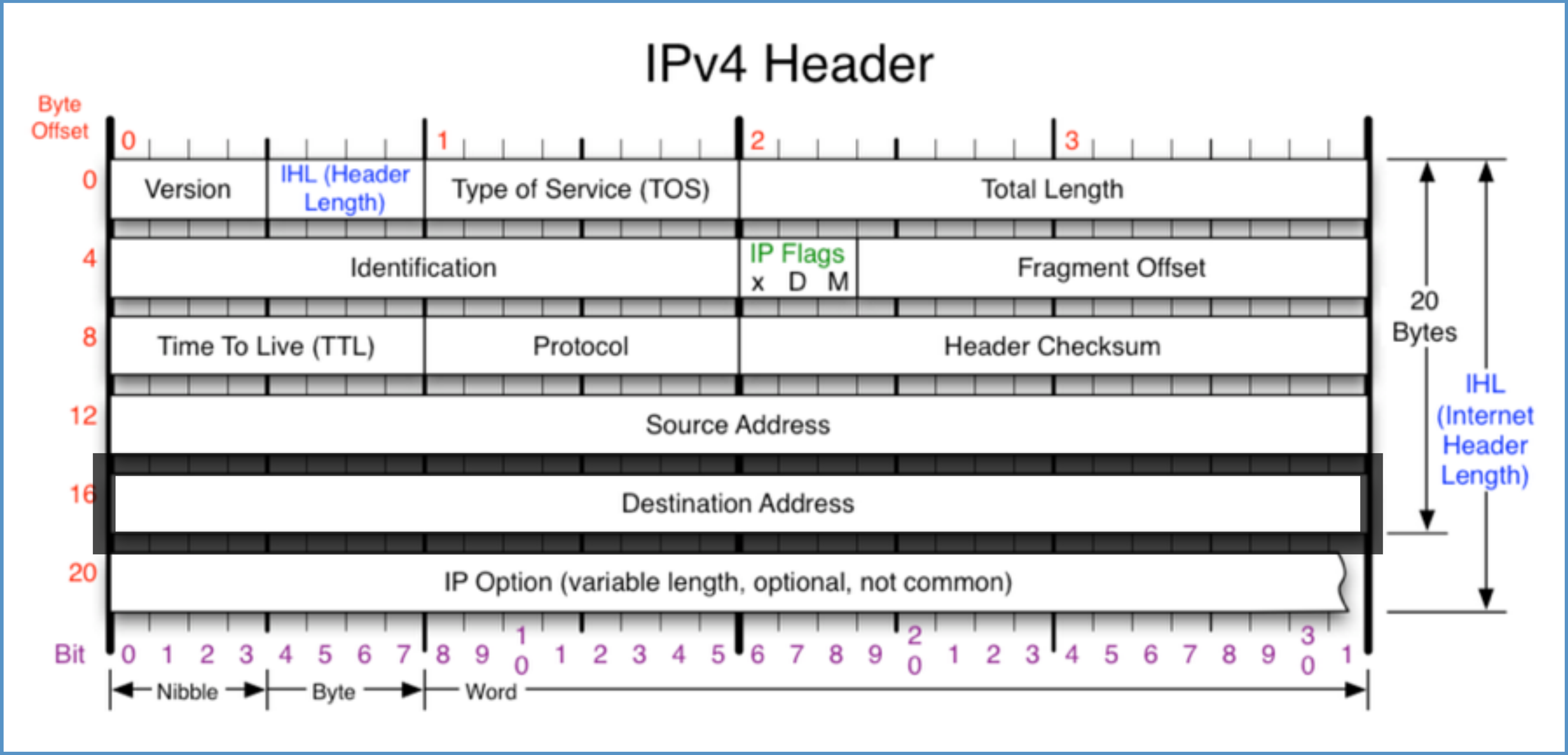

Destination: IP address of receiver (may change)

IPv4 vs IPv6

- IPv4 first deployed as part of the ARPANET in 1983
- It was apparent that the pool of available IPv4 addresses was being depleted at a rate that was not initially anticipated in the original design of the network address system
- Some factors which led to IPv4 address exhaustion:
  - Rapidly growing number of Internet users
  - Always-on devices — ADSL modems, cable modems
  - Mobile devices — laptop computers, PDAs, mobile phones

IPv4 vs IPv6

- The threat of exhaustion was the motivation for remedial technologies. Included are:
  - Network address translation (NAT)
  - Dynamic Host Configuration Protocol (DHCP)
  - Tighter control by regional Internet registries over the allocation of addresses to local Internet registries
  - Network renumbering to reclaim large blocks of address space allocated in the early days of the Internet

IPv4 vs IPv6

- This limitation stimulated the development of IPv6 in the 1990s, which has been in commercial deployment since 2006
- IPv4 uses 32-bit (4-byte) addresses (2^{32} = 4,294,967,296)
- IPv6 uses 128-bit (16-byte) addresses (2^{128} = 3.4 x 10^{38})
- IPv4 finally suffered exhaustion on February 3, 2011

IPv4 vs IPv6

via ‘ifconfig’

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~ ifconfig
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stf0: flags=0<> mtu 1280
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether a4:5e:60:e9:a7:85
        inet6 fe80::a65e:60ff:fee9:a785%en0 prefixlen 64 scopeid 0x4
        inet 172.19.131.92 netmask 0xffffff00 broadcast 172.19.131.255
        nd6 options=1<PERFORMNUD>
        media: autoselect
        status: active
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Subnets

- IP addresses can be divided into ranges
- Each address in the range is composed of a *network prefix* and a *host identifier.* A *subnet mask* designates which bits belong to the network prefix
- Network Prefix = IP address & subnet mask
- Host Identifier = IP address & ~subnet mask
- Format:
  - 192.168.5.130/24

Subnets

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- Each address in the range is composed of a *network prefix* and a *host identifier.* A *subnet mask* designates which bits belong to the network prefix
- Network Prefix = IP address & subnet mask
- Host Identifier = IP address & ~subnet mask
- Common format: Mask
  - 192.168.5.130/**24**

Example

Applying the Subnet Mask

A device with address 192.0.0.1 belongs to network 192.0.0.0

	High order bits Prefix /16		Low order bits	
	192 .	0 .	0 .	1
Host Address	11000000	00000000	00000000	00000001
Subnet Mask	255	255	0	0
	11111111	11111111	00000000	00000000
Network Address	11000000	00000000	00000000	00000000
Network	192 .	0 .	0 .	0

Example

via ‘ifconfig’

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```

Special Addresses

- Loopback
  - 127.0.0.0/8 (IPv4)
  - ::1 (IPv6)
- Private Addresses
  - 192.168.0.0/16 (IPv4)
  - fc00::/7 (IPv6)
- Broadcast
  - 255.255.255.255 (IPv4)
  - N/A (IPv6)

Exercise

- Using the output in *ifconfig*, determine the valid IPv4 address range for the CQ4 subnet

DNS

- IP address => routing and network interface identification
- Domain name => host on the Internet, e.g., www.example.com
- The use of domain names requires translating, called resolving, them to addresses and vice versa
- The translation between addresses and domain names is performed by the Domain Name System (DNS)
- DNS is a hierarchical, distributed naming system which allows for sub-delegation of name spaces to other DNS servers

ARP

- maps IP to MAC address
- sender: whose MAC address belongs to this IP?
- “going down” the ISO model

ping

- uses Internet Control Message Protocol (ICMP)
- sender: ICMP ECHO (notes local time)
- receiver: ICMP ECHO REPLY
- sender: (computes time difference)

traceroute

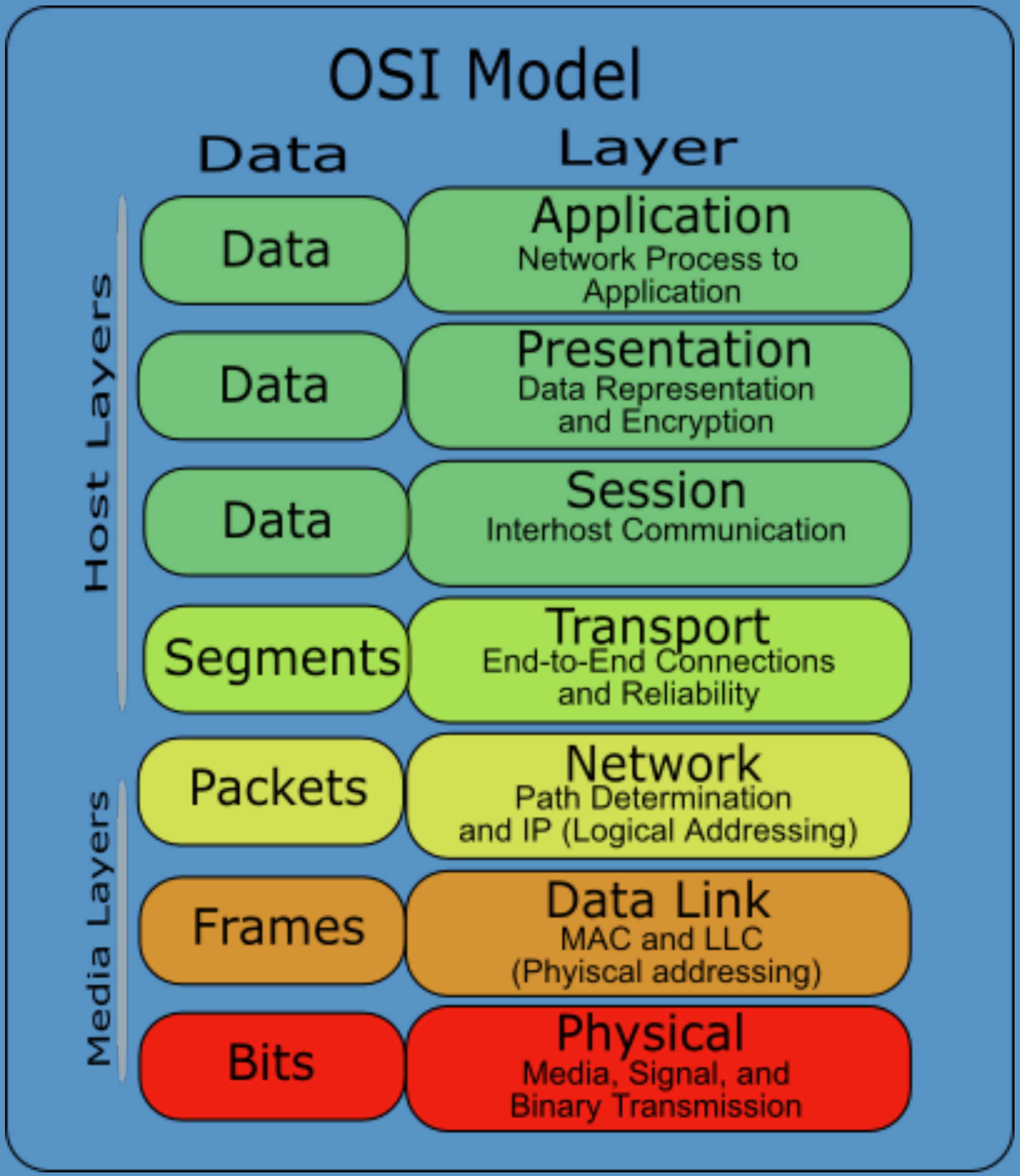
- uses TTL field in packet
- each “hop” on network reduces TTL
- when 0, packet is dropped and ICMP Time Exceeded sent back to sender
- else if destination, packet dropped

Exercises

- Using the output in *dig*, resolve ‘c4q.nyc’ to its IP address
  - Hint: A records map to IPv4 records
- Using the output of “*arp -an*”, determine whose IP and MAC addresses are in your ARP cache
- Ping www.google.com and www.tajmahal.gov.in. Note the difference in roundtrip times.
- Traceroute www.stanford.edu, www.tajmahal.gov.in, www.google.com and other sites and note the number of hops.

Layer 4

Layer 4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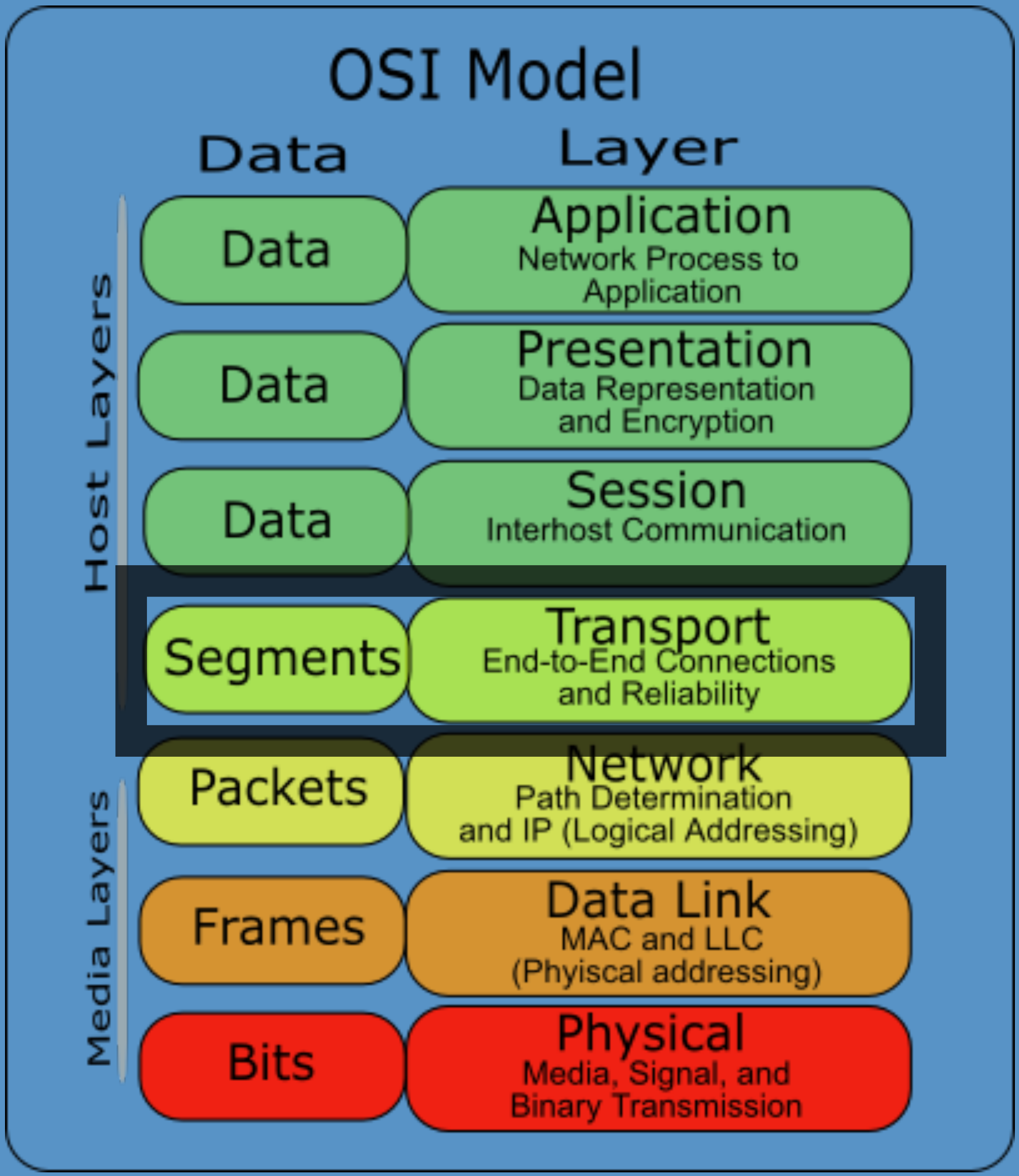
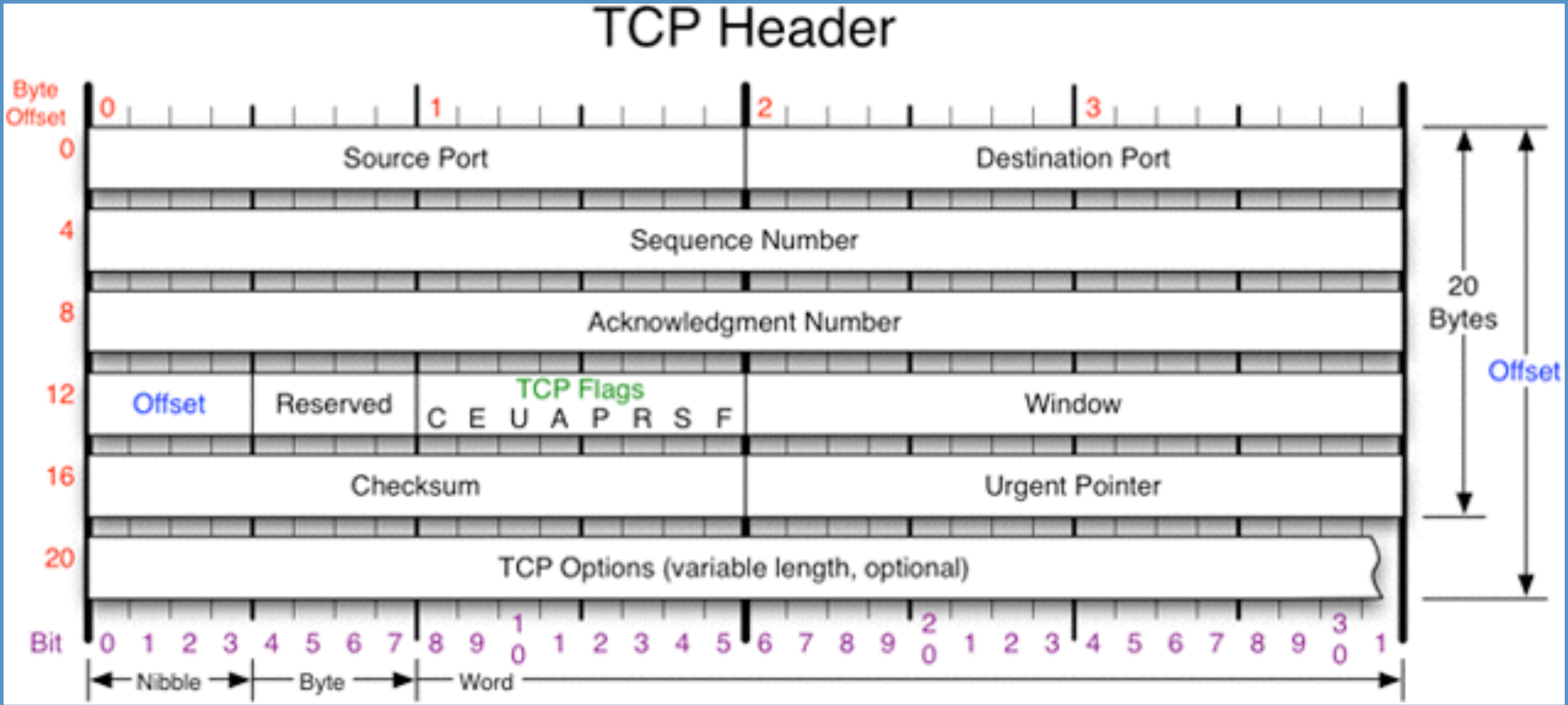

OSI Model
Data
Layer
Host Layers
Media Layers
Data
Application
Network Process to Application
Data
Presentation
Data Representation and Encryption
Data
Session
Interhost Communication
Segments
Transport
End-to-End Connections and Reliability
Packets
Network
Path Determination and IP (Logical Addressing)
Frames
Data Link
MAC and LLC (Phyiscal addressing)
Bits
Physical
Media, Signal, and Binary Transmission

Layer 4: Transport Layer

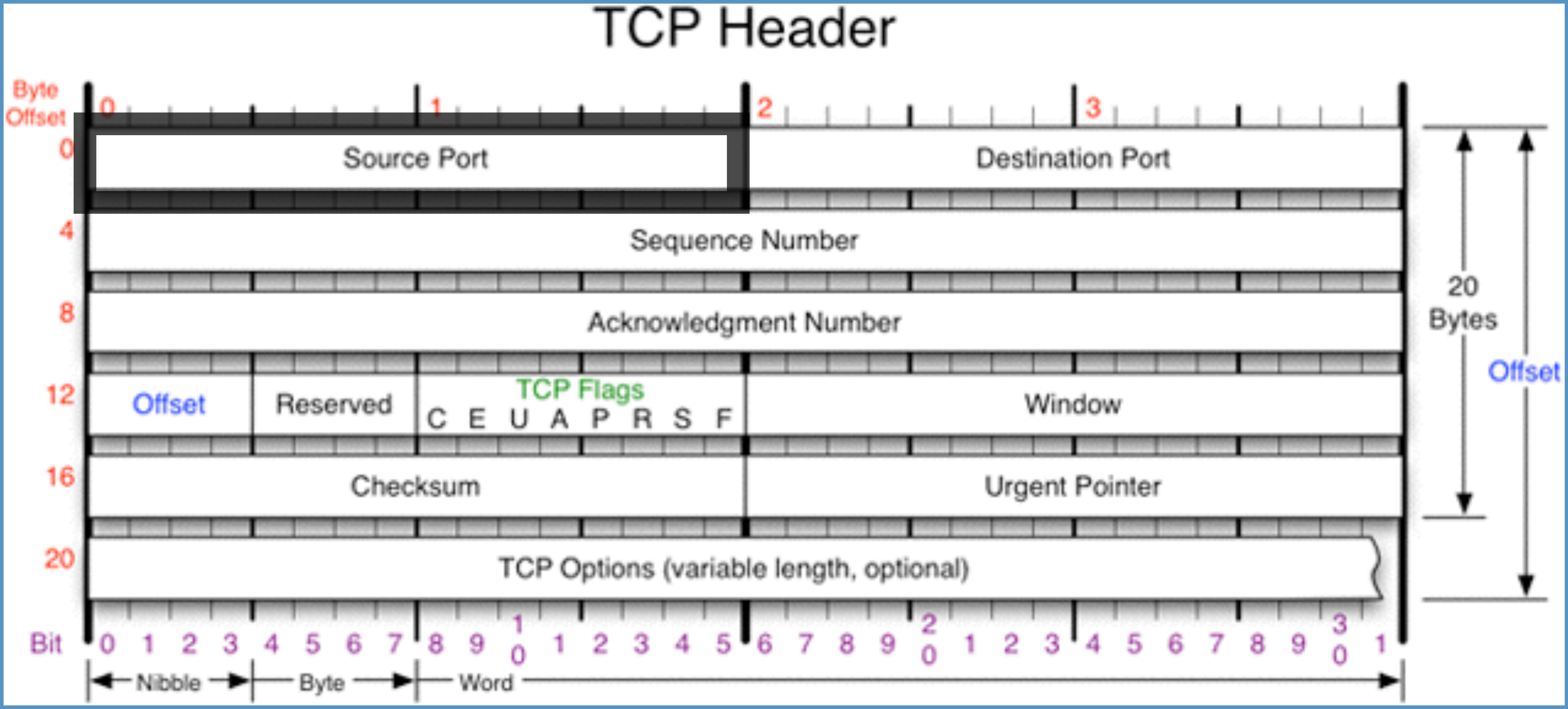
- Now that we can route from machine to machine, what about process to process?
- defines “segments” between different processes of different hosts
- port - a machine-specific number assignment to an application connecting to the Internet
- TCP: reliable messaging
- UDP: unreliable

TCP



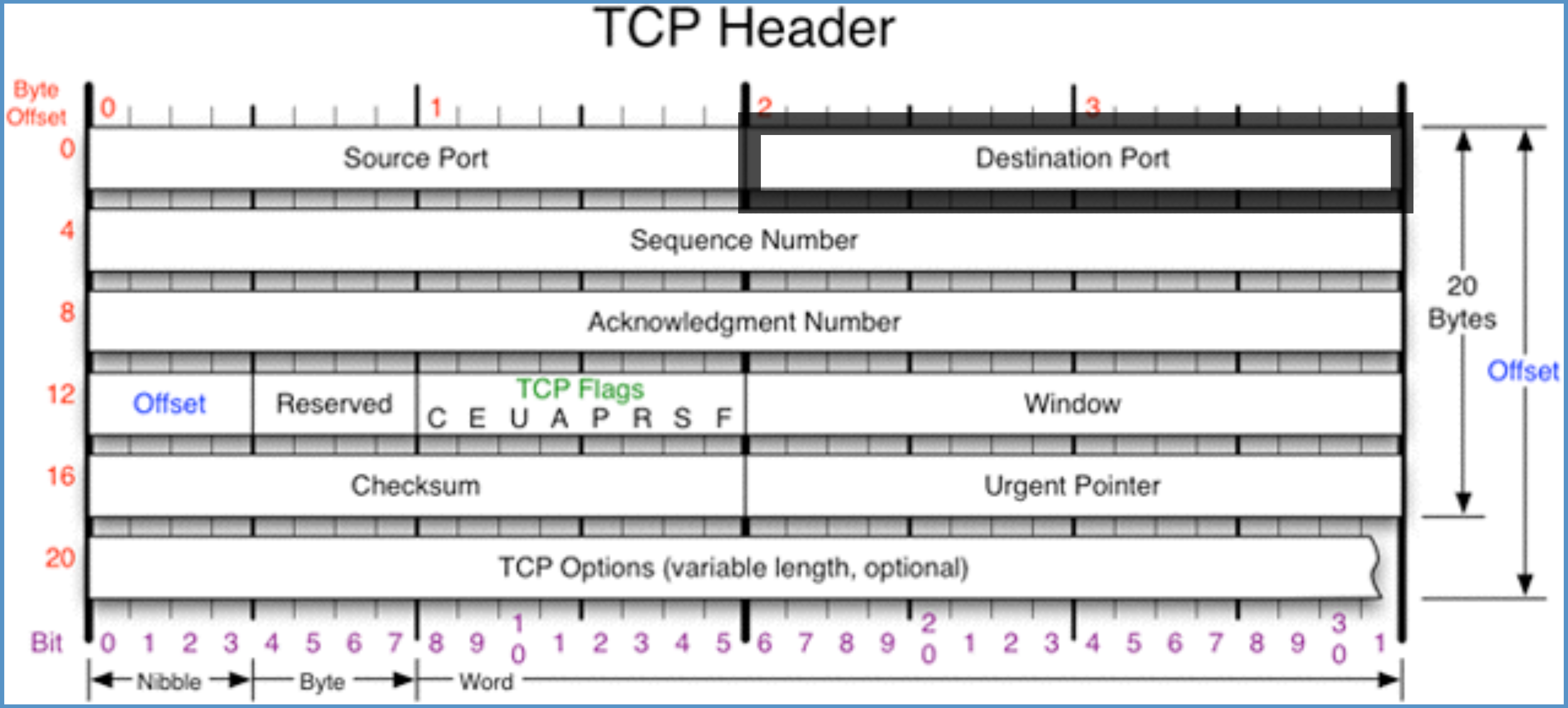
TCP Header
Byte Offset
0
4
8
12
16
20
0
1
2
3
Source Port
Destination Port
Sequence Number
Acknowledgment Number
Offset
Reserved
TCP Flags
C E U A P R S F
Window
Checksum
Urgent Pointer
TCP Options (variable length, optional)
20 Bytes
Offset
Bit
0 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1
Nibble
Byte
Word

TCP



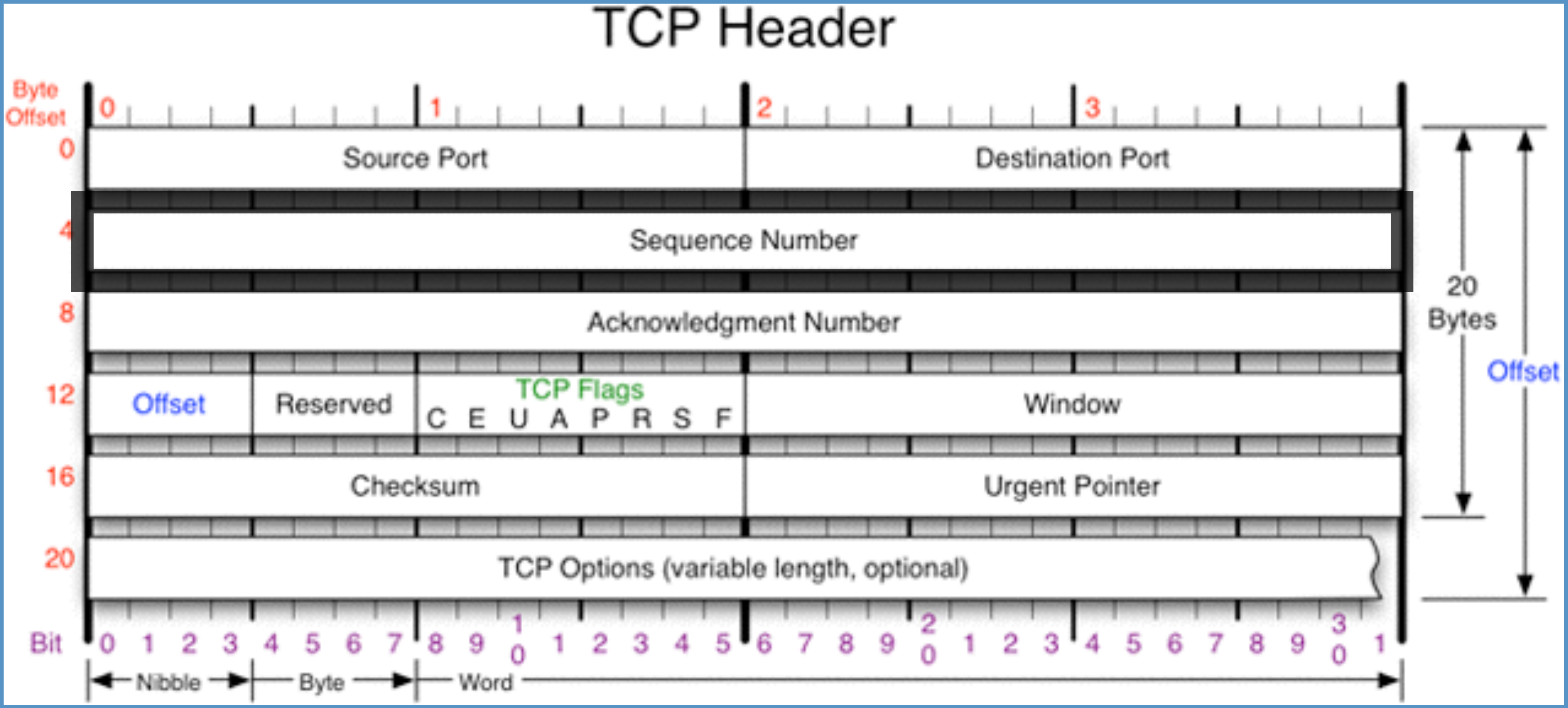
Source: the port assigned to sending application

TCP



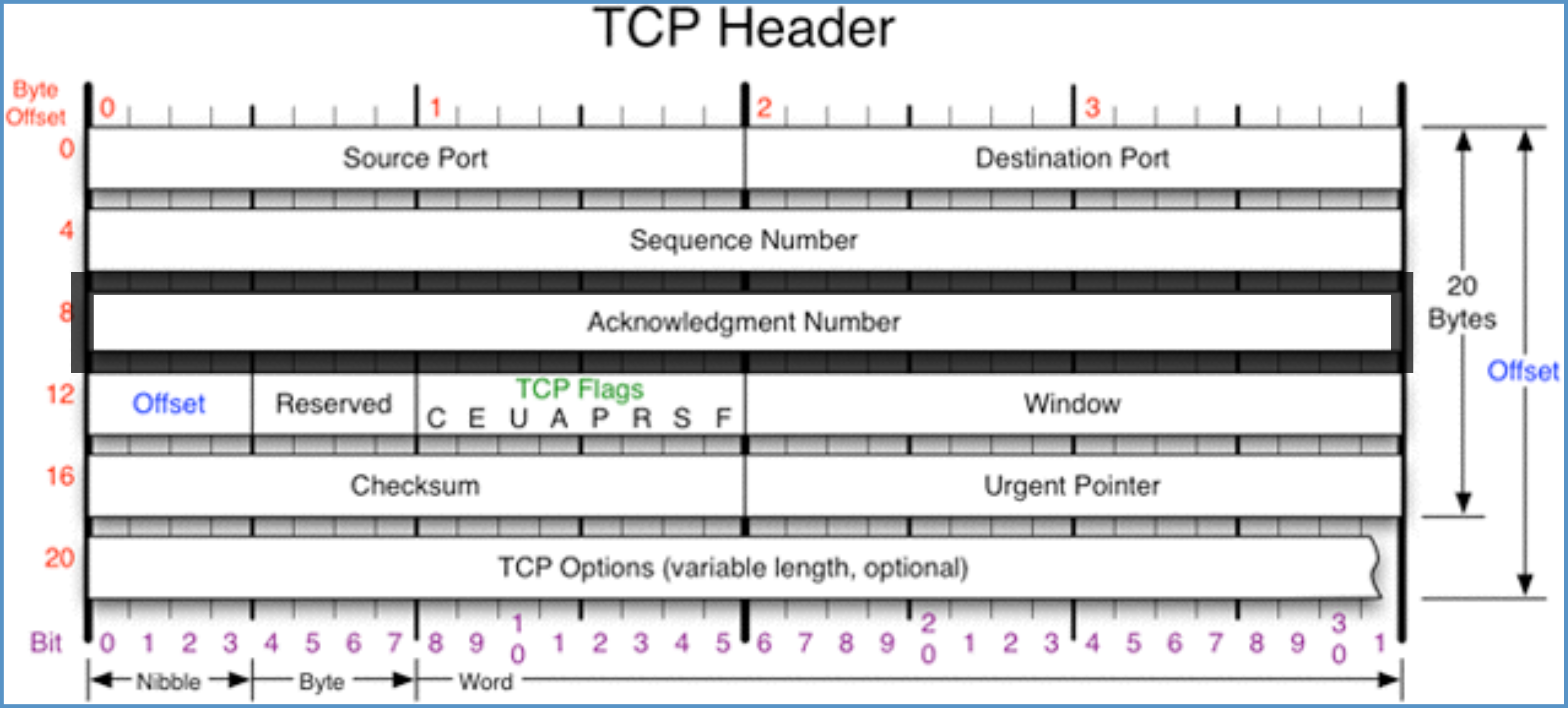
Destination: the port assigned to receiving application

TCP



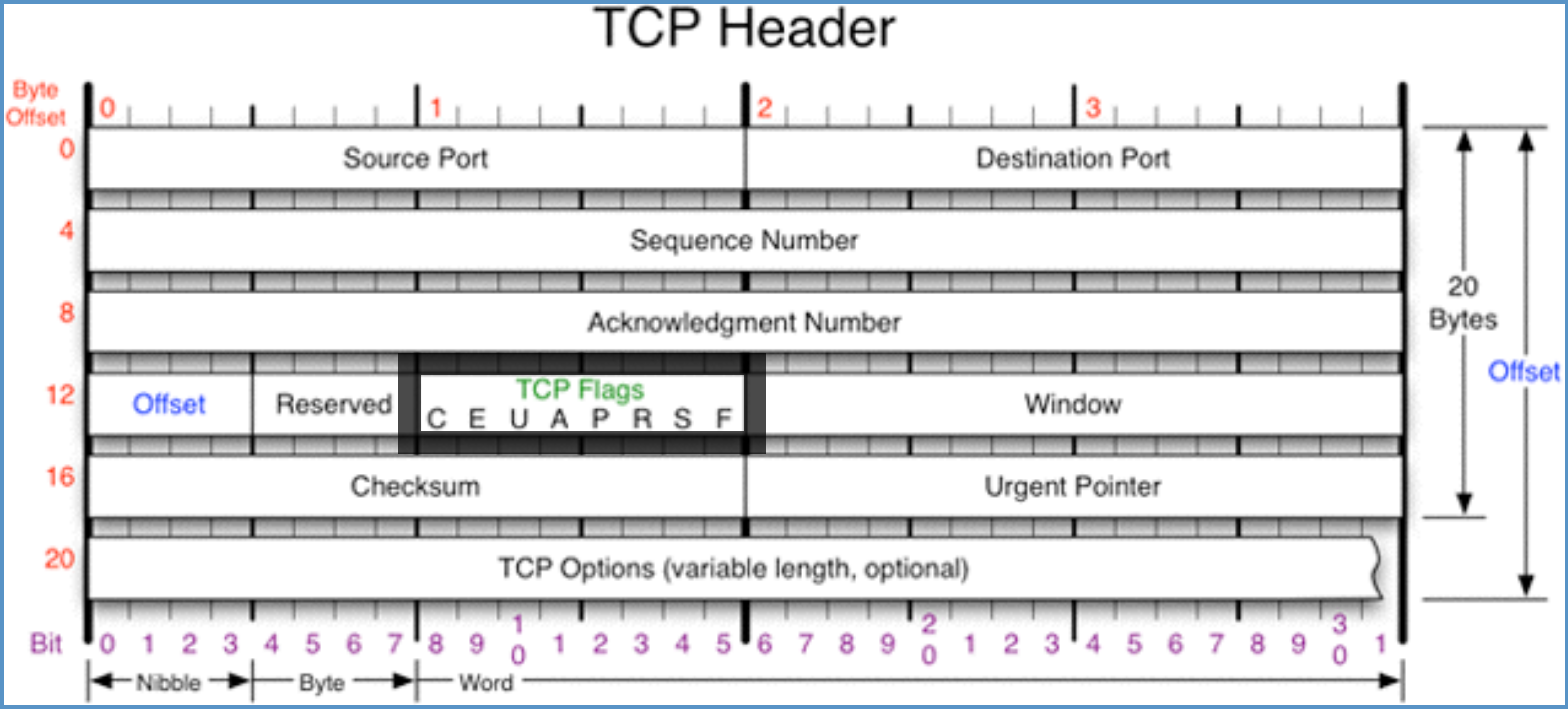
Sequence #: the "tag" assigned to this segment

TCP



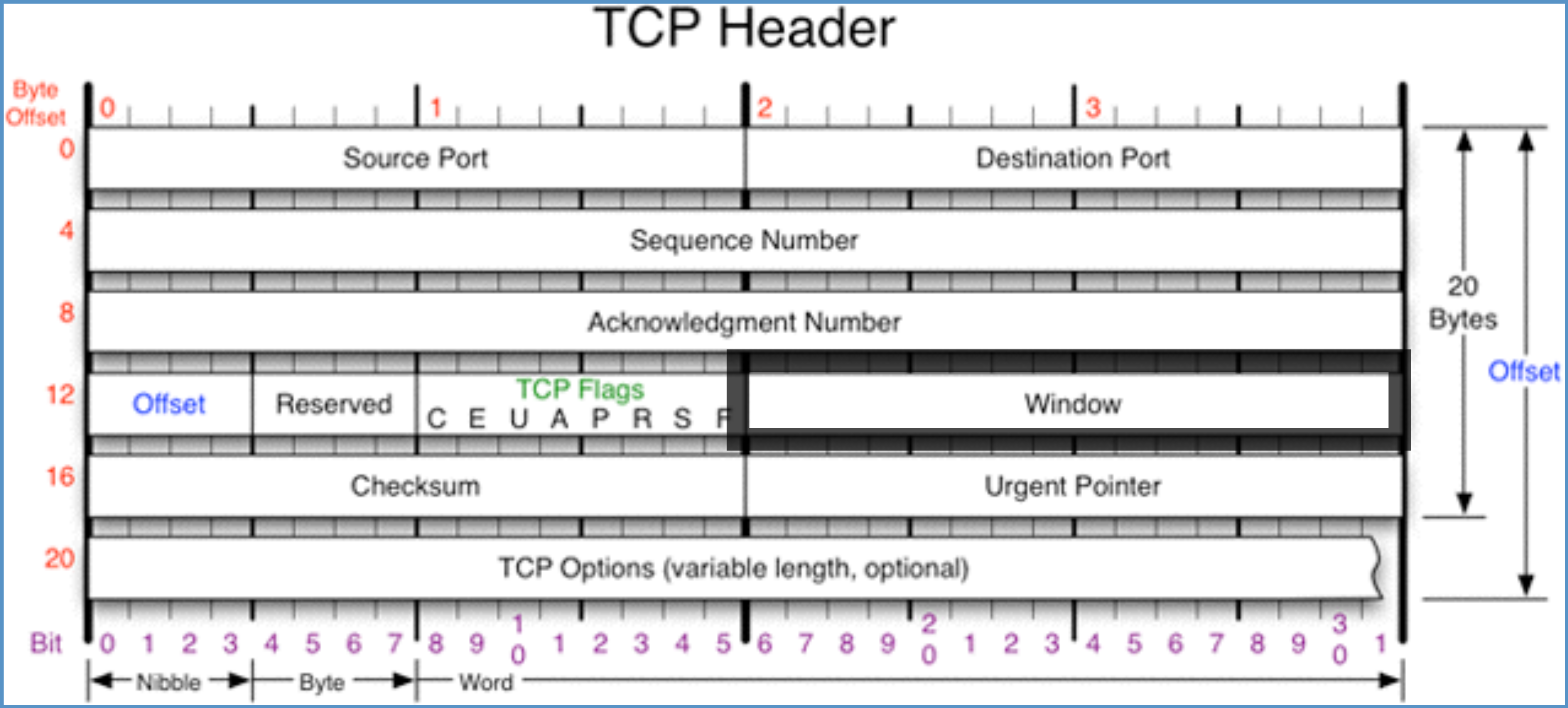
Ack #: the *next* sequence # expected by receiver

TCP



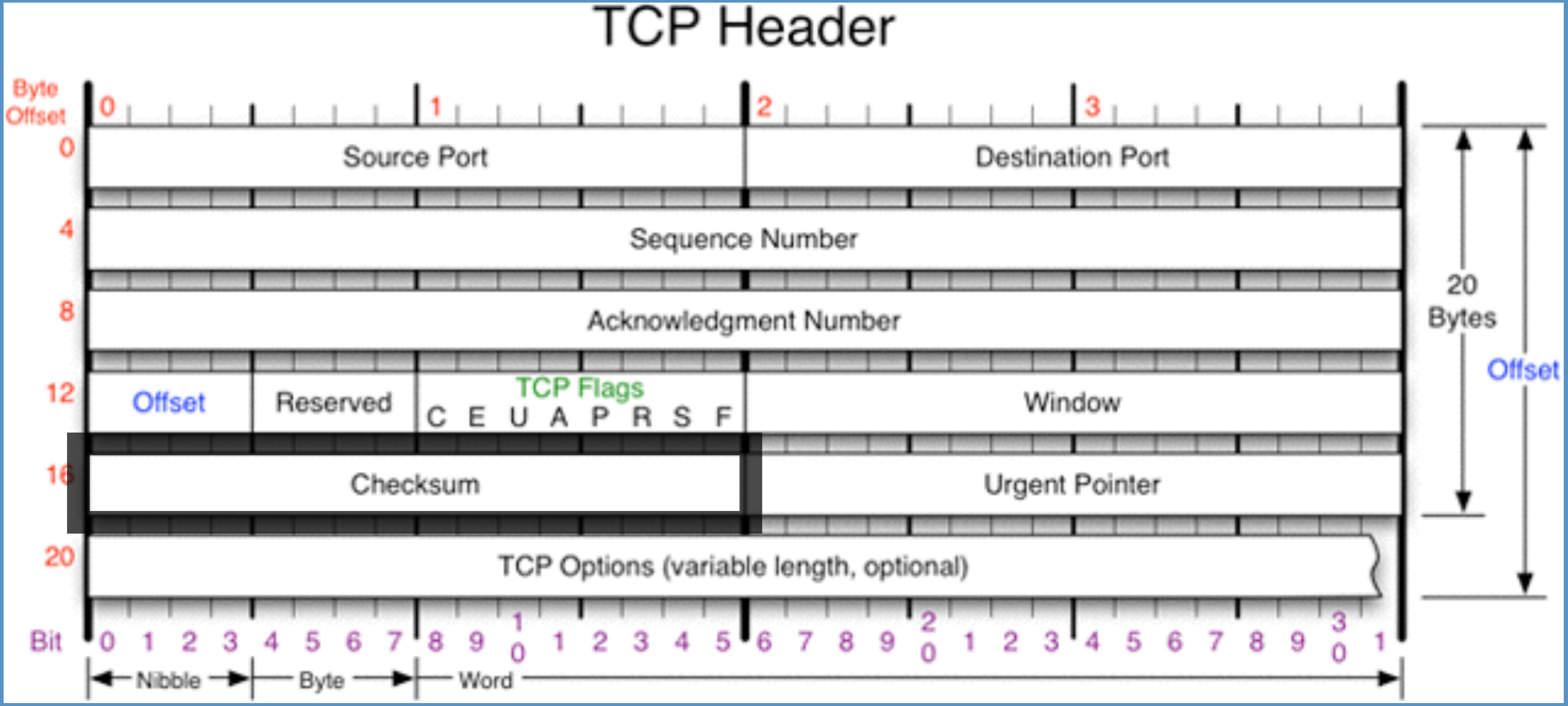
Flags: SYN, ACK, FIN…

TCP



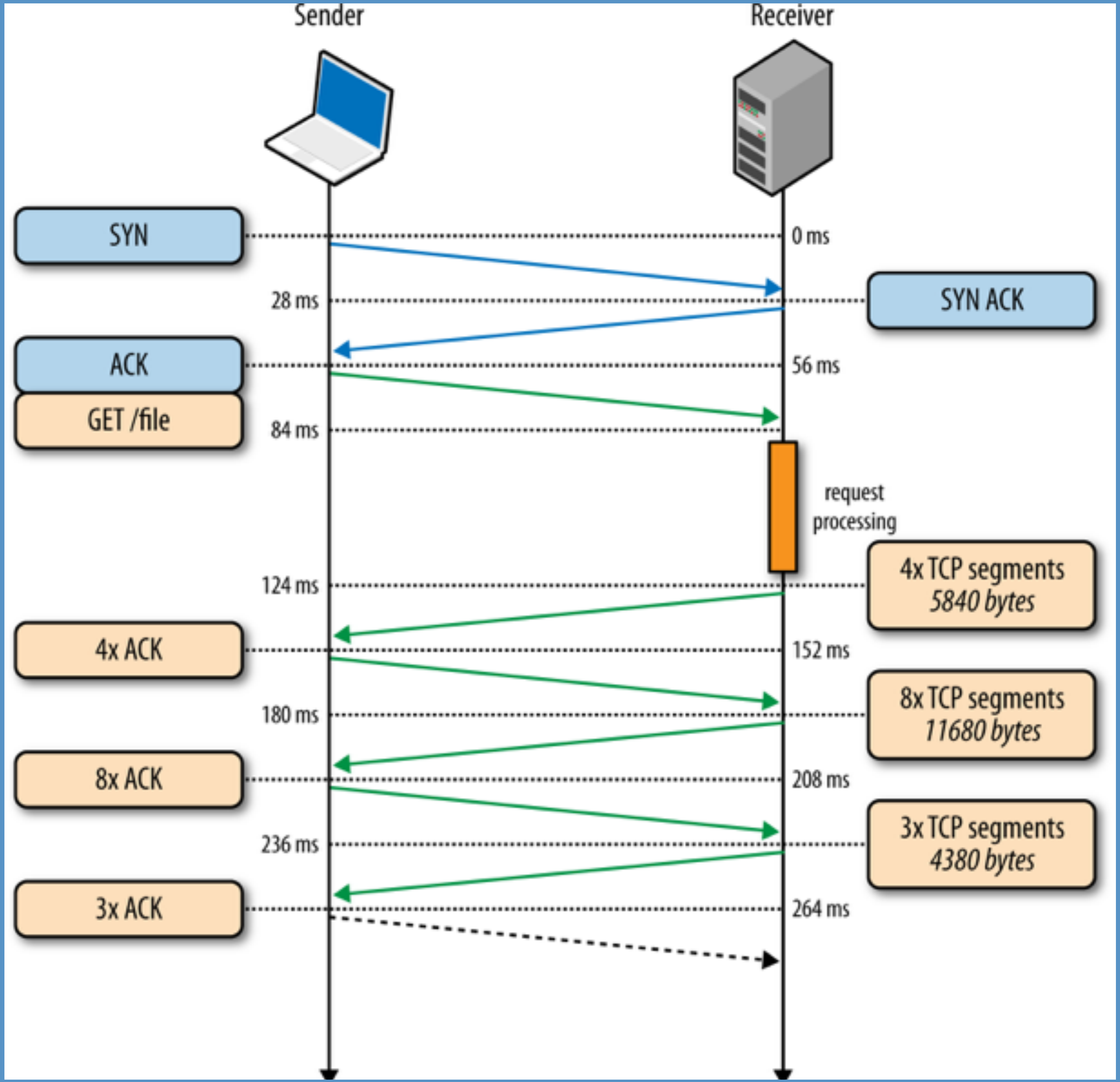
Window: size of the “*receive window*”, dynamic!

TCP

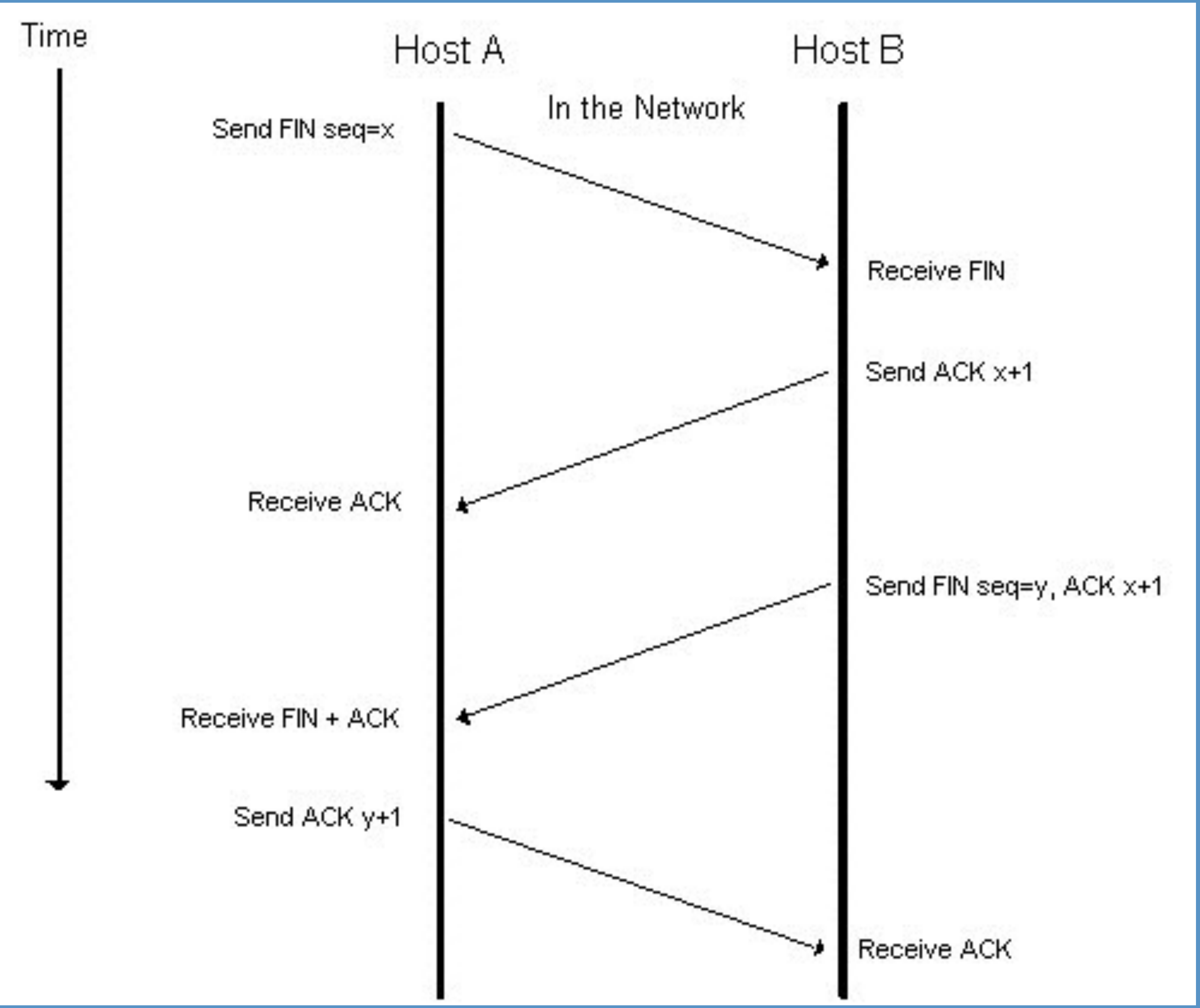


Checksum: data checksum

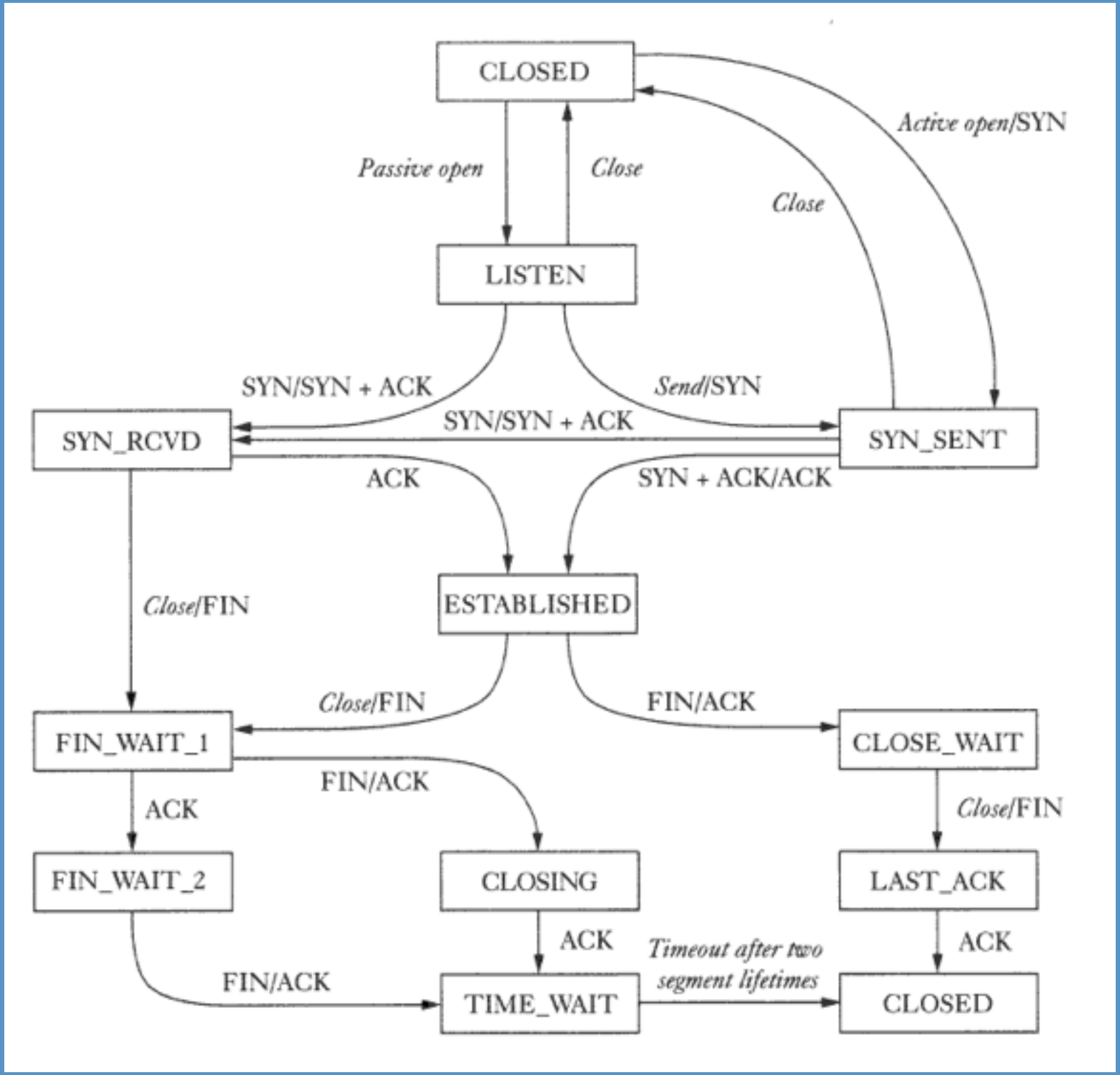
TCP: Connection Start



TCP: Connection End



TCP States


CLOSED
Passive open
Close
Close
Active open/SYN
LISTEN
SYN/SYN + ACK
Send/SYN
SYN/SYN + ACK
SYN_RCVD
SYN_SENT
ACK
SYN + ACK/ACK
Close/FIN
ESTABLISHED
Close/FIN
FIN/ACK
FIN_WAIT_1
CLOSE_WAIT
FIN/ACK
ACK
Close/FIN
FIN_WAIT_2
CLOSING
LAST_ACK
ACK
Timeout after two
segment lifetimes
ACK
FIN/ACK
TIME_WAIT
CLOSED

Wireshark

- Graphical front-end open-source packet analyzer
- Great tool for learning networking concepts!
- Can capture and filter packets
- Command line equivalent (powerful!): tcpdump

Exercise

- Use “lsof -i TCP -n -P” to list the TCP connections currently taking place on your laptop

Sockets

- Socket => file descriptor
- TCP (UDP, etc.) uses ports, OS uses sockets
- How an application communicates over the internet

References

- https://github.com/revmischa/learn-software-engineering/wiki/How-The-Internet-Works

Homework

- Create a server that accepts a UTC offset and returns the time in ISO 8601 format. Write a client that prompts the user to test.

Exit Ticket

- See Slack channel