NETWORKING 101 / 102

"Climbing" the Network "Tower"

(Network Standards and Topologies)

&

Focus On IPv4 Addressing

Climbing Carl

Chapter 30
South Bend, IN

Society of Broadcast Engineers
The Association for Broadcast and
Multimedia Technology Professionals

Walter Streeter

WSBT TV

Assistant Chief Engineer

14+ Years Cisco CCDA and CCNA Certified

9+ Years Cisco CCNP Certified

20+ Years working in networking

9+ Years working in broadcasting

NETWORKING 101

Standards Organizations

Relevant IEEE & IETF Standards

OSI & TCP/IP Conceptual Models

Hardware Correlations to the OSI Model

Encapsulation & Decapsulation

TCP/IP Protocols

LAN & WAN Technologies

Physical Ethernet Options

Summary

AGENDA

NETWORKING 101 / 102

- International Organization for Standardization – ISO (not an acronym, Greek for equality)
    - Nongovernmental
    - Standards bodies from over 160 countries
    - Collaborate in development of international standards for technology (and other things)
- International Telecommunication Union (ITU)
    - Founded in 1865
    - Facilitates international connectivity in communications networks,
    - Allocate global radio spectrum and satellite orbits
    - Develops the technical standards that ensure networks and technologies seamlessly interconnect
- Institute of Electrical & Electronic Engineers (IEEE)
    - Leading developer of international standards that underpin many of today's telecommunications, information technology, and power-generation products and services
    - Portfolio of nearly 1,032 standards
    - Includes the 802® standards for local, metropolitan, and other area networks, including Ethernet and Wireless LAN (commonly referred to as Wi-Fi®)

ISO

ITU

IEEE

Standards Organizations

- IEEE Project 802® Standards
  - IEEE 802®: Overview & Architecture
  - IEEE 802.1™: Bridging & Management
    - IEEE 802.1Q: VLAN
    - IEEE802.1ad: QinQ
    - IEEE 802.1D: Spanning Tree Protocol (STP) bridge protocol
    - IEEE 802.1w: Rapid Reconfiguration of Spanning Tree
    - IEEE 802.1s: Multiple Spanning Tree Protocol (MSTP)
  - IEEE 802.2™: Logical Link Control
  - IEEE 802.3™: Ethernet
  - IEEE 802.11™: Wireless LANs
  - IEEE 802.15™: Wireless Specialty Networks (WSN)
  - IEEE 802.16™: Broadband Wireless MANs
  - IEEE 802.19™: Wireless Coexistence
  - IEEE 802.21™: Media Independent Handover Services
  - IEEE 802.22™: Wireless Regional Area Networks
  - https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=68

IEEE 802 Standards

- Internet Engineering Task Force (IETF)
  - Founded in 1986
  - Standards development organization for the Internet
  - Makes voluntary standards that are often adopted by Internet users, network operators, and equipment vendors
  - Helps shape the trajectory of the development of the Internet
  - "…the overall goal of the IETF is to make the Internet work better." RFC 3935
  - Standards published as Request For Comment (RFC)
    - See https://www.rfc-editor.org/
  - Requirement Levels (RFC 2119):
    - MUST/REQUIRED/SHALL
    - MUST NOT/SHALL NOT
    - SHOULD/RECOMMENDED
    - SHOULD NOT/NOT RECOMMENDED
    - MAY/OPTIONAL

I E T F®

https://www.rfc-editor.org/

- **Humorous RFC's:**
  - RFC 1149 - Standard for the transmission of IP datagrams on Avian Carriers
  - RFC 2549 - IP over Avian Carriers with Quality of Service
  - RFC 2324 - Hyper Text Coffee Pot Control Protocol (HTCPCP/1.0)

- **KEY RFC's to Review:**
  - RFC 2119 - Key words for use in RFCs to indicate requirement levels
  - RFC 3339 - Date and time on the Internet: timestamps
  - RFC 1918 - Address allocation for private internets
  - RFC 1912 - Common DNS operational and configuration errors
  - RFC 2822 - Internet message format
  - RFC 7231 - Hypertext Transfer Protocol (HTTP/1.1): Semantics and content

IETF Standards

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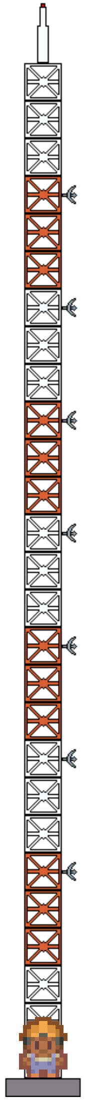

Layer Number	OSI Model		TCP/IP Model Layer Name
7	Application		Application
6	Presentation		
5	Session		
4	Transport		Host – Host
3	Network		Internetwork
2	Data Link	LLC	Network Interface
		MAC	
1	Physical		

The **Transmission Control Protocol / Internet Protocol (TCP/IP)** and its related protocols are maintained by the **Internet Engineering Task Force (IETF)** and predates the OSI model. The TCP/IP layers will be compared with the OSI model layers in the diagram to the left for reference.

https://www.ietf.org/standards/rfcs/
https://www.rfc-editor.org/rfc-index-100a.html

The **Open Systems Interconnection (OSI)** model was developed by the International Organization for Standardization (ISO) to provide a conceptual reference of how information flows and is communicated between devices on a network.

https://www.iso.org/standard/20269.html

OSI & TCP/IP Models

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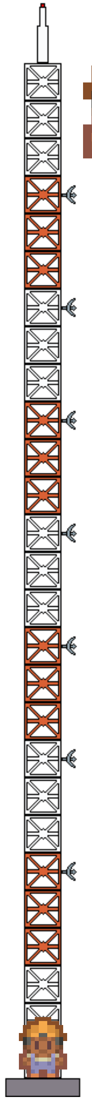

Layer Number	OSI Model	Memorization Key
7	Application	Away
6	Presentation	Pizza
5	Session	Sausage
4	Transport	Throw
3	Network	Not
2	Data Link (MAC / LLC)	Do
1	Physical	Please

Please Do Not Throw Sausage Pizza Away

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OSI Memorization Method

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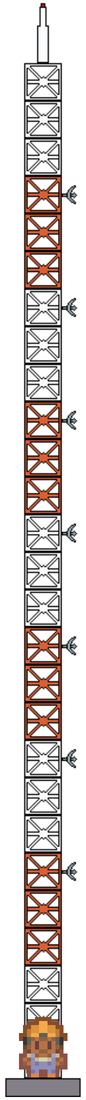
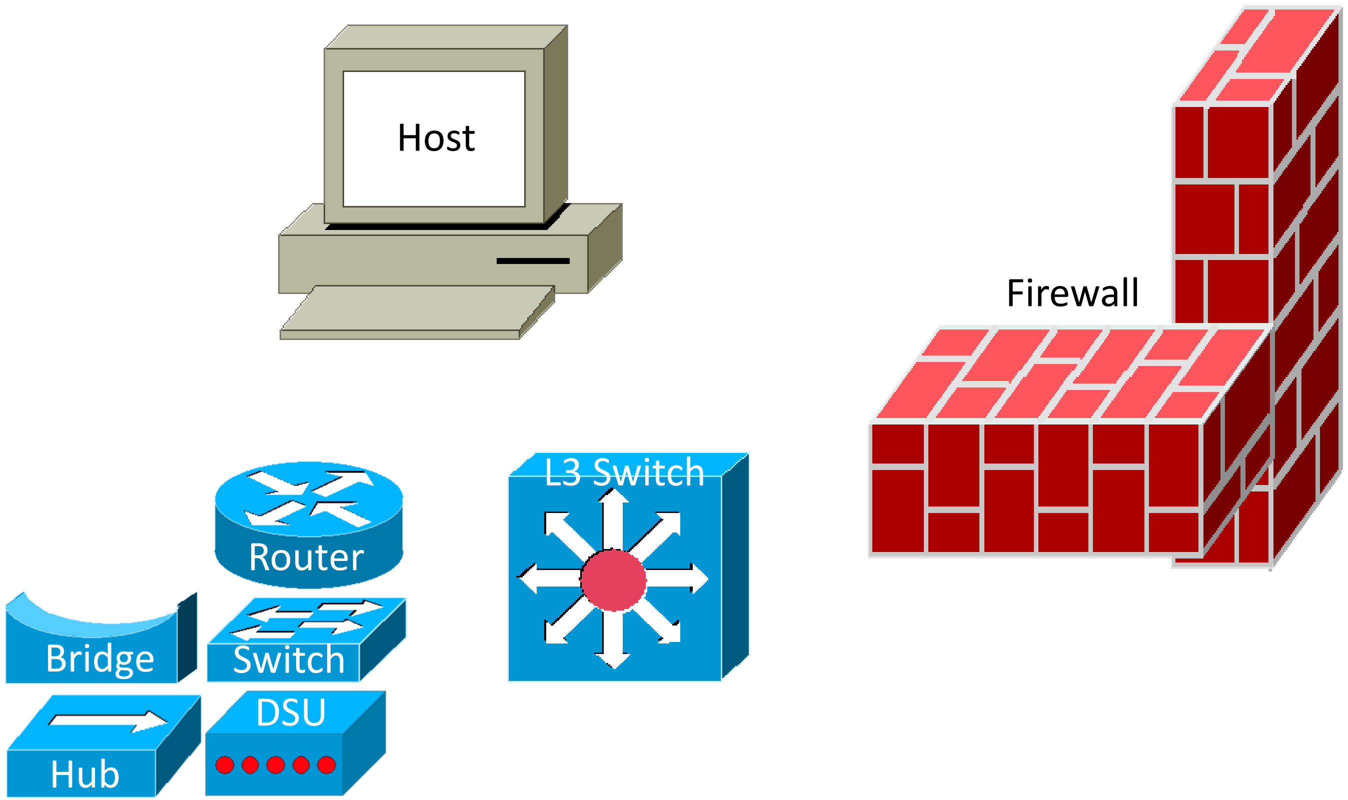


Layer Number	OSI Model	
7	Application	
6	Presentation	
5	Session	
4	Transport	
3	Network	
2	Data Link	LLC
		MAC
1	Physical	



Devices

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OSI Device Correlation

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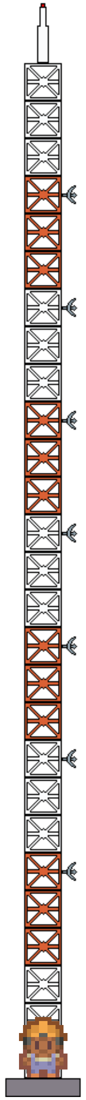
Layer Number	OSI Model		Data Unit	Example Protocols
7	Application		Data	HTTP, FTP, DNS, SMTP, SNMP, Telnet
6	Presentation		Data	SSL, TLS (Format Data, Encryption)
5	Session		Data	NetBIOS, PPTP (Start/Stop Sessions)
4	Transport		Segment	TCP, UDP, FCP, etc.
3	Network		Packet	IP, ICMP, IPSec
2	Data Link	LLC	Frame	Ethernet II/IEEE 802.3, 802.2, PPP, ATM
		MAC		
1	Physical		Bits	Ethernet, USB, Bluetooth, IEEE802.11



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OSI Data Units

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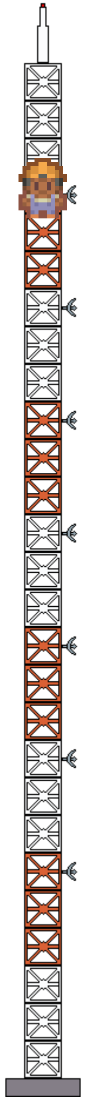


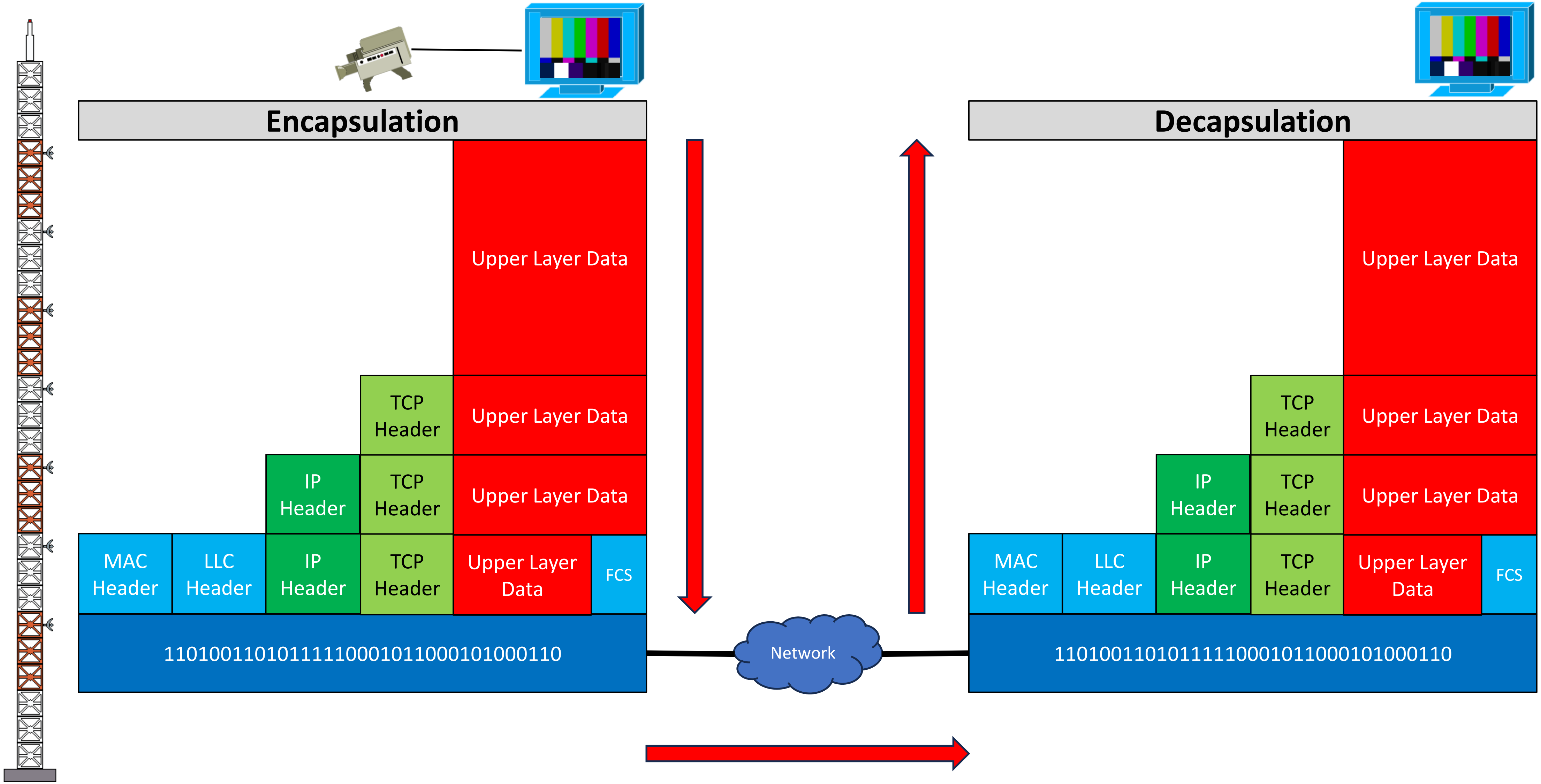
Layer Number	OSI Model	Data Unit	Encapsulation
7	Application	Data	Upper Layer Data
6	Presentation	Data	
5	Session	Data	
4	Transport	Segment	TCP Header, Upper Layer Data
3	Network	Packet	IP Header, TCP Header, Upper Layer Data
2	Data Link (LLC / MAC)	Frame	MAC Header, LLC Header, IP Header, TCP Header, Upper Layer Data, FCS
1	Physical	Bits	11010011010111110001011000101000110

OSI Encapsulation

NETWORKING 101

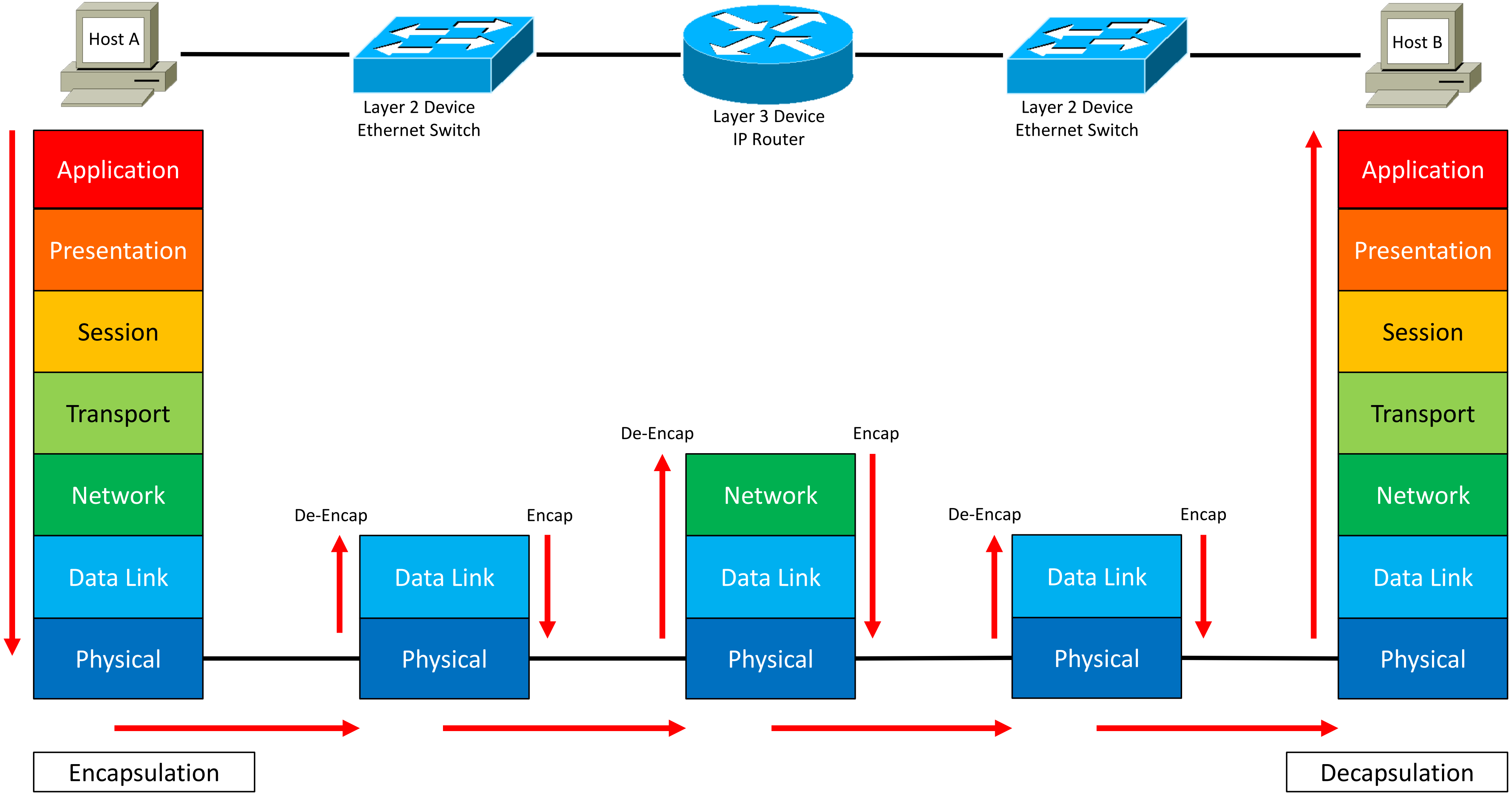
OSI Encapsulation & Decapsulation

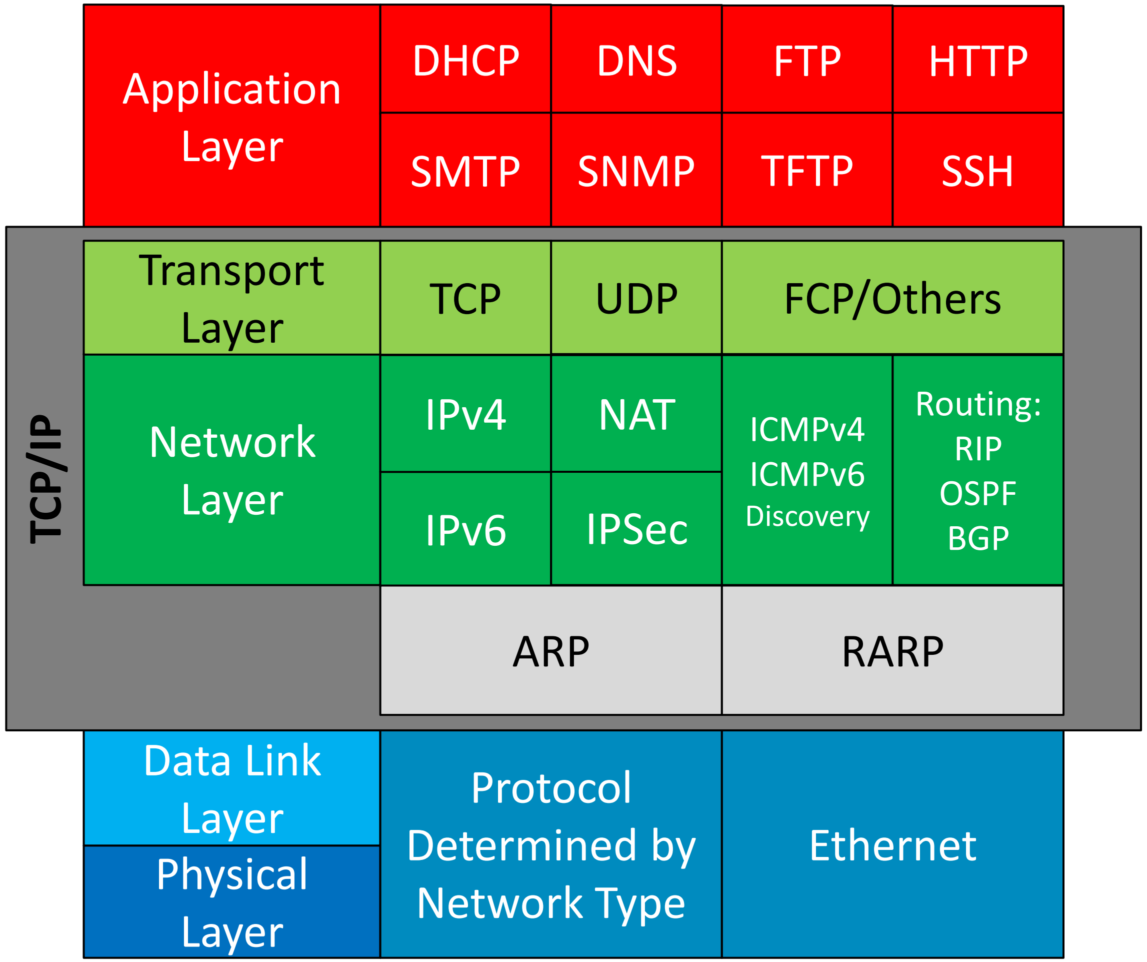
NETWORKING 101



OSI End-to-End

NETWORKING 101





TCP/IP Network Protocols

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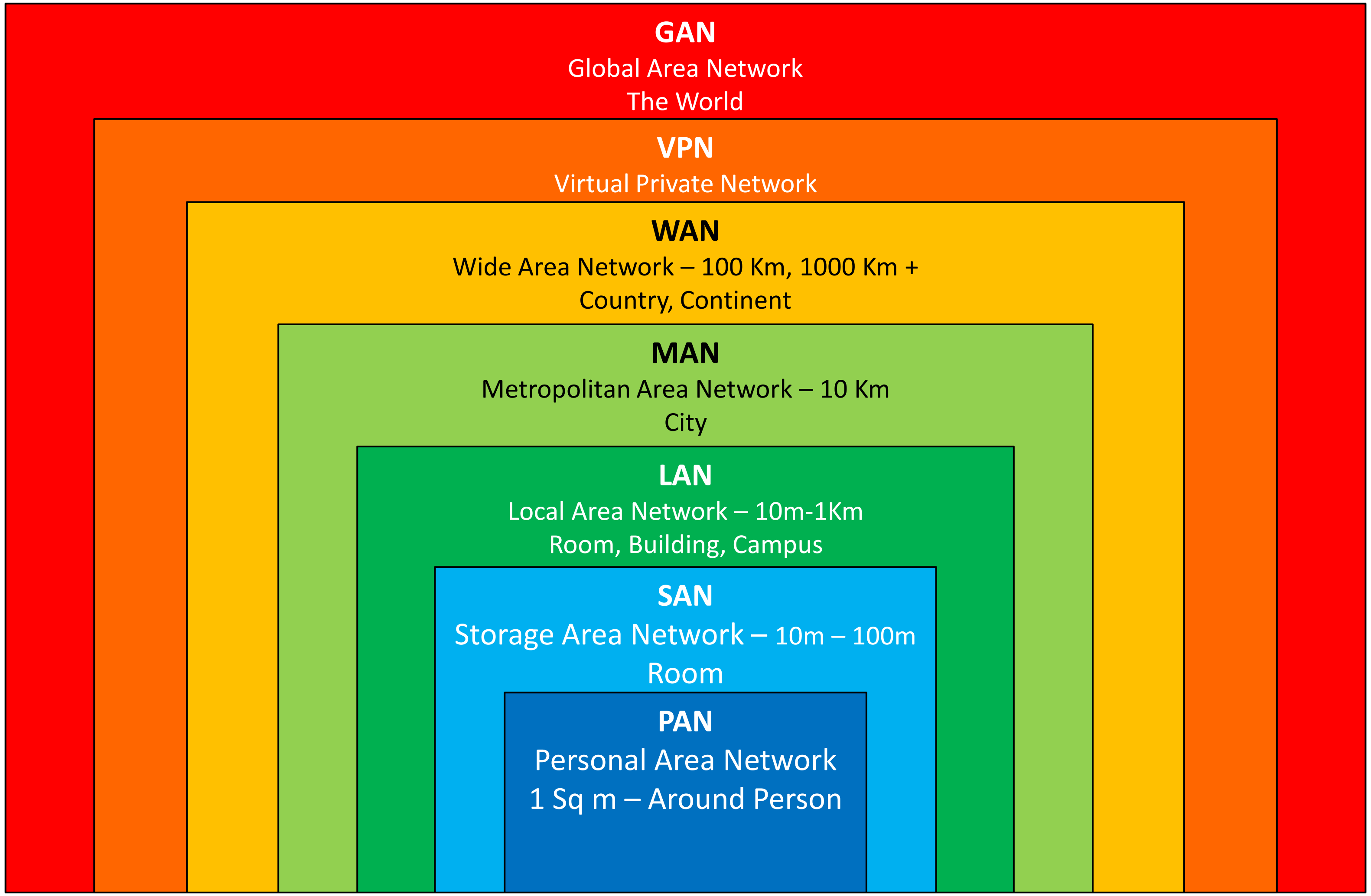


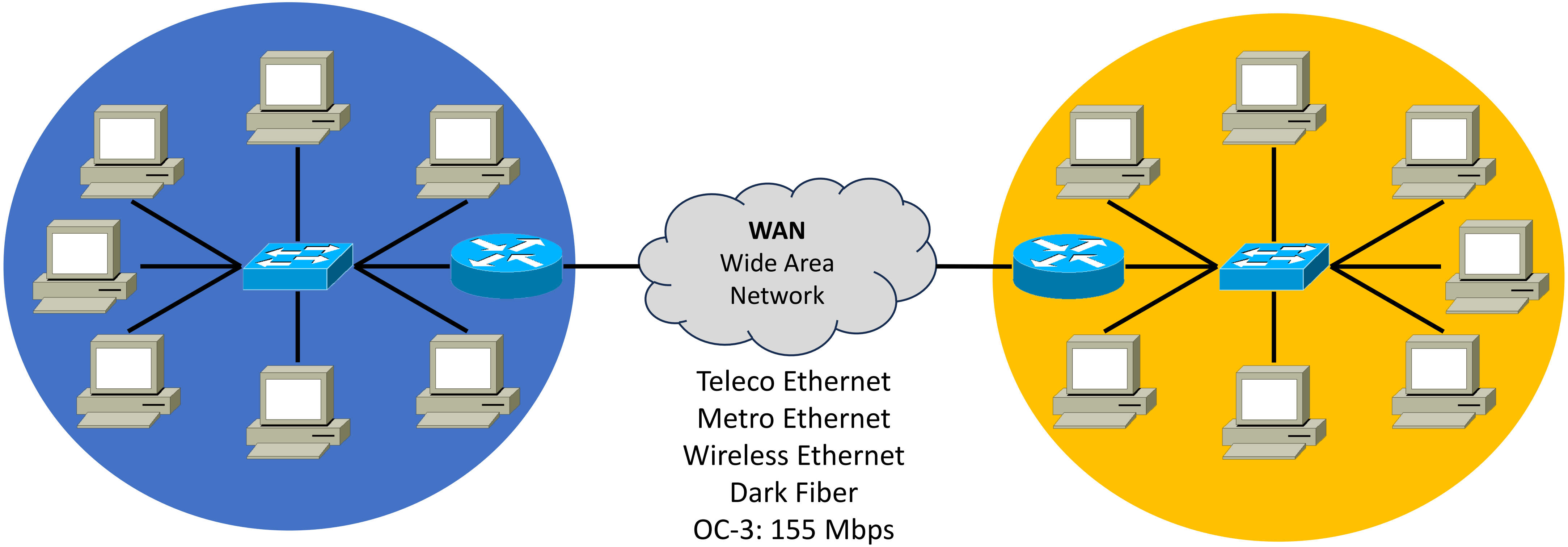
Internetwork
Network of multiple networks
The Internet

Network Host
Physical device that can be connected to a network

Host Device Requirements
IETF RFC 1122, 1123
ARP, ICMP, TCP, DNS

Network Types

NETWORKING 101



Teleco Ethernet
Metro Ethernet
Wireless Ethernet
Dark Fiber
OC-3: 155 Mbps
DS-3: 45 Mbps
DS-1: 1.5 Mbps
DS-0: 64 Kbps
ISDN PRI: 1-1.5 Mbps (US)
ISDN BRI: 64-128 Kbps

LAN-WAN Illustrated

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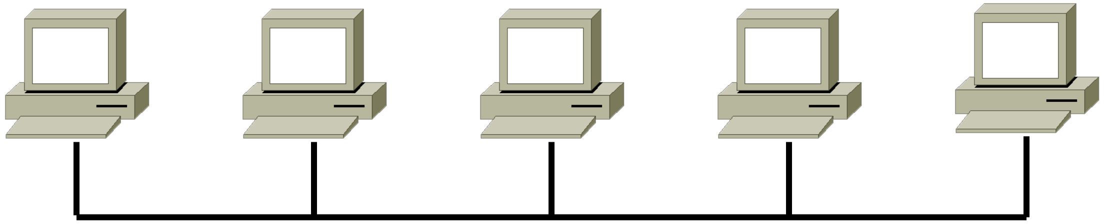

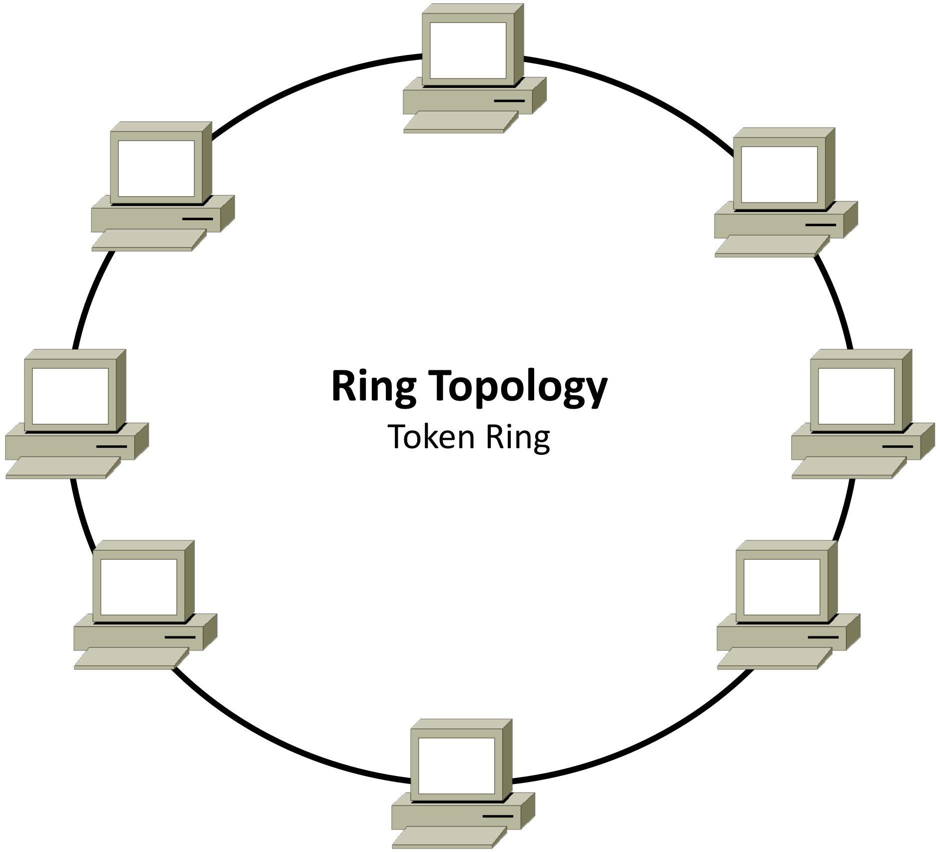

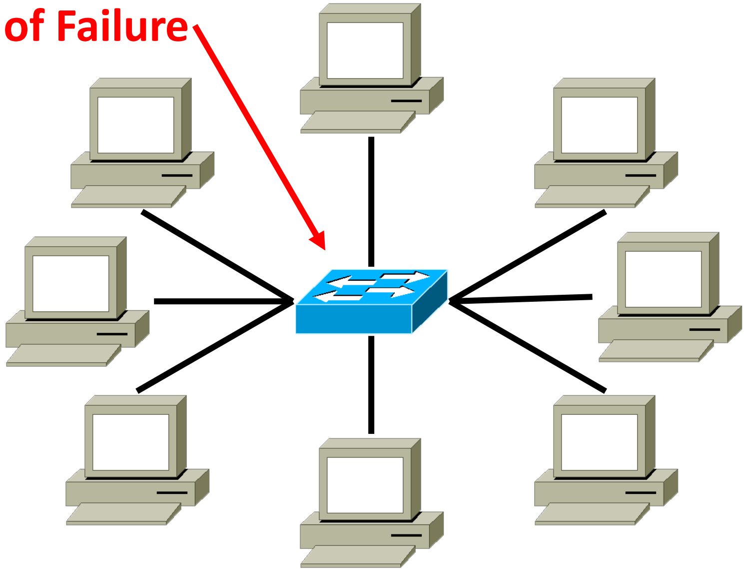

Network Topologies

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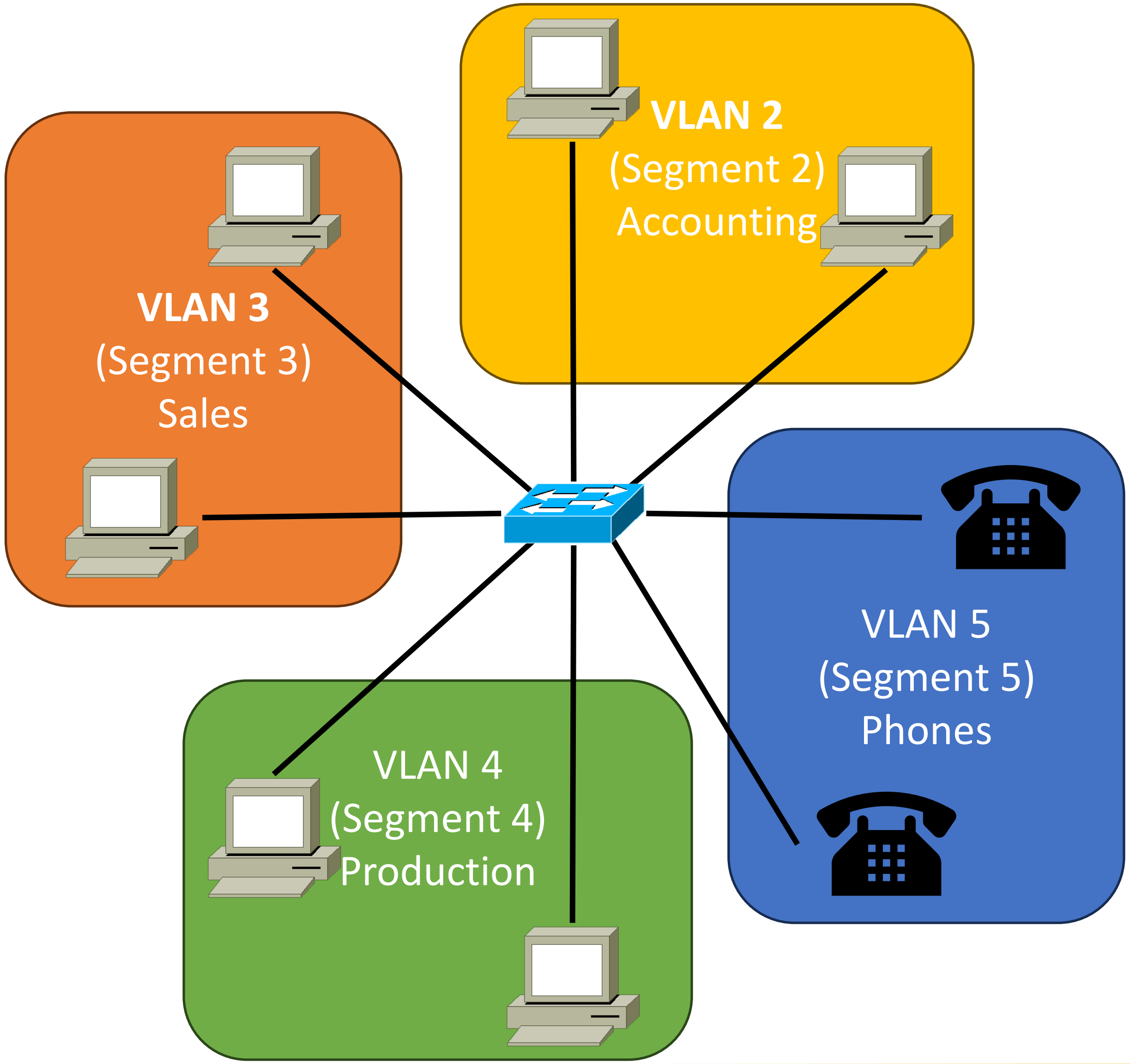
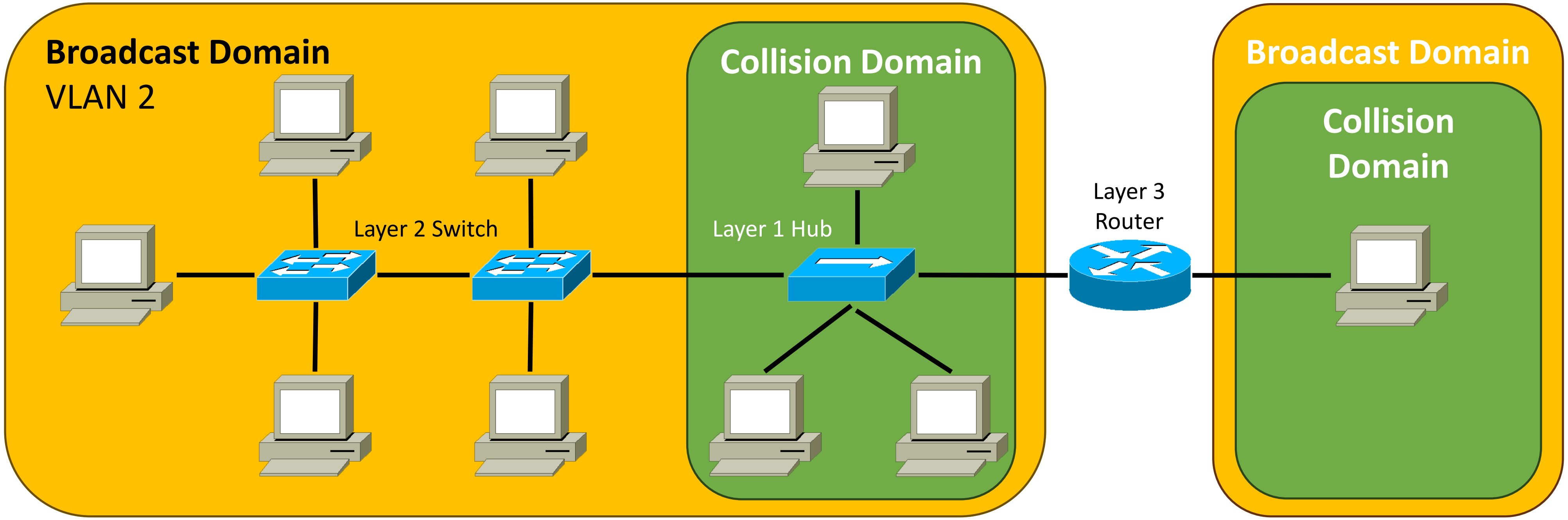
Why Segment?

- Flexible Architecture
- Performance
- Security



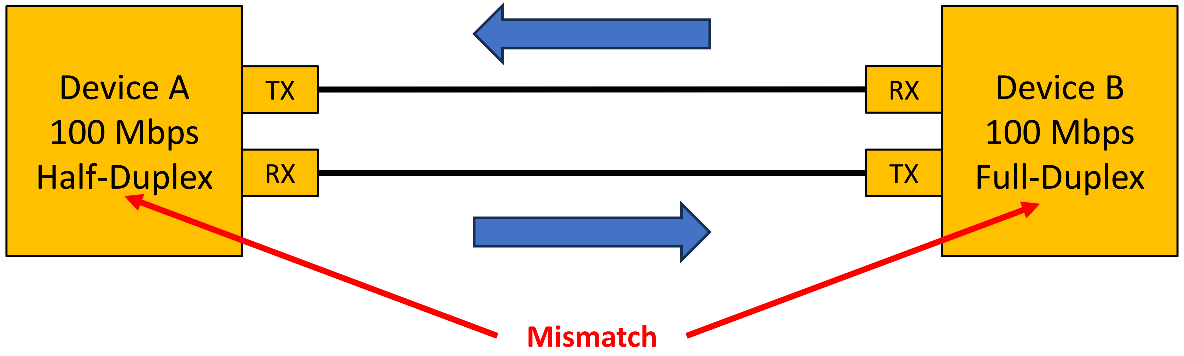
Network Segmentation

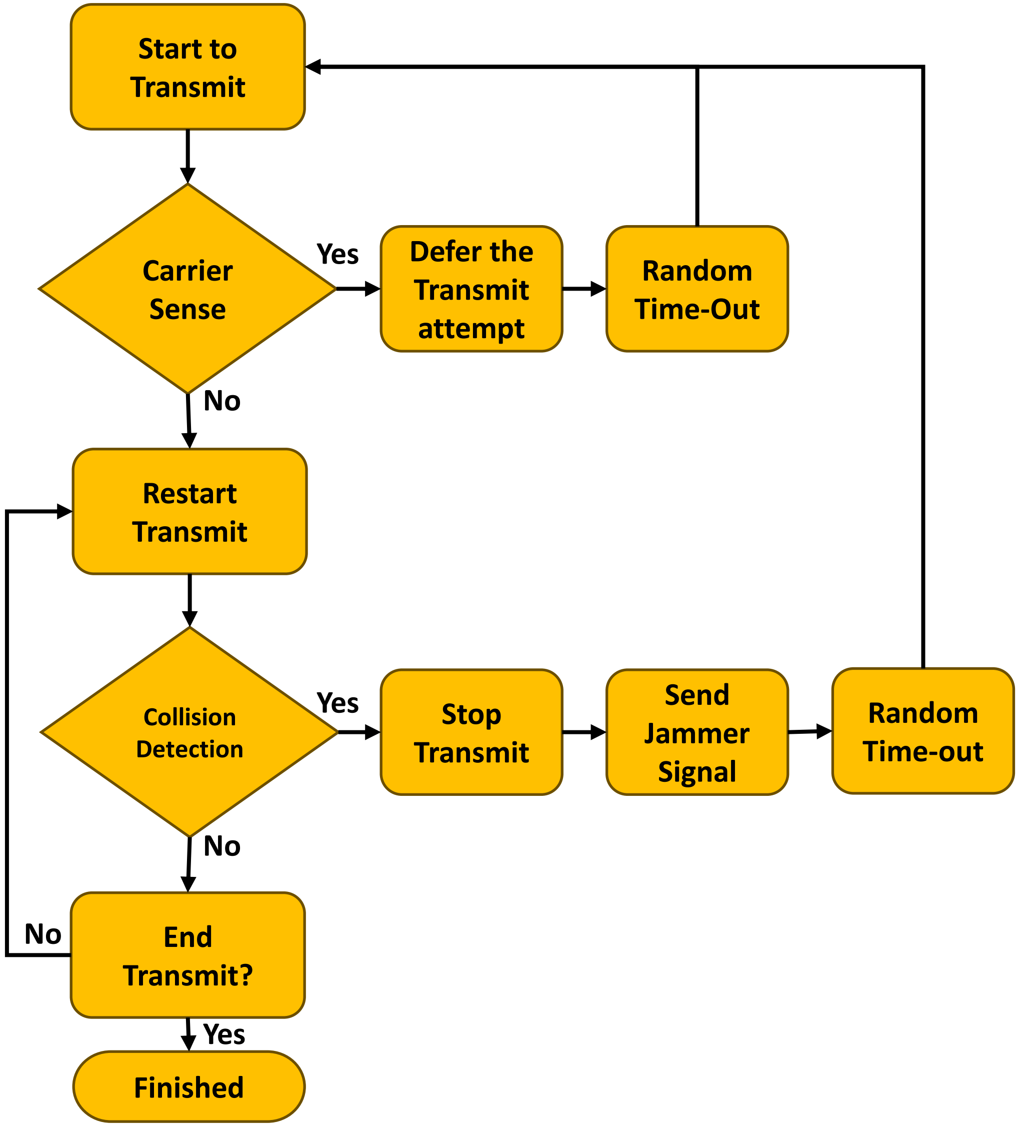


Broadcast & Collision Domains

NETWORKING 101

- Modes
  - Half-Duplex – host receives OR transmits
  - Full-Duplex – host receives AND transmits
- Half-Duplex mode is used when the media is shared (i.e. hub)
- CSMA/CD algorithm enabled
  - Carrier-Sense, Multiple Access / Collision Detect
- Auto-Negotiation
  - Attempts to set host interface speed & duplex
  - Introduced with Fast Ethernet (100BASE-T)
  - Results sometimes questioned or mistrusted
  - Duplex mismatch results in collisions but no CSMA/CD
  - Performance significantly affected
  - Gigabit Ethernet improved / required (see 802.3ab)





Ethernet Standard – Some Details

NETWORKING 101

IEEE Std	Date	Name	Data Rate	Cable Type
802.3i	1990	10BASE-T	10 Mbps	Cat3
802.3u	1995	100BASE-TX	**100 Mbps**	Cat5
802.3z	1998	1000BASE-SX 1000BASE-LX/EX	1 Gbps	Multimode fiber Single mode fiber
802.3ab	1999	1000BASE-T	**1 Gbps**	Cat5e or higher
802.3ae	2003	10GBASE-SR 10GBASE-LR/ER	10 Gbps	Laser Optimized MMF Single mode fiber
802.3an	2006	10GBASE-T	**10 Gbps**	Cat6A
802.3bq	2015	40GBASE-T	**40 Gbps**	Cat8 (Class I & II)
802.3ba	2010	40GBASE-SR4/LR4 100GBASE-SR10/LR4/ER4	40 Gbps 100 Gbps	Laser Optimized MMF or SMF Laser Optimized MMF or SMF
802.3bm	2015	100GBASE-SR4	100 Gbps	Laser Optimized MMF or SMF
SG	2016	Under Development	400 Gbps	Laser Optimized MMF or SMF
			Auto Negotiate	

Ethernet Cabling Standards

NETWORKING 101

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- CAT-5
  - 5 twists/inch
- CAT-5e
  - 5 twists/inch, Pairs twisted
- CAT-6
  - 6 twists/inch, Separator
- Multimode Fiber (MMF)
  - Shorter distances
  - Larger core
  - Types include OM1 – OM4
  - Typical wavelength 850 & 1300 nm
  - Typically orange or aqua
  - Cheaper than SMF
- Single Mode Fiber (SMF)
  - Longer distance – 100 Km
  - Smaller core
  - Typical wavelength 1310 / 1550 nm
  - Typically yellow
  - OS1 (indoor, 10 Km) & OS2 (outdoor 200 Km)
  - More expensive than MMF

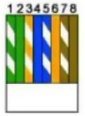

Cat5


Cat5e


Cat6

T568A	
Wire #	Wire Color
1	Green / White
2	Green
3	Orange / White
4	Blue
5	Blue / White
6	Orange
7	Brown / White
8	Brown

T568B	
Wire #	Wire Color
1	Orange / White
2	Orange
3	Green / White
4	Blue
5	Blue / White
6	Green
7	Brown / White
8	Brown

T568A


T568B


TYPE	COLOR	CORE	SPEED (Gbps)	C1	C2	C3	C4	C5
OM1	Orange	62.5 µm	1/10	275 m	550 m	33 m	N/A	N/A
OM2	Orange	50 µm	1/10	550 m	550 m	82 m	N/A	N/A
OM3	Aqua	62.5 µm	1/10/40/100	550 m	550 m	300 m	100 m	100 m
OM4	Aqua	62.5 µm	1/10/40/100	550 m	550 m	400 m	150 m	150 m

C1 = 1000BASE-SX
C2 = 1000BASE-LX
C3 = 10BASE-SR/LR/ER
C4 = 40GBASE-SR4
C5 = 100BASE-SR4

Ethernet Cabling Information

NETWORKING 101

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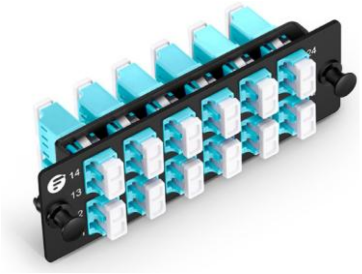
- LC
    - Lucent Connector
    - To remember think LC = Little Click
    - Smaller connector
    - Connects to Fiber SFP modules
- SC
    - Snap-in Connector
    - To remember think C = Click
- ST
    - Straight-Tip
    - To remember think T = Twist
    - Larger connector
- MTP/MPO
    - 12/24 fibers, 1 small connector
- FC
    - Ferrule Connector



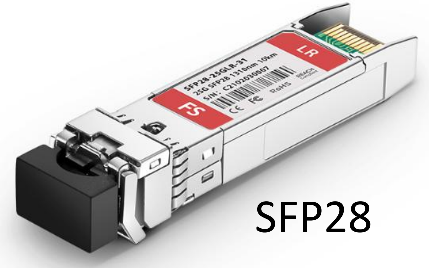
Fiber Optic Connector Types

NETWORKING 101

- SFP Transceivers
- Small Form-factor Pluggable
- 6 Relevant Types of SFPs
  - SFP – 1 Gbps
  - SFP+ – 10 Gbps
  - QSFP – 4 Gbps
    - Q = Quad SFP
  - SFP28 – 25 Gbps
    - IEEE 802.3by (25GBASE-CR)
  - QSFP+ – 40 Gbps
    - IEEE 802.3ba
  - QSFP28 – 40/100 Gbps
    - IEEE 802.3bm
  - QSFP56 – 100 to 400 Gbps

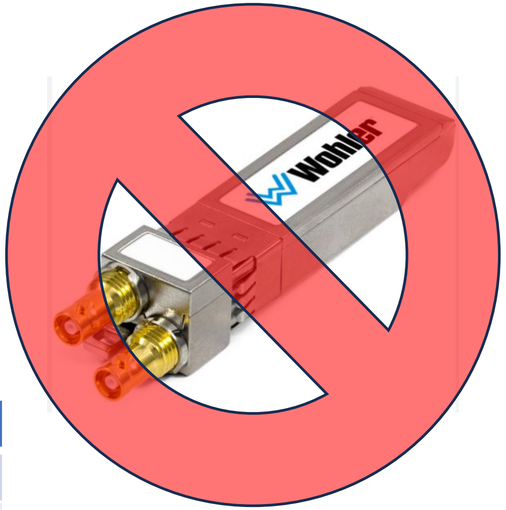
SFP+

QSFP28



SFP28

Standard	Cable Type	Distance
T	Cat5/6	100 m
SX	MMF	550 m
LX/LM	MMF SMF	550 m 10 Km
EX	SMF	40 Km
ZX	SMF	70 Km



Do not confuse data and video SFPs
- 3G-SDI
- 6G-SDI
- 12G-SDI
- Coax and Fiber options
- Other signal types

Ethernet SFP Transceivers

NETWORKING 101

- Consumer wireless, “Wi-Fi”, defined by IEEE 802.11
  - Wi-Fi 5
    - IEEE 802.11ac
    - Published 2013
    - Up to 3.5 Gbps
  - Wi-Fi 6
    - IEEE 802.11 ax
    - Published 2021
    - Theoretical data rate of 9.6 Gbps
    - Data rate meant to address dense Wi-Fi traffic
  - Wi-Fi 7, IEEE 802.11be, under development
- Licensed Wireless
- Outdoor point-to-point.
- Frequencies
  - Good write –up: https://www.cablefree.net/wirelesstechnology/wireless-lan/wlan-frequency-bands-channels/

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- Knowing the OSI Model is Essential
  - Please Do Not Throw Sausage Pizza Away!
  - Encapsulation – Application Down to Physical Layer
  - Decapsulation – Physical Up to Application Layer
- Physical Layer
  - Layer 1
  - Ethernet most prevalent
  - Ever increasing bandwidth & additional applications
  - SFP transceivers provide flexibility
- Data Link Layer
  - Layer 2
  - Switches limit collision domains
- Network Layer
  - Layer 3
  - Routers (or L3 switches) limit broadcast domains
- Fiber optic and wireless links must be engineered
- Standards Bodies
  - IEEE and IETF primary
  - ISO and ITU also involved

Layer Number	OSI Model		Memorization Key
7	Application		Away
6	Presentation		Pizza
5	Session		Sausage
4	Transport		Throw
3	Network		Not
2	Data Link	MAC / LLC	Do
1	Physical		Please

Please Do Not Throw Sausage Pizza Away

Layer Number	OSI Model		Data Unit	Encapsulation					
7	Application		Data					Upper Layer Data	
6	Presentation		Data						
5	Session		Data						
4	Transport		Segment				TCP Header	Upper Layer Data	
3	Network		Packet			IP Header	TCP Header	Upper Layer Data	
2	Data Link	MAC / LLC	Frame	MAC Header	LLC Header	IP Header	TCP Header	Upper Layer Data	FCS
1	Physical		Bits	1101001101011111000101100010100011 0					

Summary

NETWORKING 101

NETWORKING 102

"Addressing" the Layer

IPv4 Packets

IPv4 Addresses

IPv4 Classes and Default Masks

IPv4 Reserved Address Space

VLSM and CIDR

The 10 Commandments of IPv4 Addressing

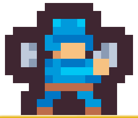
Examples and Exercises

Summary

“Addressing” the Layer

- OR -

The OSI Layer for IP Addressing



Nah, nah, nah, nah, nah, nah, nah, nah, Bitman!

Layer 3 (Network) Layer

Layer Number	OSI Model	Data Unit	Encapsulation
7	Application	Data	Upper Layer Data
6	Presentation	Data	
5	Session	Data	
4	Transport	Segment	TCP Header, Upper Layer Data
3	Network	Packet	IP Header, TCP Header, Upper Layer Data
2	Data Link (LLC, MAC)	Frame	MAC Header, LLC Header, IP Header, TCP Header, Upper Layer Data, FCS
1	Physical	Bits	11010011010111110001011000101000110

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"Addressing" the Layer

NETWORKING 102

IPv4 Packets

- OR -

IPacketology – Dissecting the IP Packet

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RFC 791 – IPv4

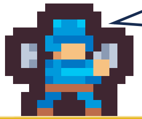
- **Version** – 0100 = IPv4, 0110 = IPv6
- **IHL** – Internet Header Length, the number of 32-bit words
- **Precedence/ToS** – Type of Service to provide indication of desired quality of service
- **Total Length** – Length of the datagram measured in octets, including internet header and data, 20 to 65,535 Bytes
- **Identification** – Datagram fragment ID
- **Flags** – Marks fragmentation eligibility
- **Fragment Offset** – Fragment location

32 bits

20 – 65,535 Bytes

20 Bytes

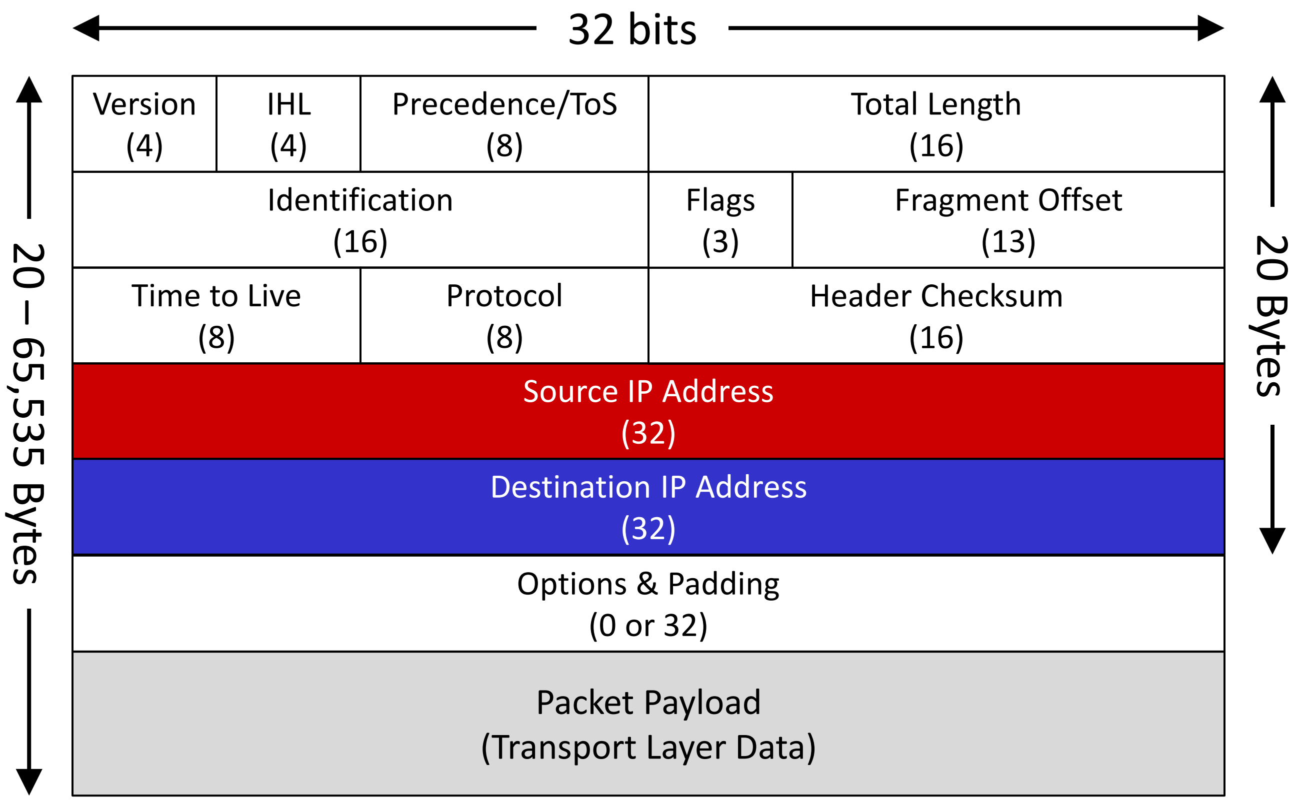
Version (4)	IHL (4)	Precedence/ToS (8)	Total Length (16)	
Identification (16)			Flags (3)	Fragment Offset (13)
Time to Live (8)		Protocol (8)	Header Checksum (16)	
Source IP Address (32)				
Destination IP Address (32)				
Options & Padding (0 or 32)				
Packet Payload (Transport Layer Data)				



RFC 791 – https://datatracker.ietf.org/doc/html/rfc791
RFC 820 – https://datatracker.ietf.org/doc/html/rfc820

RFC 791 – IPv4

- **Time to Live** – Maximum time datagram allowed to remain in internet system
- **Protocol** – Next level protocol used in the data portion of the datagram, see RFC 820
- **Header Checksum** – Header error checking, redone at each hop
- **Source IP Address** – Self-explanatory
- **Destination IP Address** – Self-explanatory
- **Options** – Security, timestamps, route recording, etc.
- **Padding** – Ensure header ends on a 32-bit boundary
- **Packet Payload** – Packet data

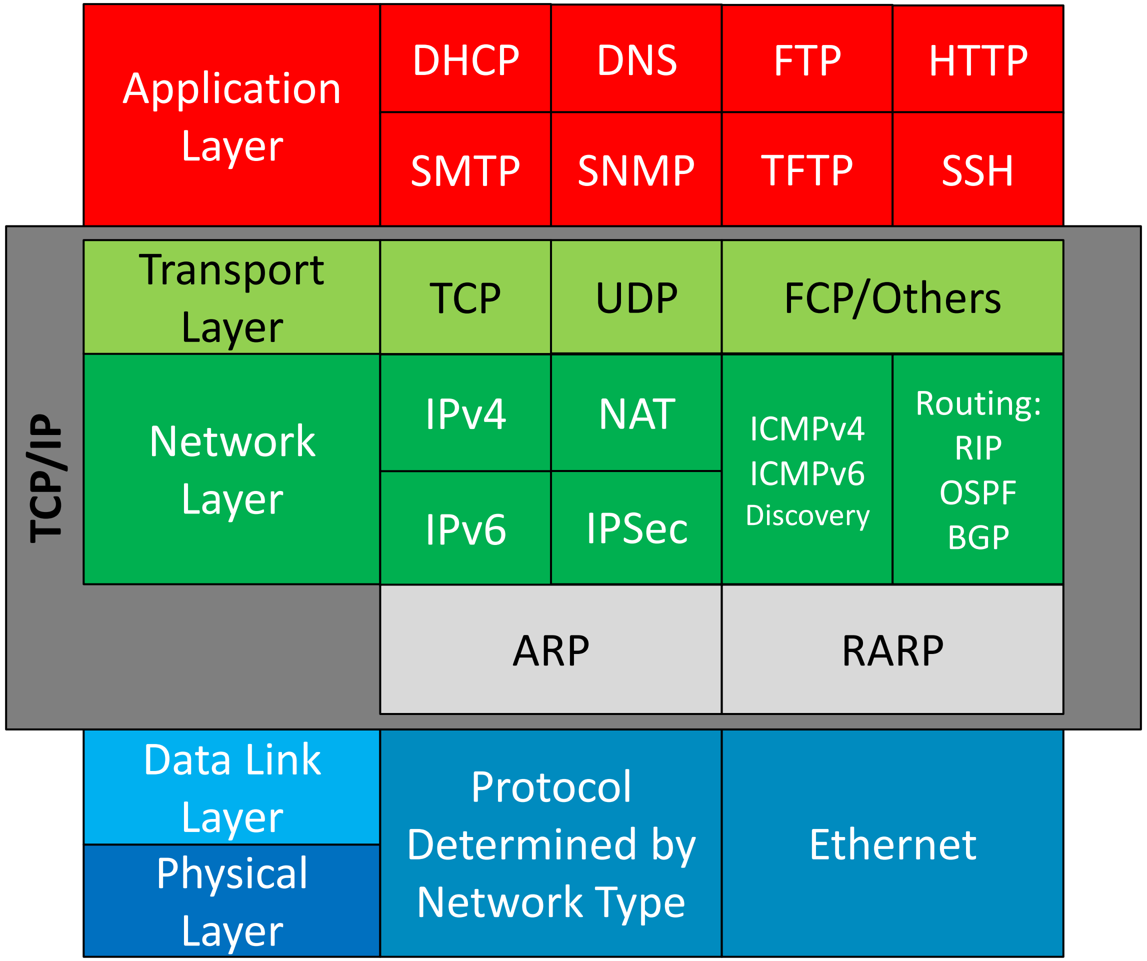


RFC 791 – https://datatracker.ietf.org/doc/html/rfc791
RFC 820 – https://datatracker.ietf.org/doc/html/rfc820

TCP/IP Network Protocols

NETWORKING 102

- **Network Layer Protocols**
  - ARP – Address Resolution Protocol
    - Bridge between Layer 2 & 3
  - RARP – Reverse Address Resolution Protocol
    - Functions between Layer 2 & 3
  - ICMP – Internet Control Message Protocol
- **Transport Layer Protocols**
  - TCP – Transmission Control Protocol
  - UDP – User Datagram Protocol
- **Application Layer Protocols**
  - DHCP – Dynamic Host Configuration Protocol
  - DNS – Domain Name Service
  - FTP – File Transfer Protocol
  - HTTP – HyperText Transfer Protocol
  - SMTP – Simple Mail Transfer Protocol
  - SSH – Secure SHell



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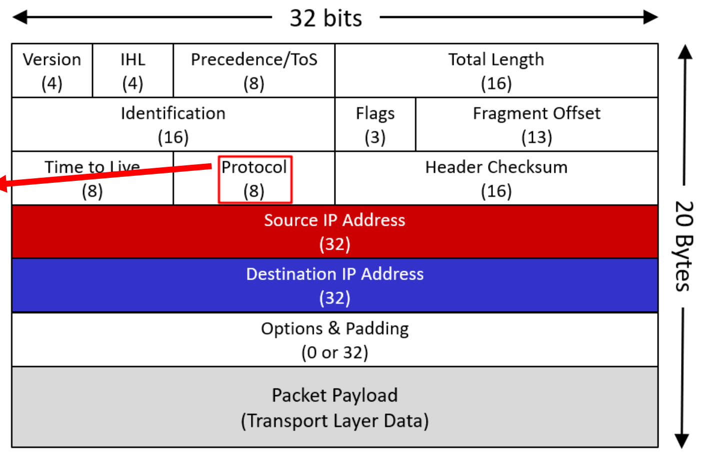
Decimal	Octal	Protocol	Decimal	Octal	Protocol
0	0	Reserved	23	27	Trunk-1
1	1	ICMP	24	30	Trunk-2
2	2	Unassigned	25-60	31-74	Unassigned
3	3	Gateway-to-Gateway	61	75	any host internal protocol
4	4	CMCC Gateway Monitoring Message	62	76	CFTP
5	5	Stream (ST)	63	77	any local network
6	6	Transmission Control (TCP)	64	100	SATNET and Backroom EXPAK
7	7	UCL	65	101	MIT Subnet Support
8	10	Exterior Gateway Protocol (EGP)	66	102	MIT VAX Remote Disk Protocol
9	11	Unassigned	67	103	Internet Pluribus Packet Core
10	12	BBN RCC Monitoring	68	104	Unassigned
11	13	NVP	69	105	SATNET Monitoring
12	14	PUP	70	106	Unassigned
13-14	15-16	Unassigned	71	107	Internet Packet Core Utility
15	17	Cross Net Debugger (XNET)	72-75	110-113	Unassigned
16	20	Chaos Stream	76	114	Backroom SATNET Monitoring
17	21	User Datagram (UDP)	77	115	Unassigned
18	22	Multiplexing	78	116	WIDEBAND Monitoring
19	23	DCN Measurement Subsystems	79	117	WIDEBAND EXPAK
20	24	Host Monitoring (HMP)	80-254	120-376	Unassigned
21	25	Packet Radio Measurement	255	377	Reserved
22	26	XEROX NS IP			



Assigned Internet Protocol Numbers

https://datatracker.ietf.org/doc/html/rfc820

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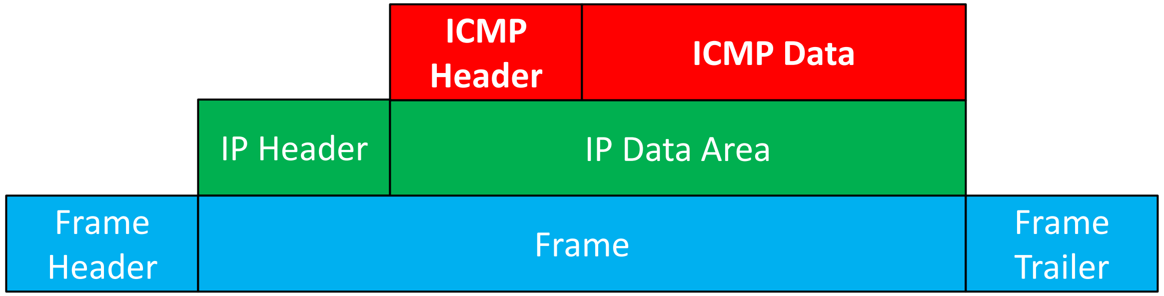
South Bend, IN

- Network Layer Protocol (ICMP)
  - RFC 1256, https://datatracker.ietf.org/doc/html/rfc1256
- Used by hosts for:
  - Error messaging/control
  - Network diagnosis
- Common messages
  - 0 – Echo Reply
  - 3 – Destination Unreachable
  - 5 – Redirect Message
  - 8 – Echo Request
  - 11 – Time Exceeded
- Not associated with any transport layer protocol
- Typically associated with Layer 3
- Common applications
  - Ping – Packet Inter-Network Groper
    - Source host sends ICMP “echo request”
    - Destination host receives, replied with ICMP “echo reply”, RTT returned
  - Traceroute

Type	Name	Reference	Type	Name	Reference
0	Echo Reply	[RFC792]	20-29	Reserved (for Robustness Experiment)	[ZSu]
1	Unassigned		30	Traceroute (Deprecated)	[RFC1393][RFC6918]
2	Unassigned		31	Datagram Conversion Error (Deprecated)	[RFC1475][RFC6918]
3	Destination Unreachable	[RFC792]	32	Mobile Host Redirect (Deprecated)	[David_Johnson][RFC6918]
4	Source Quench (Deprecated)	[RFC792][RFC6633]	33	IPv6 Where-Are-You (Deprecated)	[Simpson][RFC6918]
5	Redirect	[RFC792]	34	IPv6 I-Am-Here (Deprecated)	[Simpson][RFC6918]
6	Alternate Host Address (Deprecated)	[RFC6918]	35	Mobile Registration Request (Deprecated)	[Simpson][RFC6918]
7	Unassigned		36	Mobile Registration Reply (Deprecated)	[Simpson][RFC6918]
8	Echo	[RFC792]	37	Domain Name Request (Deprecated)	[RFC1788][RFC6918]
9	Router Advertisement	[RFC1256]	38	Domain Name Reply (Deprecated)	[RFC1788][RFC6918]
10	Router Solicitation	[RFC1256]	39	SKIP (Deprecated)	[Markson][RFC6918]
11	Time Exceeded	[RFC792]	40	Photuris	[RFC2521]
12	Parameter Problem	[RFC792]	41	ICMP messages utilized by experimental	[RFC4065]
13	Timestamp	[RFC792]	42	Extended Echo Request	[RFC8335]
14	Timestamp Reply	[RFC792]	43	Extended Echo Reply	[RFC8335]
15	Information Request (Deprecated)	[RFC792][RFC6918]	44-252	Unassigned	
16	Information Reply (Deprecated)	[RFC792][RFC6918]	253	RFC3692-style Experiment 1	[RFC4727]
17	Address Mask Request (Deprecated)	[RFC950][RFC6918]	254	RFC3692-style Experiment 2	[RFC4727]
18	Address Mask Reply (Deprecated)	[RFC950][RFC6918]	255	Reserved	[JBP]
19	Reserved (for Security)	[Solo]			

https://www.iana.org/assignments/icmp-parameters/icmp-parameters.xhtml#icmp-parameters-types

IANA: Internet Assigned Numbers Authority



Internet Control Message Protocol (ICMP)

NETWORKING 102

IPv4 Addresses

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South Bend, IN

The Virtual IPv4 Address

- 32-bit binary address
- 32-bit binary subnet mask
- 2^{32} equals 4,294,967,296 addresses
- 32 bits are divided into four (4) octets/Bytes
- The virtual IPv4 address is expressed in “Dotted Decimal” (aka a “Dotted Quad”) format, i.e. 192.168.1.1
- The IPv4 subnet mask is similarly expressed, i.e. 255.255.255.0

Version (4)	IHL (4)	Precedence/ToS (8)	Total Length (16)
Identification (16)		Flags (3)	Fragment Offset (13)
Time to Live (8)		Protocol (8)	Header Checksum (16)
Source IP Address (32)			
Destination IP Address (32)			
Options & Padding (0 or 32)			
Packet Payload (Transport Layer Data)			

32 bit IP Address 11000000.10101000.00000001.01001001 (3,232,235,849; 0xC0.A8.01.49)			
Octet 1	Octet 2	Octet 3	Octet 4
11000000	10101000	00000001	01001001
192	168	1	73

4 Bytes

32 bit Subnet Mask 11111111.11111111.11111111.00000000			
Octet 1	Octet 2	Octet 3	Octet 4
11111111	11111111	11111111	00000000
255	255	255	0
Network Bits			Host Bits

4 Bytes

IPv4 Classes and Default Masks

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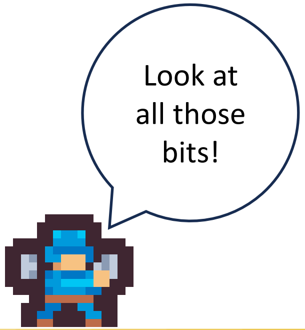
	32 bits			
	8 bits	8 bits	8 bits	8 bits
Class A	Network	Host	Host	Host
	8 bits	24 bits		
	Default Mask: 255.0.0.0			
Class B	Network	Network	Host	Host
	16 bits		16 bits	
	Default Mask: 255.255.0.0			
Class C	Network	Network	Network	Host
	24 bits			8 bits
	Default Mask: 255.255.255.0			
Class D	Multicast			
Class E	Experimental			



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IPv4 Classes and Default Masks

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	Class A	Class B	Class C
Octet 1 Range	1 - 126	128 – 191	192 – 223
Network Range	1.0.0.0 – 127.0.0.0	128.0.0.0 – 191.255.0.0	192.0.0.0 – 223.255.255.0
Available Networks ($2^{network\_bits}$)	126	16,384	2,097,152
Available Hosts/Network (2^{host_bits})-2	16,777,214	65,534	254
Network bits	8	16	24
Host bits	24	16	8
Default Mask	255.0.0.0	255.255.0.0	255.255.255.0
	0	1 0	1 1 0
	Octet 1	Octet 1	Octet 1

Note: 127.x.x.x is reserved for loopback IP addresses. See RFCs 820 & 5735.

Class A - Octet 1

00000001 – 01111110

1 – 126 (0, 127 rsvd)

1.0.0.0 – 126.255.255.255

Class B - Octet 1

10000000 – 10111111

128 – 191

128.0.0.0 – 191.255.255.255

Class C - Octet 1

11000001 – 11011111

192 – 223

192.0.0.0 – 223.255.255.255

bits / Base2							
7	6	5	4	3	2	1	0
128	64	32	16	8	4	2	1

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IPv4 Classes and Default Masks

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IPv4 Reserved Address Space

Special Use (aka "Reserved") IPv4 Address Space – RFC 5735

https://datatracker.ietf.org/doc/html/rfc5735

IP Address Range	Assigned Use	RFC(s)
0.0.0.0/8	Source hosts on "this" network	1122
10.0.0.0/8	Private networks; Not routed on the Internet	1918
127.0.0.0/8	Loopback address, 127.0.0.1/32 (localhost)	1122
169.254.0.0/16	Link local; Auto-config when DHCP unavailable	3927
172.16.0.0/12	Private networks; Not routed on the Internet	1918
192.168.0.0/16	Private networks; Not routed on the Internet	1918
224.0.0.0/4	Multicast; Formerly Class D	3171
240.0.0.0/4	Reserved for future use; Formerly Class E	1112 S4
255.255.255.255/32	Limited Broadcast Address	919, 922

And so, 2^{32}, or about 4.3 billion, becomes approximately 3.7 billion usable IPv4 addresses.

VLSM and CIDR

Variable Length Subnet Masking

and

Classless Inter Domain Routing

Variable Length Subnet Masking and Classless Internet Domain Routing

RFC 1009, 1517, 1518, 1519, 1520

Variable Length Subnet Masking (VLSM)

- Allows "classless" subnetting
  - Mask information is explicit
- Allows a subnet to be subnetted
  - Takes from host bits
- Some advantages include:
  - Subnet size is variable
  - Less IP space waste
  - More efficient
  - Greater flexibility
  - More scalable

Classless Internet Domain Routing (CIDR)

- Classes (i.e. A, B, C) no longer apply
- IP addresses can be allocated and routed based on network prefix instead of class
- Allows supernets to be created
  - Combines a group of class networks
- CIDR notation is often used
  - Also called slash notation
  - ex. 255.255.240.0 = /20 (20 network bits)
  - Use: 192.168.1.1/24 (255.255.255.0 mask)
- Some advantages include:
  - Efficient use of IP addresses
  - Flexibility
  - Improved routing

VLSM and CIDR – What's the Difference?

Variable Length Subnet Masking (VLSM)

- Defined as the capability to specify a different subnet mask for the same network number on different subnets.
- Helps optimize available address space.
- Allows bits to be borrowed from the host bits.

Classless Internet Domain Routing (CIDR)

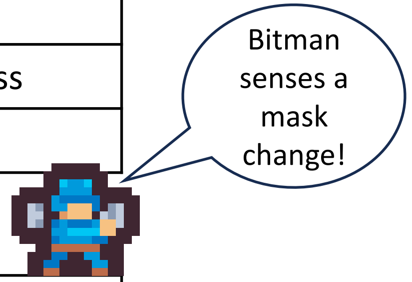
- A technique that is supported by BGP-4 and based on route aggregation.
- Refers to the network and subnet bits of the network mask.

VLSM Illustrated

Classful Network/Host Boundaries			
A			
B	B		
C	C	C	
Octet 1	Octet 2	Octet 3	Octet 4

192	168	1	1
Network Address	Network Address	Network Address	Host Address
Octet 1	Octet 2	Octet 3	Octet 4

VLSM allows mask to be moved



Network	Host
20 subnet mask bits = /20 = 255.255.240.0	12 host bits, $2^{12} - 2 = 4094$ hosts

Octet 1	Octet 2	Octet 3	Octet 4

Network/host boundary can be moved to any bit, back into network this case

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Classful Addressing:
- 192.168.1.1
- 255.255.255.0 mask implied

VLSM Addressing:
- 192.168.1.1 255.255.240.0
- 255.255.240.0 explicit mask

CIDR (aka “Slash”) Notation:
- 192.168.1.1/20

bits / Base2							
7	6	5	4	3	2	1	0
128	64	32	16	8	4	2	1

VLSM and CIDR Example:
- Both have 20 network bits
- Remember the powers of 2, see chart above
- A 255 means there’s a 1 in each position (add all the values)
- The 240 from the example, add bits 7 – 4

EXAMPLE

Classful

		Network	**Host**
24 subnet mask bits = /24 = 255.255.255.0			8 host bits, $2^8 - 2 = 254$ hosts
Octet 1	Octet 2	Octet 3	Octet 4

VLSM

		Network	**Host**
20 subnet mask bits = /20 = 255.255.240.0			12 host bits, $2^{12} - 2 = 4094$ hosts
Octet 1	Octet 2	Octet 3	Octet 4

I wear a mask. And that mask, it's not to hide who I am, but to specify a different subnet mask and optimize available address space.

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IPv4 Address Mask Formats

NETWORKING 102

The 10 Commandments of IPv4 Addressing

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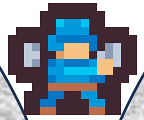


IP Addressing 10 Commandments

I. Thou shalt have a unique Network ID.

II. Thou shalt have a unique Host ID.

III. Thine IP address shalt have a subnet mask, implied shalt be the classful network masks, explicit shalt be the classless network masks.

IV. Thou shalt not use the first IP address of thine network for thine host, for it is thine network.

V. Thou shalt not use the last IP address of thine network for thine host, for it is thine broadcast.

IP Addressing 10 Commandments

VI. Public IP address space shalt be routable over the global Internet.

VII. IP address allocation shalt be governed by the IANA.

VIII. Private IP address space shalt not be routed over the global Internet by any means, to do so is abomination.

IX. Private IP address space shalt be freely assignable by thine organization.

X. Thou shalt cherish thine home (localhost, 127.0.0.1/32, RFC 1122) and all RFC's.

Now, let's work through some examples and exercises…

Examples and Exercises

Learn By Doing!

Description	Octet 1	Octet 2	Octet 3	Octet 4
Class A Subnet Mask (Bin)	11111111	00000000	00000000	0000000
Class B Subnet Mask (Bin)	11111111	11111111	00000000	00000000
Class C Subnet Mask (Bin)	11111111	11111111	11111111	00000000
IP Address (Dec)	192	168	195	39
IP Address (Bin)	11000000	10101000	11000011	00100111
Class Subnet Mask (Bin)	11111111	11111111	11111111	00000000
Class Subnet Mask (Dec)	255	255	255	0
Network Address (Bin)	11000000	10101000	11000011	00000000
Network Address (Dec)	192	168	195	0
Mask 2 (Bin)	11111111	11111111	11110000	00000000
Mask 2 (Dec)	255	255	240	0
Network Address 2 (Bin)	11000000	10101000	11000000	00000000
Network Address 2 (Dec)	192	168	192	0
Network bits | Host bits				

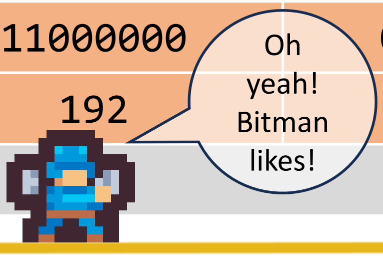
Logical AND

&

=

&

=



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IPv4 Examples and Exercises

NETWORKING 102

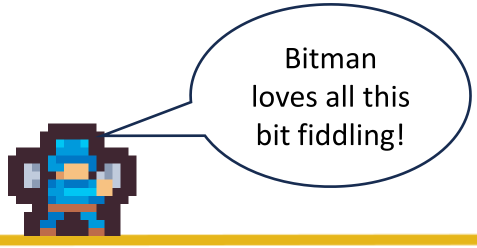
Logical AND

Description	Octet 1	Octet 2	Octet 3	Octet 4
IP Address (Dec)	192	168	222	67
IP Address (Bin)	11000000	10101000	11000011	01000011
Subnet Mask (Bin)	11111111	11111111	1111111	11100000
Subnet Mask (Dec)	255	255	255	224
Network Address (Bin)	11000000	10101000	11000011	01000000
Network Address (Dec)	192	168	222	64
Broadcast Address (Bin)	11000000	10101000	11000011	01011111
Broadcast Address (Dec)	192	168	222	95
Network bits | Host bits				

&

=

Host bits all 1’s



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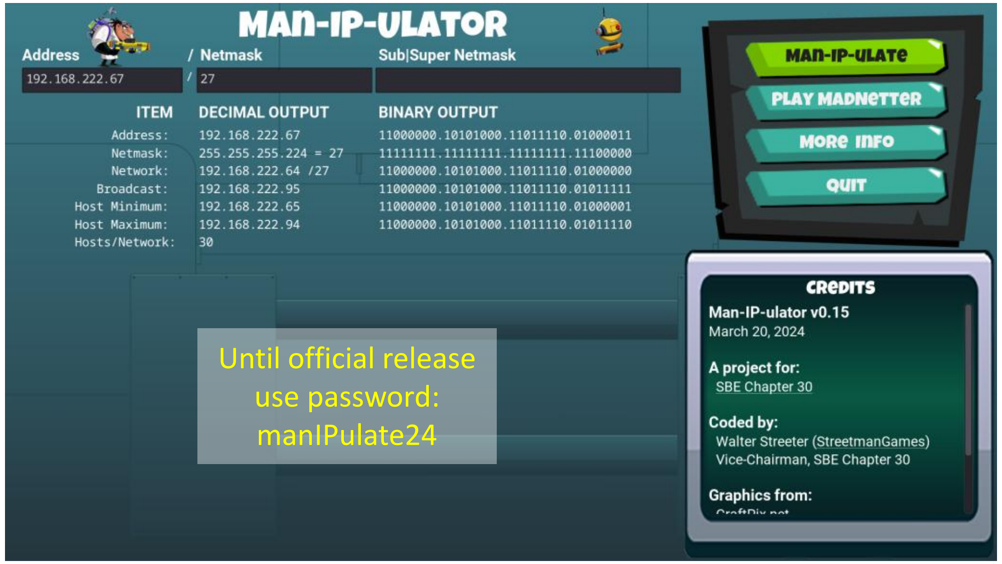
Continuing with examples and exercises…

Understand how & why, then use IP Subnet Calculators

One I've written is…

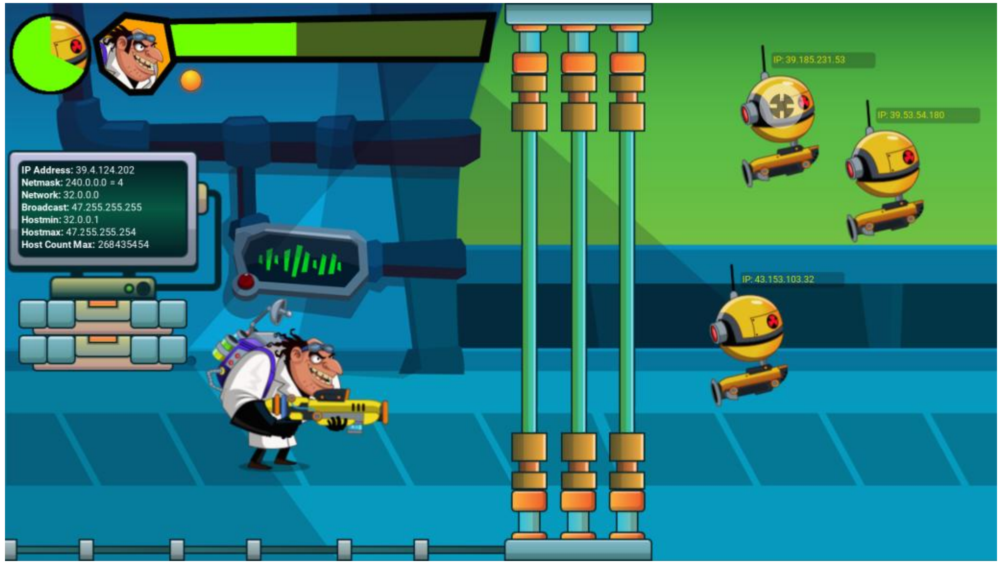
Man-IP-ulator

https://streetmangames.itch.io/man-ip-ulator



Note: Requires graphics card (and browser) that supports WebGL. Most systems do these days, but some older machines don't, or drivers might need updates.

Work continues on the IPv4 address training game part, Mad Netter, but it's somewhat playable.



Summary

Summary

NETWORKING 102

- Understanding IPv4 addressing is essential for the Broadcast Engineer.
- Every host must have a unique network ID.
- Every network must have a unique network ID.
- Every IP address has either an implied or explicit subnet mask.
- There are a number of reserved IP address blocks (RFC 5735).
- VLSM has replaced classful address, but it's important to remember classes.
- It's important to recognize CIDR notation and be able to convert to dotted-decimal.
- Remember the key RFC's and use them to locate information you need.
- Use an IP subnet calculator to double-check or quickly calculate needed information, but endeavor to remember how IP addressing works!

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NETWORKING 101 / 102

"Climbing" the Network "Tower"

(Network Standards and Topologies)

&

Focus On IPv4 Addressing

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