

Introduction To Data Comm & Networking Module 1 - Intro

By Mr. Donald Privitera (CC-BY-SA)

Kennesaw State University

Marietta Campus

College of Computing and Software Engineering

IT Department

dprivit2@kennesaw.edu

What is Data?

DEFINTION OF “DATA”:

Information, especially in a scientific or computational context, or with the implication that it is organized.

From:

[data - Wiktionary](https://en.wiktionary.org/wiki/data)

<https://en.wiktionary.org/wiki/data>

What is Communications?

DEFINTION OF “COMMUNICATIONS”:
Telecommunications, the science and
technology of communicating, especially
by electronic means.

From:

[communications – Wiktionary](https://en.wiktionary.org/wiki/communications)

<https://en.wiktionary.org/wiki/communications>

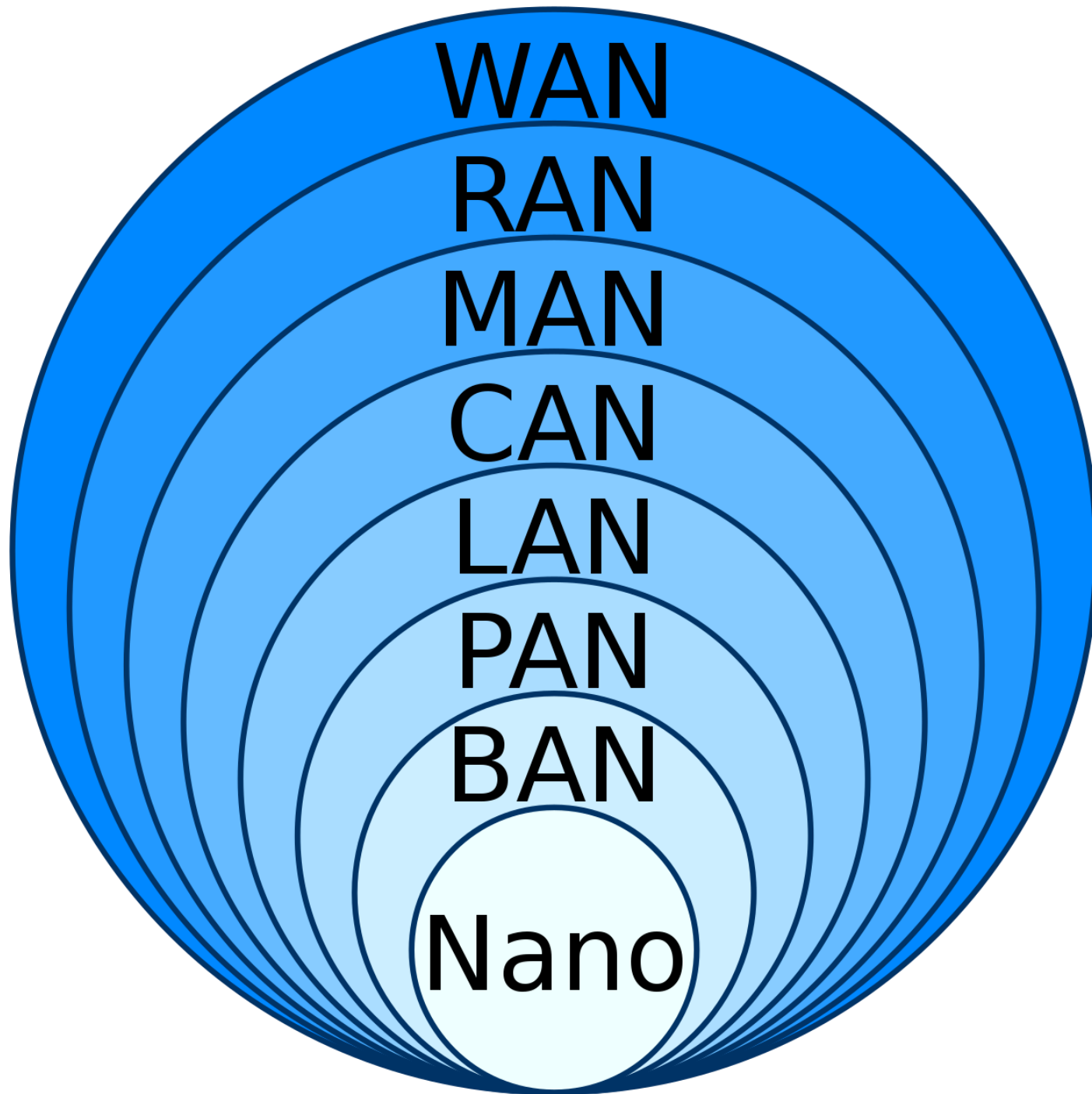
What is Networking?

DEFINTION OF “NETWORKING”:
The use of computer networks.

From:

[networking - Wiktionary](https://en.wiktionary.org/wiki/networking)

<https://en.wiktionary.org/wiki/networking>



Computer Network Types (Spatial Scope)

There are many kinds of computer data networks that can be distinguished by spatial coverage.

Common types are:

[Wide | Regional | Metropolitan | Campus | Local | Personal | Body | Nano] Area Networks.

[Local area network - Wikipedia](https://en.wikipedia.org/wiki/Local_area_network#/media/File:Data_Networks_classification_by_spatial_scope.svg)

https://en.wikipedia.org/wiki/Local_area_network#/media/File:Data_Networks_classification_by_spatial_scope.svg

RS-232 – old serial comm (computers)

RS-485 - Industrial

Ethernet - Computers

SPI – Serial Peripheral Interface (embedded)

CAN – Controller Area Network (vehicles)

LIN – Local Interconnect Network (vehicles)

I2C – Inter-Integrated Circuit (circuit boards)

etcetera

Computer Network Types (By Bus Type)

Many kinds of data communication methods and protocols exist for a variety of uses. Each has its own unique capabilities in terms of media, speed, distance, and number of nodes.

[List of network buses - Wikipedia](#)

https://en.wikipedia.org/wiki/List_of_network_buses

WAN - Backbone/Backhaul

Cars

Airplanes

Boats

Factories

Utility Companies

Space

Military

etcetera

Computers are
everywhere and so
are different kinds
of data networks

AT&T

Verizon

T-Mobile

etcetera

Major providers have high-capacity backbone and backhaul networks made to move a lot of data over long distances.

Guided Media
(physical)

Unguided Media
(wireless)

Media types
fall into two
major
categories.

Metal Wire
(electrical)

Fiber Optic
(light)

Guided
(physical)
media types

Radio

Light

Sound

Unguided
(wireless)
media types

History of communications

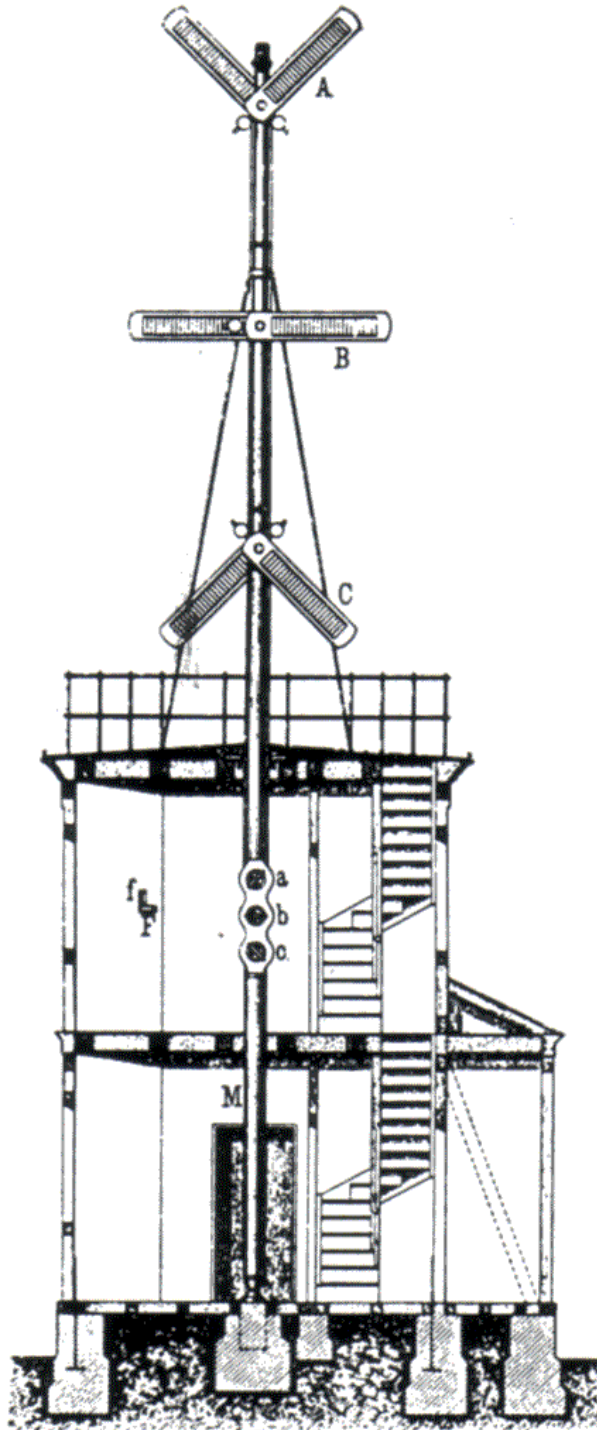
History – Great Wall of China used beacon fires 400 BC



Telegraphy – Wikipedia

<https://en.wikipedia.org/wiki/Telegraphy>

<https://youtu.be/jmowzoZlYqc>

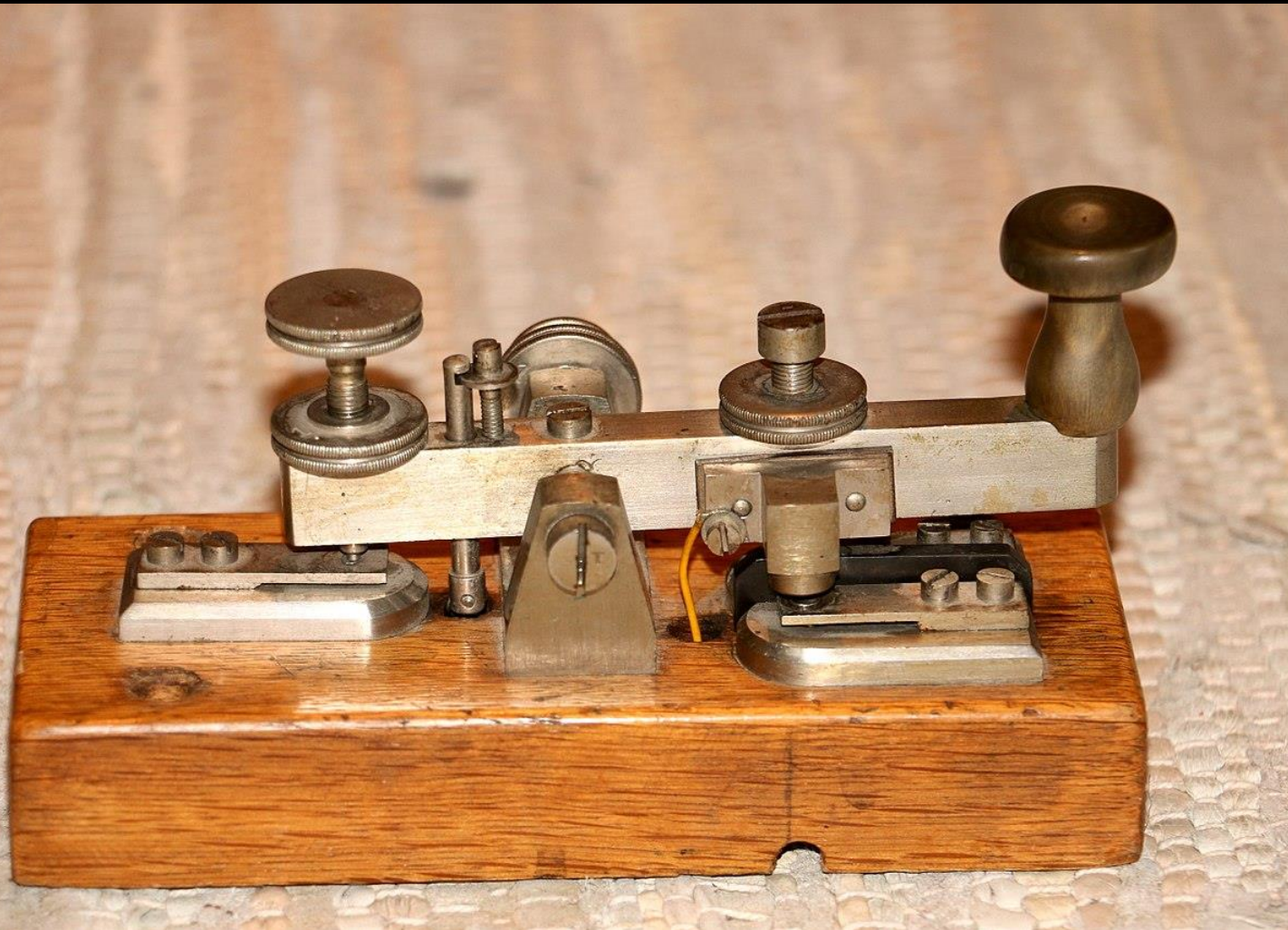


French Optical Telegraph using Semaphores 1793

This optical method of communication allowed messages to be conveyed over long distances as practically observed through a telescope.

[Telegraphy - Wikipedia](https://en.wikipedia.org/wiki/Telegraphy)

<https://en.wikipedia.org/wiki/Telegraphy>



Morse Electric Telegraph 1844

Electricity allowed messages to be relayed over wires run from point-to-point. In the US, Morse invented the telegraph which used pulses of short and long duration to encode alphabetic letters allowing arbitrary messages.

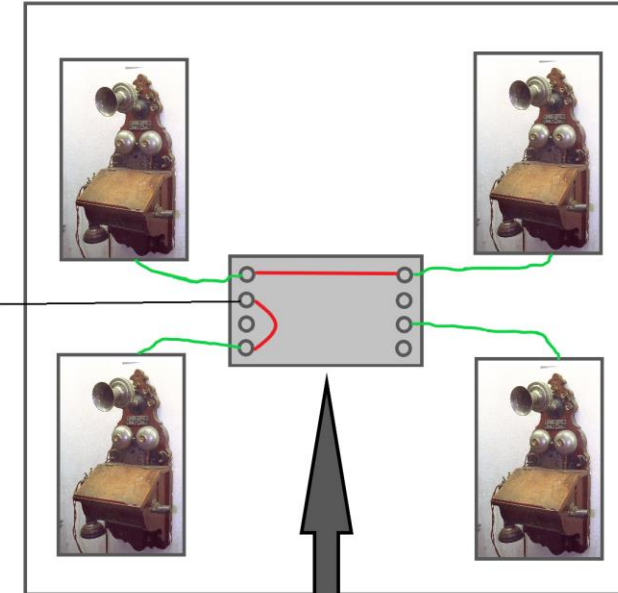
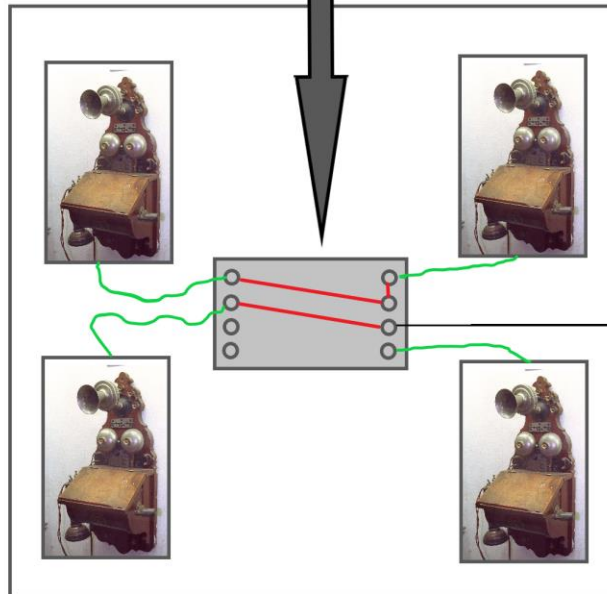
<https://en.wikipedia.org/wiki/Telegraphy>

Circuit Switched Telephone Network Concepts

Public Switched Telephone Network Example



Human operators worked in a switching office and were responsible for setting up the circuits connecting telephones end to end. Technology eventually replaced human operators increasing the speed at which circuits were setup.



Circuit Switched Telephone Network

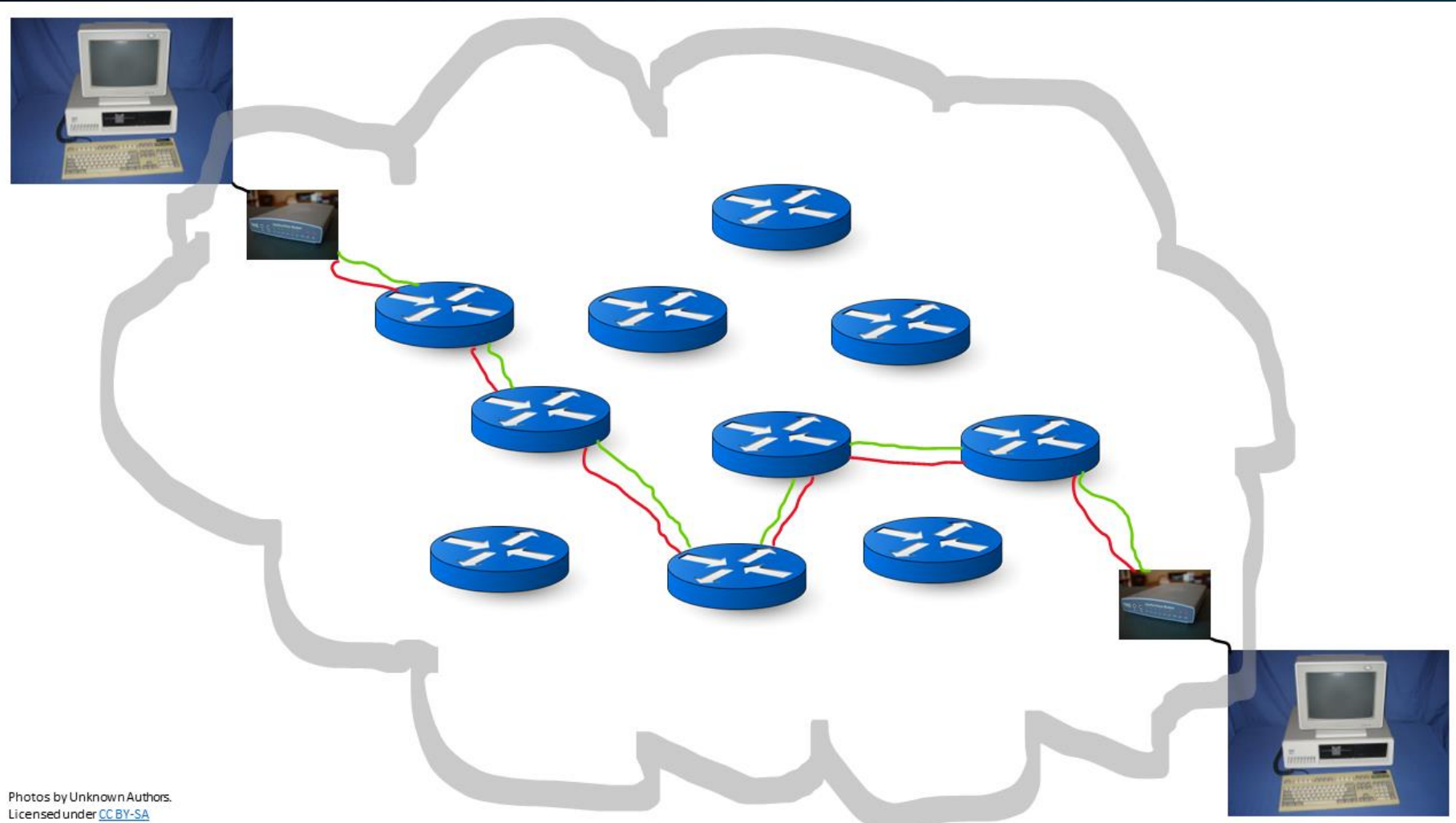
The old analog telephone system used to use a pair of wires to connect 2 telephones together using 48 volts DC. Electricity flowed from one phone to another making a true circuit. Listen to what the old analog system sounded like; due to the imperfect nature of analog systems, you can hear things like attenuation, noise, crosstalk, and the setup of the circuit. NOTE: circuit switched telephone network is synonymous with public switched telephone network (PSTN).



<https://youtu.be/eiQ2MwMdYPk>

Circuit Switched Data Network

Circuit switched telephone networks began to be used for data transmission using modems which allow digital signals to be converted to analog signals which were compatible with the old PSTN.



Circuit Switching

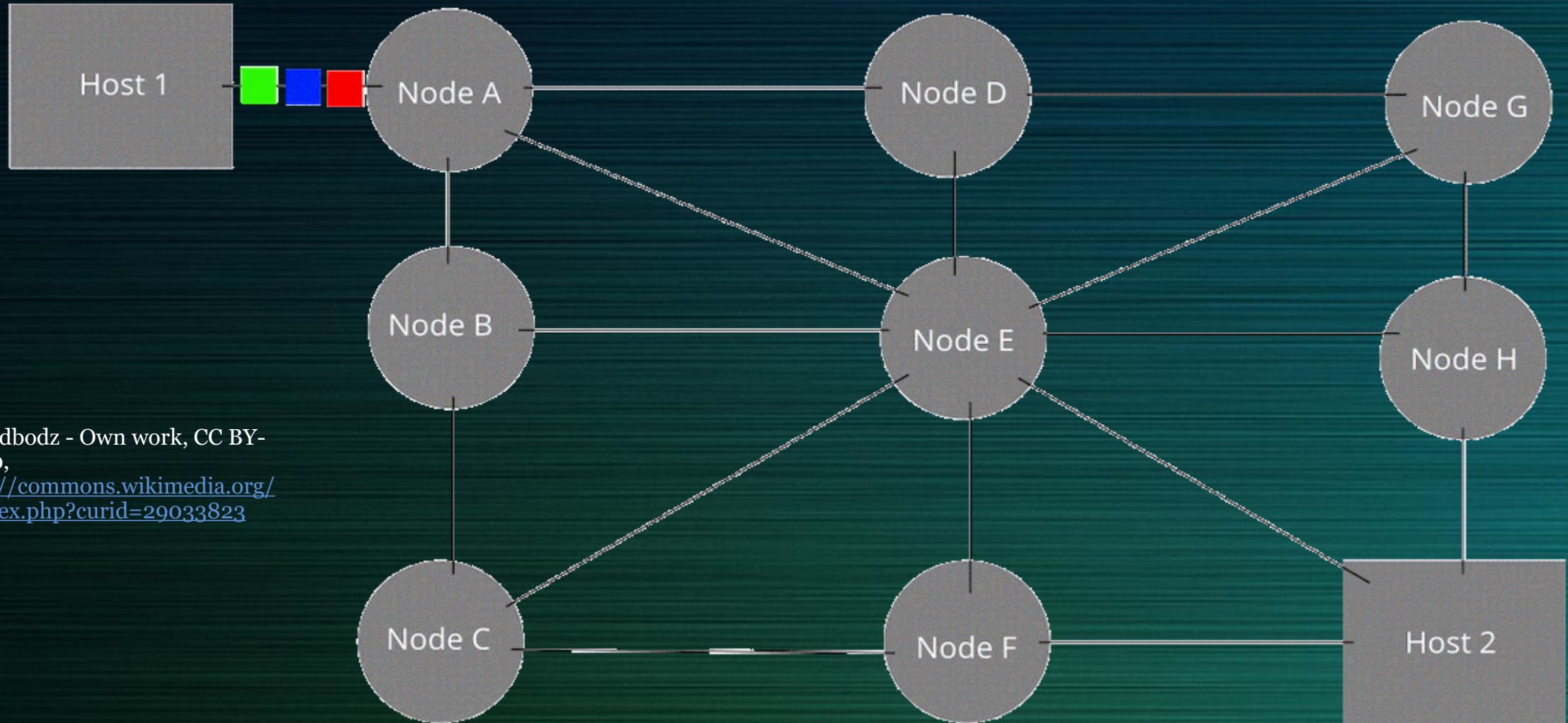
- Circuit switched networks dynamically create a dedicated circuit from point-to-point.
- Circuits are dedicated while in use tying up resources.
- Most applications do not take full advantage of the resources making this approach inefficient.
- When the call is completed, the circuit resources are released and only then can be reallocated.

Packet switching

- Packet switching breaks up the data into packets and uses addresses and routes to move packets the most efficient way possible and can automatically adjust for loading and/or damage to the network automatically re-routing on the fly.
- Packets often arrive out of order and must be reassembled.
- Missing packets (due to congestion or noise) are tracked and resent.
- Algorithms can adjust speed to fit the parameters of the transmission medium and conditions.

Packet switching is more efficient

The original message is **Green**, **Blue**, **Red**.



By Oddbodz - Own work, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=29033823>

Packet Switching history

- Concept originated around 1961 by Rand Corporation.
- Independently developed in UK in 1965.
- US, UK, French developed first networks around 1970's.
- TCP/IP conceived in 1974.
- SOURCE:
https://en.wikipedia.org/wiki/Packet_switching

Packet switching network

- There are many packet switching networks.
- Ethernet TCP/IP is the most popular networking standard.

Networks have layers just like onions and ogres

https://www.youtube.com/watch?v=q_ialpeGLoM

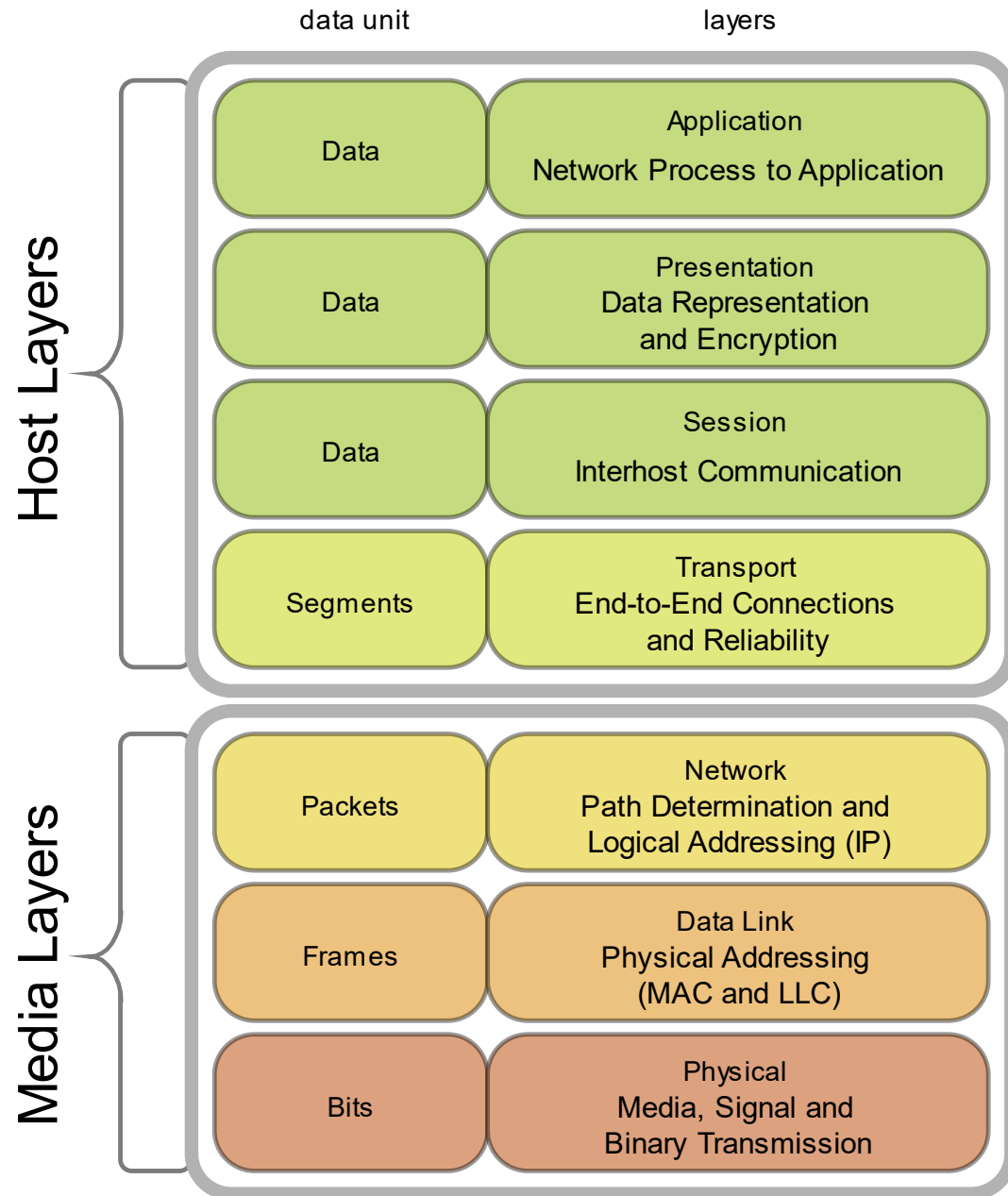


A conceptual model for networking



Russian nesting dolls illustrate the concept of layers. Similarly, network models use layers that encapsulate data within other layers.

<https://images.freeimages.com/images/large-previews/6a4/russian-nesting-doll-1187383.jpg>

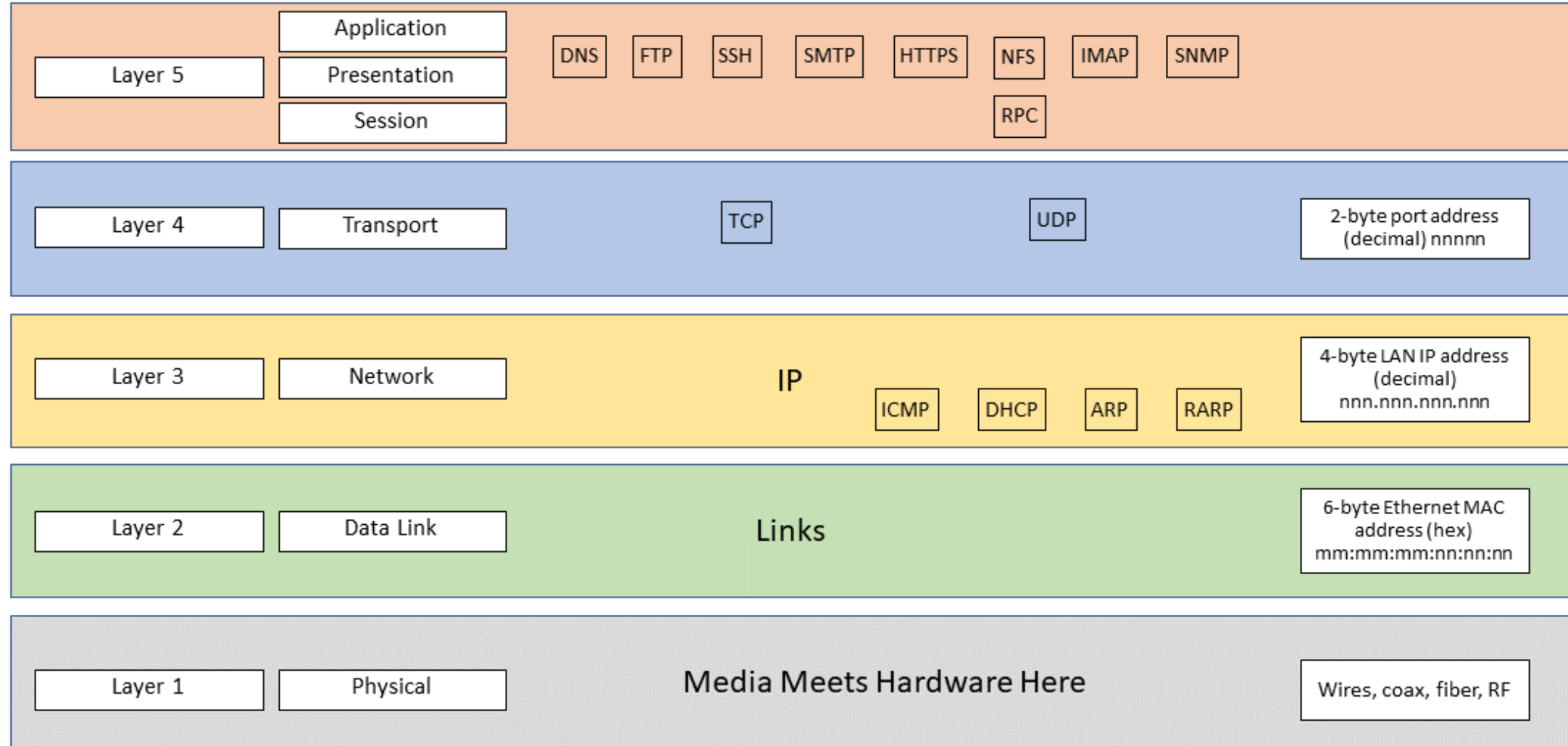


Open Systems Interconnection (OSI) 7-Layer Network Stack Model

This is a conceptual reference model for abstracting and breaking up the complexity of data communication into logical layers. This approach allows a modular design architecture facilitating flexibility and changes at each layer to fit implementations.

https://upload.wikimedia.org/wikipedia/commons/8/8d/OSI_Model_v1.svg

TCP/IP 5-Layer Network Stack Model



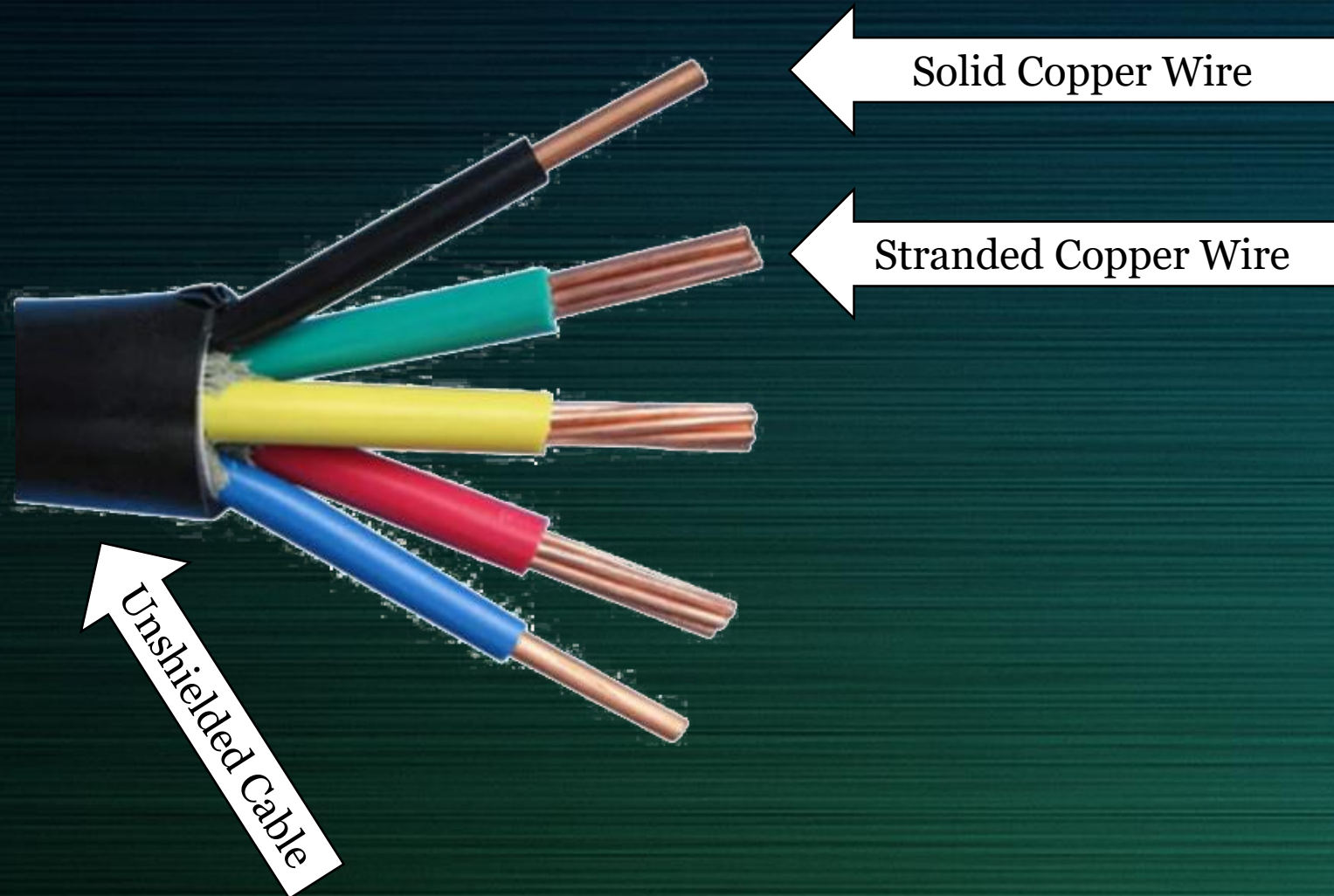
Media

- The very bottom layer is actually the media/medium.
- Remember it's guided or unguided.

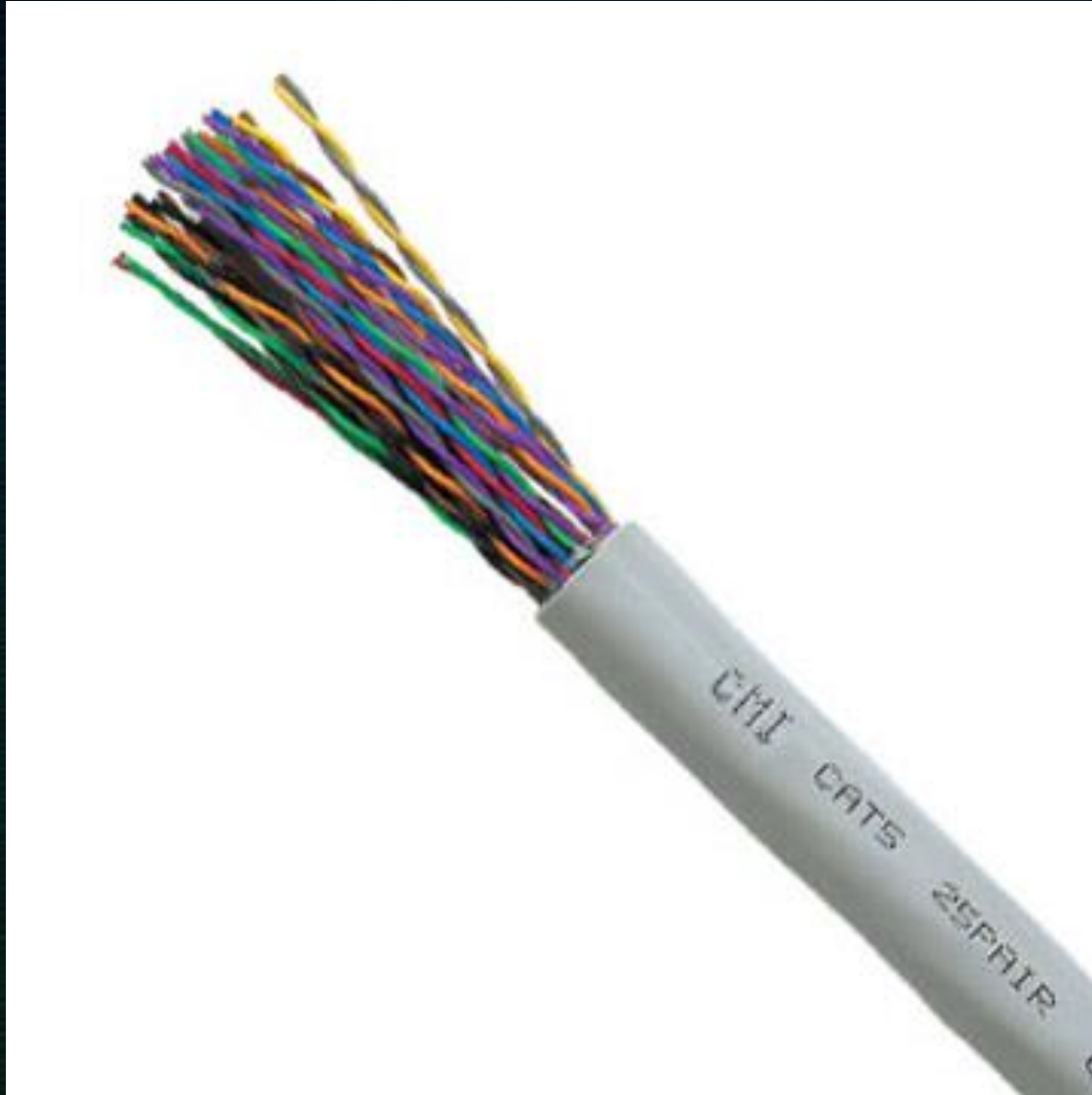
Guided Media - WIRE

- There are many different kinds of wire.
- Wire can vary by diameter, metal, insulation, twist, arrangement, shielding, conductors, stranding, etc.
- Copper is commonly used for wire because it has high conductivity and low cost. Copper wire can be solid or stranded; stranded wire is more flexible.
- Wire can be linear or twisted; twisted wire suppresses noise.
- Wire can be unshielded (less costly) or shielded; shielded wire suppresses noise.
- Wire can be parallel or coaxial.

Guided Media – WIRE - Example



Guided Media – WIRE – Phone



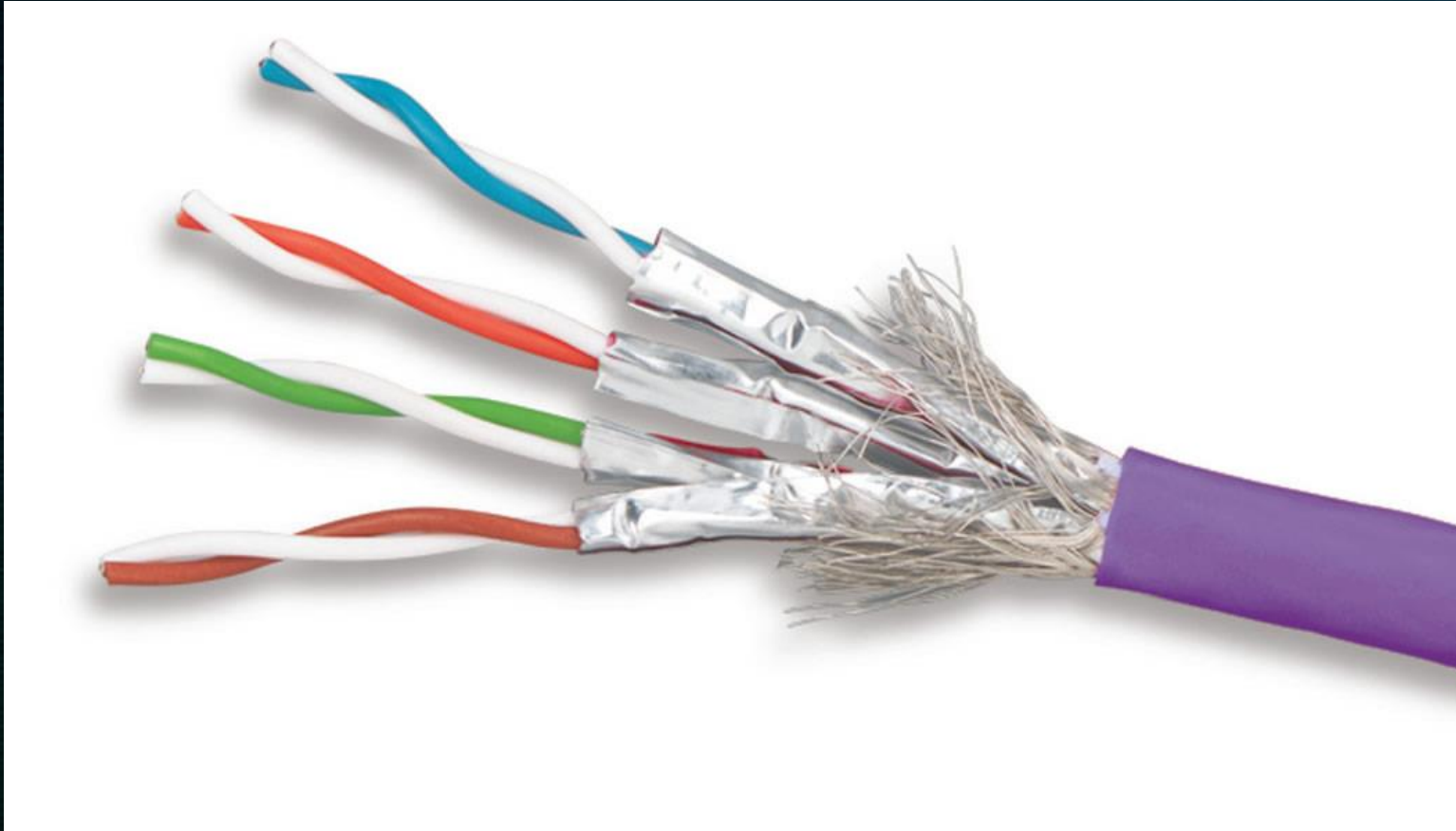
This cable contains 25 twisted pairs of solid copper wire for telephone analog voice applications. This is Category (Cat) 5 type wire which uses small conductors 24 American Wire Gauge (AWG). NOTE: Cat5 data cable only contains 4 pairs because of crosstalk considerations.

Guided Media – WIRE – Legacy Data Cables



Three Cat5 data cables. From left to right: shielded twisted pair, unshielded twisted pair, and a fully terminated cable with an RJ45 modular plug connector.

Guided Media – WIRE – Data Cables



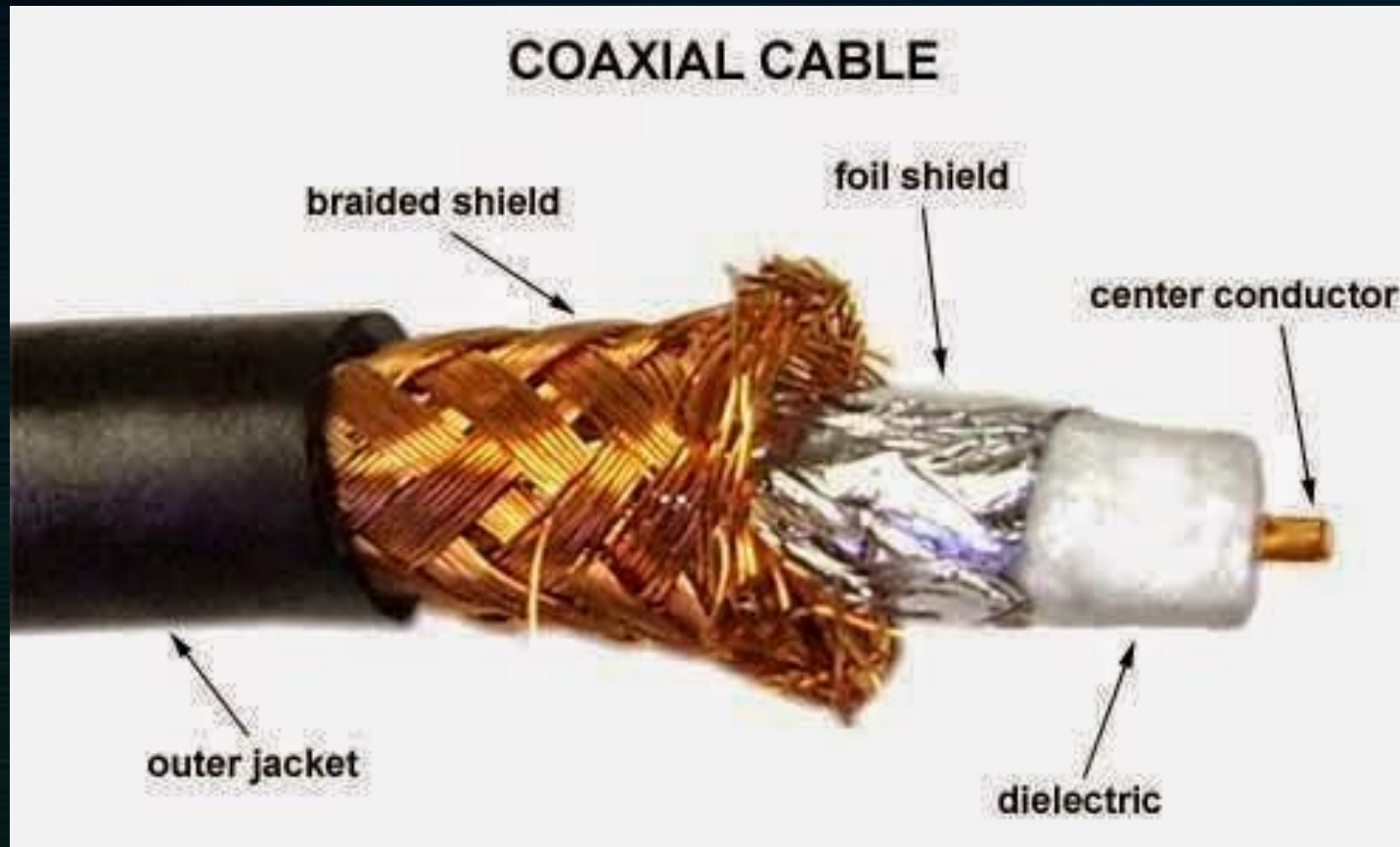
Cat7 and Cat8 shielded twisted pair cable is the current standard for high-speed data communication over wire. Note that each pair is also shielded individually to mitigate crosstalk.

Guided Media – WIRE – Twisted Pair

Category	Bandwidth (Mhz)	Nominal Data Transfer Speed (Gbps)	Max Data Transfer Speed (Gbps)	Shielding overall	Shielding over individual pairs
Cat5e	100-350	100	1	Optional	None
Cat 6	250-350	1	1	Optional	None
Cat 6e	500-550	1	10	Optional	None
Cat 7	600	10	10	Mandatory	Mandatory
Cat 8	2000	25	40	Mandatory	Mandatory

Note: The maximum distance for twisted pair Ethernet cable is typically 100 meters at nominal speed. Max Data Transfer Speed typically is only achievable over a reduced distance. See official IEEE specifications for details.

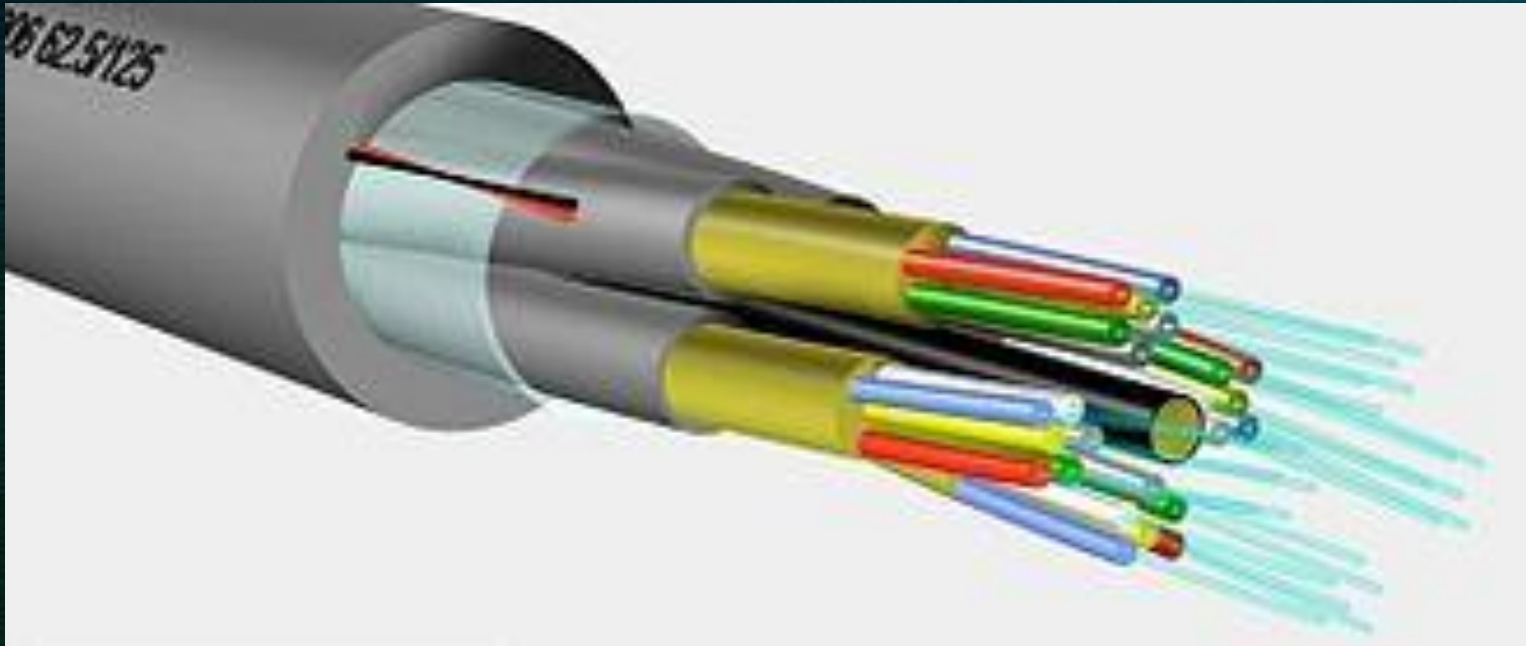
Guided Media – WIRE – Coaxial



Coaxial cable is most notably used in television applications. Though once predominantly used for analog transmissions, coaxial cable now predominantly carries digital transmissions. Coaxial cable is more expensive and bulkier than the more common unshielded twisted pair used in Cat5e and Cat6 applications.

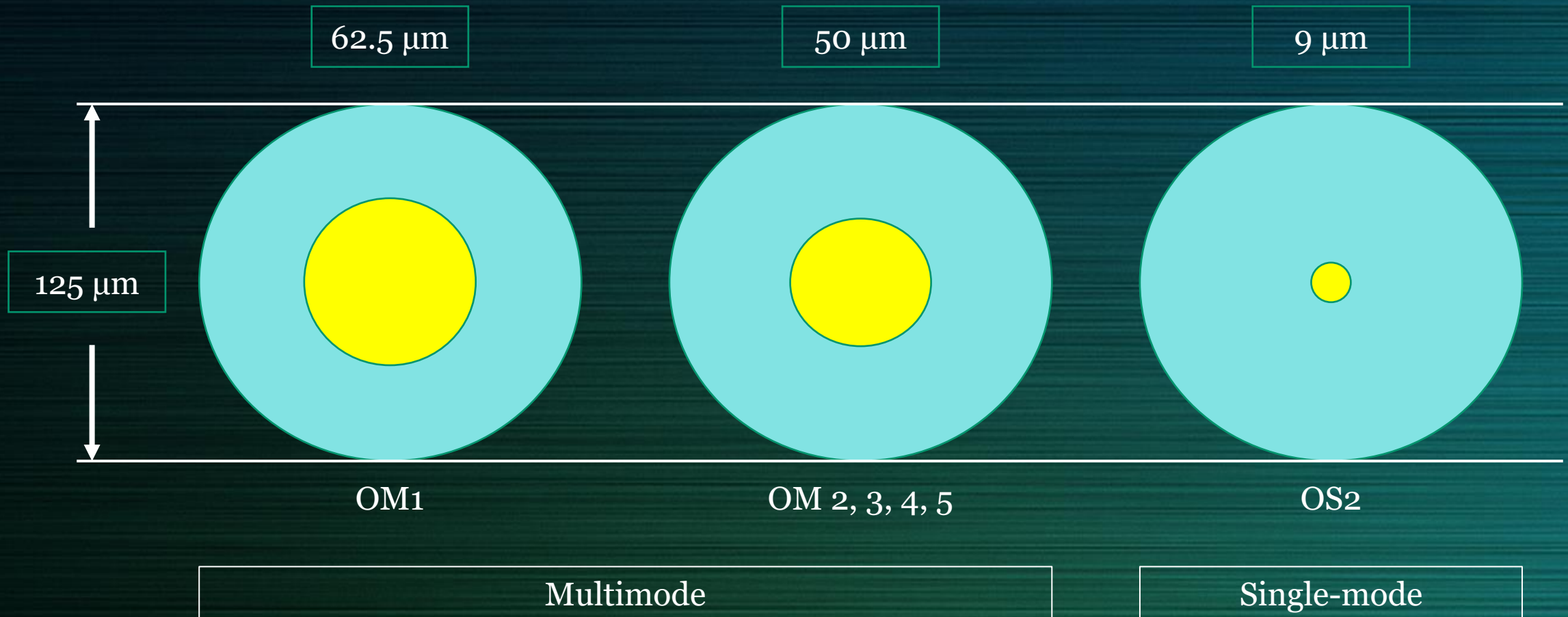
Guided Media – Fiber Optic

Fiber optic uses modulated light (usually laser) to transmit data. Typically, a pair of fibers are required per connection as there is a fiber for transmit and a fiber for receive. Fibers are hollow; light is transmitted through this hollow core. Fiber has special reflectivity characteristics. Fiber is fragile so the construction of fiber cable includes numerous sheaths to protect the fiber. Some fiber cables include a steel member for added strength.



Guided Media – Fiber Optic Cores

Fiber optic strands are hollow. Laser light bounces through the hollow core. There are 2 major categories of fiber optic strands: multi-mode and single mode. Multi-mode is ideal for shorter distances, is less costly to implement, and is more widely used. Single mode is specialized, more costly to implement, and is ideal for high-bandwidth applications over longer distances.



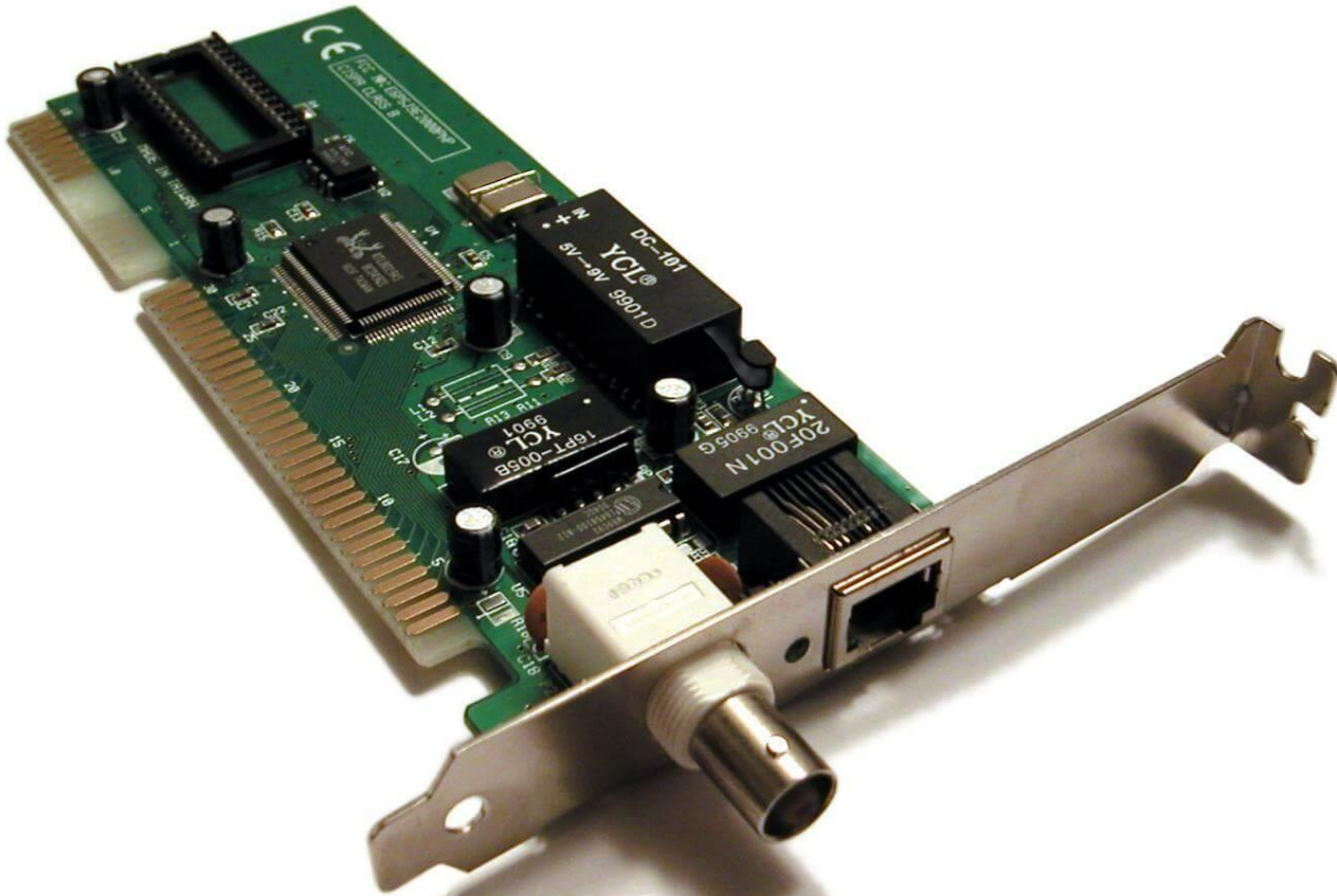
Guided Media – General Differences

	Unshielded Twisted Pair	Shielded Twisted Pair	Coaxial Cable	Fiber Optic Cable
Cost	Low	Medium	Medium	High
Node-to-Node Distance	100m	100m	~1000m	~5890Km*
Bandwidth	1 Gbps	10 Gbps	Medium	High
Nodes	Point-to-Point	Point-to-Point	Multi-Point	Point-to-Point
RF Immunity	Low	Medium	Medium	High

*https://www.theregister.com/2015/02/05/british_boffinry_doubles_the_distance_of_fiber_optic_data_transmission_and_boosts_bandwidth/#:~:text=That%205890km%20distance%2C%203659%20miles%2C%20is%20enough%20to,at%20the%20Nyquist%20frequency%22%20within%20a%20single%20cable.

<https://community.fs.com/blog/the-difference-between-fiber-optic-cable-twisted-pair-and-cable.html#:~:text=Speed%2C%20Bandwidth%20%26%20Distance%20%20%20%20Cable,MHz%20%28default%29%20%20%20Up%20to%20500m%20>

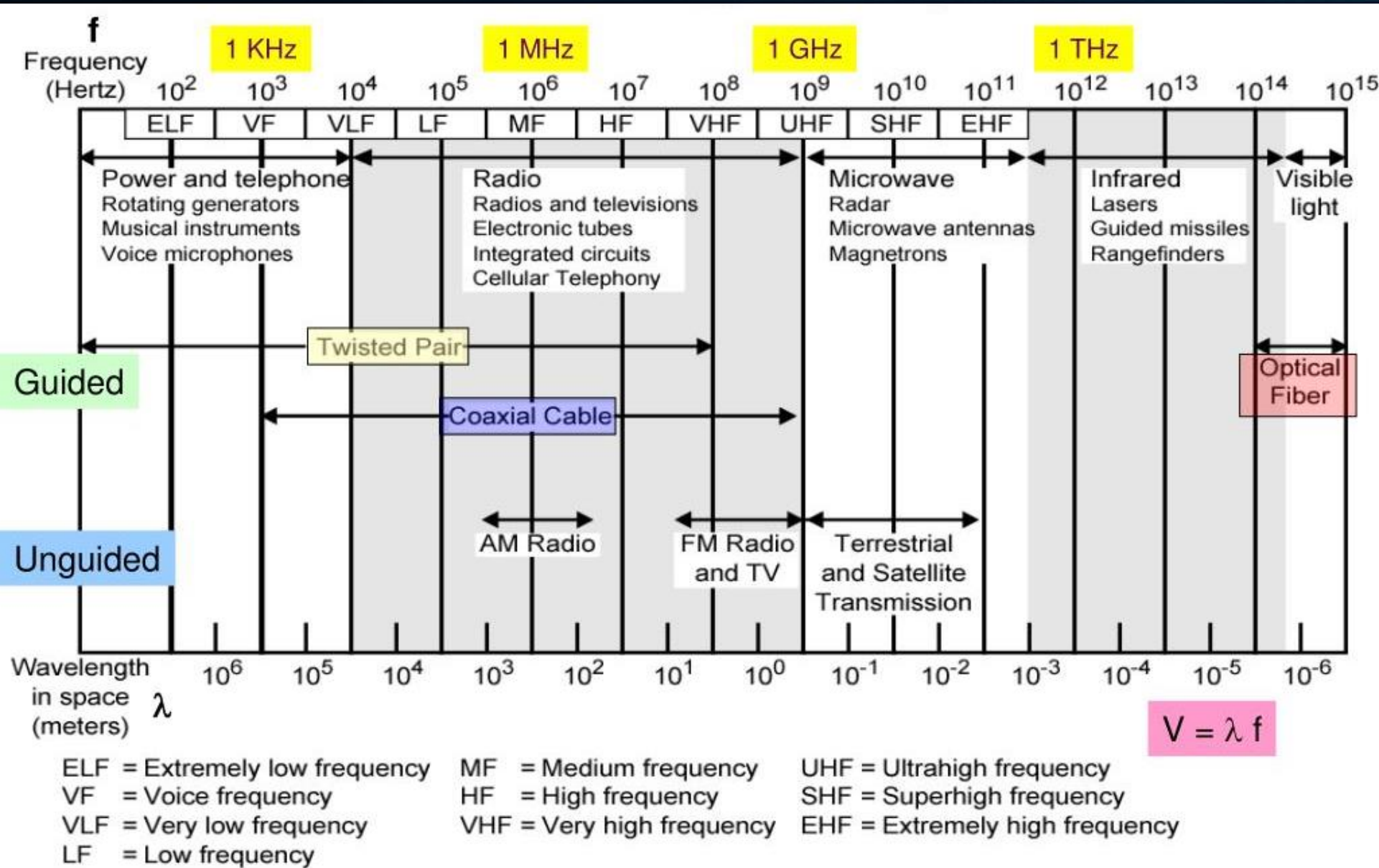
Guided Media – Network Cards



NOTE: an older Network Interface Controller (NIC) card for PC with media support for either coaxial cable or Ethernet twisted pair.

https://upload.wikimedia.org/wikipedia/commons/9/9e/Network_card.jpg

Electromagnetic Spectrum Common Uses



Note the parts of the EM spectrum which are typically associated with guided and unguided media.

<https://image1.slideserve.com/2945707/part-of-the-electromagnetic-spectrum-1.jpg>

Unguided Media – Radio (Metropolitan Area Network)



Point-to-point microwave beaming is used for long distances.

Unguided Media – Radio (Local Area Network)



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Unguided Media – Radio (Personal Area Network)



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Unguided Media – Hacking RF/EM Emanations



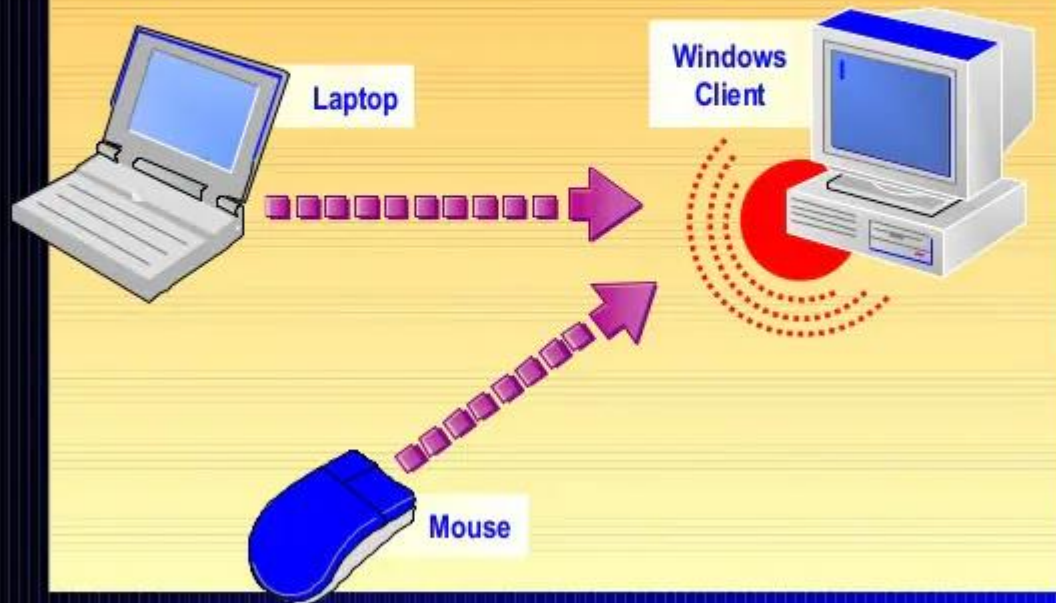
Watch out! All electronic devices (except rare special “rf hardened”) emit radio frequencies which can be intercepted and analyzed to determine what the device was doing. Also known as side-channel hacking.

<https://www.tau.ac.il/~tromer/radioexp/untethered-pita-with-baudline---fullres.jpg>

Unguided Media – Light

Infrared Data Association (IrDA)

Wireless Communication by Using IrDA



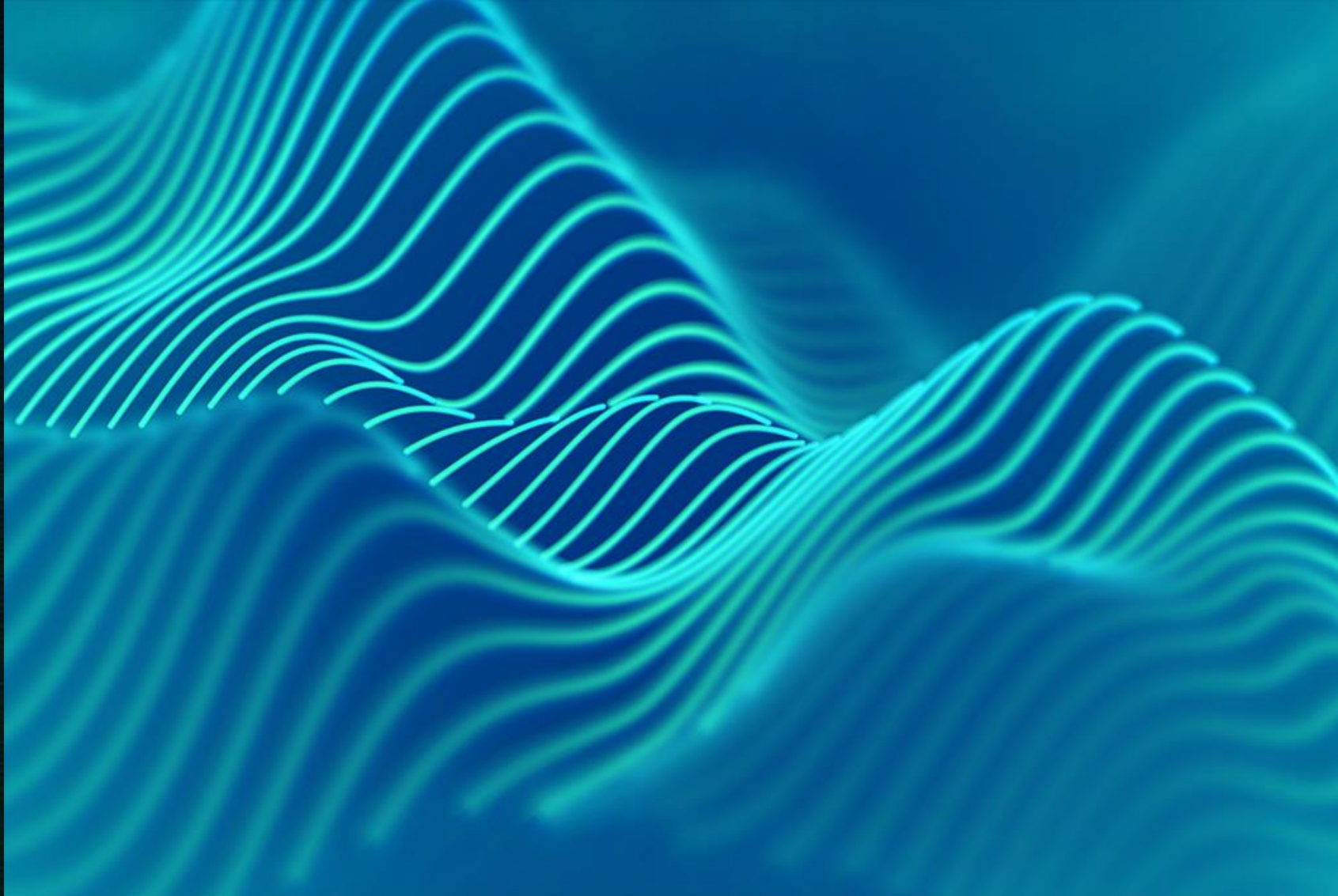
21

<https://image.slidesharecdn.com/network9-150124085834-conversion-gate01/95/network-connet-21-638.jpg?cb=1422111625>



<https://networkencyclopedia.com/wp-content/uploads/2020/05/infrared-data-association-IrDA.jpg>

Unguided Media – Sound



Data can be transmitted over sound; for example, via inaudible ultrasonic frequencies.

<https://innovationatwork.ieee.org/transferring-data-over-sound/>

Types of communication

TYPE	MODE	EXAMPLE
Simplex	One way	Television
Half-Duplex	One-at-a-time	Walkie-talkie
Duplex	Simultaneous	Telephone

Signaling Concepts

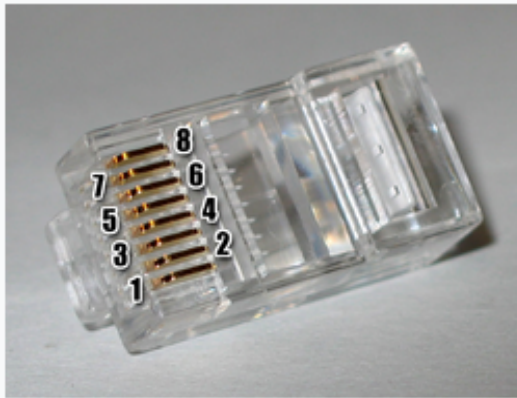
- Digital (square wave) signaling is fundamentally analog at the physical level. Thus, a square wave signal loses its shape the closer you look at it.
- Electronic components are not perfect and operate within tolerances. For example, a digital “zero” could be represented by voltages of 0 volts – 2 volts while a digital “one” could be 3 volts – 5 volts. This means that if a voltage signal is in the undefined range of 2 volts to 3 volts, behavior would be unpredictable. This sometimes accounts for glitches in equipment.
- Zeros and ones are often interpreted when voltage transitions.
- Data transmission may be synchronous or asynchronous.
- Data is surrounded by many header and trailer signals which identify beginning and ending of data and error detection resulting in more actual bits being sent than just the data. These extra bits consume bandwidth and add to latency creating “overhead”.

Ethernet Speed Evolution

Year	IEEE Std.	Name	Data Rate	Cabling
1990	802.3i	10BASE-T	10 Mbps	Cat 3
1995	802.3u	100BASE-TX	100 Mbps*	Cat 5
1998	802.3z	1000BASE-SX, 1000BASE-LX/EX	1 Gbps	Multimode fiber (MMF) Single-mode fiber (SMF)
1999	802.3ab	1000BASE-T	1 Gbps*	Cat 5e
2003	802.3ae	10GBASE-SR, 10GBASE-LR/ER	10 Gbps	Laser-optimized MMF SMF
2006	802.3an	10GBASE-T	10 Gbps*	Cat 6A
2010	802.3ba	40GBASE-SR4/LR4 100GBASE-SR10/LR4/ER4	40 Gbps 100 Gbps	Laser-optimized MMF or SMF Laser-optimized MMF or SMF
2015	802.3bq	40GBASE-T	40 Gbps*	Cat 8 (class I & II)
2015	802.3bm	100GBASE-SR4	100 Gbps	Laser-optimized MMF
2018	802.3bs	400GBASE-SR8 400GBASE-SR4.2	400 Gbps	MMF OM3, OM4, OM5

* = with auto negotiation

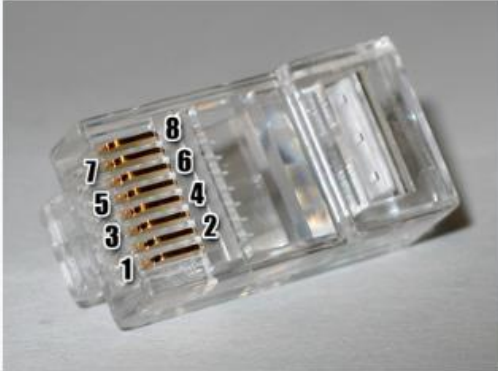
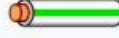
ANSI/TIA568 Wiring Pinout (RJ45)

Pin	T568A pair	T568B pair	10BASE-T 100BASE-TX ^[10]	1000BASE-T signal ID ^[11]	Wire	T568A color	T568B color	Pins on plug face
1	3	2	TX+	DA+	tip	 white/green stripe	 white/orange stripe	
2			TX-	DA-	ring	 green solid	 orange solid	
3	2	3	RX+	DB+	tip	 white/orange stripe	 white/green stripe	
4	1		not used	DC+	ring	 blue solid		
5			not used	DC-	tip	 white/blue stripe		
6	2	3	RX-	DB-	ring	 orange solid	 green solid	
7	4		not used	DD+	tip	 white/brown stripe		
8			not used	DD-	ring	 brown solid		

There are 2 main standards for terminating RJ45 jacks and plugs: TIA568 A & B. Whichever standard is used, it must be used on both ends of a network cable. Network cables follow a standard wire color scheme. Note in the diagram, “tip” and “ring” are legacy terms for telephone system wiring and are provided for backward compatibility. NOTE: 10BASE-T & 100BASE-TX only use 2 of the 4 pairs of wires.

Straight vs Crossover Cables

Two pairs crossed, two pairs uncrossed 10BASE-T or 100BASE-TX crossover^[5]

Pin	Connection 1: T568A			Connection 2: T568B			Pins on plug face
	signal	pair	color	signal	pair	color	
1	BI_DA+	3	 white/green stripe	BI_DB+	2	 white/orange stripe	
2	BI_DA-	3	 green solid	BI_DB-	2	 orange solid	
3	BI_DB+	2	 white/orange stripe	BI_DA+	3	 white/green stripe	
4		1	 blue solid		1	 blue solid	
5		1	 white/blue stripe		1	 white/blue stripe	
6	BI_DB-	2	 orange solid	BI_DA-	3	 green solid	
7		4	 white/brown stripe		4	 white/brown stripe	
8		4	 brown solid		4	 brown solid	

A crossover cable is required to connect a computer directly to another computer; otherwise, a hub or switch is required.

[Ethernet crossover cable – Wikipedia](https://en.wikipedia.org/wiki/Ethernet_crossover_cable)

https://en.wikipedia.org/wiki/Ethernet_crossover_cable

Modern RJ45 connector attachment



Modern RJ45 jack attachment



https://www.youtube.com/watch?v=qVa_Zrg_ERg

Standards

- Over time, different ways of transmitting data have evolved.
- Each way/method is unique and typically can only work when devices follow the exact same way/method.
- Different ways/methods are known as protocols.
- Protocols define precisely how data should be transmitted.
- Protocols evolve over time (versions) and are ratified by standards bodies.

Major Standards Bodies

- ANSI = American National Standards Institute
- BICSI = Building Industry Consulting Service International
- IEC = International Electrotechnical Commission
- IEEE = Institute of Electrical and Electronic Engineers
- IETF = Internet Engineering Task Force
- ISO = International Standards Organization
- ISOC = Internet Society
- ITU = International Telecommunication Union
- TIA = Telecommunications Industry Association

The IEEE 802 standard

“IEEE 802 is a family of Institute of Electrical and Electronics Engineers (IEEE) standards for local area networks (LAN), personal area network (PAN), and metropolitan area networks (MAN). The IEEE 802 LAN/MAN Standards Committee (LMSC) maintains these standards. The IEEE 802 family of standards has twelve members, numbered 802.1 through 802.12, with a focus group of the LMSC devoted to each...”

Copied from https://en.wikipedia.org/wiki/IEEE_802 on 8/16/21

IETF Request For Comment (RFC)

The Internet Engineering Task Force (IETF) uses Request For Comment (RFC) to generate standards for Internet related technologies.

Network Working Group
Request for Comments: 1122

Internet Engineering Task Force
R. Braden, Editor
October 1989

Requirements for Internet Hosts -- Communication Layers

Status of This Memo

This RFC is an official specification for the Internet community. It incorporates by reference, amends, corrects, and supplements the primary protocol standards documents relating to hosts. Distribution of this document is unlimited.

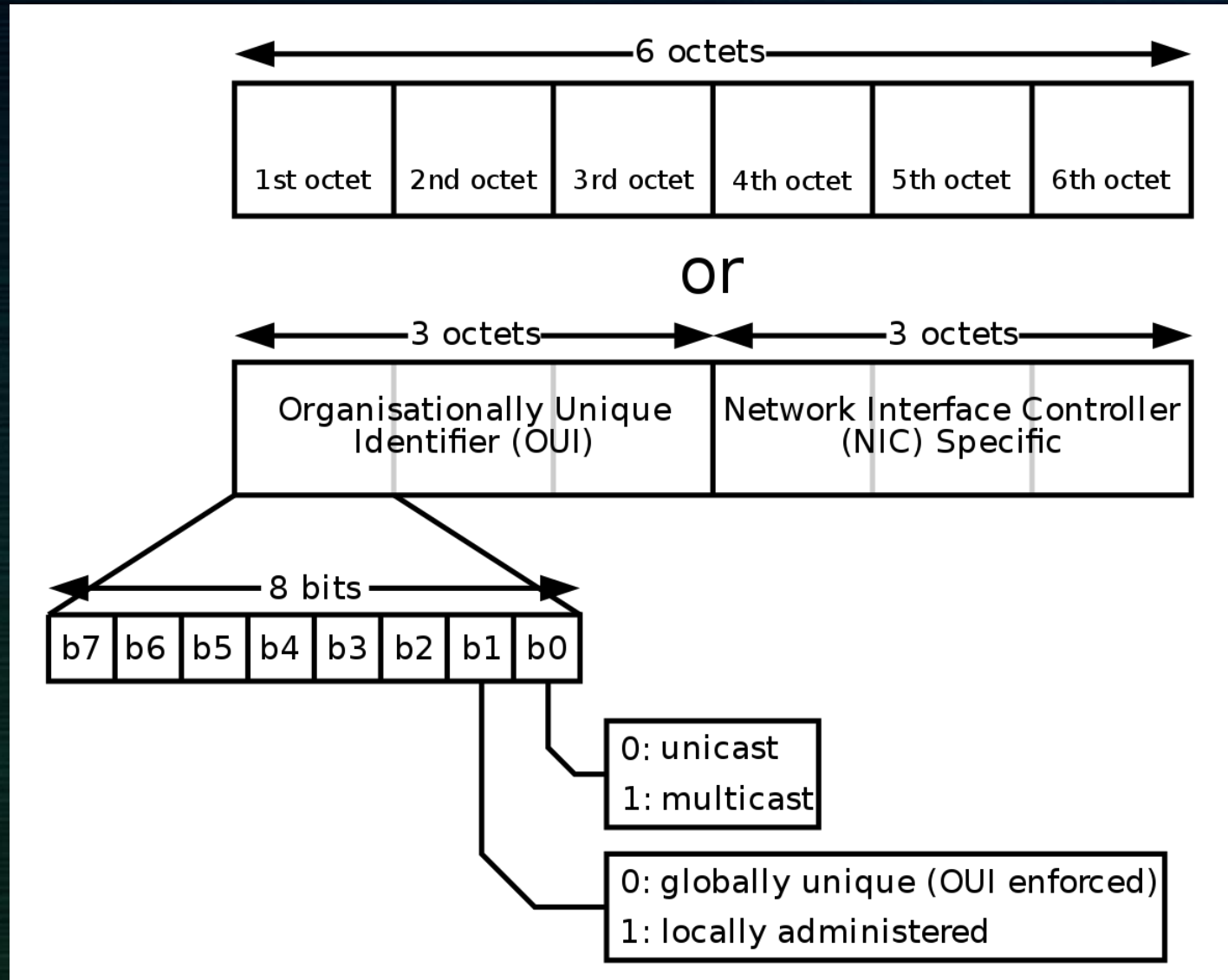
Summary

This is one RFC of a pair that defines and discusses the requirements for Internet host software. This RFC covers the communications protocol layers: link layer, IP layer, and transport layer; its companion RFC-1123 covers the application and support protocols.

TCP/IP Concepts

- TCP/IP refers to the major networking standards used in the world's most popular method of data networking.
- It is based on layers.
- Ethernet is a low-level method of communicating data at the level of bits and at the network (or LAN) layer.
- Each device that supports Ethernet will have a MAC address for each Ethernet interface.
- An Ethernet interface can be a physical RJ45 port, or it can be a WiFi adapter or both. For the case of both, a device will have 2 MAC addresses.
- The MAC address is a unique 6-byte address.

Anatomy of an Ethernet MAC address



SOURCES (page 1):

<https://en.wiktionary.org/wiki/data>

<https://en.wiktionary.org/wiki/communications>

<https://en.wiktionary.org/wiki/networking>

https://en.wikipedia.org/wiki/Local_area_network#/media/File:Data_Networks_classification_by_spatial_scope.svg

https://en.wikipedia.org/wiki/List_of_network_buses

<https://en.wikipedia.org/wiki/Telegraphy>

<https://youtu.be/jmOwzoZlYqc>

[https://en.wikipedia.org/wiki/File:Photograph_of_Women_Working_at_a_Bell_System_Telephone_Switchboard_\(3660047829\).jpg](https://en.wikipedia.org/wiki/File:Photograph_of_Women_Working_at_a_Bell_System_Telephone_Switchboard_(3660047829).jpg)

https://en.wikipedia.org/wiki/File:Wall_Hanging_Telephone_with_Detachable_Earpiece_-_Communication_Gallery_-_BITM_-_Calcutta_2000_211.JPG

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<https://community.fs.com/blog/the-difference-between-fiber-optic-cable-twisted-pair-and-cable.html#:~:text=Speed%2C%20Bandwidth%20%26%20Distance%20%20%20%20Cable,MHz%20%28default%29%20%20%20Up%20to%20500m%20>

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SOURCES (page 2):

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<https://www.tau.ac.il/~tromer/radioexp/untethered-pita-with-baudline---fullres.jpg>

<https://image.slidesharecdn.com/network9-150124085834-conversion-gate01/95/network-connet-21-638.jpg?cb=1422111625>

<https://networkencyclopedia.com/wp-content/uploads/2020/05/infrared-data-association-IrDA.jpg>

<https://innovationatwork.ieee.org/transferring-data-over-sound/>

<https://en.wikipedia.org/wiki/ANSI/TIA-568>

https://en.wikipedia.org/wiki/Ethernet_crossover_cable

<https://www.youtube.com/watch?v=ZTe3PZd1HxE>

https://www.youtube.com/watch?v=qVa_Zrg_ERg

https://en.wikipedia.org/wiki/IEEE_802 on 8/16/21

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