Computer Networks

Open Systems Interconnection (OSI) Model

Layers 1 and 2: **Ethernet**

Lecture Contents

- OSI Layers
- Network Topologies
- Ethernet
  - Coaxial: 10 Base 2, 10 Base 5
  - Fiber: 10 Base F
  - Twisted Pair: 10, 100, 1000, … Base T.

OSI Model Layers

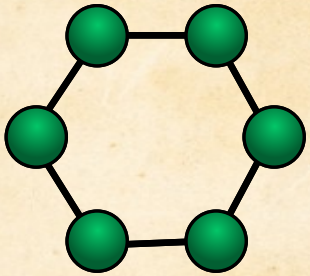
- Seven Layers
  - **Physical**
  - **Data Link**
  - Network
  - Transport
  - Session
  - Presentation
  - Application

Physical Layer

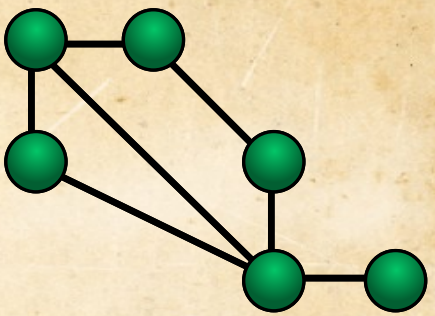
- Lowest layer of the OSI model
- Transmission of raw bits over a physical medium
  - Digital over analog
  - Copper, fiber optics, electromagnetic waves
- Electrical, mechanical, procedural
  - Shapes and properties of connectors and cables
  - Frequencies (electromagnetic spectrum frequency allocation), bandwidth
  - Signal strength
  - Coding system (synchronization, carrier sense, collision detection)
- Examples: PCI Express, 802.11 WiFi, USB, Bluetooth, Ethernet, NFC, SONET, 5G, X10, LVDS

Network Topologies

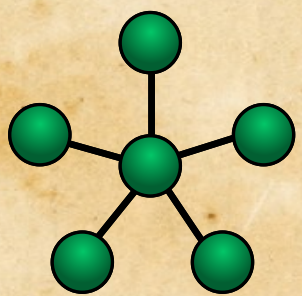
- Memorize these. What topology is the internet?



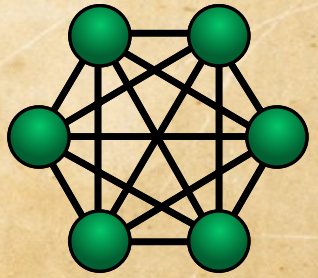
Ring



Mesh

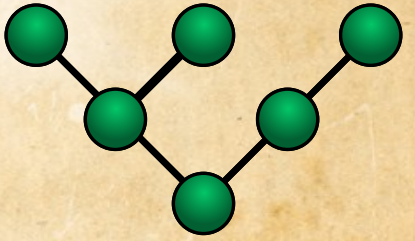


Star

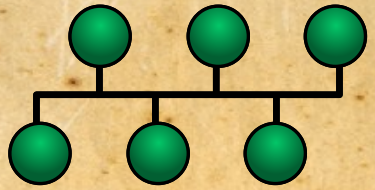


Fully Connected

Line



Tree



Bus

Ethernet Physical Layer

- Standard: IEEE 802.3
- Complements the MAC layer and logical link layer

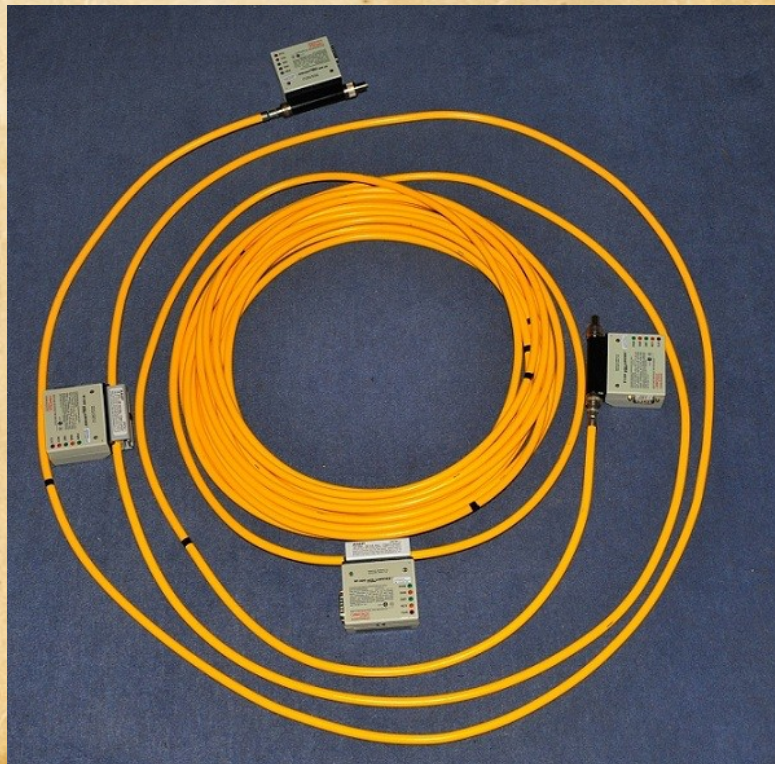
Background: 10Base__

- 10Mbps
- Baseband (not modulated)
- Manchester encoding
- Physical Connections:
  - 10Base5: original thick coaxial cable, up to 500m
  - 10Base2: thin coaxial cable, up to 185m
  - 10Base-T: twisted pair
  - 10Base-F: fiber

10Base5 “Thick Ethernet”

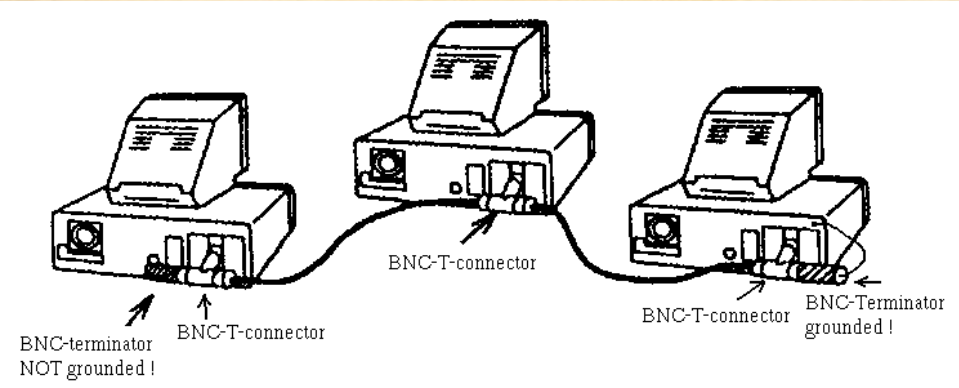
- First commercially available ethernet, IEEE 802.3-1983 (obsolete 9/2003)
- Thick coaxial cable (9.5mm)
- Bus topology

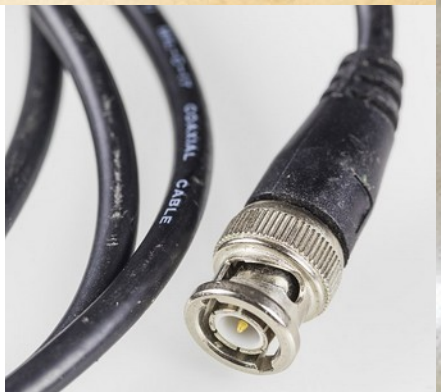
Media Attachment Unit (MAU)
(using vampire taps)



10Base2: Thin Ethernet; Cheapernet

- Specification: IEEE 802.3a-1988 (obsolete 9/2011)
- Bus topology
  - Failure at any point tends to prevent all communication
- BNC connectors
  - T connectors direct to NIC
  - Bus must be terminated (reflection=collision)



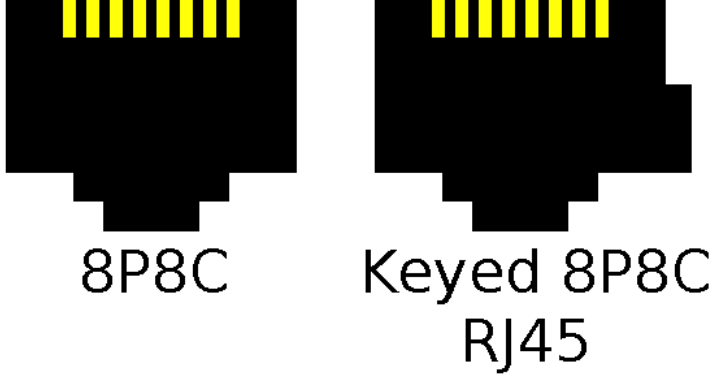


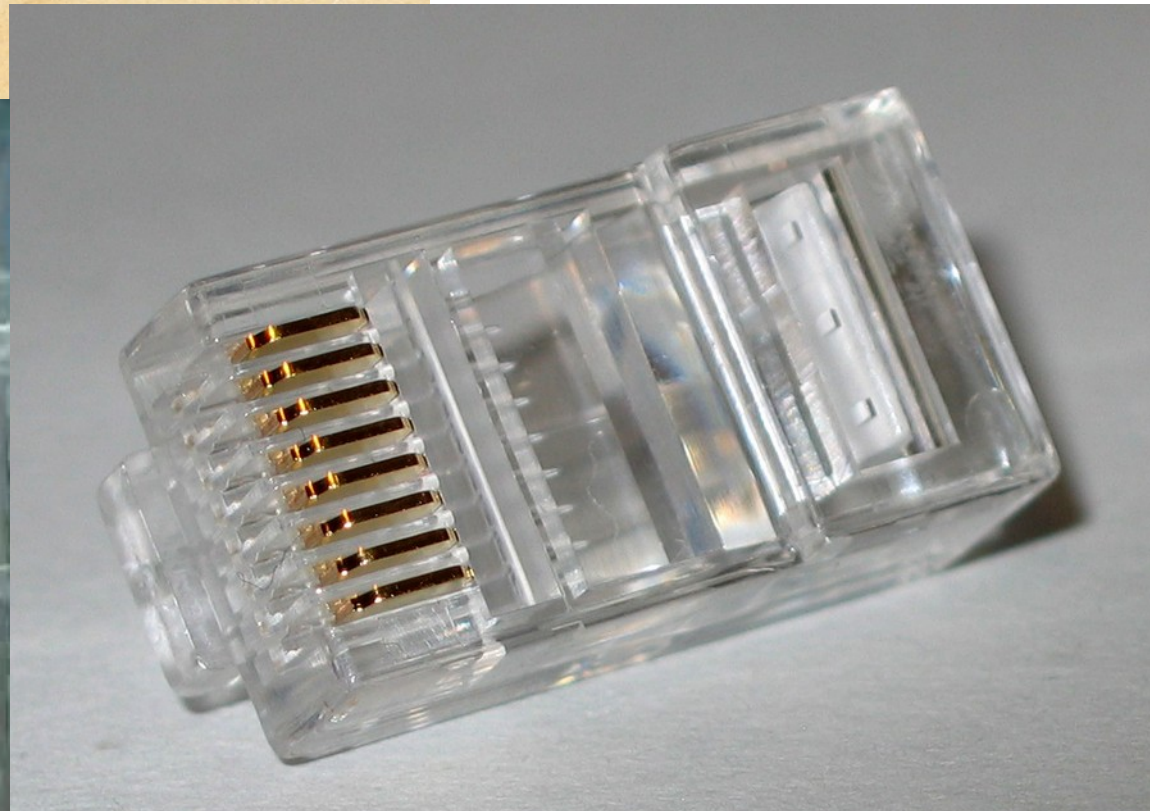
10Base-F

- Specification: IEEE 802.3d-1987; 802.3j-1993 (largely obsolete)
- Two strands of multimode fiber 62.5/125µm (full duplex)
- 1000m or longer

10Base-T

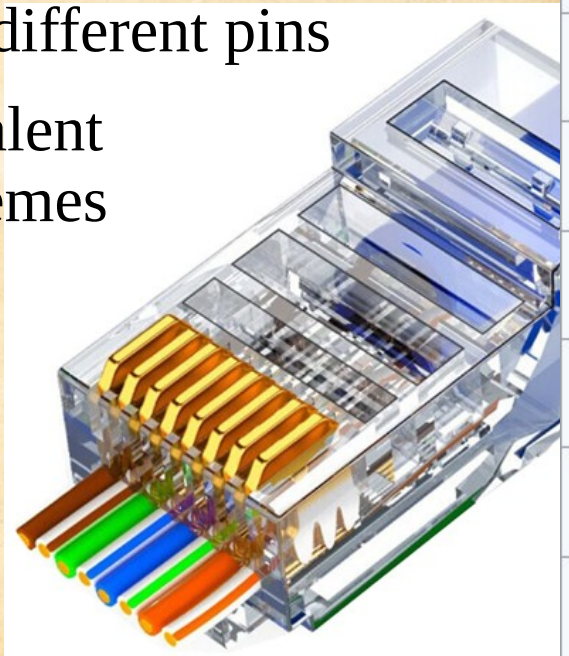
- 8 position 8 contact (8P8C) connector
  - Not actually RJ45

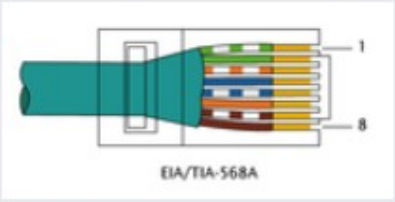
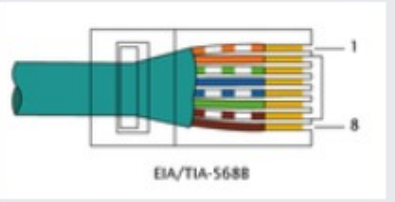




10Base-T

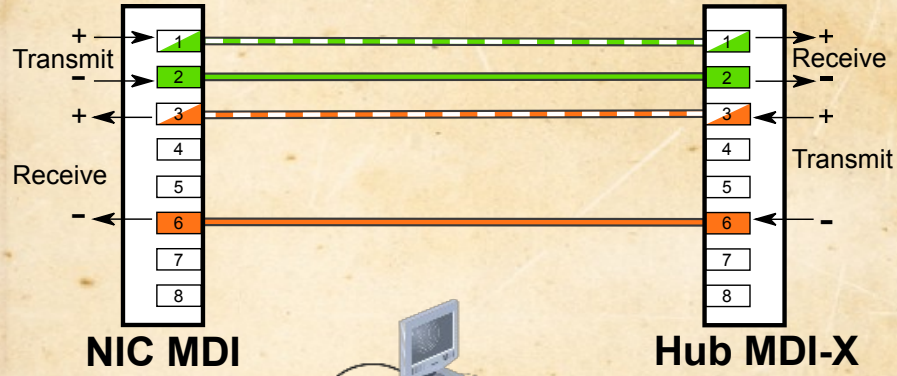
- Same wiring on both ends (straight through)
- NIC and host transmit and receive on different pins
- Two equivalent wiring schemes

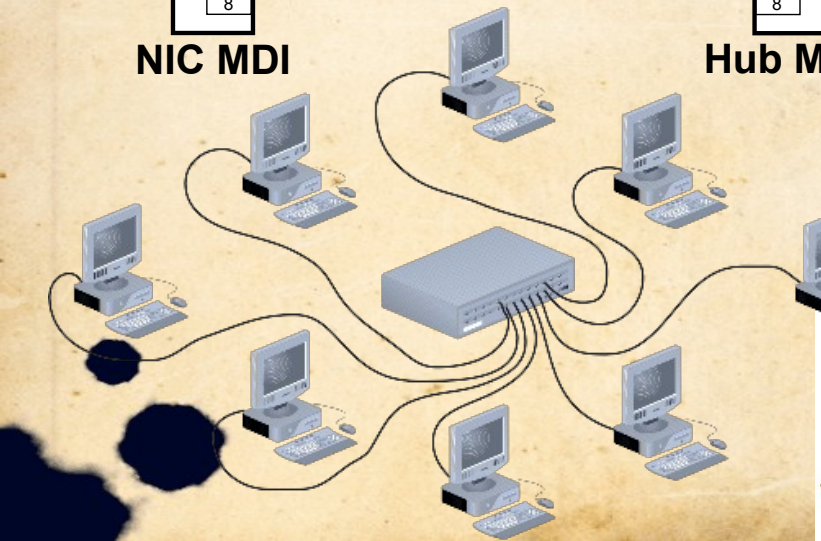


Pin	Connection 1: T568A 			Connection 2: T568B 		
	signal	pair	color	signal	pair	color
1	BI_DA+	3	white/green stripe	BI_DB+	2	white/orange stripe
2	BI_DA-	3	green solid	BI_DB-	2	orange solid
3	BI_DB+	2	white/orange stripe	BI_DA+	3	white/green stripe
4		1	blue solid		1	blue solid
5		1	white/blue stripe		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

10Base-T

- Straight Through Cables

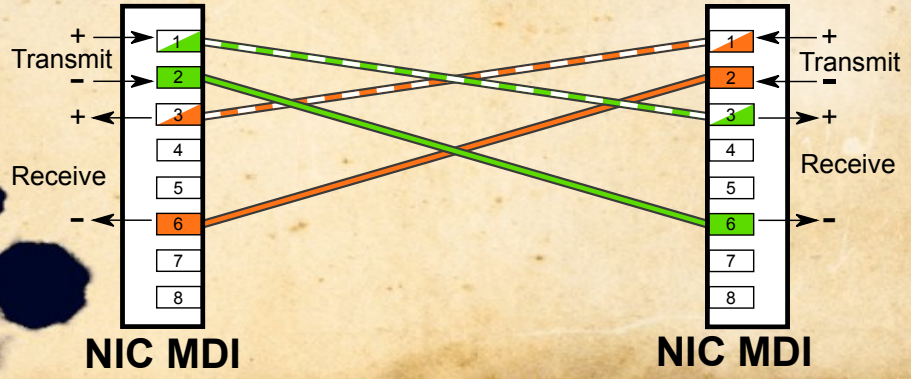


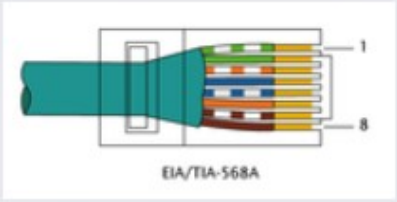
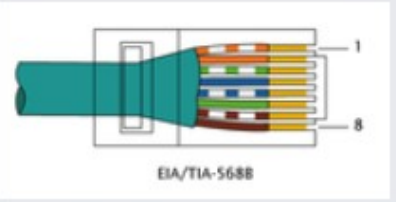


Pin	Connection 1: T568A			Connection 2: T568B		
	signal	pair	color	signal	pair	color
1	BI_DA+	3	white/green stripe	BI_DB+	2	white/orange stripe
2	BI_DA-	3	green solid	BI_DB-	2	orange solid
3	BI_DB+	2	white/orange stripe	BI_DA+	3	white/green stripe
4		1	blue solid		1	blue solid
5		1	white/blue stripe		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

10Base-T

- Crossover Cables
  - 10, 100Base-T use only **2 pairs**
  - Other lines may be used for telephone or other purpose
  - Not necessary for modern devices due to “Auto MDI-X” (Medium-Dependent Interface)



Pin	Connection 1: T568A 			Connection 2: T568B 		
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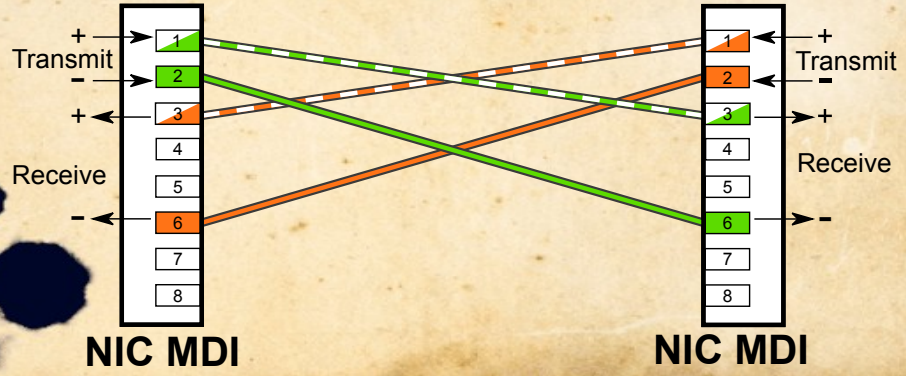
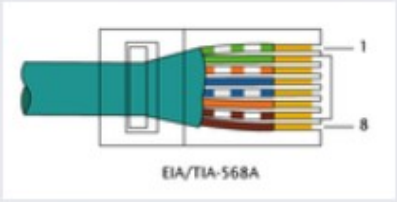
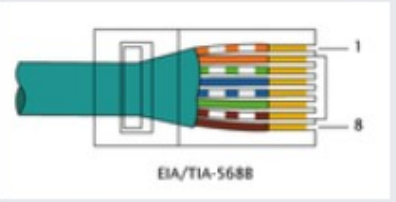
2	BI_DA-	3	green solid	BI_DB-	2	orange solid
3	BI_DB+	2	white/orange stripe	BI_DA+	3	white/green stripe
4		1	blue solid		1	blue solid
5		1	white/blue stripe		1	white/blue stripe
6	BI_DB-	2	orange solid	BI_DA-	3	green solid
7		4	white/brown stripe		4	white/brown stripe
8		4	brown solid		4	brown solid

10Base-T

- Straight Through vs Crossover Cables



Pin	Connection 1: T568A 			Connection 2: T568B 		
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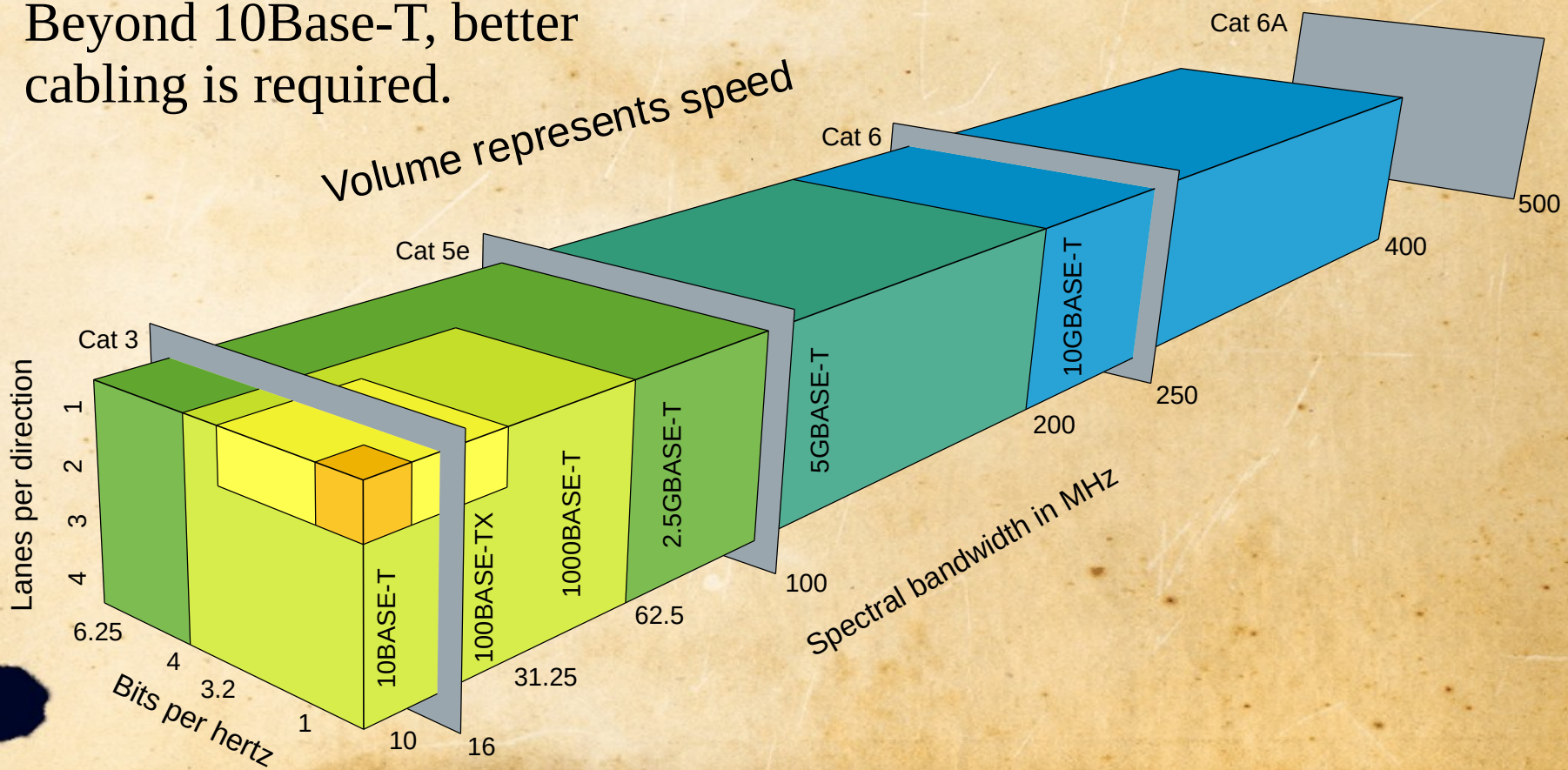
Ethernet Twisted Pair Cable Categories

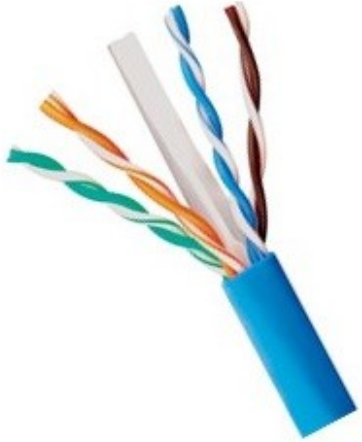
- Beyond 10Base-T, better cabling is required.



Ethernet Twisted Pair Cable Categories

- Beyond 10Base-T, better cabling is required.

Cat5e



Cat6

Cat6a

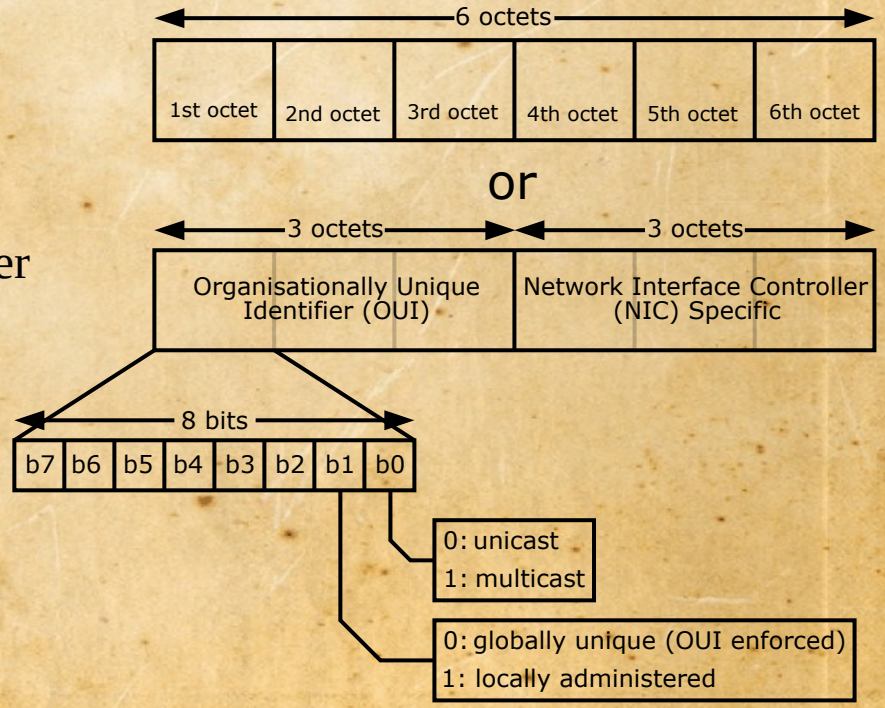
Cat7

Media Access Control (**MAC**) Addresses

- Unique identifier for a particular Network Interface Controller (NIC)
  - Hardcoded into the hardware of each NIC
  - 48 bits 6 bytes → 12 digits in hex – FF:FF:FF:FF:FF:FF

Media Access Control (**MAC**) Addresses

- Unique identifier for a particular *Network Interface Controller* (NIC)
  - 48 bits: FF:FF:FF:FF:FF:FF
  - Manufacturer's code (*Organizationally Unique Identifier*, **OUI**)
    - Remaining 3 octets assigned by manufacturer
    - 16 million MAC addresses each
  - Locally administered addresses (LAA; versus universal UAA)
    - Override burned-in addresses
    - 2nd LSB of first byte set to 1



Media Access Control (**MAC**) Addresses

- Unique identifier for a particular Network Interface Controller (NIC)
  - Hardcoded into the hardware of each NIC
  - 48 bits 6 bytes → 12 digits in hex – FF:FF:FF:FF:FF:FF
  - Target lifetime: until 2080
    - MAC-48 was just ethernet; EUI-48 ethernet and other (i.e.: bluetooth)
    - IEEE encourages EUI-64 for non-ethernet applications

Ethernet Frame

802.3 Ethernet packet and frame structure

Layer	Preamble	Start frame delimiter (SFD)	MAC destination	MAC source	802.1Q tag (optional)	Ethertype (Ethernet II) or length (IEEE 802.3)	Payload	Frame check sequence (32-bit CRC)	Interpacket gap (IPG)
	7 octets	1 octet	6 octets	6 octets	(4 octets)	2 octets	46-1500 octets	4 octets	12 octets
Layer 2 Ethernet frame	(not part of the frame)		← 64–1522 octets →						(not part of the frame)
Layer 1 Ethernet packet & IPG	← 72–1530 octets →								← 12 octets →

Ethernet Frame

- Physical later framing
  - What might the preamble be for?

Preamble and SFD representations as bits, decimal, bytes, and nibbles

Representation	56-bit (7-byte) Preamble														SFD byte	
uncoded on-the-wire **bit pattern** transmitted from left to right (used by Ethernet variants transmitting serial bits instead of larger symbols)[1]:sections 4.2.5 and 3.2.2	10101010		10101010		10101010		10101010		10101010		10101010		10101010		10101011	
decimal in Ethernet LSb-first ordering[1]:sections 3.2.2,3.3 and 4.2.6	85		85		85		85		85		85		85		213	
hexadecimal LSb-first **bytes** for 8-bit wide busses (GMII bus for Gigabit Ethernet transceivers)	0x55		0x55		0x55		0x55		0x55		0x55		0x55		0xD5	
hexadecimal LSb-first **nibbles** for 4-bit wide busses (MII bus for Fast Ethernet or RGMII for gigabit transceivers)	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0x5	0xD

Ethernet Frame

- Physical later framing
  - Preamble is for clock synchronization
  - Start Frame Delimiter signals end of preamble.

Preamble and SFD representations as bits, decimal, bytes, and nibbles

Representation	56-bit (7-byte) Preamble														SFD byte	
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Ethernet Frame

- Minimum frame size 64 bytes (layer 2)
  - Minimum overhead: 18
  - So… minimum payload 46 bytes (octets padded if less data to be sent)

802.3 Ethernet packet and frame structure

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Ethernet Frame

- Ethertype
  - <= 1500 means length
  - 1536 – 65535 is EtherType (what protocol is encapsulated)

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Ethernet Frame

- Ethertype
  - <= 1500 means length
  - 1536 – 65535 is EtherType (what protocol is encapsulated)
    - Inter-packet Gap (IPG) of 96 bits, and valid FCS then used to delineate packet

802.3 Ethernet packet and frame structure

Layer	Preamble	Start frame delimiter (SFD)	MAC destination	MAC source	802.1Q tag (optional)	Ethertype (Ethernet II) or length (IEEE 802.3)	Payload	Frame check sequence (32-bit CRC)	Interpacket gap (IPG)
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Ethernet Frame

- Frame Check Sequence
  - A 32-bit CRC

802.3 Ethernet packet and frame structure

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Address Resolution Protocol (ARP)

- Used for discovering the *data link* layer (layer 2) address for a layer 3 address
  - ARP frame is sent requesting the network layer (e.g.: IPv4) address
  - For ethernet, EtherType `0x0806` is used to identify an ARP frame
  - Frame is broadcast (MAC `FFFF:FFFF:FFFF`)

Internet Protocol (IPv4) over Ethernet ARP packet

Octet offset	0	1
0	Hardware type (HTYPE)	
2	Protocol type (PTYPE)	
4	Hardware address length (HLEN)	Protocol address length (PLEN)
6	Operation (OPER)	
8	Sender hardware address (SHA) (first 2 bytes)	
10	(next 2 bytes)	
12	(last 2 bytes)	
14	Sender protocol address (SPA) (first 2 bytes)	
16	(last 2 bytes)	
18	Target hardware address (THA) (first 2 bytes)	
20	(next 2 bytes)	
22	(last 2 bytes)	
24	Target protocol address (TPA) (first 2 bytes)	
26	(last 2 bytes)	

Address Resolution Protocol (ARP)

- Fields
  - **HTYPE**: data link protocol (ethernet=1)
  - **PTYPE**: network protocol (IPv4=`0x0800`)
  - **HLEN**: length of data link address in octets (ethernet=6)
  - **PLEN**: length of network address in octets (IPv4=4)
  - **Operation**: 1 request, 2 reply

Internet Protocol (IPv4) over Ethernet ARP packet

Octet offset	0	1
0	Hardware type (HTYPE)	
2	Protocol type (PTYPE)	
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Address Resolution Protocol (ARP)

- Fields
  - **HTYPE**: data link protocol (ethernet=1)
  - **PTYPE**: network protocol (IPv4=`0x0800`)
  - **HLEN**: length of data link address in octets (ethernet=6)
  - **PLEN**: length of network address in octets (IPv4=4)
  - **Operation**: 1 request, 2 reply
  - Four **Addresses**: you figure these out…😉

Internet Protocol (IPv4) over Ethernet ARP packet

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26	(last 2 bytes)	

ARP Questions

- What does a host (or router) do if it needs to send an IP packet with an unknown destination MAC address?
- How does it differ if the IP address is not in the local network? (And how would the host know?)

ARP Questions

- What does a host (or router) do if it needs to send an IP packet with an unknown destination MAC address?
  - It broadcasts an ***ARP request*** (asking “Who has this IP address?”)
  - The device with the matching IP address responds with an ***ARP reply*** providing it’s MAC address
  - Sender updates its ***ARP table***
  - If no response, the *ARP request* will timeout/retry, returning an error to the network layer, specifying the host is unreachable

ARP Questions

- How do *ARP requests* differ if the IP address is not in the local network? (And how would the host know?)
  - The host checks the network's ***subnet mask*** to determine if the address is local
  - If local, the *ARP request* is performed
  - If not local… where is the packet sent?

ARP Questions

- How do *ARP requests* differ if the IP address is not in the local network? (And how would the host know?)
  - The host checks the network's ***subnet mask*** to determine if the address is local
  - If local, the *ARP request* is performed
  - If not within the subnet, the packet is sent to the MAC address of the ***default gateway***
    - If the MAC address of the *default gateway* is not in the ARP table, an ARP request will be made for its MAC
    - The layer 2 will be addressed to the *default gateway* while the IP address will be addressed to the distant host

Computer Networks

Open Systems Interconnection (OSI) Model

Layers 1 and 2: **Ethernet**