COEN-4720 Embedded Systems Design
Lecture 12
Introduction to Ethernet

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Overview

- Open Systems Interconnection (OSI)
- The Internet
- Internet Protocol (TCP/IP Protocol)
- Ethernet History
- Ethernet
  - Frame structure
  - Physical layer
  - MAC

Open Systems Interconnection (OSI) Model

- The Open Systems Interconnection (OSI) model:
  - **Prescription** of characterizing and standardizing the functions of a communications system in terms of **abstraction layers**.
- Similar communication functions are grouped into logical layers.
- A layer serves the layer above it and is served by the layer below it.

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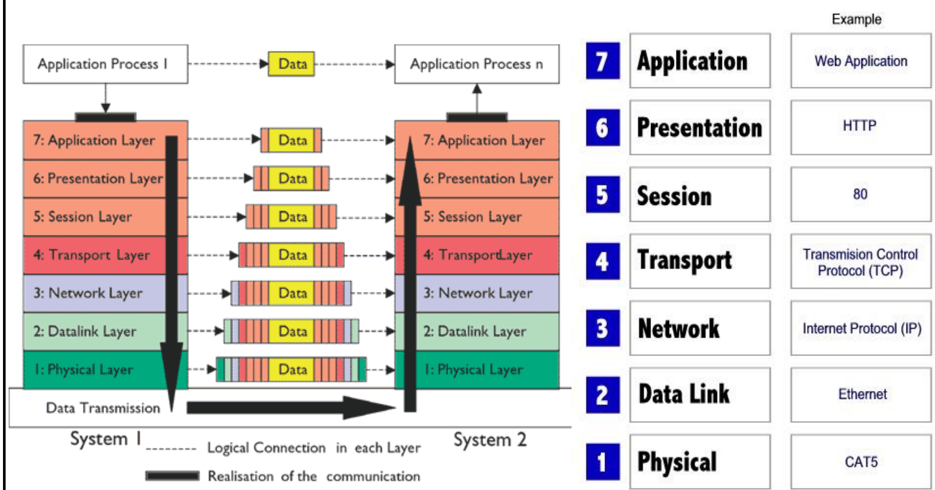
OSI – 7 Layers



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OSI – 7 Layers

1. **Physical layer**:
   - Defines electrical and physical specifications for devices
2. **Data Link Layer (DLL)**:
   - Provides the functional and procedural means to transfer data between network entities and to detect and possibly correct errors. Has 2 sublayers:
     - Logical Link Control (LLC), upper
     - Medium Access Control (MAC), lower
3. **Network layer**:
   - Provides the functional and procedural means of transferring variable length data sequences from a source host on one network to a destination host on a different network
4. **Transport layer**:
   - Provides transparent transfer of data between end users, providing reliable data transfer services to the upper layers

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OSI – 7 Layers

5. Session layer:
- Controls the dialogues (connections) between computers.
- It establishes, manages and terminates the connections between the local and remote application.
- It provides for full-duplex, half-duplex, or simplex operation, and establishes checkpointing, adjournment, termination, and restart procedures.

6. Presentation layer:
- Provides encryption services, decryption, data compression, and decompression.

7. Application layer:
- Checks resource usability and synchronization with the remote partner.

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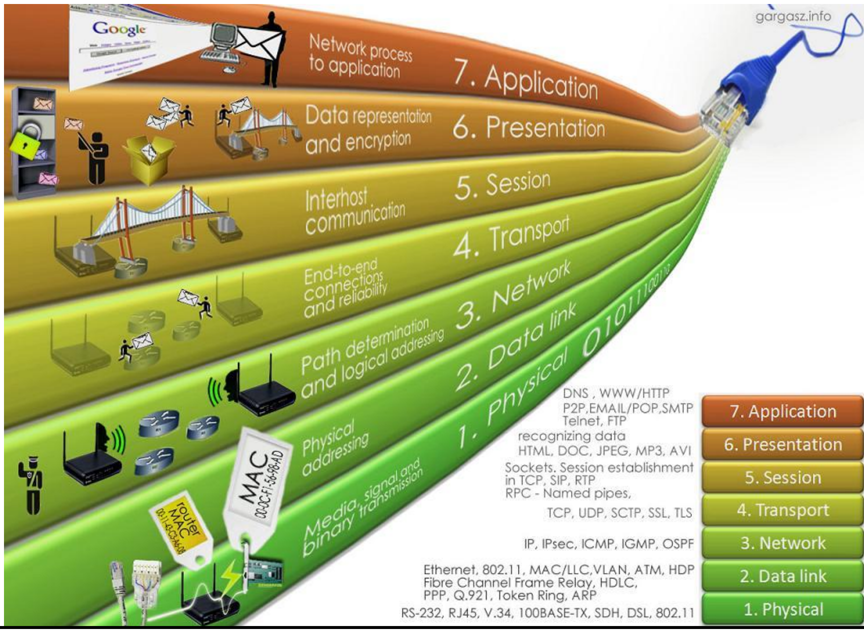
OSI Model – Examples, View #1



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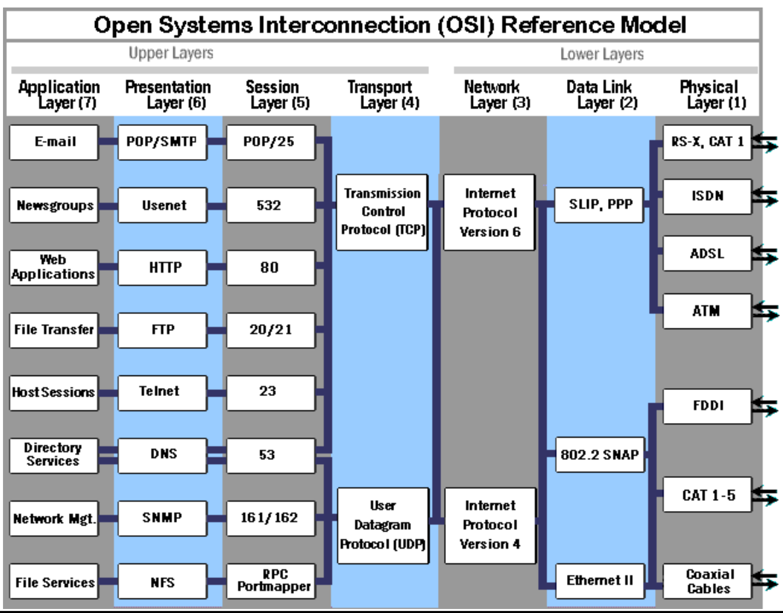
OSI Model – Examples, View #2



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The Internet

- The Internet:
  - A global system of interconnected computer networks that use the standard Internet Protocol suite (**TCP/IP**) to serve billions of users worldwide.
  - A **network of networks** that consists of millions of private, public, academic, business, and government networks, of local to global scope, that are linked by a broad array of electronic, wireless and optical networking technologies.

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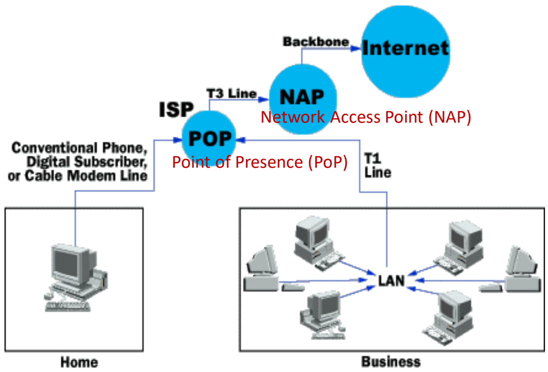
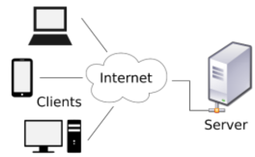
Simplified Internet Architecture





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Internet Protocol (or TCP/IP Protocol)

- The Internet Protocol suite:
  - The set of communications protocols used for the Internet and similar networks.
  - The most popular protocol stack for wide area networks.
- It is **commonly known as TCP/IP**, because of its most important protocols:
  - Transmission Control Protocol (TCP)
  - Internet Protocol (IP)

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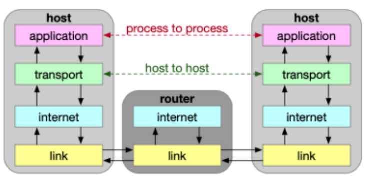
Internet Protocol – 4 Layers

1. **Link layer:**
   - Contains communication technologies for a local network.
2. **Internet layer (IP):**
   - Connects local networks, thus establishing internetworking.
3. **Transport layer:**
   - Handles host-to-host communication.
4. **Application layer:**
   - Contains all protocols for specific data communications services on a process-to-process level.
   - It focuses more on network services, APIs, utilities, and operating system environments.



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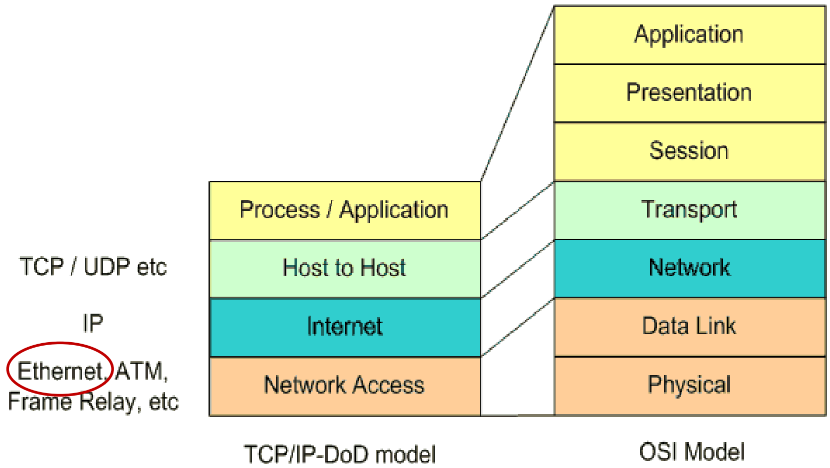
TCP/IP vs. OSI



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Data Encapsulation

- A network packet is nothing more than a chunk of data that an application wants to deliver to another system on the network.
- This chunk of data has information added to the front and back that contains instructions for where the data needs to go and what the destination system should do with it once it arrives.
- The addition of this routing and usage information is called **encapsulation**.

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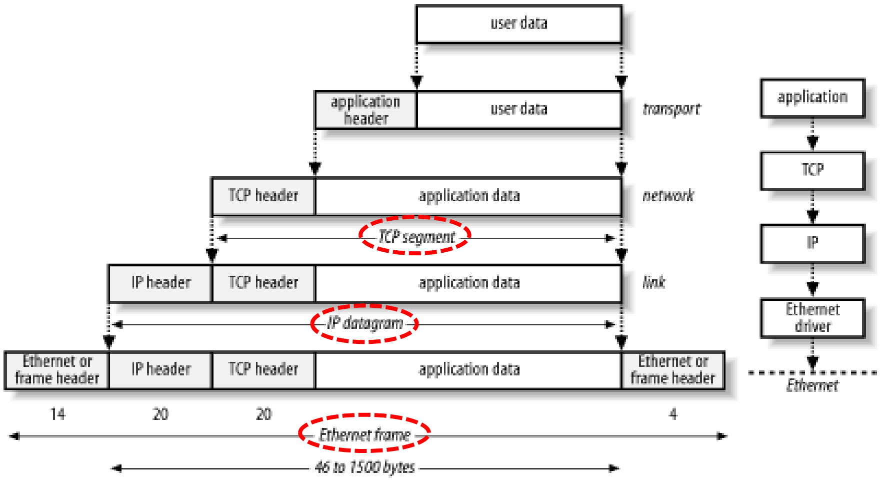
Data Encapsulation



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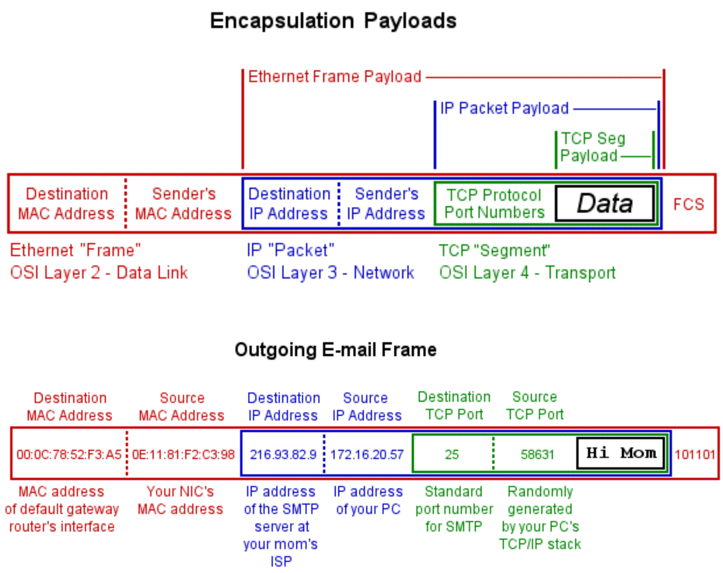
Data Encapsulation



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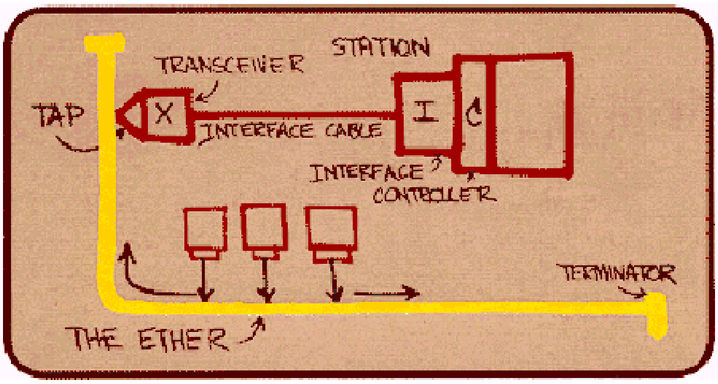
Ethernet History



The Original Design of Ethernet from Robert Metcalfe

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Ethernet History: Speed matters - how Ethernet went from 3Mbps to 100Gbps… and beyond

- On May 22, 1973, Bob Metcalfe at Xerox PARC, Palo Alto CA, documented the invention of Ethernet in a memo, which described communication across different "ethers" - including cable, telephone, and radio - building on the ALOHAnet protocol
- Bob Metcalfe, David Boggs, and Tat Lam built the first Ethernet prototype at 2.94 Mbps
- 1980, Digital, Intel, and Xerox developed the standard of 10Mpbs DIX Ethernet (a.k.a. Ethernet II)
- 1992, the Grand Junction Network Company brought up the structure of 100Mbps Ethernet
- 1998, addressed the standard of Gigabit Ethernet
- 2002, 10 Gigabit standard published
- 2002-2010 40 Gigabit proposals
- 2010 100 Gigabit
- Terabit Ethernet?

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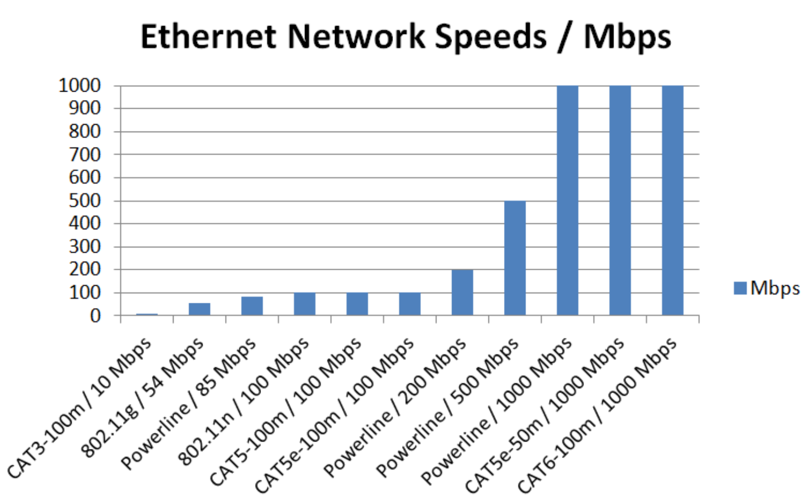
Speed of Ethernet



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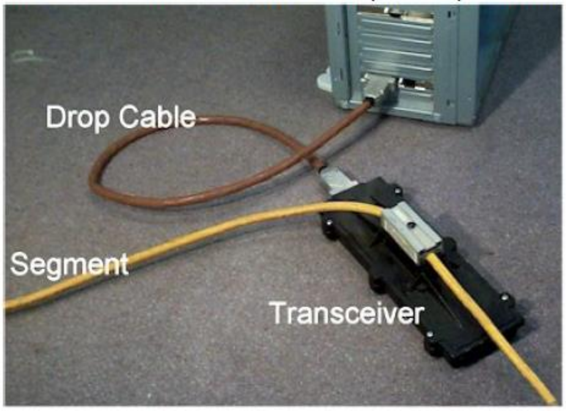
History

10Base-5 “Thicknet”

Shared coax bus with “vampire tap” tranceivers



Yellow color suggested by the 802.3 standard

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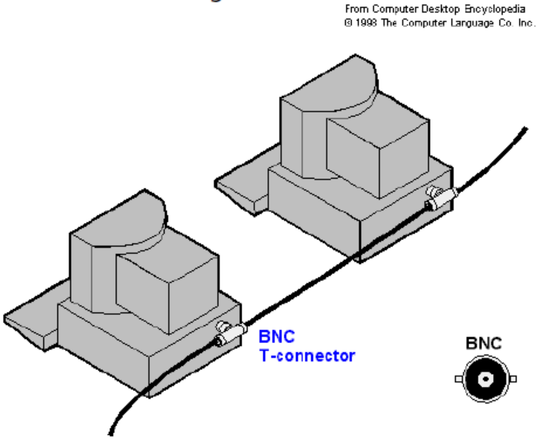
History

10Base-2 “Thinnet”

50-Ohm coax segments with BNC “T” connectors



Coax invariably black

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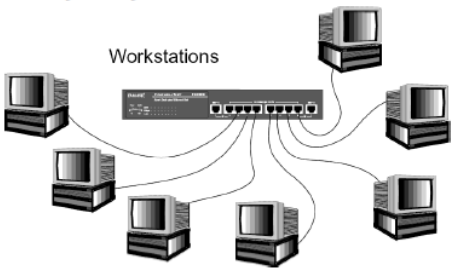
History

10Base-T and 100Base-T

Put the shared medium in a hub: a star topology.
Everybody uses it now.



Star topology

Choice of colors

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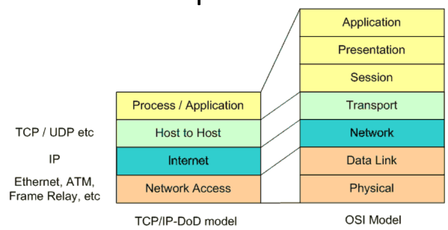
Ethernet

- Carrier-sense multiple access/carrier detect (**CSMA/CD**) protocol/algorithm:
  - A media access control (MAC) method used most notably in **Ethernet** technology for local area networking (LAN). Procedure:
    1. Is a frame ready for transmission? If not, wait for a frame.
    2. Is medium idle? If not, wait until it becomes ready.
    3. Start transmitting and monitor for collision during transmission.
    4. Did a collision occur? If so, go to collision detected procedure.
    5. Reset retransmission counters and complete frame transmission
- **Ethernet**: a family of networking technologies
- **Ethernet Protocol** is made up of several components:
  1. Structure of Ethernet frames
  2. Physical Layer (i.e., the Media)
  3. MAC operation



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1. Frame Structure

bytes	8	6	6	2	46 - 1500	4
	Preamble	Destination	Source	Type	Data Unit	CRC

DIX Ethernet Packet

bytes	7	1	6	6	2		46 - 1500		4
	Preamble		Destination	Source	Length	LLC	Data Unit	Pad	FCS

IEEE 802.3 Frame

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Frame Structure

- Information is sent around an Ethernet network in discreet messages known as frames.
- The frame structure consists of the following fields:

1. The Preamble - This consists of seven bytes, all of the form "10101010". This allows the receiver's clock to be synchronized with the sender's.
2. The Start Frame (SOF) Delimiter - This is a single byte ("10101011") which is used to indicate the start of a frame.
3. The Destination Address - This is the address of the intended recipient of the frame. The addresses in 802.3 use globally unique hardwired 48 bit addresses.
4. The Source Address - This is the address of the source, in the same form as above.
5. Type of packet, 0x0800 for IP, 0x0806 for ARP, etc. Length of the data in the Ethernet frame can be anything from 0 to 1500 bytes.

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Frame Structure

6. Data - This is the information being sent by the frame.
7. Pad - 802.3 frame must be at least 64 bytes long, so if the data is shorter than 46 bytes, the pad field must compensate. The reason for the minimum length lies with the collision detection mechanism. In CSMA/CD the sender must wait at least two times the maximum propagation delay before it knows that no collision has occurred. If a station sends a very short message, then it might release the ether without knowing that the frame has been corrupted. 802.3 sets an upper limit on the propagation delay, and the minimum frame size is set at the amount of data which can be sent in twice this figure.
8. Checksum - This is used for error detection and recovery.

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2. Physical Layer

- Concerned with the low-level electronic way in which the signals are transmitted.
- Signals are transmitted using Manchester Phase Encoding (MPE). This encoding is used to ensure that clocking data is sent along with the data, so that the sending and receiving device clocks are in sync.
- Logic levels are transmitted along the medium using voltage levels of ±0.85V.

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Types of Ethernet Cables

Cable type	**Max speed**	**Max Length**	**Operating Frequency**
CAT5	100 Mbps	100 m	100 MHz
CAT5e	1 Gbps	100 m	100 MHz
CAT6	10 Gbps	50 m	250 MHz
CAT6a	10 Gbps	100 m	500 MHz
CAT7	40/100 Gbps	50/100 m	2000 MHz

- All backwards-compatible

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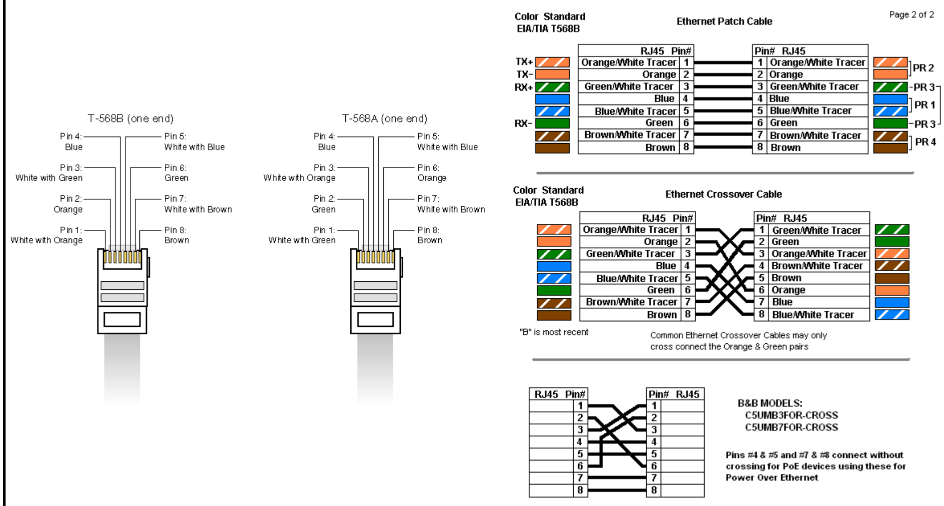
Cable Structure



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3. Media Access Control (MAC)

- To send a frame, a station on an 802.3 network first listens to check if the medium is busy.
  - If it is, then, the station uses the 1-persistent strategy, and transmits after only a short fixed delay (the inter-frame gap) after the medium becomes idle.
  - If there is no collision, then this message will be sent normally.
  - If the device detects a collision however, the frame transmission stops and the station sends a jamming signal to alert other stations of the situation. The station then decides how long to wait before re-sending using a truncated binary exponential backoff algorithm.
  - After 16 continuous collisions, the MAC layer gives up and reports a failure to the layer above.

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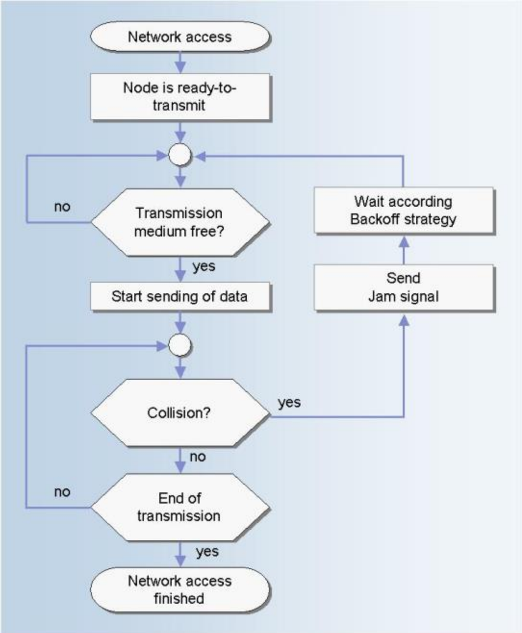
MAC Flow Graph



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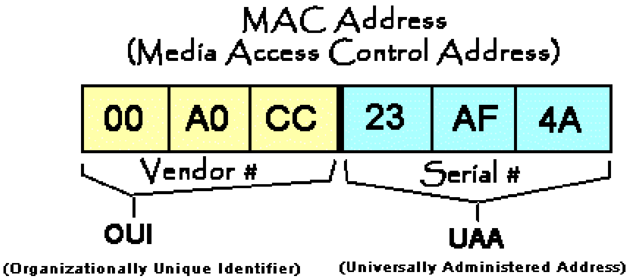
How Addressing takes place in Ethernet

- Addressing in Ethernet takes place with MAC Addresses - 6 byte long (48 bits)
- **MAC address** is also called **Ethernet address** or **Hardware address** or **Physical address**
- This address is of the physical Ethernet card or NIC (network information card) which is installed on a system
- It's programmed into the chip of a network card (burned into the ROM of the NIC)



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Ethernet (MAC) Addresses

- Address fields

  48 bits ≈ 281 trillion (world population: 6.5 billion)
  Bits 48–24: Vendor code
  Bit 41: 0=ordinary, 1=group (broadcast) address
  Bits 23–0: Serial number

- Example:

  $ ifconfig eth0
  eth0 Ethernet HWaddr **00:08:74**:23:CC:AB
  OUI (Organizationally Unique Identifier):
  00:08:74 is Dell Computer

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An Ethernet Frame

00d006269c00	Destination MAC address (router)
00087423ccab	Source MAC address (desktop)
0800	Type = IP packet
45	IPv4, 5 word (20-byte) header
00	Normal service
0028	Total length = 40 bytes
c31c	Identification (unique)
4000	“Don’t Fragment”
4006	hops to live
06	TCP protocol
3ff1	**Header checksum (one’s complement)**
803b1372	Source IP 128.59.19.114 (desktop)
40ec6329	Destination IP 64.236.99.41

deac 0050 bf49 9ba6 a1a4 8bed 5010 ffff 1093 0000

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Checksum

- A checksum is a value that is computed from data packet to check its integrity.
- Integrity: a check on whether the data received is error free or not (because while traveling on network a data packet can become corrupt; there has to be a way at the receiving end to know that data is corrupted or not)
- This is the reason the checksum field is added to the header.
- Calculated only for the header bytes (with the checksum bytes set to 0)

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IP Header Checksum Computation

One's complement addition on 16-bit elements
16-bit carry out becomes carry in
Computed on elements of IP header:

Computing	Checking
4500	4500
0028	0028
c31c	c31c
4000	4000
4006	4006
0000 ← checksum hole	3ff1 ← checksum
803b	803b
1372	1372
40ec	40ec
+6329	+6329
2c00c (two's complement)	2fffd (two's complement)
c00e (one's complement)	0000 (one's complement—OK)
3ff1 (inverted)	

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IP Header

31 … 28	27 … 24	23 … 16	15 … 13	12 … 0
Version = 4	Words in Header	Type of Service (typically 0)	Total number of bytes in the IP packet	
Identification Number (which packet)			Flags - DF MF	Fragment Offset (which fragment)
Time-to-Live (hops left)		Protocol 6=TCP, 17=UDP	Header checksum (one's complement sum)	
Source IP Address				
Destination IP Address				

⋮

Options and padding

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IP Addresses (Layer 3 – Network layer)

- 32-bit (4 byte) software stored address: assigned to represent the same NIC as MAC address represents
- The 32-bit IP address is like a shorter nickname for the 48-bit MAC address
- Main point in differentiating IP from MAC addresses:
  - Direct-connected transmission uses Layer 2 - **MAC addresses** for **frame** delivery
  - Routed transmission uses Layer 3 - **IP addresses** for **packet** delivery

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IP Addresses

32 bits ≈ 4 billion (world population: 6.5 billion)
First n bits indicate network (n = 8, 16, 24)
For example, Google owns the range:
  173.194.0.0 - 173.194.255.255

Magical addresses:

127.0.0.1	"Me"
192.168.x.x	Never assigned worldwide
10.x.x.x	Never assigned worldwide
255.255.255.255	Broadcast

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MAC Addresses vs. IP Addresses

- MAC address
  - It's just a manufacturer code and a serial number
  - There's no structure to it beyond that, and so no way to route packets efficiently
  - MAC address is used purely to address machines on a local network segment
- IP address
  - Introduced to address machines outside a network segment
  - IP addresses have an inherent hierarchy with the use of subnet masks, etc., allowing large networks to be addressed in a block for efficient routing

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User Datagram Protocol (UDP)

- UDP is one of the **core members** of the Internet Protocol suite
- With UDP, computer applications can send messages, (referred to as **datagrams**), to other hosts on an Internet Protocol (IP) network without prior communications to set up special transmission channels or data paths
- It has no handshaking dialogues → exposes any unreliability of the underlying network protocol to the user's program
- UDP is suitable when error checking and correction is either not necessary or performed in the application

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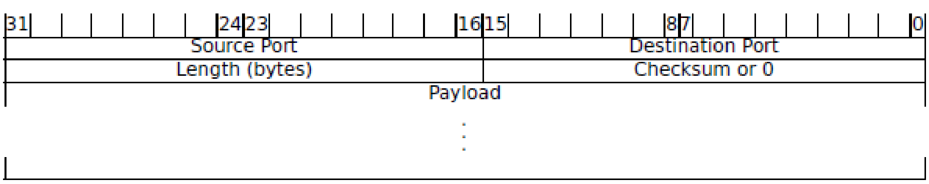
UDP Packets



Dumb packet protocol: unreliable, danger of out-of-order delivery

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Credits, References

- Ethernet Introduction, Ross MCIlroy, 2004; http://www.dcs.gla.ac.uk/~ross/Ethernet/index.htm
- Cable images; http://image.pinout.net/pinout_network_rj45_files/
- LPC17xx user manual, 2010; http://www.nxp.com/documents/user_manual/UM10360.pdf
- https://www.erg.abdn.ac.uk/users/gorry/course/lan-pages/csma-cd.html
- And many others… (see Lab#12 of this course for more references)

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