Ethernet and TCP/IP

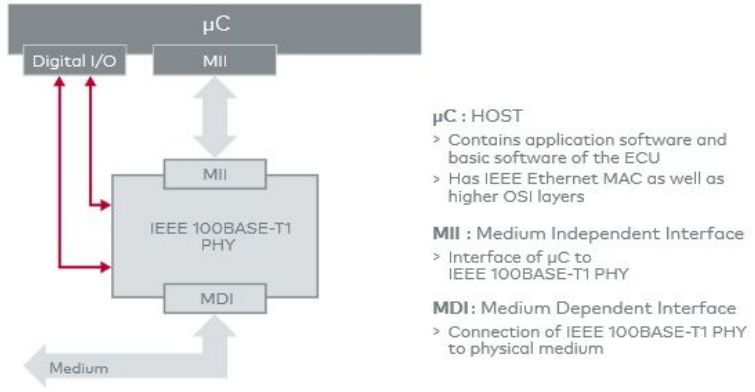
Communication Protocols

Ethernet

- A well established, flexible and scalable network technology
  - Used in networking and communication systems
  - Describes how network devices can format and transmit data
  - The working group 802 of IEEE has responsibility for Ethernet
    - E.g., IEEE 802.1, IEEE 802.2, IEEE 802.3, etc.
    - First standardization in 1983 as IEEE 802.3
  - Defines the Data Link Layer and Physical Layer of the OSI model
    - Supports a large number of physical media
  - Used in Local Area Networks (LAN) for transferring data with 10Mbps to 1Gbps
  - Used by different protocols in the network layer of the OSI model. E.g. IP in TCP/IP
  - The OPEN Alliance SIG (**Special Interest Group**) was founded in the automotive industry in 2011.
    - It works with the IEEE on the transformation of Automotive Ethernet into general standards

Ethernet - Physical Layer

- In the physical layer, Ethernet defines:
  - Cabling, connectors and electrical features of the layer
  - Sending and receiving the bit streams over the medium
  - Data encoding and decoding
  - Collision detection



- Ethernet supports a large number of physical media
  - Coaxial cable, twisted pair wires and optical fiber
  - There are so many different standards (Ethernet physical layer)
  - Example standards: **10BASE-2, 10BASE-T, 100BASE-TX, 100BASE-FX and 1000BASE-T**
  - Physical media are protocol-neutral; by providing a medium independent interface (MII)
    - Other transmission technologies can also be easily developed and adapted
  - In the Automotive Ethernet **IEEE 100BASE-T1, IEEE 100BASE-TX and IEEE 1000BASE-T** are used

Ethernet - Physical Layer (Automotive IEEE 100BASE-T1)

- Originally developed by Broadcom and standardized as IEEE 100BASE-T1
- The transformation into an IEEE standard was done by the Open Alliance SIG
- A twisted pair cable with symmetrical differential signaling is used
- IEEE 100BASE-T1 PHY uses 4B3B, 3B2T, and PAM3 methods to encode, decode and generate the differential voltages
- Data link layer sends 4 parallel bits with clock rate 25 MHz (100 Mbps)
- The PHY converts these 4 bits to 3 bits and increases the clock rate to 33.33 MHz to maintain the 100 Mbps bit rate
- Master-slave arrangement, slave is synchronized to the master clock
- Max distance: 15 meters; impedance: 90 Ω to 110 Ω
- Supports full-duplex: to send; the level of value is added and to receive, the level of the value is subtracted

3-bit data	TA	TB
000	-1	0
001	0	1
010	-1	1
011	0	1
100	1	0
101	0	-1
110	1	-1
111	0	-1

Table 3. 100BASE-T1 idle symbol mapping [9].

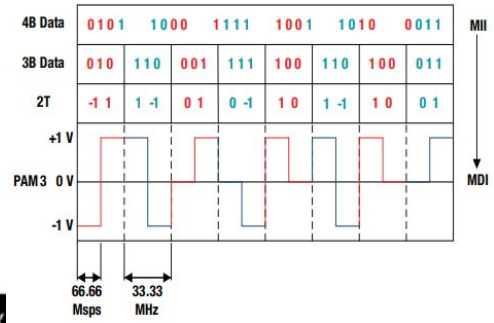
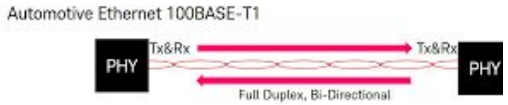
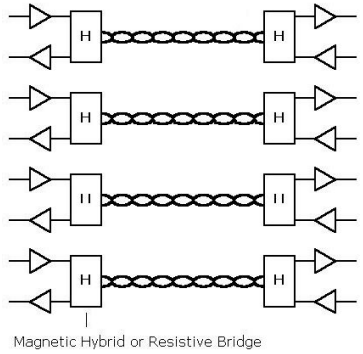


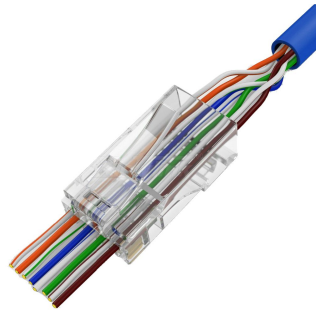
Figure 3. GPHY data conversion from MII to MDI [10].

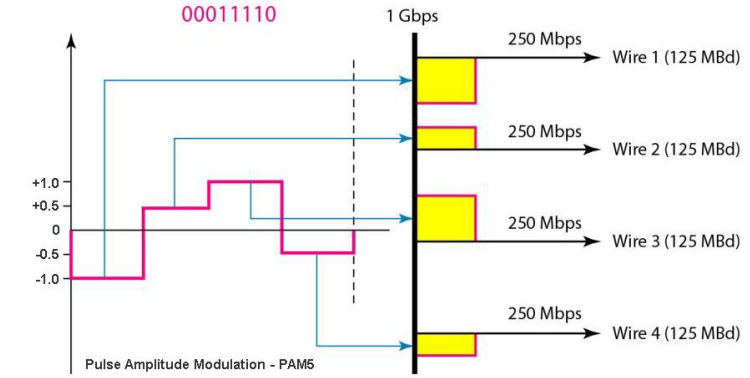


Ethernet - Physical Layer (IEEE 1000BASE-T)

- Requires 4 channels of twisted wires
- Standardized Cat5e cables and RJ45 connectors are used
- Maximum length: 100 meters
- Symmetrical differential signaling is used
- On each channel symbol rate is: 125 Msps
- It uses 8B1Q4, Trellis, Viterbi, and PAM5 for encoding and decoding
- Each symbol carries two bits
- Bit rate of each channel is 250 Mbps
- Total bit rate of all 4 channels is 1000 Mbps
- Supports full-duplex: to send; the level of the value is added and to receive, the level of the value is subtracted
- Master-slave arrangement, slave is synchronized to the master clock.
  - ➢ Unlike 100BASE-T1, the roles are not fixed and can be negotiated by an auto negotiation mechanism

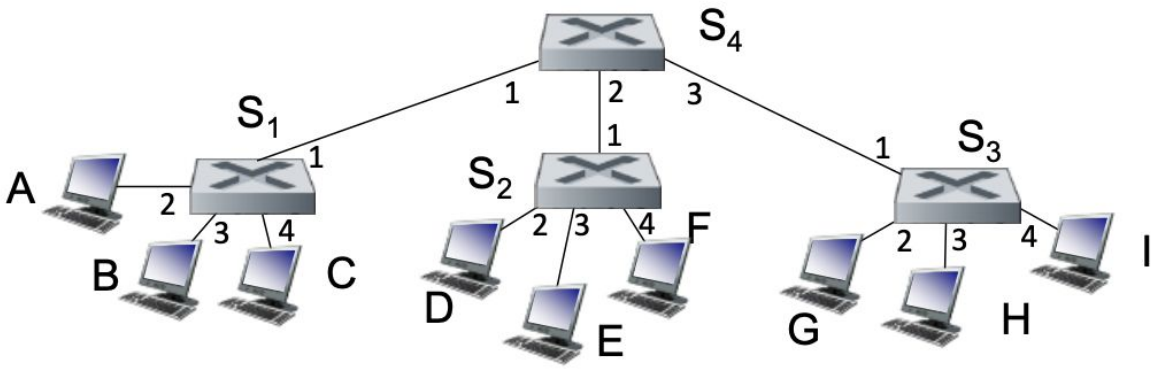


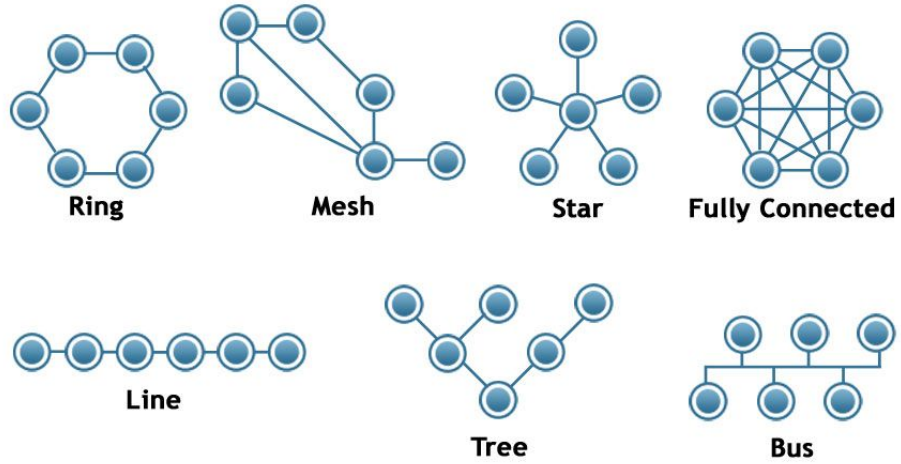




Ethernet - Topology

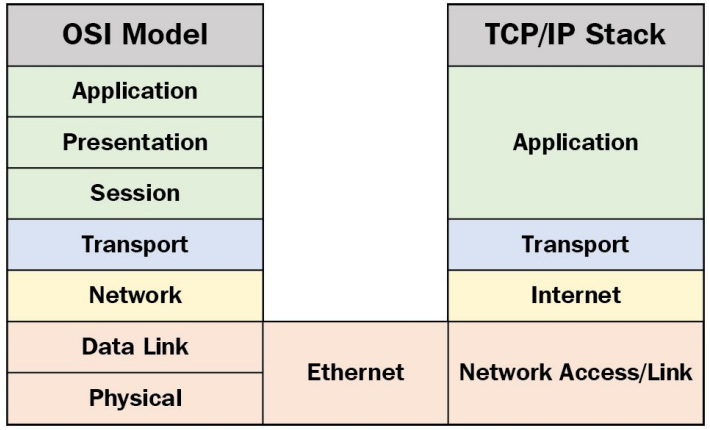
- Ethernet supports point-to-point, bus, star and hybrid
- Bus is not fault tolerant, it is not used any more.
  - It was used by 10BASE-X standard
- Most basic topology is point to point.
  - Coupling elements like hub, switch or router are used to make other topologies





Ethernet - Data Link Layer

- In the data link layer, Ethernet defines:
  - Providing services and interfaces to the upper layer
  - Addressing (MAC address)
  - Media Access Control (CSMA/CD)
  - Ethernet Framing
  - Error Detection



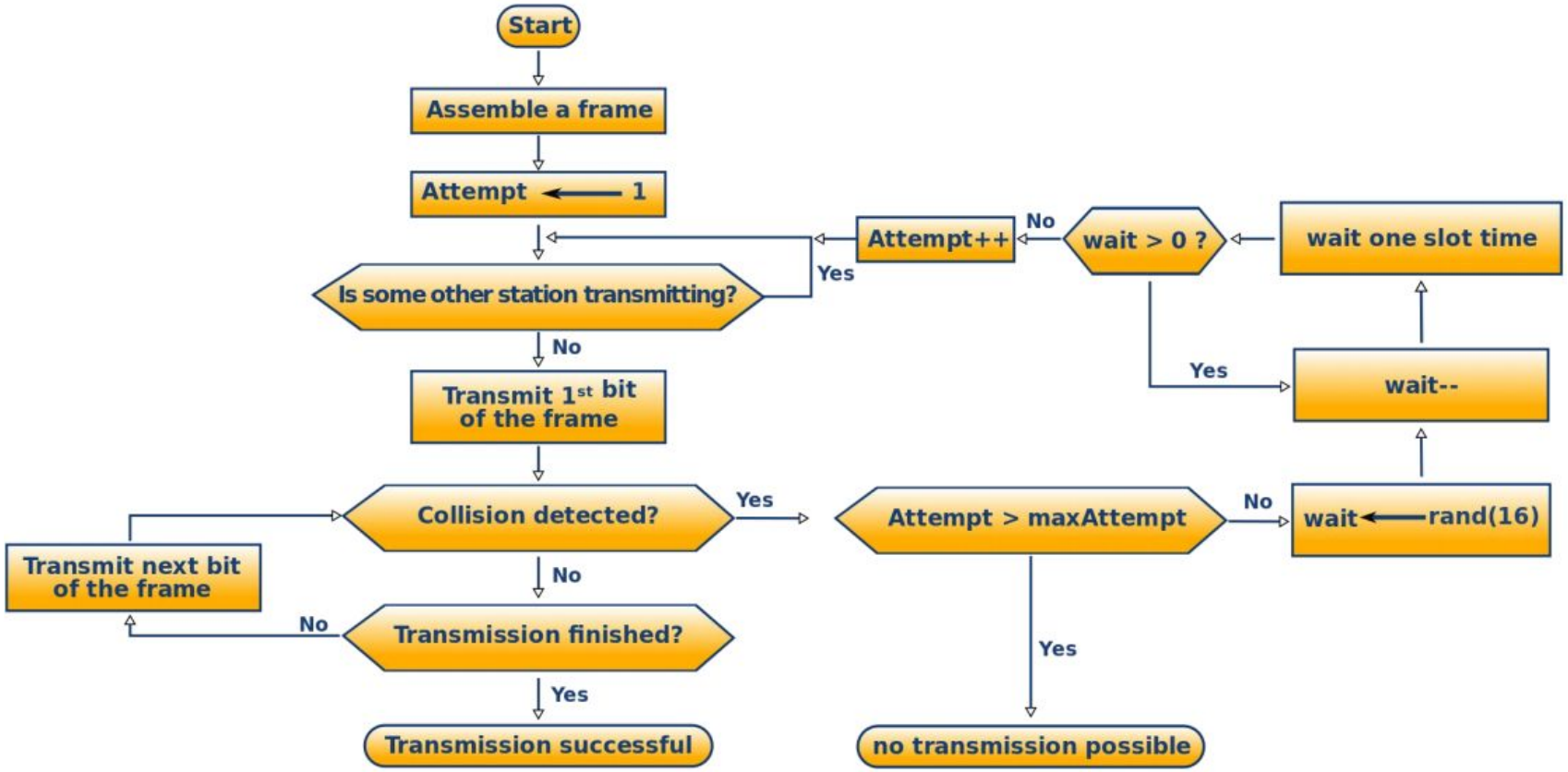
- Node Addressing
  - Every node has a unique MAC address (Medium Access Control Address)
  - This address is a physical address which has been burnt in the NIC by the manufacturer
  - Is a 6-byte address (48 bits - 12 hex). E.g. 18:db:f2:05:96:a5 - Dell Inc
    - The first 3 bytes are the unique identifier of the NIC manufacturer
    - The next 3 bytes are the unique identifier of the NIC

Ethernet - Data Link Layer

- Media Access Control (CSMA/CD)
  - Carrier Sense Multiple Access/Collision Detection (CSMA/CD) method is used
  - The Ethernet NIC, before sending, listens on the physical medium (carrier sense)
  - If the medium is free, the Ethernet controller can begin its transmission
  - Since multiple nodes may access to the bus at the same time (multiple access)
    - Collisions may occur on classic bus networks if two nodes begin sending
    - In the case of collision, each Ethernet NIC has a collision detection function which is used to stop the transmission.
    - To prevent a second collision, the node resends only after expiration of a random time.
    - Each sender must calculate this random time by itself
  - Collisions normally don't occur on **IEEE 100BASE-T1, IEEE 100BASE-TX, and IEEE 1000BASE-T**. Because these is no bus a the physical media support full-duplex.

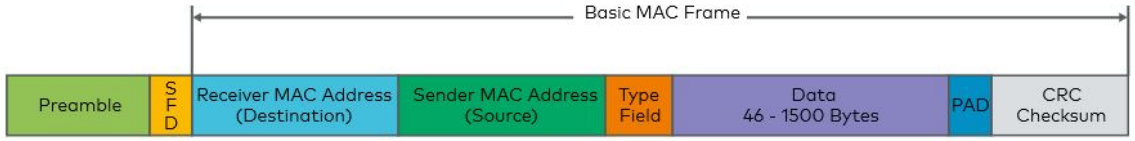
Ethernet - Data Link Layer

- Media Access Control (CSMA/CD)



Ethernet - Frame Format

- The IEEE defines different formats for Ethernet frames
- Ethernet II Frame is the most used one and it is directly used by Internet Protocol
- The automotive industry typically uses the Ethernet II frame



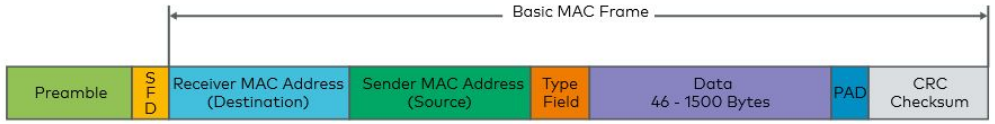
- Ethernet II Frame Fields:
  - **Preamble**(7 bytes): A series of 56 bits alternating with 1 and 0 (0x55)
    - It is used for synchronisation. It basically is the sender's clock
  - **SFD**(1 byte): Start of frame delimiter (10101011)
    - Indicates to the receiver that the actual data is on its way
  - **Receiver MAC Address** (6 byte): The physical address of the receiver
  - **Sender MAC Address** (6 byte): The physical address of the sender

Ethernet - Frame Format

- Ethernet II Frame Fields:
  - **Type Field**(2 bytes): The upper layer protocol that uses the frame to send data.
    - A code of 2 bytes is assigned to every protocol that is developed for Ethernet.
  - **Data Field**(46 - 1500 bytes): Contains the data to be sent
    - The data received from the upper layer protocol
  - **PAD**: The variable length padding bits to ensure the minimum length of the data field(46 bytes).
  - **CRC Checksum**(4 bytes): A 4-byte CRC value
    - It is calculated over all fields of the Ethernet II frame and therefore assures the integrity of the entire message

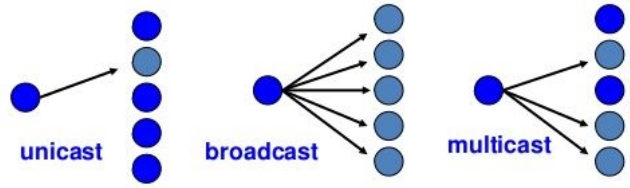
Some examples of Type Field

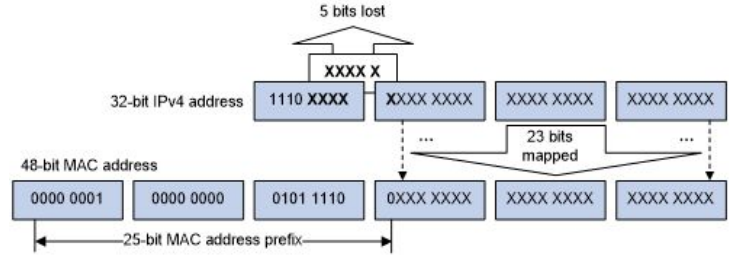
Type Field	Description
0x0800	Payload contains IPv4 packet
0x0806	Payload contains ARP packet
0x22F0	Audio/Video Transport Protocol (AVTP)
0x22EA	Multiple Stream Registration Protocol (MSRP)
0x8100	Ethernet VLAN Frame, Ether Type follows after tag
0x86DD	Payload contains IPv6 packet
0x88F5	Multiple VLAN Registration Protocol (MVRP)
0x88F6	Multiple MAC Registration Protocol (MMRP)
0x88F7	Precision Time Protocol (PTP)



Ethernet - Addressing

- In addition to unicasting, multicasting and broadcasting are supported
- Multicasting: Messages are delivered to multiple nodes
  - The least significant 23 bits of an IPv4 multicast address are mapped to the first 23 bits of destination MAC address of the frames.
  - Multicast IP addresses are in the range of 224.0.0.0 – 239.255.255.255
  - A node might receive unwanted multicast data at the data link layer
    - Such frames need to be filtered by the upper layer



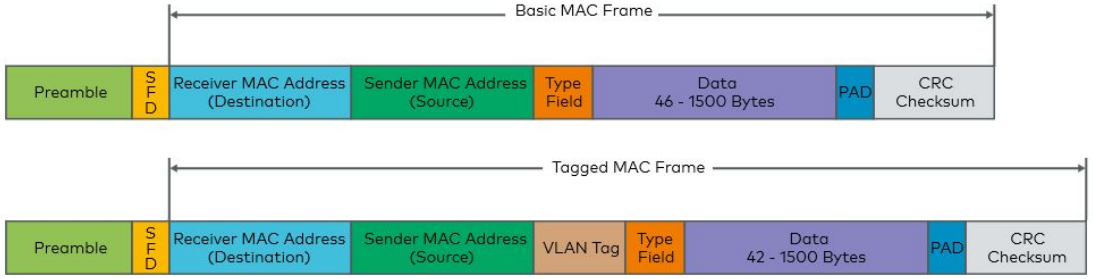


Multicast MAC address

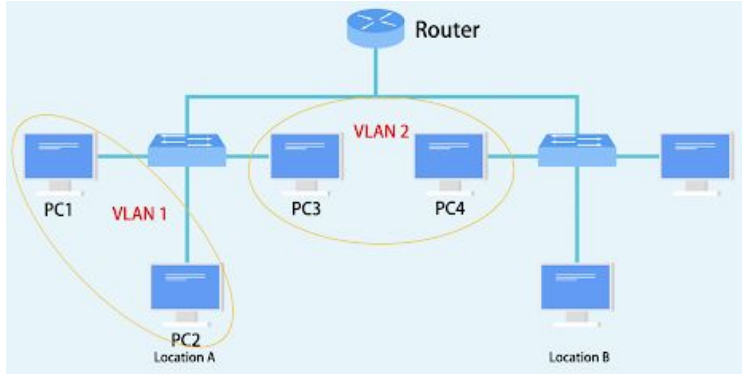
- Broadcasting: Messages are delivered to all nodes
  - The destination MAC address of the frames is FF:FF:FF:FF:FF:FF

Ethernet - Virtual LAN (VLAN)

- A broadcast domain that is partitioned and isolated in a LAN at the data link layer
- The IEEE 802.1Q is the standard that supports virtual LANs on an Ethernet network
  - It describes 4 extra bytes (VLAN tag) in the Ethernet frame
  - A VLAN has its own broadcast domain and data are only transmitted within a VLAN
    - To have communication between VLANs, routing is required. Like separate LANs
  - A node can be a member of multiple VLANs
  - VLAN frame length: 64 - 1522 bytes
  - VLAN is frequently used in the automotive industry

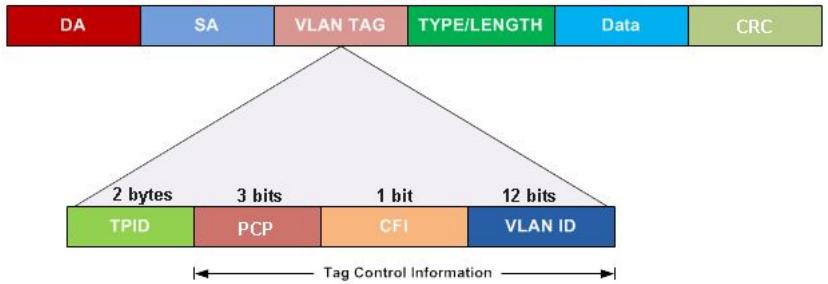


E.g. In a school, VLAN1 for students and VLAN2 for teachers



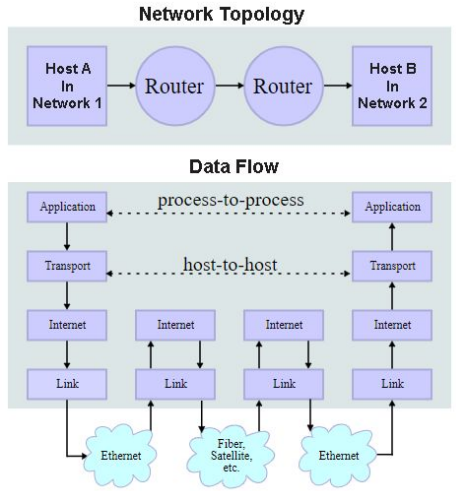
Ethernet - Virtual LAN (VLAN tag)

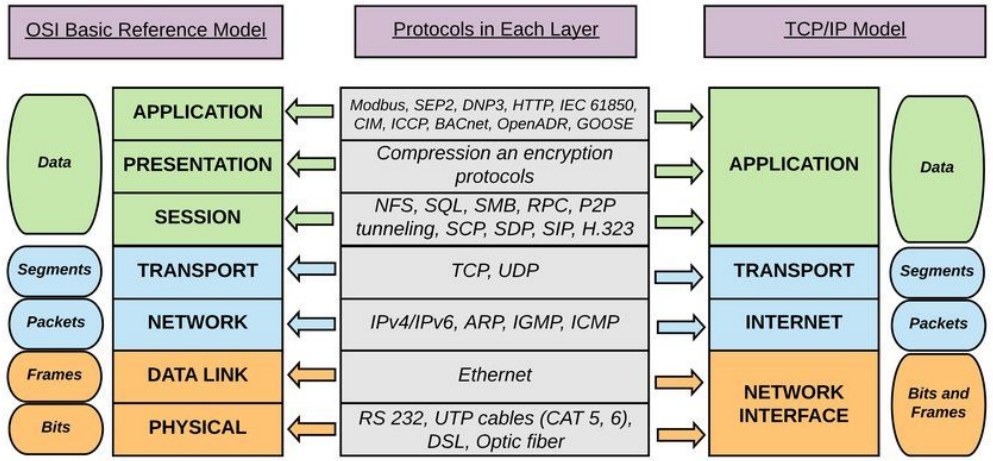
- VLAN tag is 4 bytes, divided into 2 fields
  - **Tag Protocol Identifier (TPID)**: The ID of the IEEE 802.1Q protocol which is 0x8100 (2 bytes)
  - **Tag Control Information (TCI)**: Contains information about the tag (2 bytes)
- Tag Control Information (**TCI**) consists of 3 fields
  - Priority Code Point (PCP)
    - It provides the option of defining priorities for messages to improve real-time behavior
  - Canonical Form Indicator (CFI): The IEEE802.1Q is only developed for Ethernet or Token Ring
    - This bit is 0 for Ethernet and 1 for Token Ring
  - VLAN ID: Identifier of the VLAN
    - 4094 possibilities. 0xFFF is reserved and 0x000 is used for NO VLAN (frames with priority)



Transmission Control Protocol / Internet Protocol (TCP/IP)

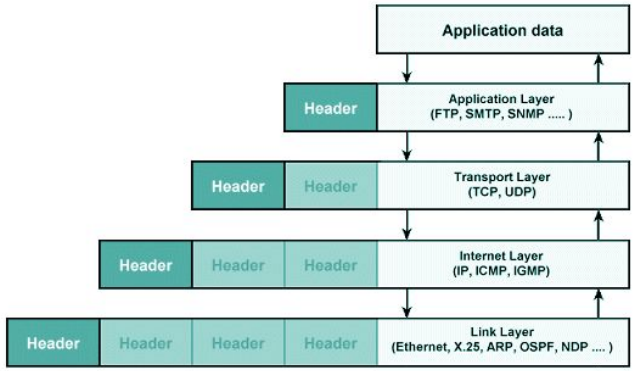
- A set of standard protocols designed for communication over internet (interconnected networks) consisting of different network segments that are linked by routers
- An internet (internetwork) is a very general concept
  - An internet is not limited in size. It can be
    - A couple of networks or
    - The worldwide **I**nternet (capital **I**)
- A model which has 4 layers
  - But the central layers in this model are
    - The internet layer
    - The transport layer





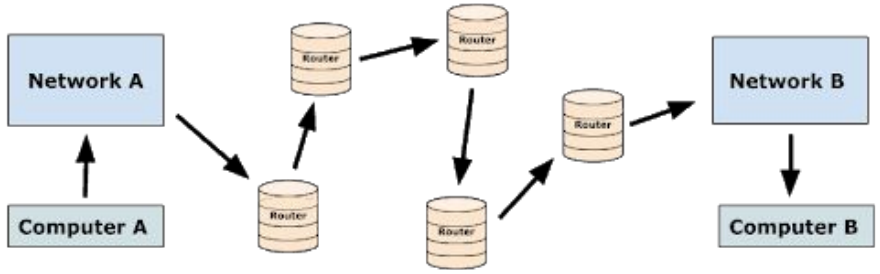
Internet Protocol - IPv4/IPv6

- Enables communication beyond the boundaries of a local network (LAN)
  - By abstracting the lower layers (data link layer and physical layer) in a way that
    - A destination node can be reached in the same network or across multiple networks
- Defines the network layer of the OSI model
- IP is responsible to deliver a variable length data from one place to another by
  - Logical addressing of devices on the network uniquely - IP addresses
  - Creating IP packets by adding a header including source and destination IP addresses
  - Routing the IP packets over the internet
- Does not provide error detection & correction for the data field
  - But the header is protected by a checksum



Internet Protocol - IPv4/IPv6

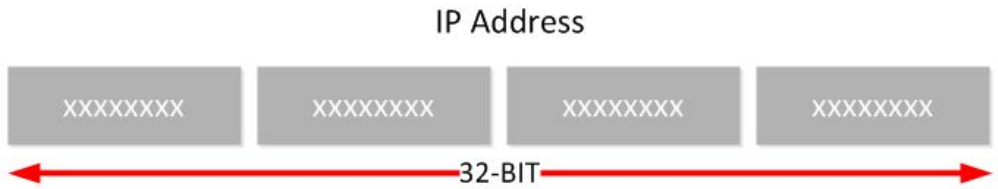
- There are two versions of the Internet protocol
  - IP version 4 - IPv4 (32-bit addresses)
  - IP version 6 - IPv6 (128-bit addresses)



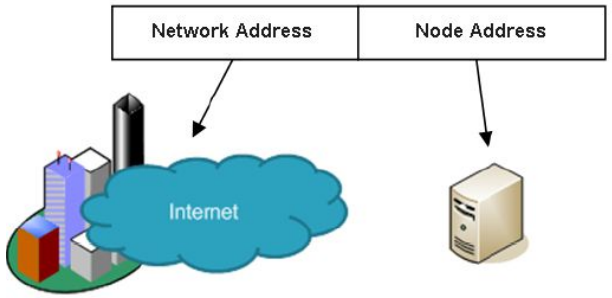
- Routers and IP Packet Routing
  - In order to interconnect various networks, a router is used as a coupling element
  - A router is a node that belongs to more than one network and has more than one IP addresses
  - IP Routing is the process of determining the path that data follows in order to travel across multiple networks from its source to its destination
- IP is a connectionless protocol. No fixed physical connection is created
  - Each packet can travel independently through a different route to the same destination.
  - Fragmentation and reassembly of packets are done by Internet Protocol if it's required

Internet Protocol - IPv4

- 32-bit addresses and they can be written in different ways
  - 208.80.154.224 (most used)
  - 0xD0509AE0
  - 0xD0.0x50.0x9A.0xE0
  - 3494943456



- There are two types of address: General or Public and Local or private
  - Public IP addresses can be accessed over the Internet
  - Private IP addresses can't be accessed over the Internet and routers do not forward them to the Internet.
    - E.g. The IP addresses on the LAN of our school



- An IP address is composed of Network and Node Addresses

Internet Protocol - IPv4

- Addresses and classes
  - For public and private addresses there are different classes
  - If an IP packet is to be sent to multiple nodes, both Multicast addresses and Broadcast addresses can be used
  - The highest value of a host address range always corresponds to the associated broadcast address.
    E.g. 192.168.10.**255**

Public IPv4 Addresses

Class	Start Address	End Address	Properties
A	0.0.0.0	127.255.255.255	127 networks / 16 777 214 nodes
B	128.0.0.0	191.255.255.255	16 384 networks / 65 534 nodes
C	192.0.0.0	232.255.255.255	2 097 152 networks / 254 nodes
D	224.0.0.0	239.255.255.255	268 435 456 multicast groups
E	240.0.0.0	255.255.255.255	Reserved

Private IPv4 Addresses

Class	Start Address	End Address	Properties
A	10.0.0.0	10.255.255.255	1 network / 16 777 214 nodes
B	172.16.0.0	172.31.255.255	16 networks / 65 534 nodes
C	192.168.0.0	192.168.255.255	256 networks / 254 nodes

Internet Protocol - IPv4

- Special IP addresses
  - 127.0.0.1 - localhost (loopback)
  - 169.254.x.x - auto generated when no address is given
  - IP used by DNS servers. E.g. 8.8.8.8 - Google DNS
- Subnetting and Subnet Masks
  - Subnetting is a technique to make several subnets from a given IP address
  - The router filters the subnet addresses from the IP address by means of subnet masks
    - The bits that represent the subnet address have the value 1
    - The bits that represent the host addresses have the value 0
  - E.g. a company works with IP address 172.23.0.0 (class B)
    - Subnet mask is 255.255.0.0 or 1111 1111 1111 1111 0000 0000 0000 0000

Internet Protocol - IPv4

- If the entire company has to be divided into 10 different subnets.
  - All subnets can be linked to each other via a router
    - With 4 bits, 16 different combinations can be created.
    - The required 10 subnets can be created by adding 4 bits to the Network address
    - Subnet mask is 1111 1111 1111 1111 **1111** 0000 0000 0000

Table 3.4: Subnetting and subnet masks

BYTE 3 (binary code)	BYTE 3 (decimal value)	Subnet	Subnetmask
0000 0000	0	172.23.0.0	255.255.240.0
0001 0000	16	172.23.16.0	255.255.240.0
0010 0000	32	172.23.32.0	255.255.240.0
0011 0000	48	172.23.48.0	255.255.240.0
0100 0000	64	172.23.64.0	255.255.240.0
0101 0000	80	172.23.80.0	255.255.240.0
0110 0000	96	172.23.96.0	255.255.240.0
0111 0000	112	172.23.112.0	255.255.240.0
1000 0000	128	172.23.128.0	255.255.240.0
1001 0000	144	172.23.144.0	255.255.240.0

- Classless Inter-Domain Routing (CIDR)
  - A new way of addressing for the Internet which can lead to a more efficient use of IP addresses in comparison to the classes A,B and C
  - The Network address is not limited to 8,16 or 24 bits
  - A CIDR address contains the 32-bit IP address and the number of bits that are part of the network address. E.g. 192.168.0.0/28

```
Network:   192.168.0.0/28
Broadcast: 192.168.0.15
HostMin:   192.168.0.1
HostMax:   192.168.0.14
Hosts/Net: 14
```

Internet Protocol - IPv6

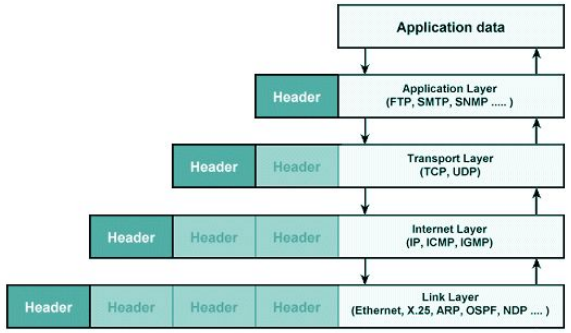
- IPv6 (128-bit addresses) was mainly developed because of
  - The shortage of addresses of IPv4
  - Optimization of the routing process
    - Comparing to IPv4, the number of fields in the IPv6 header has been reduced from 12 to 8 fields
- IPv6 addresses are written by grouping two bytes in hex format separated by a colon
- Four zeros are typically written as only one zero or are completely omitted
- Examples of IPv6 addresses:
  - 1080:0:0:0:8:800:200C:4170 or 1080::8:800:200C:4170
  - FF01:0:0:0:0:0:0:101 or FF01::101
  - 0:0:0:0:0:0:0:1 or ::1(loopback address)
- IPv4 addresses can also be implemented in IPv6. E.g. ::FFFF:129.140.55.138

Internet Protocol - Extension protocols

- There are some extension protocols in the internet layer which are supporting IP
  - The Dynamic Host Configuration Protocol (DHCP)
    - It is able to automatically assign IP addresses to nodes
  - The Internet Control Message Protocol (ICMP)
    - Is part of every IP implementation and is used for control tasks
    - Typical application examples are **ping** and **tracert**
    - Size of control messages is 48 bits
  - The Address Resolution Protocol (ARP)
    - It is used to determine the relation between IP and MAC addresses.
    - If an IP node does not know the MAC address of a destination, it can be requested using ARP
    - The node broadcasts an ARP request to the network, the response contains the MAC address
  - And etc.

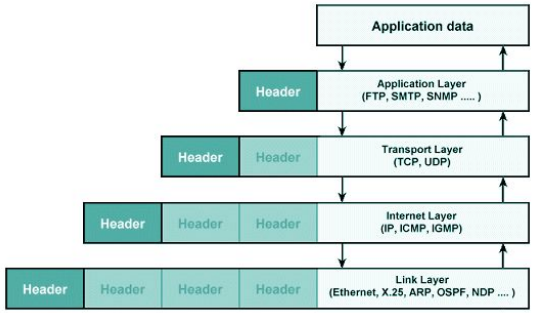
Transport layer - TCP and UDP

- There are two transport protocols in Layer 4 of the OSI model:
  - Transmission Control Protocol (TCP) - connection-oriented transmission
  - User Datagram Protocol (UDP) - connectionless transmission
- Both protocols split the data that are to be transmitted into smaller parts.
  - These splitted data are called segments in TCP and datagrams in UDP
- To reach the destination node, data are transmitted via the Internet Protocol (IP)
- To address the services and applications in the upper layers,
  - **Ports** are provided
  - If a port is opened, data can be exchanged with the associated service or application
  - 64k port addresses are supported



Transport layer - User Datagram Protocol (UDP)

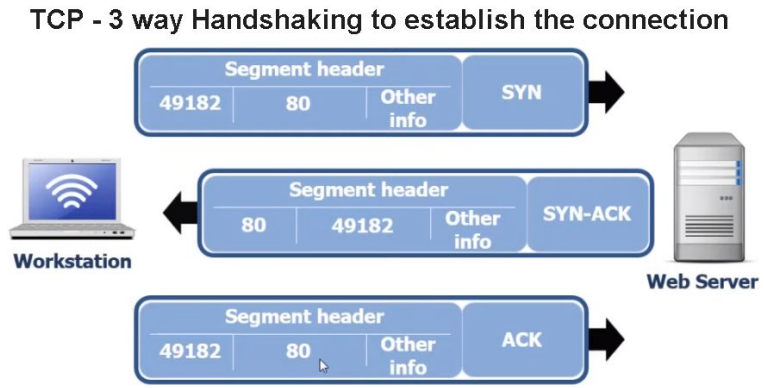
- Is a connectionless transport protocol that transports datagrams
- There is no flow & error control to ensure proper data transmission
  - There is no mechanism to guarantee data transmission
  - There is no error detection and correction mechanism
  - There is no packet order checking
  - If it is required, such mechanisms can be implemented in the higher layer
  - E.g. Voice Over IP (VOIP)



- Advantage: Faster than TCP and can be used to send datagrams as Multicast or Broadcast
- UDP datagrams are fragmented and encapsulated in IP packets by adding the UDP header including the source and destination **ports** and sent using the Internet Protocol
- Reassembling of UDP datagrams are done

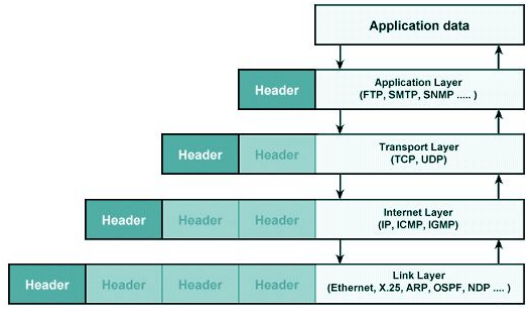
Transport layer - Transmission Control Protocol (TCP)

- TCP represents a connection-oriented transport protocol
  - A connection between two nodes must be established before the actual data transmission
  - The nodes are identified by IP addresses and port numbers
- Stateful connection: A three-way handshake: SYN, SYN-ACK, ACK
- Data arrives in order and duplicate data is discarded
- Reliable data transmission.
- Lost or corrupted segments are resent
- Data of segments is protected by CRC checksum
- Broadcasting and multicasting are not possible.
  - Because a connection between two nodes is required.



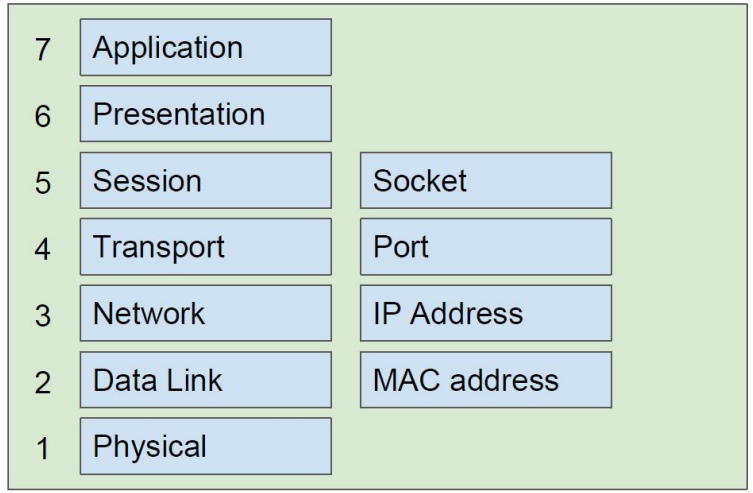
Transport layer - Transmission Control Protocol (TCP)

- Includes traffic congestion control
- Acknowledgment is used for every segment
  - If no acknowledgment within a defined time period, the segment will be sent again
- When all data being exchanged and acknowledged, the connection can be closed
  - A node sends a segment with set **FIN** flag, which signals the connection termination
  - The receiver of this **FIN** segment must respond with an acknowledgment
  - If the receiver also wants to terminate the connection, it sends a **FIN** segment to the original sender. If this is also acknowledged, the connection termination is complete
- A TCP segment is fragmented and encapsulated in IP packets by adding a TCP header including sequence numbers, the source and destination ports and sent using the Internet Protocol
- Reassembling of TCP segments are done



The OSI Model Addressing - TCP/IP

- Ports are service point addresses which are used by applications and services.
- UDP/TCP/IP provides 64k port numbers
- Ports 0-1023 as standardized ports, known as system ports
- Example of such ports:
  - 20-21: FTP - File Transfer Protocol
  - 22: SSH - Secure Shell
  - 53: DNS - Domain Name Service
  - 80: HTTP - HyperText Transfer Protocol
  - 123: NTP - Network Time Protocol
  - 443: HTTPS - HTTP Secure



- A socket is an endpoint (combination of an IP address and a port number) of a two-way communication. Sockets are provided by the session layer; A socket looks like a file descriptor.

Ethernet and TCP/IP

- Some useful links
  - How Ethernet Works and IEEE 802.3 Specification
  - How the Internet Protocol (IP) Works
  - How the Transmission Control Protocol (TCP) Works
  - Ethernet Basics
  - Subnetting explained
  - Network IDs and Subnet Masks
  - Socket Programming Tutorials In C For Beginners (Part 1 and Part 2)
  - Running the Winsock Client and Server Code Sample
  - Multicast IPv4 address to MAC address mapping
  - Socket programming in C on Linux