Automotive Ethernet

1- Physical Layer

General Ethernet :

Ethernet is used for `Bandwith`

In vehicles, low power consumption is important. Also , requirement for ECU(Electronic Control Unit) is to be able to comletely wake up from sleep under 100 miliseconds.

Standard 4 wires ethernet cannot handle this speed currently.

So instead of standard ethernet, we use `Automotive Ethernet` which can take care of these issues.

Bus techologies , compared to ethernet, can be more cost effective given cabling prices all through the vehicle.

Comparing Ethernet to CAN(Controller Area Network) and FLEXRAY

CAN:

it is a multidrop (bus) technlogy where user can add / remove nodes.

Multidrop or bus technology means every node or every ecu is pysically, electrically connected to the same wires as ever other node.

single twisted pair copper wire. => low cost/ light weight easy for `plug and play` `Message` or `Packet` based communication.

Unique for CAN is that **Non-Destructive Arbitration** for handling message or packet `collisions`.

This is handled in the arbitration section or the arbitration ID of the can network. So when there is a possible collision risk , the arbitration ID is used to identify the message or packet. and the packet or the message with the smaller ID is sent first, whereas the packet or the message with the larger ID is sent later but *WITHOUT A NEED FOR RE-TRANSMISSION*.

so lower ID number transmits first, other one waits, not not getting killed just waits. And nodes that transmits the higher ID packet also understands the situatuin and also waits.

This has a drawback: nodes that lost the arbitration (the ones sending the higher ID packet) will have to wait. *this maskes CAN not as time-critical and accurate in time*.

This is why FlexRay was developed

FlexRay:

it is similar to CAN in terms of wiring. it is a *MultiDrop* technology BUT `all nodes must be pre-programmed wit a fixed configuration`

up to 10Mb/s. speed. also good for plug and play. message or packet based communication.

==> *Collision avoidance is based on time slots for each node*

Eveyn node in FlexRay is aware of time base so this helps each node to understand when it is allowed to transmit. So basically there is a cycle time, and it is divided into slices and each node has its own time slot where it is allowed to transmit. So colisions dont happen in flexray.

This helps very accurate in time and security critical.

Automative Ethernet :

(100Base-T)/(1000Base-T)

==> base means this is the speed at the slowest rate ==> T1 means single twisted cable

Modern ethernet technologies, be it automotive or not, is NOT a bus technology anymore. Instead, it is *point-to-point technology*. This means that each node is connected to only one other node. for multiple communication, we need to introduce a `SWITCH`.

Switch distributes the traffic to the nodes within a network based on their `pysicall adress` that.

Today commercially there are 100base and 1000base ethernet, 100 meaning 100Mb/s, 1000 meaning 1Gb/s.

Note that automotive ethenetnet is very cost effective network but not enough for `uncompressed audio and video streaming` since they handle around 10MBits.

Automotive Ethernet
(100BASE-T1 / 1000BASE-T1)

- Pros
  - Up to 1000 Mb/s
    (each direction and each leg)
  - Widely used technology
    (much support)
  - Good clock synchronization technology available (based on IEEE 1588)
  - History of adaptation to solve new problems.

- Cons
  - Requires a switch
  - Not possible to add or remove nodes unless the switch has spare ports
  - Tools cannot just connect and sniff the bus

Infotainment Head Unit (Switch)
A B C

Display   Amp   Aux Display
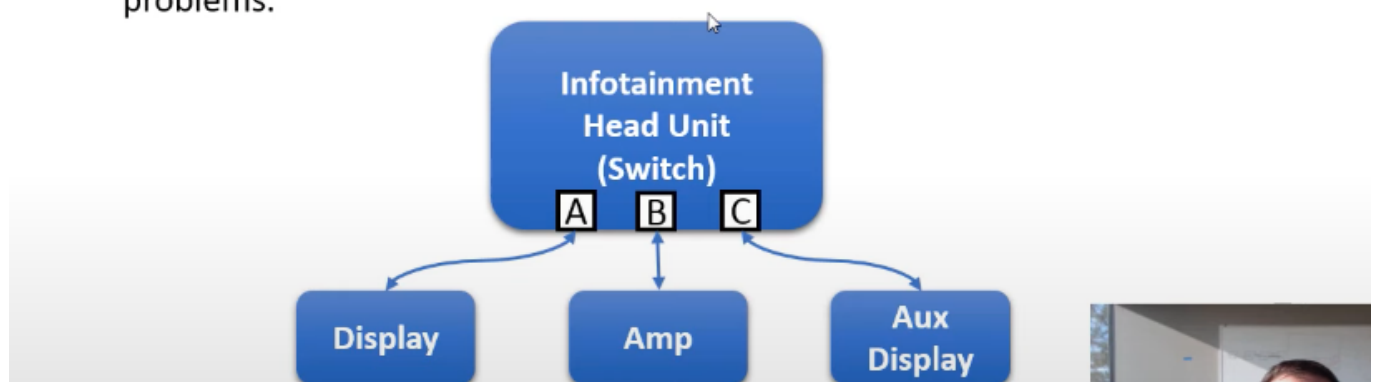
In bus technology, all the node load can be used and it is locked to 100 or 1000 mbits. in ethernet, however, it is not the case, aggregate bandwith can exceed 100 or 1000.

Networking Topologies :

- Defines how device are connected to each other.
- Defines how the device commulicate with each other.
- Determines network characteristics.
- Simple Technologies:
-     ○ Point to Point(port)
-     ○ Ring (Also Etnernet, used for safety critical technologies)
-     ○ Star (ethernet) like one switch with many ports
-     ○ Bus (chained or attached) like CAN , FLEXRAY
- Complex topologies can combine these(like mesh)

Hierarchical Star topology :

also known as `tree` topology, where each star topology represents a node and they are also intercoonected to each other via a switch. you can add / remove nodes without effecting the rest of the nodes.

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Note that today's ethernet network are a `switched network`, devcices connected through switch, it optimizes the traffic flow, buffering eliminates the colisions.

Today's Ethernet Network

- Original Ethernet (Like CAN)
    - Bus architecture
    - Multiple Nodes / Single Medium
    - Collisions + Arbitration = Inefficient
- Most modern networks are a switched network
    - Devices connected through switches
    - Optimized traffic flow
    - Buffering eliminates collisions
- Each leg (A,B,C) acts as its own network.
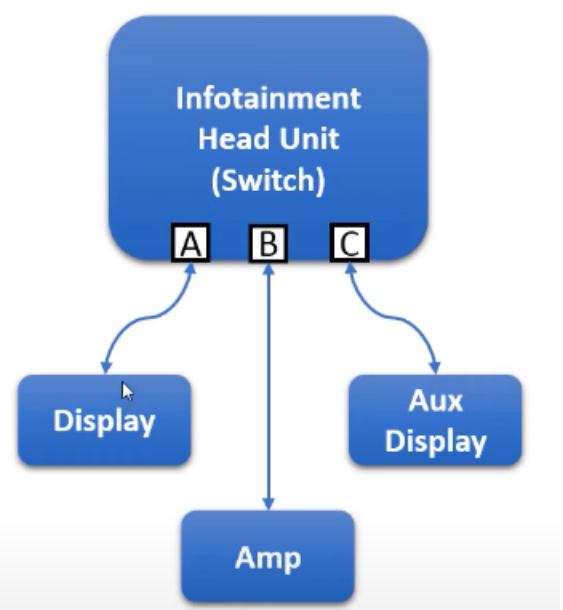
In this pic , there are three ports (A,B,C) and physically A is connected to only it's corresponding Port(Display), same for B and C. and Under each node, it works as a separate network. This eliminates the

possibility of colisions because each node is communicating through only one dedicated port.

(this is the difference between this and CAN/FlexRay)

OSI Model
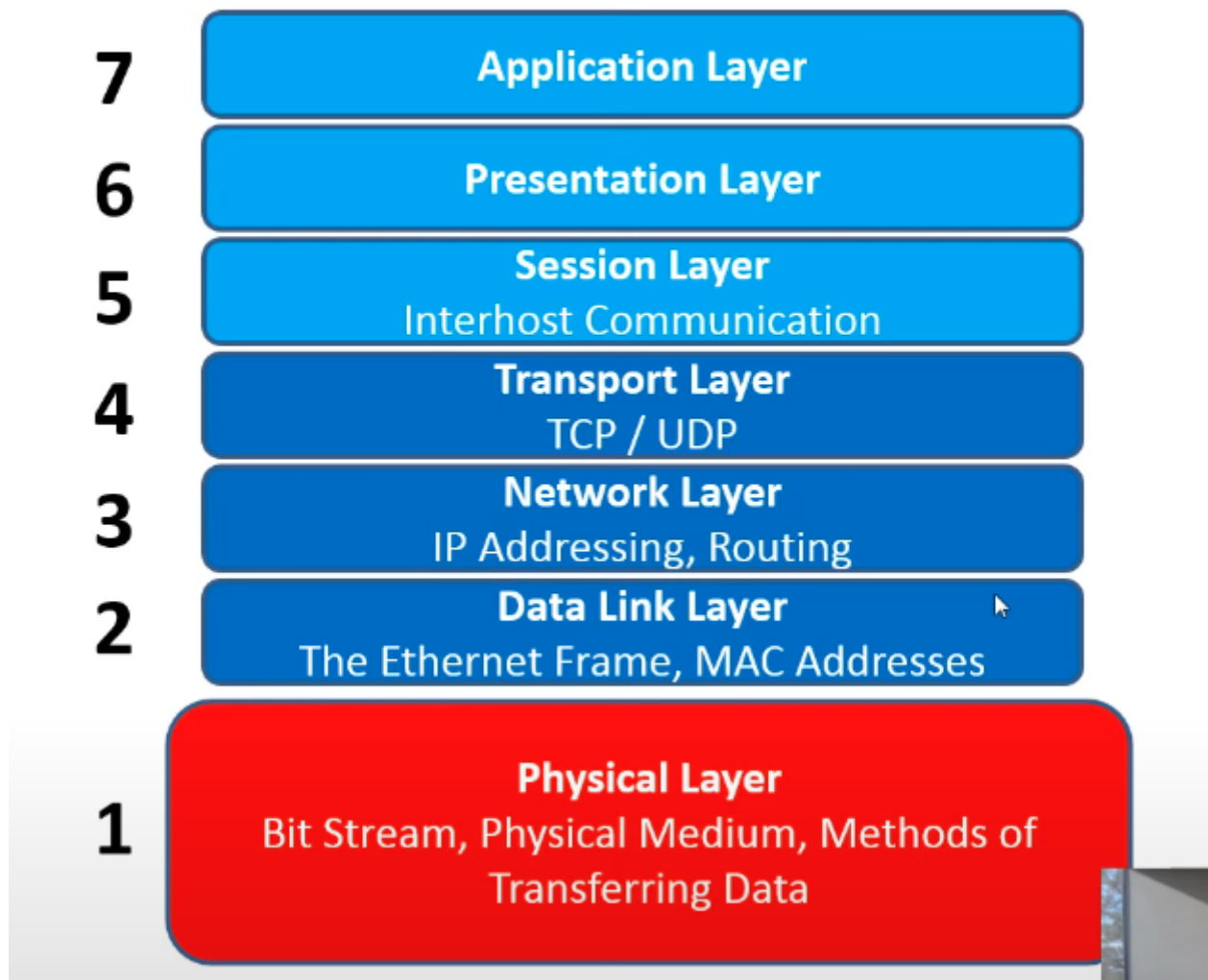
Automotive ethernet, compared to normal ethernet, proioritizes the Physical layer of OSI model.
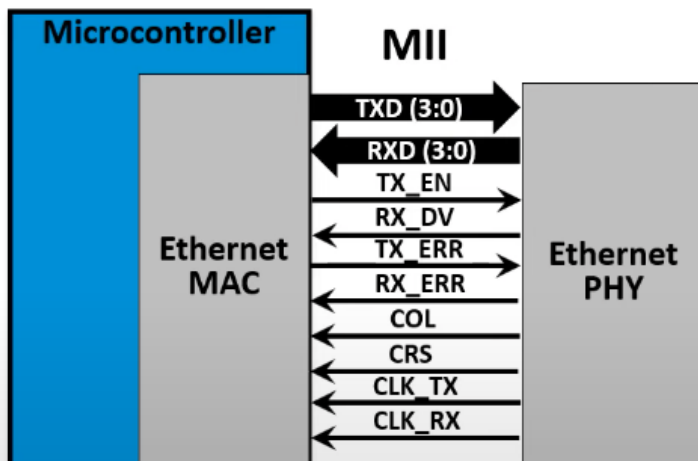
The Power of MII

- Ethernet Node
  - Microcontroller
  - Ethernet MAC controller
  - Ethernet physical layer (PHY).

- MII
  - Media Independent Interface
  - Industry standard digital interface
  - enables different PHYs to be used with any MAC.
  - Evolved into a few variations
    - RMII: Reduced
    - GMII: Gigabit
    - RGMII: Reduced Gigabit
    - SGMII: Serial Gigabit

- Ethernet PHY = Physical layer
- MII = Media Independent Interface
- Ethernet MAC = Media Access Control

MII is connected to Ethernet MAC.

Punchline: Why Ethernet is Used and how it changes between regular vs automotive

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MAC stays constant and all the layers under Pyhsical layer are also stays
constant. This MAC table, once connected, hosts all the addresses etc and
statically keeps these. So it gives ability to easily swap the Ethernet
PHY and MAC stays the same, also all the other layers are intact.

This gives ability to change and adapt overtime.

Automotive internet is an adaptation of it where only the physical layer
is changed.
Hence talking about `Automotive Ethernet` basically meaning a change in
the Pyhsical layer only
This is adaptability and flexibility for the thanks to Ethernet!
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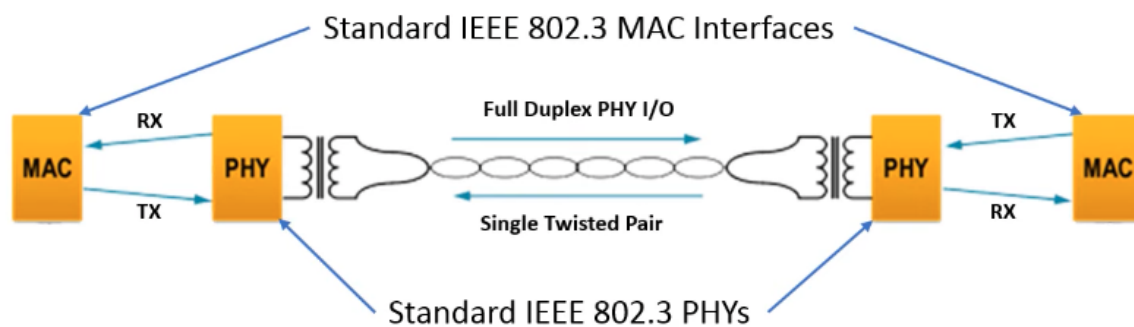
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Consumer Ethernet Media:

Coax ==> 100Base-2 ==> half duplex ==> obsolete in commercial, used in industry for `DiagnosticsOverIP` purposes. (OBD port)

10/100 Ethernet 100MB/s ==> 10/100BASE-TX ==> full duplex => 2 twisted=4 wires.

Gigabit Ethernet 1Gb/s ==> 1000BASE-T ==> full duplex => 4 twisted=8 wires.

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Automotive Physical Layer
100/1000 Mbps

Standard IEEE 802.3 MAC Interfaces

Full Duplex PHY I/O

| MAC | | PHY | | | | | | PHY | | MAC |

RX
TX
TX
RX

Single Twisted Pair

Standard IEEE 802.3 PHYs

- IEEE 802.3bw: 100BASE-T1
    - 66.6 Mbaud
    - 33.3 MHz Clock
    - Max length 25 meters
    - 2 symbols provide 3 bits of info: 66.6M x 3/2 = 100 Mb/s
- IEEE Std 802.3bp: 1000BASE-T1
    - 750 MBaud
    - 125 MHz Clock
    - Max length 15 meters

PAM-3

1
0
-1
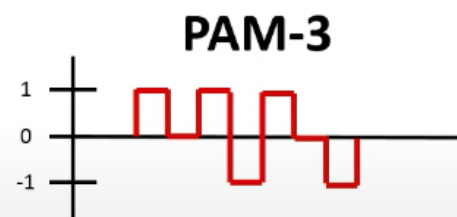
in Bus systems like CAN, FLEXRAY, there is a `binary` state at a given time on the pyhsical layer. Whereas in ethernet, more than 2 logical states can be passed. In Gigabit ethernet this is 5 different states(PAM-5). In automotive physical layer of 100/1000mbps, there are 3 different states(PAM-3).

Operates at base frequency of 33.3 MhzClock.(Gigabit on automative operates at base freq of 125Mhz)

Gotcha Points :

Why Ethernet is good over bus topologies?

1. Ethernet is, DC-wise electronically isolated. So it is either capacitive coupled or transformer coupled. (capacitive or transformers are used to bridge)

This is another point why ethernet is so dominant in the industry. Because you can have lots of ground differences in and around the network and ethernet remains unaffected.

2. *Point2Point* ethernet is, in all moderns forms are `duplex` which means one node can communicate data in one direction `at full speed` and `at the same time` the other node can communicate data in the other direction `at full speed`

Which means, lets say 2 nodes communicating in two-directions in full speed, at 100BaseT connection, it makes 100 * 2 = 200 Mbit per second data transfer. as for gigabit, thats 2 gbits aggregate data.

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A newer Ethhernet Technology that is getting commercially Available nowayays:

10Base-T1S

- This is an ethernet technology that is A BUS TECHNOLOGY, and created to compete CAN.

- To take advantage of cost-effectiveness of Bus technologies, this etthernet type is created.

- 10Base-T1S means `10 Mbit/s` and `single twisted cable` but `sitting on a bus topology`

- works very closely to FlexRay, using transmission cycle time, in each cycle a beacon is signalled and every node cross-checks its own time based on the beacon. Once it sees its own beacon, it transmits data.

- Puncline is : 10Base-T1s is a `time divided type of network` and this is how it avoids colisions.

10BASE-T1S
Differentiating Features

- **Goals**
  - Full bandwidth utilization
  - Reduce latency
  - Quality of Service (QoS)

10 Mbps shared

- **Principle**
  - Avoid physical collisions on the medium by organizing the media access
    - Called Physical Layer Collision Avoidance (PLCA)
- **How it is done**
  - Only the PHY that owns a transmit opportunity is allowed to send data
  - Transmit opportunities are given in a round robin manner
  - A new cycle of transmit opportunities is started when the master node sends a BEACON
 - Works on top of Carrier Sense Multiple Access/Collision Detection (CSMA/CD)

Transmission Cycle

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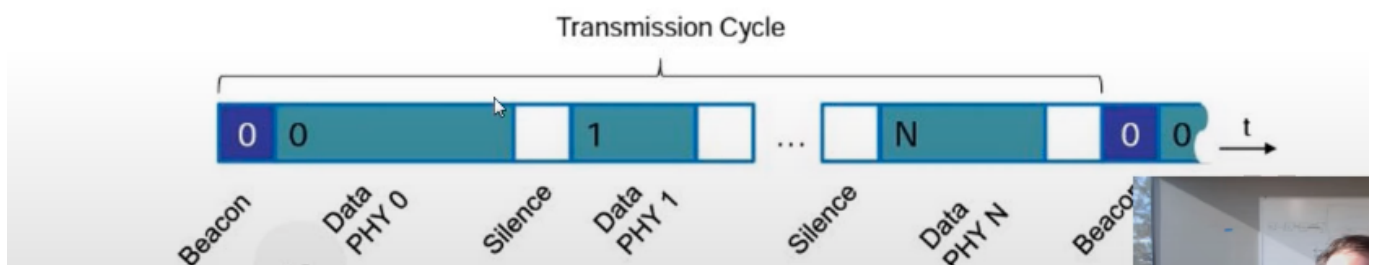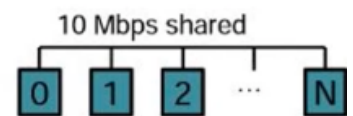
Mixing Pyhsical Medium

It is possible to mix the two technologies, for example, 1000Base-T and 100Base-TX(standard known ethernet in every laptop).

- T implies 8-wire and backward compatible with 4-wire media(TX)
- Auto negotiation resolves the speed since two components have different speed rates.
- Does not work for all media, like optical cable into electrical connector.
- T/TX is are not compatible with T1
- So plugs are not compatible. Needs a media converter and `MII` in between.

A Media Converter connects 2 dissimilar media

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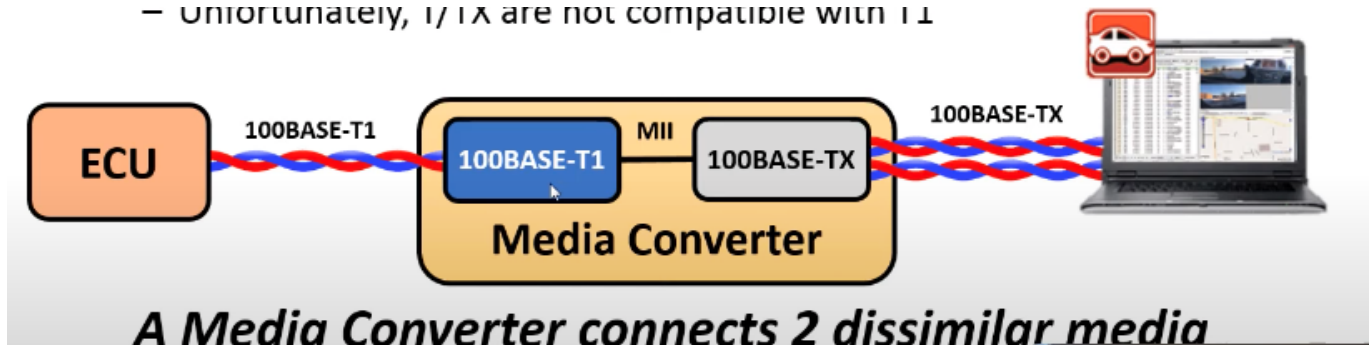
All these things so far are differences between standard ethernet and automotive ethernet and differences live in OSI model layer 8, which is Physical layer. Everything above Layer 8 (7..1) are the same under the hood.

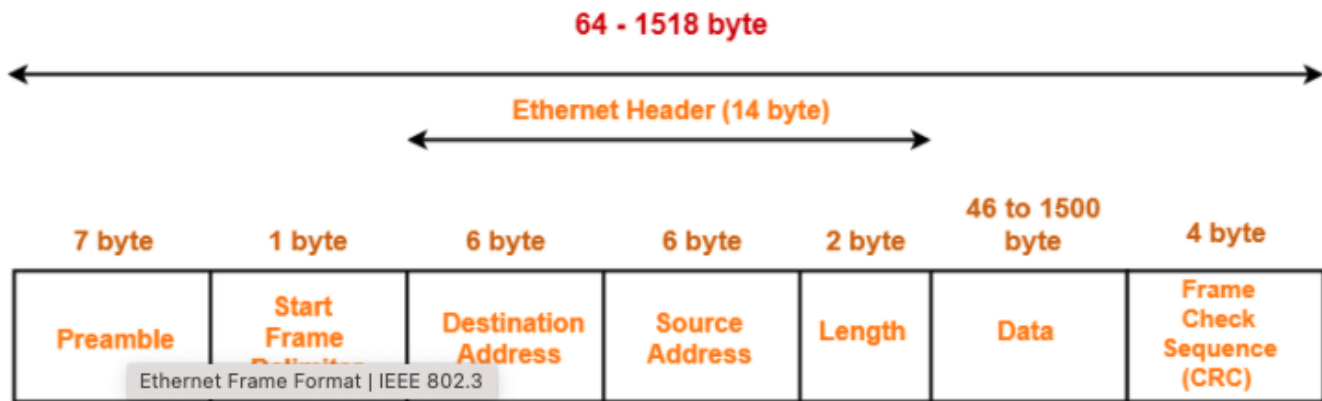====================***====================

2- Data Link Layer

In data link layer lives the Ethernet Frame and MAC Addresses.

The Ethernet Frame:

the lowes level structure to carry all data the data on Ethernet to meet the neetds of Layer2.

- Device Addressing
- Message Formattings
- Error Detection
- QoS (Quality of Service)

=> Frames can carry 46 to 1500 bytes of data.

IEEE 802.3 Ethernet Frame Format

Ethernet Frame architecture:

-> **Preamble** holds 7 octets which helps the syncronization with the rest of the data.

-> **Start of Frame** is a 1 octet field which is used to identify the start of the frame.

-> **Destination MAC Address** is 6 octets, unique. that is the first information that is transmitted and used. Also called the `Physical Address of the Network`

-> **Source MAC Address** is 6 octets, unique. Who transmits the message.

-> **802.1Q Tag** is 4 octets, optional. VLAN Tag. in most cases expecially in WWW it is not used. but in `Automative Ethernet` especially in real-time transmission and protocols that use this real-time transmission do use this for `Routing and QoS` purposes.

-> **EtherType** is 2 octets, identifies the type of the message. Essentuially just a number, that represents the type of data that is coming next in the `payload`. A very common type is `0x0800 for IPV4.` So means the next octet is the first octet of the IPV4 packet.

-> **Payload** is the data that is being transmitted.

-> **CRC** is 4 octets, CRC stands for `Cyclical Redundancy Check`, makes sure that the receiver received all the prior bits in the correct order. **NOTE THAT** if a receiving node receives a frame with a bad CRC like short frame, long frame or a fragment of a frame, it **should** drop the frame and don't tell anybody that you dropped it. So in the low level ,there is no re-transmission. We handle this problem in ethernet with higher level protocols which will come soon down here.

A Comparison: In a given time of 110 miliseconds, the ethernet can transmit 12.336 bits at 100mbps whereas CAN can transmit only 8 bytes of data.

wow!

1) MAC Address:

MAC address is Low-level/pyhsical address of the network.

Example (00-17-4f-08-5D-69)

- Programmed into hardware devices,
- 6 bytes loing,each node globally unique.
- First 3 bytes is a Organizationally Unique Identifier(OUI)
- **in AutomotiveEthernet, MAC Address = Ethernet Address.**

Unicast Addresses:

Point2Point adresses, used to send data to `specific` node. -> `Universally Administered Addresses` ==> UAA : globally unique.

-> `Locally Administered Addresses` ==> LAA : probably not unique outside an `engineered network`

Multicast Addresses:

-> One to Many addresses.

-> Specific MAC address that **certain** NICs are programmed to accepts.

-> USed for protocol, process, or vendor specific messaging.

-> LSB of the first octet is 1. (01:xx:xx:xx:xx:xx)

-> When MAC address is all 1's (ff:ff:ff:ff:ff:ff) this is called `Broadcast Address` which is a special case where **all** NICs are programmed to accept the message.

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2) VLANs

QoS at layer 2 hardwqare. Virtual Lan means, I want to `virtually` separate the traffic in a network so that I can get practicvally multiple networks that are `logically` separated on the `same pyhsical network`.

Ports assigned to Virtual Lans.

-> Switch enforces forwarding restrictions based on VLAN config. -> VLAN traffic is blocked on ports not `a memeber` of that VLAN. -> Used to optimize bandwith use with `least` resources.

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Common Automotive Ethertypes

```
General Use:
0x0800 for IPV4
0x0806 for ARP
0x86DD for IPV6
0x8100 for VLAN (single tag)
0x9100 for VLAN (double tag)
0x88F5 for Multiple VLAN Reservation Protocol


AVB:
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0x22F0 for IEEE 1722
0x88F7 for generalized precision Time Protocol
0x22EA for Multiple Stream Reservation Protocol

V2X:
0x88DC for Wave Short Message Protocol
```