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WorldFIP - Message

- Polling mechanism- different periodicity requirements of the individual variables.
- Macrocycle- compiled at configuration time from several microcycles
- Ensure each variable sampled at reqd rate
- $No. of\ \mu cycles = \frac{LCM\ of\ periods}{GCD\ of\ periods}$
- Numerical Problem: if sampling rates are 6,12,3,4 what is the number of microcycles?
- If sampling rates are 12,6,4,3 = 12/ 1 = 12

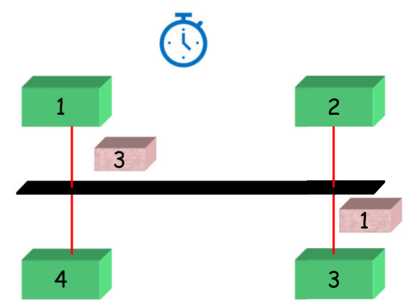
Analysis– Polling

- Master Polls Slave
- Slave has to wait until it is polled
- Master waits only for a certain time for slave response

Explicit – Token Passing

- Target token rotation time T_{TR}
- How long a node can occupy the bus ???

Token Passing



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Explicit – Token Passing

- If node receives the token after the timer is expired- send one high-priority message before passing token again.
- Time available for each node depends on the amount of time all the other nodes in the network hold the token
- Vary from round to round - aperiodic data / retransmissions

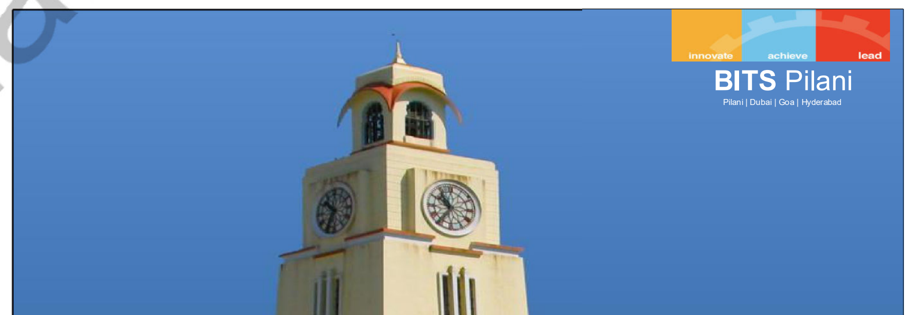
Implicit – Token Passing

- Token is simulated by two counters
- Idle Period Counter
- Access Counter
- 32 Nodes

0, 1, 2, 3, 4, 5 40	1
40, 41,42 50	2
....	
350, 351, ...360	32

Analysis– Token Passing R3.2 V3 14.0

- TP is deterministic
- High Utilizations – very efficient
- Low Utilization – high overhead
- Minimum and Maximum Token Holding Time



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Industrial Network
Field Bus MAC -CSMA

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CSMA

- Destructive (Ethernet) – CSMA/CD
- Non-Destructive (CAN) – Collision Arbitration – CSMA/CA
- Avoid Collisions

What is CAN ?

- Controller Area Network
- Multi-Master System
- Serial commn protocol
- Efficiently supports distributed real-time control with a very high level of security
- CAN has been subdivided into different layers
  - (CAN-) object layer
  - (CAN-) transfer layer
  - physical layer

CAN - Stack

Appln Layer

Object Layer
- Message Filtering
- Message & Status Handling

Transport Layer
- Fault Confinement
- Error Detection & Signaling
- Message Validation
- Ack
- Arbitration
- Message Framing
- T/f rate & Timing

Physical Layer
- Signal level & Bit Repsn
- Tx medium

CAN - Stack

Appln Layer

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CAN - Stack

Appln Layer

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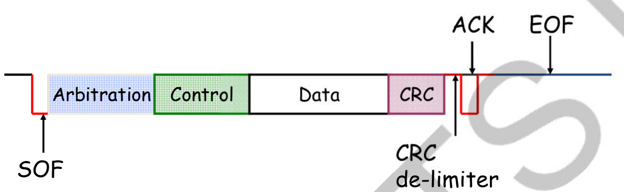
Transport Layer
- Fault Confinement
- Error Detection & Signaling
- Message Validation
- Ack
- Arbitration
- Message Framing
- T/f rate & Timing

Physical Layer
- Signal level & Bit Repsn
- Tx medium

Message Transfer in CAN

- Message sent in Frames
- Data Frame
  - Remote Frame
  - Error Frame
  - Overload Frame
- Frames are separated by IFS
- Bit – Dominant/Recessive
  - Wired AND – 0 Dominant
  - Wired OR – 1 Dominant

Frame Format



Arbitration & Control

Arbitration Field

I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0	RTR

Control Field

R	R	DL3	DL2	DL1	DL0

Node ID – 08

D D D D R D D D

Node Id – 07
D D D D D R R R

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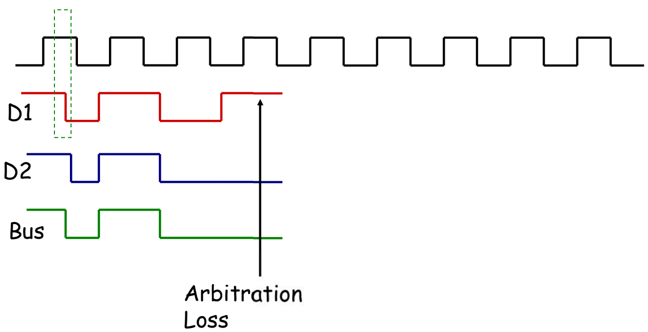
Arbitration Process



Industrial Network

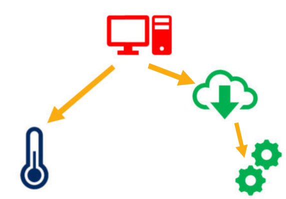
Field Bus MAC -ModBus

ModBus

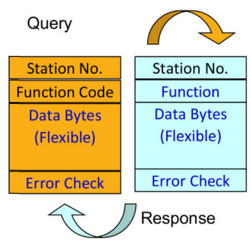
- Developed by Modicon® in 1979 for PLCs
- Transmitting info serially
- Device requesting info -Modbus Master
- Devices supplying info- Modbus Slaves
- One Master
- 247 Slaves- unique Slave Address from 1 to 247
- Connects a supervisory computer with a remote terminal unit (RTU)

ModBus -Versions

- Serial
  - Modbus RTU (Remote Terminal Unit)
  - Modbus ASCII
- Ethernet
  - Modbus TCP



Modbus Query Response



Modbus Query Response

Request

The code: 11 03 006B 0003 7687

- 11: Slave Address ($11_H = 17_D$)
- 03: Function Code 3 - Read Analog Output Holding Registers
- $006B_H$: Address of the first register requested - ($006B_H = 107_D + 40001 = 40108_D$)
  0003: Total no. of registers requested (read 3 registers 40108 to 40110)
- 7687: The CRC (cyclic redundancy check) for error checking.

Response

The code: 11 03 006B 0003 7687

- 11: Slave Address ($11_H = 17_D$)
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- 7687: The CRC (cyclic redundancy check) for error checking.

Request – Response – FC03

Request

11 03 006B 0003 7687

- 11: Slave Address ($11_H = 17_D$)
- 03: Function Code 3 - Read Analog Output Holding Registers
- $006B_H$: Address of the first register requested - ($006B_H = 107_D + 40001 = 40108_D$)
  0003: Total no. of registers requested (read 3 registers 40108 to 40110)
- 7687: The CRC (cyclic redundancy check) for error checking.

Response

11 03 06 AE41 5652 4340 49AD

- 11: Slave Address
- 03: Function Code 3
- 06: Number of data bytes to follow (3 registers x 2 bytes each = 6 bytes)
- AE41: The contents of register 40108
  5652: The contents of register 40109
  4340: The contents of register 40110
- 49AD: The CRC

Remote Terminal Unit – Serial Modes – ASCII

[redacted]

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Serial Modes -ASCII

[redacted]

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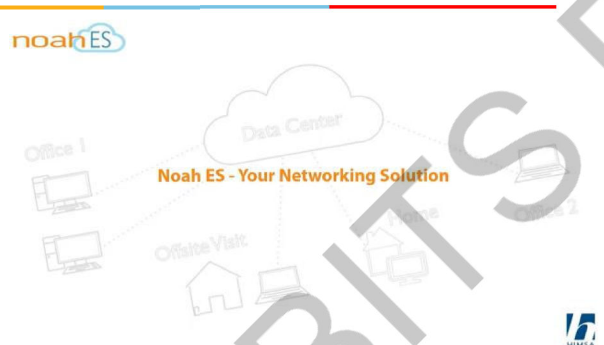
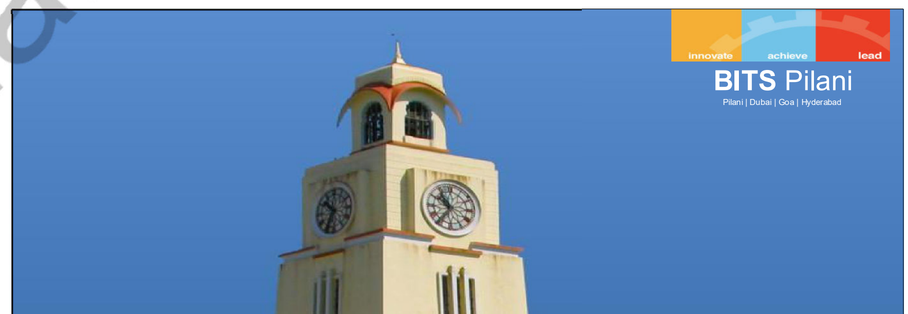
Industrial Network - N.O.A.H

Network Optimised Adaptive Harmonisation

NOAH





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Questions?

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Thank you

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Industrial Ethernet and Fieldbus Protocols

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Start Recording

Industrial Ethernet

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Industrial Ethernet aims to bring deterministic and robust networking to factory environments

- Ethernet - an alternate to mid-level fieldbus systems
- Connection of PLCs
- Inherent lack of determinism
- Techniques - give priority for RT traffic over NRT needed
- Automation & office domain - in principle connected to one single enterprise network

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Ethernet Issues

Lack of deterministic communication
→ Standard Ethernet does not guarantee predictable transmission timing.
Synchronization of actions
→ Difficult to coordinate precise execution timing between multiple devices.
Efficient exchange of small data records
→ Industrial systems often require frequent transmission of small-sized, time-critical data packets.

Ethernet Requirements

- **Seamless migration to Real-Time Ethernet (RTE)**
→ Ensure backward compatibility with existing systems.
- **Use of standard Ethernet components**
→ Leverage widely available and cost-effective hardware.
- **Compatibility with Ethernet and TCP/IP protocols**
→ RTE solutions must maintain interoperability with conventional network layers.
- **Support for standard internet protocols (e.g., HTTP, FTP)**
→ Enables remote diagnostics, configuration, and data access.

Application Classes in Industrial Ethernet

Low-Speed Class (≈100 ms)
- Used for **human-machine interaction**
- Example: Manual input panels, supervisory control

Medium-Speed Class (≈10 ms)
- Suitable for **process control** systems
- Example: PID loops, sensor monitoring

High-Speed Class (≈1 ms)
- Designed for **motion control** and real-time actuation
- Example: Servo motors, robotic arms

All classes typically use 100 Mbps Ethernet
- Ensures sufficient bandwidth for industrial needs

IEC Requirements – Industrial Ethernet

- **Delivery Time**
Guaranteed message delivery within specified time frames
- **Scalability**
Support for many end nodes
- **Network Topology**
Flexibility to support line, ring, star, and mesh topologies
- **Switching Performance**
Minimized number of switches between nodes to reduce latency

IEC Requirements – Industrial Ethernet

- **Real-Time Ethernet (RTE) Throughput**
  Sufficient bandwidth for time-critical data
- **Non-RTE Bandwidth Allocation**
  Ensure background or maintenance traffic does not disrupt RTE communication
- **Time Synchronization Accuracy**
  High precision clock synchronization (in microseconds)
- **Redundancy and Recovery Time**
  Fast network recovery in case of link or device failure

Requirements – Industrial Ethernet

- **Frequent exchange of small packets**
  Common in real-time control (e.g., sensor updates, actuator commands)
- **Occasional transmission of large packets**
  Used for configuration, logging, or diagnostics
- **Time-critical data handling**
  Requires deterministic delivery with minimal delay and jitter
- **High node contention**
  Networks must support many simultaneous devices without performance degradation

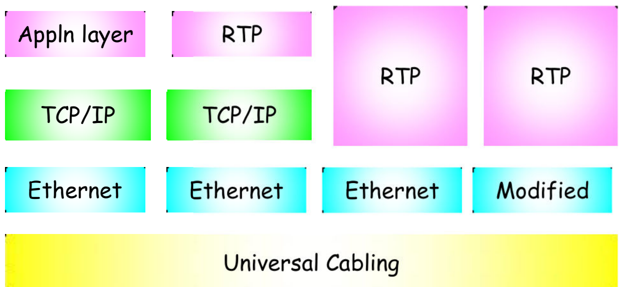
Requirements – Industrial Ethernet

- **Standard Ethernet is not sufficient for Real-Time Ethernet (RTE)** -Cannot guarantee low latency or deterministic delivery needed for automation
- **Need for protocol modifications** - Various enhancements have been proposed to adapt Ethernet for industrial environments
- **Modifications occur at different levels of the protocol stack**, such as:
  - **MAC Layer** – Prioritization, full-duplex communication
  - **Transport Layer** – Replacing TCP with UDP for reduced latency
  - **Application Layer** – Custom industrial protocols (e.g., EtherCAT, PROFINET)

Field Bus vs. Industrial Ethernet

Feature	Fieldbus	Industrial Ethernet
Communication Speed	Slower (kbps to a few Mbps)	Faster (100 Mbps to 1 Gbps and beyond)
Topology	Bus or ring	Star, tree, or ring
Determinism	High determinism	Achieved with special protocols
Standardization	Many proprietary standards (e.g., Profibus, CANopen)	Based on Ethernet standards (IEEE 802.3)
Scalability	Limited	Highly scalable
Integration with IT	Poor	Good (can integrate with enterprise networks)

Protocol Layers



Industrial Ethernet – Modified Ethernet

Modified Ethernet

Modified Ethernet refers to enhancements made to standard Ethernet to meet industrial requirements, such as:

- Real-time data handling
- Increased robustness (EMI protection, temperature, vibration resistance)
- Deterministic communication (using Time-Sensitive Networking (TSN), or protocols like EtherCAT, PROFINET, etc.)

Industrial Ethernet

- **Applied at the lower levels of the Automation Pyramid**
  → Focused on machine-level and real-time control layers
- **Requires hardware modifications**
  → Network devices (e.g., controllers, IO modules) are optimized for deterministic behavior
- **Infrastructure changes**
  → Use of specialized **switches, bridges,** and **real-time capable** devices
- **Supports industrial topologies**
  → Enables **bus** or **ring topology** cabling, not just traditional star
- **Modifications are mandatory within Real-Time (RT) segments**
  → All devices in the RT domain must comply with protocol-specific timing and behavior

Industrial Ethernet

- Priority in MAC mechanism
- UDP instead of TCP
- Producer–consumer
- Publisher - subscriber
- Switching/ collision of fewer domains
- More appropriate physical and logical topologies
- Segmenting and routing into real-time and non–real–time domains
- Communication planning
- High speed
- Full duplex mode

Industrial Ethernet

Robustness

- Physical
- Electrical robustness (EMC)
- Safety
- Security by implementing security mechanisms from IT

Industrial Ethernet

Common communication technology in the entire information and control pyramid

- High efficiency of design
- High efficiency of commissioning
- Simple Internet access
- Possibility to utilize Internet technologies
- Remote monitoring
- Low-cost standard Ethernet interface modules

Synchronization in Industrial Ethernet

- Ethernet TCP/IP – principal non-deterministic
- By using distributed real-time clocks, a decoupling of the execution time grid of the application and the communication time grid can be achieved
- Synchronization protocols from the IT world as NTP and SNTP cannot fulfill the special requirements of automation
- Necessity to implement a cheap synchronization mechanism into the Ethernet TCP/IP protocol in order to improve its real time ability.
- The mechanism must not load much performance of individual entities
- Perspective solution - PTP (Precision Time Protocol) by the IEEE 1588 standard

Modified Ethernet

SERCOS III – Communication Architecture

- **Two logical communication channels:**
  - * **Real-Time (RT) Channel** – for time-critical control data
  - * **Non-Real-Time (IP) Channel** – for standard TCP/IP or UDP/IP communication
- **Telegram types used:**
  - * **MDT (Master Data Telegrams)**
    - # Maximum of 4 per cycle
    - # Sent from master to all slaves
    - # Contains control and synchronization information
  - * **AT (Acknowledgement Telegrams)**
    - # Sent from slaves back to the master
    - # Up to 4 ATs for RT and 4 ATs for IP channel

Industrial Ethernet – Modified Ethernet - SERCOS

sercos the automation bus

SERCOS

- The **Serco's** (**se**rial **r**eal-time **co**mmunication **s**ystem) interface is a globally standardized open digital interface for the communication between industrial controls, motion devices (drives), and input-output devices (I/O).
- It combines on-the-fly packet processing for delivering real-time Ethernet and standard TCP/IP communication to deliver low-latency industrial Ethernet.
- A Serco's III slave processes the packet by extracting and inserting data to the Ethernet frame on-the-fly to achieve low latency.
- Serco's III separates input and output data into two frames. Serco's III supports ring or line topology.
- Serco's III can have 511 slave nodes in one network and is most used in servo drive controls.

SERCOS

- Master station - controlling device
- 1 -254 slave devices each with two Ethernet ports
- Basic network topology - daisy-chain / ring
- Switches not permitted between any two nodes
- Free port of last slave in daisy chain - may connect to a switch
  - Configuration
  - Communication with devices via TCP/IP or UDP/IP

SERCOS - Communication

- 2 different logical communication channels
  - RT channel (RT channel)
  - IP channel (NRT channel)
- Communication done using MDT, AT
- MDT – Master Data Telegrams (max - 4)
- AT – Ack Telegrams (max - 4 RT, 4 IP)
- Number & lengths of the RT-data telegrams fixed according to configuration - determined at initialization

SERCOS - Communication

- All Serco's III telegrams conform to the IEEE 802.3 and ISO/IEC 8802-3 MAC (Media Access Control) frame format.
- Destination Address The destination address for all Serco's III telegrams is always 0xFFFF FFFF (all 1s), which is defined as a broadcast address for Ethernet telegrams. This is because all telegrams are issued by the master and are intended for all slaves on the network. Source address The source address for all Serco's III telegrams is the MAC address of the master, as it issues all telegrams.

SERCOS - Communication

- Ethernet types A unique Ether Type value has been assigned via the IEEE Ether Type Field Registration Authority for Serco's III (0x88CD).

- Serco's III header :

The beginning of the Ethernet-defined data field always begins with a Serco's III header, which contains control and status information unique to Serco's.
Serco's III data field The Serco's III header is followed by the Serco's III data field, which contains a configurable set of variables defined for each device in the network.

SERCOS - MDT

MDTs (Master Data Telegrams) are sent from the **SERCOS master** to all **slave devices** during each communication cycle.

- **Functions of MDT:**
  – **Synchronization pulse** for time-aligned operation
- **Data record transmission**
  - Specific control and monitoring data sent to each slave
- **Control information**
  - Start/stop commands, status requests, and system flags
- **Service channel data**
  - For configuration or diagnostics
- **Command data**
  - Instructions for process execution or motion control
- **Max MDTs per cycle:**
  – Up to **4 MDTs** can be sent in a single cycle

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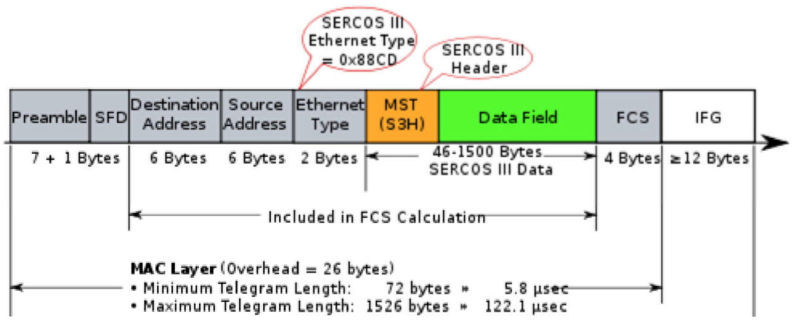
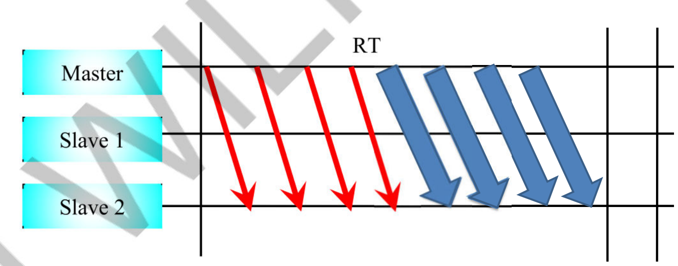
SERCOS – Telegram format



SERCOS



SERCOS

- Cycles -31.25, 62.5, 125, 250µs
- Integer Multiples of 250µ s upto 65,000µs
- Time slots for RT ,AT, IP are sent at the start so every slave is aware
- FPGA is used to separate RT from IP

Performance indicators for SERCOS

Performance indicator	Profile 16/3[a]	Profile 16/3[b]
Delivery time	<39.8 µs	<513 µs
Number of end-stations	≤9	≤139
Number of switches between end-stations	0	0
Throughput RTE	11.2 M octets/s	≤9.248 M octets/s
Non-RTE bandwidth	0%	25%
Time synchronization accuracy	—	—
Non-time-based synchronization accuracy	<1 µs	<50 µs
Redundancy recovery time	0	0

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Working of SERCOS -1

Consider a Scenario:

You have installed a SERCOS network with following devices:

- 4 servo drives
- Each drive exchanges 32 bytes of data (input + output)
- Controller sends 32 bytes and receives 32 bytes from each drive
- Communication overhead per frame: 100 bytes
- Network speed: 100 Mbps

What is the minimum cycle time?

Working of SERCOS -1 Solution

Total Data per Cycle

For 4 drives:
Total I/O data = 4 drives × 2 directions × 32 bytes = 256 bytes
Total data = 256 bytes + 100 bytes overhead = 356 bytes

Convert to bits:
356 bytes×8=2848 bits

Transmission Time:
2848 bits/(100×10^6 bits/s)=28.48 μs

Add network delay and processing time (assume 20 μs total):
minimum cycle time ≈ 48.48 μs

Working of SERCOS -2

A SERCOS network operates at **100 Mbps** and uses **500 bytes** per cycle for cyclic real-time data. What percentage of the bandwidth is used if the cycle time is 250 μs?

Solution:

Data per second:

Cycles per second = 1/250μs = 4000 cycles /second

Data per second:

500x4000 = 2,000,000 bytes/sec =2MBps or 16 Mbps

Bandwidth usage:

16Mbps/100Mbps = 16%

Bandwidth usage is 16%

Working of SERCOS -3

A SERCOS III network uses daisy-chaining with 6 drives. Each drive introduces a 0.5 μs forwarding delay. What is the total additional delay from daisy-chaining?

Solution:

Total delay = (6-1)x0.5 = 2.5μs

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Industrial Ethernet – Ether CAT

Ether CAT

- Ethernet for Control Automation Technology (Ether CAT) is a protocol that provides power and flexibility to industrial automation, motion control, real-time control systems, and data acquisition systems. Introduced in 2003, Ether CAT offers real-time communication using the master/slave configuration mentioned above.
- This protocol increases speed in two ways:There is only one device sending data.
- By using a technique called "processing on the fly," which is when a "slave" node extracts only the information it needs from a data packet and sends the data downstream simultaneously.

Ether CAT

- Ether CAT was originally developed by Beckhoff to enable on-the-fly packet processing and deliver real-time Ethernet to automation applications and that can provide scalable connectivity for entire automation systems, from large PLCs all the way down to the I/O and sensor level.
- Ether CAT, a protocol optimized for process data, uses standard IEEE 802.3 Ethernet Frames. Each slave node processes its datagram and inserts the new data into the frame while each frame is passing through. The process is handled in hardware, so each node introduces minimum processing latency, enabling the fastest possible response time.

Ether CAT

- Ether CAT is the MAC layer protocol and is transparent to any higher-level Ethernet protocols such as TCP/IP, UDP, Web server, etc.
- Ether CAT can connect up to 65,535 nodes in a system, and Ether CAT master can be a standard Ethernet controller, thus simplifying the network configuration. Due to the low latency of each slave node, Ether CAT delivers flexible, low-cost, and network-compatible industrial Ethernet solutions.

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Working of EtherCAT

You are controlling 10 servo drives with EtherCAT.
Each drive requires 32 bytes of input and 32 bytes of output.
EtherCAT operates at **100 Mbps**.
Cycle time requirement: **1000 µs**
Is it feasible within 1000 µs?
(Assume EtherCAT overhed of 100 bytes and propagation +delay = 40µs)

Working of EtherCAT

Solution:

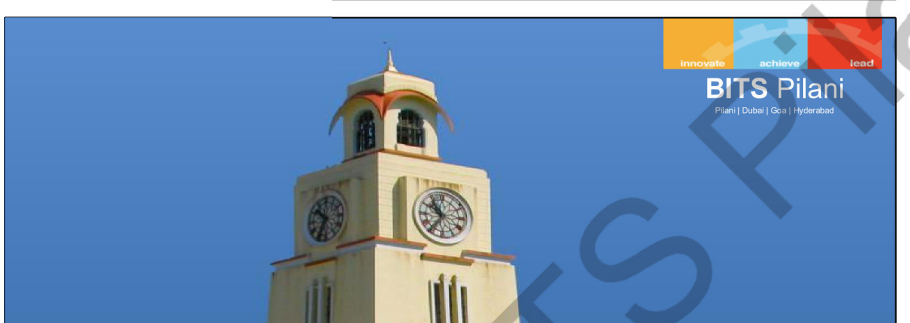
Total I/O per drive = 64 bytes
Total for 10 drives = 640 bytes

Add EtherCAT protocol overhead ≈ 100 bytes
Total = 740 bytes

Convert to bits:
740×8=5920 bits740 × 8 = 5920
Transmission time:
5920/100×10^6=59.2 µs

Add propagation and switch delay (~40 µs total)

Total estimated time: ~100 µs,
This is well within 1000 µs.



Industrial Ethernet – MODBUS Protocol

MODBUS Protocol

- Modbus is a serial communications protocol originally published in 1979 for use with its programmable logic controllers (PLCs).
- Simple and robust, it has since become a de facto standard communication protocol.
- The main reasons for the use of Modbus in the industrial environment are:
  - Developed with industrial applications in mind.
  - openly published and royalty-free.
  - Easy to deploy and maintain.

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MODBUS ASCII Frame Format

Modbus ASCII frame format

Name	Length (char.)	Function
Start	1	Starts with colon (:) (ASCII hex value is 0x3A)
Address	2	Station address
Function	2	Indicates the function codes like read coils / inputs
Data	n	Data + length will be filled depending on the message type
LRC	2	Checksum
End	2	Carriage return – line feed (CR/LF) pair (ASCII values of 0x0D & 0x0A)

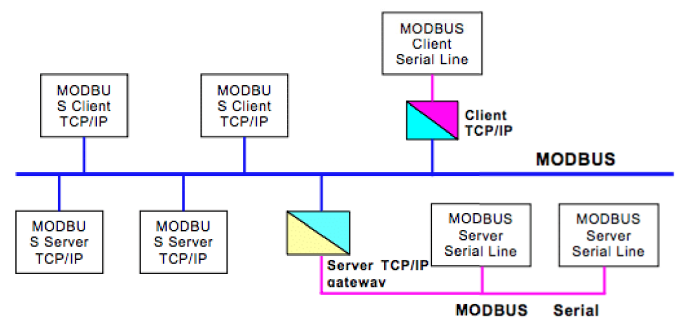
MODBUS Limitations

- Modbus was designed in the late 1970s.
- No standard way exists for a node to find the description of a data object.
- Since Modbus is a master/slave protocol, there is no way for a field device to "report by exception".
- Modbus is restricted to addressing 247 devices on one data link.
- Modbus transmissions must be contiguous which limits the types of remote communications devices.
- Modbus protocol itself provides no security against unauthorized commands or interception of data.

MODBUS TCP/IP

- Modbus TCP/IP (Transmission Control/Protocol and Internet Protocol) was the first industrial Ethernet protocol to be launched and is a variation of the Modbus family of communication protocols that were developed for the supervision and control of automated equipment.
- This protocol transfers discrete data between control devices using a simple master-slave communication. With this type of transmission, the "slave" node cannot transfer data until it has been commanded to do so by the "master" node. This protocol is not considered to be real-time.

MODBUS TCP/IP Communication



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Industrial Ethernet – Top of the Ethernet

Top of the Ethernet

- **Application Layer Protocols** that sit on top of standard Ethernet
→ Commonly used at the **cell level** in the **Automation Pyramid**
- **No hardware modification required**
→ These protocols work with **standard Ethernet hardware**
- **Custom protocol handling via EtherType field**
→ Special protocols are identified using a unique **EtherType** value in the Ethernet frame

Top of the Ethernet Objectives

- **Guaranteed transmission of time-critical data**
→ Ensures timely delivery within **short, precise, and configurable synchronous cycles**
- **High-precision synchronization of network nodes**
→ Time alignment in the range of **microseconds (µs)** for deterministic communication
- **Handling non-time-critical data efficiently**
→ Transmitted through a **reserved asynchronous communication channel**
→ Prevents interference with time-sensitive operations

Top of Ethernet

- **Ethernet Powerlink (EPL)**
  *Real-time communication using **slot-based scheduling**
  *Master–slave architecture
- **TCnet (Time-Critical Network)**
  *High-speed **cyclic transmission** with redundancy
  *Supports synchronous and asynchronous messaging
- **EPA (Ethernet for Plant Automation)**
  *Distributed real-time protocol using **time slicing**
  *Enables both periodic and non-periodic transmissions
- **PROFINET CBA (Component-Based Automation)**
  *Uses **object-oriented communication**
  *Suitable for **modular system design and integration**

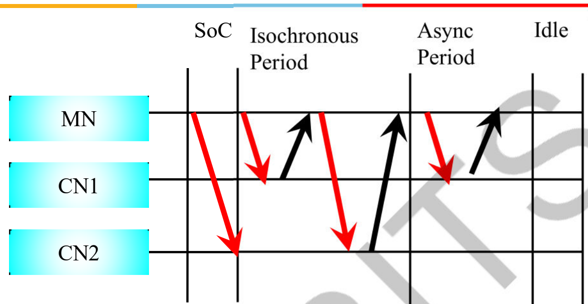
Industrial Ethernet – Top of Ethernet - EPL

ETHERNET POWERLINK

EPL

- Master–Slave scheduling - shared Ethernet segment
- Slot Communication Network Management (SCNM)
- Master - managing node (MN)
  - Ensures RT access to cyclic data
  - Allows NRT TCP/IP -only in reserved time slots
- Other nodes - controlled nodes (CN)
  - Sent on request by the MN

EPL



EPL- Communication

- 2 different logical communication channels
- Protected Ethernet
- Non- EPL nodes are not permitted - protected Ethernet - corrupt the SCNM access mechanism
- MNs of different protected Ethernet segments are synchronized based on distributed clock.
- IEEE 1588 protocol
- MNs can do routing - including IP address translation

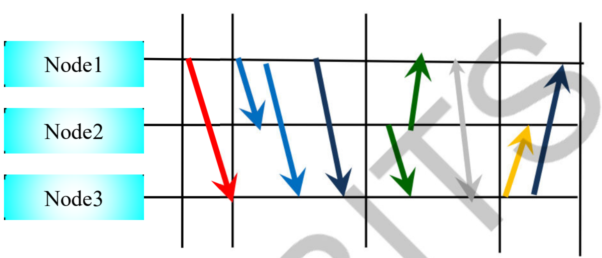
Industrial Ethernet – Top of Ethernet - TCNet

TCNet

- **Synchronous Communication Levels**
- Supports **multiple priority levels**:
  - **High**, **Medium**, and **Low** priority synchronous channels
  - Used for **cyclic, time-critical control data**
- **Asynchronous Communication Support**
  - Allows **sporadic or event-driven messages**
  - Suitable for status updates, alarms, or diagnostics
- **Redundant Transmission Media**
  - Ensures **fault tolerance and high availability**
  - Enables seamless operation even during network failures

TCNet

High –speed Tx period



TCNet

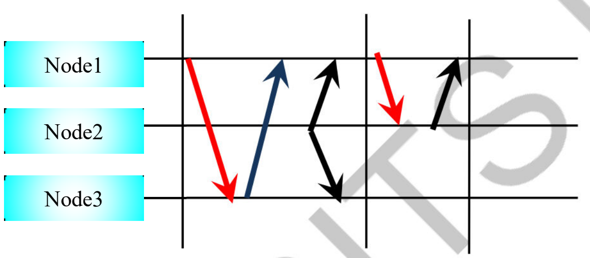
- **Network Topology Example**:
- **Node 1**, **Node 2**, **Node 3** connected in a real-time Ethernet segment
- **High-Speed Transmission Period**:
- TCNet enables **cyclic data exchange** in tightly scheduled time slots
- Ensures minimal latency for **real-time control loops**
- **Usage**:
- Common in **robotics**, **factory automation**, and **motion control systems**

Industrial Ethernet – Top of Ethernet -EPA

EPA

- Ethernet for Plant Automation
- Distributed approach- realize deterministic commn based on a time slicing mechanism inside the MAC
- Two Phases
  - Periodic (T_P)
  - Non-Periodic (T_n)
- Last part - device's periodic message –nonperiodic-message announcement
- All devices which announced nonperiodic messages content using normal CSMA/CD to send in this phase

EPA



EPA numerical

An industrial Ethernet network designed to carry the following traffic:

Cyclic I/O traffic: 64 bytes per device, 20 devices, 1000 Hz cycle
Camera stream: 10 Mbps for monitoring
Engineering PC access: 5 Mbps sporadically
Network speed: 100 Mbps

Find the bandwidth utilisation.

Solution

I/O traffic:
64 bytes × 20 devices = 1280 bytes/cycle
1280 bytes × 1000 Hz = 1.28 MB/s = 10.24 Mbps

Bandwidth utilisation:

I/O traffic: 10.24 Mbps
Camera: 10 Mbps
Engineering PC: 5 Mbps
Total = 25.24 Mbps

Percentage utilisation: 25.24/100 = 25.24%

Industrial Ethernet – Top of TCP/IP

Top of TCP/IP

- Several RTE solutions use the TCP/UDP/IP protocol stack without any modification
- Possible to communicate over network boundaries transparently, also through routers.
- It is possible to build automation networks reaching almost every point of the world –IoT
- Requires reasonable resources in processing power and memory and introduces nondeterministic delays in communication

Top of TCP/IP

- **Use of Standard TCP/UDP/IP Stack**
  *Many **Real-Time Ethernet (RTE)** solutions run on unmodified standard protocol stacks.
  *Ensures **compatibility with existing IT infrastructure**.
- **Seamless Communication Across Networks**
  *Communication is **transparent across routers, subnets**, and even the internet.
- **Foundation for Industrial IoT (IIoT)**
  *Enables **global connectivity** for automation systems.
  *Supports remote monitoring, diagnostics, and control.
- **Trade-offs**
  *Requires **higher processing power and memory** in devices.
  *May introduce **non-deterministic delays**, unsuitable for strict real-time applications.

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Industrial Ethernet – Top of TCP/IP – Modbus/TCP

Modbus – TCP

- TCP connection-based protocol
- The Master (or Client in Modbus TCP) establishes a connection with the Slave (or Server)
- The Server waits for an incoming connection from the Client
- The Server then responds to the queries from the Client until the client closes the connection

Modbus/TCP

Request

11 03 006B 0003 7687

03 006B 0003 -PDU

MBAP header (Modbus Application Header)

0001 0000 0006 11 03 006B 0003

- 0001: Transaction Identifier
- 0000: Protocol Identifier
- 0006: Message Length (6 bytes to follow)
- ADU

Modbus/TCP

			ADU	
		TCP Header	ADU	
	IP Header	TCP Header	ADU	
Ethernet Header	IP Header	TCP Header	ADU	FCS

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Summary and Comparison Industrial Ethernet for modern automation

Fieldbus for legacy knowledge Industrial Ethernet for modern automation trends and future careers.

Feature	Fieldbus	Industrial Ethernet
Speed	Low (< 12 Mbps)	High (10 Mbps – 1 Gbps)
Real-Time Capability	Built-in	Achieved with special protocols
Topology	Bus, point-to-point	Star, ring, line
Integration	Limited (proprietary systems)	Seamless with IT networks
Scalability	Limited	Highly scalable
Future-Readiness	Suitable for legacy systems	Ideal for Industry 4.0 applications

"**Modified Ethernet** = Ethernet + Industrial Power"

Modified Ethernet, or **Industrial Ethernet**, is an enhanced version of standard Ethernet tailored for industrial use. It supports **real-time**, **high-speed**, and **reliable** communication in harsh environments, enabling seamless integration between factory systems and enterprise networks—making it ideal for **automation** and **Industry 4.0** applications.

Understanding SERCOS, EtherCAT, EPL, TCNet, EPA

1. SERCOS (Serial Real-time Communication System)
- **Purpose**: Real-time communication for **motion control** (servo motors, drives).
- **SERCOS III** uses **Ethernet** as the physical layer.
- Very **deterministic**—ideal for precise machine control (e.g., CNC, robotics).

2. EtherCAT (Ethernet for Control Automation Technology)
- Developed by **Beckhoff**.
- Extremely **fast** and **deterministic**.
- Uses a "processing-on-the-fly" method—data is processed **while passing through** devices.
- **Ideal for**: Motion control, robotics, packaging machines.

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Understanding SERCOS, EtherCAT, EPL, TCNet, EPA

3."Top of Ethernet" (General Concept)
- Refers to **application-layer protocols** that run **on top of Ethernet**.
- These protocols leverage Ethernet hardware but add their own **real-time or industrial-specific features**.
- Examples: EtherNet/IP, PROFINET, etc.

4.EPL (Ethernet PowerLink)
- Developed by **B&R Automation**.
- Real-time Industrial Ethernet protocol.
- Uses **time slicing** for deterministic communication.
- Master-slave communication.
- **Used in**: Automation, robotics, and synchronized motion systems.

Understanding SERCOS, EtherCAT, EPL, TCNet, EPA

5.TCNet (Toshiba Control Network)
- Developed by **Toshiba**.
- High-speed network used in Toshiba's **industrial controllers**.
- Designed for **real-time factory automation**.
- Less common globally—mostly used in Toshiba ecosystems.

6.EPA (Ethernet for Plant Automation)
- Developed by **HollySys** (China).
- A **Chinese standard** for Industrial Ethernet.
- Based on PROFINET and adapted for local industry needs.
- Combines fieldbus and Ethernet features for **plant-wide automation**.

Ethernet IP and Other Protocol

Protocol	Real-Time	Speed	Used For	Fun Fact
EtherCAT	yes	Very High	Robotics	Processes data **in transit**
SERCOS III	yes	High	CNC, motion ctrl	Uses ring topology
EPL	yes	High	Motion systems	Uses **time slots** for comm
TCNet	yes	Medium	Toshiba systems	Proprietary by Toshiba
EPA	yes	Medium	Plant automation	Chinese standard protocol

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Thank you

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Top of TCP/IP – Overview

- Operates at the Application Layer of the TCP/IP model
- Includes protocols like Modbus TCP/IP, HTTP, FTP, SMTP
- Uses TCP for reliable data transmission and IP for addressing
- Enables communication between devices over Ethernet networks
- Widely used in industrial automation and IT systems
- Supports interoperability, scalability, and remote access

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Modbus over TCP/IP

Modbus over TCP/IP is the classic Modbus protocol adapted to run over Ethernet using TCP/IP. It enables communication between devices on standard networks, using TCP port 502, and follows a client-server model. It's widely used in industrial automation for easy, scalable, and remote device control—but isn't inherently real-time or secure without extra measures.

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Network Embedded Applications
(CSIW ZG656)

Automotive Networked Embedded Systems

CS 13 & 14

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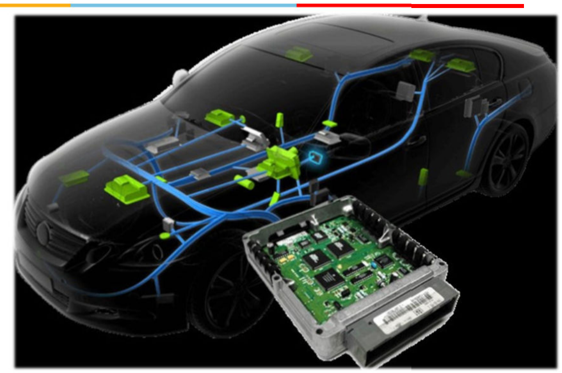
IMP Note to Self

Start Recording

IMP Note to Students

- It is important to know that just login to the session does not guarantee the attendance.
- Once you join the session, continue till the end to consider you as present in the class.
- IMPORTANTLY, you need to make the class more interactive by responding to Professors queries in the session.
- **Whenever Professor calls your number / name ,you need to respond, otherwise it will be considered as ABSENT**

Auto Electronics



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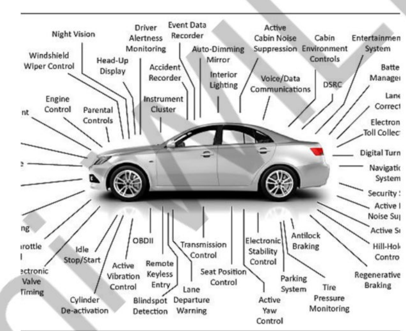
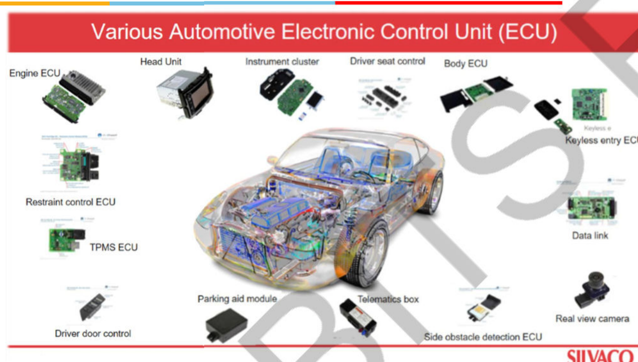
Electronic Control Unit (ECU)

- ECU is an electronic device that controls a specific function.
- ECU may range from controlling the engine to controlling the wiper to controlling the brakes.
- Modern cars can have 100 Electronic Control Units or even more.
- An ECU might control only one system in a vehicle, or it could control multiple systems.

Explosion of ECUs



- Pretty much every function is turning into an electronic component.



Elements of Electronic Control Unit (ECU)

- Microcontroller
- Memory
- Communication
- Electronics Control Unit software
- Inputs
- Outputs

Microcontroller
•A Microcontroller is a small computer. It contains one or more CPUs.

Memory
- RAM
- EEPROM
- Flash memory.

Communication
- Bus Transceivers for CAN bus, K-Line etc

Electronic Control Unit Software
- Software Bootloader
- ECU and Software Identification, Checksums, Version Management, Application

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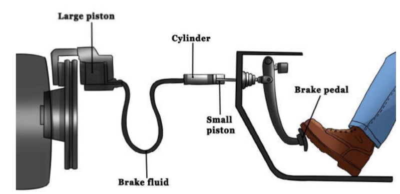
Elements of Electronic Control Unit (ECU)

Inputs
- ECU receives inputs from different sources depending on its functions.
- For example, door lock ECU receives input when a passenger presses the button on a car door.
- The inputs can be from sensors, other ECUs. It could be Analog or digital.

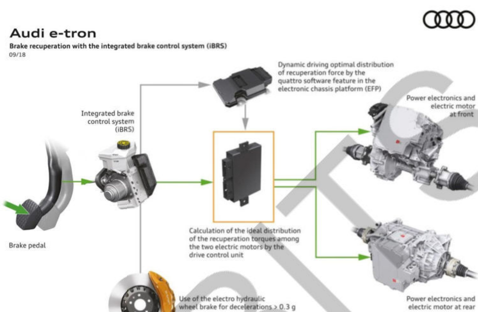
Outputs
- ECU communicates to an actuator to perform an action based on the inputs it received.

Why do we need automotive networks?

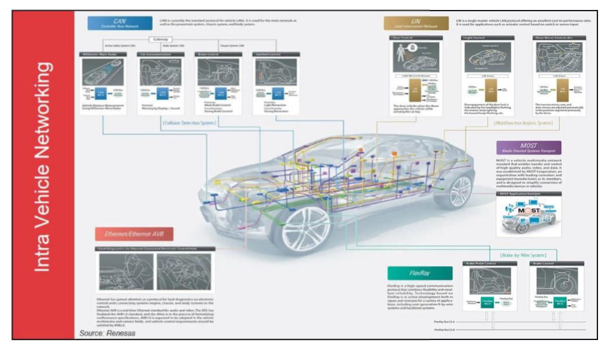
- **Evolution of the Electronic Control Unit (ECU)**
- a few 10s of ECUs to more than 100s of ECUs in each car.



Why do we need automotive networks?



Automotive Networks in car *Intra-vehicle networks types, protocols and applications*



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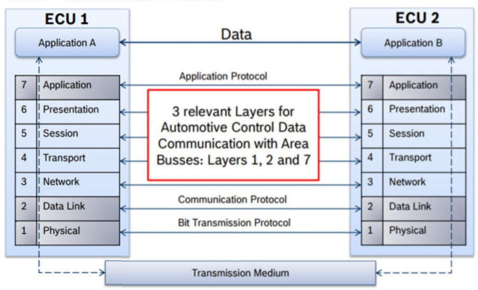
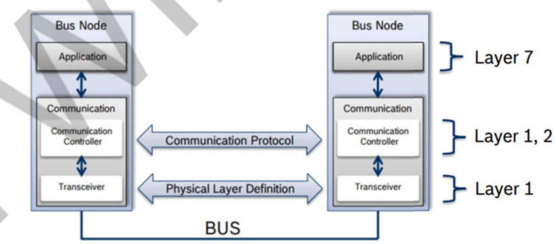
OSI Layers in Automotive Networks

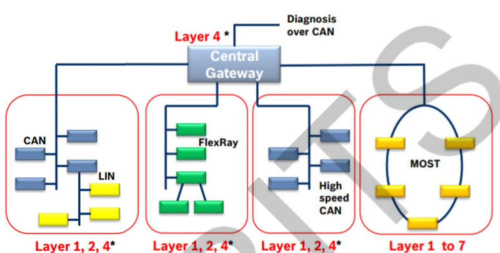
OSI Reference Model



Simplified generic Architecture for Automotive Serial Busses

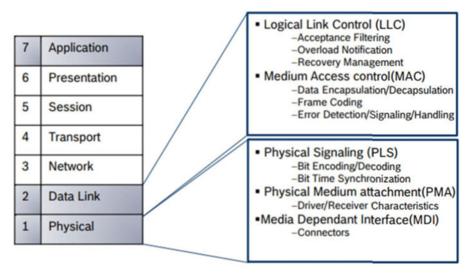


Basic Automotive E/E Architecture



* Layer 4 is used in this case for Diagnosis Services

Automotive Bus Systems in the OSI Model: Example of the CAN Bus



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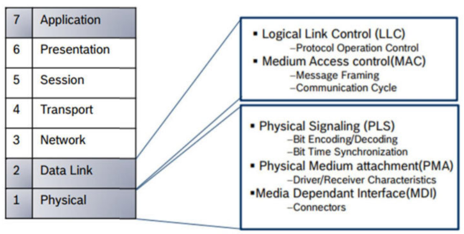
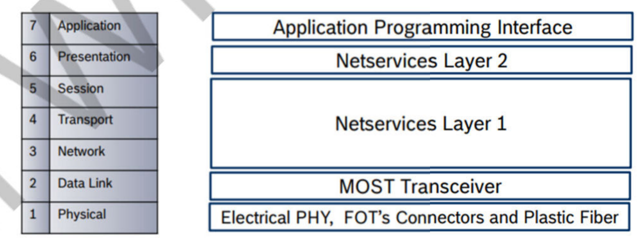
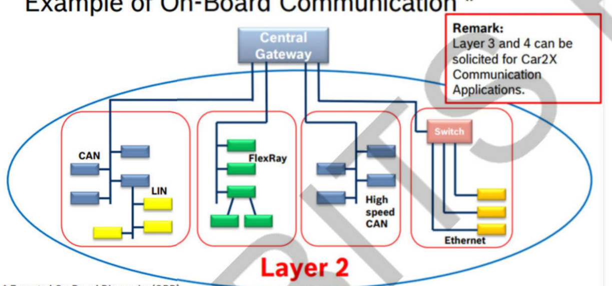
Automotive Bus Systems in the OSI Model: Example of the FlexRay Bus



Automotive Bus Systems in the OSI Model: Example of the MOST Bus

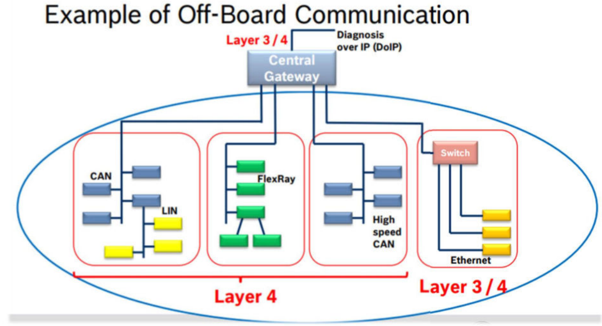


Ethernet Impact on Automotive Bus Layering: Example of On-Board Communication *



* Excepted On-Board Diagnosis (OBD) which needs a Layer 4 support

Ethernet Impact on Automotive Bus Layering: Example of Off-Board Communication



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- In reference to the OSI Data Communication Model, the Serial Interface of CAN, FlexRay and LIN Busses typically needs 3 OSI Layers for On-Board Communication excepted OBD: the **Physical Layer**, the **Data Link Layer** and the **Application Layer**
- The MOST Bus covers all the 7 OSI Layers for On-Board Communication
- The **Transport Layer** is used for Off-Board Communication like Diagnosis and also for OBD on these typical Automotive Area Networks.
- The Layers 3 and 4 can be used for Vehicle On-Board Communication in Car2X Communication Applications

- Therefore, for a Control Data Communication that occurs in an In-vehicle closed Network, the need of the Layer 2 is justified.
- On top of that, Layer 3 Routing Processes require more infrastructure (eg. IP stack implementation, software implementation, memory need . . .) and costs investments than Layer 2 solutions from an Automotive Perspective
- For In-vehicle Control Applications which require a very low Latency, a Layer 2 solution is more pragmatic than a Layer 3 solution
- However, Diagnosis over IP, Car2X and In-Car Wireless Communication Applications need Layer 3 Routing Support

Domains & Data Latency

A vehicle has three communication domains: **Powertrain (1 Mbps)**, **Safety/Chassis (500 kbps)**, and **Infotainment (100 Mbps)**. A critical safety message (200 bits) must propagate through a gateway from the Safety domain to the Powertrain domain. Assume an overhead delay of 500 µs due to the gateway processing. Calculate the total latency (in microseconds) for delivering this message across domains.

Solutions:

Transmission delay (Safety domain at 500 kbps):

Transmission in Safety domain:

200 bits / 500 kbps = 400 µs

Gateway processing delay: 500 µs

Transmission delay (Powertrain domain at 1 Mbps):

Transmission in Powertrain domain: 200 bits / 1 Mbps = 200 µs

Total Latency = 400 + 500 + 200 = 1100 µs.

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TTP/C and TTP/A

TTP/C Cycle Utilization

A TTP/C system has 10 nodes. Each node transmits 128 bytes per cluster cycle. If the total cluster cycle duration is 5 ms, calculate the minimum bandwidth requirement (in Mbps) to handle this configuration without data loss.

Solution:

- Data per cycle:

10×128 bytes = 1280 bytes =10,240 bits

- Bandwidth:

(10,240 bits / 5×10^{-3} s) = 2.048 Mbps

Time-Triggered Protocol (TTP/C)

A TTP/C cluster with 8 nodes runs with a cluster cycle period of 2 ms. Each node transmits a frame of 64 bytes once per cycle. Compute the minimum required bandwidth (in Mbps) of the TTP/C bus to ensure no data is lost.

Solution: TTP/C Bandwidth
Total Data per cycle:

8 nodes × 64 bytes = 512 bytes = 4096 bits

Bandwidth required:

Bandwidth = 4096 bits / 2 ms = 2.048 Mbps.

Domain Bandwidth Allocation

A modern vehicle has four distinct communication domains: **Powertrain (2 Mbps)**, **ADAS (Advanced Driver-Assistance Systems, 20 Mbps)**, **Body Control (1 Mbps)**, and **Multimedia (100 Mbps)**. The vehicle network gateway introduces an additional delay of 300 µs per message. Calculate the total latency (µs) for transmitting an ADAS-critical message (400 bits) through the gateway into the Powertrain domain.

Solution:

- Transmission in ADAS domain:
  $(400 \text{ bits} / 20\times10^6 \text{ bps}) = 20\ \mu s$
  Gateway delay:
  $300\ \mu s$
  Transmission in Powertrain domain:
  $(400 \text{ bits} / 2 \times 10^6 \text{ bps}) = 200\ \mu s$
  Total latency:
  $20 + 300 + 200 = 520\ \mu s$

FlexRay

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FlexRay Cycle Analysis

A FlexRay communication cycle consists of 80 static slots. Each slot carries 32 bytes of payload data. If the FlexRay cycle repeats every 5 ms, determine the FlexRay communication speed (in Mbps) required to support this configuration.

Solution: FlexRay Cycle
Total payload per cycle:

80 slots × 32 bytes = 2560 bytes =
2560 X 8 = 20480 bits

Required data rate:

Cycle duration = 20480 bits / 5 x 10^3s = 4.096 x 10^6 bps = 4.096 Mbps

FlexRay Slot Efficiency

A FlexRay cycle operates at 10 Mbps with a cycle duration of 2 ms. Each cycle contains 50 static slots. Calculate the maximum payload size (in bytes) per static slot.

Solution:

- Total bits per cycle:
  10 Mbps × 2 ms = 20,000 bits
- Bits per slot:
  (20,000 bits / 50 slots) = 400 bits/slot
- Payload per slot (bytes):
  (400 bits / 8)= 50 bytes/slot

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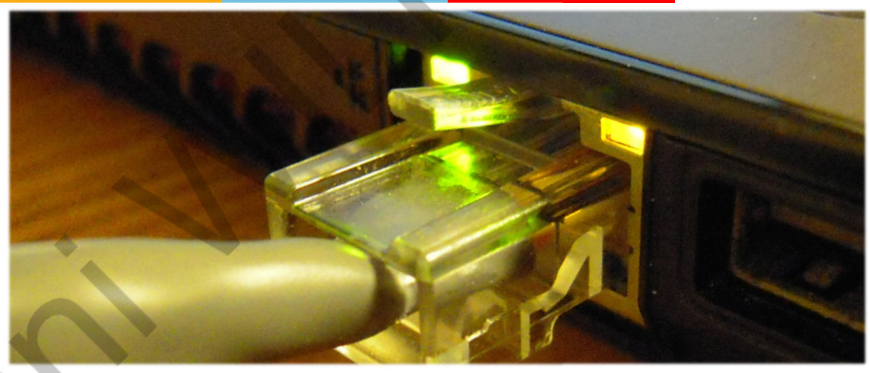
TTEthernet

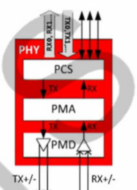
ETHERNET



ETHERNET

Anatomy of Ethernet PHY

- Typical application circuit
- Ethernet PHY block diagram
- PHY functions



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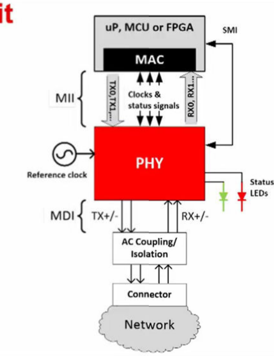
Typical application circuit



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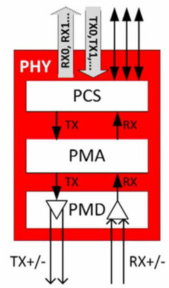
ETHERNET

Internal PHY functional blocks

- The PHY consists of three sublayers:
  - **PCS -** Physical Coding Sublayer
  - **PMA -** Physical Medium Attachment layer
  - **PMD -** Physical Medium Dependent layer



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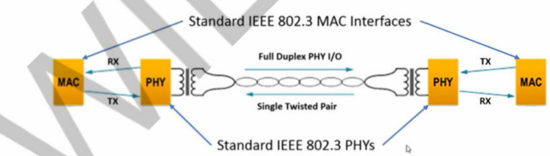
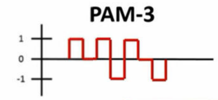
Automotive Physical Layer

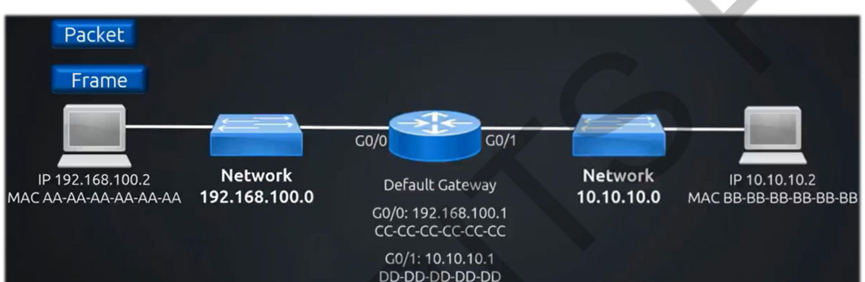
100/1000 Mbps



- 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



ETHERNET



Automotive Ethernet vs. Ethernet

Ethernet is becoming a reality in automotive as it can handle large amounts of data without adding additional complex wiring and weight to the vehicle.

But traditional Ethernet is sensitive to interference, making it less than ideal for the harsh conditions found in cars:

temperature, mechanical stress and electromagnetic compatibility (EMC) all present unique challenges and conditions that had to be taken into consideration, and thus a family of new Ethernet versions was standardized.

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