Process automation

Industrial Communication Buses

BS UNI studies, Fall semester 2025/2026

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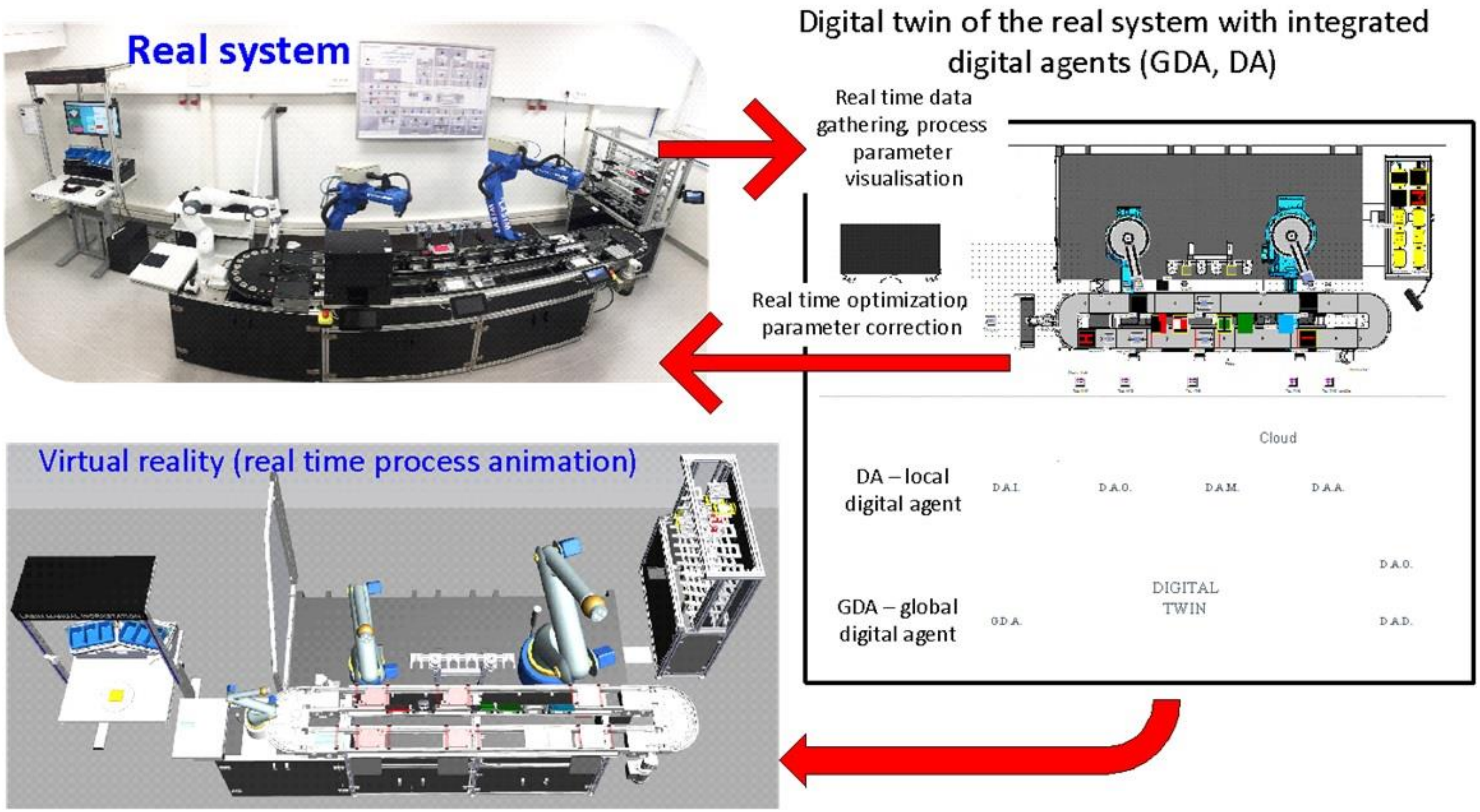
Admin stuff: preparing a visit to Smart Factory Demo Lab (UL FME LASIM)

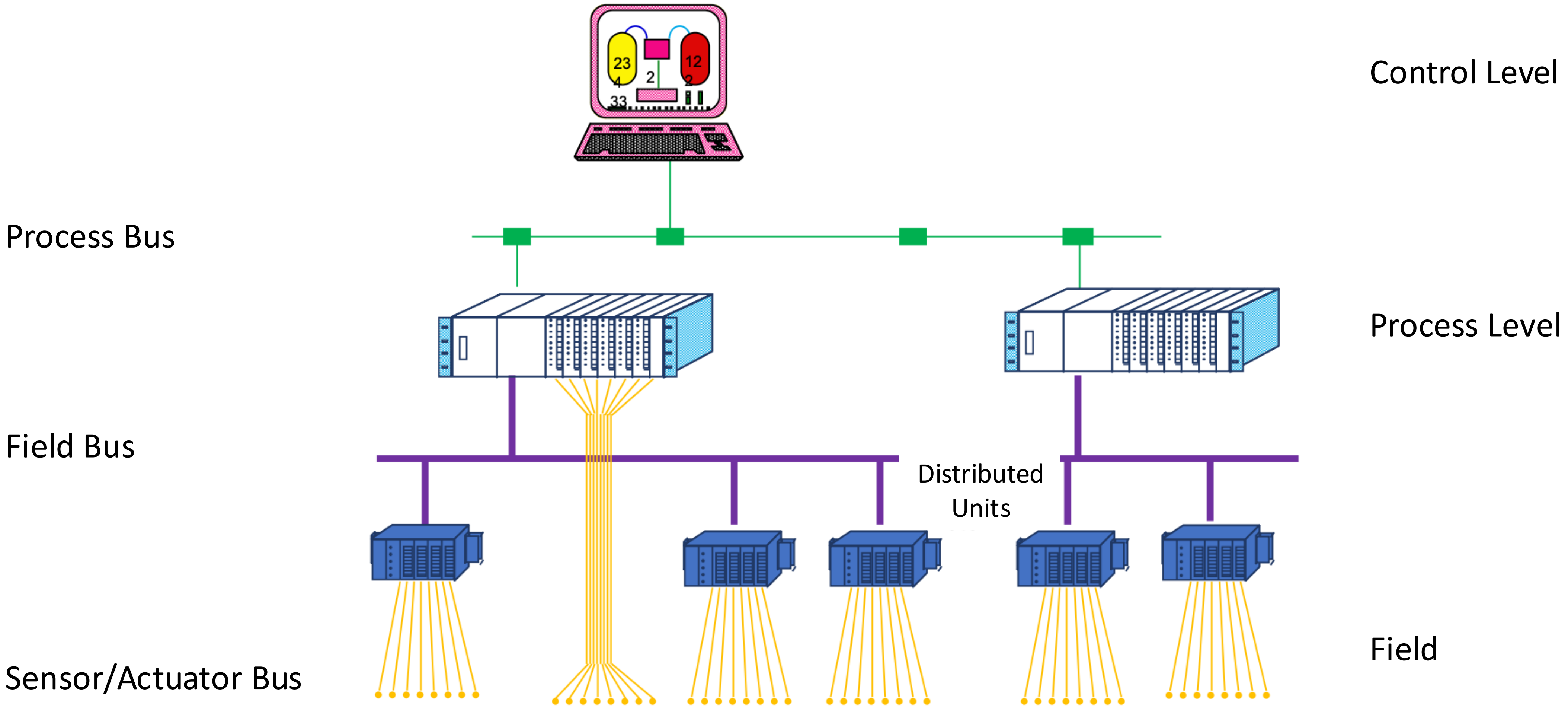


Lecture outline

- Introduction to Industrial Communication Systems
- Communication Protocols and Data Transmission Approaches
- OSI and TCP/IP Models in Industrial Applications
- Transmission Media
- Specific Protocols and Examples
- Future Trends and Real-Time Communication

Role and integration

Industrial control

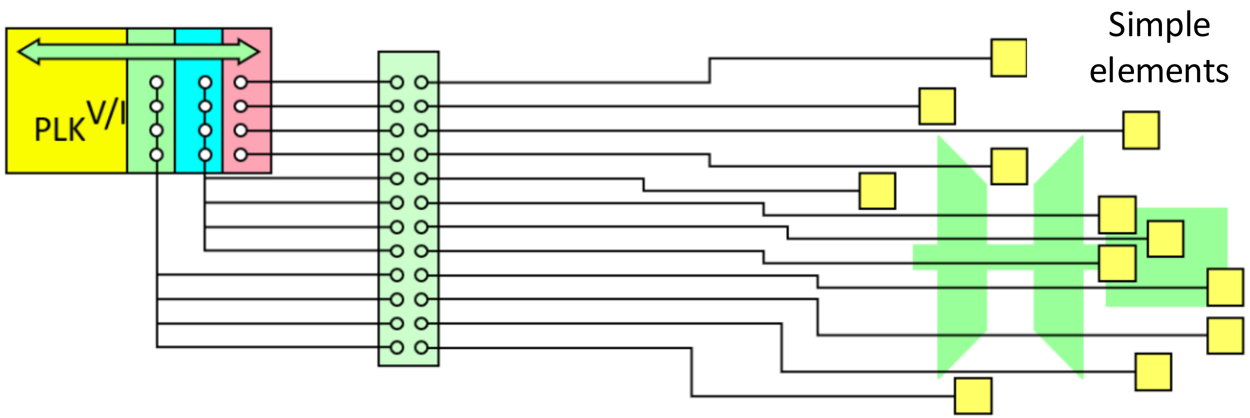


Characteristics

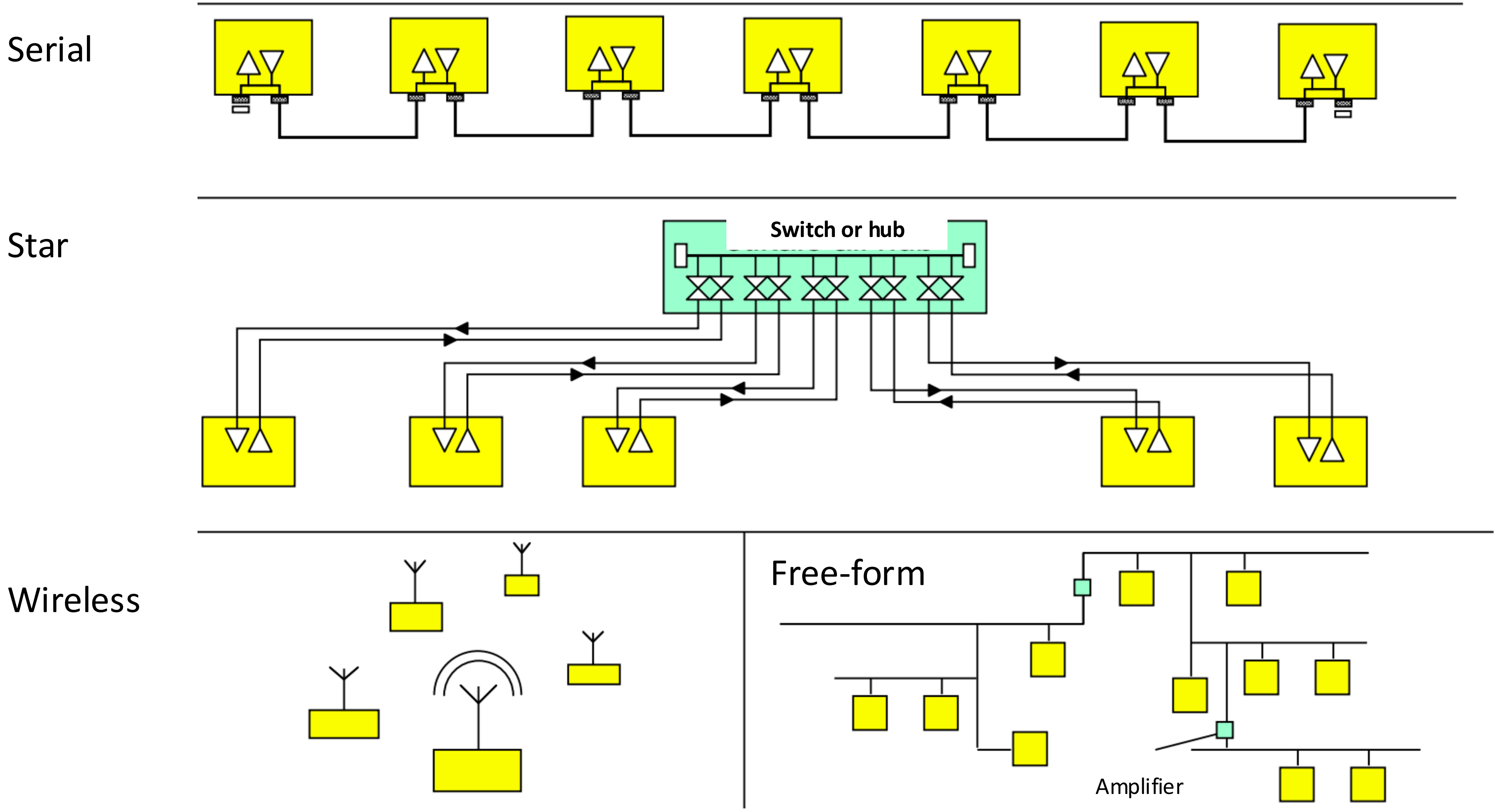
- **Process Bus**
  - Large volumes of data
  - Time is not a critical factor
- **Field Bus and Sensor/Actuator Bus**
  - Transmission of a large number of small packets with minimal delays
  - Harsh conditions:
    - Temperature, vibrations, electromagnetic interference, water, salt, etc.
  - Robust and simple installation
  - High data integrity (as few errors as possible)
  - Availability
  - Synchronization down to the microsecond level (µs)
  - Continuous monitoring and diagnostics
  - Moderate data transfer speeds: 50 kbit/s to 5 Mbit/s over long distances (4 km to 10 m)
  - Capable of operation in explosive hazard zones

Expectations

- **Reduction of physical connections**
  - The number of simple elements remains the same
  - Power supply is required for simple elements
- **Increase in system modularity**
- Easier troubleshooting
- Simplified startup
- Easier expansion or contraction of the system

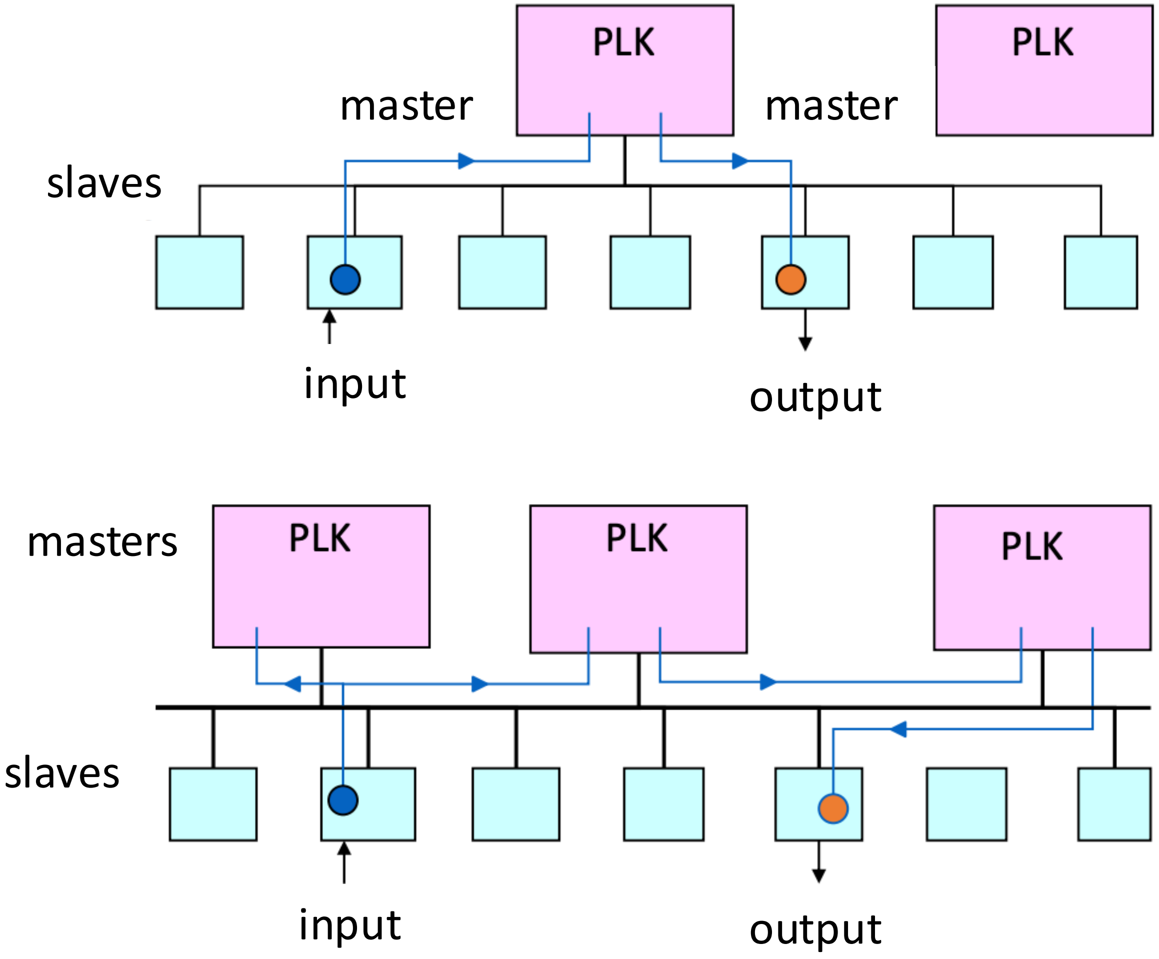


Topologies



Communication Modes

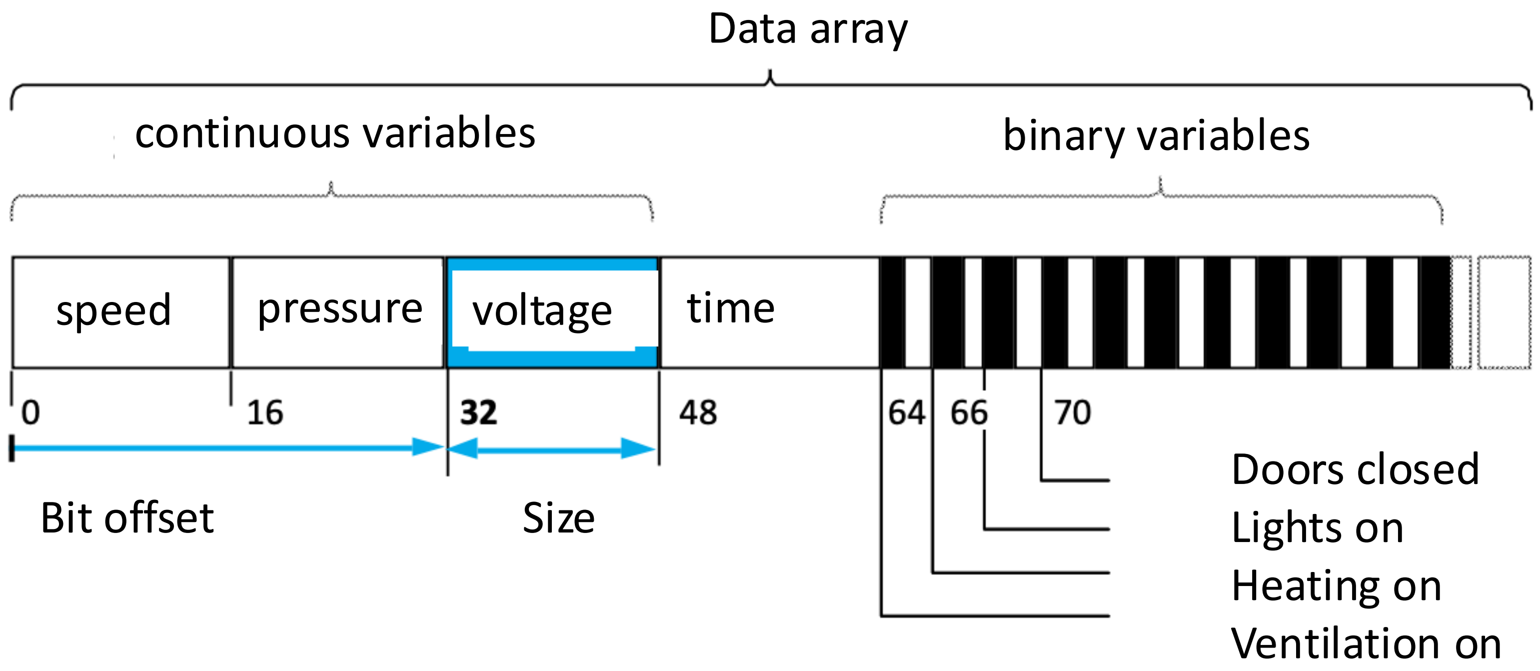
- **Master – Slave**
  - All communication goes through the master
  - Issues arise with multiple masters (master and slave functionality overlap)
- **Peer-to-Peer**
  - PLCs (Programmable Logic Controllers) can exchange data directly with one another
  - PLCs share inputs and outputs
  - Support for redundant systems
- **Broadcast**
  - For greater efficiency



Application Access to the Bus

Message

- Multiple data points are combined into a message before transfer.
- The message is treated as a whole during transmission and access.
- Example:

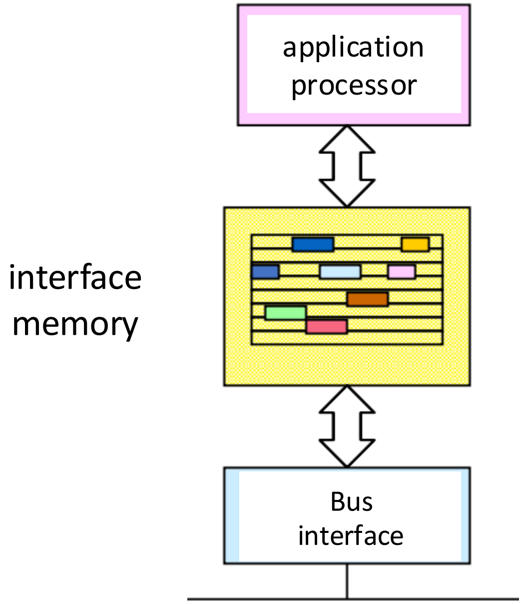


Application Access to the Bus

Cyclic

•**Writing:** The application writes to the interface memory

•**Reading:** The application reads from the interface memory

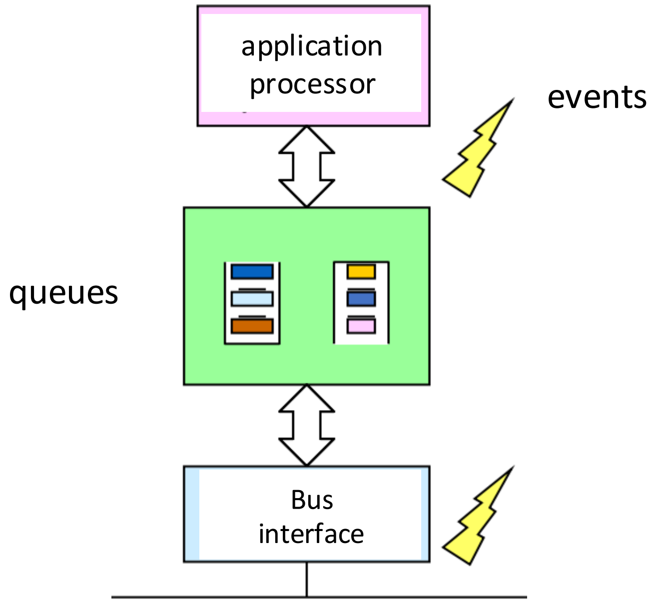


Event-Driven

•**Concept of queues**

•**Writing:** The application places data into the queue, and the interface retrieves it

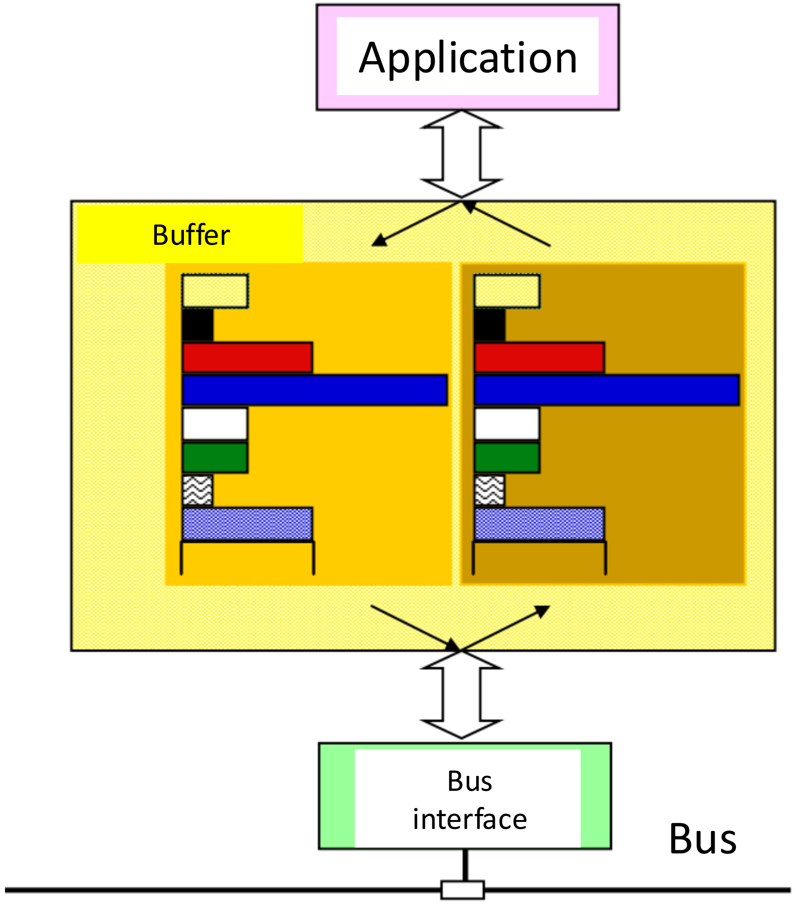
•**Reading:** The interface places data into the queue, and the application retrieves it



Application Access to the Bus

The bus and the application are separated by an interface with a buffer.

- The bus interface and the application share memory.
- Process variables are directly accessible to the application.
- Reading and writing can occur simultaneously.
- The bus and the application are not synchronized; access is not coordinated.

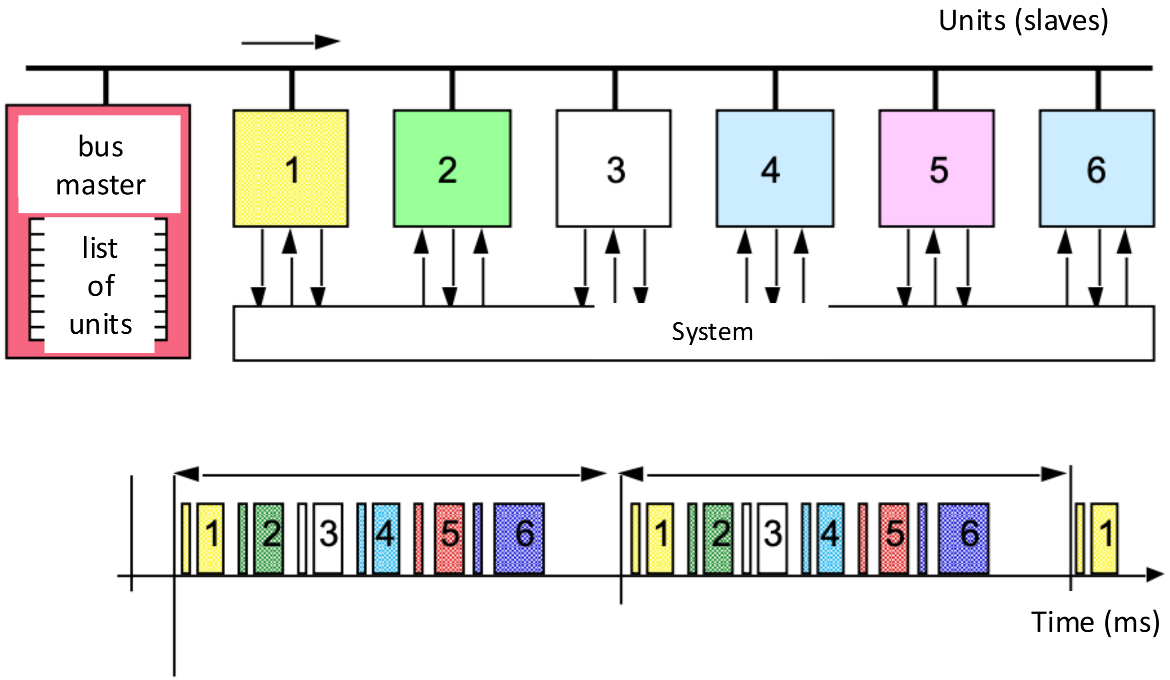


Cyclic Operation

- Supported by most field buses
- Deterministic operation at the cost of:
  - Reduced bandwidth
  - Limited sizes
- Ensures that each application occupies exactly its (time) share of the bus and no more

Cyclic Operation

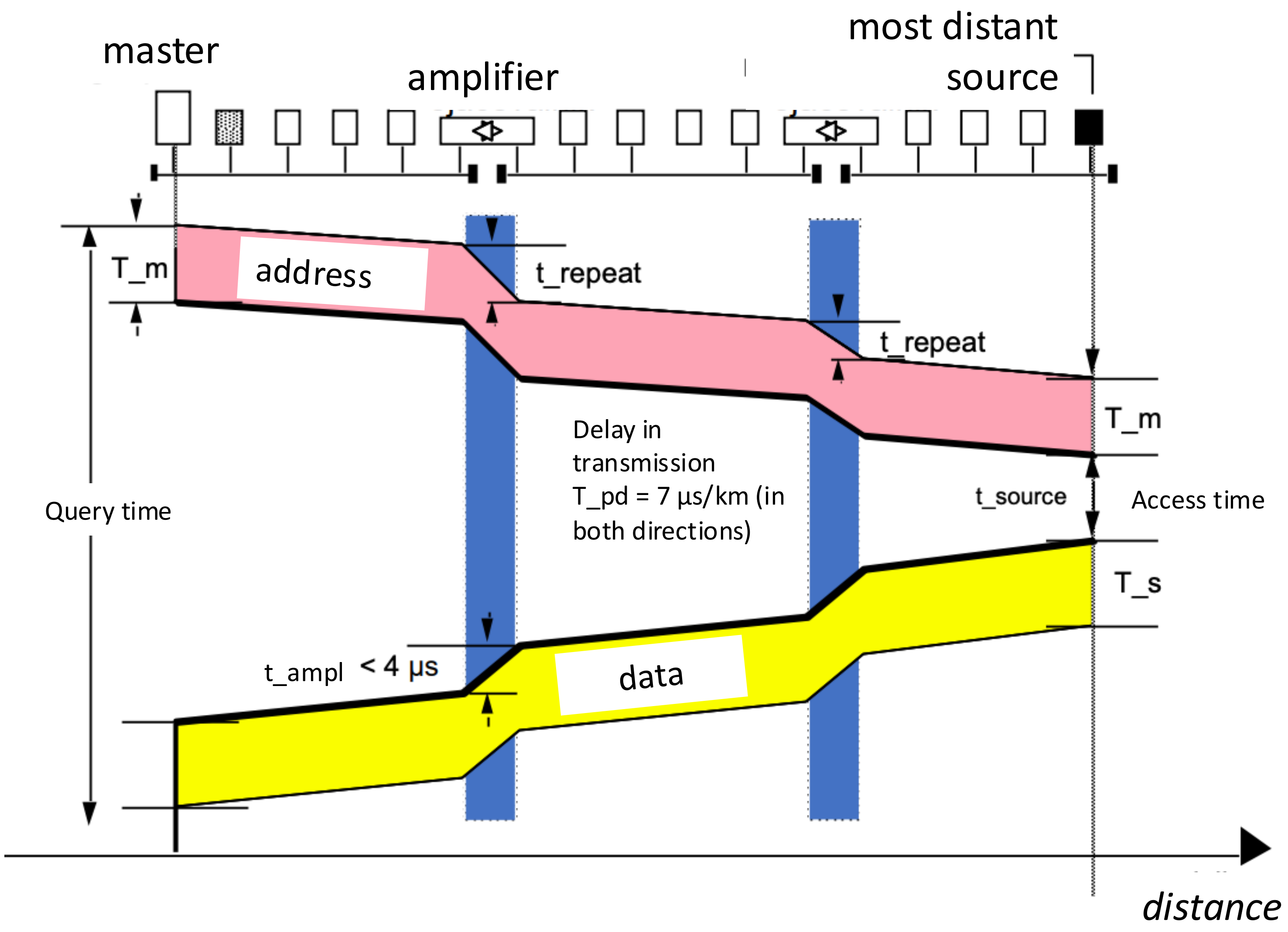
- The bus master sequentially establishes connections with all units on the bus.
- **Query on a unit:**
  - Address transmission
  - Delay
  - Data transmission



Cyclic Operation

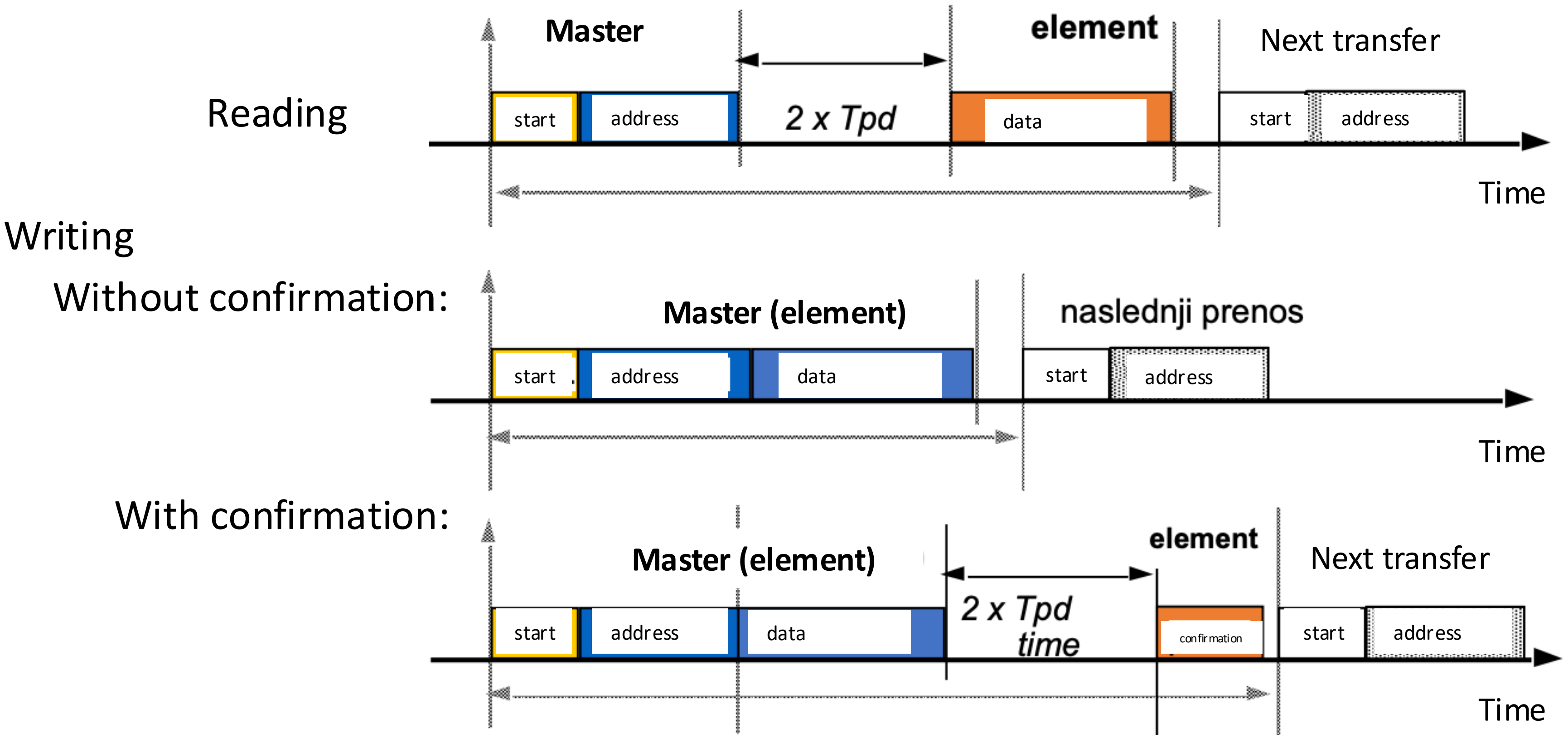
Query on a Unit

- The length of the bus affects the query time.
- The query time to the most distant element determines the cycle duration.



Cyclic Operation

- **Writing and Reading**
  - On field buses, read cycles dominate.



Tpd = propagation delay

Cyclic Operation

Data is transferred in every cycle.

- The values of variables are transferred, not the changes.
- Error correction during transfer is not necessary because the updated value will be transferred in the next cycle.

The refresh rate is deterministic and constant.

- Cycle time = number of units on the bus × query duration (e.g., $50 \times 100\ \mu s = 5\ ms$).
- To achieve short query times, small amounts of data must be transferred.
- The bus capacity is defined during configuration and cannot be changed during operation.

The bus is typically controlled by the master.

- In the case of multiple masters, they share the bus in a time-synchronized manner.

Event-Driven Response

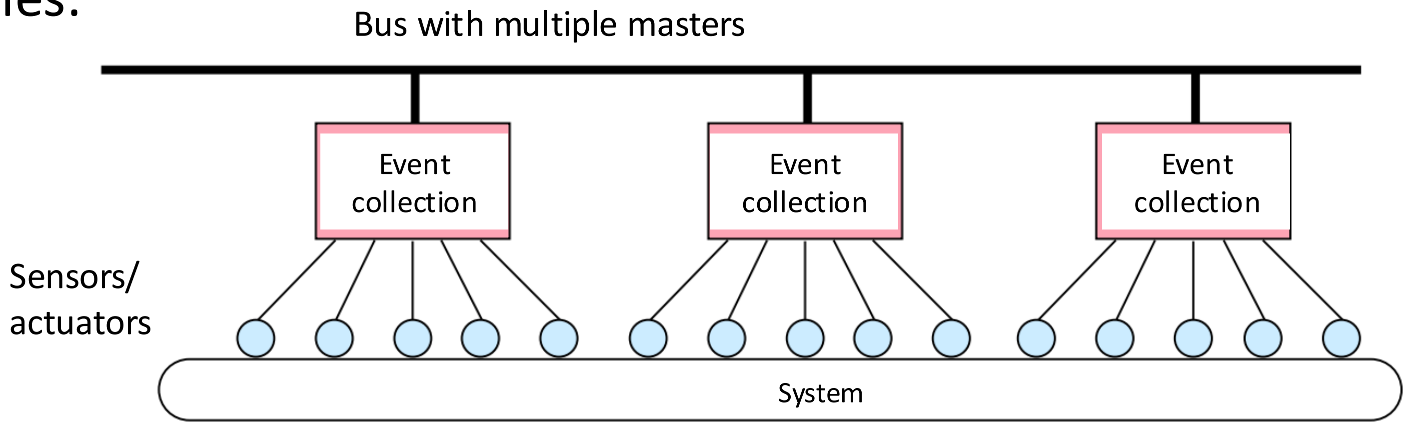
Events trigger data transfer upon a change in variable state.

The bus is not overloaded:

- Occasionally, short-term high loads occur because transfers depend on the process activity.
- High transfer rates during critical conditions (e.g., many alarms, "Christmas tree effect").

Events:

- An event is a change in one or more variables.
- What constitutes an event is determined by the application, as only the programmer knows the meaning of the variables.



Event-Driven Response

An event can occur anytime and anywhere:

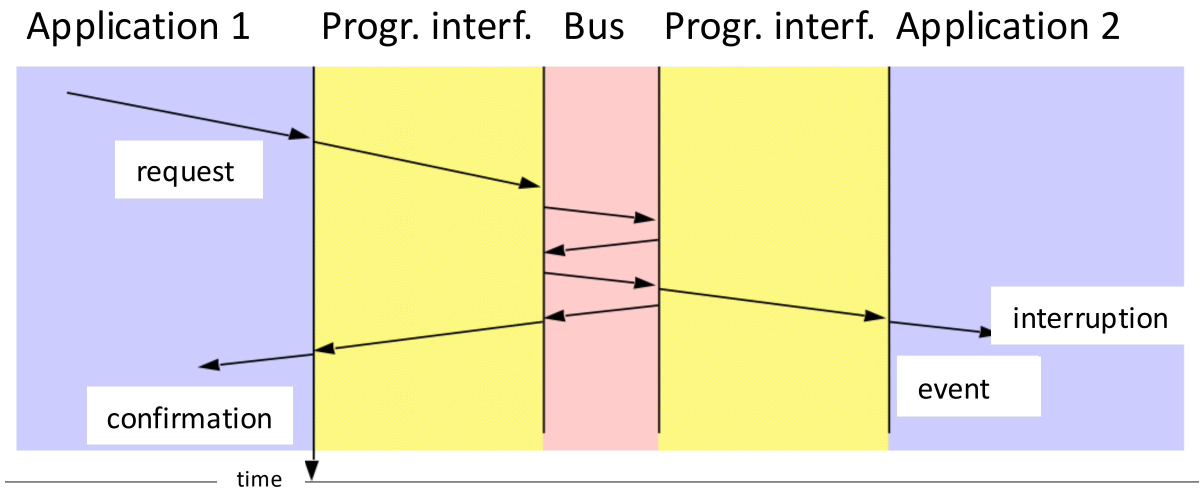
- Devices on the bus communicate spontaneously.

Collisions occur:

- Collisions delay time-critical tasks.

Multiple events directed to one unit (master):

- Sequential processing causes delays.



Event-Driven Response

Determinism

- The timing of an event is not precisely defined.
- The time required for transmission depends on:
  - The method of access to the transmission medium,
  - The size of the buffer in the bus interface,
  - Processing duration,
  - Response actions.

Access to the transmission medium:

- **Non-deterministic:** Collisions, such as in Ethernet.
- **Deterministic:** Central master, token passing, collision with a winner, etc.

Event-Driven Response

Advantages

- Enables processing of a large number of events, provided they don’t occur simultaneously.
- Supports a large number of devices.
- Better resource utilization – when there are no events, the system is not burdened.
- Uses only write transfers.

Disadvantages

- Communication is more complex.
- Shared access to resources requires arbitration.
- Transmission time is difficult to predict (analysis).
- No upper limit on response time.
- Limited by the congestion effect.
- The number of transfers depends on the number of changes in the process.

Comparison of Both Approaches

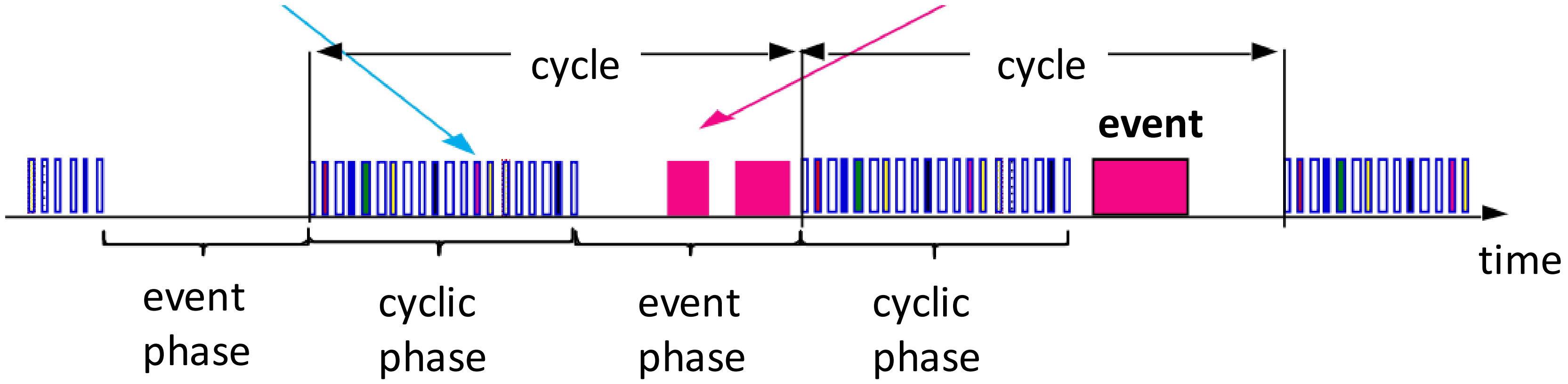
Coexistence of Cyclic Operation and Event-Driven Response

Process Datatate
Typically
•**Represent the system s** simple (short) and important
→ **Cyclic Transfer**

- Error correction protocols are not required

Event Data
•**Represent changes in the system state**
•Irregular data, longer records
→ **Occasional Transfer**

- Messages represent changes, and error correction is necessary



Comparison of Both Approaches

- Cyclic transfers account for the majority and should be used for truly critical variables.
- The method of variable refreshing (cyclic or event-driven) is determined during system configuration.
- It is desirable for an industrial communication system to support both methods.

Comparison of Both Approaches

Cyclic Operation:

- Data is transferred at fixed intervals, regardless of whether it has changed or not.
- Deterministic: transfer time is consistent.
- Worst-case transfer times are the normal transfer times.
- Resource usage is predetermined.
- Periodic, circular selection.
- Mandatory for process-critical variables.

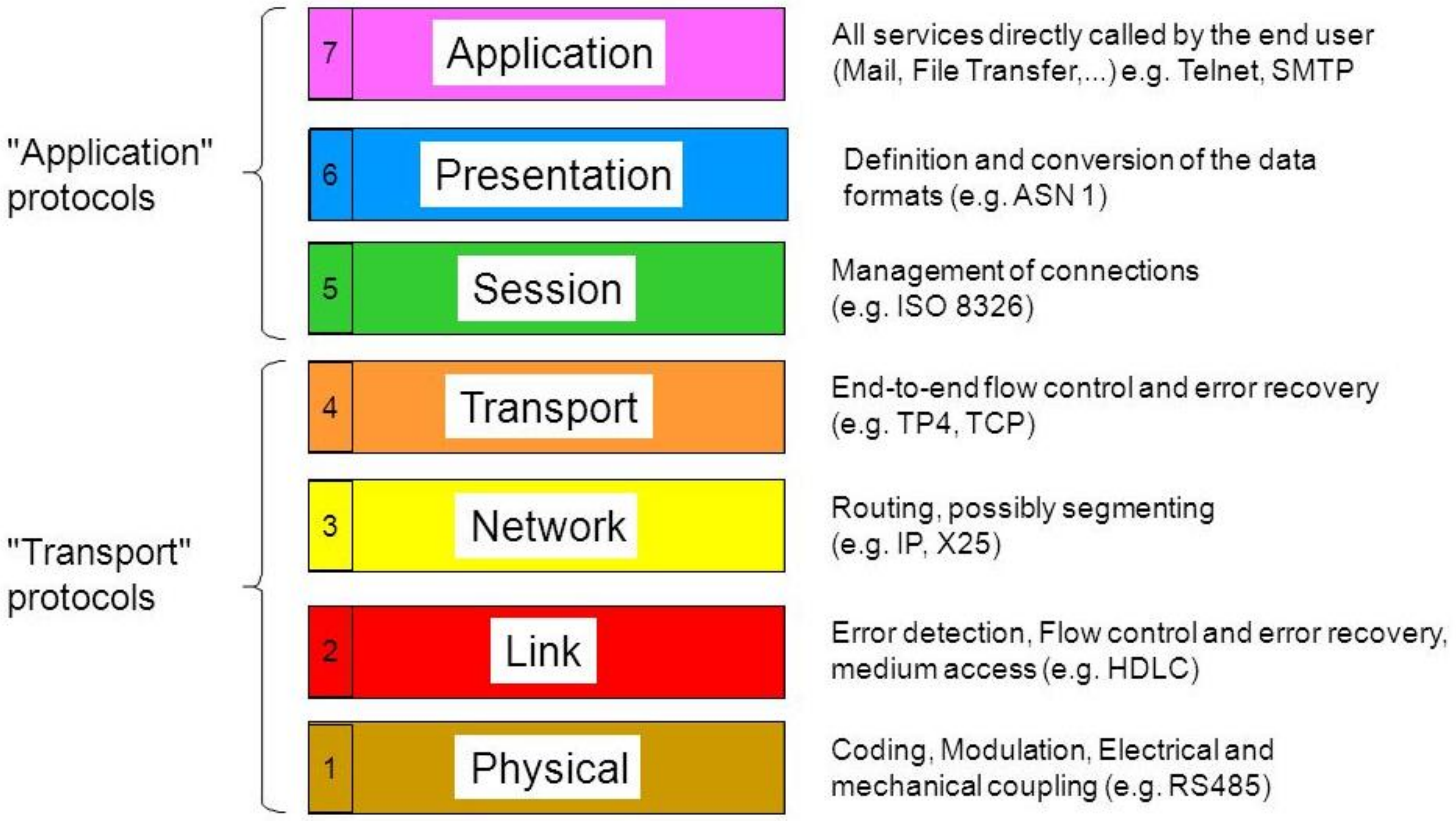
Event-Driven Response:

- Data is transferred when it changes.
- Non-deterministic: transfer time varies.
- Typical transfer times are used most of the time.
- Good resource utilization.
- Non-periodic, dependent on requirements, isolated events.
- For less time-critical tasks: communication between controllers, supervisory systems, diagnostics.

The OSI model

- OSI (**Open Systems Interconnection**)
- A standardized approach for designing communication software.
- It is a reference model, not a standard.
- Originated in the 1970s.
- Standardized by CCITT and ISO as ISO/IEC 7498.
- All communication protocols can be described using the OSI model.
- Industrial communication requires enhancements to the OSI model.

Layers of the OSI model



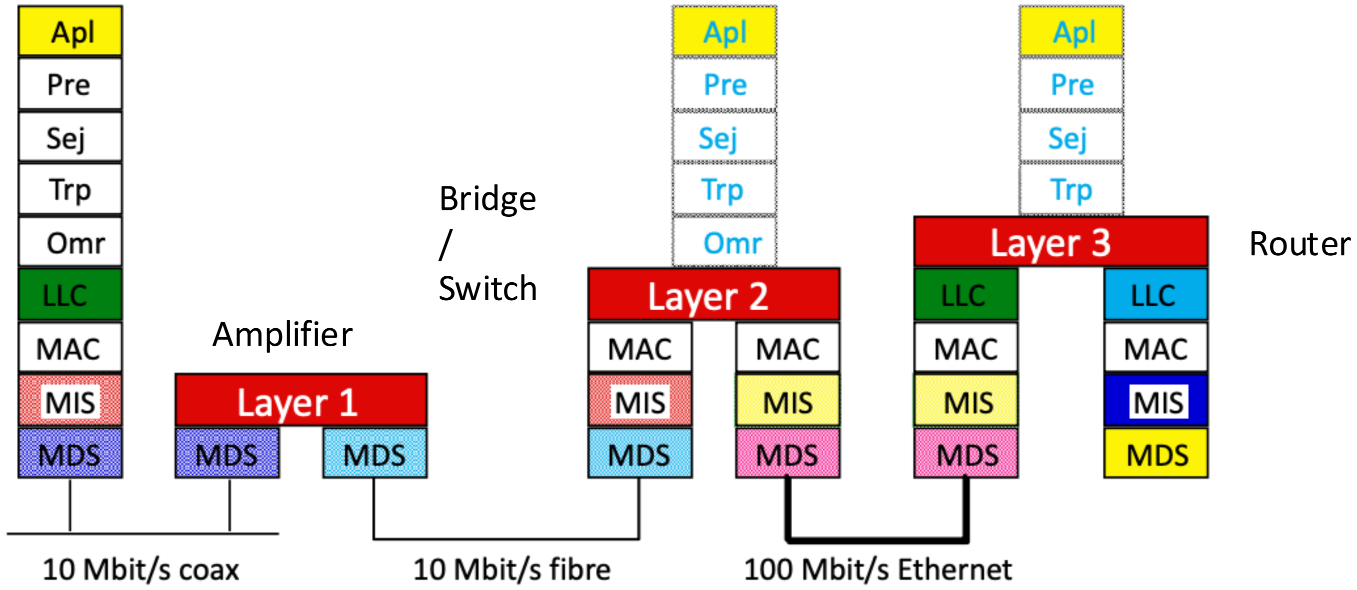
The OSI model

Basic Components

- **Amplifier**
  - Same speed, same medium, same frames.
- **Bridge, Switch**
  - Different speeds, different media, buffer, forwarding of same frames and addresses, bidirectional communication, filtering.
- **Router**
  - Different networks, same address space, same transport protocol, network segmentation.

The OSI model

- Basic componets



Legenda:

LLC	Logical Link Control
MAC	Medium Acces Control
MIS	Medium Independent Sublayer
MDS	Medium Dependent Sublayer

The OSI model

The concept of multiple layers is not ideal for implementation due to complexity and speed limitations.

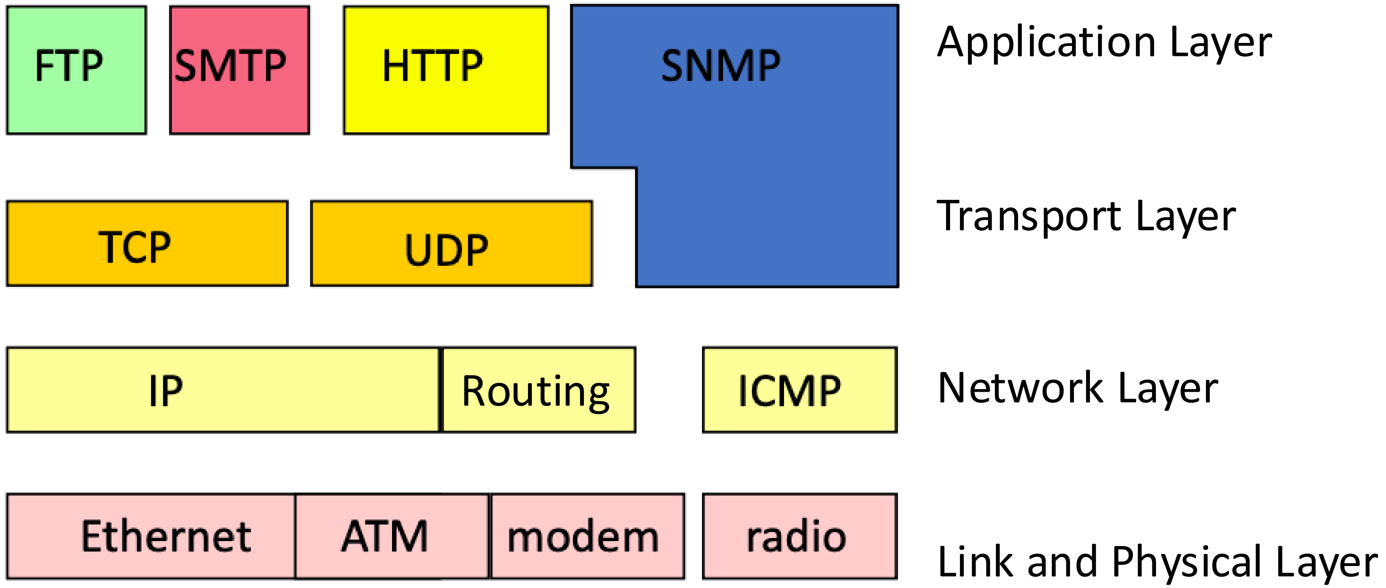
OSI Model in Industry

- **Reality:**
  - The OSI model is very general.
  - Higher layers are unnecessary for transferring small amounts of data in real-time.
  - Software is too complex; simple field devices have limited processing power.
  - The OSI model does not address real-time requirements.
- **Solution:**
  - Industrial buses use a simplified OSI model.
  - The model is extended to address real-time challenges.

The OSI model

Structure of the TCP/IP Model

- The TCP/IP model has fewer layers than OSI but is approximately as complex.
- TCP/IP was implemented and used before it was standardized.
- The TCP/IP v6 model more closely follows the OSI model.



The OSI model

The OSI model is a reference model for industrial protocols.

- **Layer Exclusions:**
- **Physical Layer:**
  - Wiring, power supply, modulation and demodulation of data and carrier signals.
- **Data Link Layer:**
  - Telegram format, start and end bits, parity, error handling.
- **Application Layer:**
  - Commands, message formats, profiles, device behavior, automatic addressing.

- **The TCP/IP model is becoming the standard for industrial communications:**
  - Rapid transition from proprietary protocols to TCP/IP.
- **Enhancements to the OSI and TCP/IP models for real-time communications.**

Transmission Media

- Comparison of Transmission Media

Type	Transmission Speed (Mbit/s) 200 m	700 m	2000 m	Price €/m	Resistance to EM Interference
Optical Fiber					
Glass, single-mode	2058	516	207	3.5	Very good
Glass, multi-mode	196	49	20	4.5	Very good
Plastic	1	0.5	-	0.6	Very good
Coaxial Cable					
50 Ohm	20	8	1	0.6	Good
75 Ohm TV 1/2"	12	2.5	1.0	1.5	Good
93-100 Ohm	15	5	0.8	1.7	Good
Twisted Cable					
Twisted pair	8	0.9	0.2	3.3	Very good
Shielded twisted pair (STP)	2	0.35	0.15	0.3	Very good
Unshielded twisted pair (UTP)	1	0.3	0.1	0.7	Good
Telephone cable	0.2	0.1	0.05	0.1	Good
Other					
Signal superimposed on power voltage	1	0.05	0.01	-	Very poor
Radio communication	1	1	-	-	Poor
Infrared (IR)	0.02	0	0	-	Good
Ultrasound	0.01	0	0	-	Poor

Electrical Transmission Media

Common Solutions:

- Shielded twisted pair cable
- Unshielded twisted pair cable
- Coaxial cable

Advantages:

- Traditional system
- Well understood
- Easy to configure
- Inexpensive

Disadvantages:

- Slow data transfer
- Expensive galvanic isolation (transformers, optical couplers)
- Susceptible to interference
- Difficult to troubleshoot (poor contacts)
- Heavy weight

Electrical Transmission Media

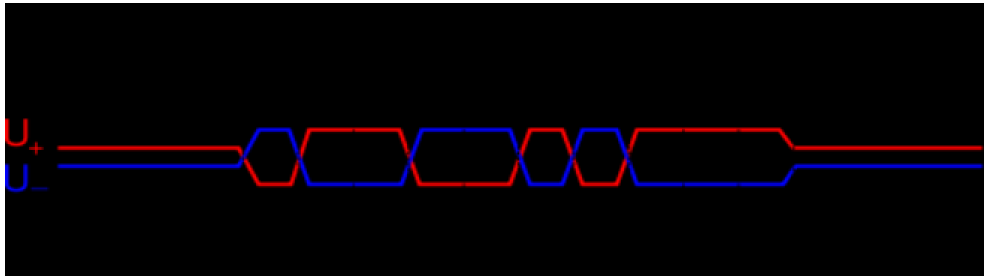
Limitations:

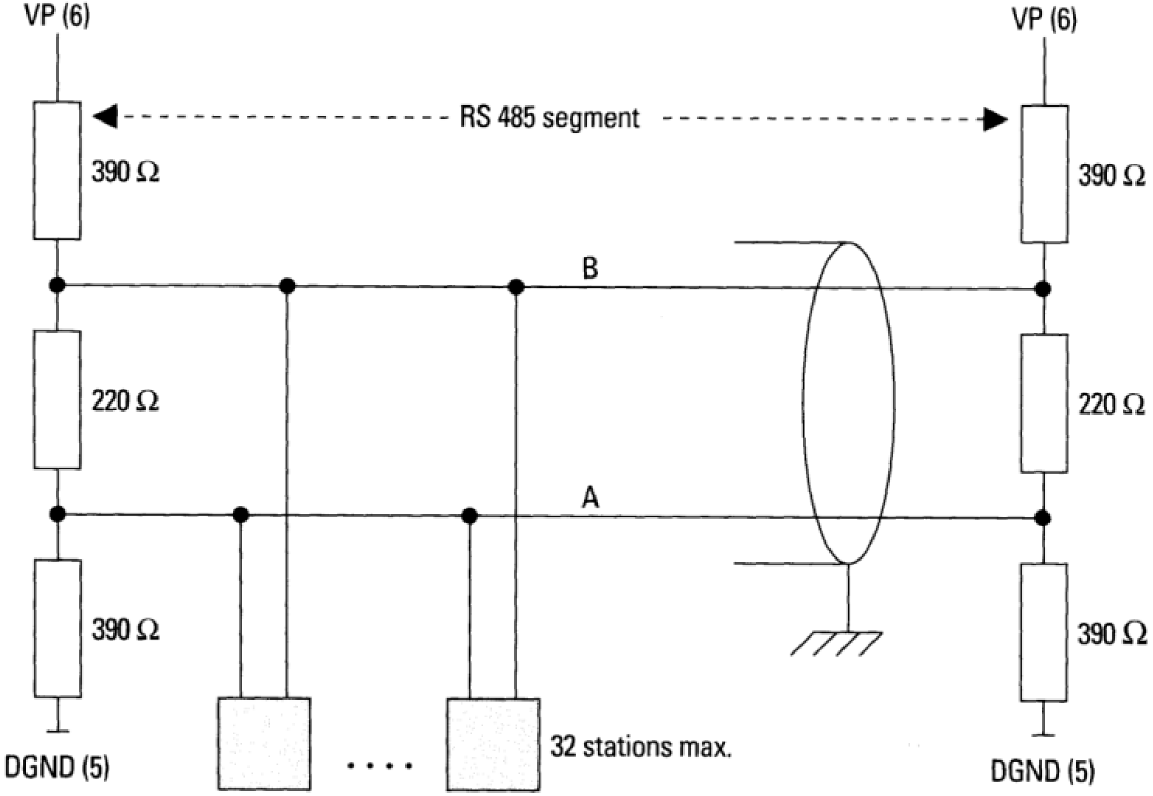
- Characteristics are frequency-dependent:
  - Characteristic impedance, losses, linear resistance, linear capacitance, reflections, etc.
  - Losses: Copper resistance, Dielectric losses
  - These factors cause signal distortion.

Electrical Transmission Media

Example: RS-485

- Most commonly used for process buses.
- Does not define an encoding method.
    - Typically paired with RS-232 for encoding.
- Half-Duplex:
    - Bi-directional communication, but not simultaneously in both directions.
- Signals:
    - A or U- or RxD/TxD-P (negative).
    - B or U+ or RxD/TxD-N (positive).
- Voltage Levels:
    - Ranges from -7 V to +12 V.
    - Difference must be at least 0.2 V.



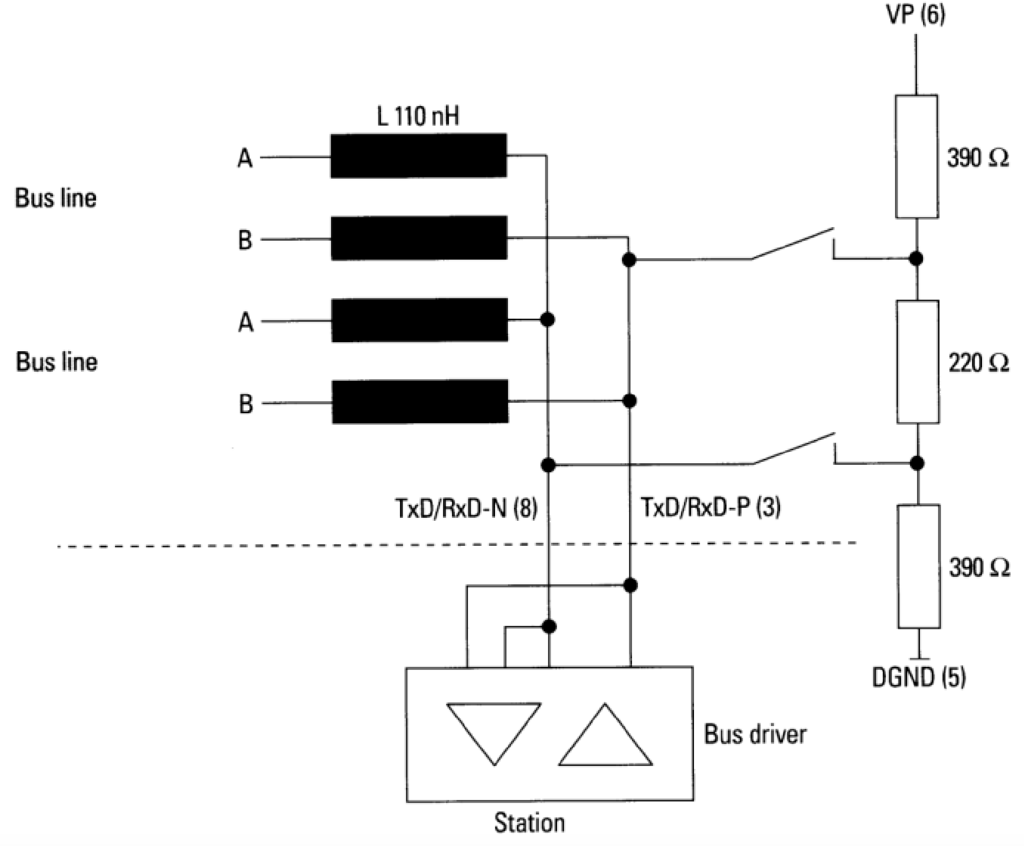


Voltage levels
- -7 to +12 V
- Difference of at least 0.2 V

Electrical Transmission Media

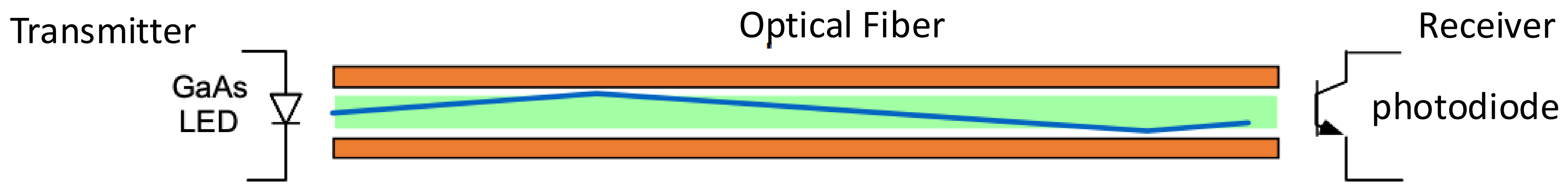
Example: RS-485

- **Connection Scheme:**
  - Termination or
  - Continuation of the bus



Optical fibers

Operating principle



- **The transmitter, fiber, and receiver must be tuned to the same wavelength.**
  - **Optical Fiber:**
    - Glass
    - Plastic
  - **Transmitter:**
    - Laser (high power)
    - Laser diode (GaAsP, GaAlAs)
  - **Receiver:**
    - **PIN diode** (*Positive Intrinsic Negative*):
    - A pure layer of silicon between P and N doped layers creates a sensitive photodetector.

Optical fibers

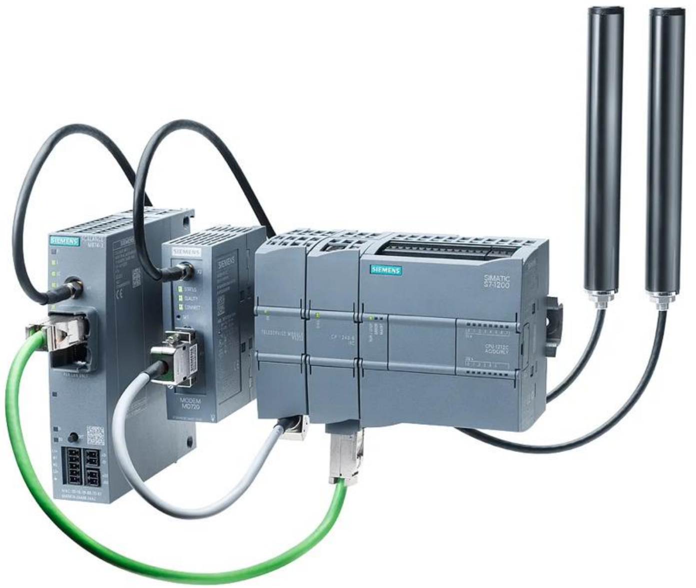
Signal propagation is as fast as in wires.

- **Advantages:**
  - High bandwidth and transmission speed.
  - Low losses (frequency-independent), allowing long distances without amplifiers.
  - Resistant to electromagnetic interference (EMI), galvanically isolated, ideal for environments with high currents.
  - Suitable for explosive environments.
  - Lightweight, low cost.
- **Disadvantages:**
  - In process control, signal propagation time is more important than its frequency.
  - Losses in electrical cables are usually minimal in most installations (up to 200 m).
  - Coaxial cables offer sufficient resistance to interference.
  - Galvanic isolation can be achieved with optical couplers.
  - Optical networks with inexpensive components are limited to a few branches.
  - Expensive installation due to the need to splice fibers.
  - Topology is limited to star or ring configurations.

Radio Connections

Radio links are slow, prone to interference, and have limited range.
Modern wireless area networks

- **Advantages:**
  - No wiring,
  - Portable,
  - Easy installation.
- **Disadvantages:**
  - Short range,
  - Limited bandwidth,
  - Coverage overlap,
  - Vulnerable to intrusions,
  - Unsuitable for powering devices,
  - Cost.



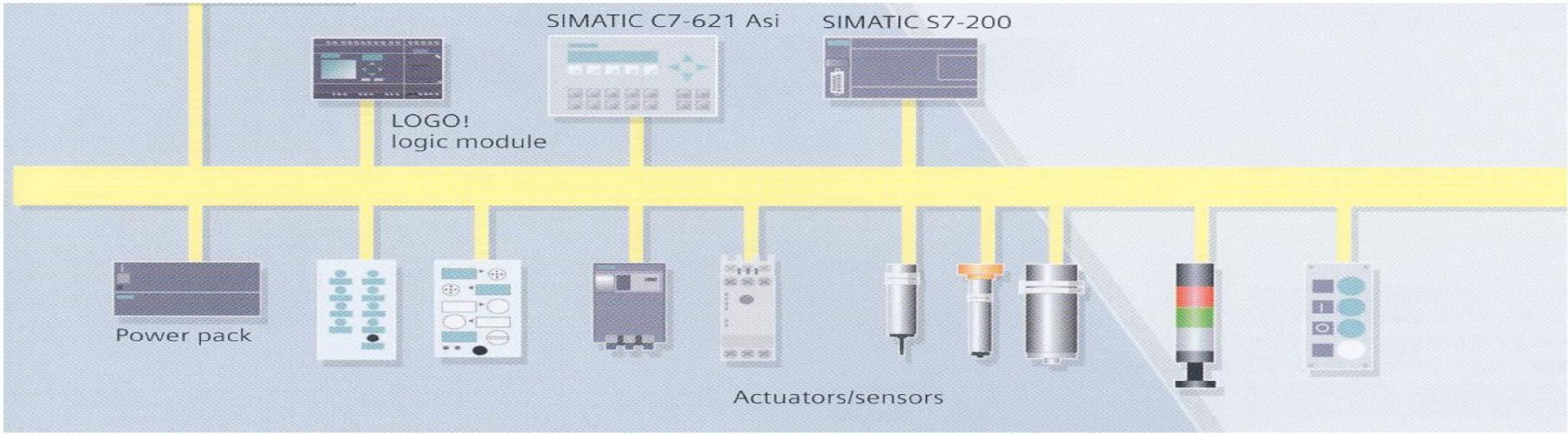
Buses in the Market

- Market share by users, target segments, and proponents

Bus	Market Share (%)	Target Segment	Proponents
CANs	25 %	Automotive and process	CiA, OVDA, Honeywell
Profibus (3 types)	26 %	Process control	Siemens, ABB
LON	6 %	Building automation	Echelon, ABB
Ethernet	50 %	Manufacturing bus	-
Interbus-S	7 %	Assembly of products	Phoenix Contact
Fieldbus Foundation, HART	7 %	Chemical industry	Fisher-Rosemount, ABB
ASI	9 %	Product assembly, buildings	Siemens
Modbus	22 %	Obsolete point-to-point	Many manufacturers
ControlNet	14 %	Process control	Rockwell

AS-i

- **AS-i – Actuator Sensor Interface**
- **Interface for sensors and actuators**
- Open international standard
- Very simple low-level bus
- **Data transmission over power wires:**
    - Special power supplies (24 VDC) with network balancing – no common ground, demodulation
    - Mostly used for binary signal transmission



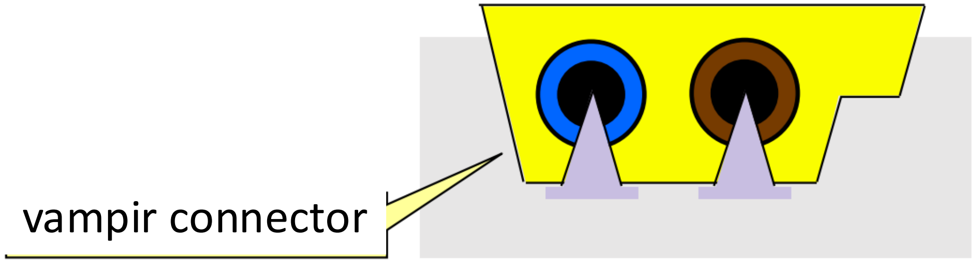
AS-i

Physical Layer

- **Two-Wire Flat Cable**
  - Two wires for transmitting power and signals.
  - 24 V / 2 A DC.
- **Connection of Elements via Cable Piercing**
  - Protection up to IP67 even after sensor removal.

Diagram Note:

- The term "vampir connector" refers to the piercing connection method shown in the diagram.



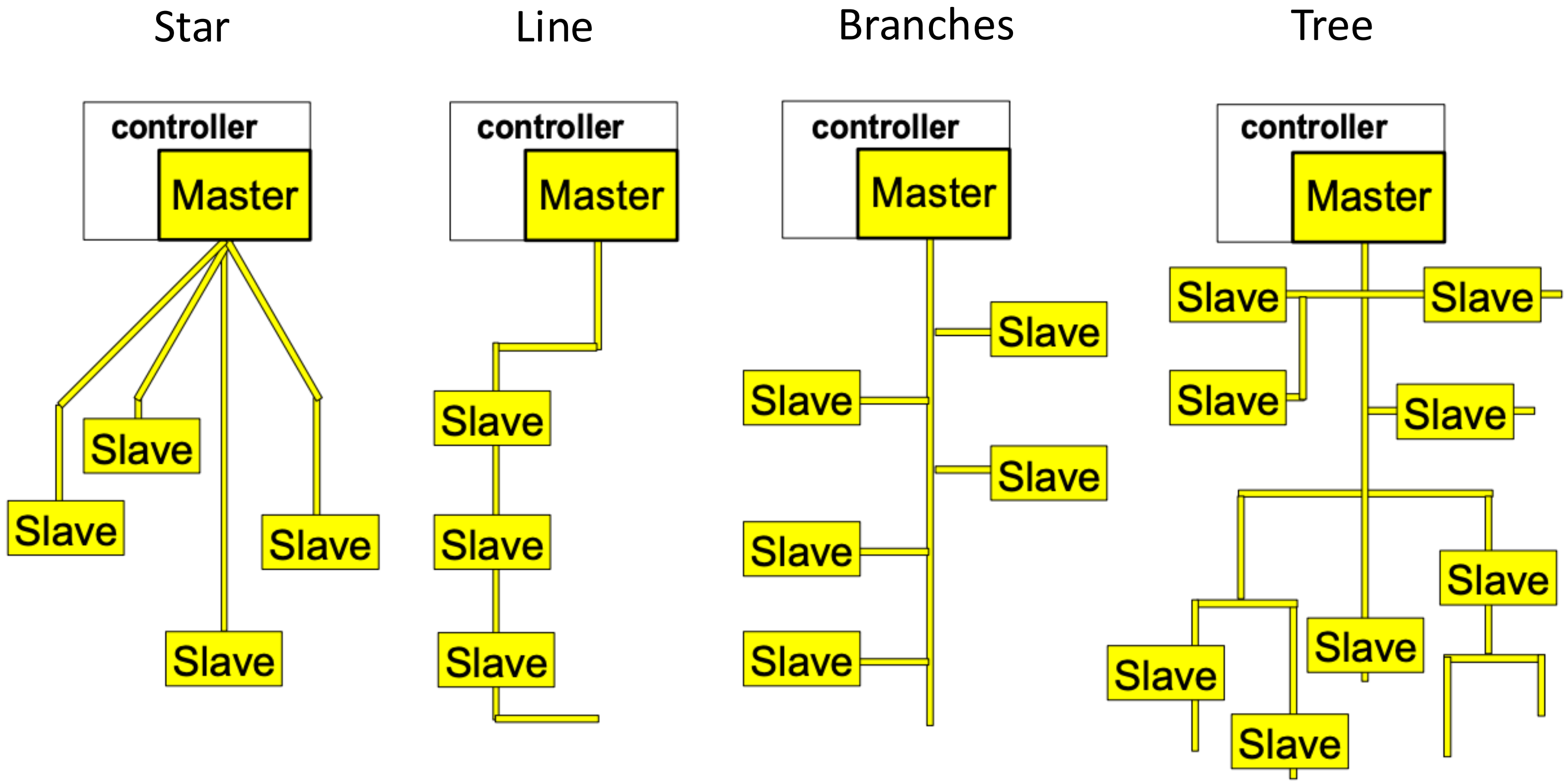
AS-i

Simple Topology

- **Segment length**: Up to 100 m (500 m with an amplifier).
- **No terminating resistors required**.

Topologies:

- **Star**: Central master connected to multiple slaves in a star configuration.
- **Line**: Slaves connected in a linear sequence to the master.
- **Branches**: Linear topology with branch connections to slaves.
- **Tree**: Hierarchical structure where the master connects to multiple levels of slaves.



AS-i

Master-Slave Communication

- Predefined message format for typical modules.
- Functional compatibility of modules from different manufacturers.

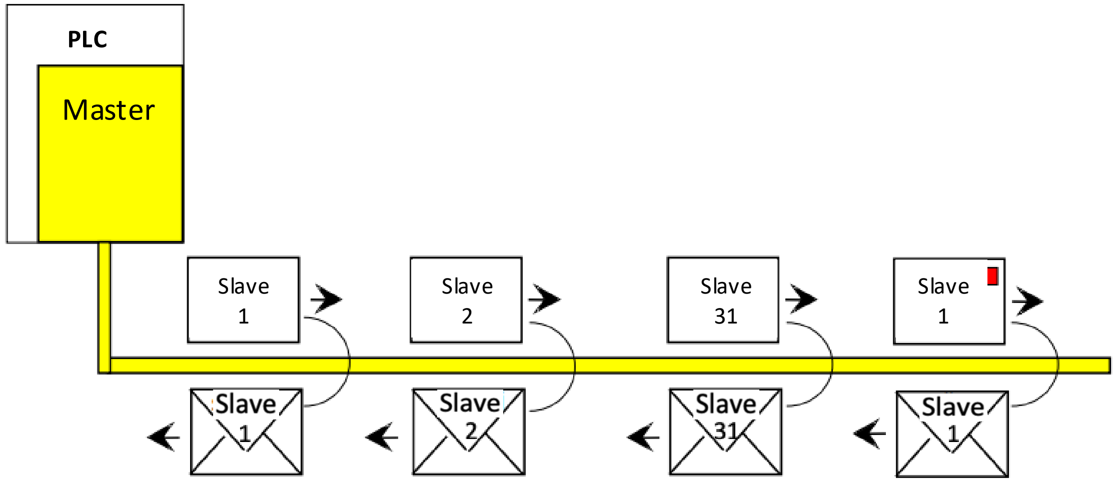
Up to 62 slaves (modules) per segment (A, B), split into 31 per channel:

- Address 0 is factory-set → A new address is assigned when connecting to the bus.

Cycle time < 5 ms

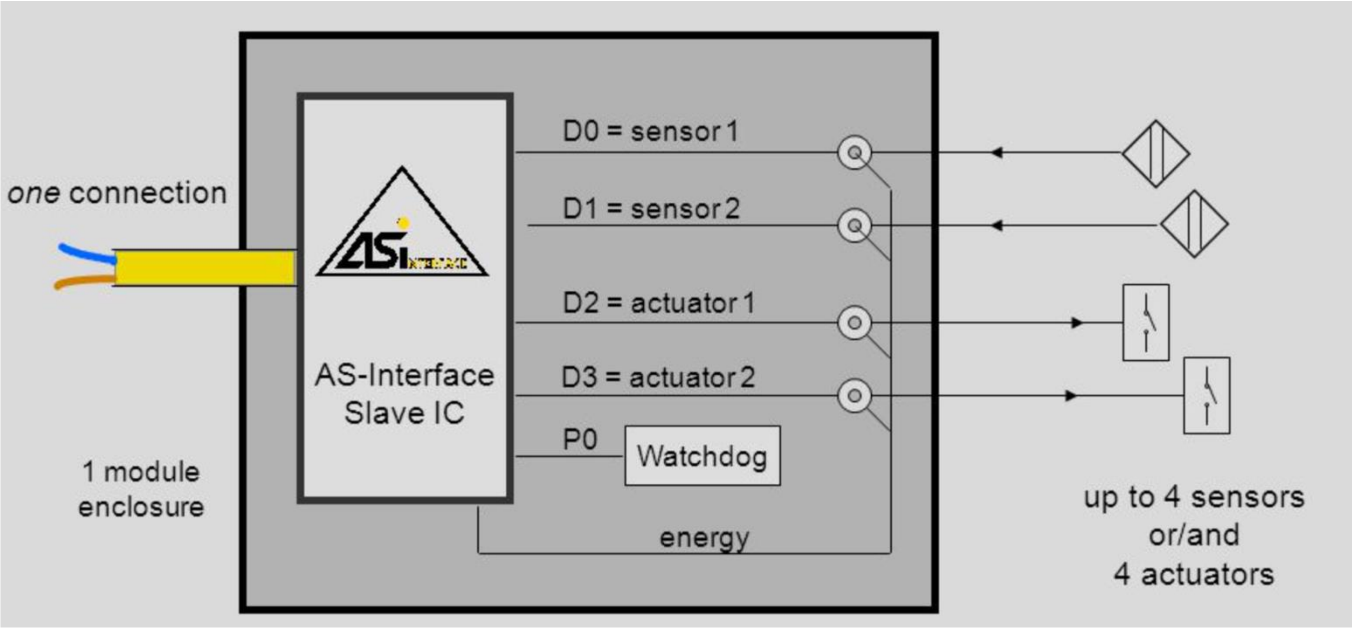
- Corresponds to sending 33 messages.

Automatic Address Assignment



AS-i

- **AS-i Modules**
  - 4 digital inputs or outputs (synchronous)
  - 4-bit parameters per module (asynchronous)
  - Analog values are transmitted over multiple queries
- **Maximum capacity**:
  - 62 x 4 = 248 digital inputs or outputs



AS-i

Data Transmission

1.Bit sequence

2.Manchester coding

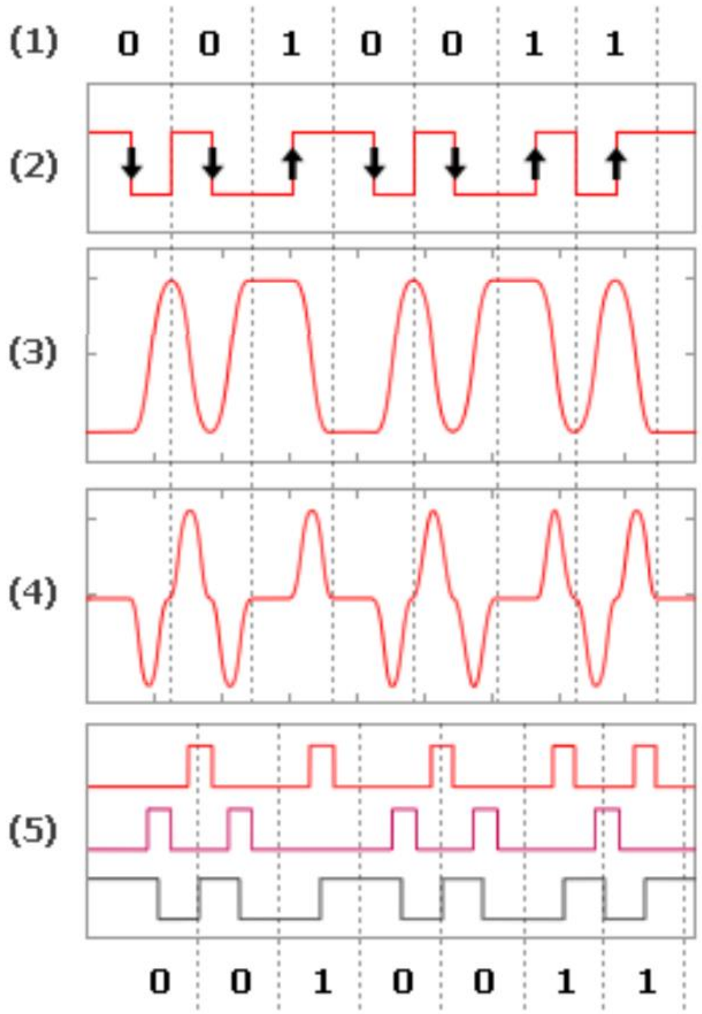
- Bit XOR clock
- Transition in every cycle

3.Transmitted current

4.Received voltage

- Differential: image (4) is the negative derivative of image (3)

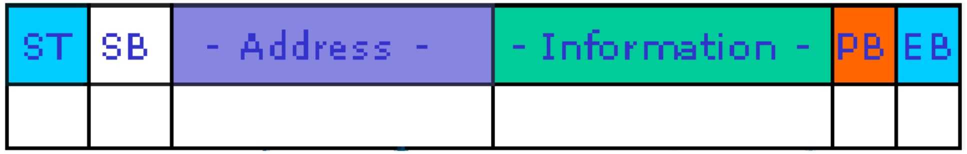
5.Decoding voltage into bits



AS-i

Telegrams

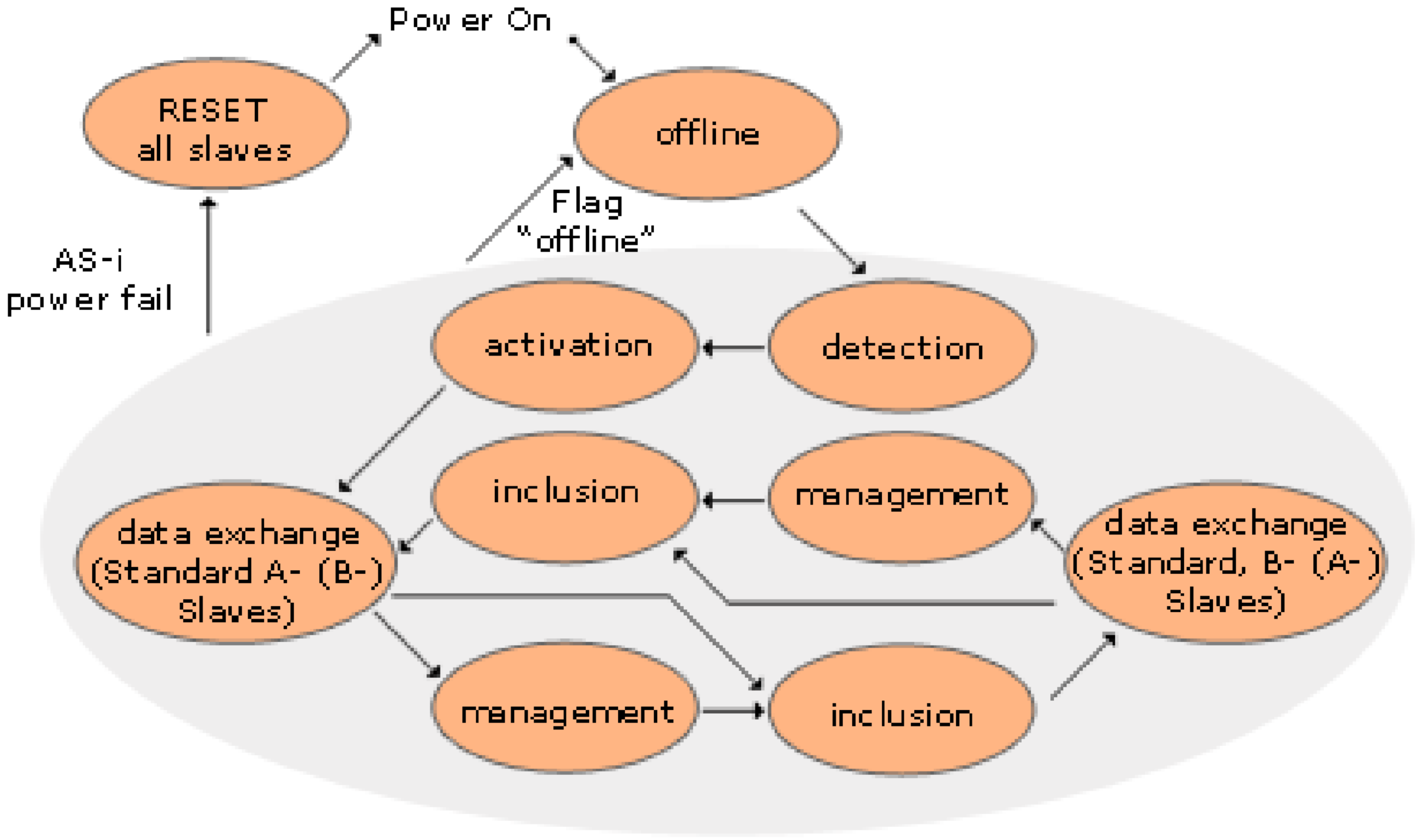
- **Basic message** (master and device)



  - **ST**: Start bit (0 = OK, 1 = Not Allowed)
  - **SB**: Control bit (0 = Data/Parameters/Address, 1 = Control Signals)
  - **Address**: A4..A0 - Device Address
  - **Information**:
    - Master: I4..I0 - Data for the device
    - Device: I3..I0 - Data for the master
  - **PB**: Parity bit (sum of all 1s in the message must equal 1)
  - **EB**: End bit (0 = Not Allowed, 1 = Correct)
- **Extension in v2.1**:
  - Bit I3 represents the address field (A or B)
- **Composite Message**
  - Consists of several consecutive single messages

AS-i

- **Application Layer**
  - Functions of the bus master



CAN

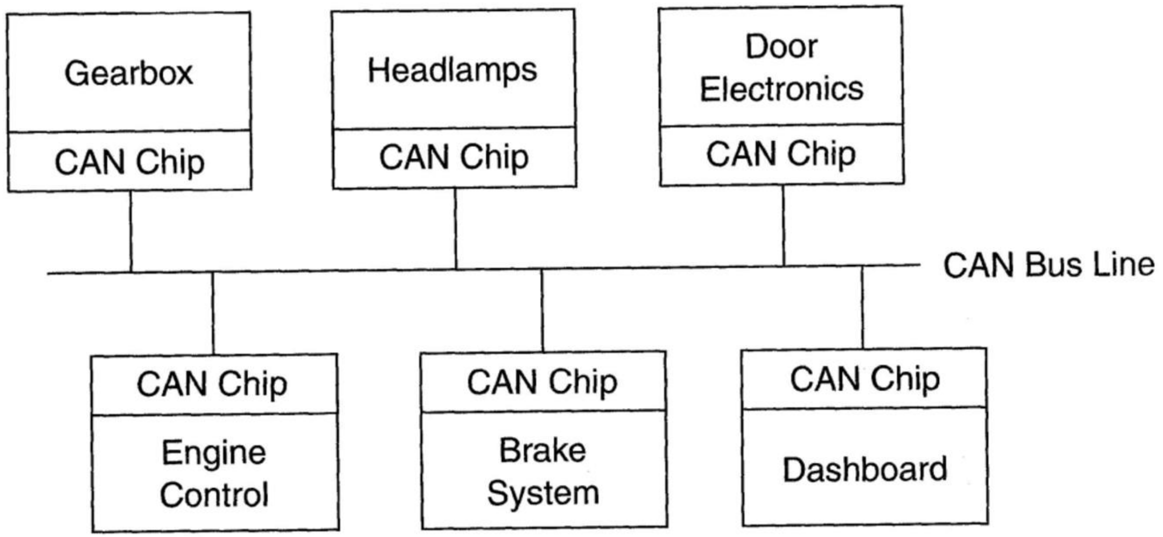
Controller Area Network Bus

- **Applications**
  - Automotive Industry
  - Developed by Intel/Bosch, also used by Honeywell and Allen-Bradley
- **Standards**
  - **SAE**: Used in the automotive industry
  - **ISO11898**: Used in frequency converters
  - Different specifications are **not compatible** with each other
- **Availability**
  - Widely supported by **many integrated circuit manufacturers**

CAN

Physical Layer

- Electric cable or optical fibers
- Electric cable
  - Trunk line with termination resistors
  - Branches without termination resistors, where devices are connected
  - Cable specifications:
    - 2 wires for power supply (24 V)
    - 2 wires for signal transmission (0–5 V)
  - Connectors are not standardized



CAN

Data Link Layer

- Sequential connection of up to 64 devices
- Bus operation is managed by a master device
- Speeds:
  - 1 Mb/s up to 40 meters
  - 100 kb/s up to 400 meters
  - 25 kb/s up to 1000 meters
- Message transmission:
  - Utilizes the NRZ protocol (Non-Return to Zero)

DeviceNet protocol

Overview

- Built on the **CAN bus** for industrial automation.
- Developed by the **Open DeviceNet Vendors Association (ODVA)**.
- Combines data and power in one cable for devices like sensors and actuators.

Key Features

- Adds industrial-specific functions to CAN.
- Simplifies wiring and device integration.
- Supports arbitration for non-deterministic communication.

Message Priority

- Lower IDs (higher priority) win arbitration.
- Critical devices like processors use lower IDs.

Field	Size	Description
Start of Message	1 bit	Signals the start of the message.
ID (Address + Command)	11 bits (5+6)	Identifies the device and command.
Ready to Receive	1 bit	Confirms receiver is ready.
Control Field	6 bits	Indicates the number of data bytes.
Data	0–8 bytes	Contains the payload.
CRC	15 bits	Error detection code.
CRC Delimiter	1 bit	Separates the CRC from other fields.
Acknowledgment	1 bit	Confirms successful transmission.
Acknowledgment Delimiter	1 bit	Separates acknowledgment.
End of Message	7 bits	Marks the message end.
Delay Before Next Msg	Min. 3 bits	Ensures bus stability before the next message.

Profibus

PROcess Field BUS

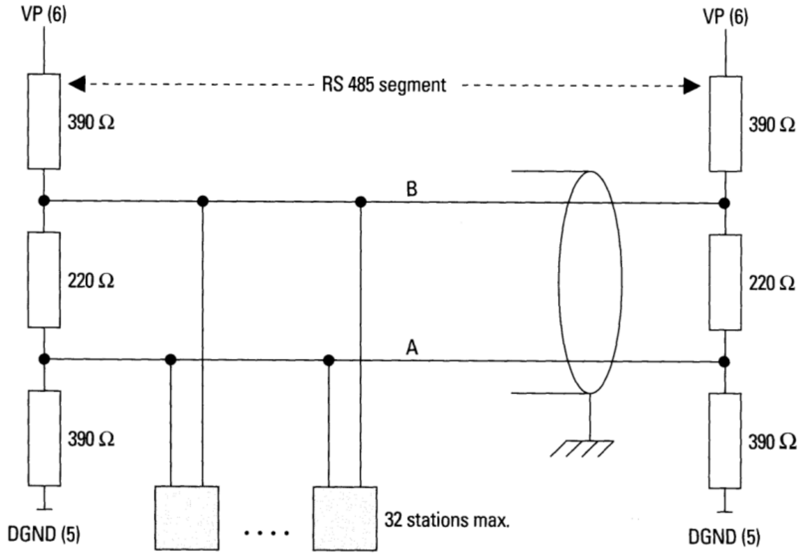
- Introduced in 1987 by Siemens, now an international standard.
- It has the most installations among fieldbuses.
- **Three Variants:**
  1. **Profibus-FMS (Fieldbus Message Specification):**
     - Designed for transferring large amounts of data.
     - Used for communication between PLCs (Programmable Logic Controllers) or between PLCs and PCs.
     - Has been largely replaced by Ethernet.
  2. **Profibus-DP (Decentralized Periphery):**
     - Used for communication between PLCs and for connecting measuring and actuator components to PLCs.
  3. **Profibus-PA (Process Automation):**
     - Developed for process automation needs in hazardous environments (explosion zones).
     - Derived from Profibus-DP.
     - Supports data transfer and power supply over the same two-wire cable.

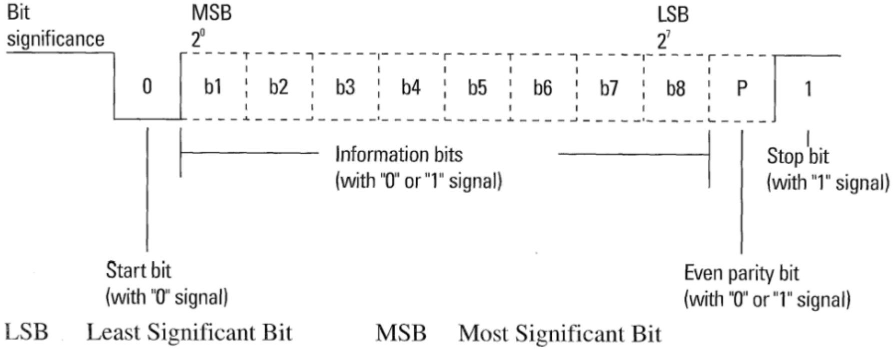
Profibus

Physical Layer: RS-485

- Shielded twisted pair with a characteristic impedance of 100 to 130 ohms, DB9 connectors.
- 11 bits (1 + 8 + 1 + 1) in NRZ (Non-Return-to-Zero)
- Half-duplex – bidirectional communication, only one direction at a time.
- Up to 127 stations, 32 per segment (without repeater).
- Transmission speeds:

Speed [kbit/s]	9.6	19.2	93.75	187.5	500	1500	12000
Distance [m]	1200	1200	1200	1000	400	200	100

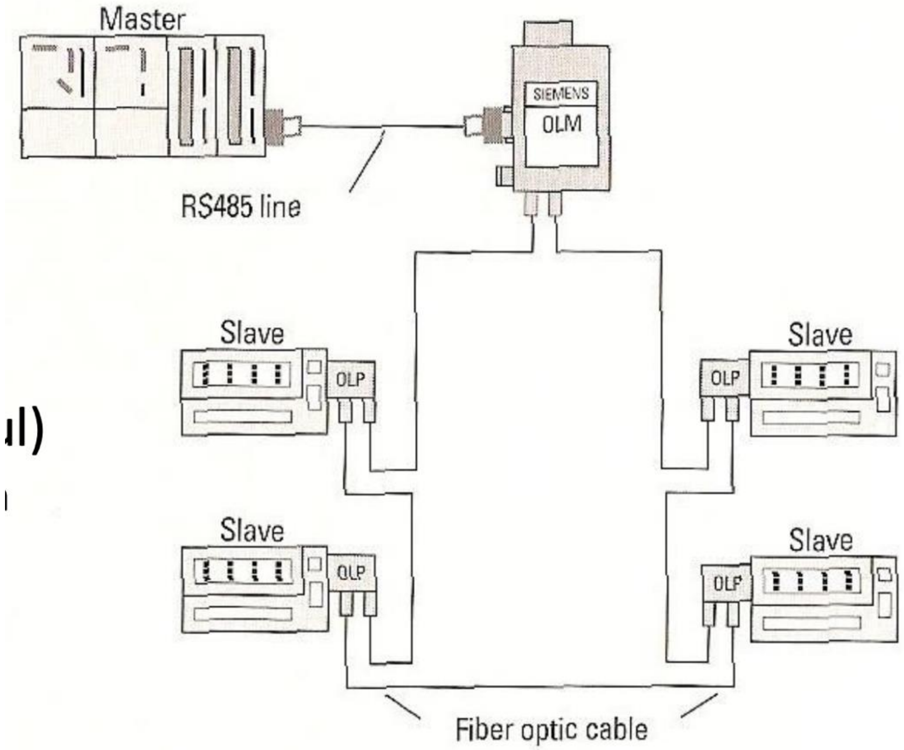




Profibus

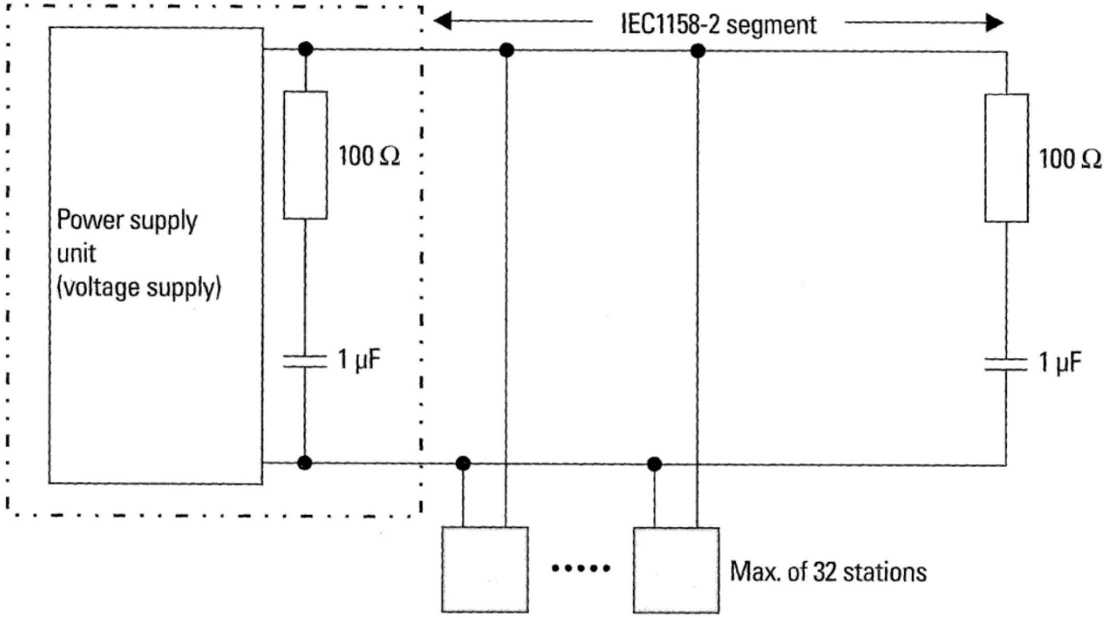
Physical Layer: Optical Fiber

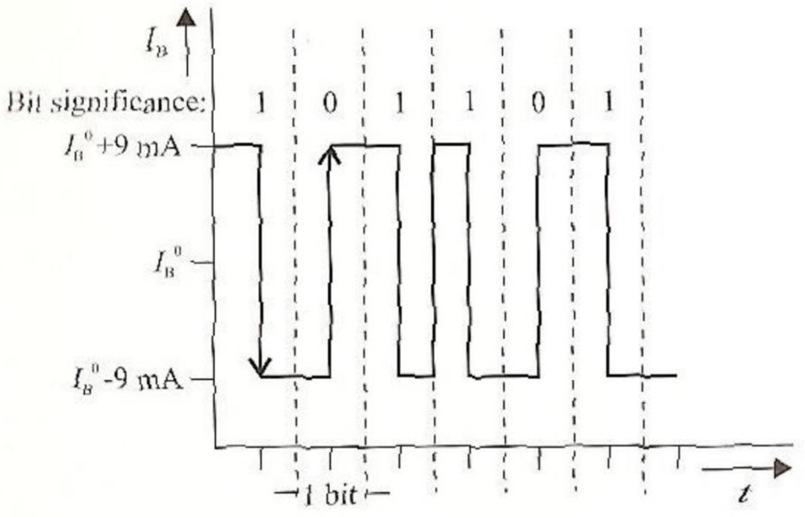
- Distance between stations:
  - Up to 15 km with glass fibers
  - Up to 80 m with plastic fibers
- OLP Technology (Optical Link Plug):
  - Connects via DB9 connector
  - Powered by devices
- OLM Technology (Optical Link Module):
  - Acts as a bridge between electrical and optical networks



Profibus

- Physical Layer: IEC 61158-2
  - Explosive Areas
  - Device Powering via Bus (Twisted Pair):
    - Signals do not contain DC components
    - Current-modulated transmission: ±9 mA at 31.25 kBit/s
  - Manchester Encoding:
    - Logical 0 → transition from 0 to 1
    - Logical 1 → transition from 1 to 0





Profibus

Data Link Layer

- Message Formats
- Frame with constant length and no data:
  | SD1 | DA | SA | FC | FCS | ED |
- Frame with constant length and data:
  | SD3 | DA | SA | FC | Data (8 bytes) | FCS | ED |
- Frame with variable length:
  | SD2 | LE | LEr | SD2 | DA | SA | FC | Data | FCS |
- Short Acknowledgement:
  | SC |
- Token Frame:
  | SD4 | DA | SA |

- SDx: Start Delimiter
- DA: Destination Address (0–126)
- SA: Source Address
- FC: Frame Control (priority)
- FCS: Frame Check Sequence
- ED: End Delimiter
- LE/LEr: Length byte (repeated)
- SC: Single Character (acknowledgement)

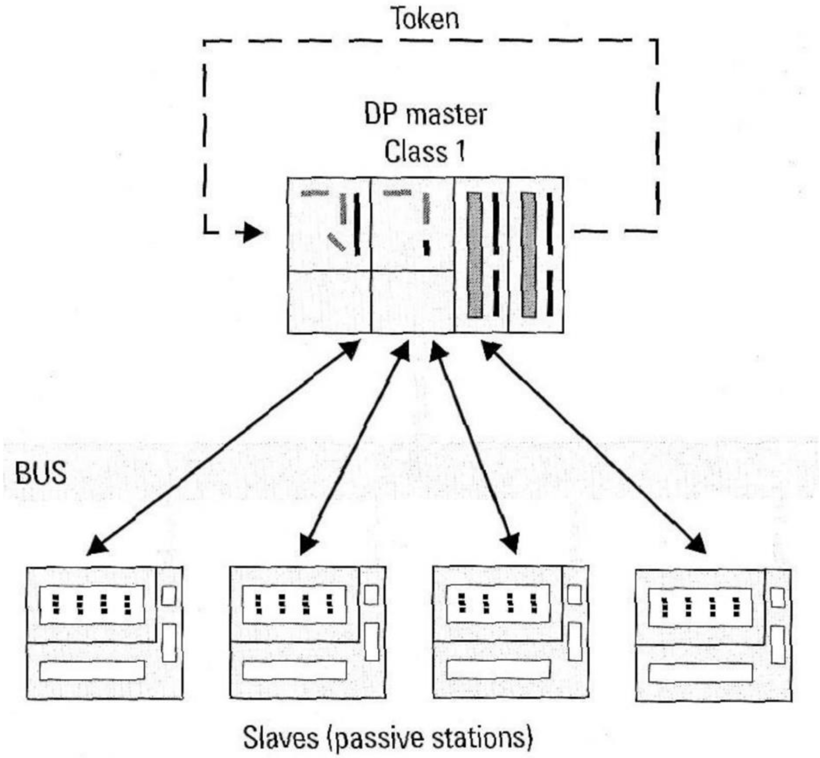
Profibus

- **Error Handling**: In the case of incorrectly transmitted messages, transmission is repeated up to eight times.
- **Possible Transmission Modes**:
  - Point-to-point or broadcast
  - With or without acknowledgment
- **Profiles**:
  - Define the meaning of bits in messages
  - Types:
    - Encoders, Drives (frequency converters)
    - Human-machine interfaces
    - Error-free data transfer (fail-safe, emergency stop button, etc.)
- **Versions**:
  - **DP-V0**: Cyclic data transfer, diagnostics
  - **DP-V1**: Acyclic data transfer, visualization, alarms
  - **DP-V2**: Extensions for drive needs (isochronous communication)

Profibus

Modes

- **Master-Slave (Active-Passive Nodes)**
  - Only one active node (PLC).
  - Sends messages to passive nodes (slaves) and waits for responses.
  - Cyclic access to passive nodes.
- **Token Passing (Between Active Nodes)**
  - Active stations pass tokens in a predetermined sequence.
  - Once an active station receives the token, it gains access to the bus.
  - After the allocated time, it passes the token to the next station.
  - The ring is adjusted if a device is lost or reconnected.



Industrial Ethernet

Why Industrial Ethernet?

- It is already a standard in office environments.
- Widely used for high-level communication in process automation.
- Well-suited for communication between field-level units.

Advantages:

- Simplifies vertical integration with higher-level control systems.

Challenges:

- Easy installation and parameterization of devices.
- Serial connection of devices for practical implementation.
- Achieving real-time communication capabilities at the Ethernet level.

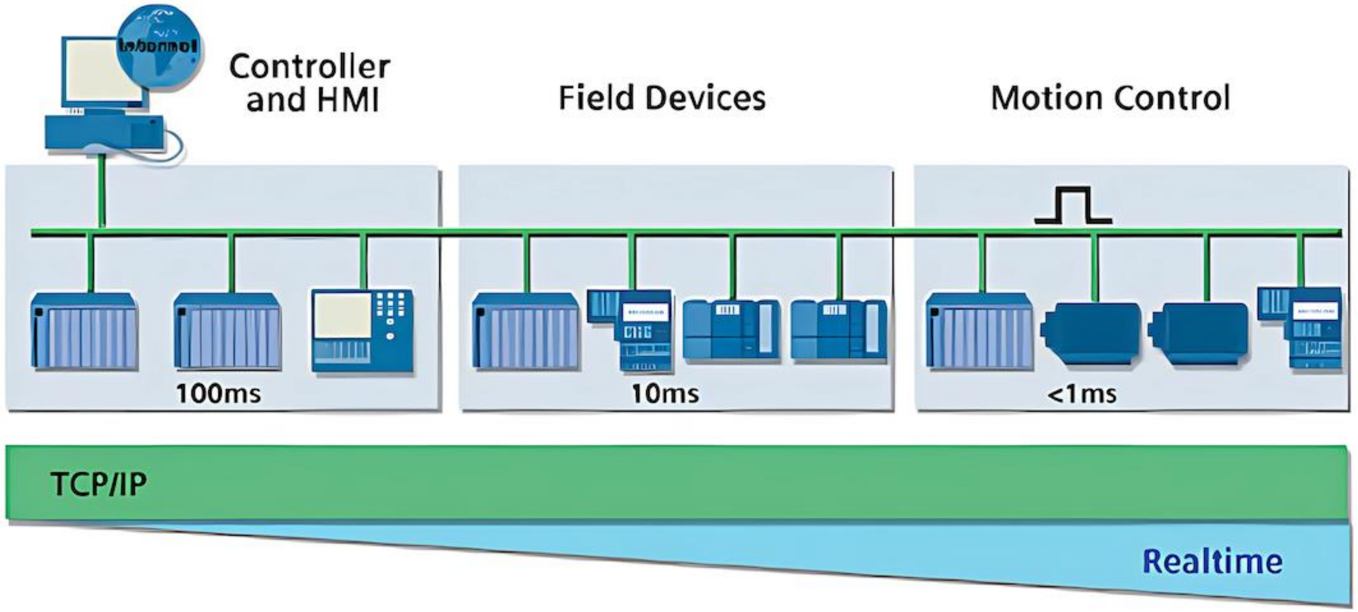
Industrial Ethernet

- Office vs. industrial environments

Office	Industrial
Fixed wiring	Wiring adapted to the system
Connection of various devices	Connected devices rarely change
Star topology	Serial connections
UTP cable (Unshielded Twisted Pair)	Cable adapted for industrial environments (STP)
Large data packets	Short packets
Responsiveness is not critical	Real-time responsiveness
Medium requirements for network availability	High requirements for network availability
Standard conditions	Harsh conditions (temperature, humidity, vibration, electromagnetic interference, mechanical and chemical damage)

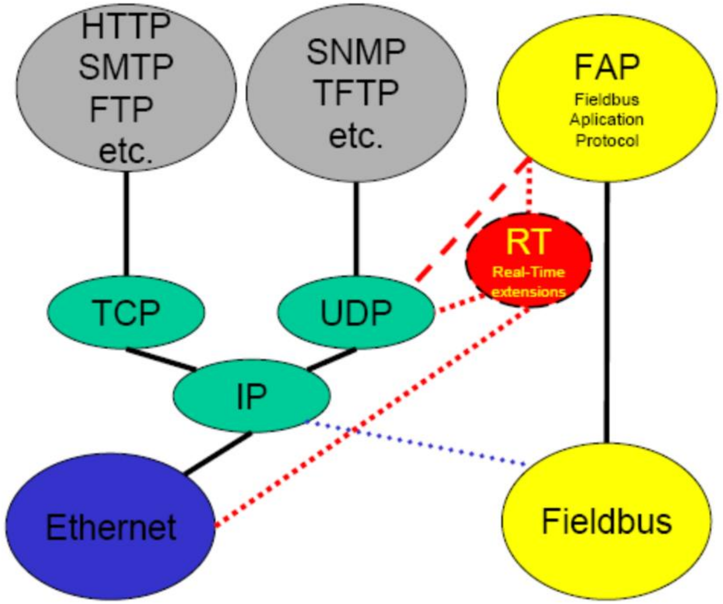
Industrial Ethernet

- Real-time problem



- Coexistence with existing TCP/IP protocols.
- Covering both small and large requirements regarding real-time needs.

Industrial Ethernet



Ethernet: Physical and Data Link Layers

- Defines the process of transmitting messages and media.

TCP (Transmission Control Protocol)

- Ensures error-free message transmission.
- Establishes connections between devices, transfers messages, and terminates connections.

UDP (User Datagram Protocol)

- Does not ensure error-free message transmission.
- Does not establish connections between devices.
- More suitable for time-critical transmissions.

Industrial Ethernet

- More ideas, standard 61784-2 covers the following:

CPF (Communication Profile Family)	Standard Protocols (CP)	Real-Time Extensions (CP RTE)
CPF2 (ControlNet™)	CP 2/2 EtherNet/IP	CP 2/3 EtherNet/IP RTE
CPF3 (PROFIBUS)	CP 3/3 PROFINET CBA	CP 3/4 PROFINET I/O
		CP 3/5 PROFINET IRT
CPF4 (P-NET®)	CP 4/3 P-NET RTE	
CPF6 (INTERBUS®)	CP 6/2 INTERBUS TCP/IP	CP 6/4 INTERBUS RTE
CPF10 (VNET/IP)	CP 10/4 VNET/IP	
CPF11 (TCnet)	CP 11/4 TCnet	
CPF12 (EtherCAT)	CP 12/4 EtherCAT	
CPF13 (EPL)	CP 13/4 Ethernet Powerlink	
CPF14 (EPA)	CP 14/4 EPA	
CPF15 (Modbus-RTPS)	CP 15/4 Modbus-RTPS	
CPF16 (SERCOS)	CP 16/4 SERCOS III	

Profinet

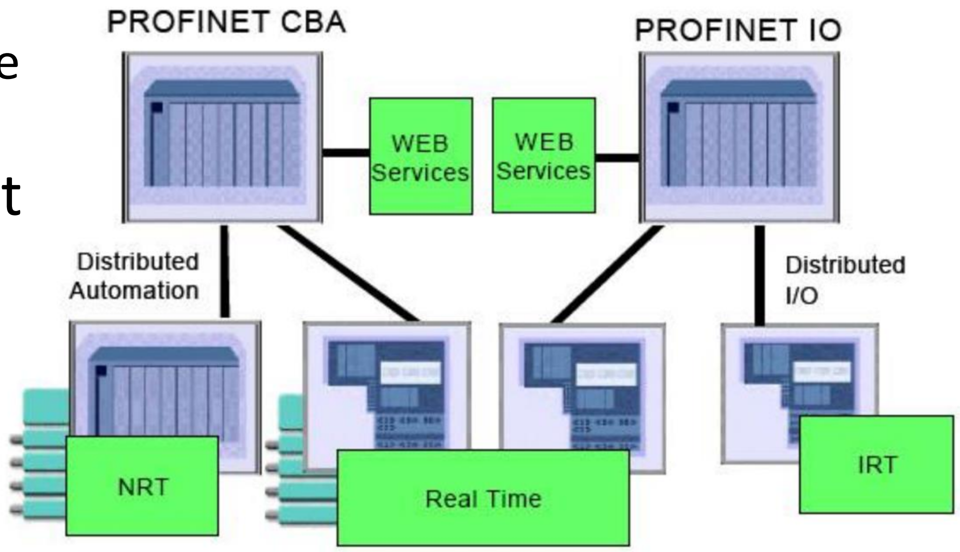
- Siemens, PNO, international standard
- **Development**
  - **2002:**
    - Distributed automation
    - Use of standard TCP/IP
    - Integration with Profibus
  - **2003:**
    - Real-time
    - Integration with the web
    - Network management
    - Connection of decentralized devices
  - **2005:**
    - Isochronous real-time
    - Safety technologies

POWERFUL
REAL-TIME
OPEN
FLEXIBLE
INTEGRATED
NET CONVERGENCE
ENTERPRISEWIDE
TRANSPARENT

Profinet

Profinet IO

- Designed for connecting field devices to the bus.
- Simplicity of communication equipment provides an advantage over traditional data transmission methods.
- To ease the transition, the Profibus concept is utilized:
  - Same peripheral devices are used as in Profibus.
  - Installation and parameterization are carried out in the same manner.
- For non-time-critical processes, standard Ethernet TCP/IP or UDP/IP offers:
  - Sufficient bandwidth.
  - Adequate determinism.



Profinet

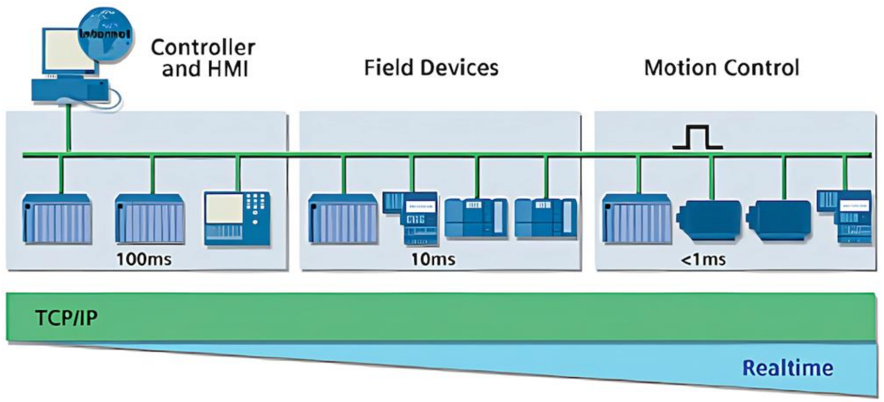
Profinet CBA (Component Based Automation)

- Designed for distributed control systems.
- Simplifies communication between various devices.
- Targets controllers and advanced programmable field devices.
- Component model describes devices as technological modules:
  - PCD file (Profinet Component Description) in XML format.
  - “Object-oriented programming” in process control.

Profinet

Profinet: Three Communication Modes

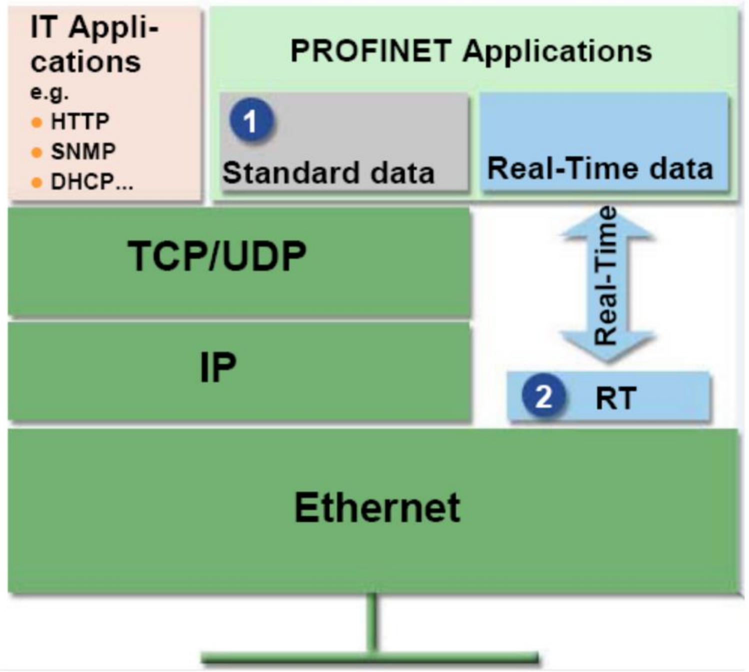
- **NRT (Non-Real Time):**
  - Standard TCP/IP.
  - Used for configuration and integration with higher-level management systems.
- **RT (Real Time):**
  - Stricter requirements for bandwidth and determinism.
  - Includes software extensions.
  - Handles process data and alarms.
- **IRT (Isochronous Real Time):**
  - Even stricter requirements for determinism.
  - Involves hardware-level extensions.
  - Suitable for multi-axis motor control.



Profinet

Profinet RT (2)

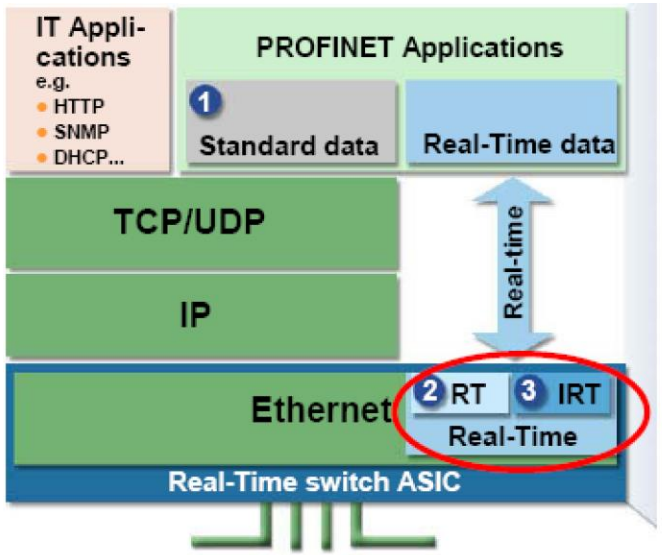
- **High-capacity data transfer:** Supports efficient and large-scale data communication.
- **Cyclic data monitoring:** Allows for continuous tracking of process data.
- **Event-based operations:** Responds to system events in real time.
- **Implementation flexibility:** Can be implemented with any Ethernet network card and any Ethernet switch.
- **Application layer dominance:**
  - Improved transfer times by a factor of 6–10.
  - Reduced start time variance by a factor of 5–8.

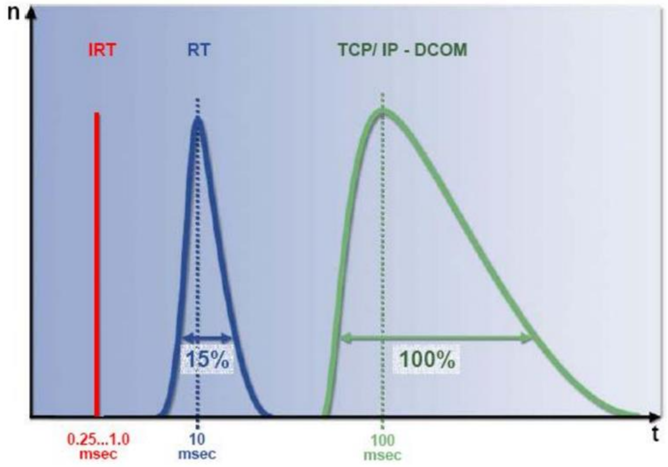


Profinet - Communication

IRT (Isochronous Real Time)

- **Highly efficient data transfer:** Supports simultaneous (isochronous) data delivery to multiple devices.
- **Guaranteed real-time transfer:**
    - Independent of network traffic.
    - Transmission start variance is less than 1 microsecond.
    - Cycle time is less than 1 millisecond.

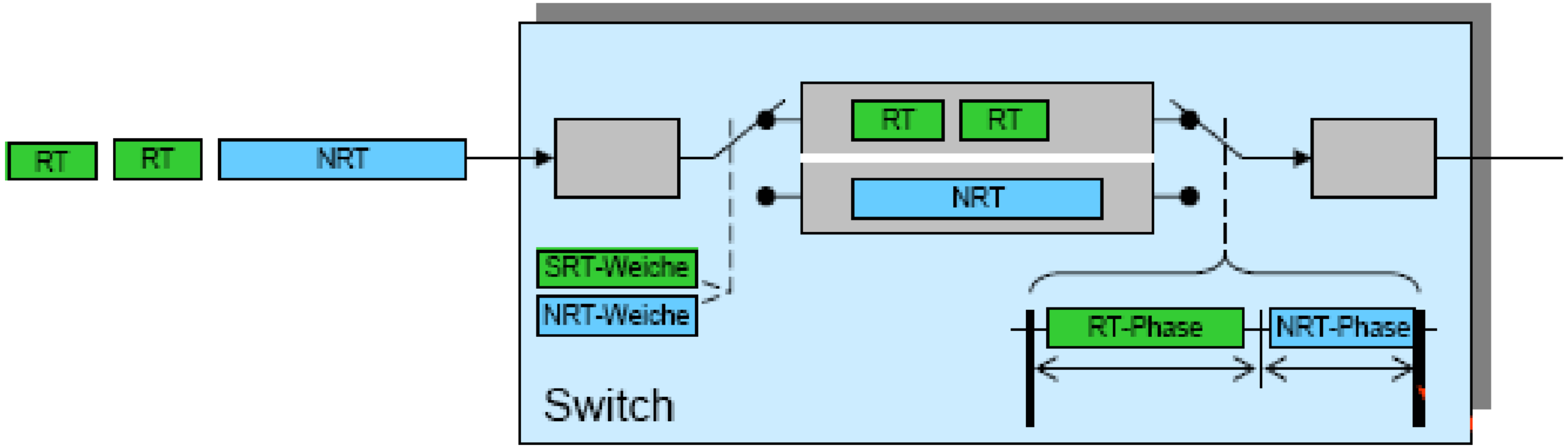




Profinet

IRT

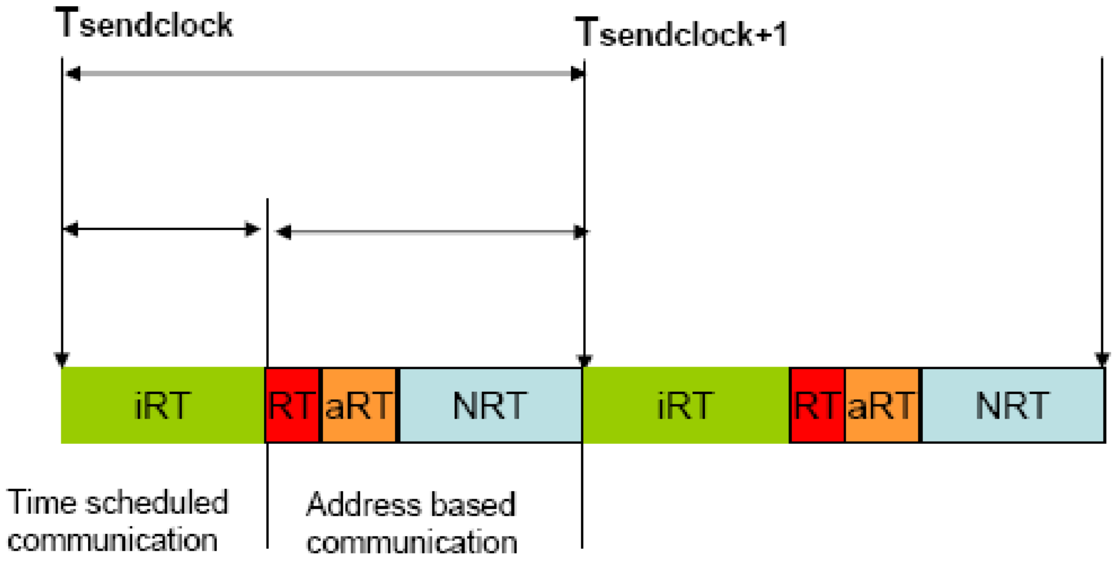
- **Special switches:**
  - Priority for IRT packets.
  - Synchronization of cycles between switches.
  - Mandatory topology configuration.



Profinet

Coexistence of NRT, RT, and IRT

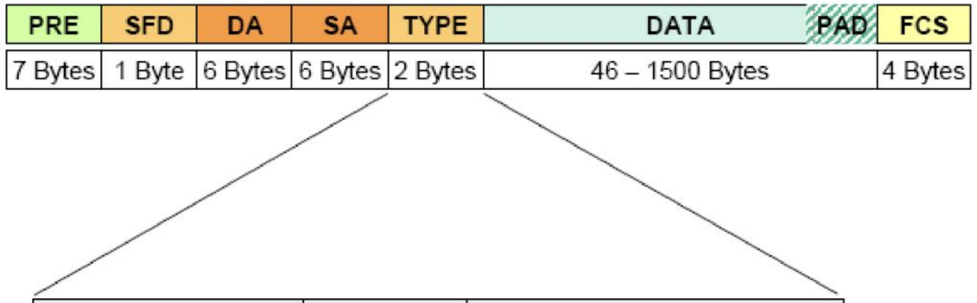
- Resource Allocation
  - Defined during bus configuration.
- Priorities within the Cycle
  - iRT - Constant length.
  - RT - Cyclic transfers.
  - aRT - Asynchronous transfers.
  - NRT - Other communication.
- Cycle length remains unchanged.



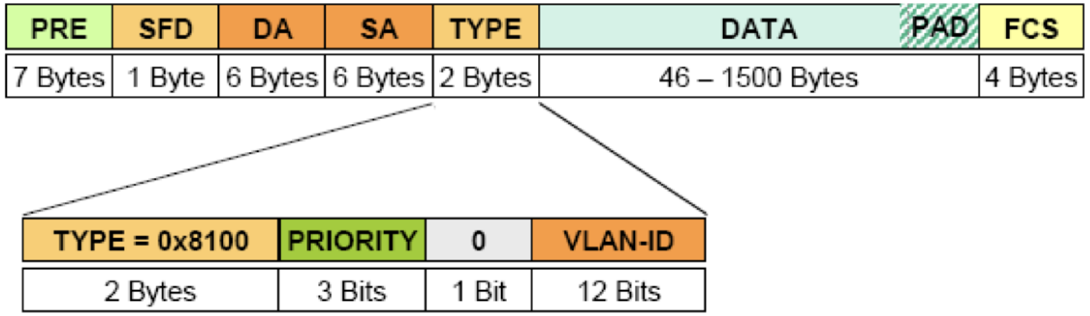
Profinet

Changes in Ethernet Telegram

- **Ethernet**
  - **802.3 Standard**
  - **TYPE Field** - Defines the size or type of the DATA block:
    - < 0x0600 - Specifies the size in bytes.
    - > 0x0600 - Specifies the type, as shown in the table below.
    - Example Types:
      - 0x0800 - IP Header
      - 0x0806 - Address Resolution Protocol (ARP)
      - 0x8100 - Virtual LAN (VLAN) Header
      - 0x8892 - Profinet Real-Time (PN-RT)
- **VLAN (Virtual LAN)**
  - **802.1q Standard**
  - **Priority Setting**
    - RT packets are given the highest priority.
    - Priorities can be configured on network switches.



TYPE	Protocol	Meaning
0x0800	IP	IP Header
0x0806	ARP	Adressresultion
0x8100	VLAN	Virtual LAN Header
0x8892	PN-RT	PROFINET Real-Time



Profinet

- Message

PRE	SFD	DA	SA	TYPE	DATA	PAD	FCS
7 Bytes	1 Byte	6 Bytes	6 Bytes	2 Bytes	46 – 1500 Bytes		4 Bytes

FrameID	RT-Data	Cycle-Counter	Data Status	Transfer Status
2 Bytes	40 - 1440 Bytes	2 Bytes	1 Byte	1 Byte

FrameID	Meaning
0x0000 – 0x00FF	Time Synchronization
0x0100 – 0x7FFF	RT Class 3 Frames (IRT)
0x8000 – 0xBFFF	RT Class 2 Frames (RT)
0xC000 – 0xFBFF	RT Class 1 Frames (RT)
0xFC00 – 0xFCFF	Acyclic transmission „high“
0xFD00 – 0xFDFF	Reserved
0xFE00 – 0xFEFC	Acyclic transmission „low“
0xFEFD – 0xFEFF	DCP
0xFF00 – 0xFFFF	reserved

Cycle-Counter	Meaning
One bit represents a time increment of 31,25µs; Big-Endian Format	**Provider:** Increments the CycleCounter (within the send cycle) and fits it in the frame. **Consumer:** Checks the CycleCounter during rceiption to identify take overs.

7	6	5	4	3	2	1	0	Data Status	Meaning
0	0			0		0		Reserved	
							X	State	Primary, leading channel in a redundant system
					X			DataValid	Data are valid
			X					ProcessState	Process is running
		X						ProblemIndicator	Set if there is no problem

Transfer Status	Meaning
0	Transmitted ok

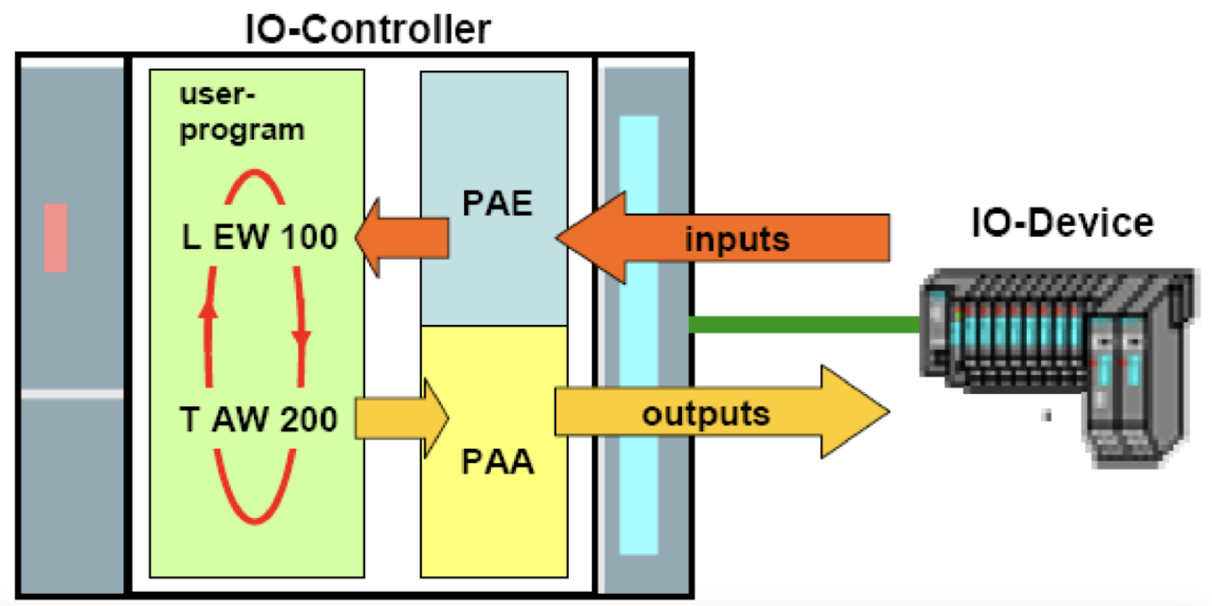
Profinet - Communication

Device Addressing:

- **IP Address** – Required for NRT (Non-Real-Time) and communication outside the network.
- **MAC Address and Symbolic Name** – Used for communication within the network.

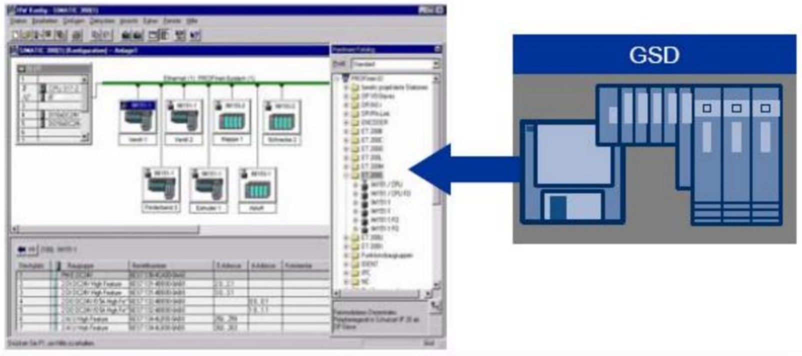
Programming Model for Field Devices:

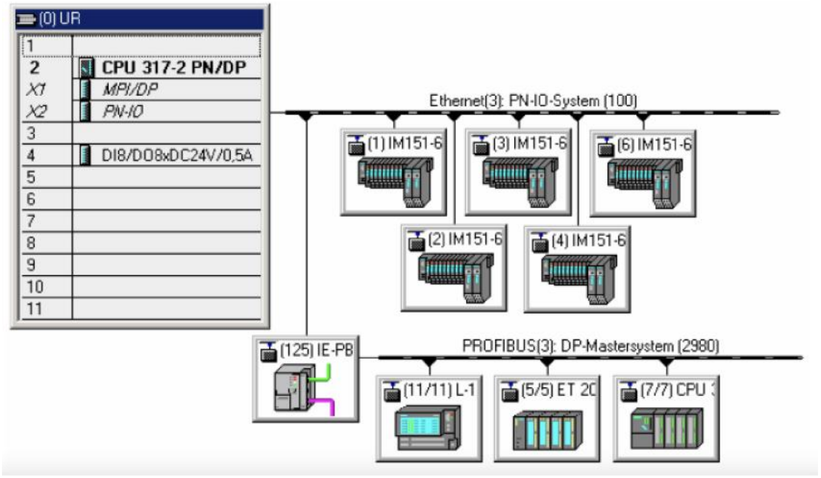
- **Mapping of Inputs and Outputs**



Profinet Engineering

- **Import GSDML File with Device Data:**
  - Prepared by the device manufacturer.
  - Includes a mapping of inputs and outputs.
- **Preparation of Hardware Configuration:**
  - Configure the structure and connections of the devices.
- **System Upload:**
  - Assign IP addresses.
  - Define device names.





Process automation

Industrial Communication Buses

BS UNI studies, Fall semester 2025/2026

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