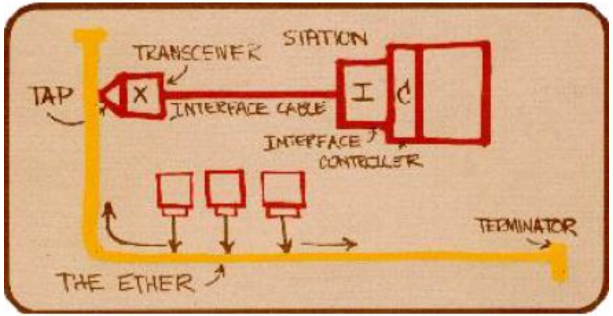
SENSOR NETWORKS - ETHERNET

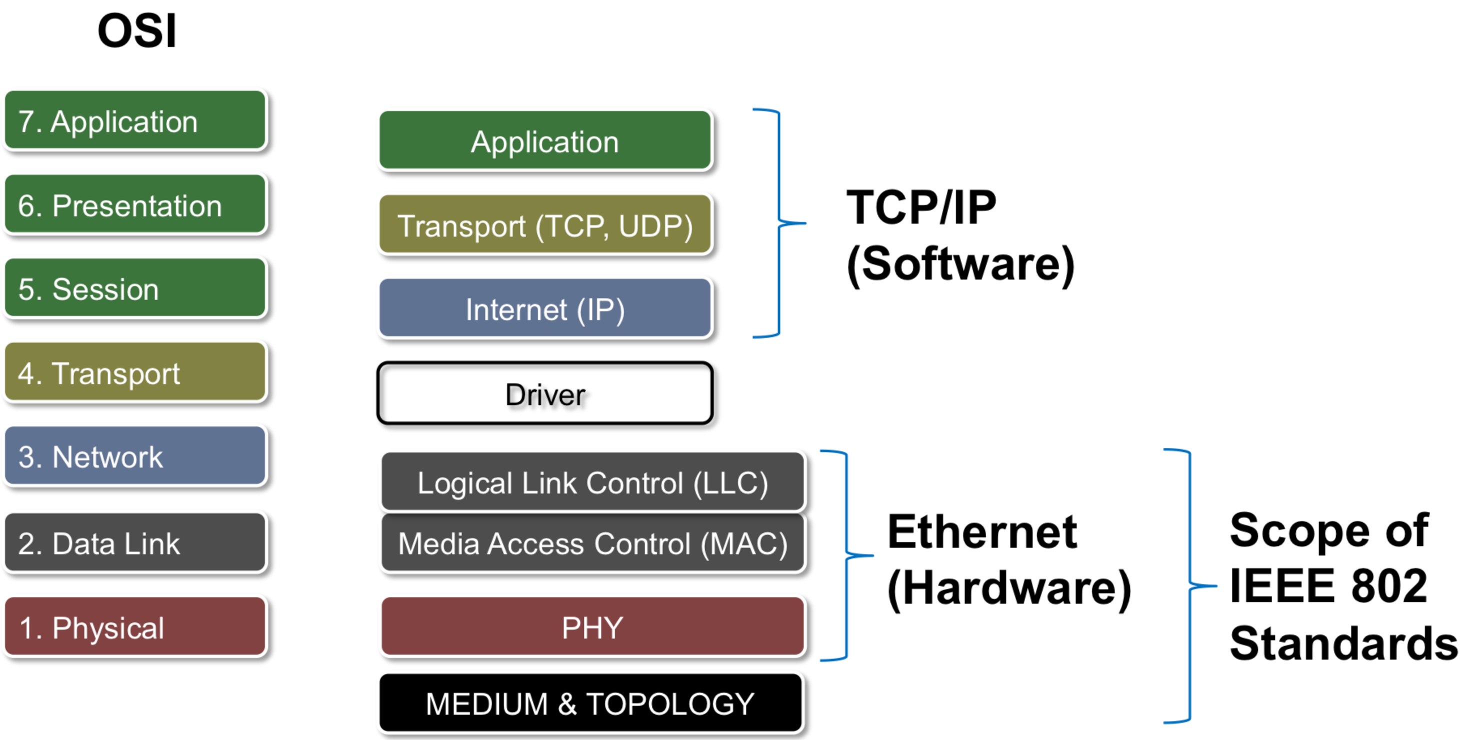
History

- It was developed from the 1970s as a communication solution for LAN system
- The first connection – 1976 Rob Metcalfe and David Boggs Palo Alto, Xerox Research centre
- First standardized in 1983, IEEE 802.3 base of the Ethernet used
- The original transfer rate was 2,94Mbit/s -> 10Mbit/s
- In the early 80s the first Network Interface Cards had been shipped (3COM, Inte, Sub Microsystems)
- Other Ethernet standards
  - Token Bus (802.4) – General motors
  - Token Ring (802.5) - IBM



SENSOR NETWORKS - ETHERNET

ISO/OSI modell



SENSOR NETWORKS - ETHERNET

Naming conventions

<BitRate><Signaling>-<Medium><PCS Encoding><#Lanes>

Bit rate

- 10, 100, 1000
- 10G

Signaling Type

- BASE – Baseband signaling
- BROAD – Broadband signaling
- PASS – Passband signaling

Medium

- T = twisted pair
- C = copper/twinax
- F = fiber (various wavelengths)
- S = 850 nm short wavelength
- L = 1300 nm long wavelength

PCS Encoding - Bit encoding schemes

- X = 8b/10b block encoding (Gigabit) or 4b/5b (Fast)
- R = 64b/66b for large blocks (10G ethernet)

SENSOR NETWORKS - ETHERNET

The most popular examples

10Base5 / Thick Ethernet

- Speed: 10 MBit/s
- Topology: Bus
- Max. segment length: 500m
- Cable: Koax

10Base-T / Ethernet / IEEE 802.3i

- Speed: 10 MBit/s
- Topology: Star
- Max. segment length: 100m
- Cable: Twisted pair, Cat3

100Base-TX / Fast Ethernet

- Speed: 100 MBit/s
- Topology: Star
- Max. segment length: 100m
- Cable: Twisted pair, Cat 5

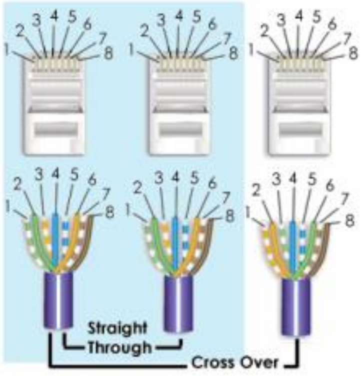
100Base-FX

- Optical transmission

SENSOR NETWORKS - ETHERNET

Phisical Layer

Pin	Colour	Function
1	green with white	+TD
2	green	-TD
3	orange with white	+RD
4	blue	unused
5	blue with white	unused
6	orange	-RD
7	brown with white	unused
8	brown	unused

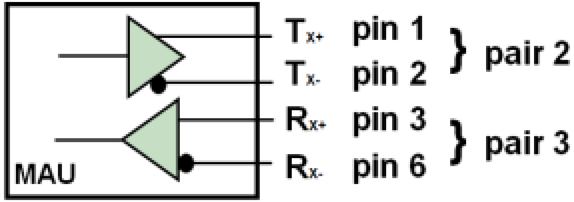


Autonegotation – Automatic Transfer rate detection

Autocrossing – Cable connection

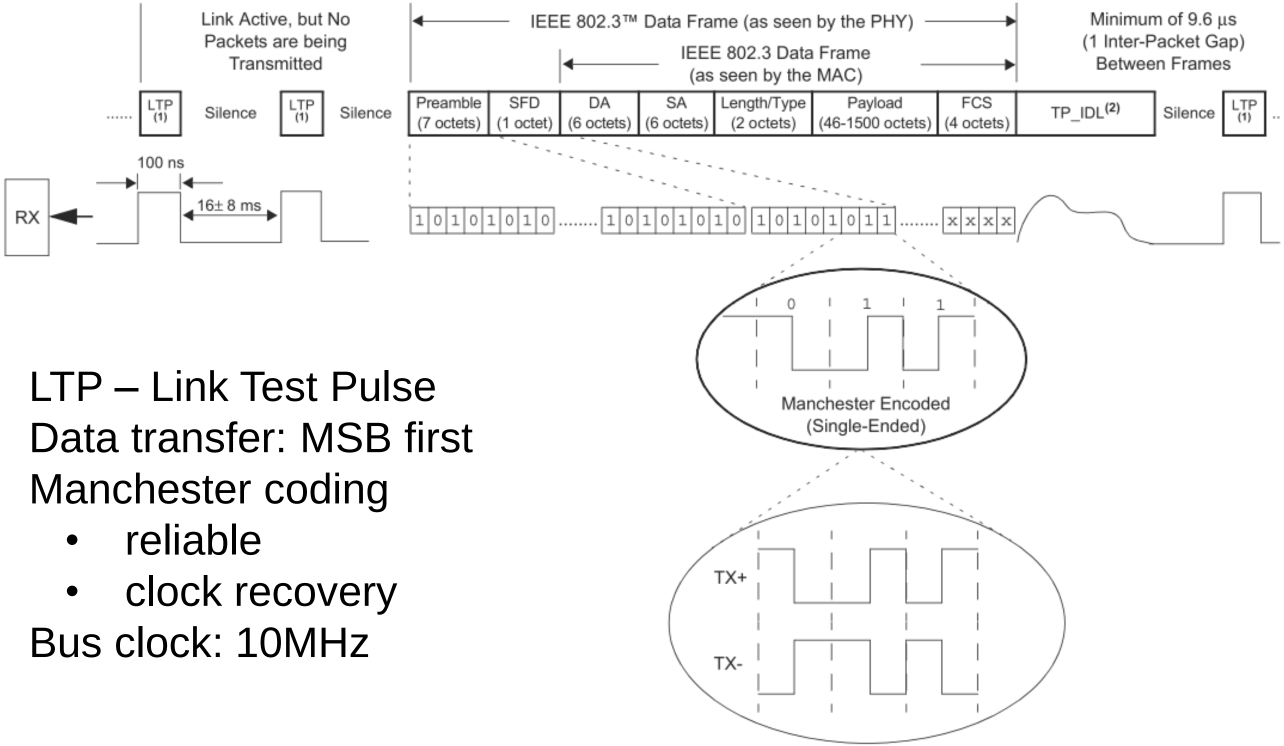
Fullduplex transfer

UTP/STP cable



SENSOR NETWORKS - ETHERNET

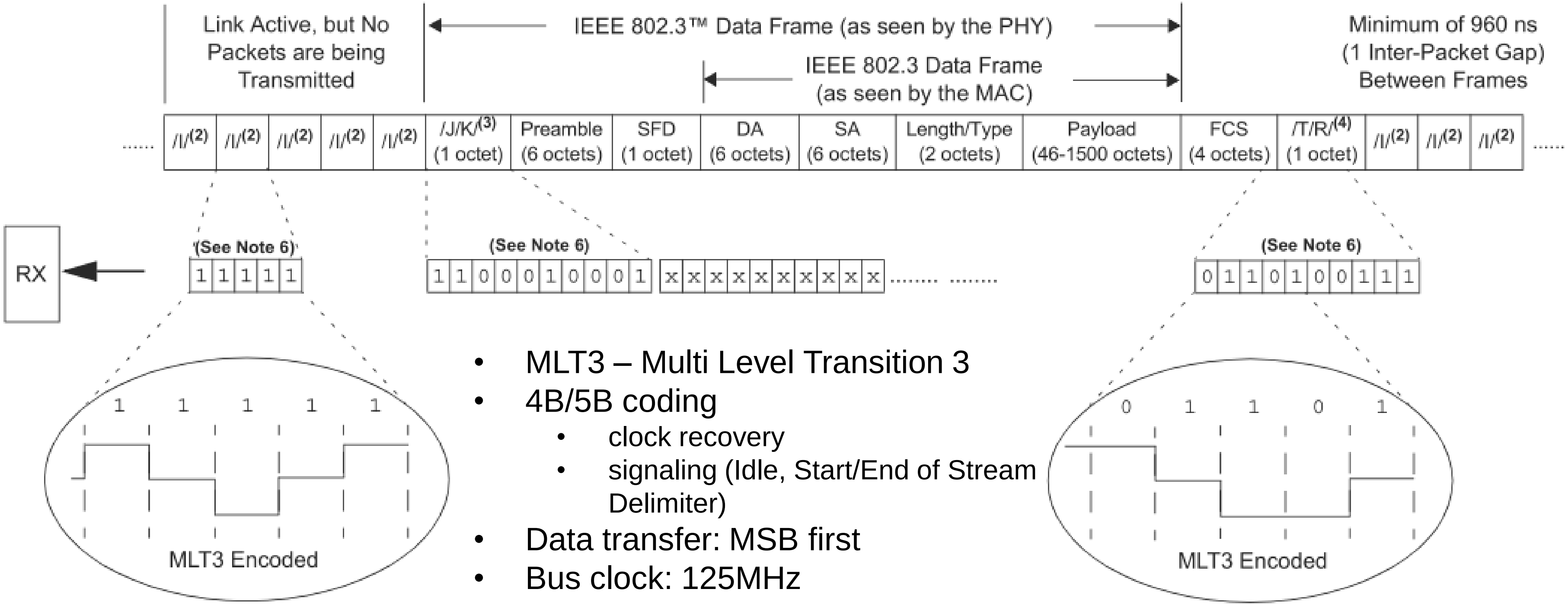
Implementation – 10BASE-T



- LTP – Link Test Pulse
- Data transfer: MSB first
- Manchester coding
  - reliable
  - clock recovery
- Bus clock: 10MHz

SENSOR NETWORKS - ETHERNET

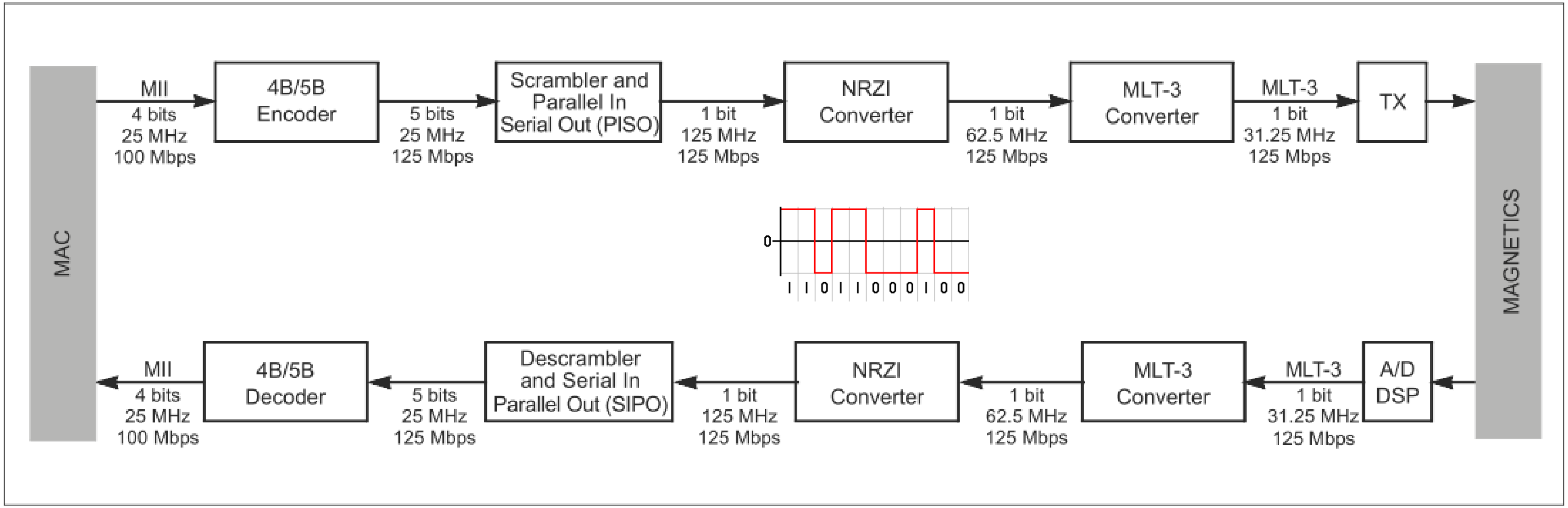
Implementation – 100BASE-T



- MLT3 – Multi Level Transition 3
- 4B/5B coding
  - clock recovery
  - signaling (Idle, Start/End of Stream Delimiter)
- Data transfer: MSB first
- Bus clock: 125MHz

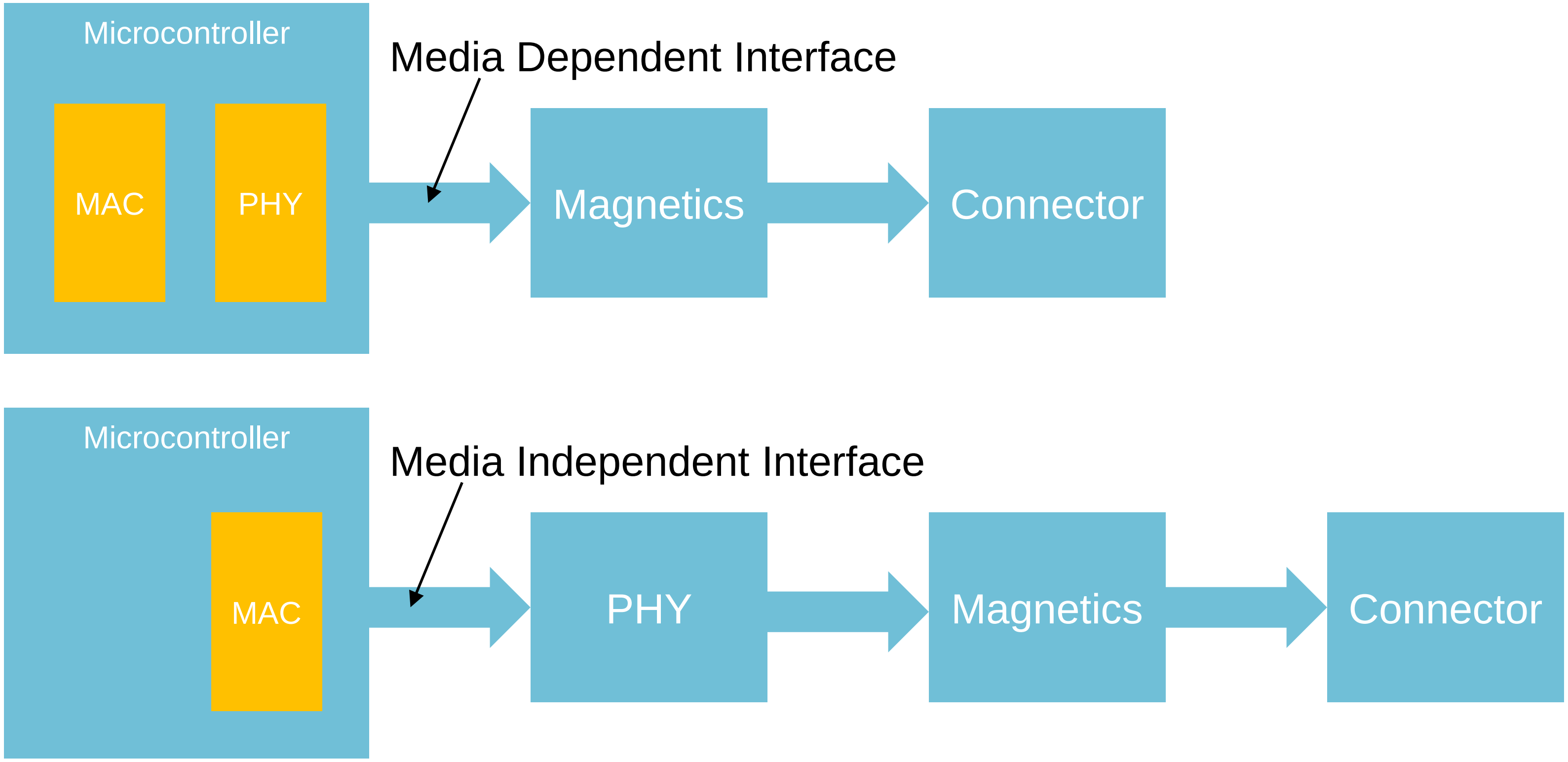
SENSOR NETWORKS - ETHERNET

Implementation – 100BASE-T



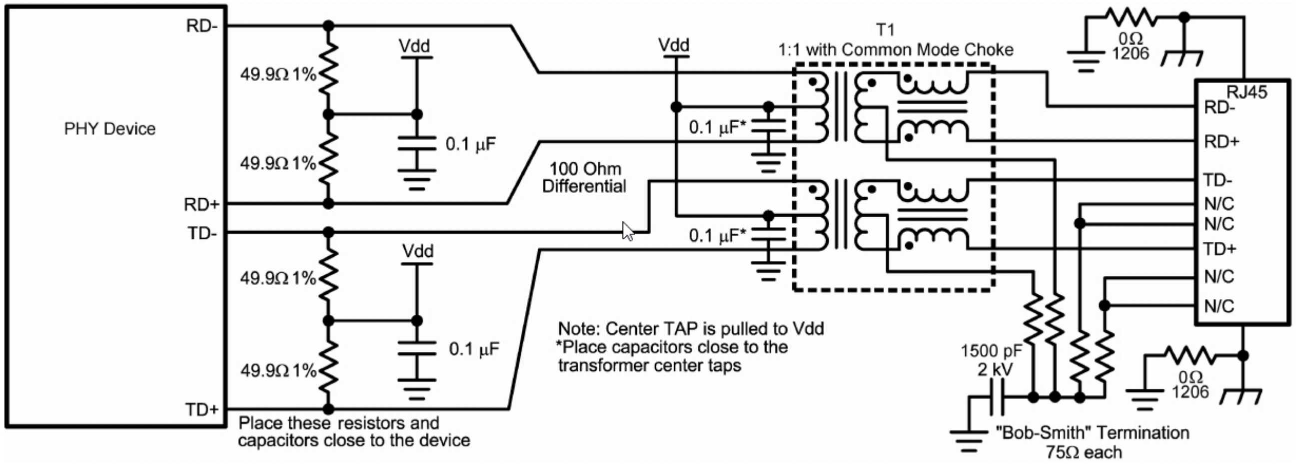
SENSOR NETWORKS - ETHERNET

Implementation – Hardware



SENSOR NETWORKS - ETHERNET

Implementation – Hardware

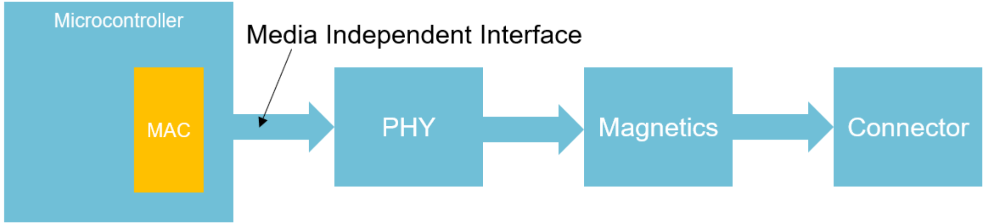


Role of the magnetics:

- ➢ electrical isolation
- ➢ signal balancing
- ➢ common-mode rejection
- ➢ impedance matching
- ➢ EMC improvement

SENSOR NETWORKS - ETHERNET

Implementation – Hardware



MII - Media Independent Interface
RMII – Reduced Media Independent Interface
GMII – Gigabit Media Independent Interface
RGMII – Reduced Gigabit Media Independent Interface
SGMII – Serial Gigabit Media Independent Interface

SENSOR NETWORKS - ETHERNET

Implementation – Hardware

MII

Signal name	Description	Direction
TX_CLK	Transmit clock	MAC to PHY
TXD[3:0]	Transmit data bit 0…3	MAC to PHY
TX_EN	Transmit enable	MAC to PHY
TX_ER	Transmit error (optional)	MAC to PHY
RX_CLK	Receive clock	PHY to MAC
RXD[3:0]	Receive data bit 0…3	PHY to MAC
RX_DV	Receive data valid	PHY to MAC
RX_ER	Receive error	PHY to MAC
CRS	Carrier sense	PHY to MAC
COL	Collision detect	PHY to MAC

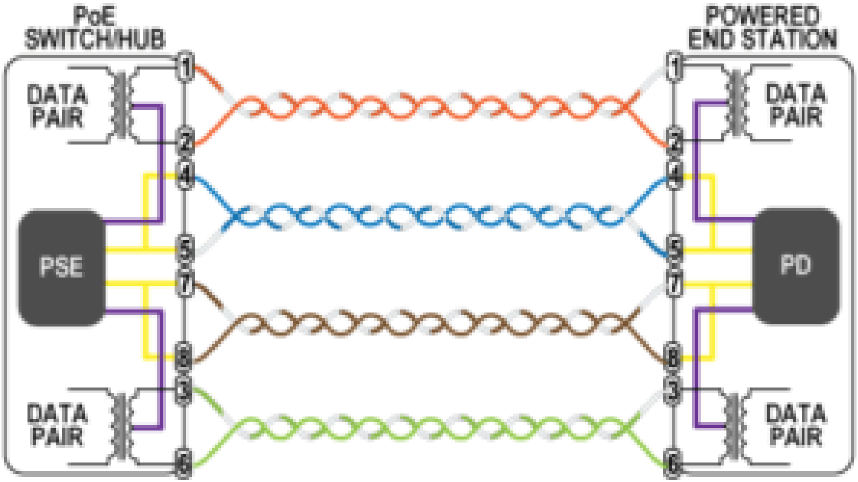
RMII

Signal name	Description	Direction
REF_CLK	Continuous 50 MHz reference clock	MAC to PHY, PHY to MAC, or external
TXD[1:0]	Transmit data bit 0 (transmitted first)	MAC to PHY
TX_EN	When high, clock data on TXD0 and TXD1 to the transmitter	MAC to PHY
RXD[1:0]	Receive data bit 0 (received first)	PHY to MAC
CRS_DV	Carrier Sense (CRS) and RX_Data Valid (RX_DV) multiplexed	PHY to MAC
RX_ER	Receive error (optional on switches)	PHY to MAC

Implementation – Power over Ethernet

Option A
Power is sent together with the data on pairs 1/2 and 3/6 (lila)

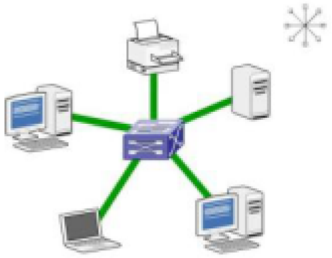
Option B
Power is sent on unused pairs 4/5 and 7/8 (yellow)



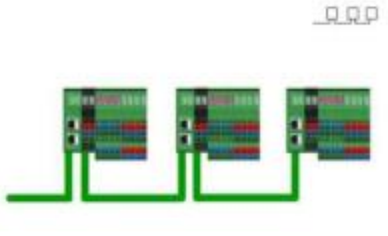
SENSOR NETWORKS - ETHERNET

Bus topologies

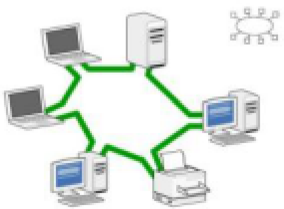
Star



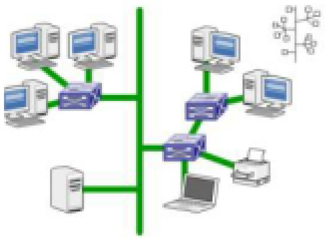
Bus



Ring



Tree



High device density
Short distances

Big distances
Bus access

Redundancy

Complex system's
Integration

SENSOR NETWORKS - ETHERNET

Ethernet Frame

7 octets	Preamble
1 octet	Start Frame Delimiter (SFD)
6 octets	Destination Address (DA)
6 octets	Source Address (SA)
2 octets	Length (≤ 1500) Type (≥ 1536)
46 octets to 1500 octets	Client Data (Payload)
	Pad (if necessary)
4 octets	Frame Check Sequence (FCS)

Preamble – 56 bit alternating 1 and 0. synchronisation, bus activity

SFD – Start of Frame Delimiter (10101011),

DA – Destination Address, 6 Byte

SA – Source Address, 6 Byte

TYPE/LENGTH –

<1500 -> data field’s length

>1536 -> protocol type of the upper layers (pl.: IPv4 = 0800h)

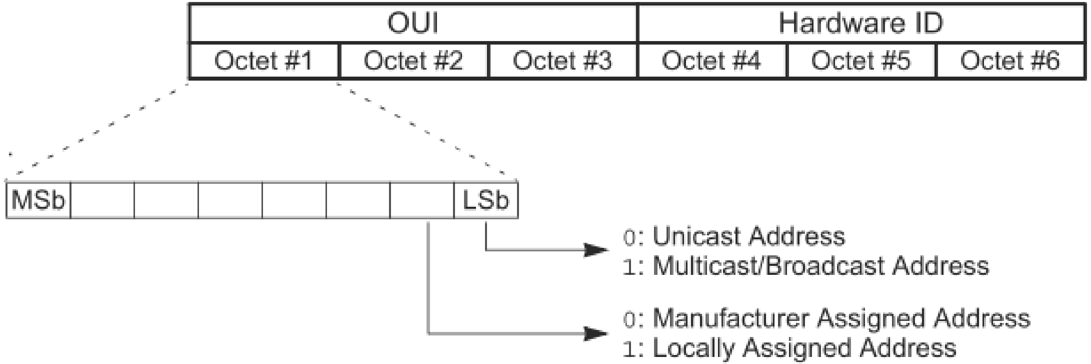
Data – Payload 46 < Data < 1500

Pad – filling bytes if the payload is less than 46 byte

FCS – Frame Check Sequence 32bit CRC

SENSOR NETWORKS - ETHERNET

Ethernet Frame

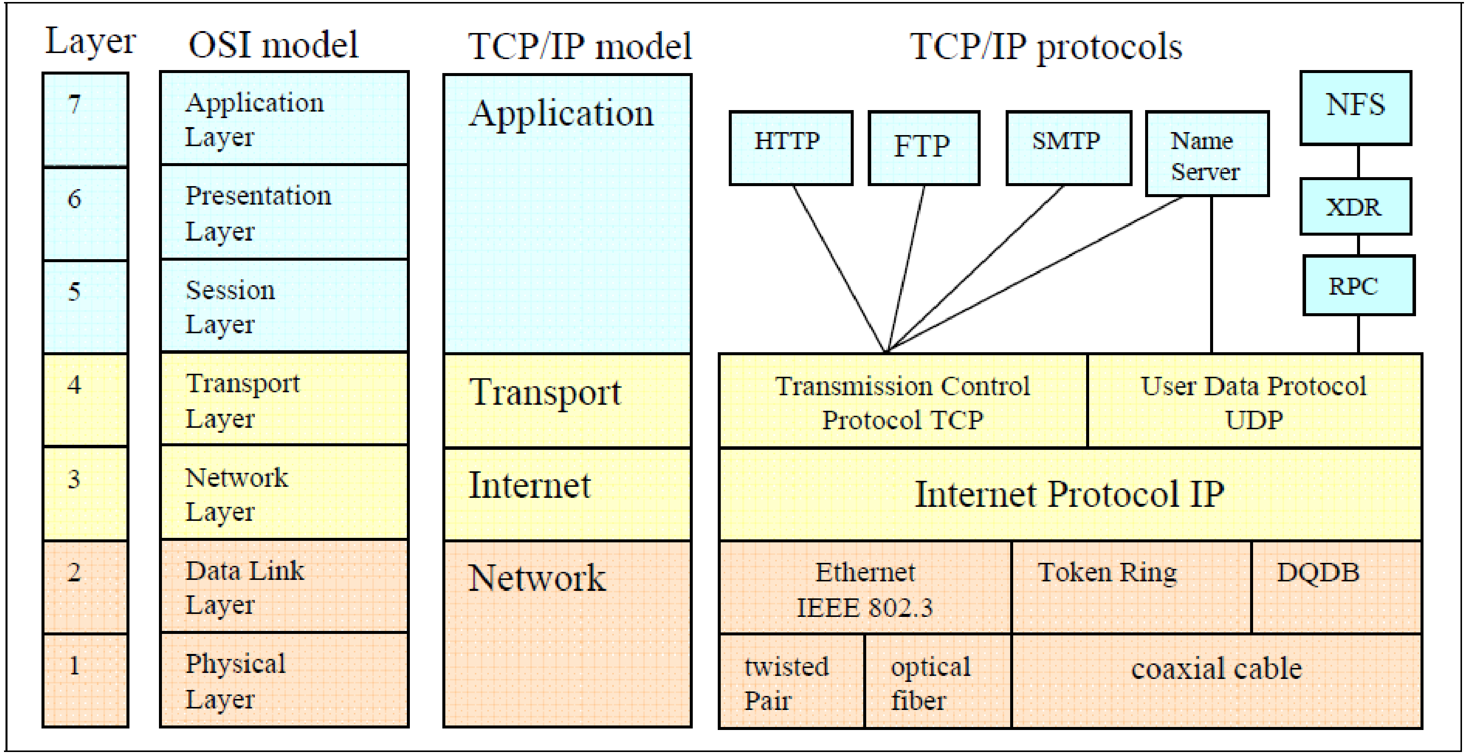


OUI – Organizationally Unique Identifier

Example:
Balluff OUI: 00:19:31

SENSOR NETWORKS - ETHERNET

Protocol stack based on Ethernet



SENSOR NETWORKS - ETHERNET

The TCP/IP model

1. **Network Access Layer**

   Combines the data link and the physical layers

2. **Internet Layer**

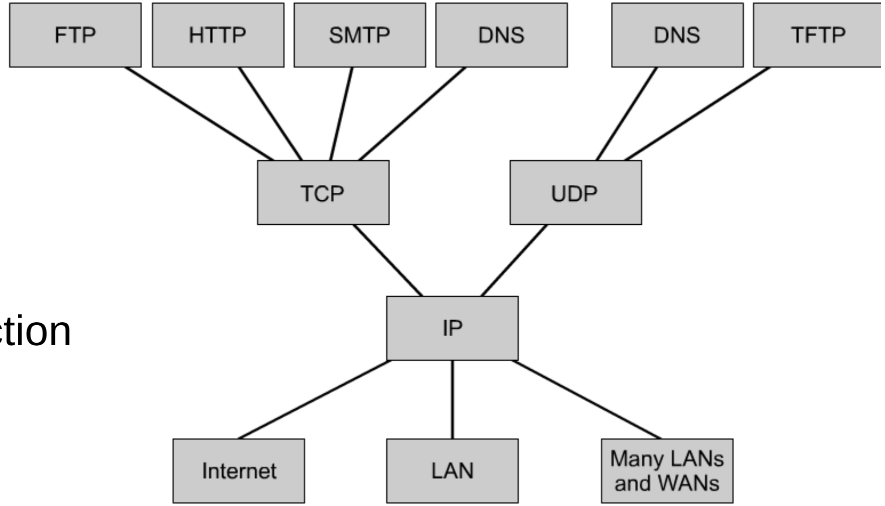
   Sending and receiving packets from and to any (sub)networks.

3. **Transport Layer**

   QoS considerations, flow-control, error correction

4. **Application Layer**

   High level protocoll, data visualisation



SENSOR NETWORKS - ETHERNET

Data packaging

				DATA		application layer

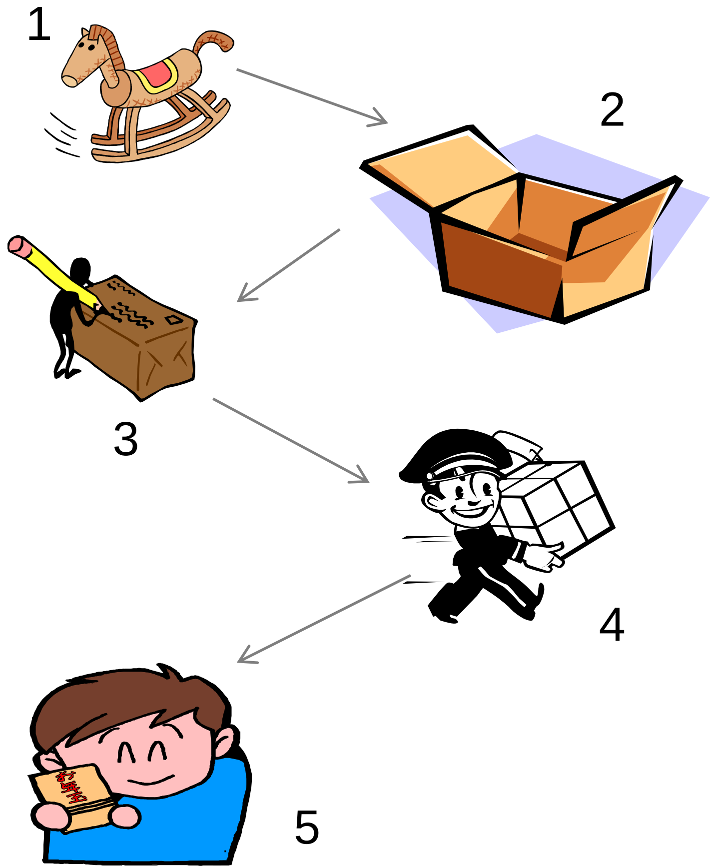
	TCP-Header	*DATA*	
respectively	UDP-Header	*DATA*	transport layer

IP Header	TCP/UDP-Header	*DATA*	network layer

MAC Header	IP Header	TCP/UDP-Header	*DATA*	FCS	data link layer

100Mbit physical layer

Idle Signal	JK SSD	Preamble/SFD 7+1Byte	MAC Header	IP Header	TCP/UDP Header	*Data*	FCS	ESD TR	Idle Signal



SENSOR NETWORKS – INDUSTRIAL ETHERNET

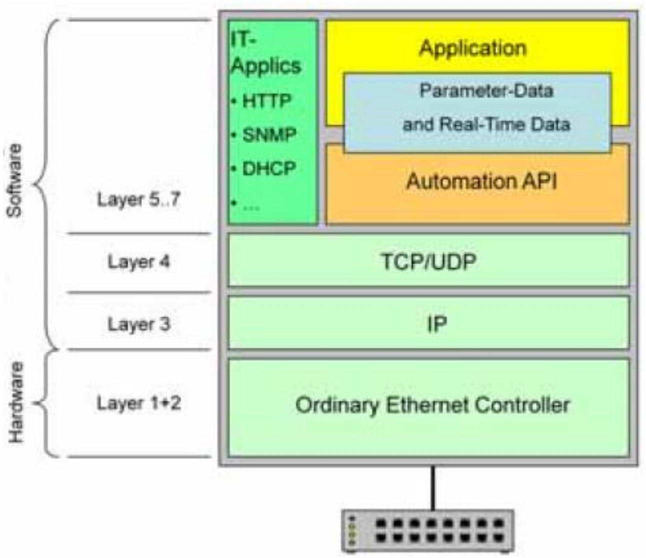
Requirements

- Design tailored to an industrial environment
  - Higher temperature range, interference-resistant cabling, robust connectors
- Redundancy
  - The failure of one participant should not cause the entire network to shut down
- Data security
  - Internet connection, viruses, firewalls
- Compatibility with other Ethernet-based solutions
  - Office networks, industrial bus systems, on the same cable
- Cost effectiveness
- Determinism (Real-Time Capability)
  - Sampling is done with very precise timings in a synchronized manner
- Good diagnostic capabilities
  - Clear separation of process events and device errors

SENSOR NETWORKS – INDUSTRIAL ETHERNET

Implementation of the requirements

1.) Standard Ethernet + Standard TCP/IP

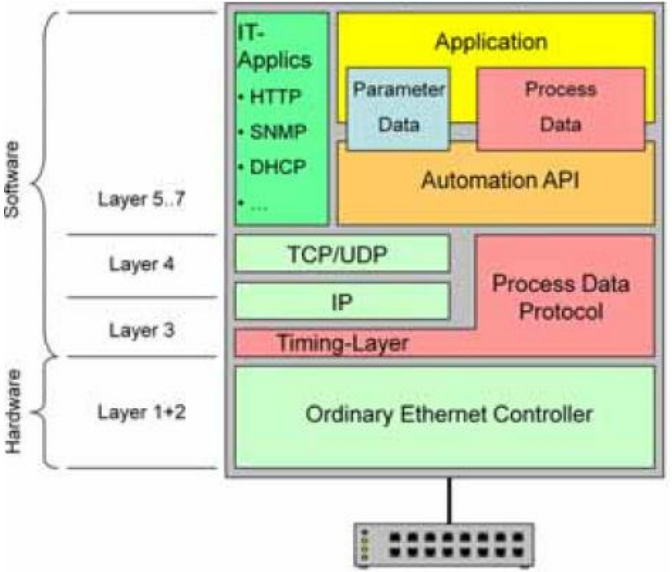


- Real-Time capabilities implemented in higher layers
- The simplest solution, however the real-time capabilities are limited

SENSOR NETWORKS – INDUSTRIAL ETHERNET

Implementation of the requirements

2.) Standard Ethernet + modified TCP/IP

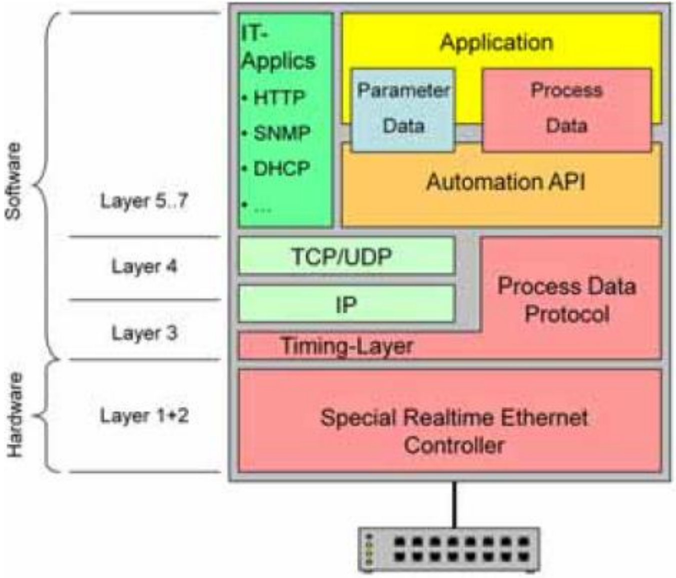


- Unmodified Ethernet „Hardware”
- Implementation of Real-Time capabilities by bypassing TCP/IP layers
- Transfer of standard protocol elements using special timing

SENSOR NETWORKS – INDUSTRIAL ETHERNET

Implementation of the requirements

3.) Modified Ethernet + modified TCP/IP

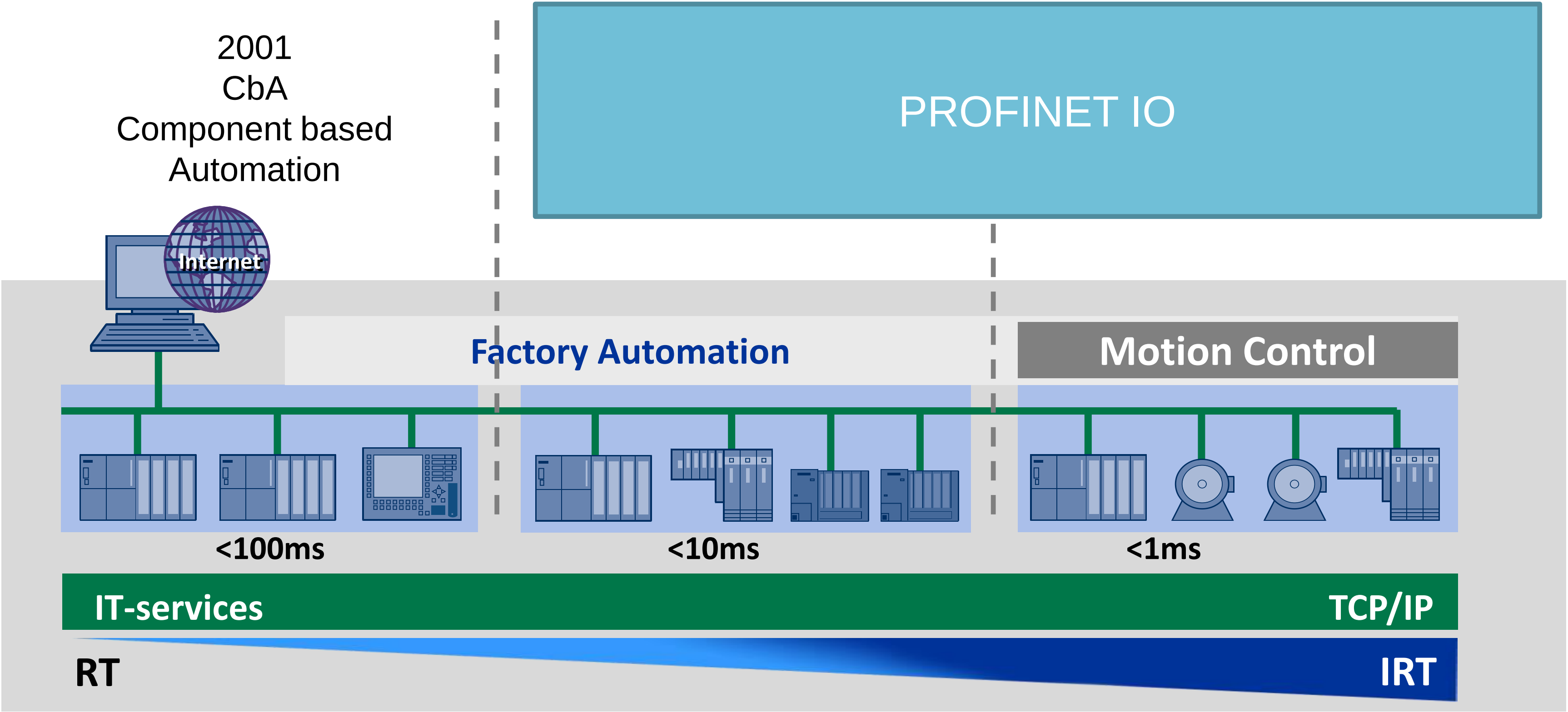


- Modified Ethernet „Hardware”
- Implementation of Real-Time capabilities using special hardware elements
- Transfer of standard protocol elements using special timing

SENSOR NETWORKS – PROFINET

Area of use

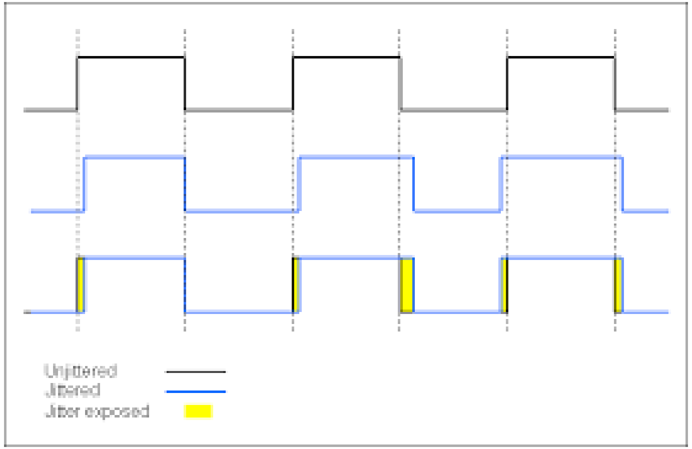
2001
CbA
Component based
Automation



SENSOR NETWORKS – PROFINET

Real-time capabilities

- ***Cycle/Update time***: time elapsed between the switching of an input signal and the switching of the connected output
- Common values:
  - Production automation: 5-10ms
  - Motion control: 1ms, jitter < 1us
- Profinet real-time classes:
  - Real –time (RT)
  - Isochronous Real Time (IRT)



SENSOR NETWORKS – PROFINET

Real-time capabilities

- **Real-Time (RT)**
  - With usage of standard components
  - Performance is slighly better than conventional Fieldbuses (Profibus)
  - Typical area uf use: Factory automation
- ***Isochronous Real-Time (IRT)***
  - Clock synchronous data transfer
  - It requires special hardware components
  - Typical area of use: motion control
- **Non Real-Time data transfer (NRT)**
  - Startup of the communicationa, parametrization
  - Integration of IT functions

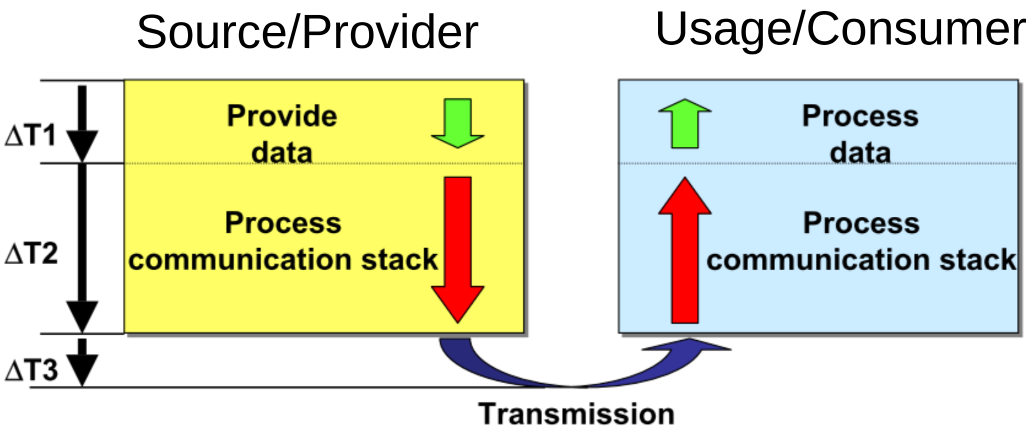
SENSOR NETWORKS – PROFINET

But how we do that?

The origin and usage of data is independent from the communication

Performance improvement can only be achieved by optimizing the signal processing within the communication stack.

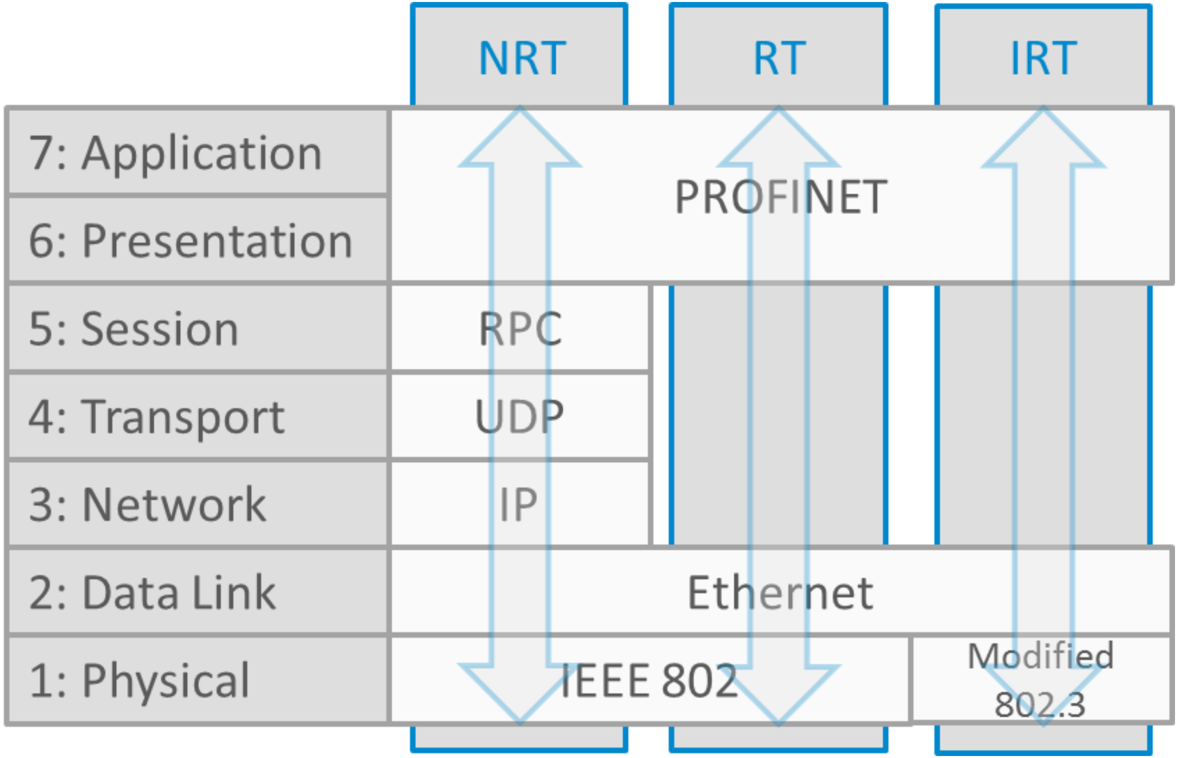
The data transfer time is essentially negligible



Focus: reduction of communication overhead

SENSOR NETWORKS – PROFINET

Layer model



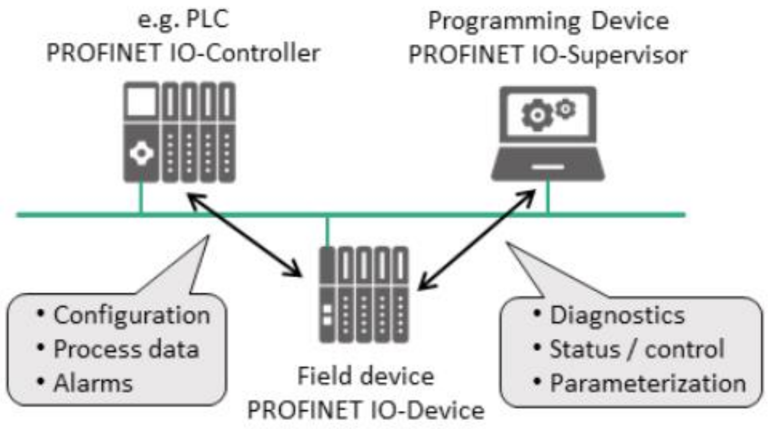
SENSOR NETWORKS – PROFINET

Communication roles

Communication model: Provider / Consumer

Communication components:

- IO-Controller
  - Communication establishment with peripheral devices, sending and receiving data (PLC)
- IO-Supervisor
  - Station for parametrization and diagnosis
- IO-Device
  - A field device, that conducts cyclic data transfer with the IO-Controller

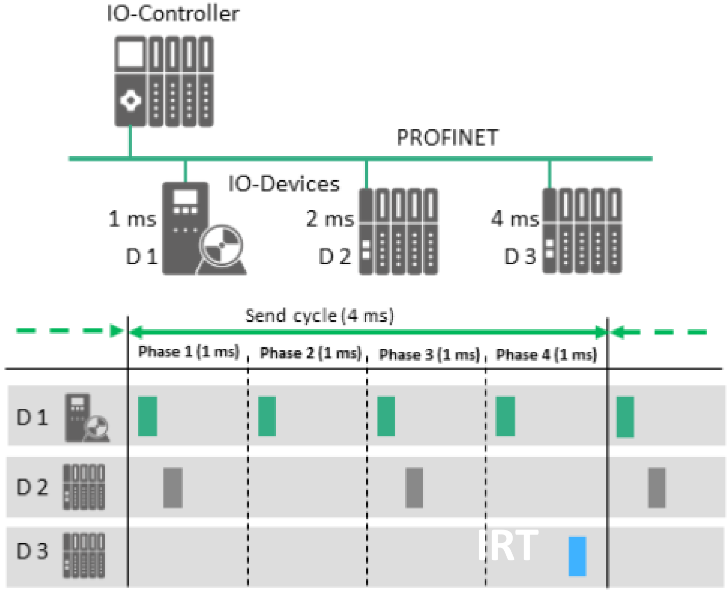


BALLUFF

SENSOR NETWORKS – PROFINET

Data transfer types

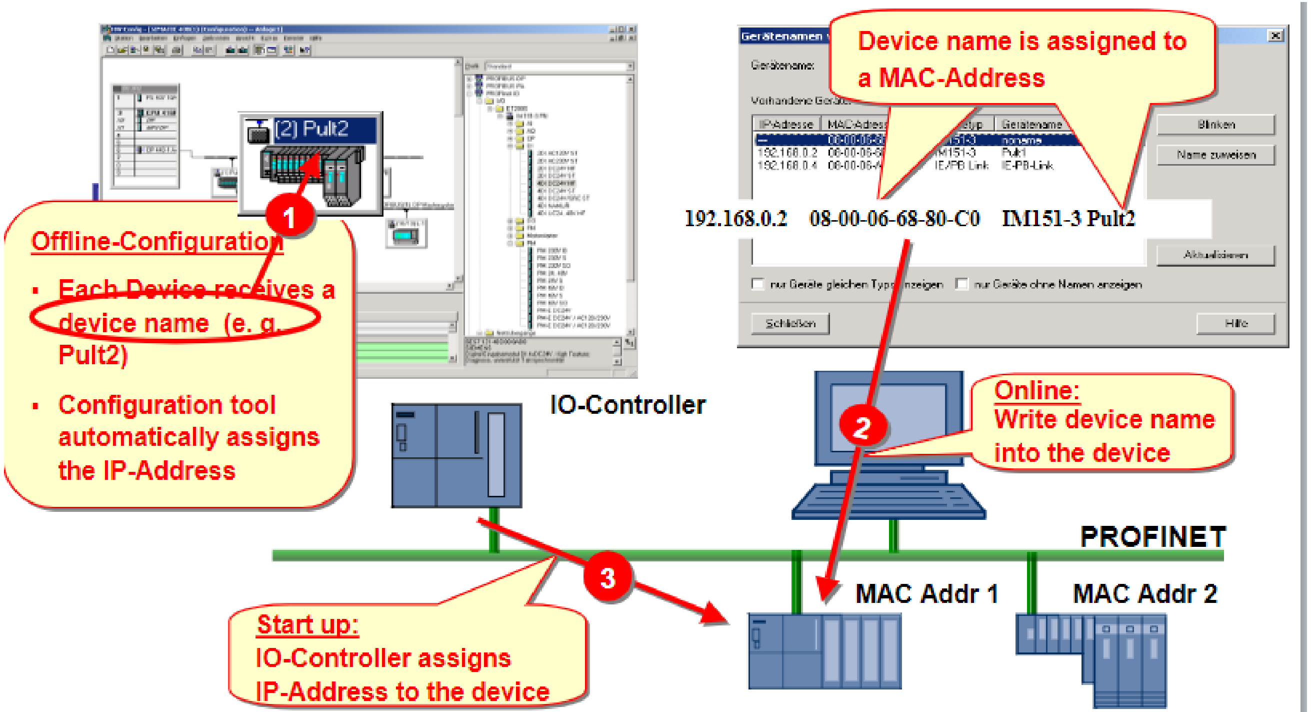
- Cyclic Data Exchange (RT ill. IRT)
  - Exchange of process data between provider and consumer parts
- Acyclic data transfer (NRT)
  - Reading and writing parameters
- Alerts (RT / NRT)
  - Acyclic data transfer for diagnostic information



SENSOR NETWORKS – PROFINET

Profinet addressing:

Name > IP address > MAC address (DCP – Discovery and Configuration Protocol



SENSOR NETWORKS – PROFINET

RT data channel:

- Dedicated Ethertype: 0x8892
- Using VLAN Tags for packet priorization
- Cyclic data transfer
- Data identification with frame-IDa (in the standard defined, and at startup negotiated)

56 Bits	8 Bits	6 Byte	6 Byte	2 byte	2 byte	2 byte	2 byte	40..1440 bytes	2 byte	1 byte	1 byte	4 byte
Preamble	SYNCH	Dest Addr	Src Addr	**Tag**	**Tag Control**	Type 8892H	Frame ID	User data	Cycle Counter	Data Status	Transfer Status	FCS

VLAN Tag

APDU-Status

APDU – Application Protocol Data Unit Status

SENSOR NETWORKS – PROFINET

RT data channel:

Min. is 64 bytes

	Frame					
Preamble mit SFD	Dest Addr	Src Addr	**Type 8892**	**Frame ID**	Application data	CRC
8 byte	6 byte	6 byte	2 byte	2 byte	<= 36*) …1472	4 byte

	Tag (optional)		
Type 8100	**Priority**	0	**VLAN-ID**
2 byte	3-bit	1-bit	12-bit

VLAN-Tag
Acc. to 802.1 Q
(Usage is appl. specific)

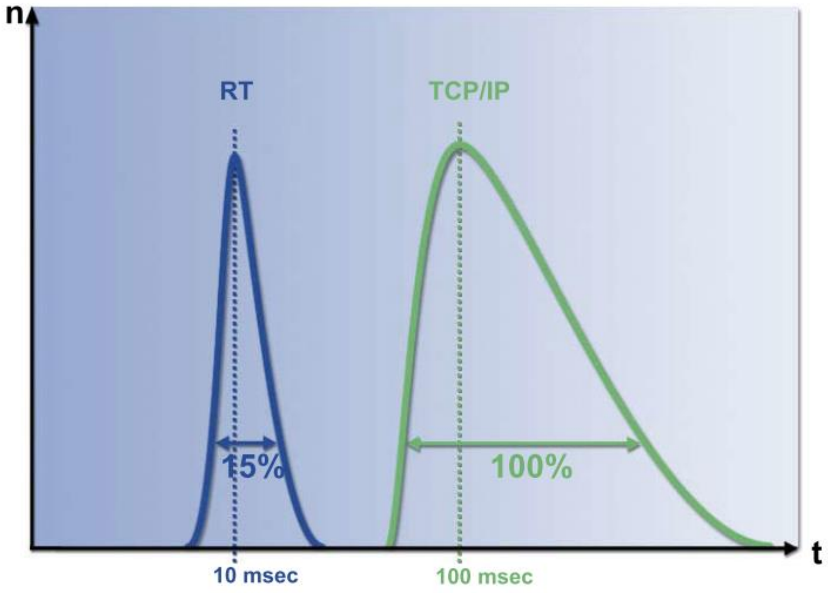
Managed switches can be used for priorization and network optimization

SENSOR NETWORKS – PROFINET

RT data channel:

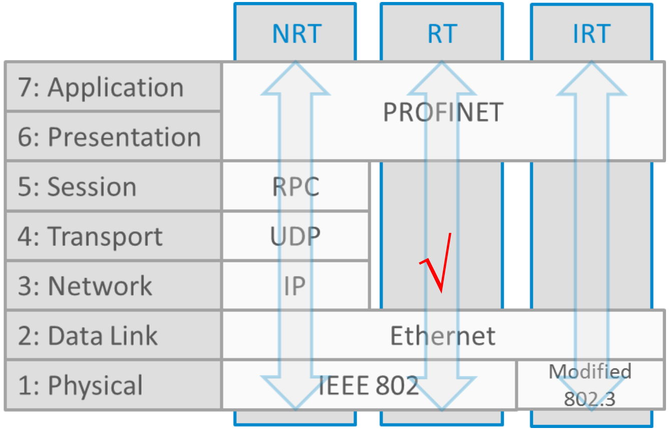
SENSOR NETWORKS – PROFINET

RT data channel:



- **RT improvements against standard TCP/IP**
  - Optimization of the absolute transmission time: factor 6-10
  - Minimization of the variance of the transmission times: factor 5-8
  - Improved behavior at replacement value: factor 7

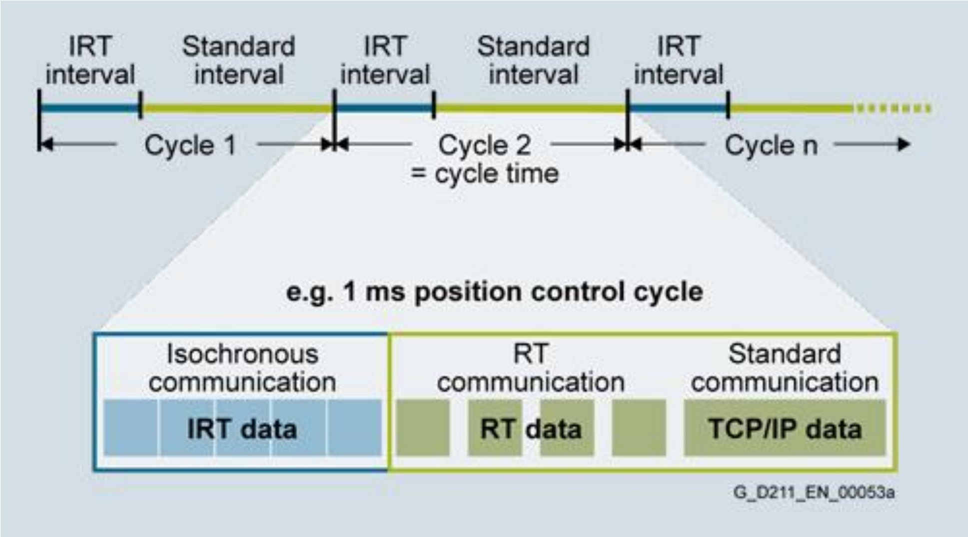
But only within one subnet!!!

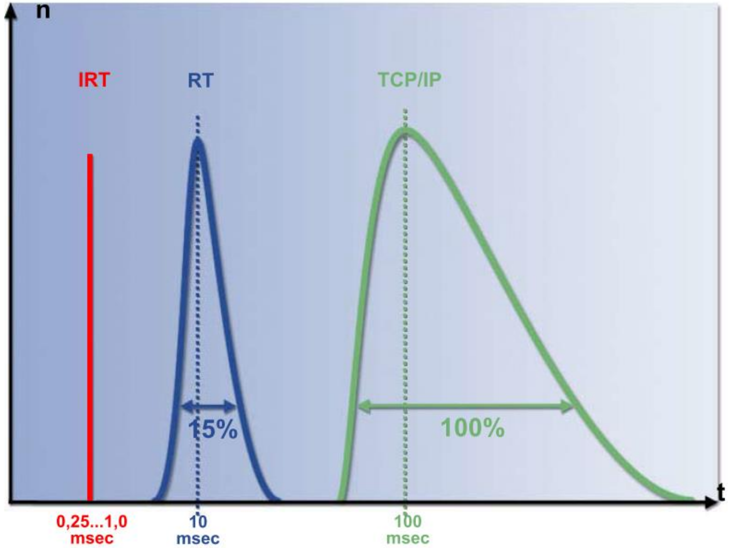


SENSOR NETWORKS – PROFINET

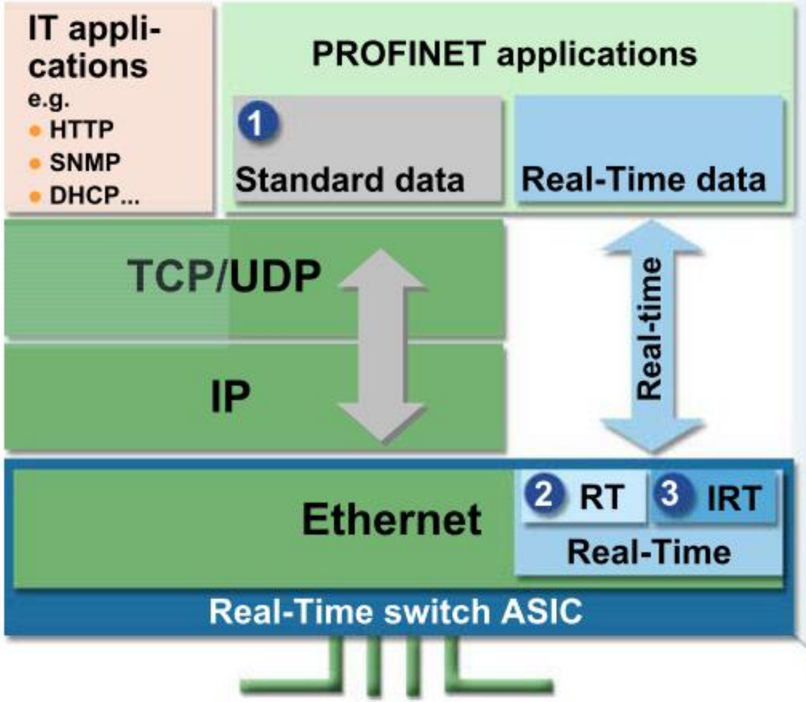
IRT data channel:

- The communication is splitted to segments
- Time based tranfer
- Clock syncronisation according IEEE1588 + Precision Time Protocol
- Special Ethertype, but no VLAN tagging





SENSOR NETWORKS – PROFINET



1 Standard channel

- Device parameterization and configuration
- Reading of diagnostics data
- Negotiation of the communi-cation channel for user data

2 Real-Time channel RT

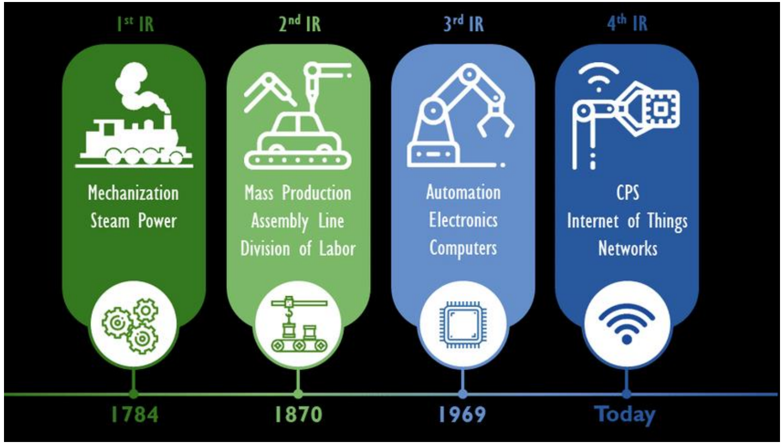
- Performant cyclic transfer of process data
- Event-controlled signals/alarms

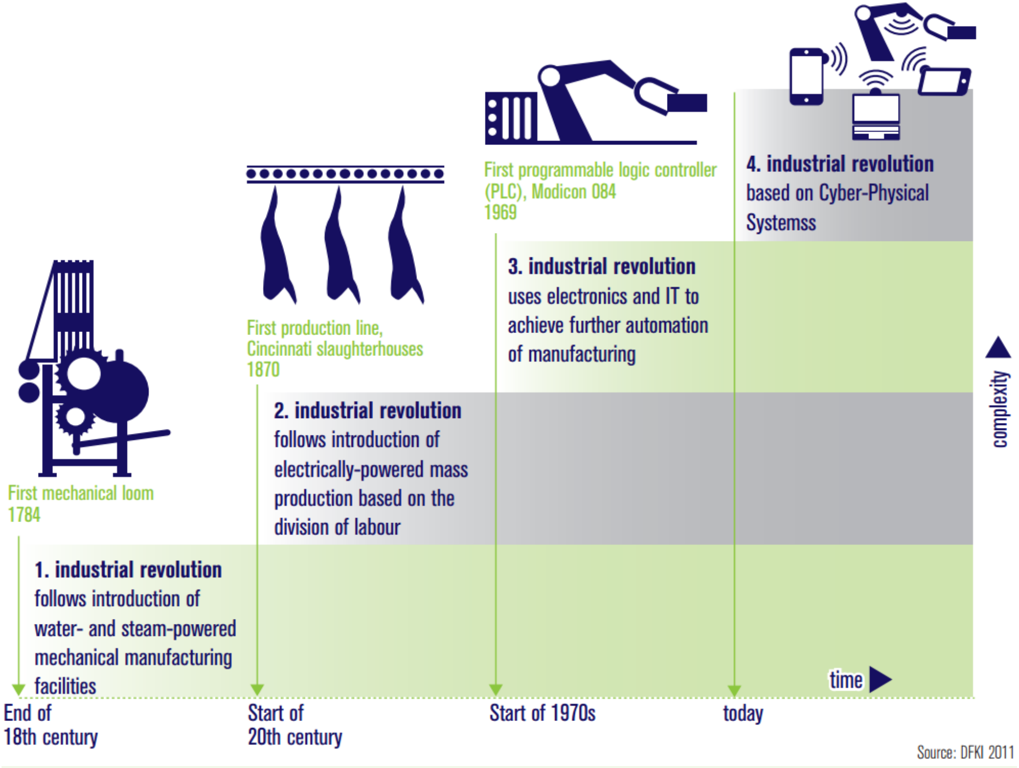
3 Real-Time channel IRT

- Isochronous transmission of process data
- Jitter <1µsec

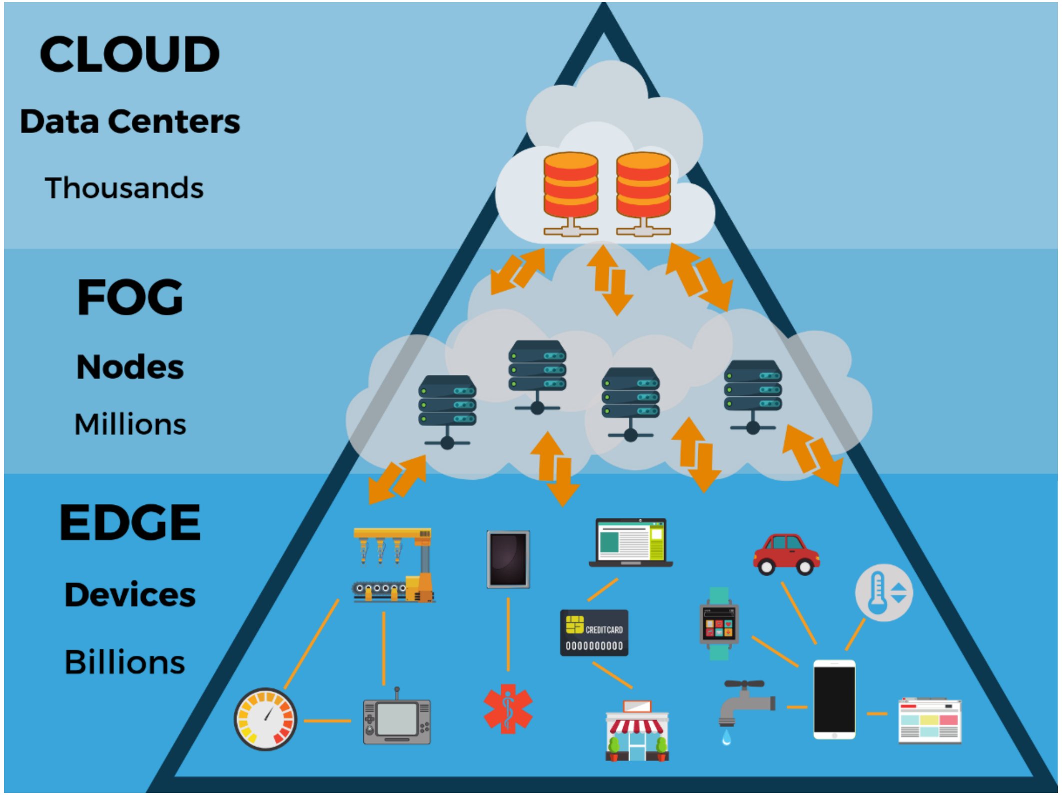
SENSOR NETWORKS – INDUSTRIAL REVOLUTIONS

1. Steam power - 1784
2. Mass production - 1870
3. Automation – 1969
4. Cyber Physics – 202x





SENSOR NETWORKS – LAYERS



Cloud applications:
- Analytics
- Planning
- Optimisation
- Reporting

Local data collection:
- Tracking
- Production statistics
- Predictive maintenance

Smart Devices/Functions:
- Embedded Condition Monitoring
- Logic Functions
- Operation Hours Counter
- Boot Cycle Counters
- BLOB etc.

SENSOR NETWORKS – LAYERS