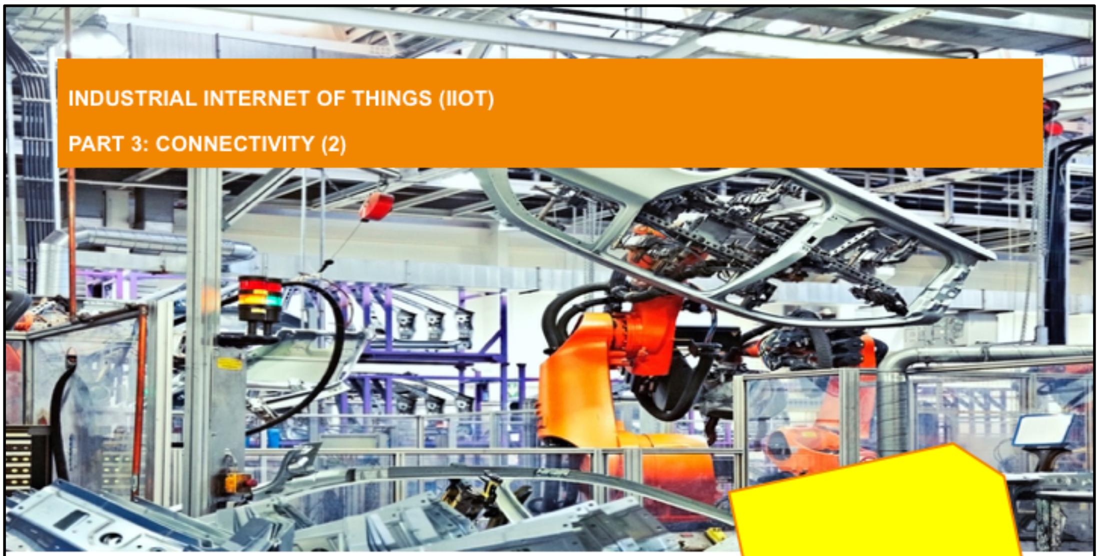


We'll start **at 14:20pm**

AV Lecture in Summer Term 2018

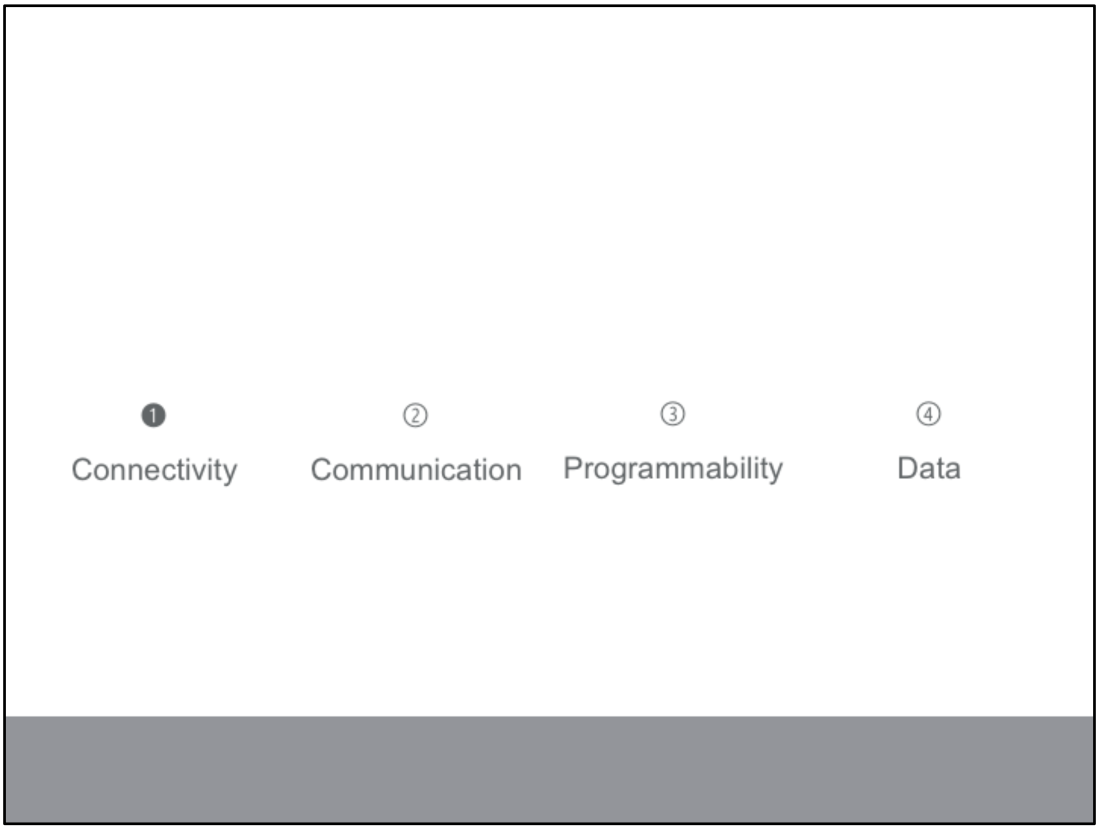
Dr.-Ing. Alexander **Willner**, Oliver Keil, Zahoor Ahmed

Fraunhofer FOKUS

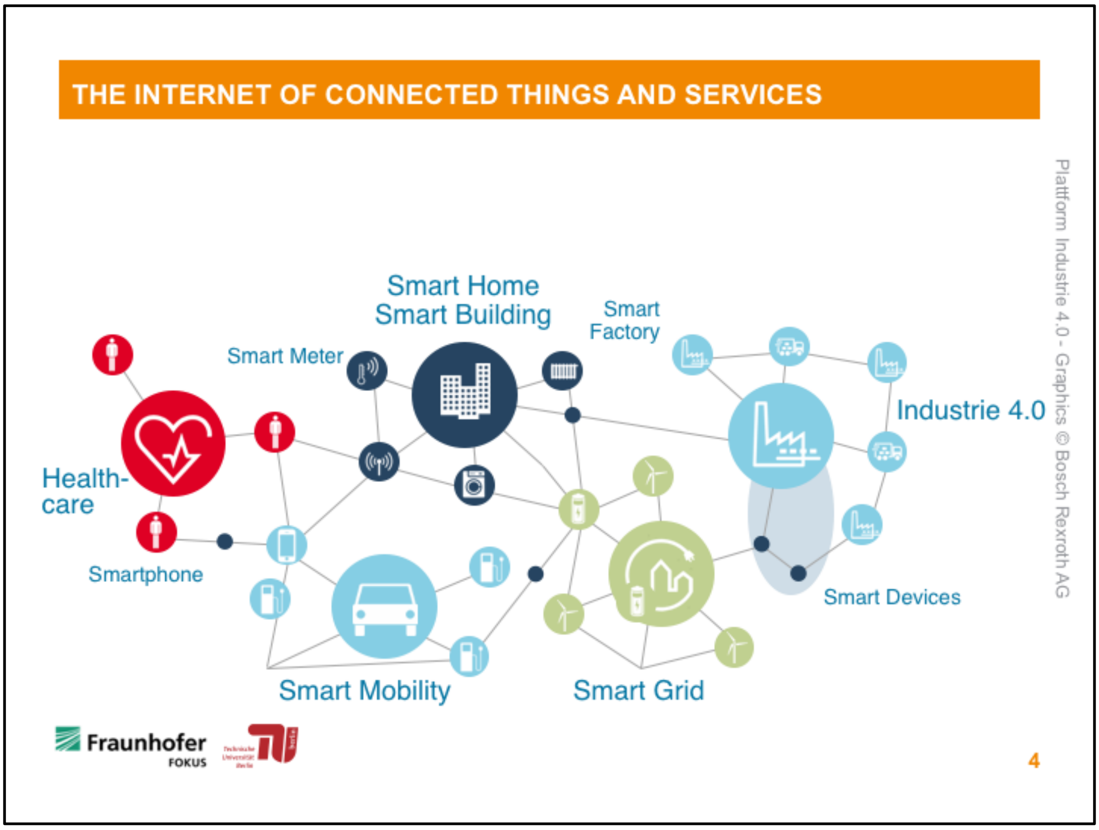
Technische Universität Berlin

THE LAST LECTURE

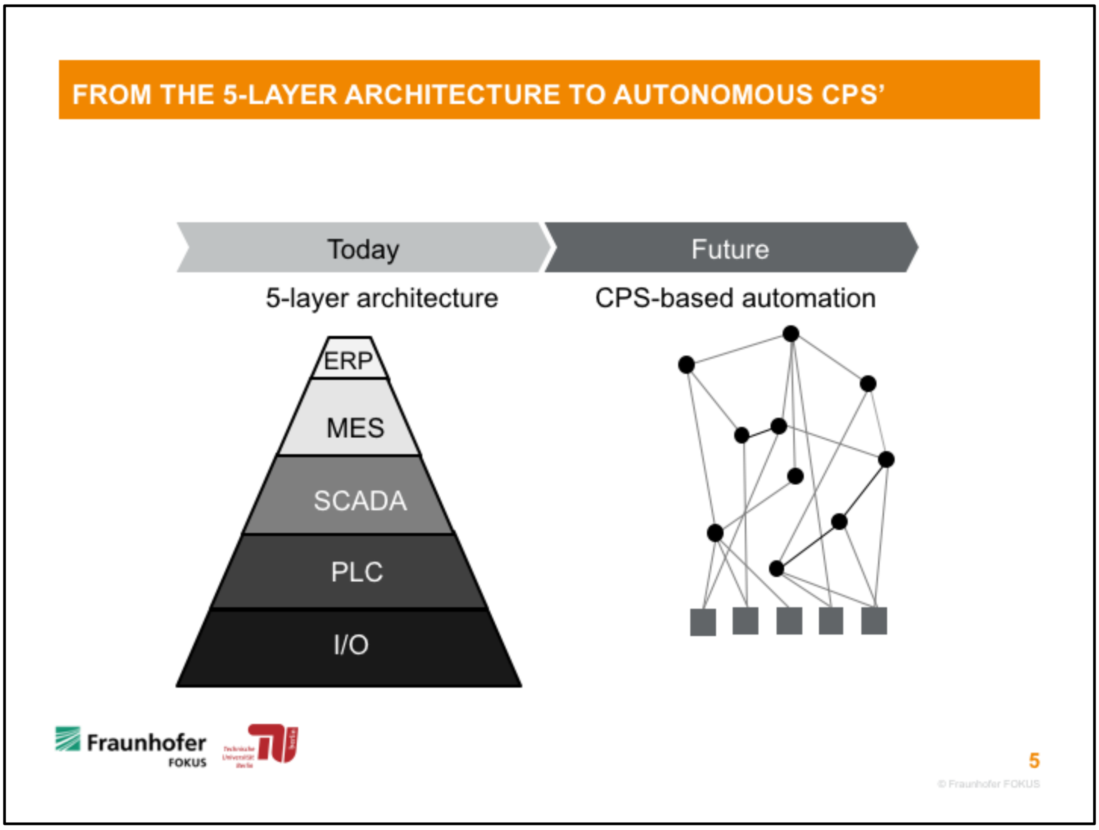
10 Minutes



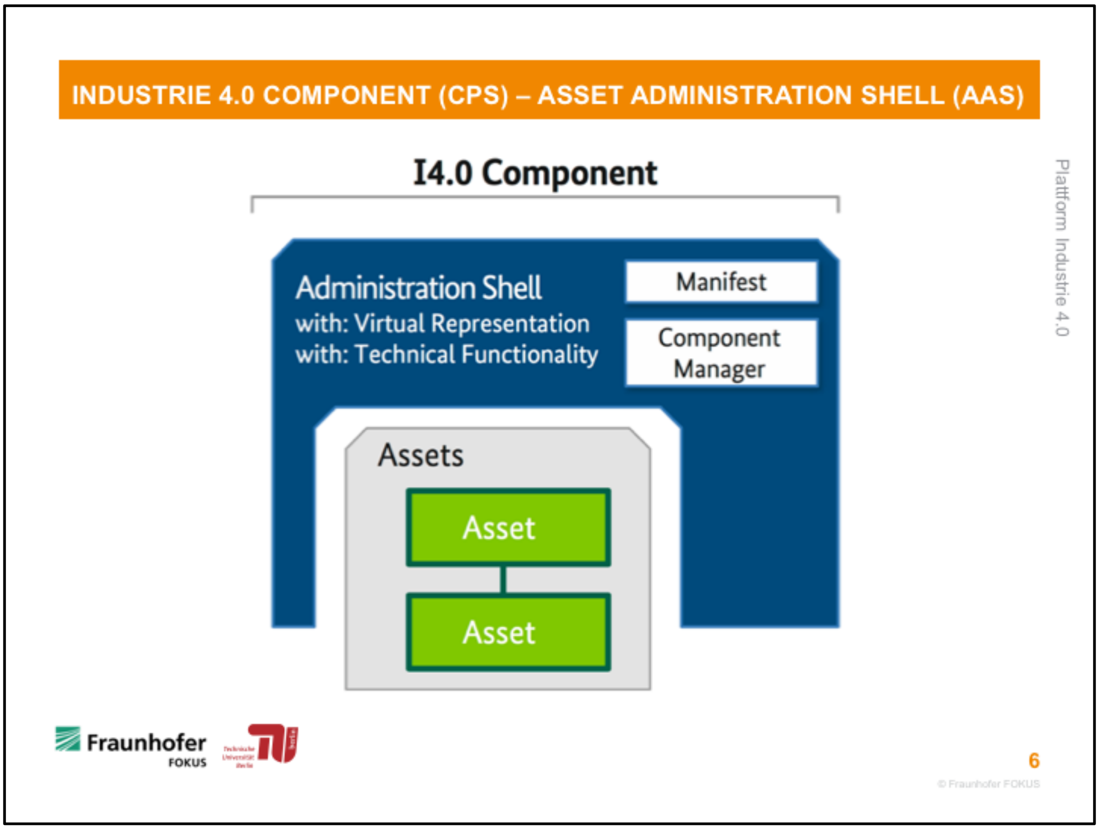
- This lecture is divided into 4 different areas
- Last time and today, we focus on the first one



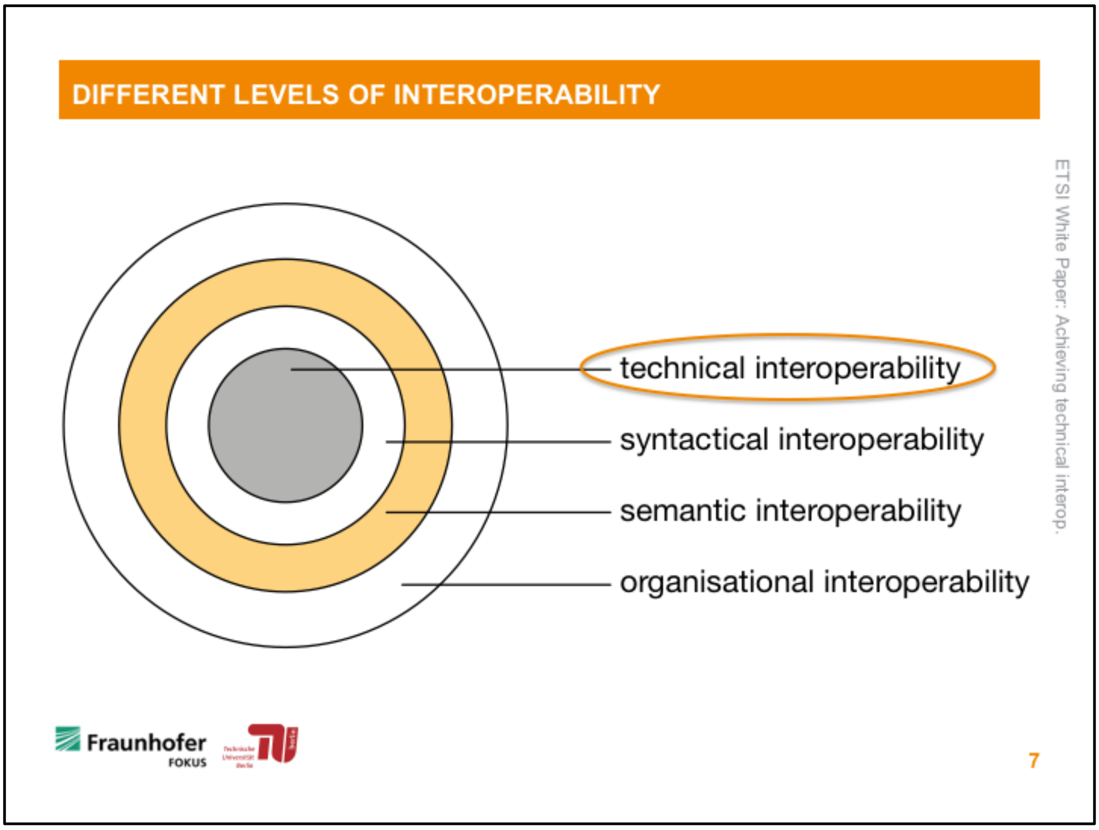
- We’ve talked about the definition of “Industrie 4.0”
- And how different “smart” application domains can be connected with each other to digitize the whole value chain



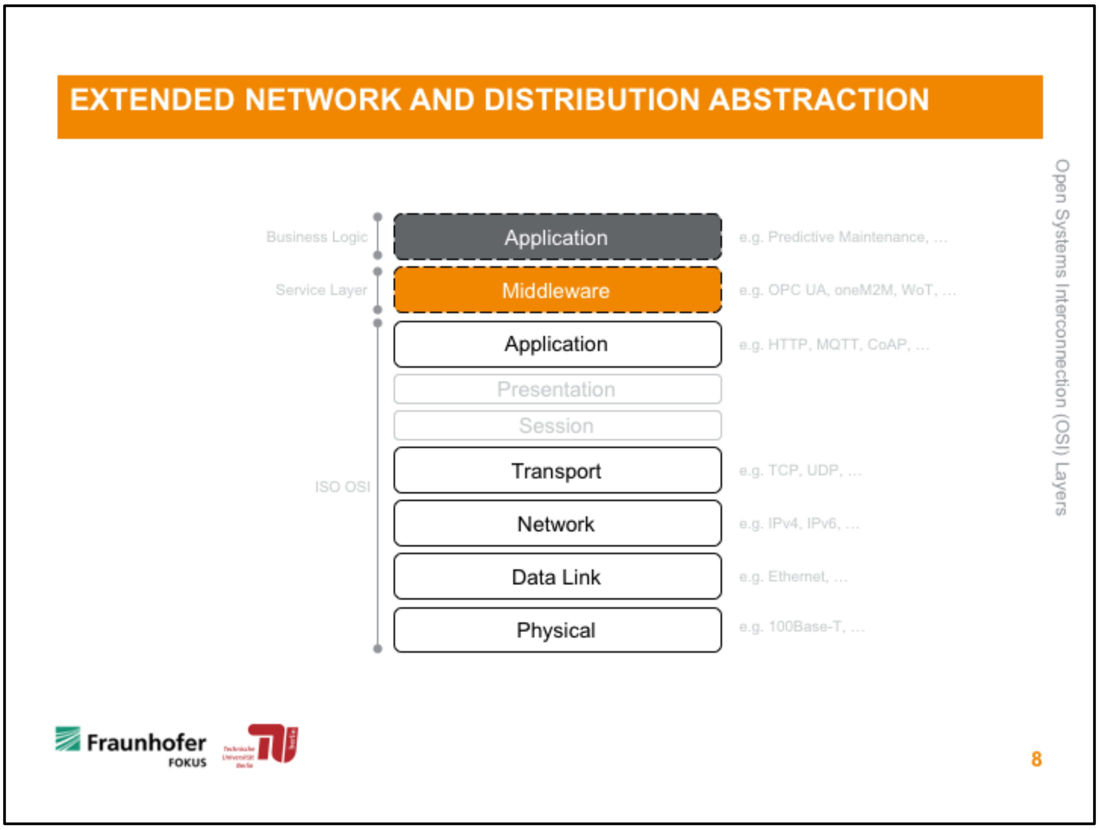
- We learned that the functionalities of the typical automation pyramid might move, step by step, towards CPS-based automation.



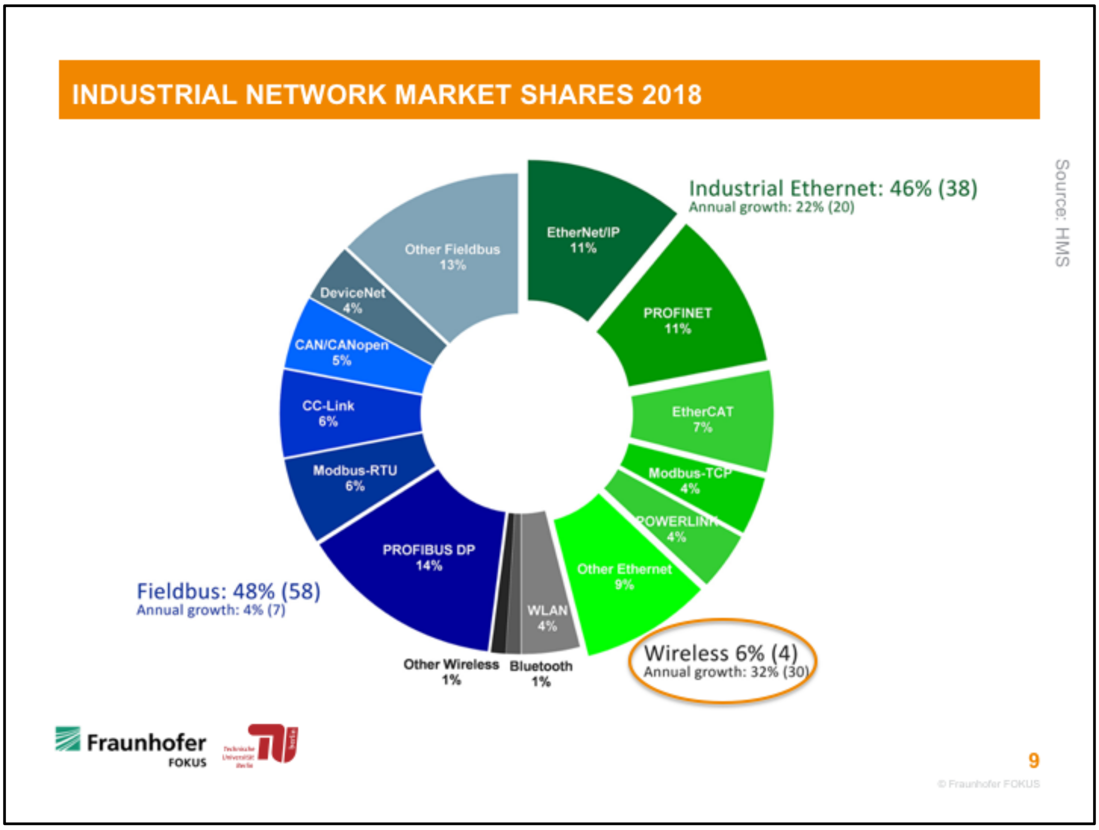
- We learned that one important concept that has been defined by the Platform Industry 4.0 is the so called Asset Administration Shell (AAS).
- Similar to the CPS defined in the IIRA.



- We said that we'll start with technical interoperability



- And that we'll extend, step by step, the ISO OSI stack.
- We're currently focusing on layers 1 + 2



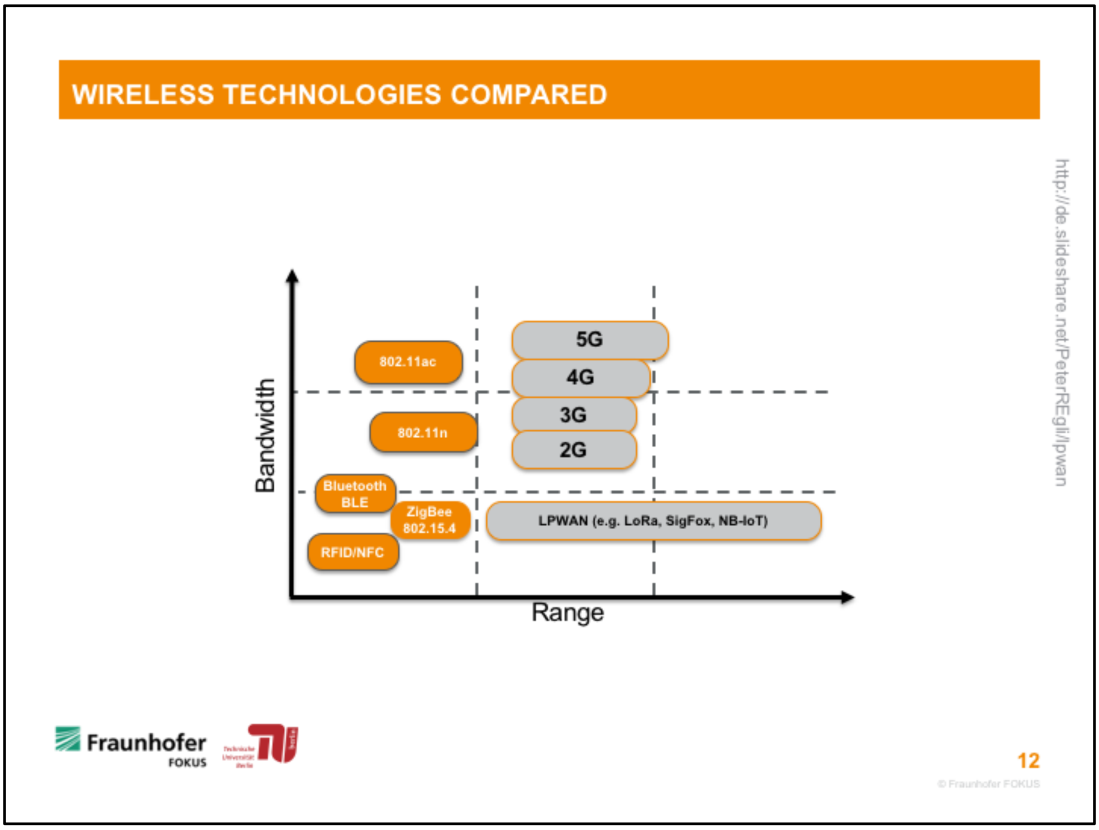
- Due to specific communication requirements, specialized connectivity technologies are being used in the factory.
- We started to talked a little bit about the basics of wireless communication

OVERALL TERMINOLOGY

Questions?

WIRELESS TECHNOLOGIES (2)

35 minutes (incl. many questions)



- Differentiation of technologies based on their range.
- Important difference: licensed vs. unlicensed band

CHARACTERISTICS OF SHORT RANGE ACCESS TECHNOLOGIES

Features	RFID	802.11 ac	Bluetooth	802.11 n	802.15.4 (ZigBee/6LoWPAN)
Security	Low digital signature	256 bits AES encryption	64/128bit AES CCM	256 bits AES encryption	128 bit, AES
Frequency band	LF: 120-150 KHz HF: 13.56 MHz UHF:433/865-928MHz Microwave: 2.45 GHz	5GHz	2.4GHz	2.4GHz; 5Ghz	868MHz; 2.4GHz
Mobility	fixed	nomadic subnet roaming	fixed	nomadic subnet roaming	Yes
Range	1m to 30m (frequency-depended)	<50m	<80 meters	<100 meters	<100 meters
Power Consumption	Very low to none	High	Medium Low (LE)	High	Low
Battery life	-	Hours	Days Years (LE)	Hours	Years
Max data rate	424 Kbit/s	6.93 Gbit/s	3 Mbit/s 1 Mbit/s (LE)	600 Mbit/s	250Kbit/s

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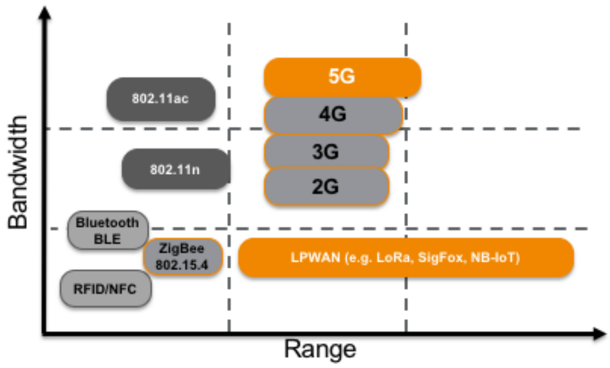
- Using usually the ISM band
- Range usually < 100m
- Most technologies are used in consumer equipment
- RFID: example are credit cards
- Wide range of data rates

WIRELESS TECHNOLOGIES COMPARED



http://de.slideshare.net/PeterREgli/lpwan

- Differentiation of technologies based on their range.
- Important difference: licensed vs. unlicensed band

CHARACTERISTICS OF LONG DISTANCE ACCESS TECHNOLOGIES

Features	LoRa	LTE-M	NB-IoT	Nwave	SigFox	Neul
Frequency band	868 MHz (EU) 915 MHz (US) 433 MHz (Asia)	Cellular	Cellular	800 MHz – 1GHz (ISM)	868MHz 902MHz	800 MHz – 1GHz (ISM or whitespace)
Technology	Narrow Band Chirp Spread Spectrum	Licensed LTE bands in-band	Licensed LTE in-band guard-band stand-alone	UNB	Ultra Narrow Band and Binary Phase-Shift keying	Direct Sequence Spreading over TV Whitespace
Standard	LoRa Alliance	3GPP	3GPP	Weightless SIG	Proprietary protocol	Weightless, planned in 3GPP
Range	<5km urban <15km subruban <45km rural	<11km	<35km	<5km urban areas <30km rural	<10km urban <50km rural	<10km
Data rate	<50kb/s in EU <100kb/s in US	<1Mb/s	<144kb/s	100 b/s	<100 b/s	<100kb/s

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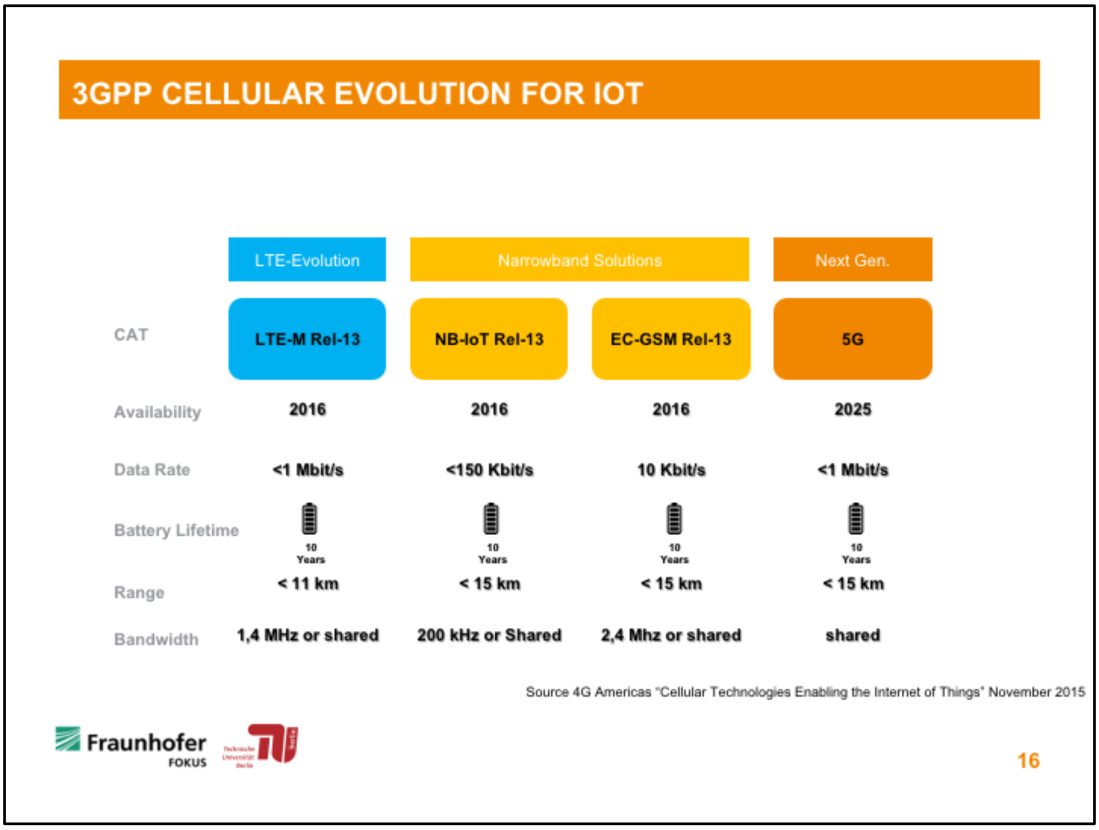
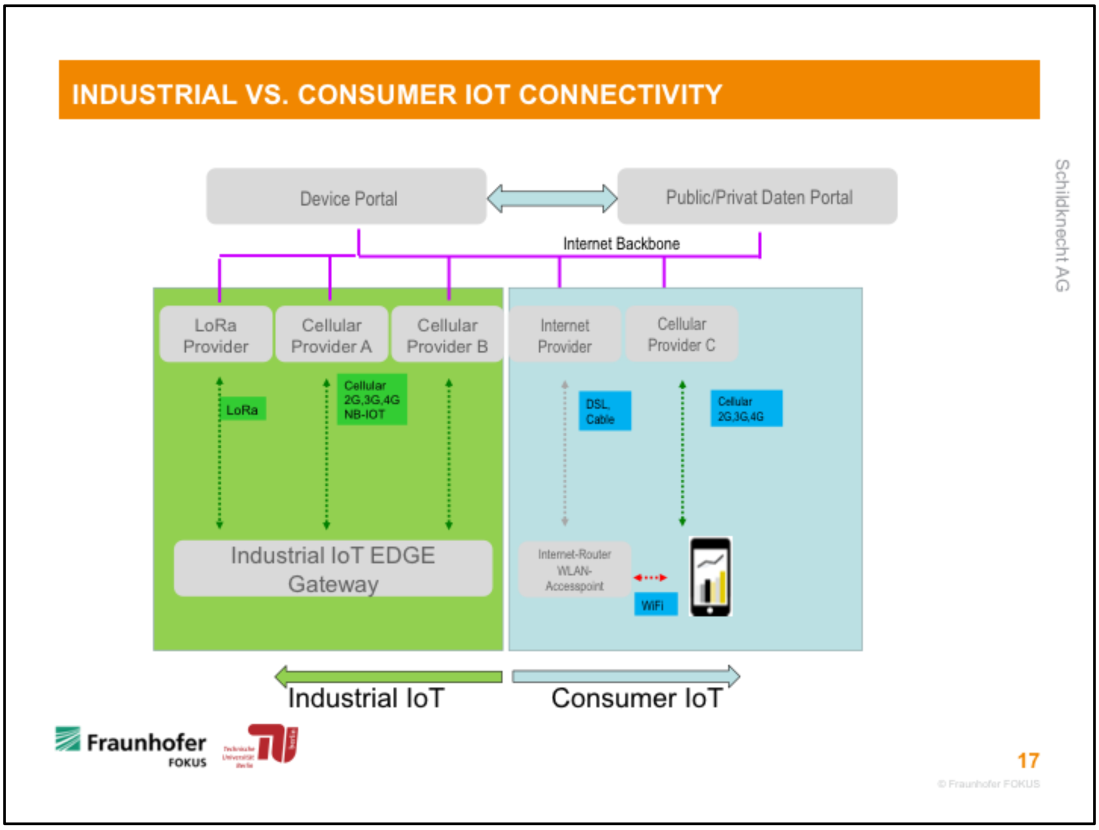
- Most promising candidate in the ISM band: LoRa (open specification)
- Most promising candidate in the licensed band: NB-IoT
- LTE-M: compatible with existing LTE network (NB-IoT is not) – we've an initial network here in Berlin
- Sigfox: other business model (cheap hardware, operators to pay royalties)



	LTE-Evolution	Narrowband Solutions		Next Gen.
CAT	LTE-M Rel-13	NB-IoT Rel-13	EC-GSM Rel-13	5G
Availability	2016	2016	2016	2025
Data Rate	<1 Mbit/s	<150 Kbit/s	10 Kbit/s	<1 Mbit/s
Battery Lifetime	10 Years	10 Years	10 Years	10 Years
Range	< 11 km	< 15 km	< 15 km	< 15 km
Bandwidth	1,4 MHz or shared	200 kHz or Shared	2,4 Mhz or shared	shared

Source 4G Americas "Cellular Technologies Enabling the Internet of Things" November 2015

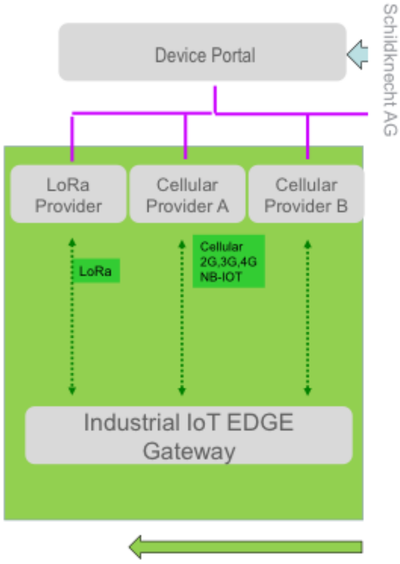
- EC-GSM: Extended Coverage Global System for Mobile communication. IoT-optimized GSM network. GSM used by 80% of phones globally.
- Battery life and bandwidth most important metrics



- Some devices might not have all required networking technologies
- Gateways in order to:
    - enable various industrial devices to communicate over long distances
    - harmonize different connectivity technologies
    - preprocess data
    - …

INDUSTRIAL IOT GATEWAY

- I/O: sensors, fieldbus interfaces, industrial ethernet, ...
- Local wirless connectivity: BLE, Wi-Fi, ...
- Form factor: IP67, DIN rail
- Power: potentially optimized for low energy consumption
- Wide area connectivity: LoRa, 2G, 3G, 4G, ...
- Identity & mobility: eSIM, roaming,
- Communication: OPC UA, REST, MQTT, ...
- Programmability: device management, updates, local analytics & actuation, ...
- Bandwidth reduction: compression, aggregation, ...
- ...



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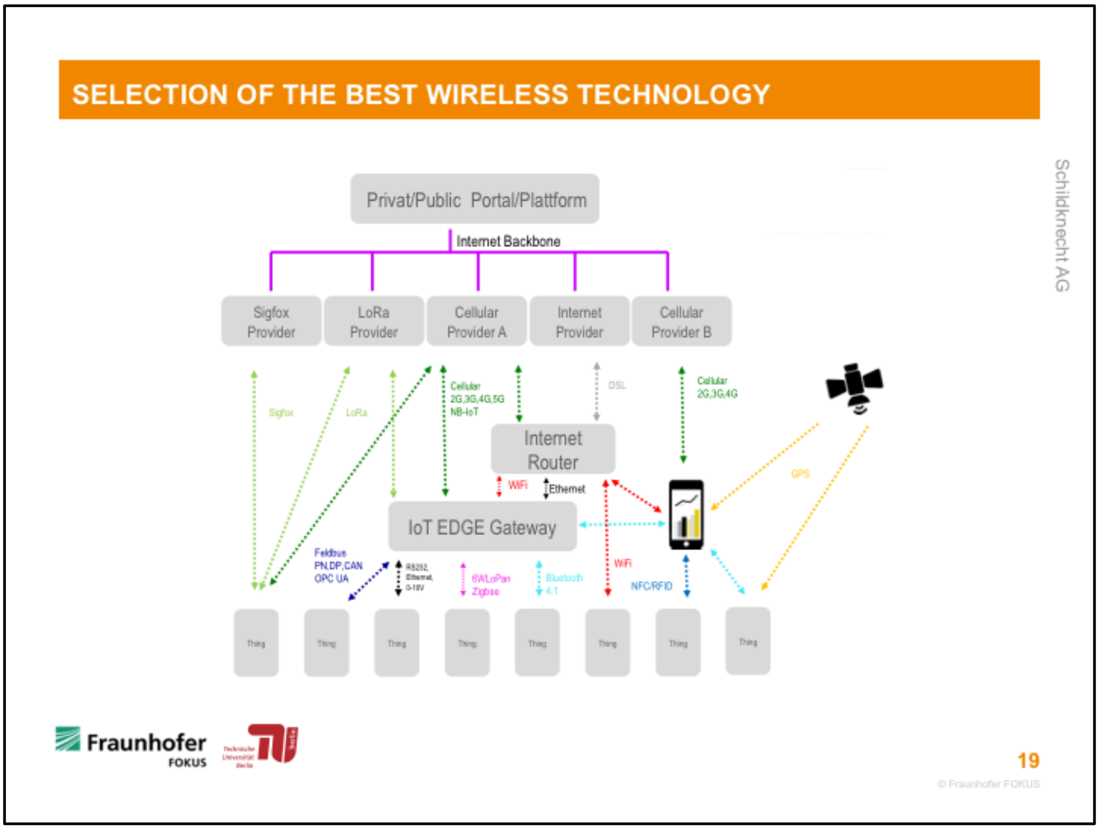
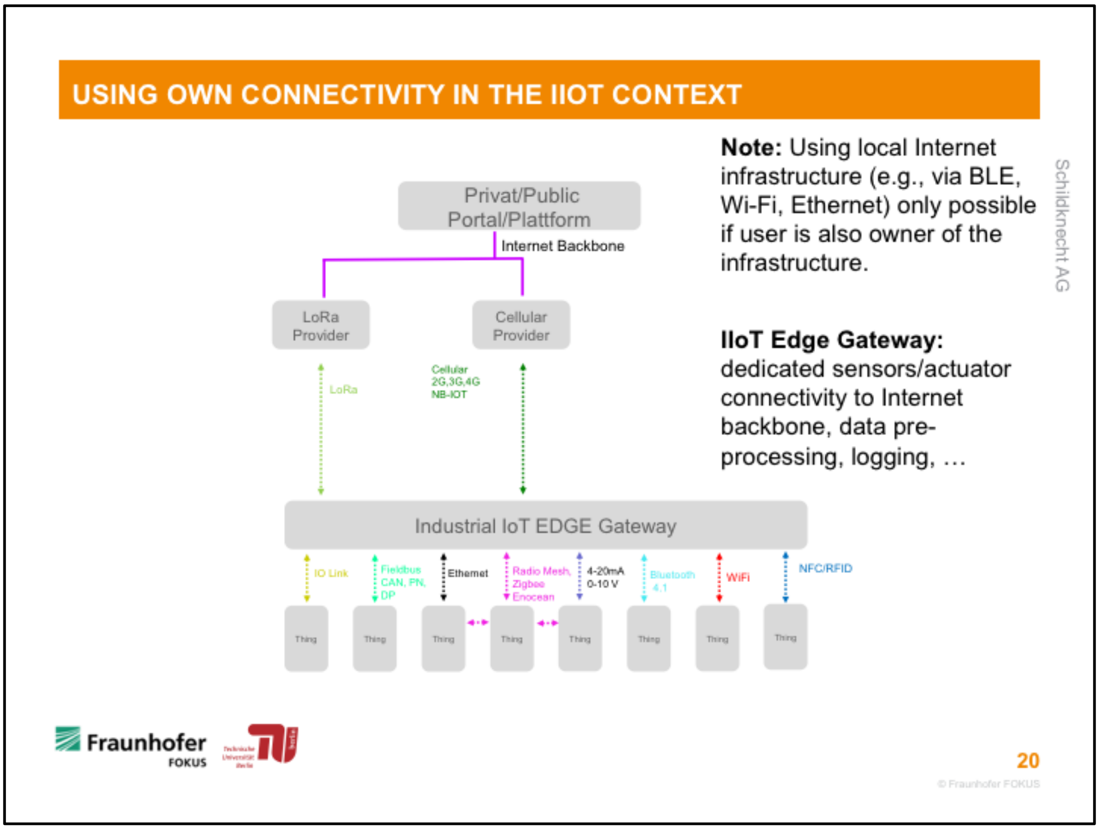
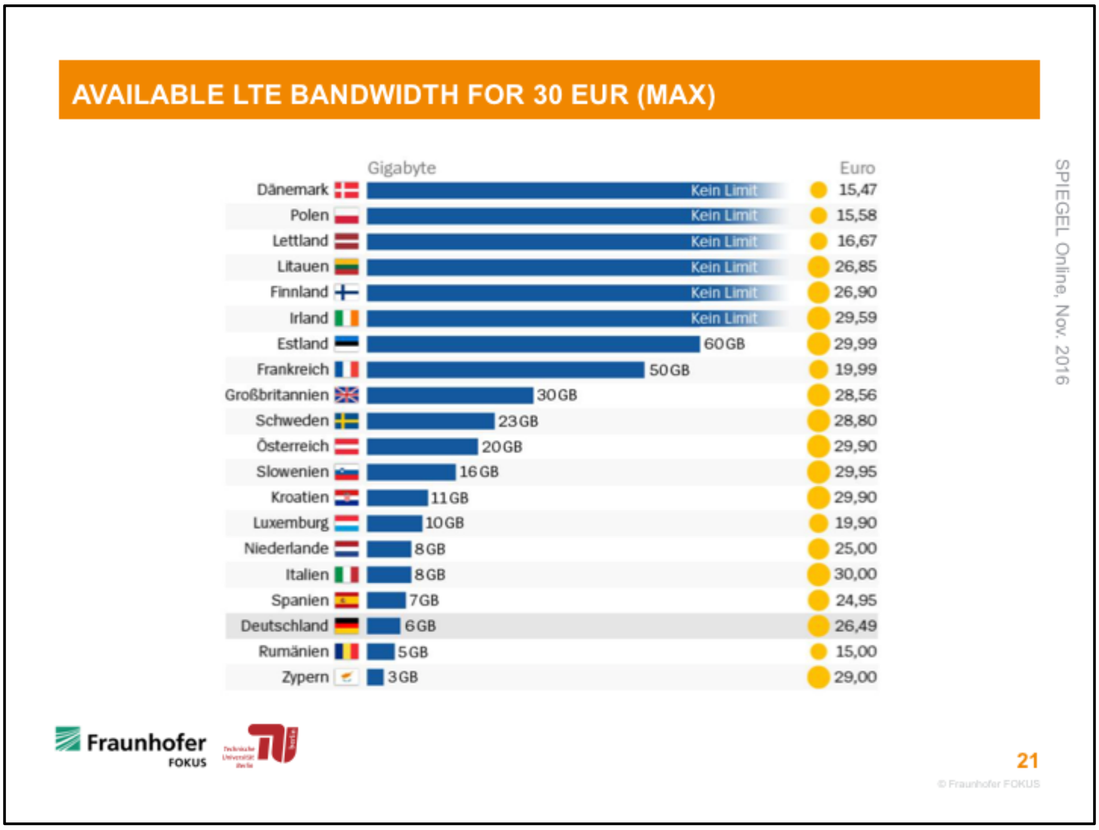
- Various requirements needed to be met by industrial gateways



- Extended example for multiple devices with gateways/routers.
- Note that „OPC UA“ in the lower left corner is technically not a connectivity technology.
- Depending on the metric one or the other technology has to be chosen (business model, energy demand, bandwith demand, interoperability, …)



- Extended example with a singe gateway



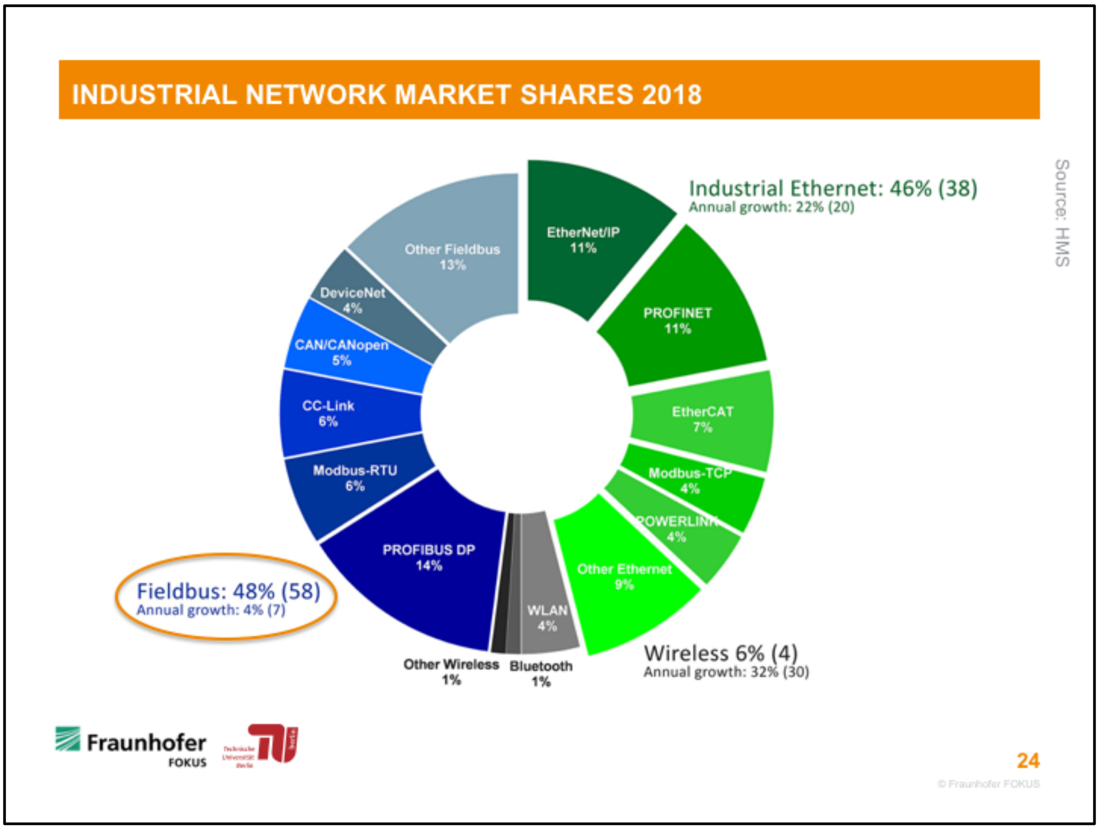
- Challenge in Germany: expensive bandwidth
- One reason: auction of licensed bands
- Auction of 5G bands: first quarter 2019
    - Lower Frequency Band: 3.4 - 3.8 GHz
    - Higher Frequency Band: 26.5 - 27.5 GHz

WIRELESS TECHNOLOGIES

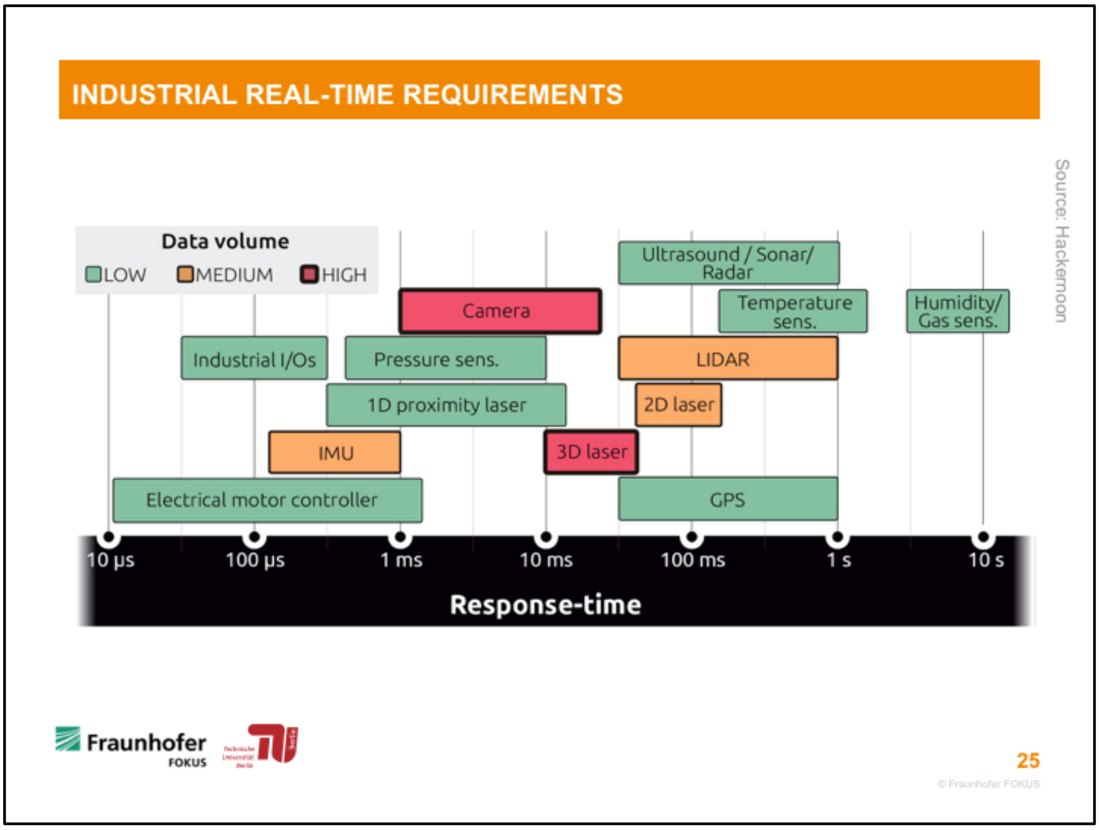
Questions?

FIELDBUS TECHNOLOGIES

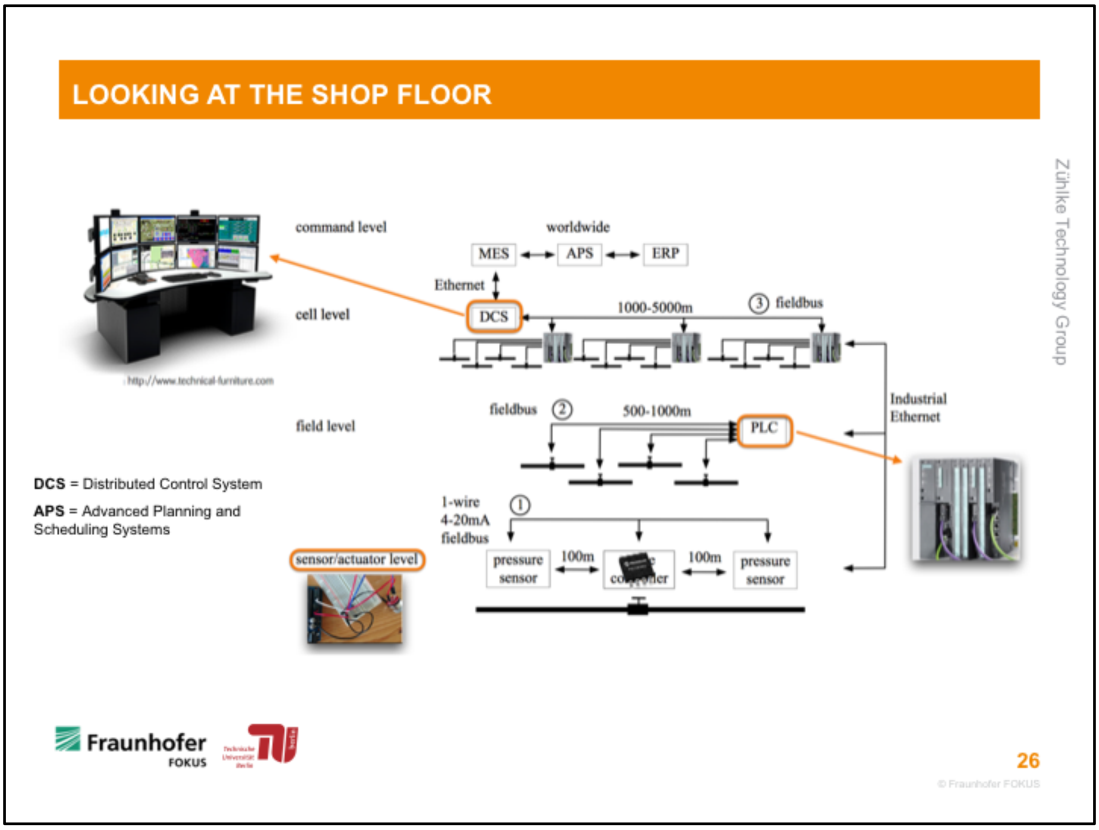
15 minutes



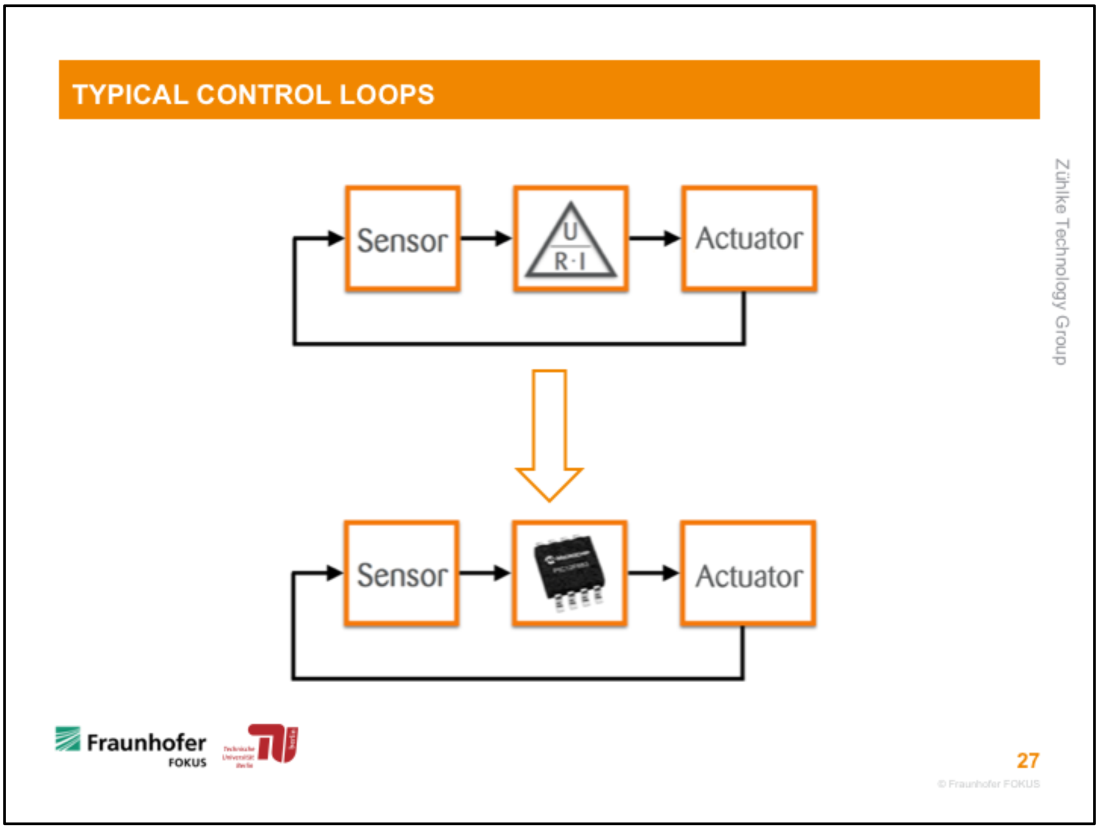
- „To know your future you must know your past“
- Let us focus a little bit about former fieldbus technologies



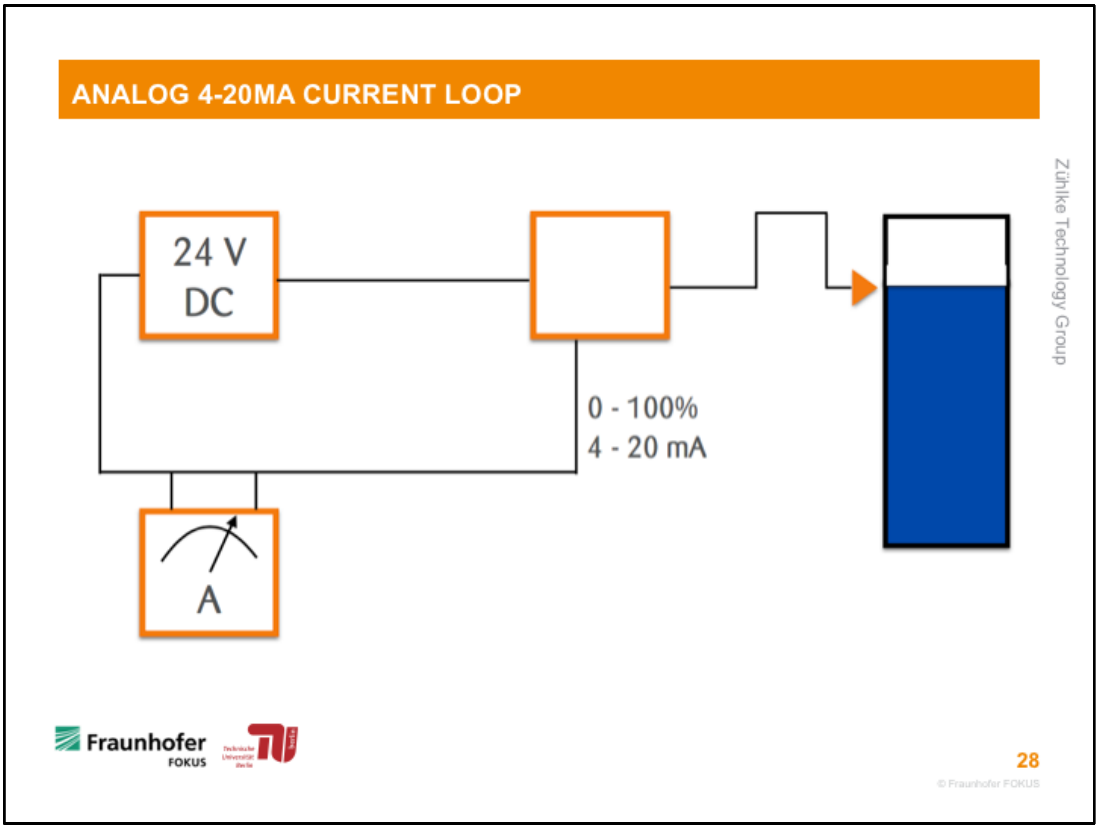
- Remember: within industrial domains, the requirements are different to typical ICT (consumer) domains.
- Hard real-time response times, very low latency, high bandwidth, … depending on the use case.



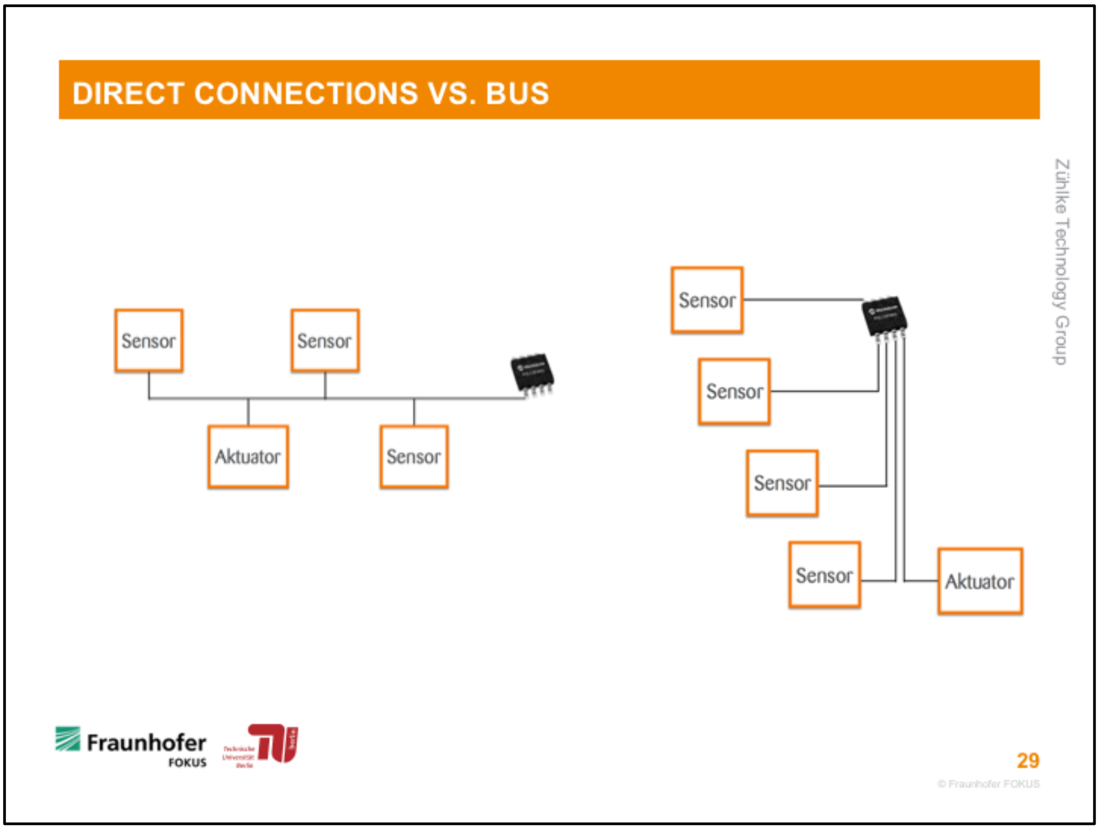
- A rough overview of the so called „shop floor“:
    - Command, cell, field, sensor levels
- Interconnected sensors and actuators
- Different types of wires
- Different types of environments (e.g. no electrical energy allowed in highly explosive contexts)
- Different length of wires



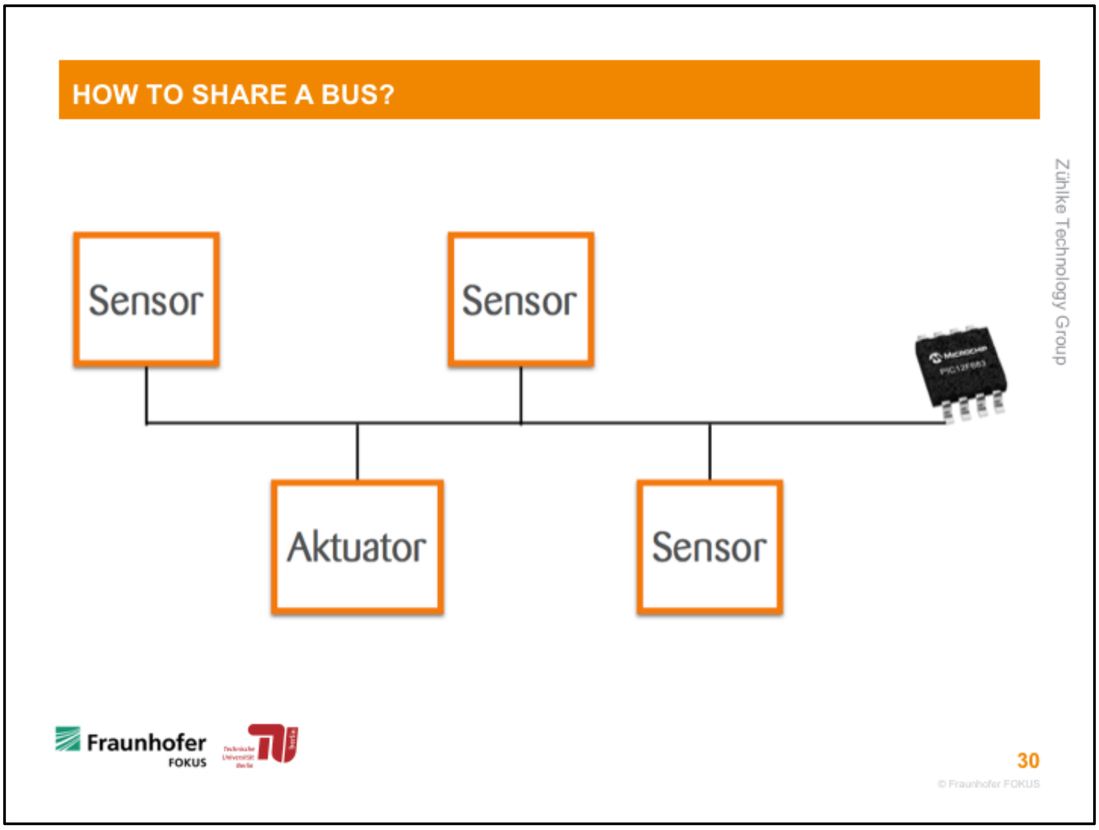
- Most basic principle: the control loop
- At the sensor or I/O level



- Historically status information were transmitted via hydraulic systems (nowadays only where no electricity is allowed)
- Since 1950 in process control the 4-20mA current loop is commonly used (DIN IEC 60381-1)
- Sensor information is encoded using the current
- Independent of of cable length and number of devices
- 0 mA -> broken cable
- 24 V DC (direct current)

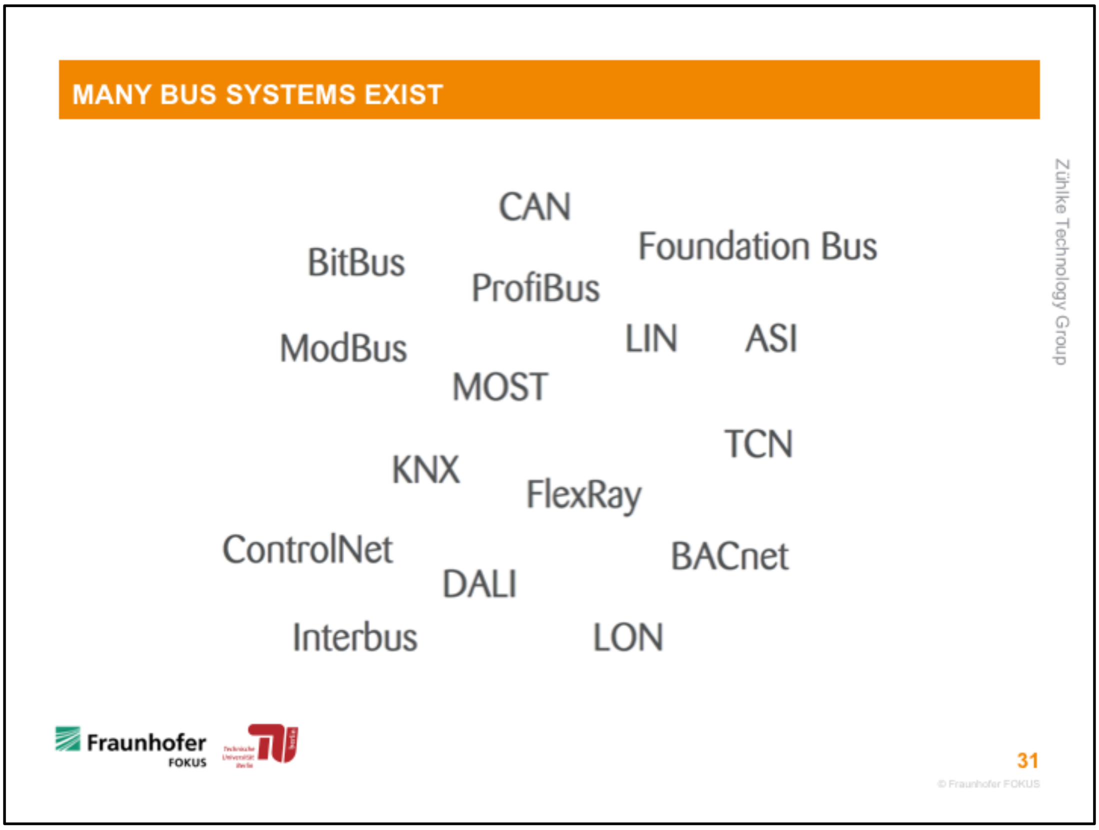


- However, such a control loop might be based on several sensor information
- Two basic options:
  - Direct
    - Simple design
    - Expensive
    - Many cables
    - No need for addressing
  - Bus
    - Reduction of costs and cables
    - Easier to install
    - Easier to extend
    - Need for addressing



- As discussed before, there are several options to access a shared medium.
- Remember: TDMA
  - Time Division Multiple Access
  - Time-slot based
  - Cyclically repetitive frame structure
  - Known from 2G cellular systems

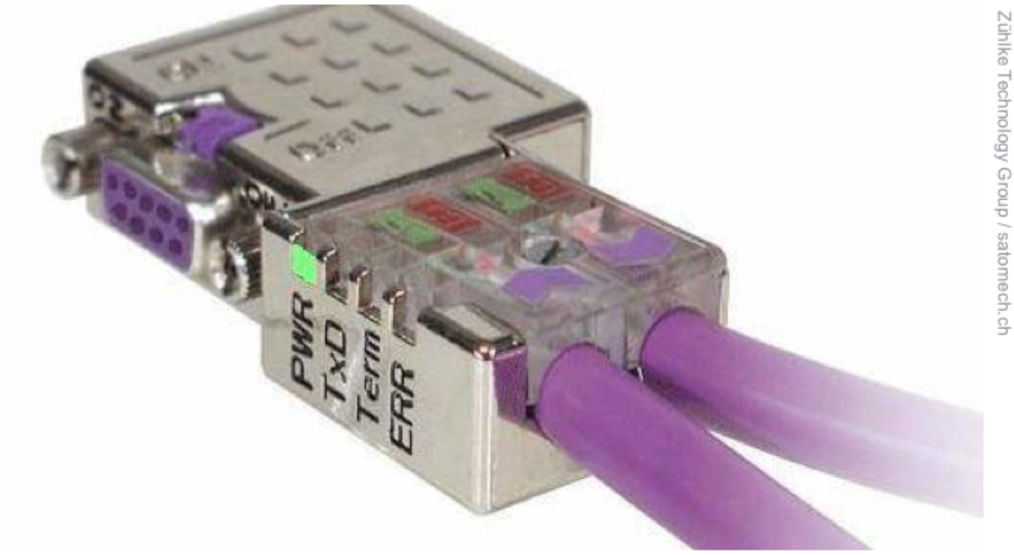
- CSMA
  - Carrier Sense Multiple Access
  - Statistical multiplexing
  - Collision Detection (CD), known from Ethernet
  - Collision Avoidance (CA), known from Wi-Fi



- Depending on the Use Case
    - Transportation
    - Buildings
    - Automation
    - …
- Depending on the Requirements
    - Real-time latency
    - Bandwidth
    - Cable length
    - OSI layers
    - …

- Dedicated Intel Hardware (i8044)
- Standardized as IEEE 1118 (1991)
- 248-byte Payload + address information
- Transmission modes
    - Synchronous: 30m, 28 slaves, 2.4 mbit/s
    - Asynchronus: 13.2km, 250 nodes, 62.5 kbit/s

EXAMPLE: PROFIBUS (1989)



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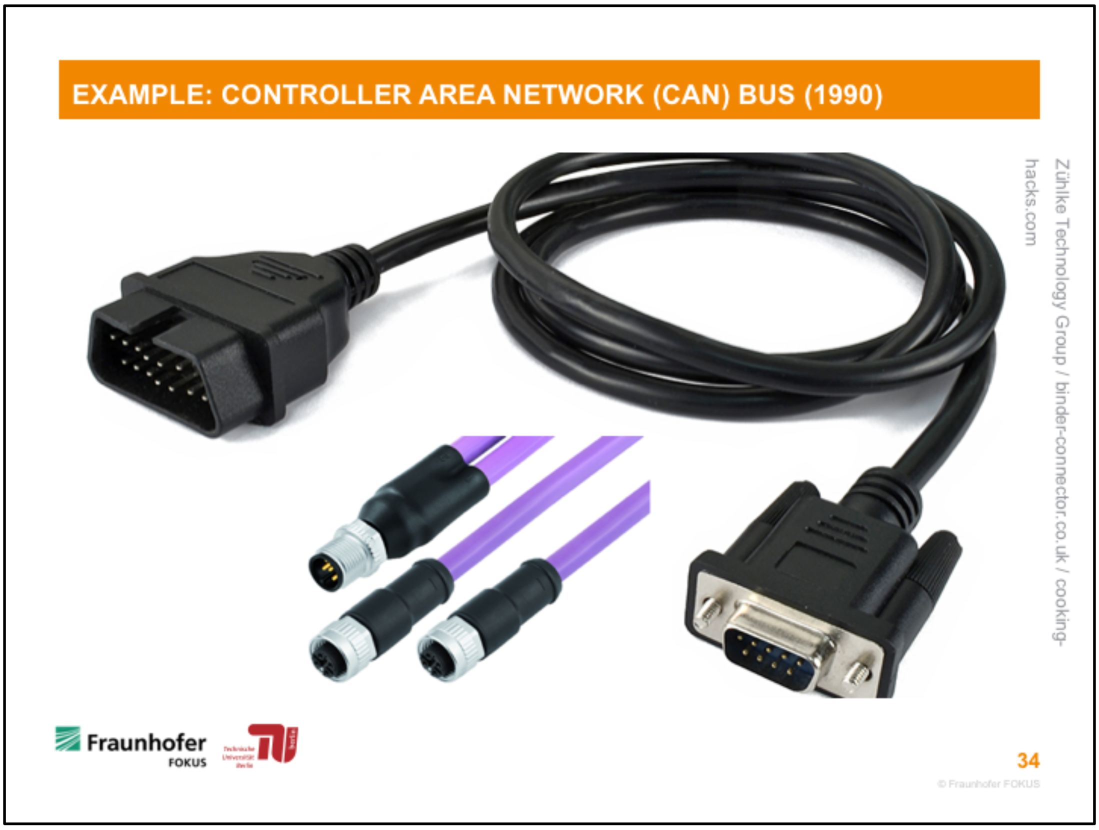
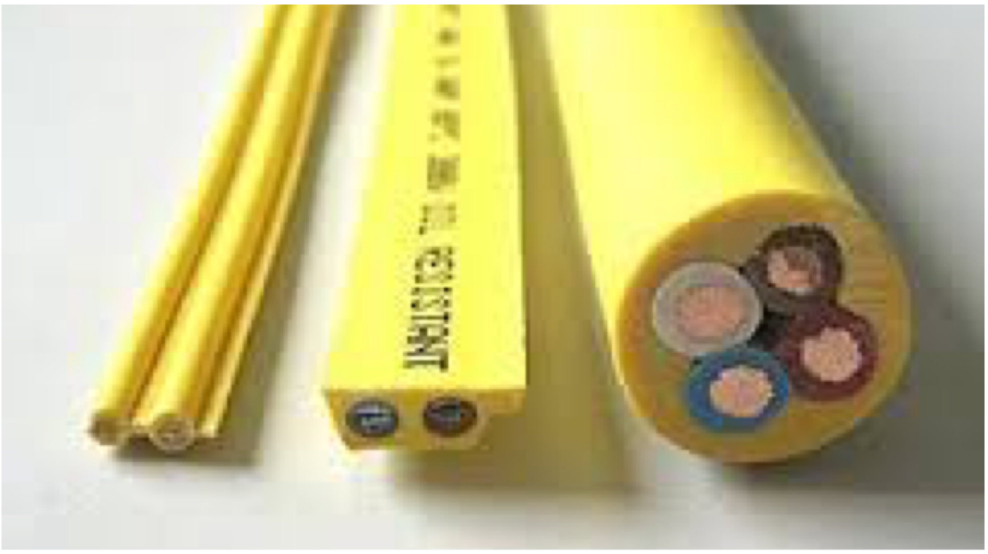
- Process Field Bus promoted by the Federal Ministry of Education and Research (BMBF)
- Standardized as IEC 61158/IEC 61784 (1999)
- ProfiBus FMS (Fieldbus Message Specification): From top floor to shop floor with complex objects
- ProfiBus DP (Decentralised Periphery)
    - 1200m, 127 nodes, 12 mbit/s
- ProfiBus PA (Process Automation)
    - same as DP but limited power consumption
    - FISCO - Fieldbus Intrinsically Safe Concept



- Etablished by Bosch (1983) and Standardized as ISO 11898-x (~1990)
- Full-duplex, linear, serial
- CSMA/CD + ‘arbitration on message priority’ (CSMA/CA)
- Different modes
    - 40m: 1 mbit/s
    - 1km: 40 kbit/s
- **Physical layer not formally specified**
- Used in the automotive context

EXAMPLE: AS-I - ACTUATOR SENSOR INTERFACE (1999)



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- Industrial networking for automatioin systems
- Standardized as IEC 62026-2
- Can also transmit power (24V, 2A)
- Partly similar to USB (host & repeater)
- Maximum 62 nodes, 500 m cabled length (incl. repeater)

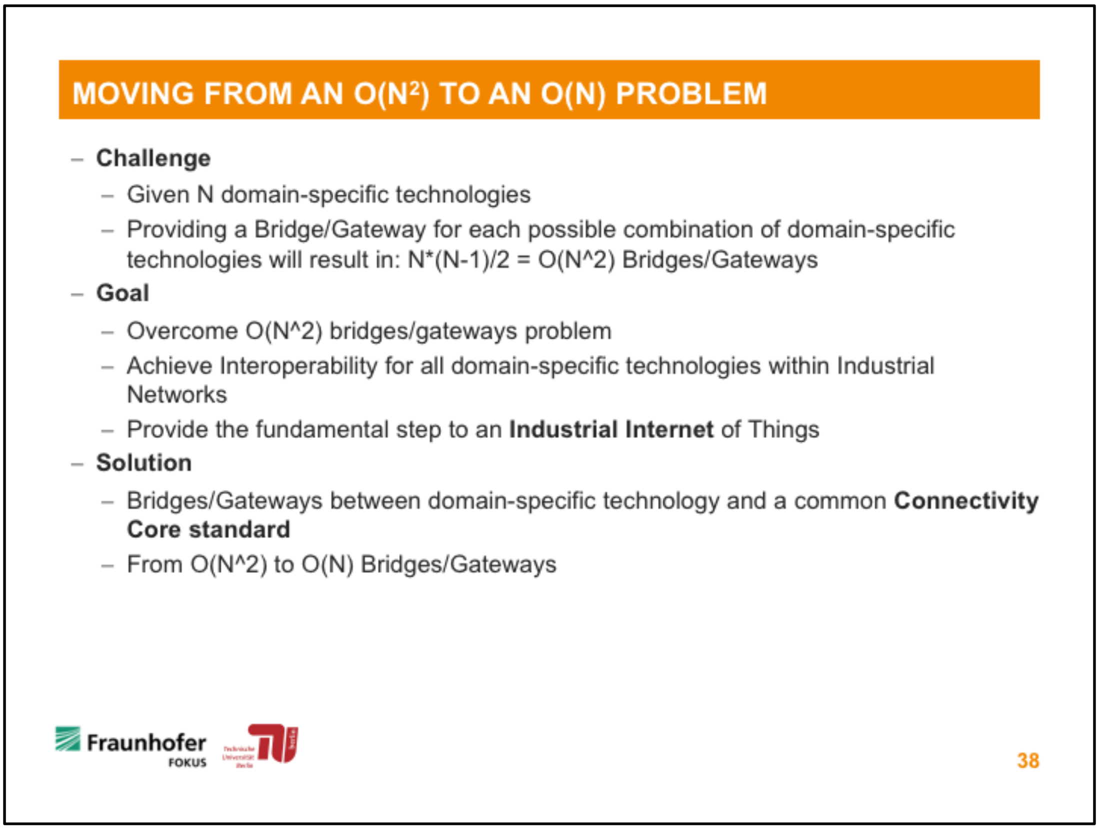
FIELDBUS TECHNOLOGIES

End

INDUSTRIAL ETHERNET TECHNOLOGIES

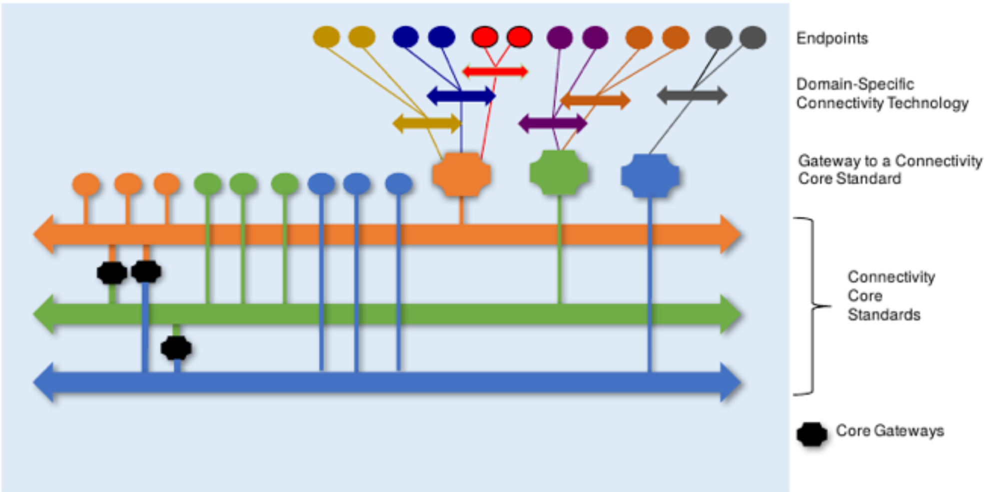
30 minutes

- Having multiple connectivity technologies with even different cables and plugs have certainly a few drawbacks…



- Open Problems: How many connectivity core standards will be needed, will they fit all requirements, what are practical impacts, …?

IIC CONCEPT OF CONNECTIVITY CORE GATEWAYS



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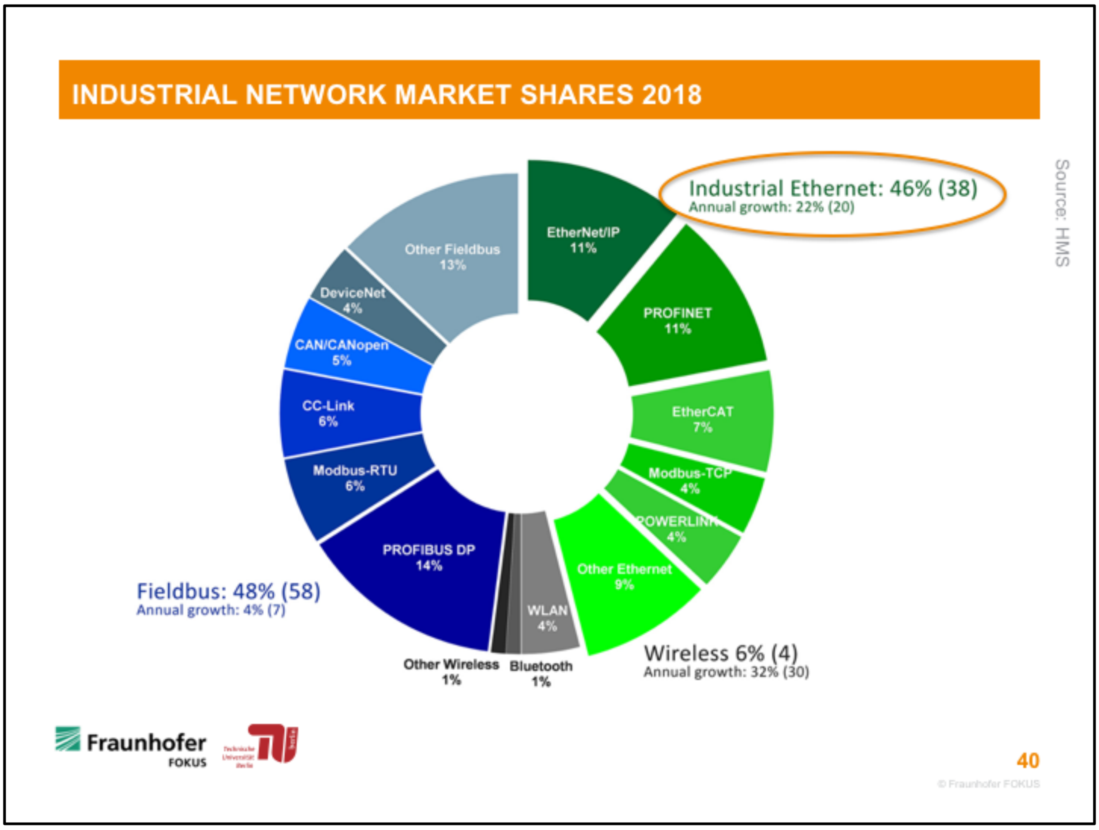
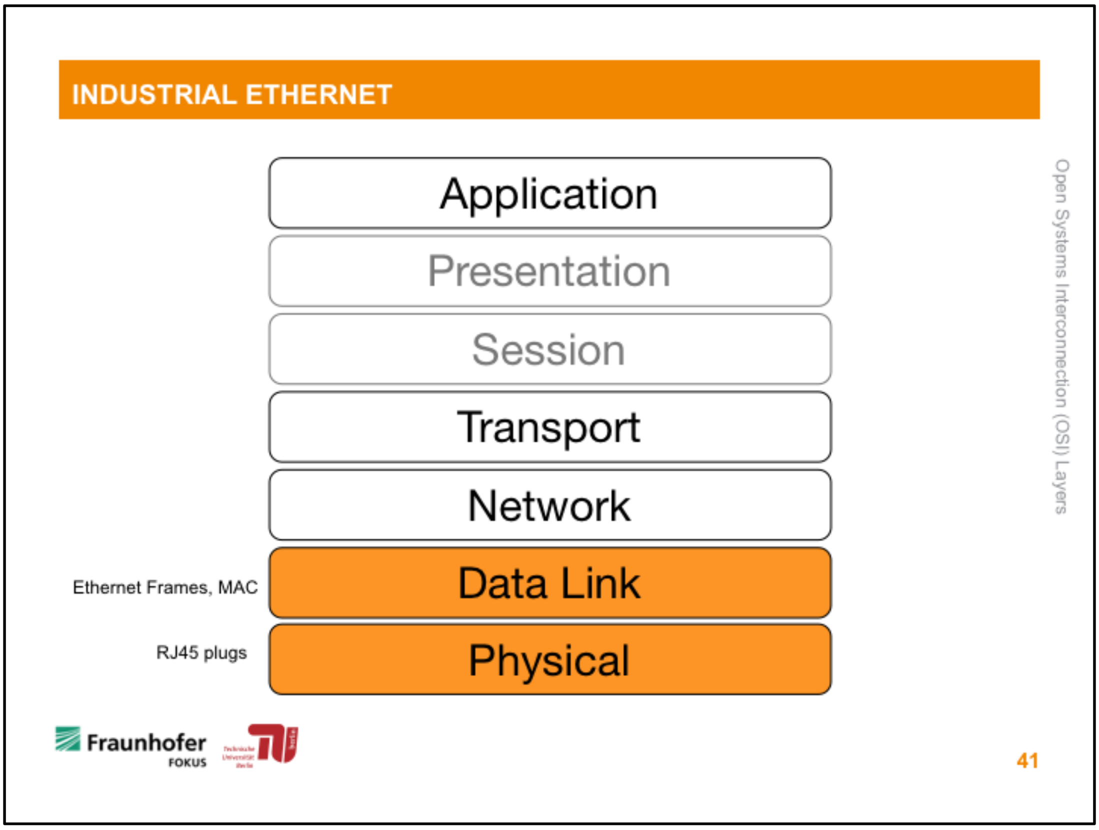
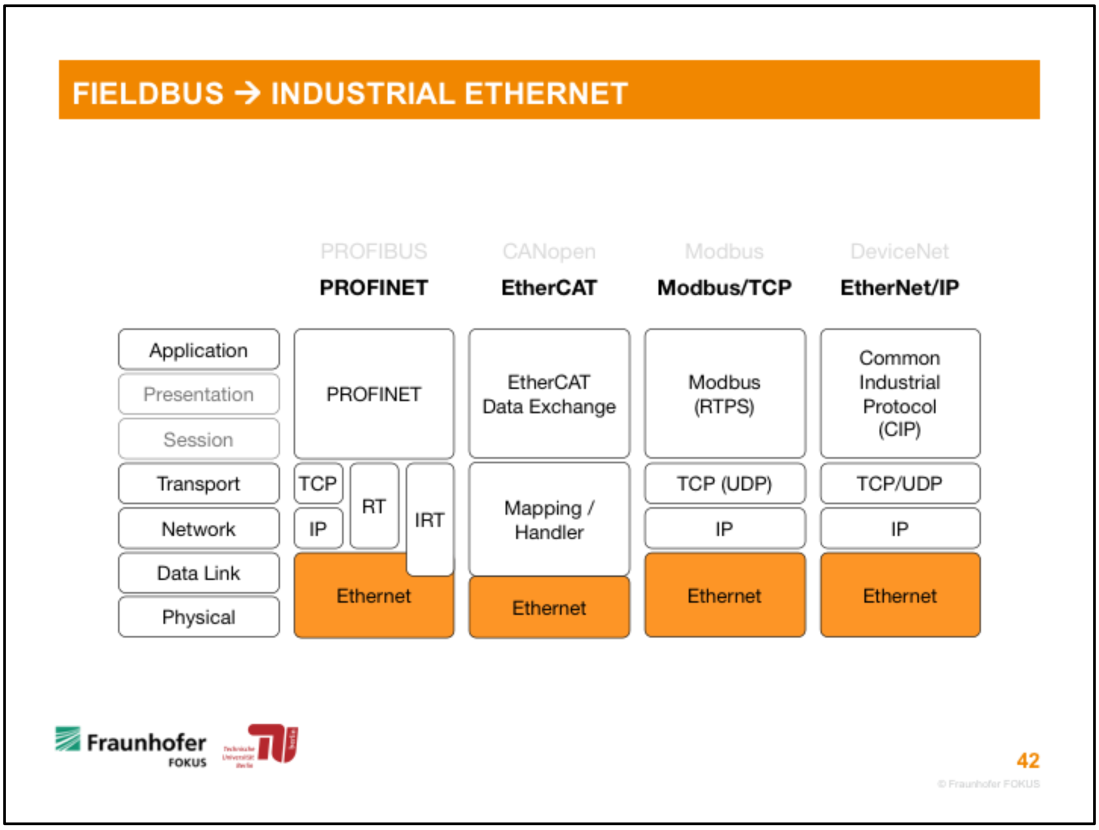
- Visualization by the IIC
- Mapping domain specific connectivity technologies using gateways (remember: wireless IIoT gateways)
- Few (core) gateways between core standards



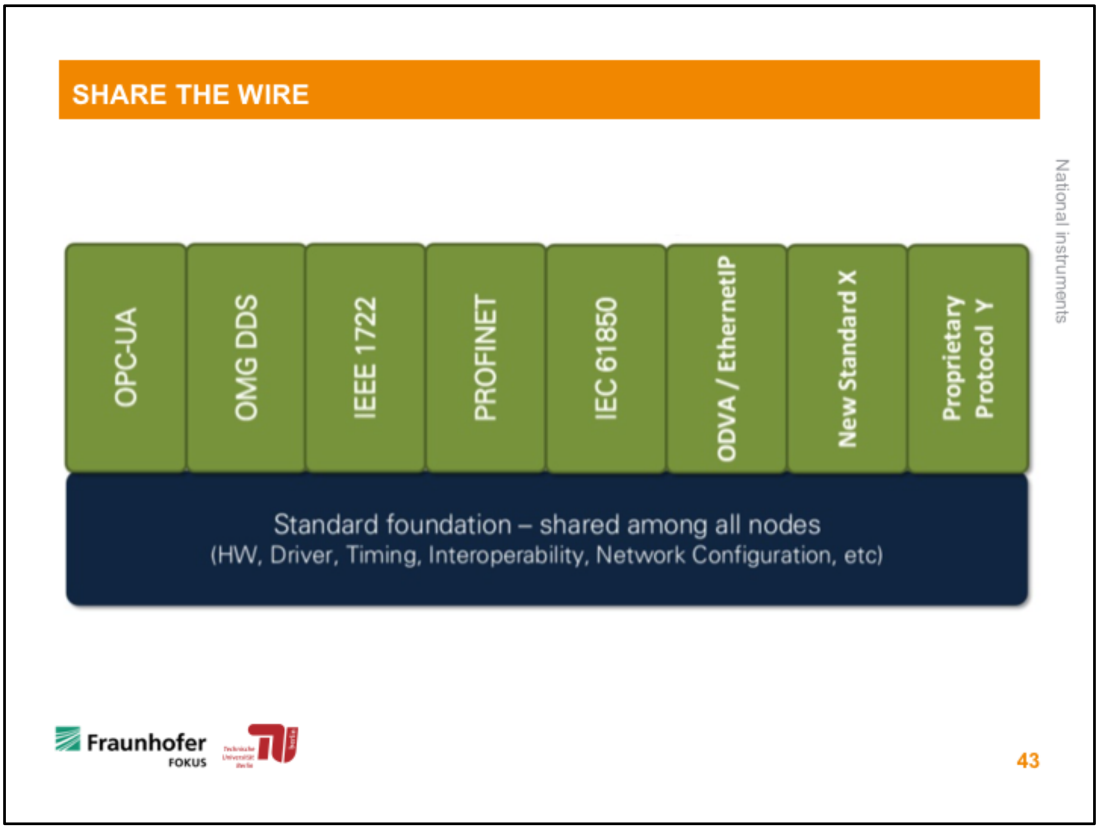
- First step: Agreement on standardized layers 1 + 2
- Industrial Ethernet: now the same market share as fieldbus systems (bigger annual growth)



- Specification of physical connectors
- Specification of MAC protocols



- Same physical connectors
- Similar MAC protocols
- Depending on the real-time requirements, modification of the data link layer



- Different approaches on higher levels (OSI 3++)
- We‘ll talk about OPC UA and DDS later

EXAMPLES

- Ethernet/IP
  - Ethernet/Industrial Protocol
  - Open DeviceNet Vendor Association (2000)
  - Adapter of the CIP on top of Ethernet/TCP/UDP/IP
- PROFINET
  - Specified (like PROFIBUS) in IEC (2004)
  - ~100ms: TCP/IP
  - ~1ms: RT (Real-Time)
  - <1ms: IRT (Isochronous RT)
- EtherCAT
  - Beckhoff Automation (2003)
  - Standardized as IEC 61158
  - 100m, up to 2^16 nodes, 100 mbit, < 100µs

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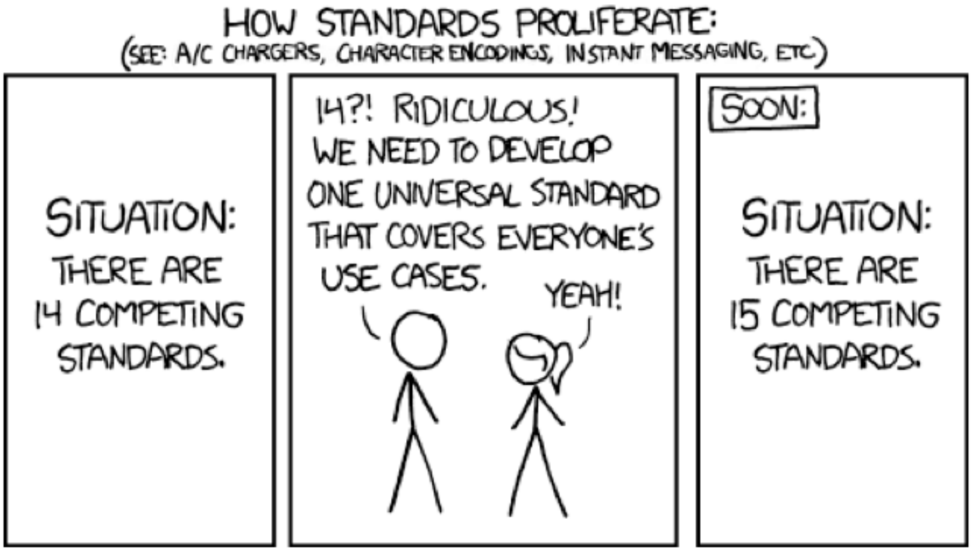
- Again a number of different approaches with different focal points

Next big step: Standardized Deterministic ISO OSI Layer 2

HOW STANDARDS OFTEN PROLIFERATE



EBV

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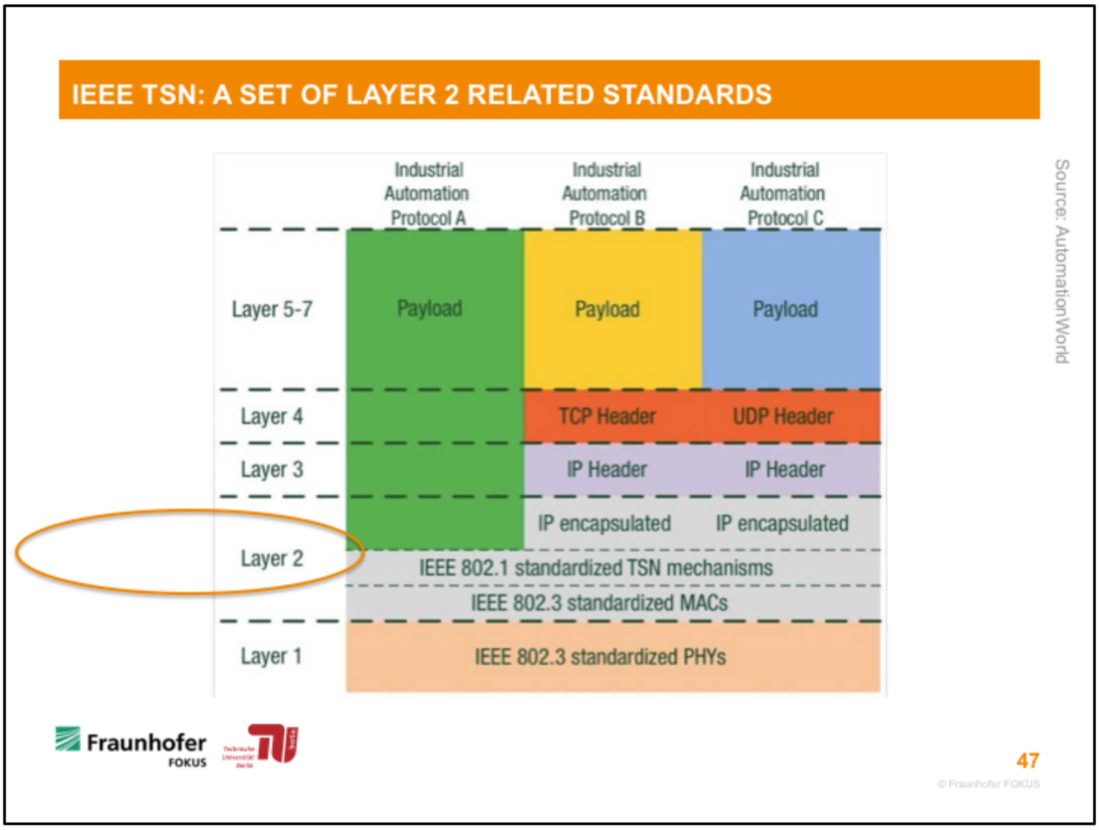
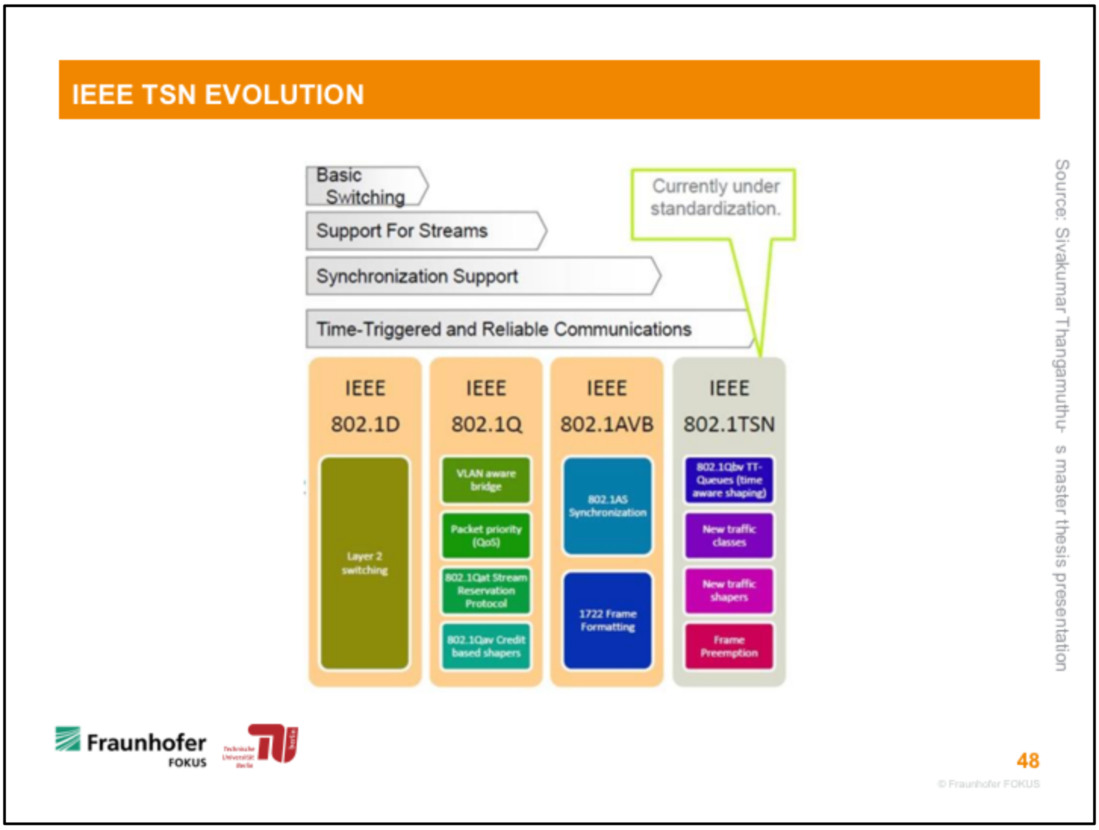
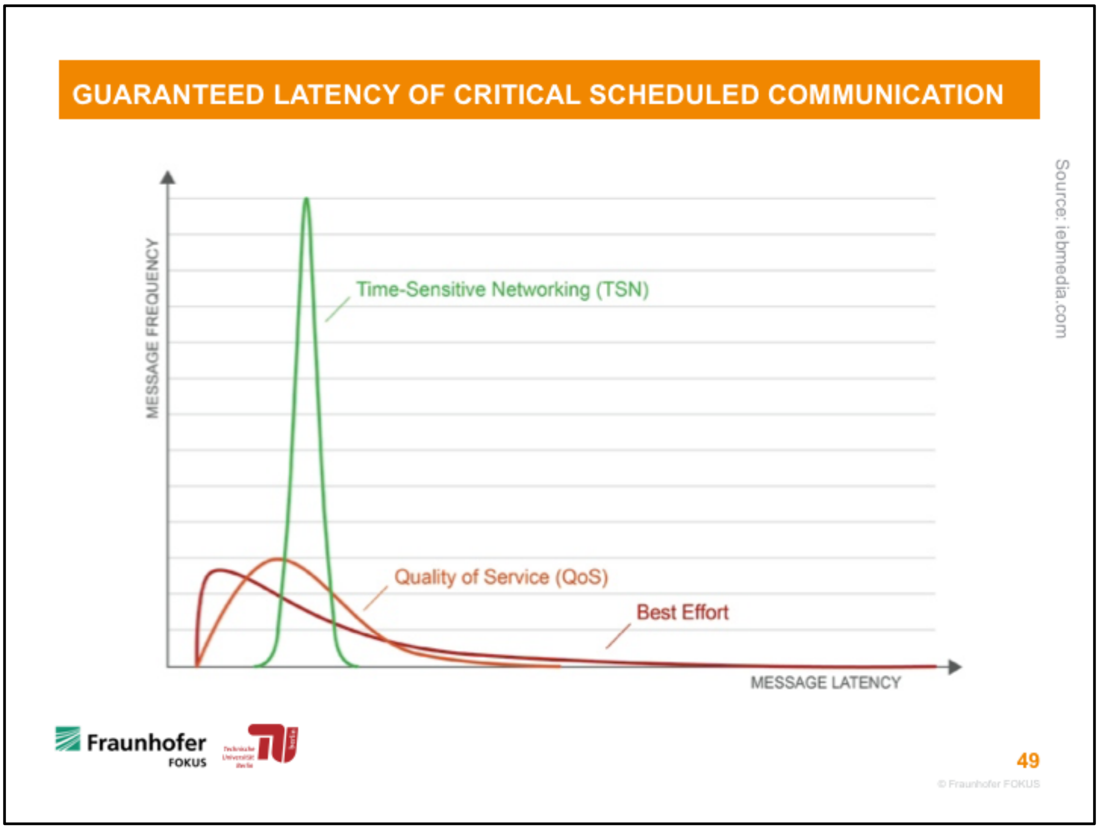


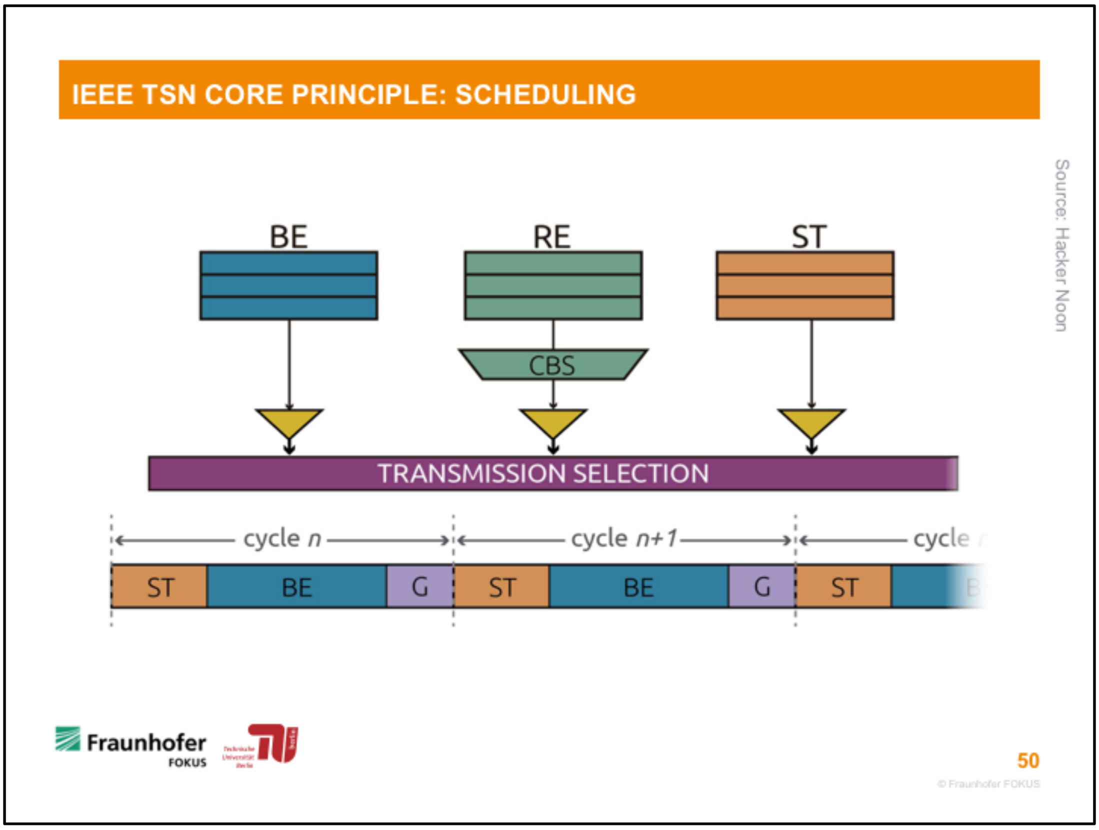
- The Institute of Electrical and Electronics Engineers (IEEE) 802.1 Time-Sensitive Networking (TSN) Task Group
- A **set** of standards for deterministic services through IEEE 802 networks
- Application domains: industrial and automotive and other deterministic networks
- Initially designed for the Audio Video Bridging (AVB) context
- Using the same connectivity technology for the office and shop floor
- Interoperable accross vendors



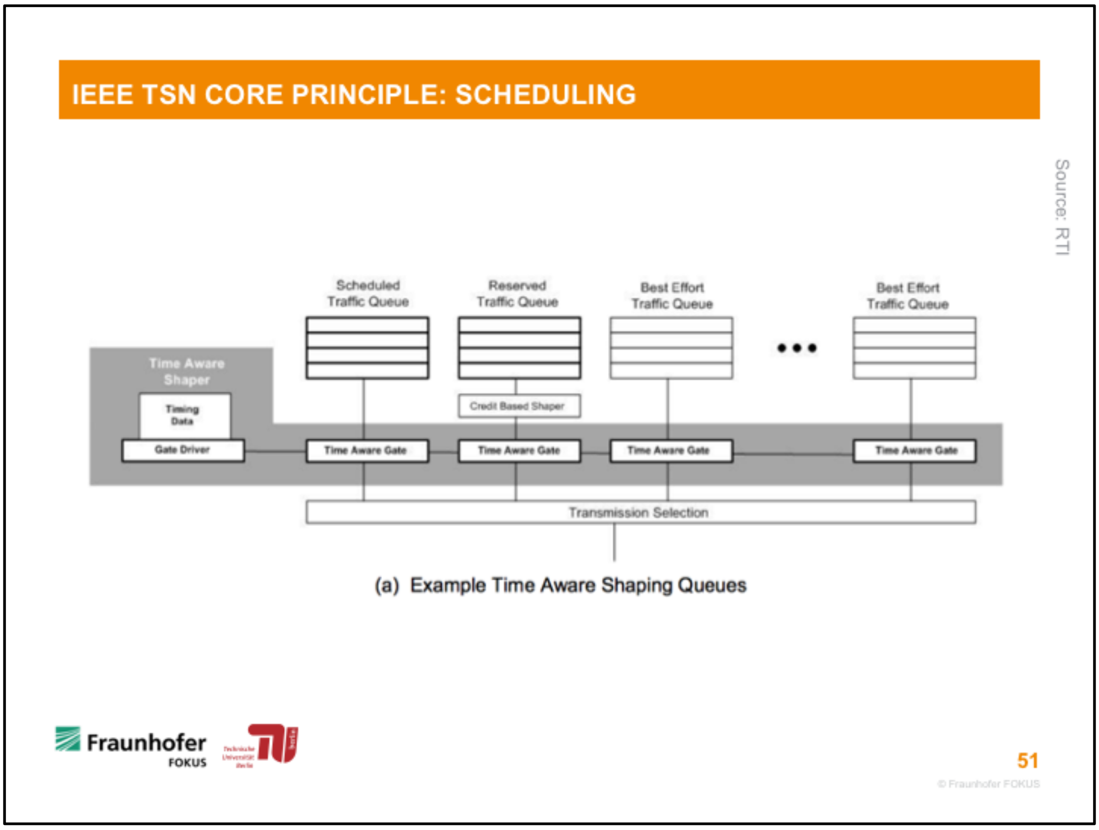
- An evolution from best effort traffice, quality of service (QoS) enabled traffic to time-sensitive networking (TSN).



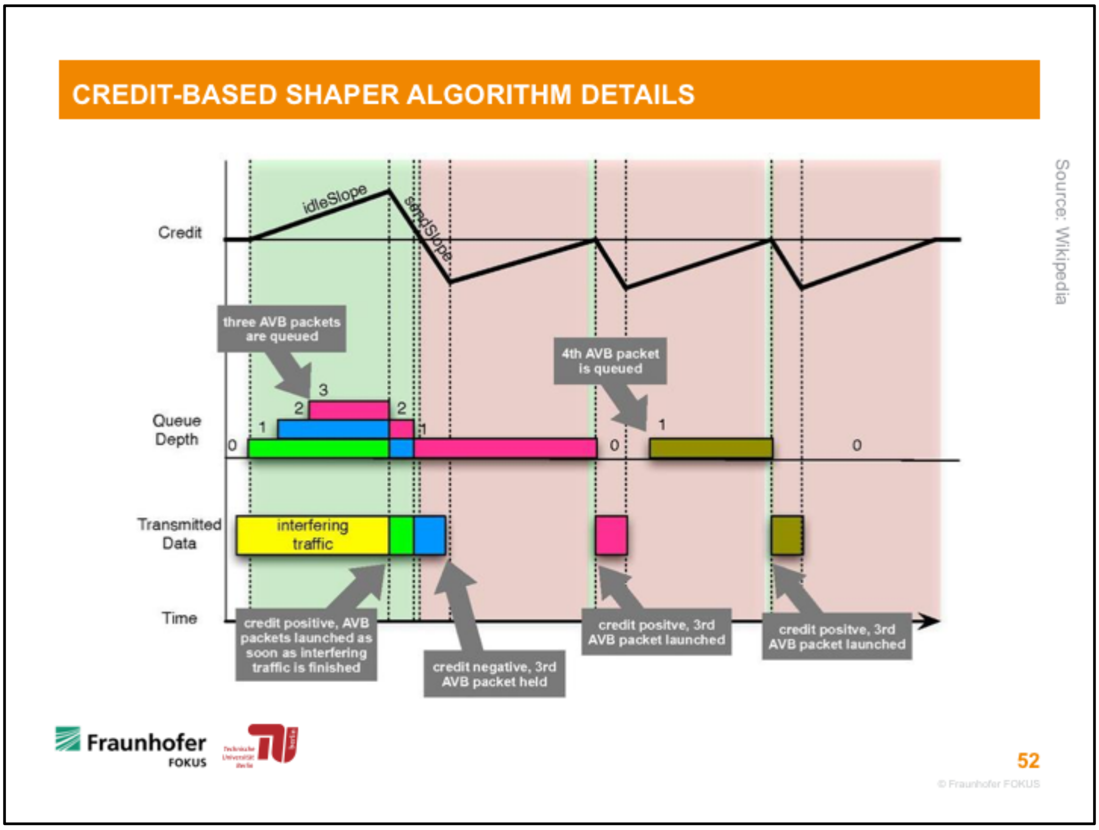
- Visualization of the afore mentioned traffic types
- Probabiliy when a package might arrive (message frequency at a given message latency)
- Red = Best Effort = 802.1D. Most packages arrive w/o additional delays – however, chances are that collisions arise
- Orange = QoS = 802.1Q. Some delay due to stream reservation, packet selection, … – however, overall chances that a package arrives till a deadline increase
- Green = TSN = 802.1TSN. Delay in communication due to cycle time, … – however, very high chances that a packet arrives in specific time slot and no chance a package will miss a deadline



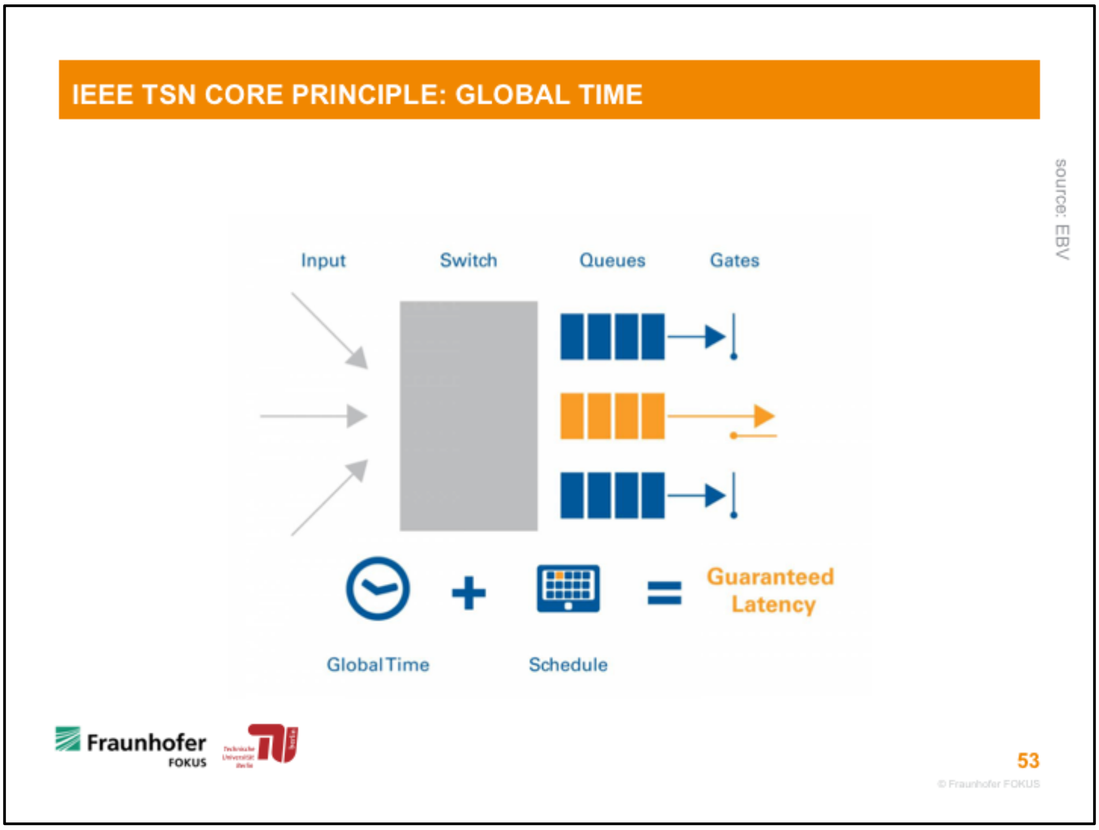
- Different queues per traffic class
    - Best Effort (BE) Traffic
    - Scheduled Traffic (ST)
    - Reserved (RE) Traffic based on a Credit Based Shaper (CBS)
    - Additionally a Guard Band (G) to ensure access without delay to the MAC for time critical traffic.
- As high priority frames sharing the same link could content them, a Time-Aware Scheduler (TAS) that is based on TDMA divide a cycle time into time slots dedicated to a specific classes (802.1Qbv).



- Another view on how BE, ST, RE, CBS and TAS relate to each other



- Detailed CBS workflow for four packets



- Time Synchronization in TSN is based on IEEE 1588v2 Precision Time Protocol (PTP)
- Two objectives for Time Synchronization in TSN
  - Providing a common time base (“global clock”)
  - Time stamping at stream source is synchronized with time stamping at stream destination
- Synchronizing multiple streams

INDUSTRIAL ETHERNET TECHNOLOGIES

End