Conversion of Fieldbusses regarding Industrial Internet of Things

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Overview

- Development of fieldbusses in Factory Automation
- Requirements from Industrial Internet of Things / Industrie 4.0
- Future impact of Time Sensitive Networks on Industrial Ethernet

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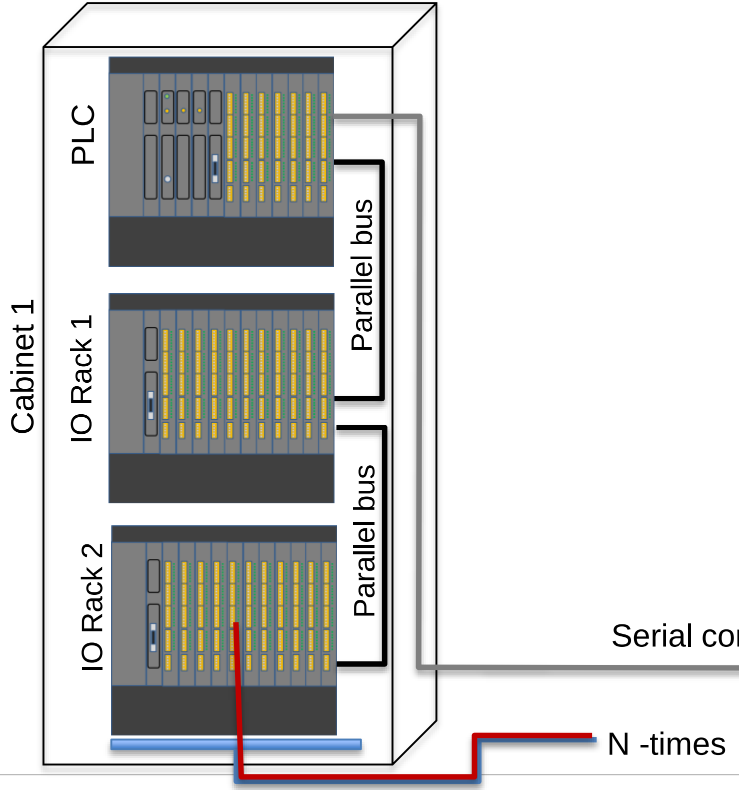
History of Fieldbusses

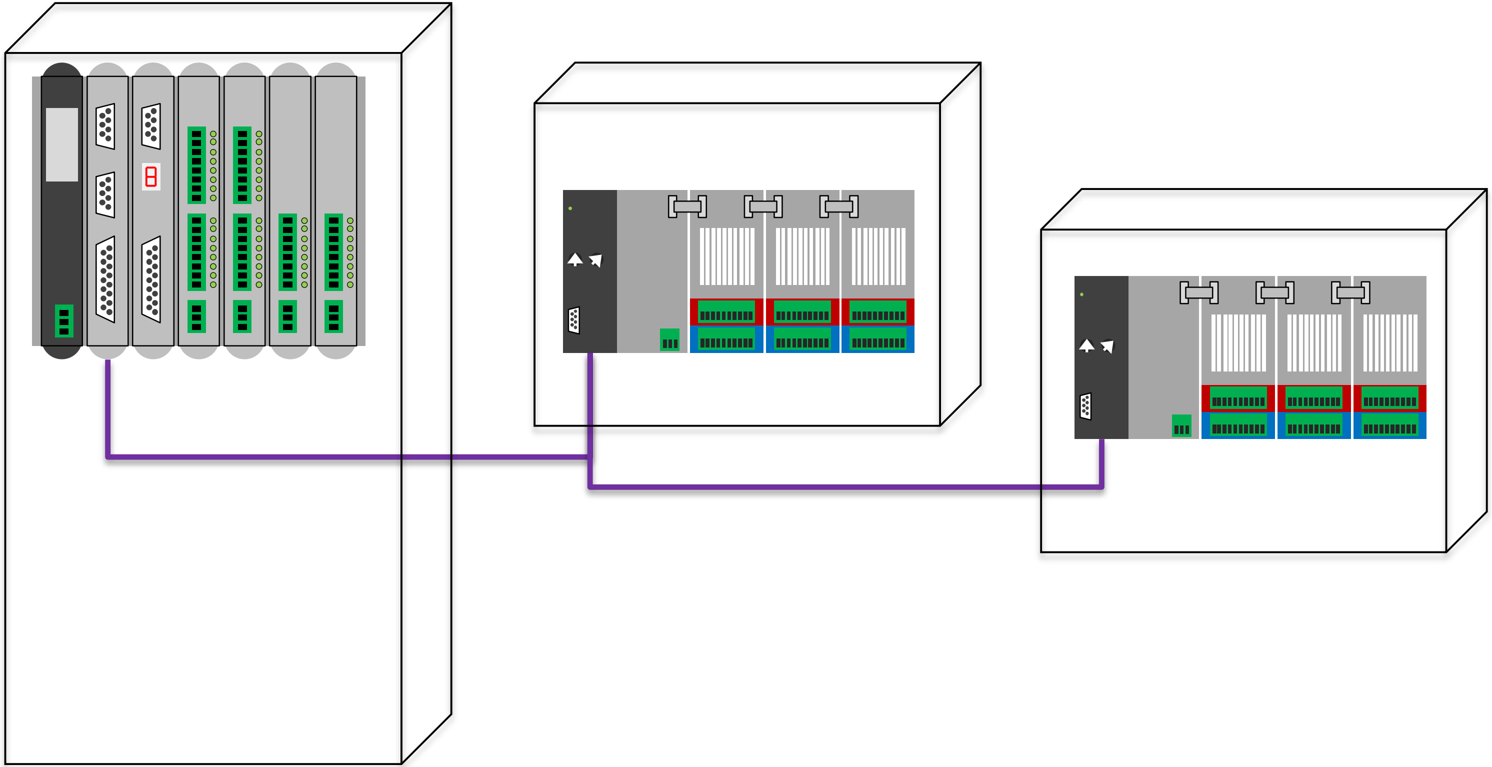
1980s

- Replacement of hardwired I/O connection to reduce wiring cost
- Data exchange between automation controllers
- Synchronized motion systems

Central I/O

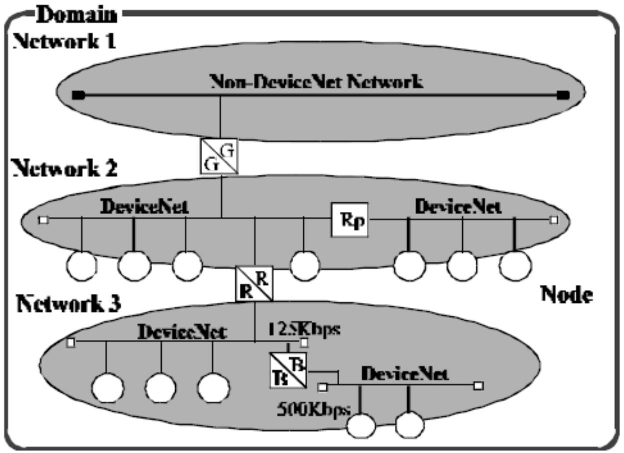

Cabinet 1
PLC
IO Rack 1
IO Rack 2
Parallel bus
Parallel bus
Serial connection
N -times
Cabinet 2
IO Rack 3
IO Rack 4
IO Rack 5
Parallel bus
Parallel bus

I/O via Fieldbus



DeviceNet

- Introduced in 1995
- Based on CAN (ISO11898)
  - widely used in vehicles
- Variety of application
  - Master / Slave
  - Client / Server
  - Peer to Peer
  - Cyclic, Change of State
  - Unicast or Multicast
- Object oriented design
- Routing and bridging



Rp *Segment Repeater* between segments
- Segments participate in the same media arbitration

B B *Subnet Bridge* between subnets
- Duplicate MAC ID check passes through
- MAC ID's on one subnet may not be duplicated on the other subnet
- Subnets may operate at different baud rates

R R *Network Router* between similar networks
- Both networks are DeviceNet

G G *Gateway* between dissimilar networks
- One network is DeviceNet, the other is not

Controller to Controller Communication

- Automation driven by automotive industries
- The 1980s: CIM, MAP/MMS driven by GM, initial point of Industrie 4.0
- Vertical integration
- Profibus/FMS was defined as a subset of MMS, main use C2C
- PC used for HMI and control → Ethernet, TCP/IP

CNC, RC and Motion Control

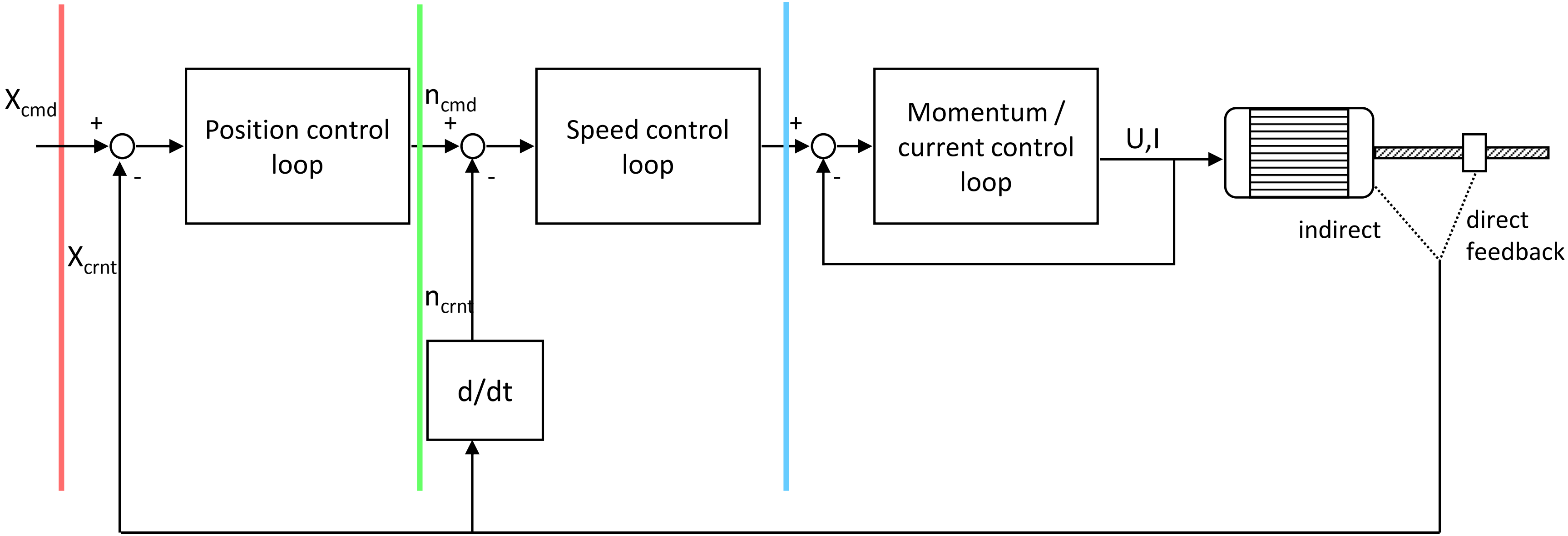
- First applied in machine tools
- High precision and fast control loops needed
  - Local control loops preferred
  - Distribution of control loops depends on application
- Commissioning mostly online

Servo drive control loops

Position control interface (Standard interface for SERCOS)

Classical analog speed control interface ±10V

Momentum/current control (used for non-cartesian systems, e.g. robotics)



CNC, RC and Motion Control

- First applied in machine tools
- High precision and fast control loops needed
  - local control loops preferred
  - Distribution of control loops depends on application
- Commissioning mostly online
- First digital interface: Sercos
  - Fiber optics for EMC
  - TDMA for real time high precision timing
  - Initially only drives
  - Specialized for synchronized motion

Differences in Application Properties

- Different usage → different properties
- Offline configuration → EDS
- Machine only working with all drives → error if one is missing

	I/O	C2C	Motion
Offline configuration	X		
Online configuration			X
Config at connection	X		X
Cycle time	5-10ms	5-100ms	0.5-4ms
Synchronization	< ±5%	-	<1µs
Browse		X	

Migration to Ethernet

- Reasons and requirements
  - Data rate insufficient in fieldbusses
  - Eliminate separate interface for commissioning
  - Enable IT integration into devices
    - Web server
      - Diagnostics
      - Change settings
    - Firmware download
    - SNMP
- How to become Ethernet deterministic

Real Time Behavior (1)

- Traditional Ethernet using CSMA/CD is not deterministic
  - Collision is detected and packets are repeated after random time
  - But can be made deterministic by a Master/Slave MAC layer (PowerLink)
- Switched Ethernet and packet prioritization achieves soft real time behavior
  - Packet delay up to 122 µs per hop
  - Still danger of overload and switches not supporting enough priorities
  - Not suitable for synchronized motion
  - Synchronized motion can be achieved using synchronization with IEEE1588
- Ultra low latency and Ethernet
  - Scheduled transfer (TDMA) and multi-device packets (Sercos, Profinet IRT)
  - Future: Time Sensitive Networks (TSN)

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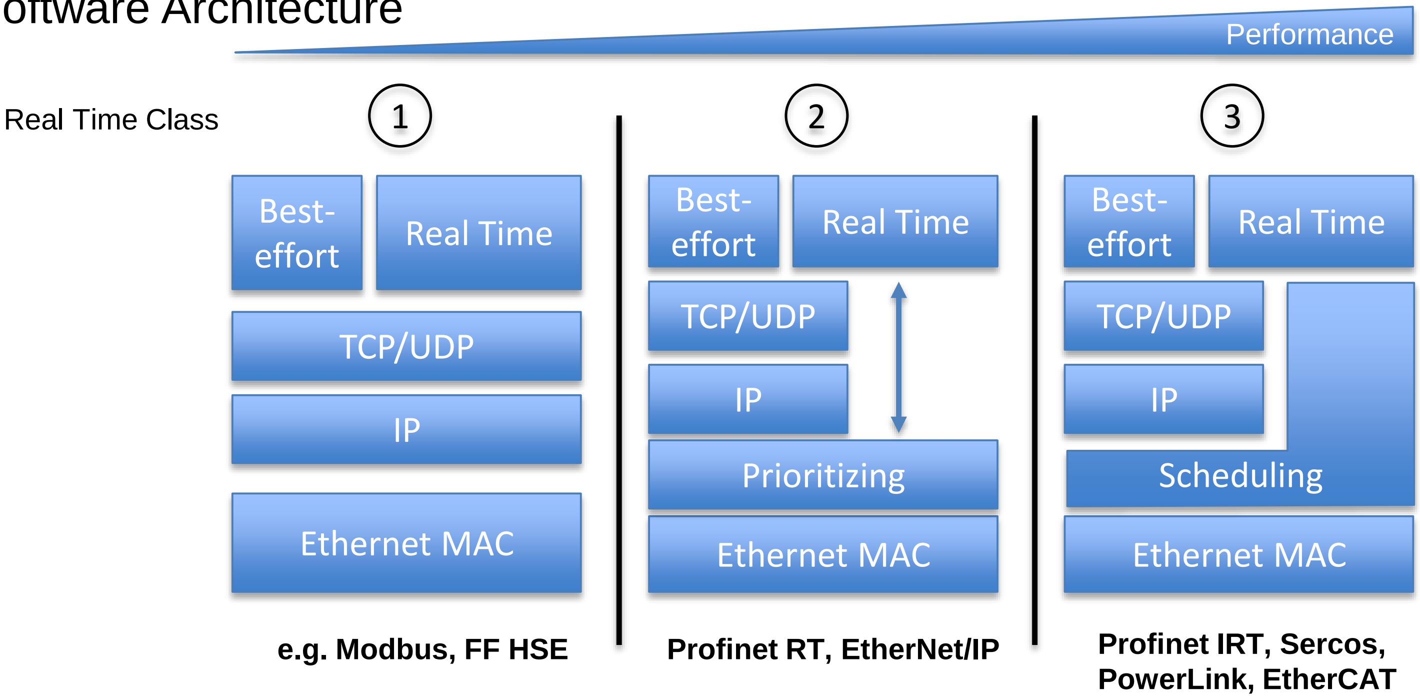
Real Time Behavior (2)

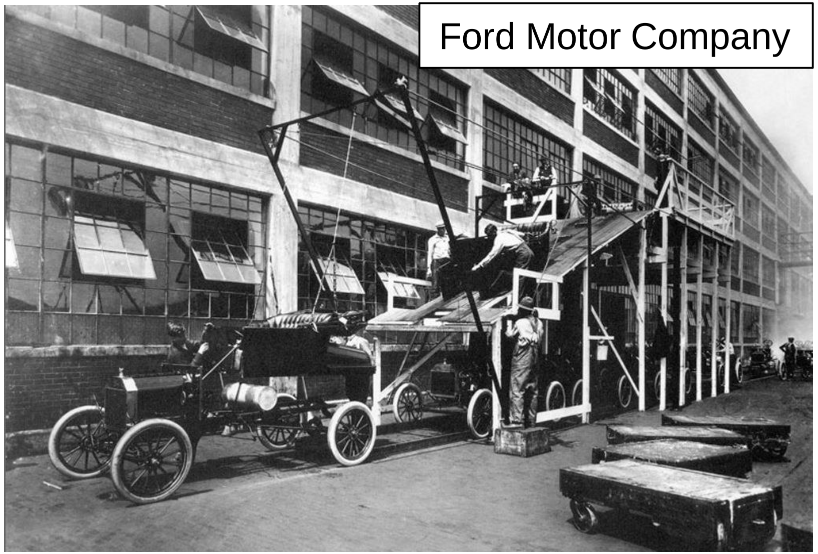
Software Architecture



Adapted from: J. Jasperneite, FH Lemgo

Market Requirements

Future: Individual products in mass production



Ford Motor Company

Minimum product variation

High variation of products, minimum buffers

Toyota

SmartFactory Demo Line

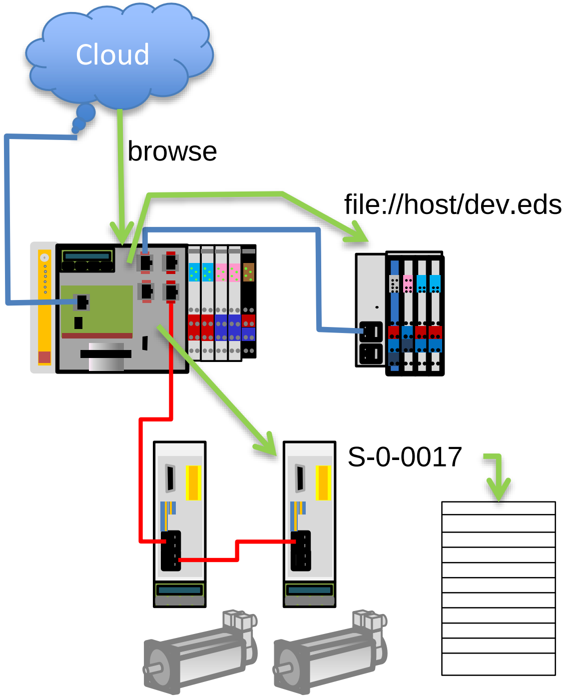
- Product: card holder
- Product contains individual manufacturing steps and quality data
- Plan to use Machine Data Model of ODVA Machinery SIG

Ubiquitous availability of information

- Every information at any place at any time
- Wireless is the key
  - Already available via mobile devices
  - In some applications also at device level
- CIP is ready
  - Objects and services
  - Bridging and routing
  - Future extension
    - DeviceNet of Things
    - EtherNet/IP in resource constrained devices
    - I/O-Link integration

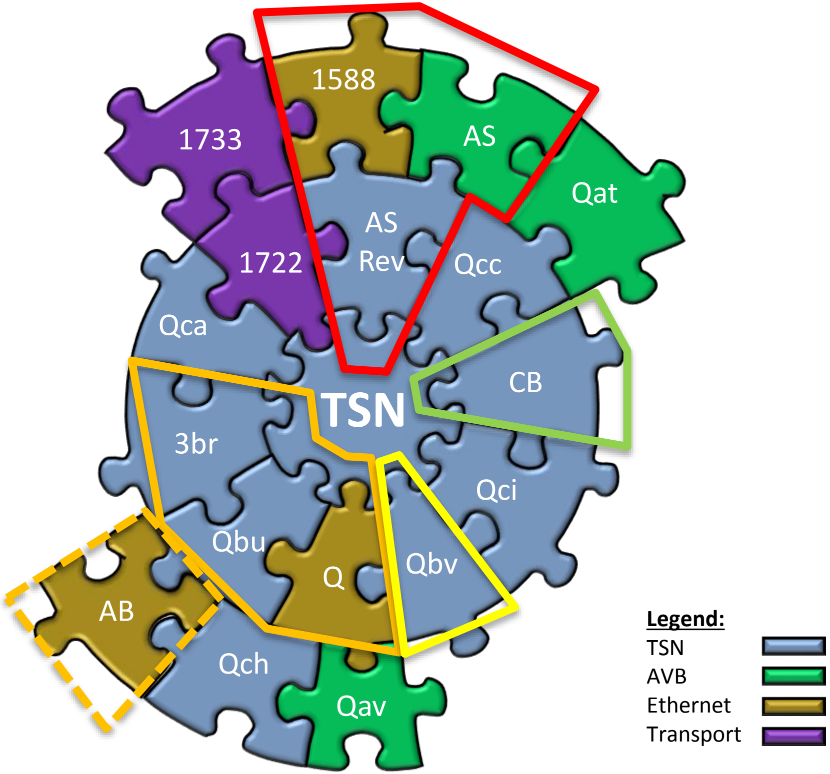
Discovery Service

- IIoT needs information to be found online
- OPC (and OPC UA) offers a browse service
- Industrial systems based on offline configuration
  → EDS files
- Systems originating from online configuration
  → built in object directory, e.g. Sercos: S-0-0017, Parameter structure contains units, names, data type, …
- Solution: link to EDS from device



TSN Standards Overview

- Set of Standards
- Time Synchronization
  - 1588, 802.1AS, 801.2ASrev
- Latency reduction
  - 802.1Qbu, 802.3br
  - 802.1AB (LLDP)
- Scheduling traffic
  - 802.1Qbv
- Redundancy
  - 802.1CB



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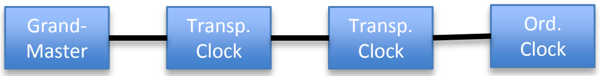
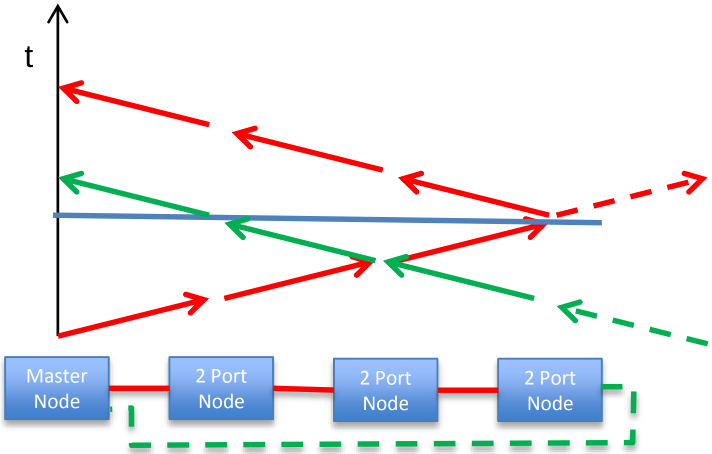
Time Synchronization

- Nearly all systems use some variant of IEEE1588
- Transparent clocks have been introduced to minimize degrading of accuracy over hop count
- Redundancy issues have been solved by sophisticated methods
- Only Sercos uses synchronization by telegram



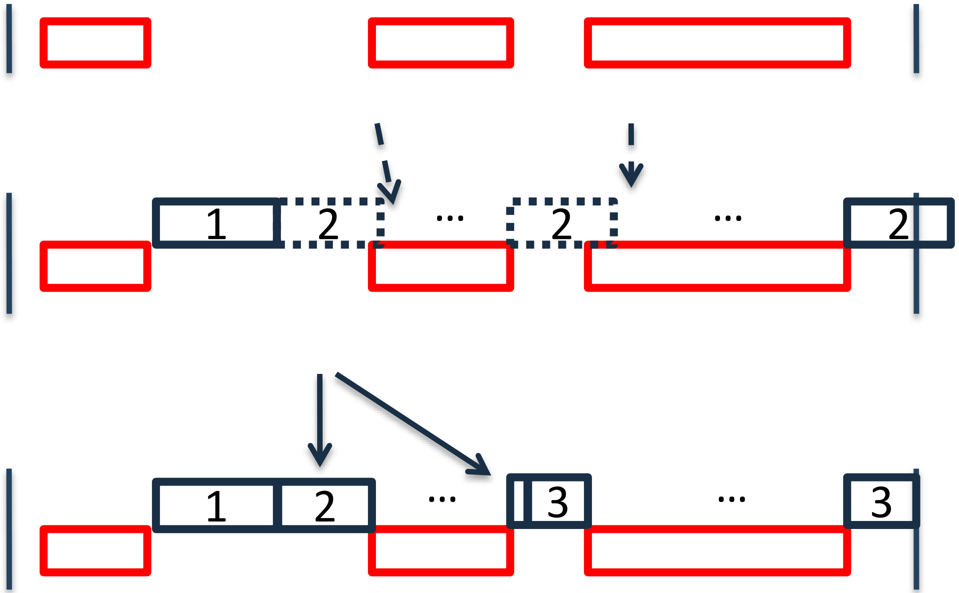
Daisy chain degrades accuracy
→ Optimum is star topology



Latency Reduction – Frame Preemption

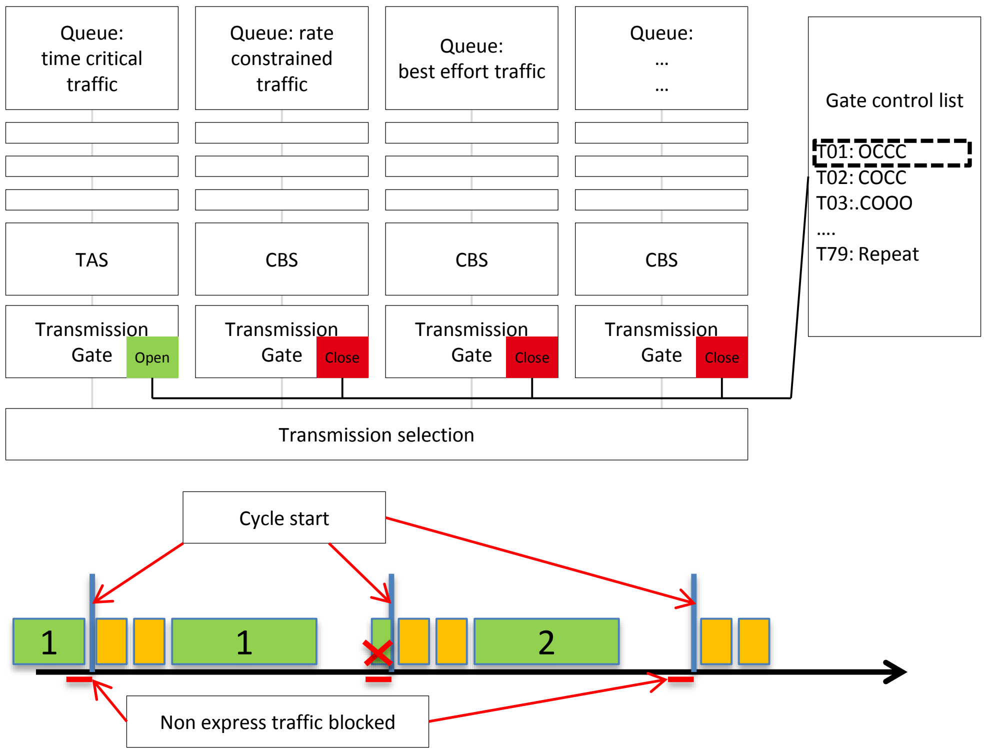
- Long frames can‘t be interrupted in traditional Ethernet
- Qbu (Frame Preemption) and 3br (Interspersing Express Traffic) solve this
- Maximum delay by low priority traffic can be reduced from 123µs to 12µs @100Mbit/s

- But this still allows this delay to be introduced at each hop



Latency Reduction – Scheduled Traffic

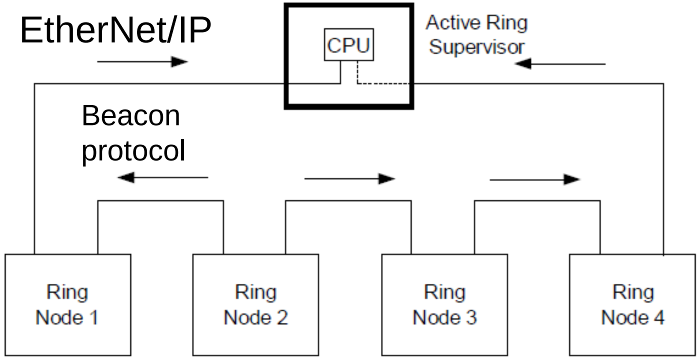
- Problem: large number of hops
  - Scheduling can reduce latency significantly
- IEEE802.1Qbv Time aware shaper
  - Block non-express traffic in the guard window immediately before cycle start
- Only in large networks
  - Probably not in EtherNet/IP
  - Needed in Sercos



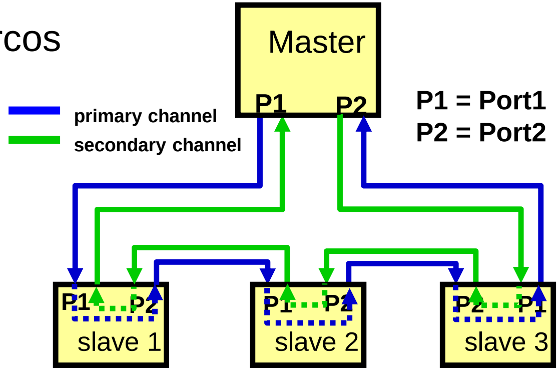
Redundancy

- Industrial networks support redundancy already
- Change to 802.1CB would introduce different procedures
  - Incompatibilities
- No need, if no requirement from application

EtherNet/IP



Sercos



100Mbit/s versus 1Gbit/s

- What happens going from 100 Mbit/s to 1Gbit/s?
  - Transmission speed increases by factor 10
  - Propagation delay stays constant (no increase in speed of light)
  - Signal conversion delay decreases insignificantly

	Packet size	100 Mbit/s	1 Gbit/s
Transmission time[1)]	64	6.7µs	0.67µs
	1518	123µs	12.3µs
Delay per hop[2)]		1.5µs	1.5µs

→Topology matters!

1) Including Start of Frame and Inter Packet Gap
2) 1 µs node delay and 0.5µs accounting for 100 m cable length

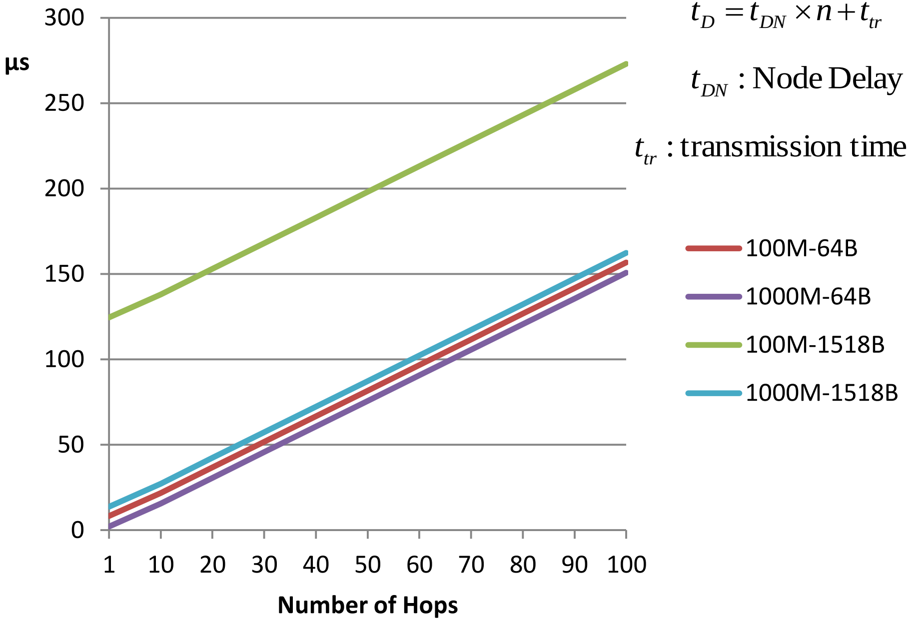
100Mbit/s versus 1Gbit/s – cut through

- Total delay with Cut through
  - Transmission time important at 100Mbit/s
  - Node delay dominant at 1Gbit/s

$$t_D = t_{DN} \times n + t_{tr}$$

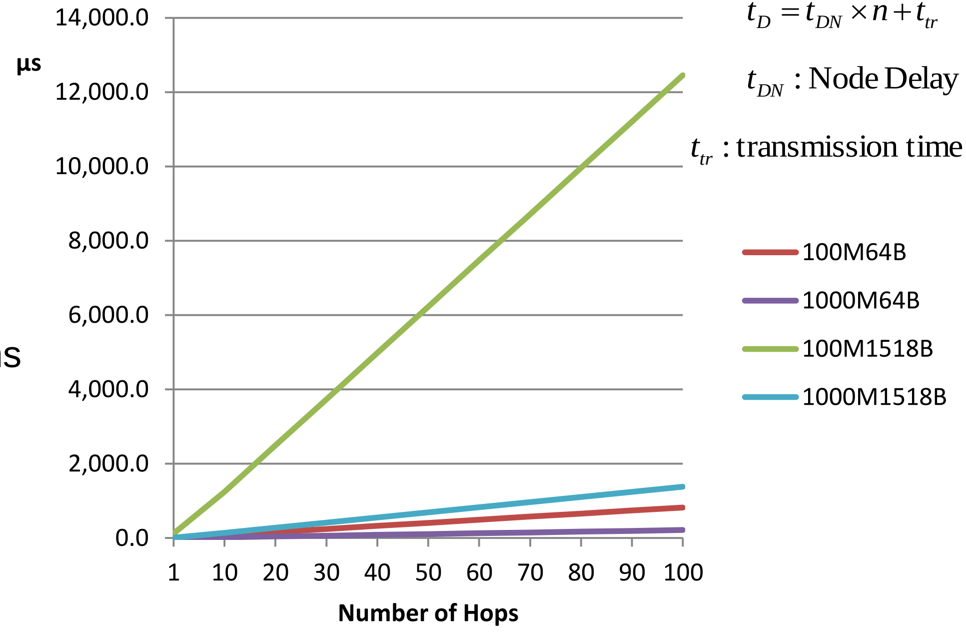
t_{DN} : Node Delay

t_{tr} : transmission time



100Mbit/s versus 1Gbit/s – store & forward

- Total delay with store & forward
  - 100Mbit/s:
    - Transmission time dominant for large packets
    - Large number of hops lead to large delay
    - Not useful for closed loop control
    - But for small packets only systems may be acceptable
    - TSN Frame preemption would be helpful
  - 1Gbit/s
    - Small packets: node delay and transmission time in same range



$$t_D = t_{DN} \times n + t_{tr}$$

t_{DN} : Node Delay

t_{tr} : transmission time

100Mbit/s versus 1Gbit/s – store & forward

- Total delay with store & forward
  - Low number of hops
  - 100Mbit/s:
    - Transmission time still important
    - closed loop control
    - But for small packets only systems may be acceptable
    - TSN Frame preemption would be helpful
  - 1Gbit/s
    - Small packets: node delay and transmission time in same range

$$t_D = t_{DN} \times n + t_{tr}$$

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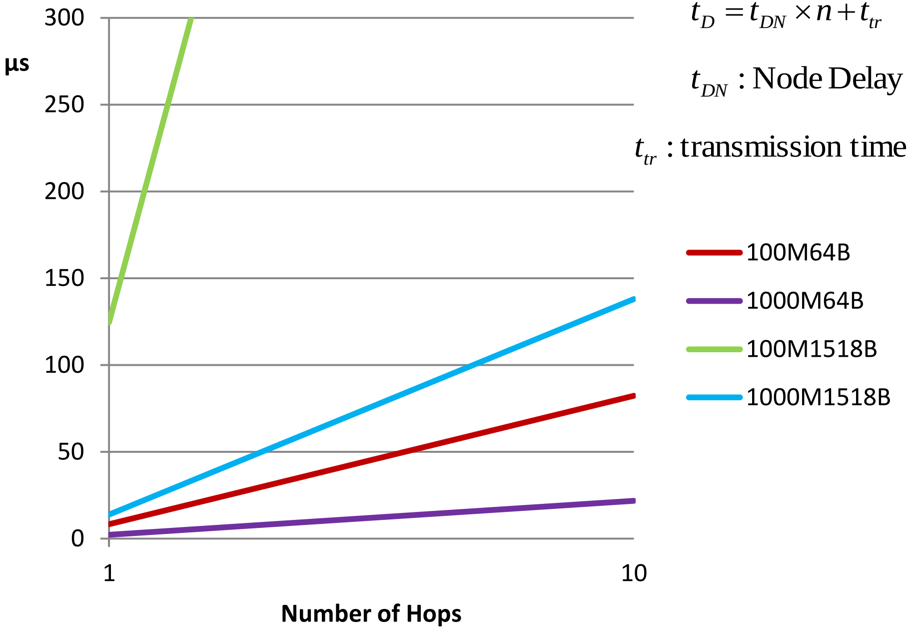

Summary

- Automation technology developed in several application fields
- Ethernet was introduced for transmission rate and IT connectivity
- ODVA uses COTS technology and supports internetworking in its specification
- CIP is ready for the Industrial Internet of Things
- Discovery service could be added
- When TSN becomes available EtherNet/IP could be easier to apply in time critical applications in the presence of IT traffic
- The formerly separated application fields can be merged into one network (this is already true for EtherNet/IP)

THANK YOU