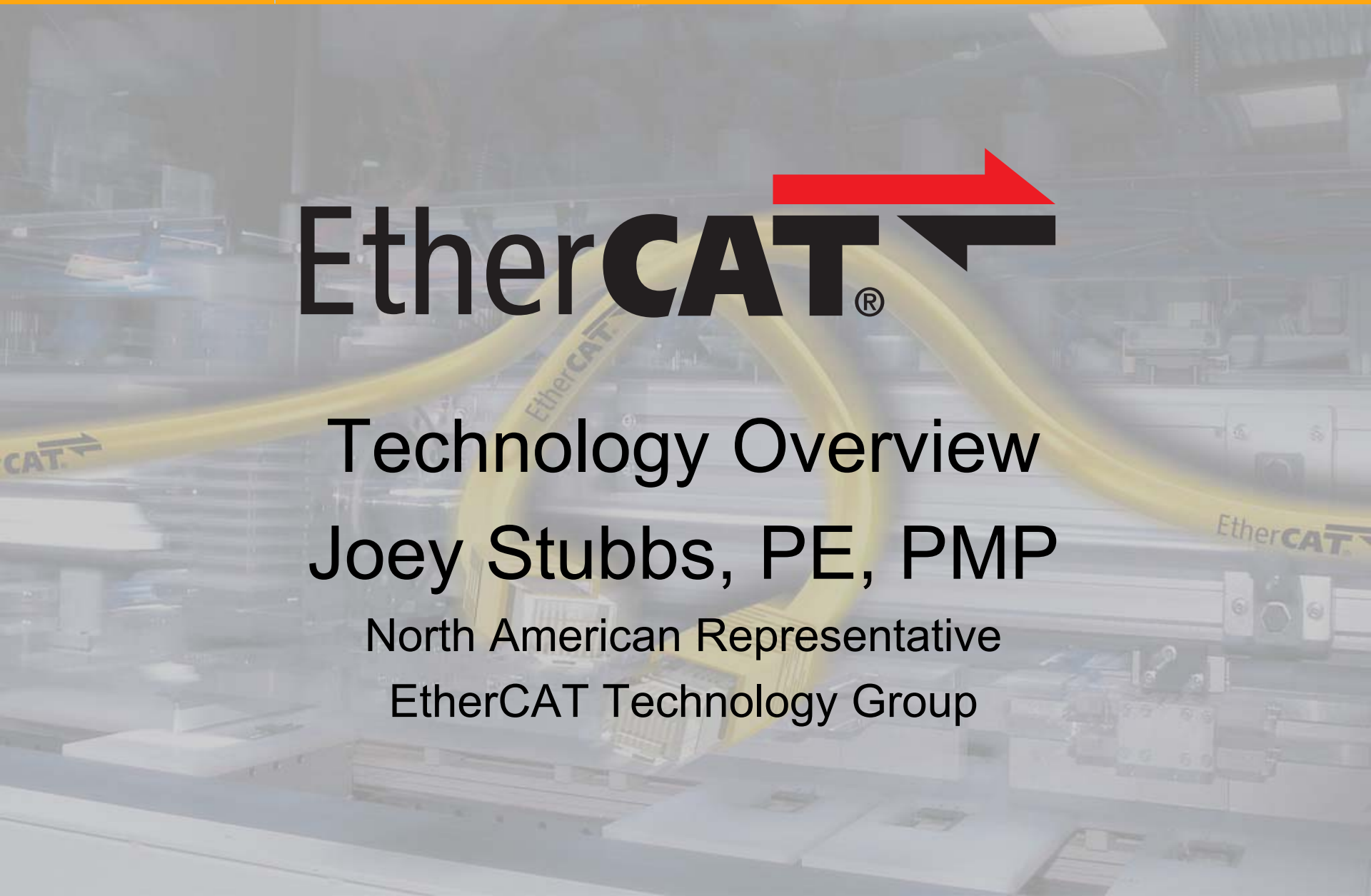


EtherCAT®

Technology Overview

Joey Stubbs, PE, PMP

North American Representative

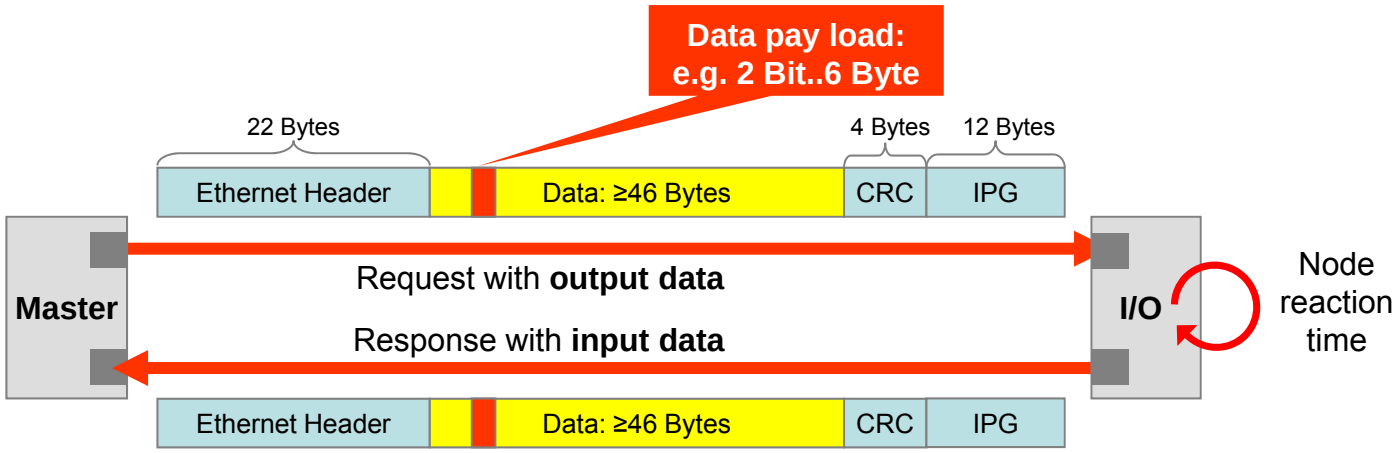
EtherCAT Technology Group

EtherCAT is faster

EtherCAT is:

- Faster
- Synchronization
- Industrial Ethernet
- Flexible Topology
- Open
- Conformance
- Safety
- Redundancy
- Versatile

- Bandwidth Usage of Ethernet for I/O and Drives:
  - Ethernet Frame: ≥ 84 Bytes
    incl. Preamble & IPG (interpacket gap)



  - with 4 Byte input + 4 Byte output per node:
    - **4.75%** application data ratio at **0 µs** reaction time/node
    - **1.9%** application data ratio at **10 µs** reaction time/node

Polling: Functional Principle (Modbus TCP example)

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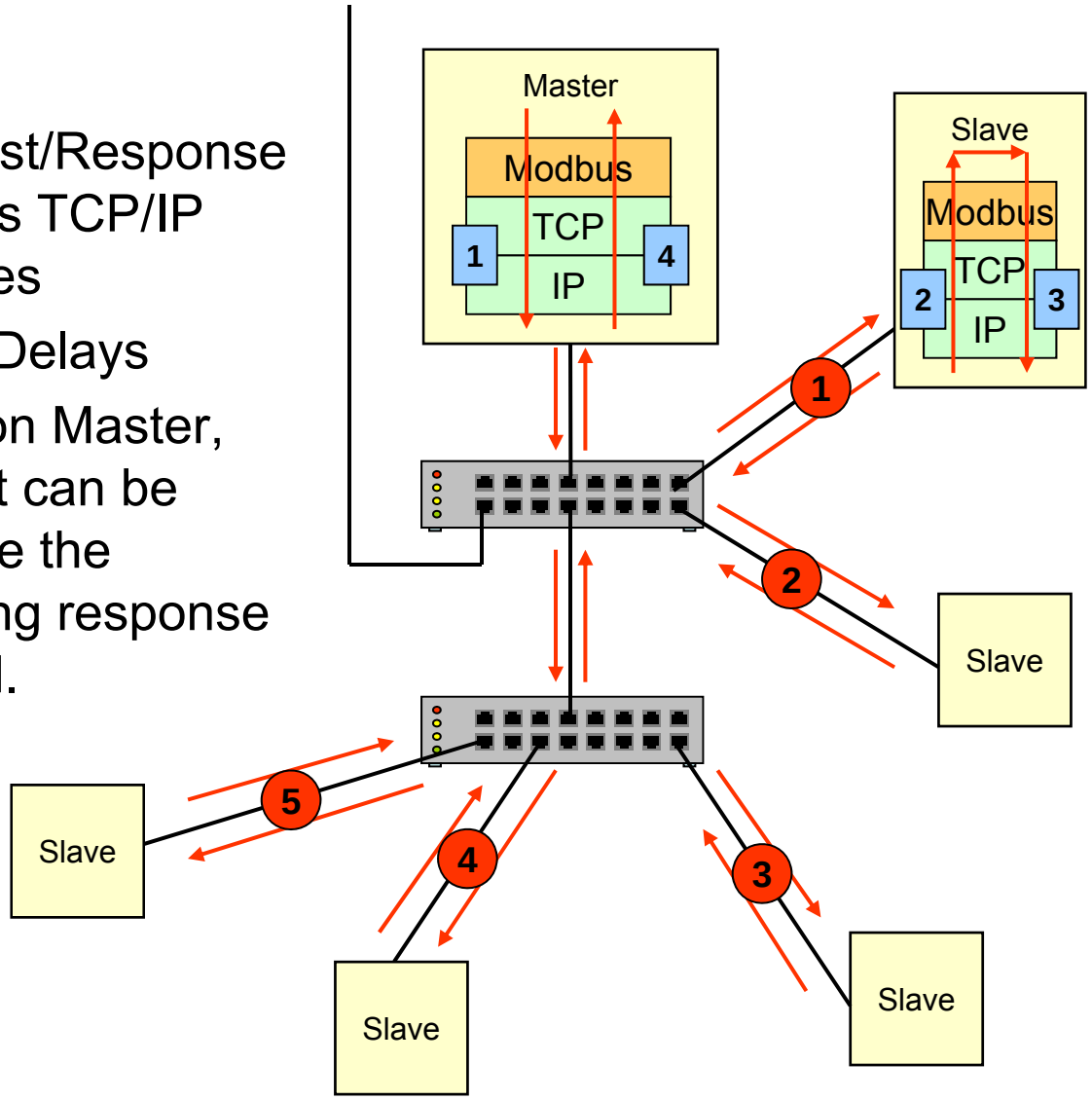
- Polling
- Each Request/Response Cycle passes TCP/IP Stack 4 Times
- plus Switch Delays
- Depending on Master, Poll Request can be issued before the corresponding response has returned.



Functional Principle: Ethernet “on the fly“

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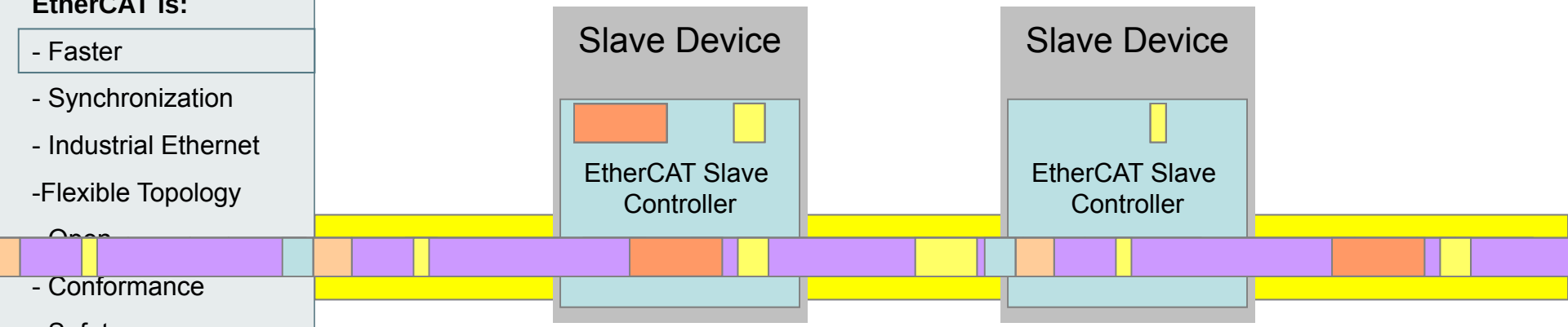

- Process data is extracted and inserted on the fly:
  - Process data size per slave almost unlimited (1 Bit…60 Kbyte, if needed using several frames)
  - Compilation of process data can change in each cycle, e.g. ultra short cycle time for axis, and longer cycles for I/O update possible
  - in addition asynchronous, event triggered communication

Frame Processing within each node

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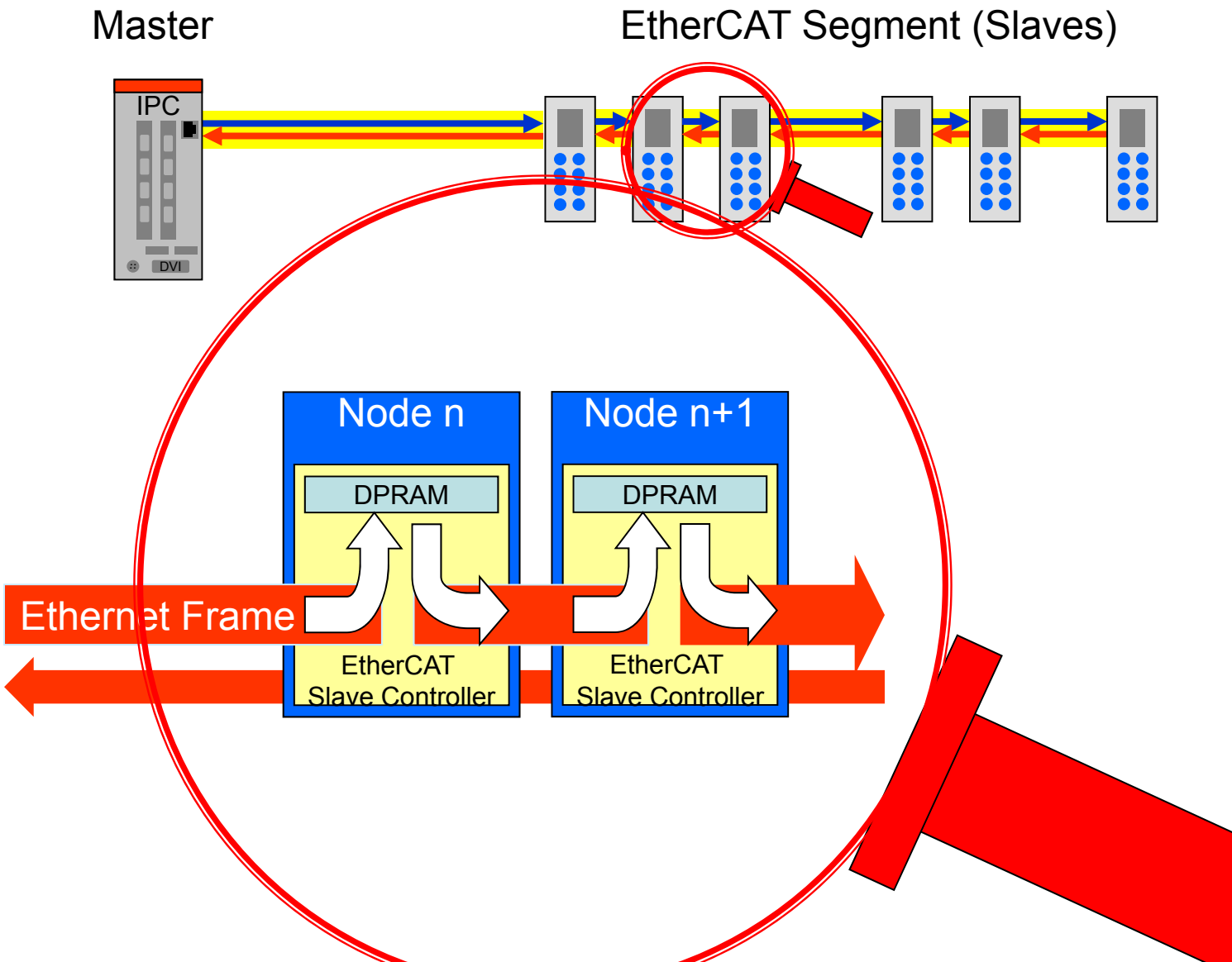

Frame Processing Order on the System

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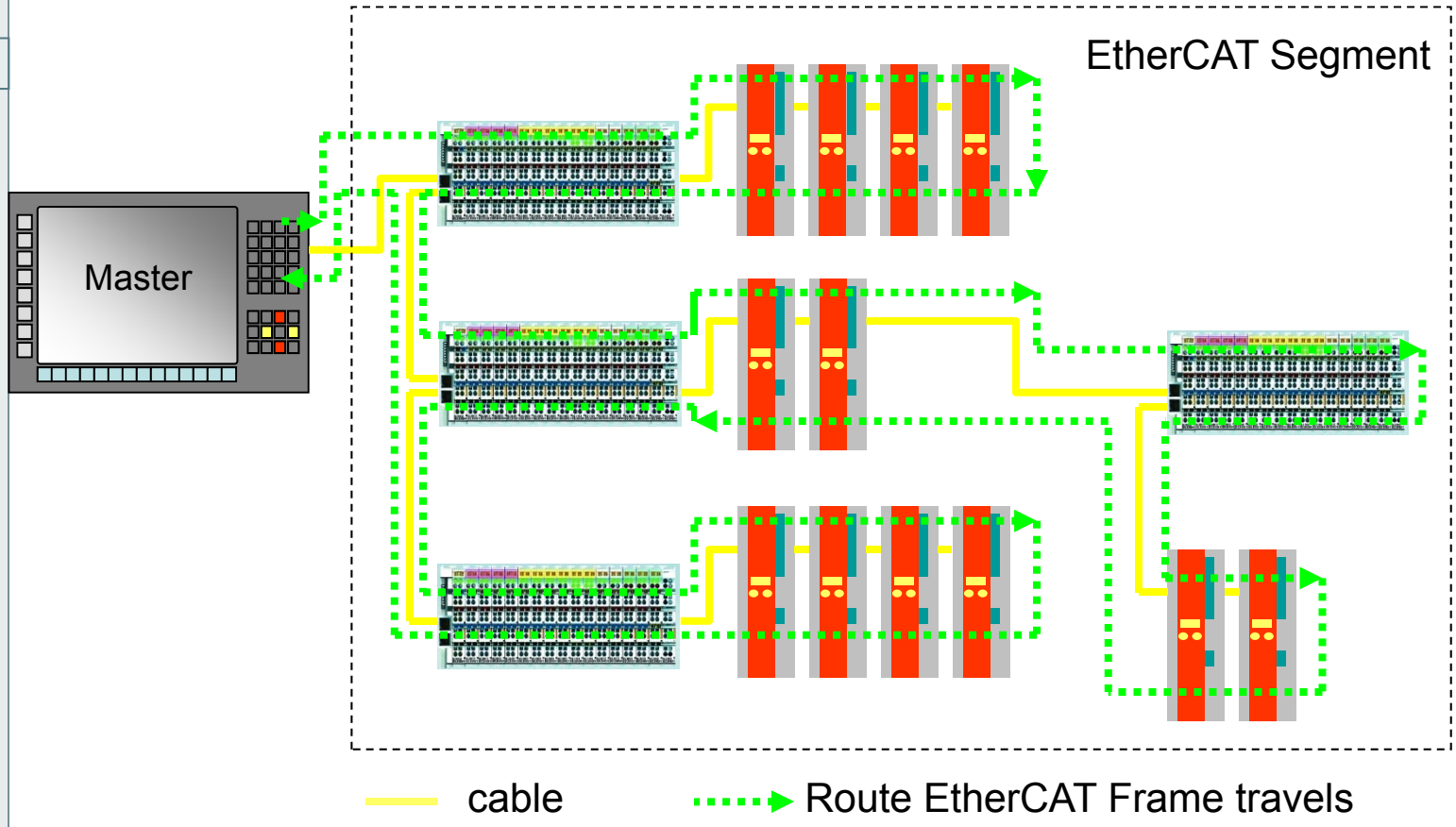

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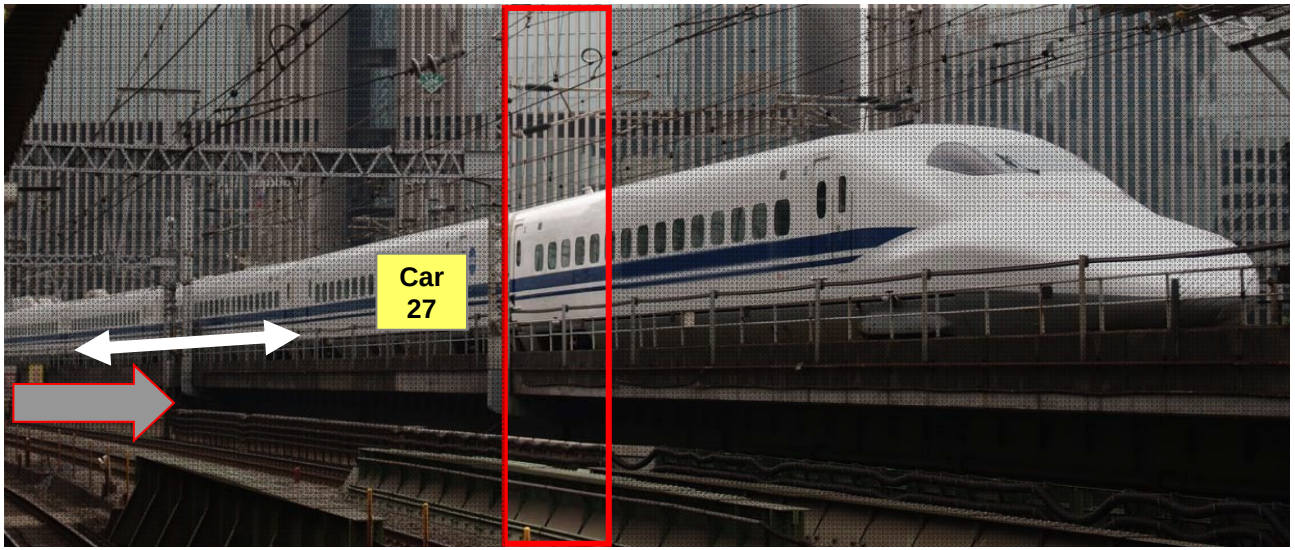

- Analogy Fast Train:
  - “Train” (Ethernet Frame) does not stop
  - Even when watching “Train” through narrow window one sees the entire “Train”
  - “Car” (Sub-Telegram) has variable length
  - One can “extract” or “insert” single “persons” (Bits) or entire “groups” (Bytes) – even multiple groups per train

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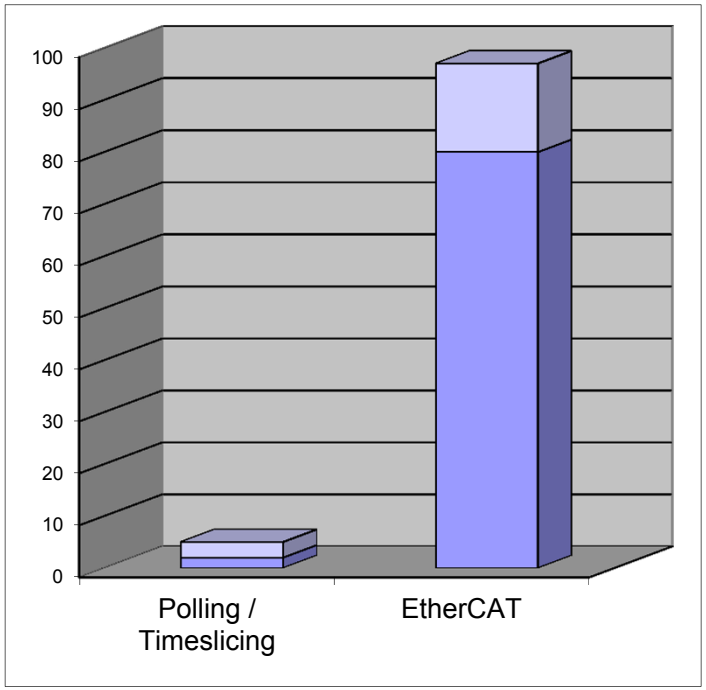
- Bandwidth Usage Comparison:
  - At 4 Byte user data per node:
    - Polling / Timeslicing: ~ 2..5 %
  - From 2 Bit user data per node:
    - **EtherCAT: ~ 80..97 % (Full Duplex, 2 x 100 MBit/s)**



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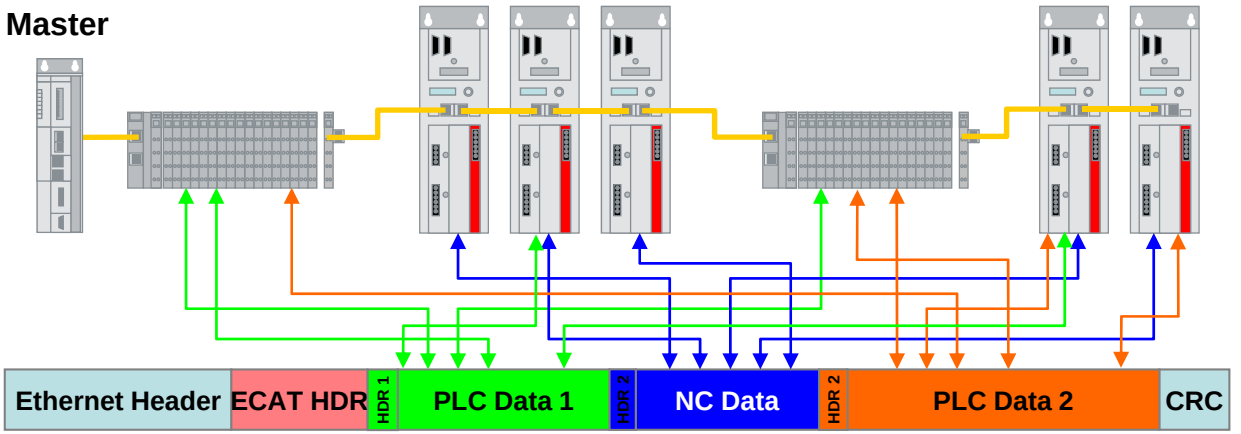

- Minimal protocol overhead via implicit addressing
  - Optimized telegram structure for decentralized I/O
  - Communication completely in hardware: maximum (and predictable!) performance
  - No switches needed if only EtherCAT devices in the network
  - Outstanding diagnostic features
  - Ethernet-compatibility maintained

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- Transmission Rate:
  - 2 x 100 Mbit/s (Fast Ethernet, Full-Duplex)

- Update Times:
  - 256 digital I/O in 11 µs
  - **1000 digital I/O** distributed to 100 nodes in **30 µs** = 0.03 ms
  - 200 analog I/O (16 bit) in 50 µs, 20 kHz Sampling Rate
  - **100 Servo-Axis** (each 8 Byte In + Out) in **100 µs** = 0.1 ms
  - 12000 digital I/O in 350 µs

Performance: Application Example

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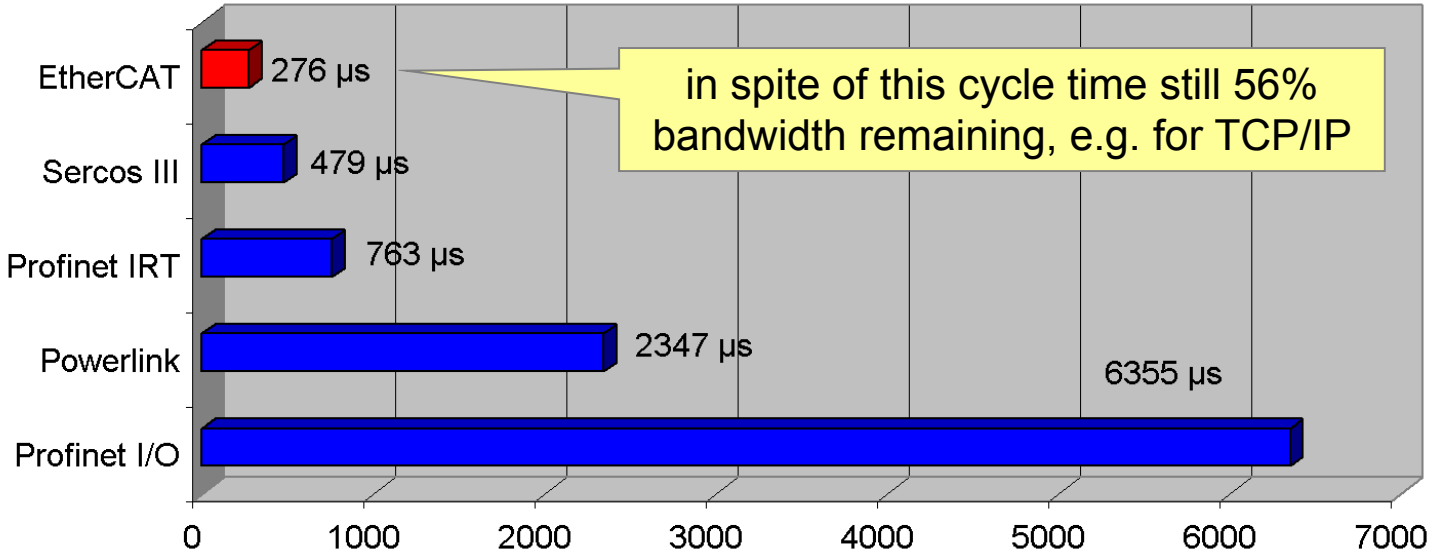
- 40 Axis (each 20 Byte Input- and Output-Data)
- 50 I/O Station with a total of 560 EtherCAT Bus Terminals
- 2000 Digital + 200 Analog I/O, Bus Length 500 m
- Performance EtherCAT: **Cycle Time = 276 µs** at 44 % Bus Load, **Telegram Length = 122 µs**
- **Note – Ethernet/IP is not shown due to scale limits of graph and number of master cards required!**



EtherCAT - The Ethernet Fieldbus.

EtherCAT is:

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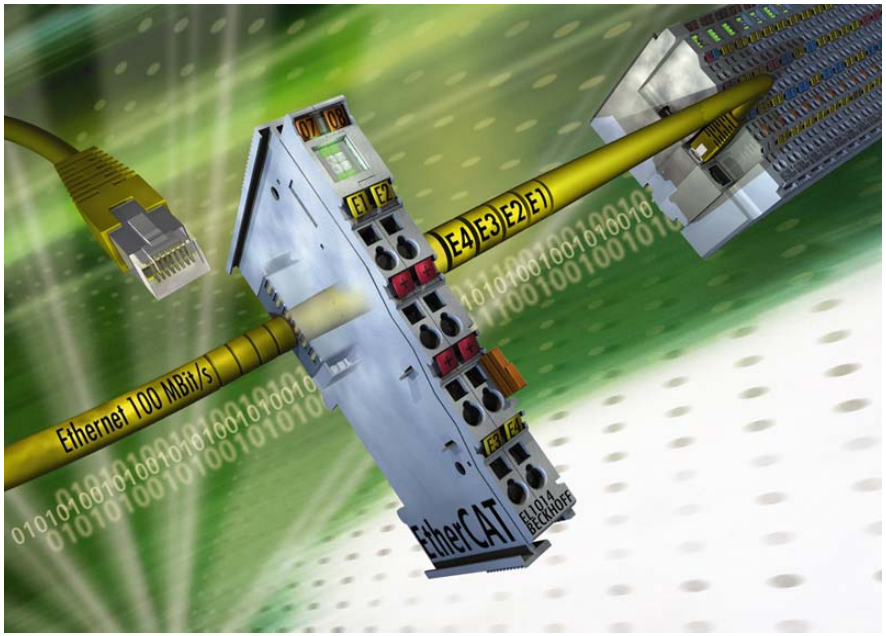
- EtherCAT is real time down to the I/O level
- No underlying sub-systems any more
- No delays in gateways
- In- and outputs, sensors, actuators, drives, displays: **everything in one system!**



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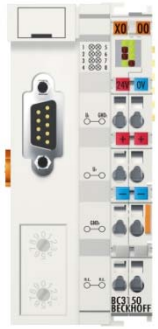
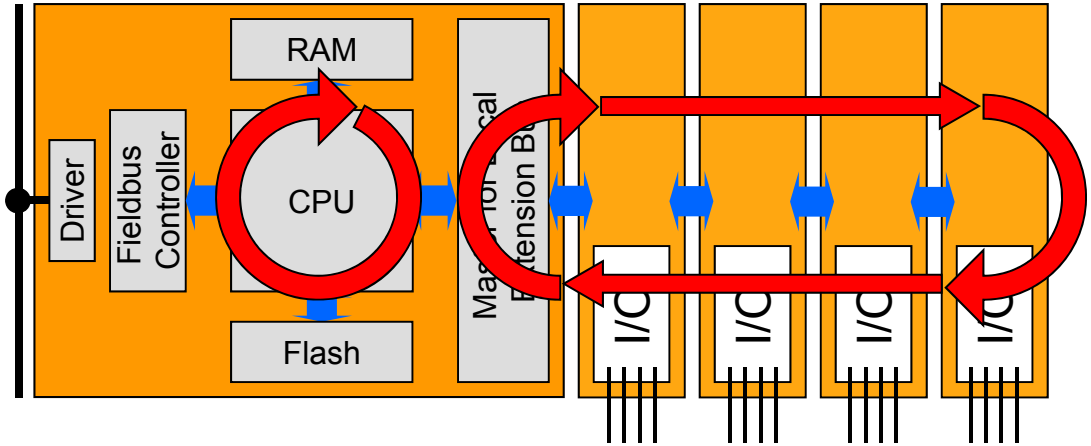
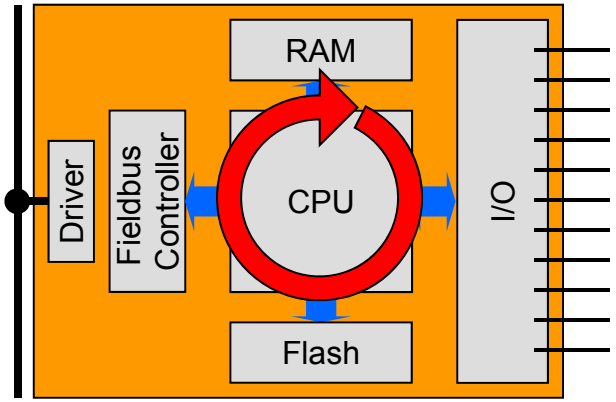
- Other technologies need local I/O cycles + gateways







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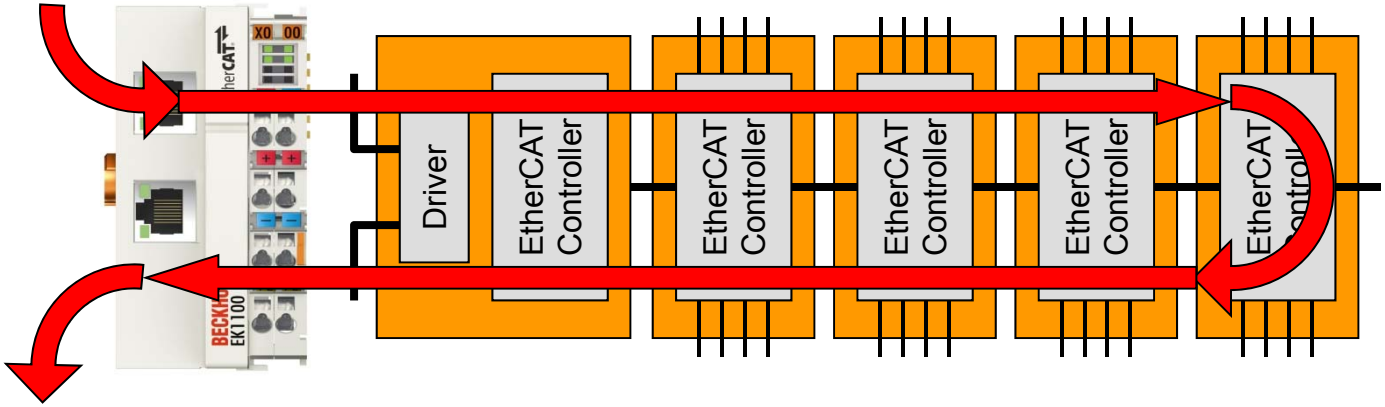

‘Slow’ Control Systems benefit, too

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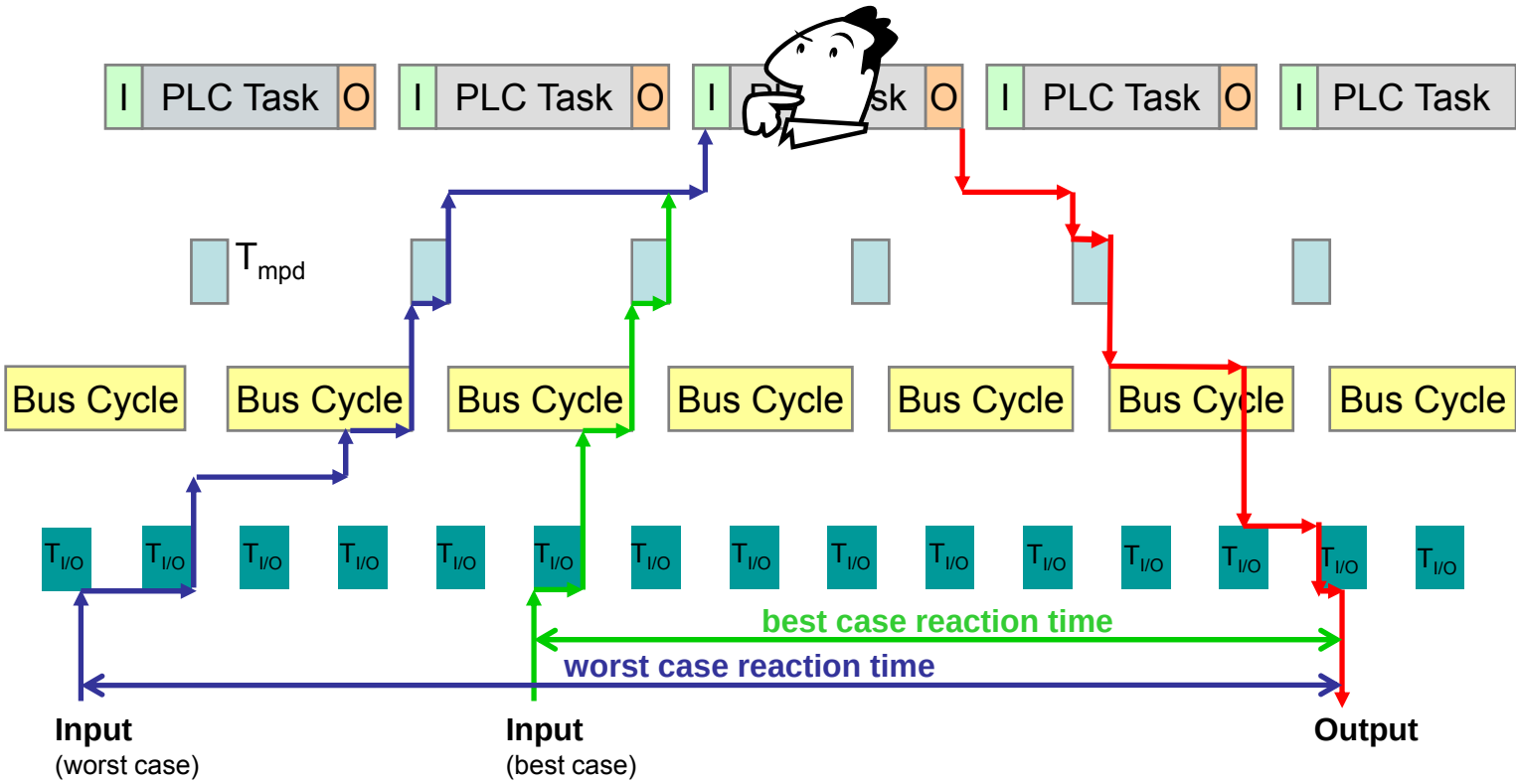
Reaction time with legacy fieldbus I/O:



T_{mpd}: Master Processing Delay

$T_{I/O}$: Local I/O Update Time
(local Extension Bus + Firmware)

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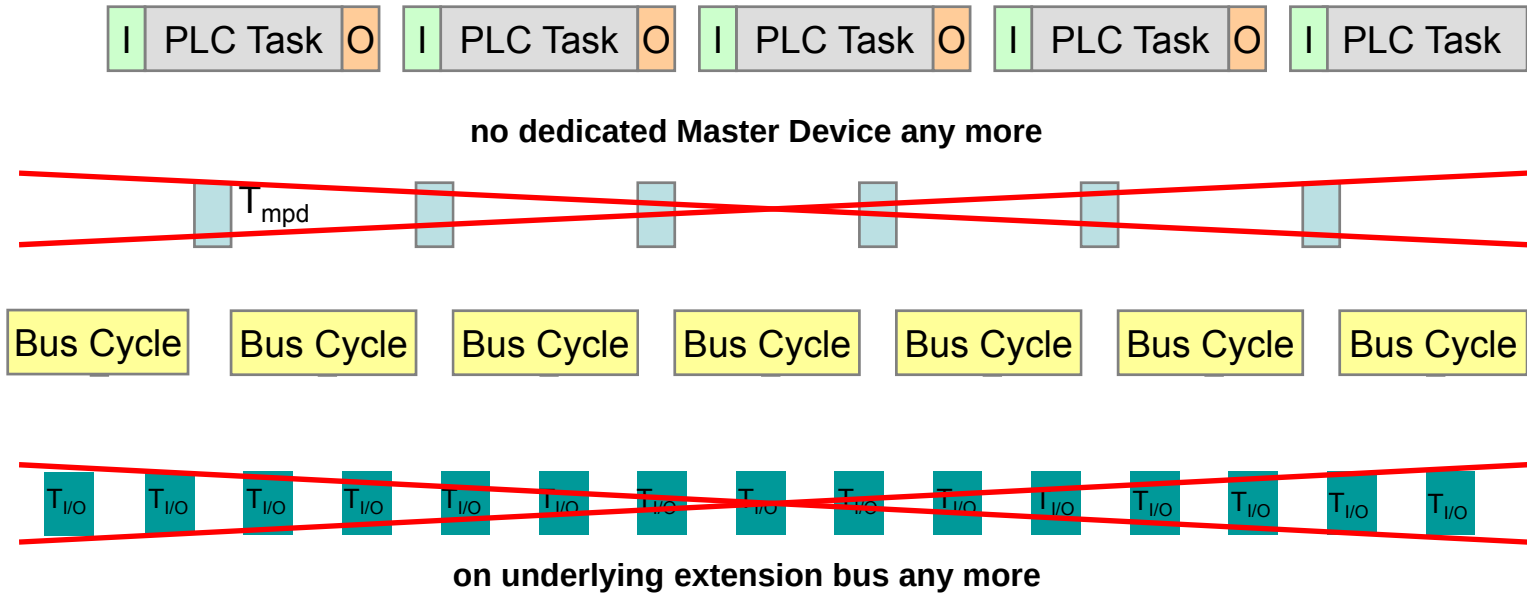
System Architecture with EtherCAT:



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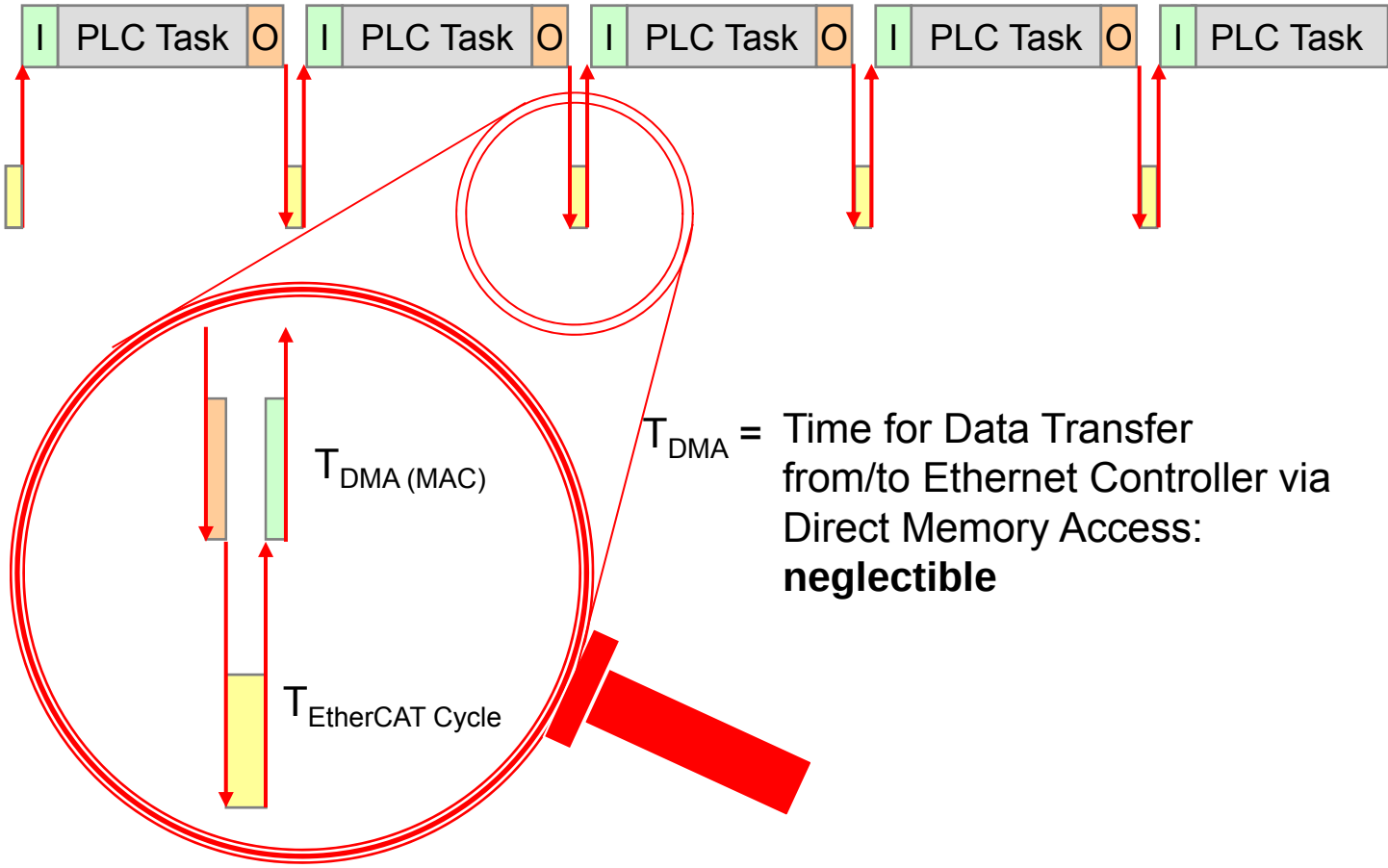

T_{DMA} = Time for Data Transfer from/to Ethernet Controller via Direct Memory Access: **neglectible**

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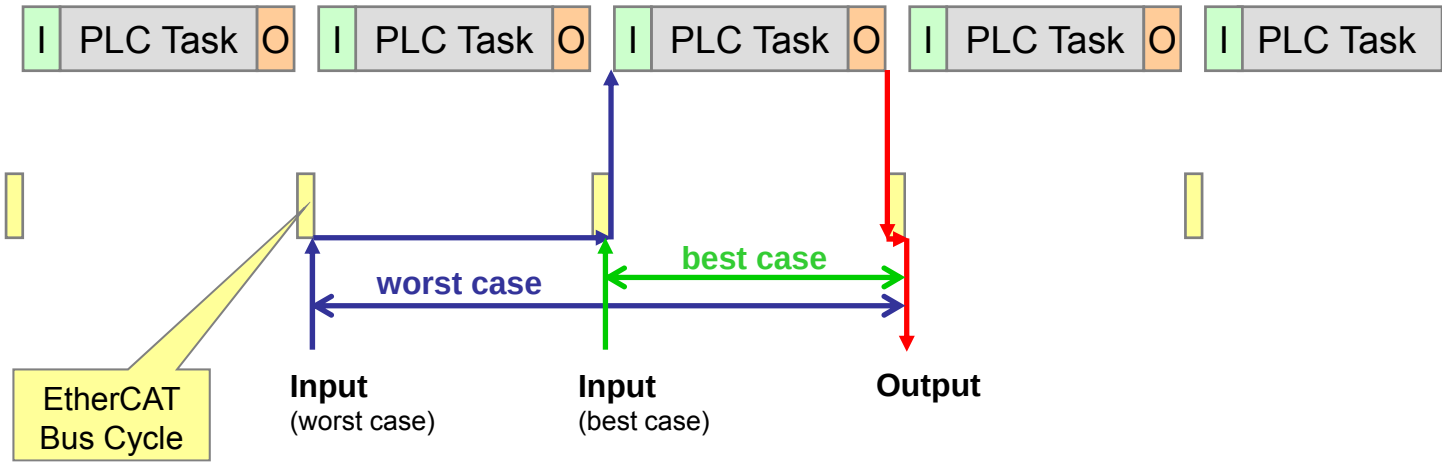
Reaction Time with EtherCAT:



- Reaction time reduced significantly with the same controller performance
- no underlying local I/O cycles and extension bus delays any more
- Due to the very simple protocol no dedicated master systems (e.g. plug-in cards) required

Fieldbus: requires Mapping in Control System

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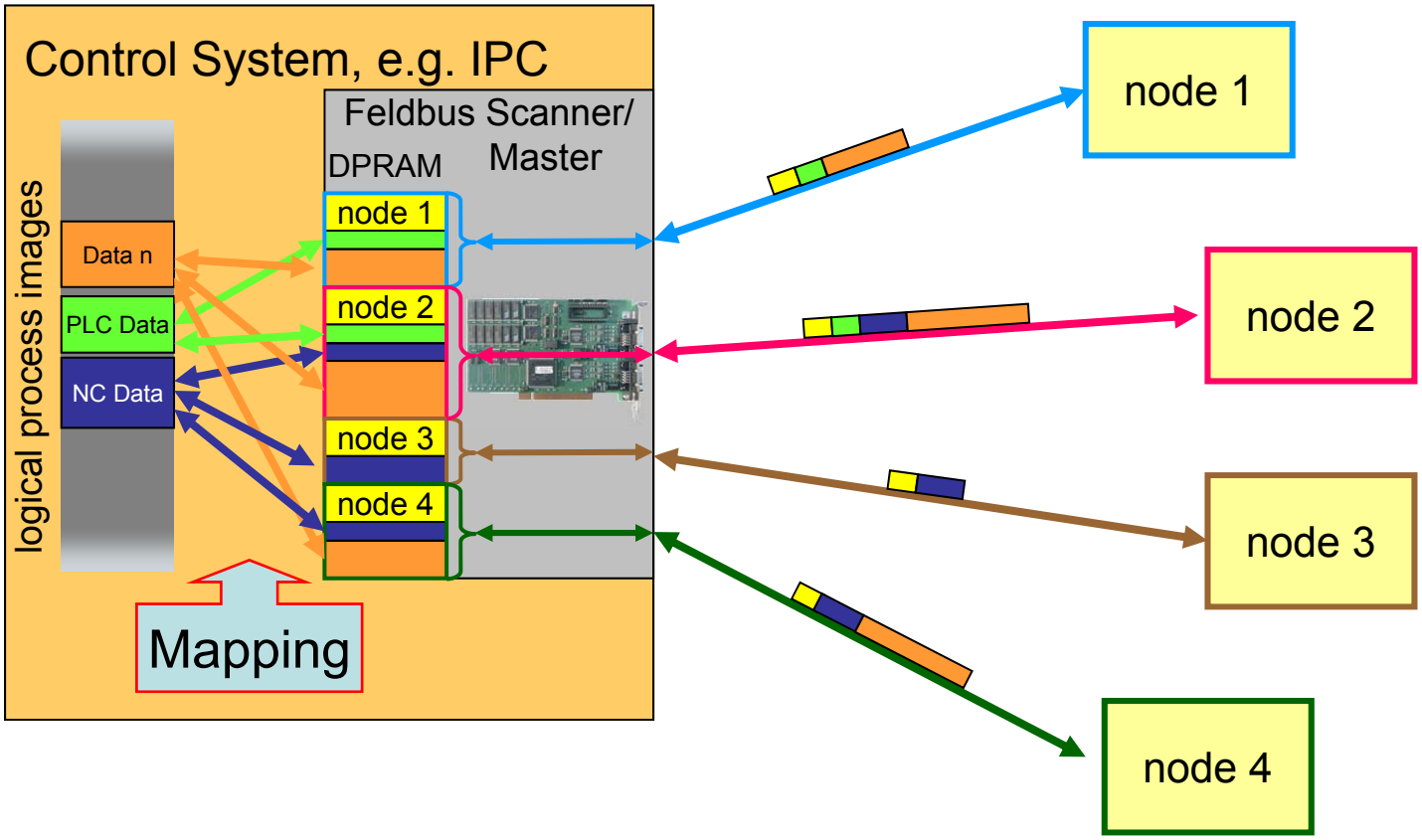
- Traditional fieldbus system generate *physical* process image
- This has to be mapped to *logical* process image(s)



Fieldbus: requires Mapping in Control System

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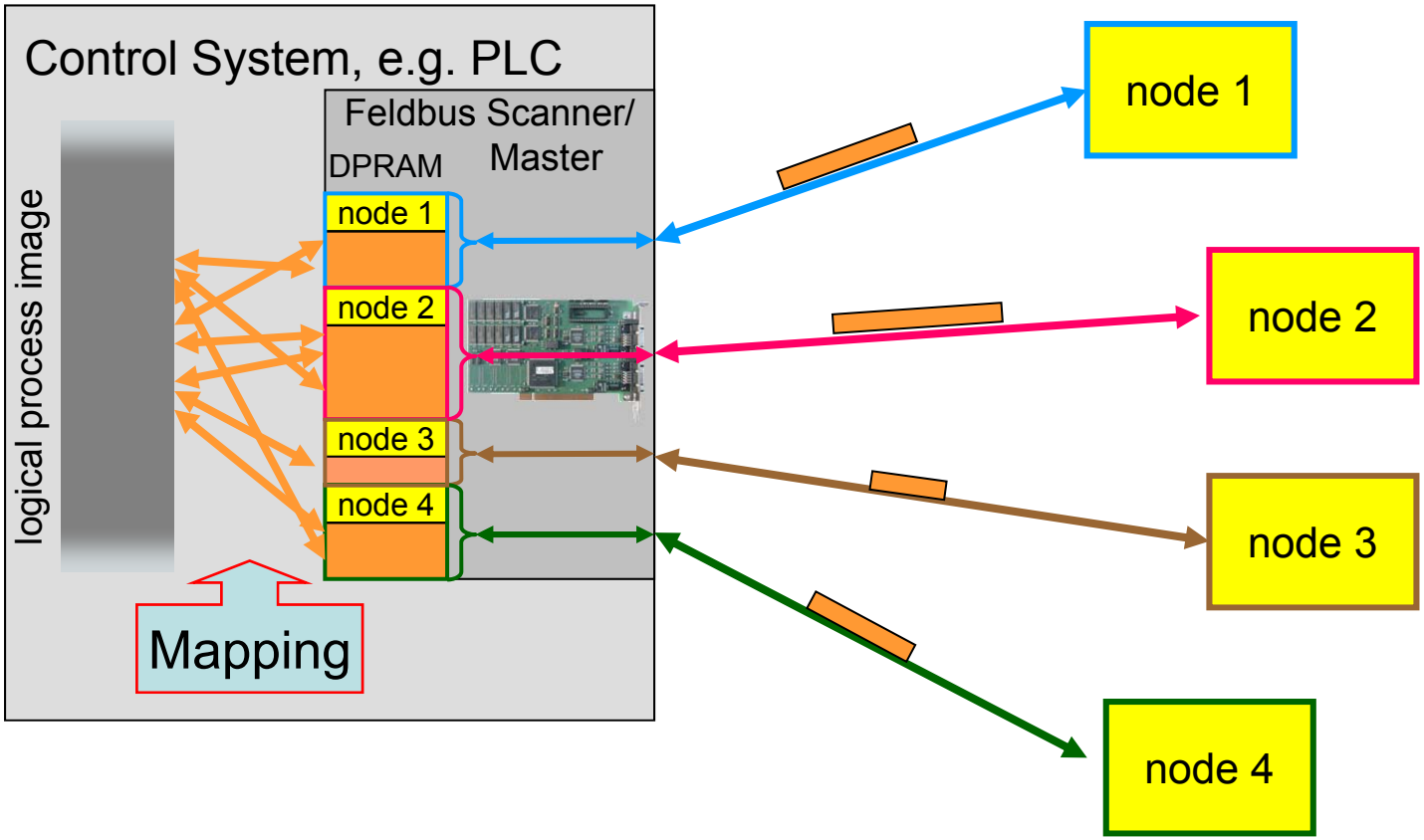
- The same applies to system with just one process image
- Resorting of process data (“Mapping”) is required, too



EtherCAT: Mapping moved into Slave Devices

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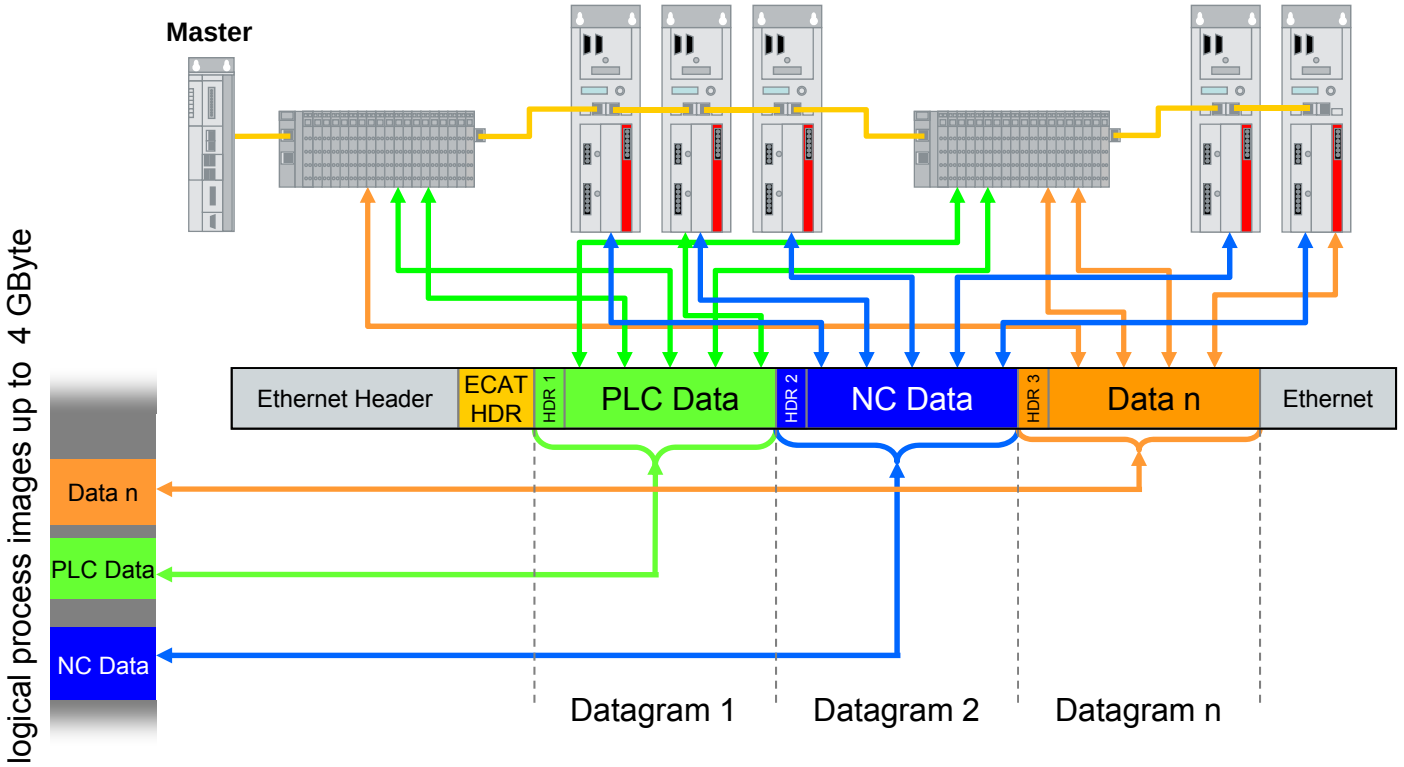

- Control System is unburdened, master becomes very simple
- Data is transmitted according to the application requirements: extremely fast, flexibly and efficiently

EtherCAT Propagation Delay Measurement (1)

EtherCAT is:

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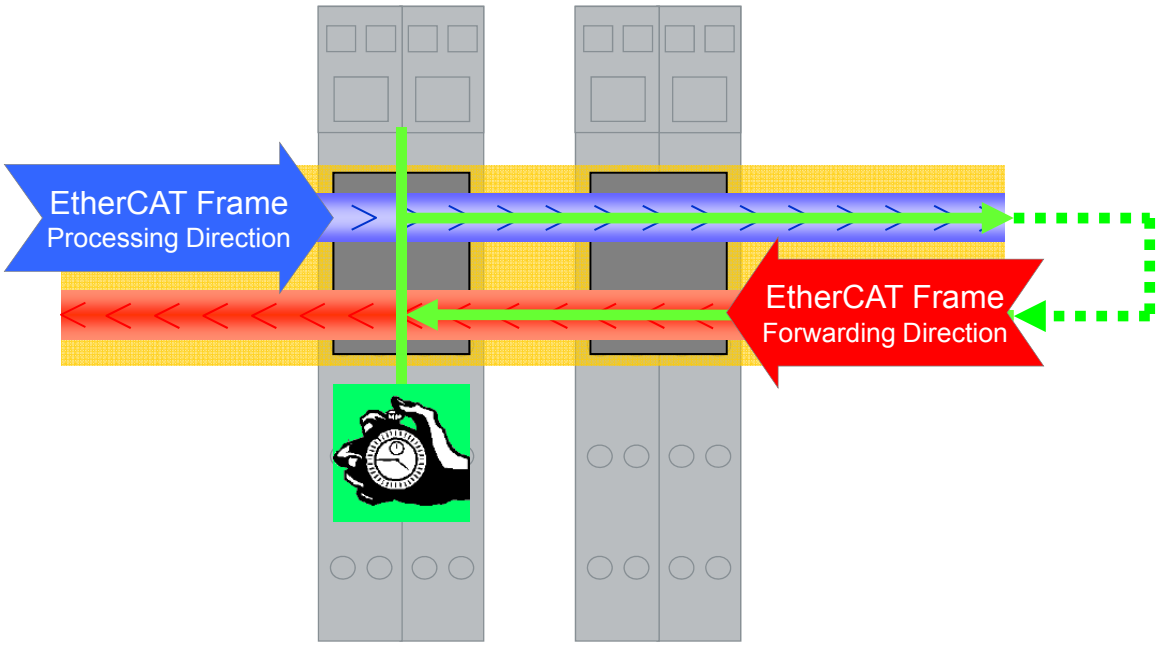
- EtherCAT Node measures time difference between leaving and returning frame



EtherCAT Propagation Delay Measurement (2)

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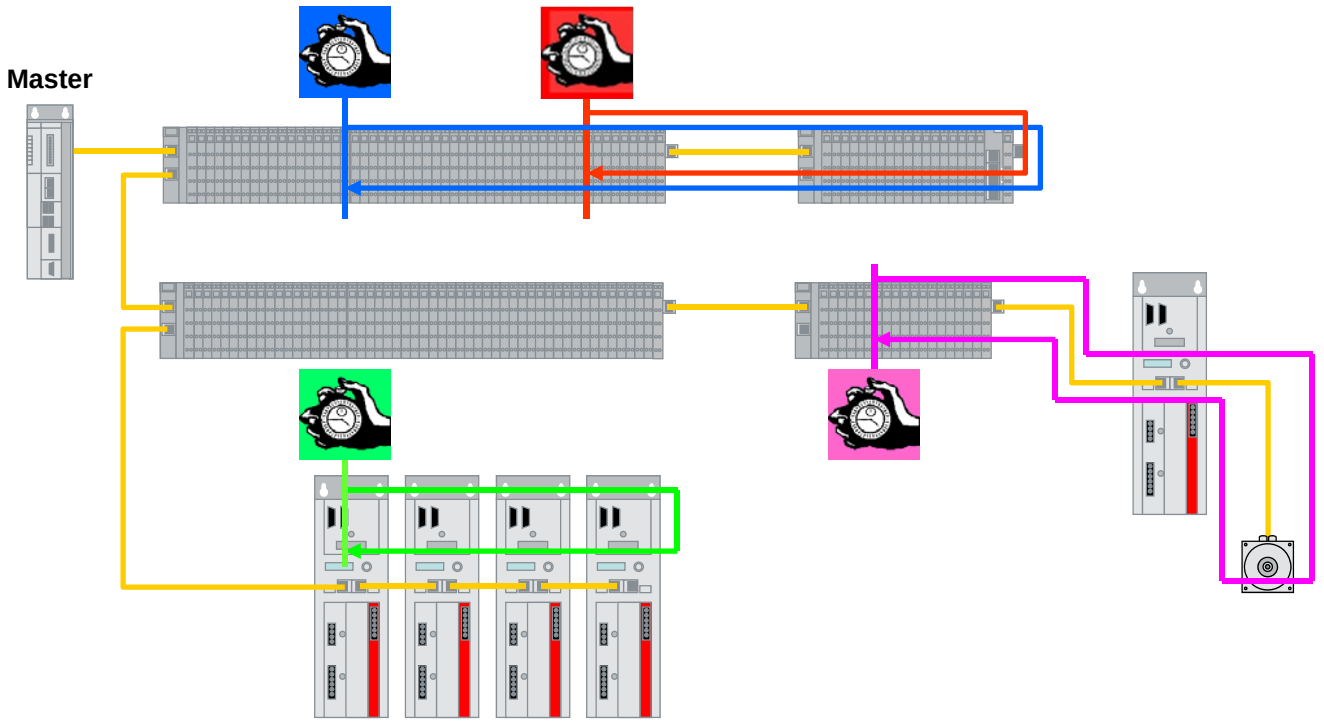

Distributed Clocks

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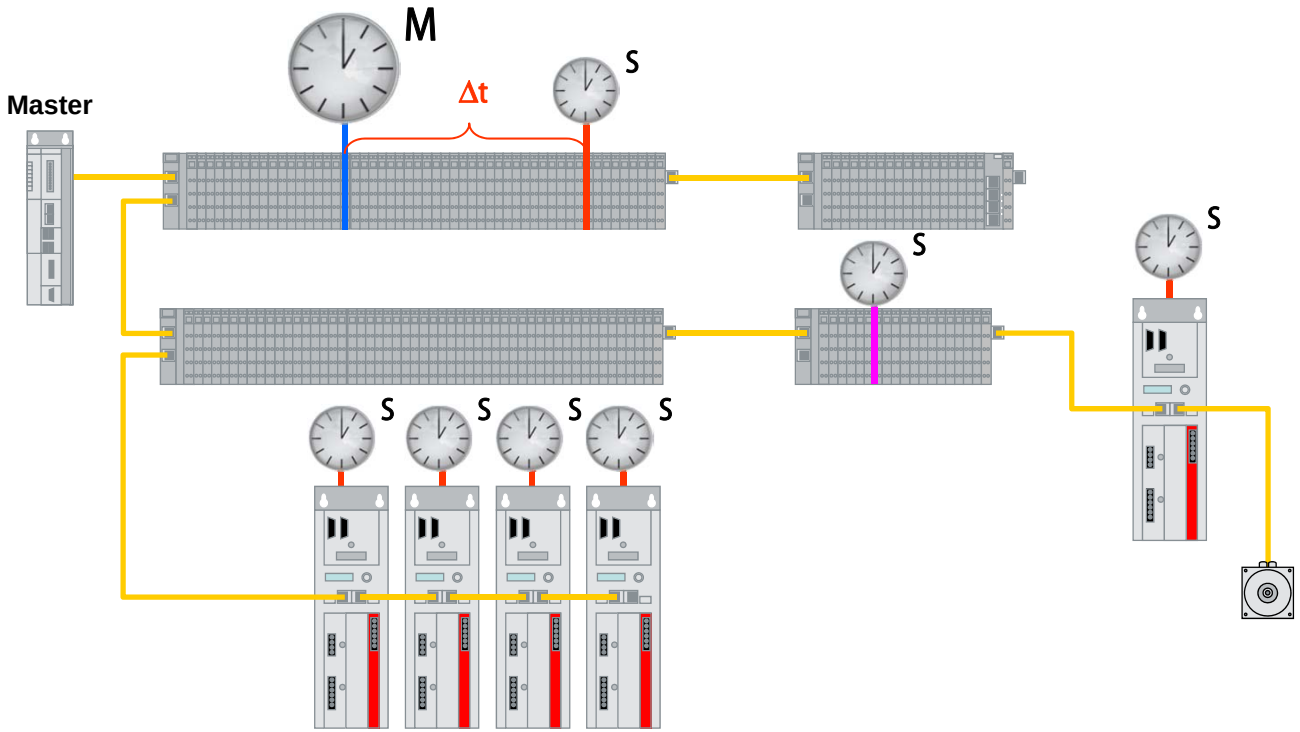
- Precise Synchronization (<< 1 µs!) by exact adjustment of Distributed Clocks



External Clock Synchronization: IEEE 1588

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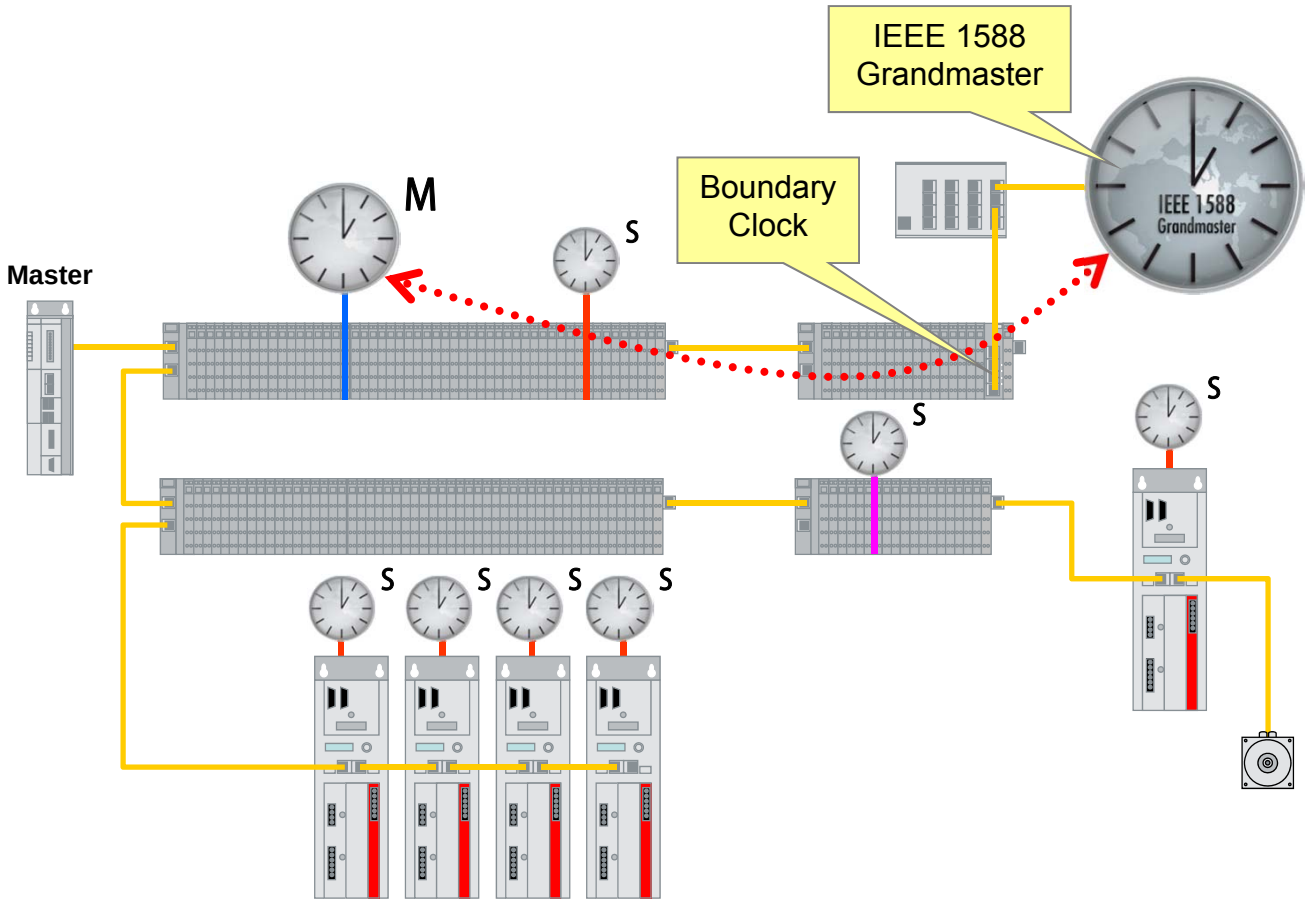
- Switchport with integrated IEEE 1588 Boundary Clock



Distributed Clocks

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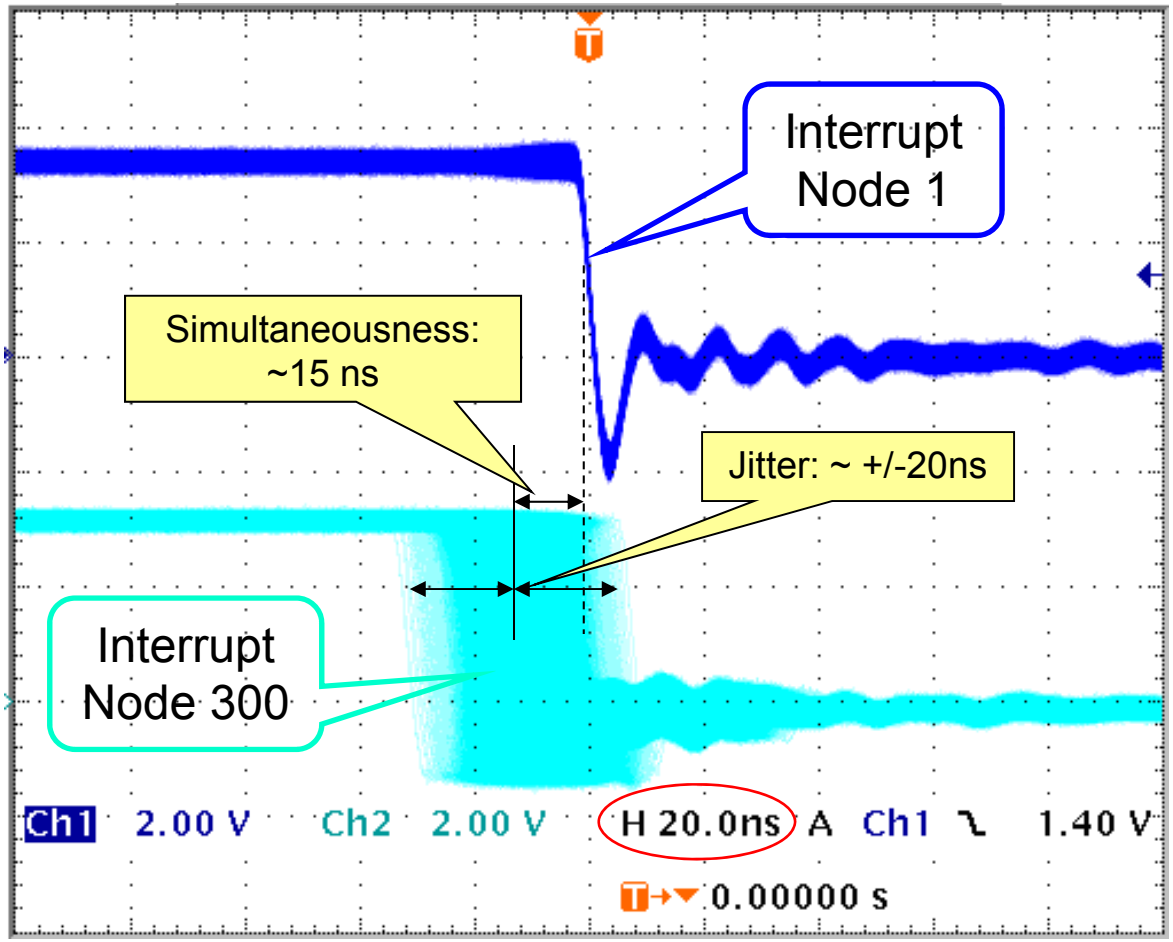
- Long Term Scope View of two separated devices
- 300 Nodes in between, 120m Cable Length



Synchronization of multiple Networks

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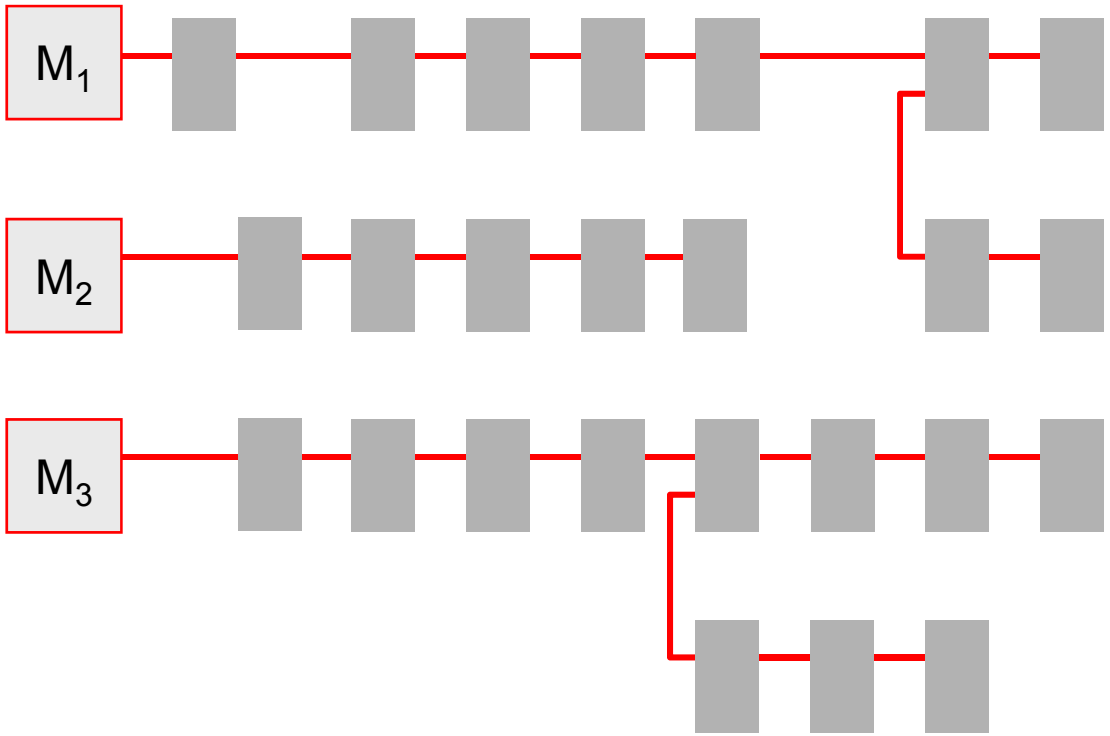
- EtherCAT networks can be coupled via EtherCAT Bridge
- Bridge provides hardware synchronization of several networks



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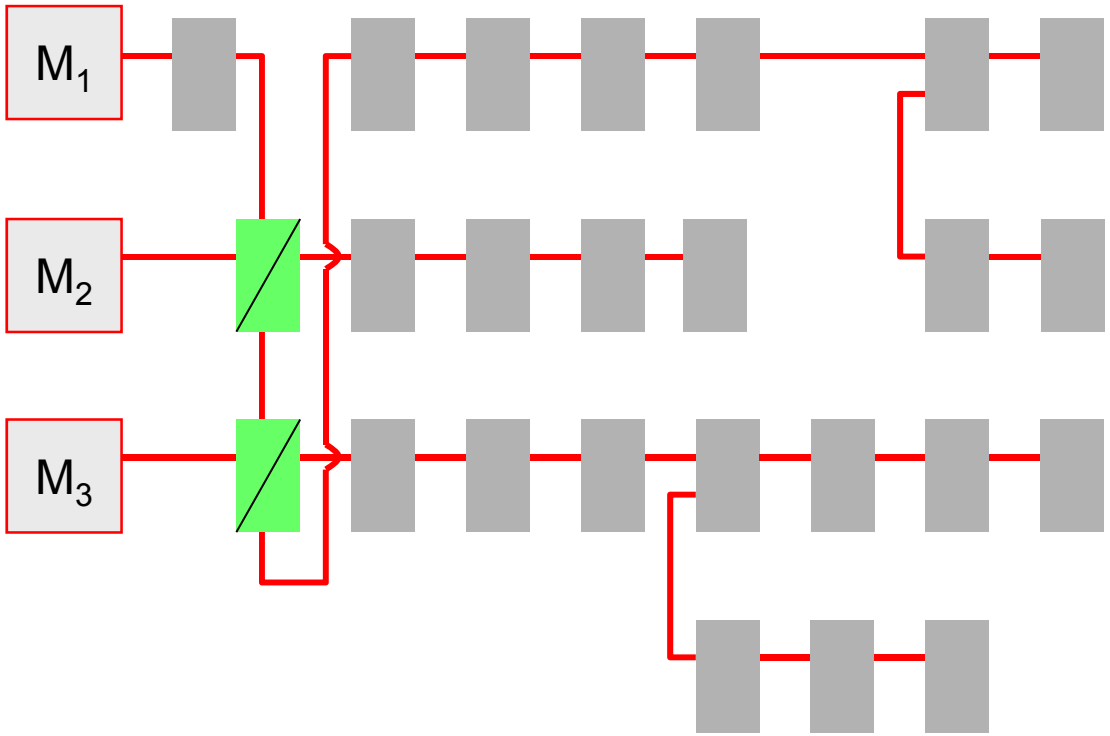

EtherCAT is Industrial Ethernet!

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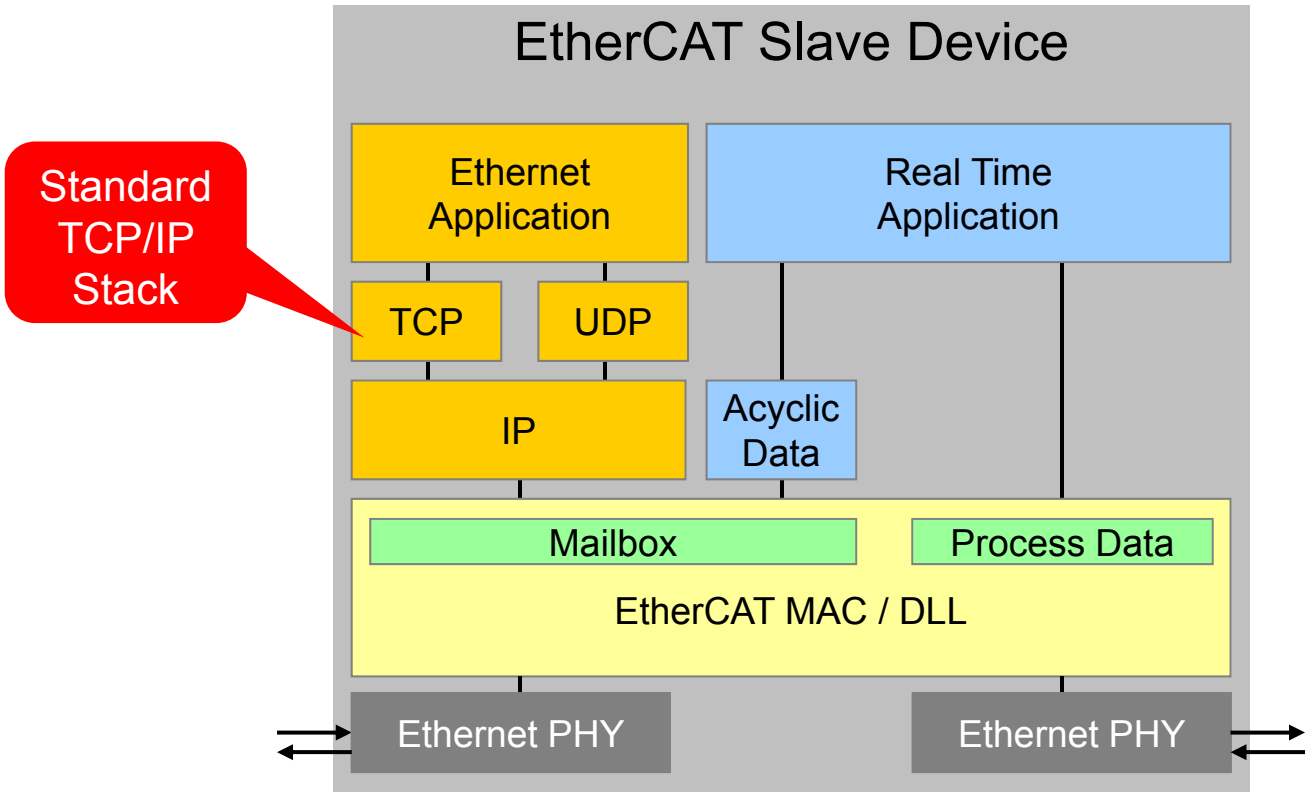
- fully transparent for TCP/IP
- all Internet technologies (HTTP, FTP, Webserver,…) available without restricting the real time capabilities!



EtherCAT is Industrial Ethernet!

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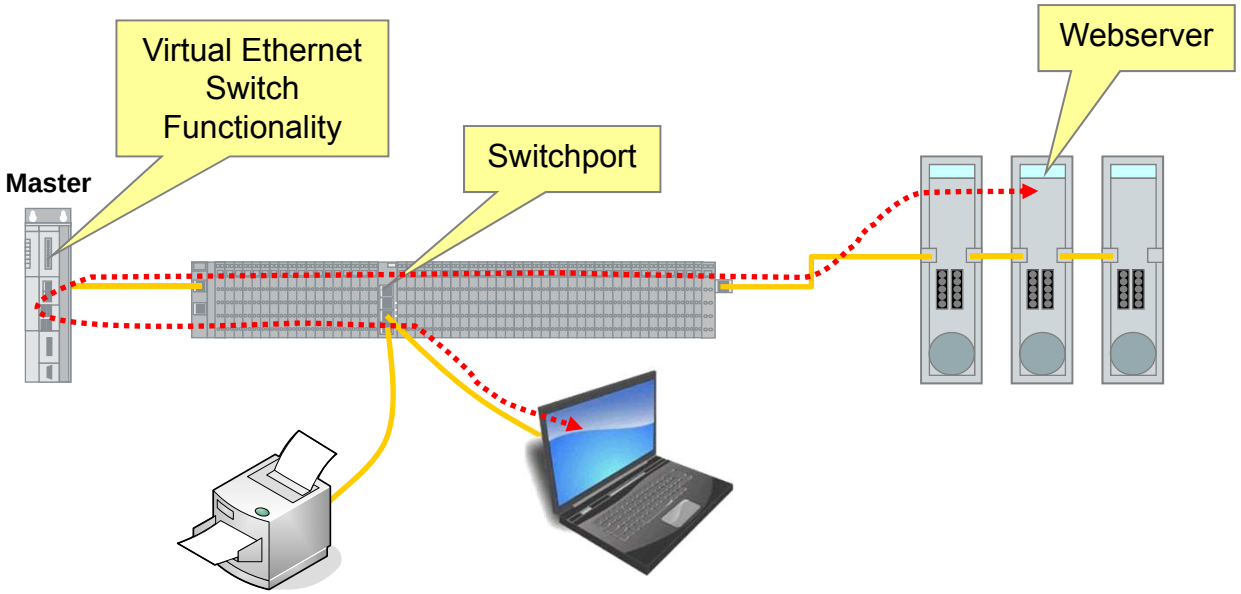
- Any Ethernet Device can be connected to Switchport
- Access to Webserver with Standard Browser



Switchport: Any Ethernet Protocol

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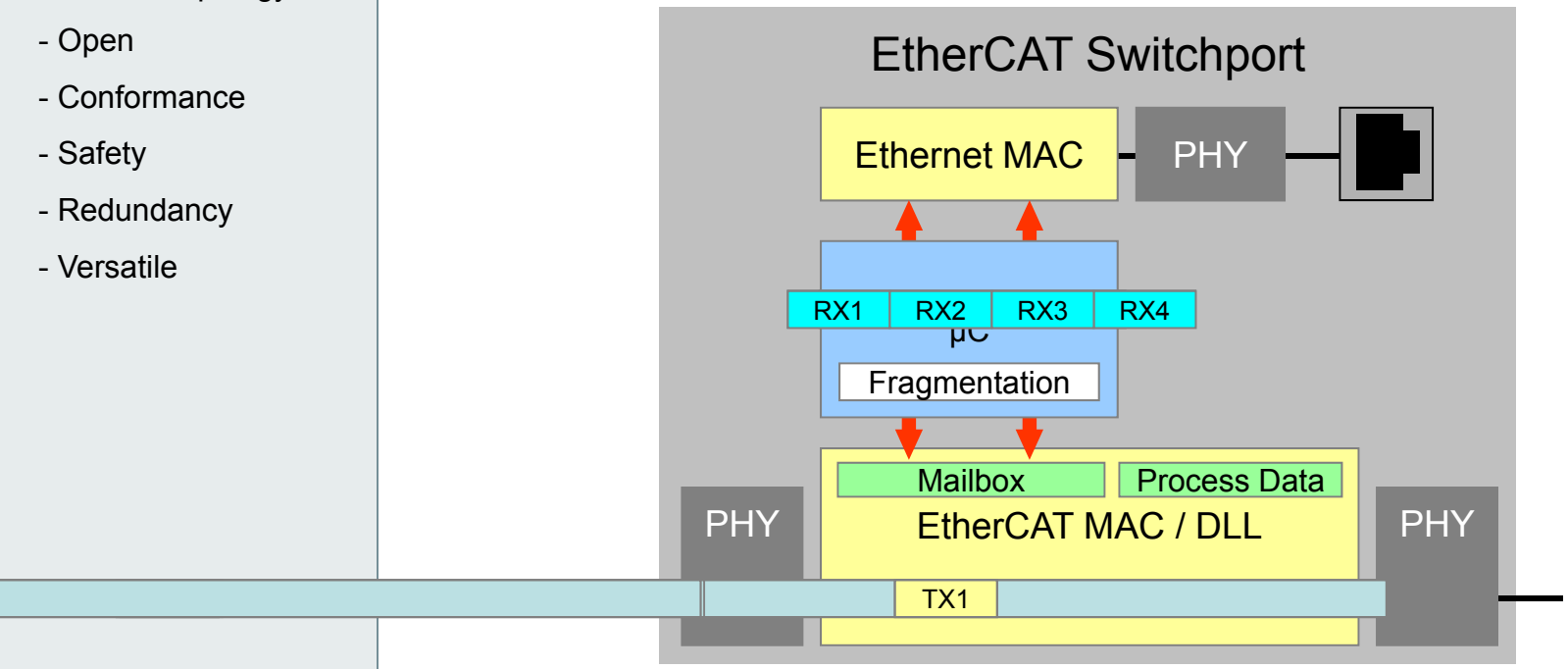
- Interface to any Ethernet Device or Network
- Ethernet Frames are inserted into EtherCAT Protocol:
  - 'Ethernet over EtherCAT'



EtherCAT is Industrial Ethernet!

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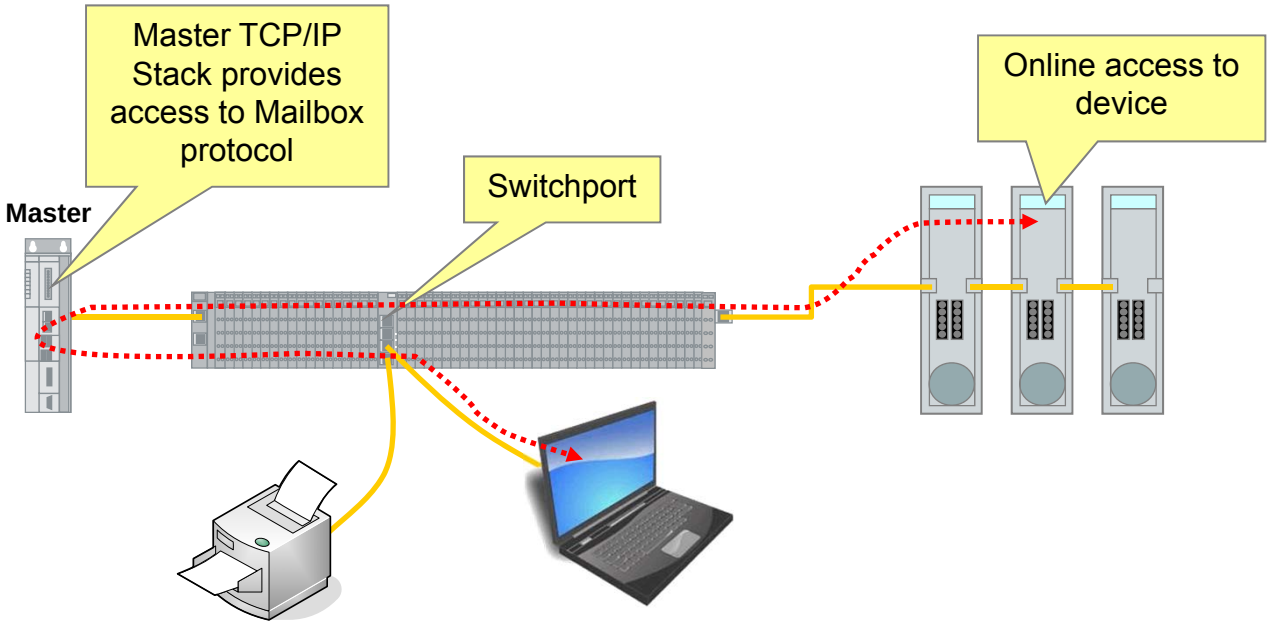
- Master TCP/IP Stack can provide remote Mailbox access via TCP/IP to any EtherCAT device – ideal for tools.
- No need for TCP/IP stack in each device: cost reduction



EtherCAT wiring is more flexible

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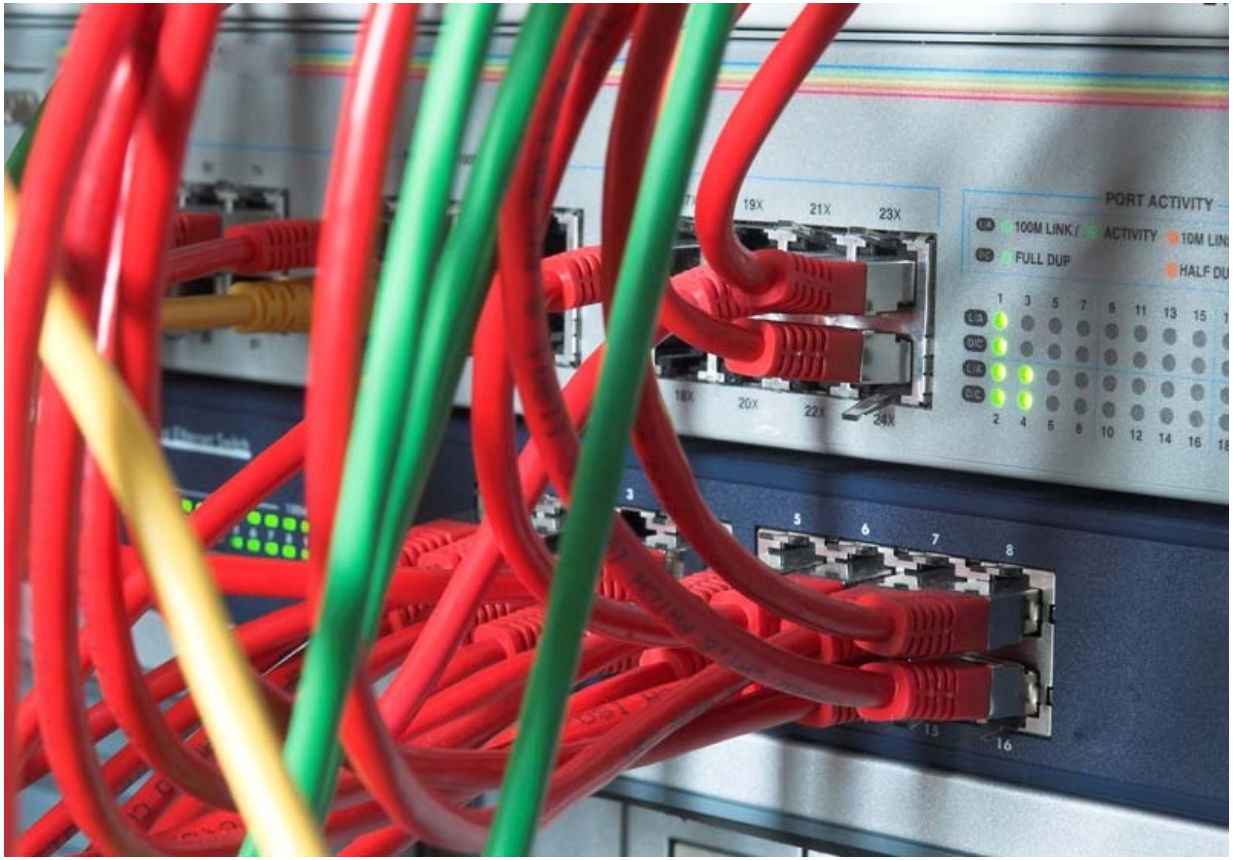
- Standard Ethernet Topology: Star



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- **-Flexible Topology**
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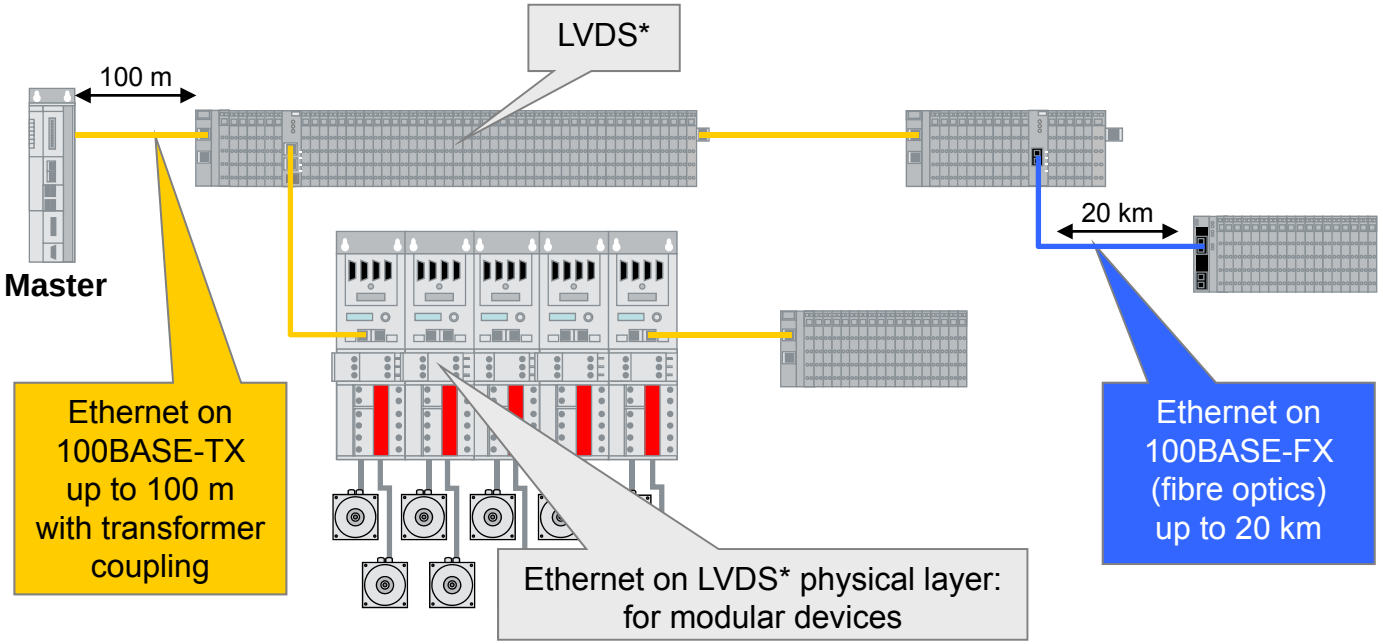
- Ethernet Signal Variants of EtherCAT:
  - 100BASE-TX (up to 100 m between 2 nodes)
  - 100BASE-FX (up to 20 km between 2 nodes (single mode fiber))
  - LVDS (for modular devices)



- Any number of physical layer changes allowed

*LVDS: Low Voltage Differential Signaling according to ANSI/TIA/EIA-644, also used in IEEE 802.3ae (10 Gigabit Ethernet)

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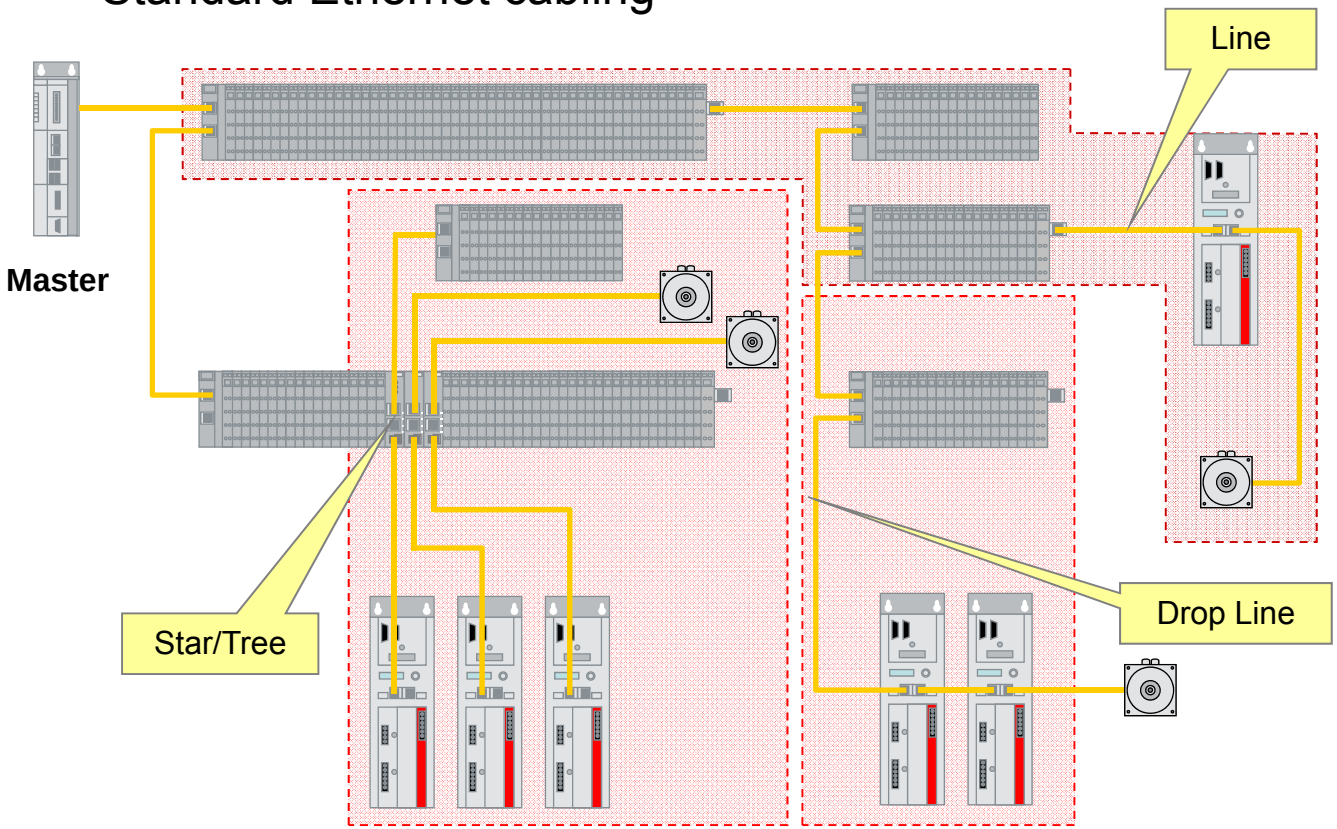
- Redundancy
- Versatile

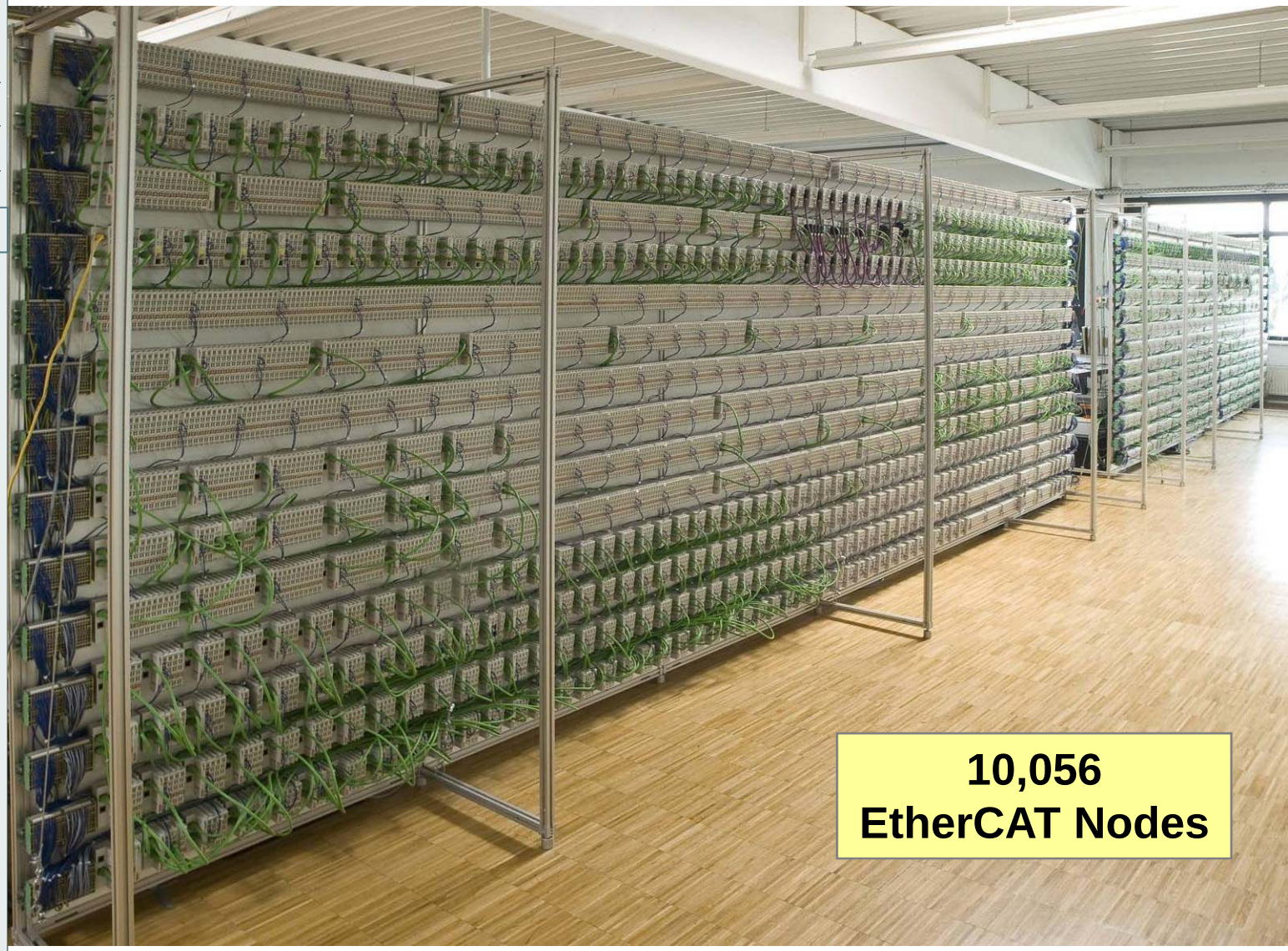
- Flexible topologies – arbitrarily extendable
  - Topology variants like Line, Star, Tree, Daisy Chain + Drop Lines possible; can be used in any combination!
  - Up to 65,535 nodes for each EtherCAT segment
  - Standard Ethernet cabling



EtherCAT Extra Large System Test

EtherCAT is:

- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
- -Flexible Topology
- Open
- Conformance
- Safety
- Redundancy
- Versatile



EtherCAT is an open technology

EtherCAT is:

- Faster ✓
- Synchronization ✓
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- Redundancy
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- Protocol is disclosed completely:
  - EtherCAT is IEC, ISO and SEMI Standard (IEC 61158, IEC 61784, ISO 15745, SEMI E54.20)

IEC Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

ISO

- Slave Controller from several sources available
- Slave Controller provides interoperability
- ETG organizes Inter-operability Testing ("Plug Fests"), Workshops and Seminars
- Conformance Testing & Certificates

Typical EtherCAT Device Architecture

EtherCAT is:

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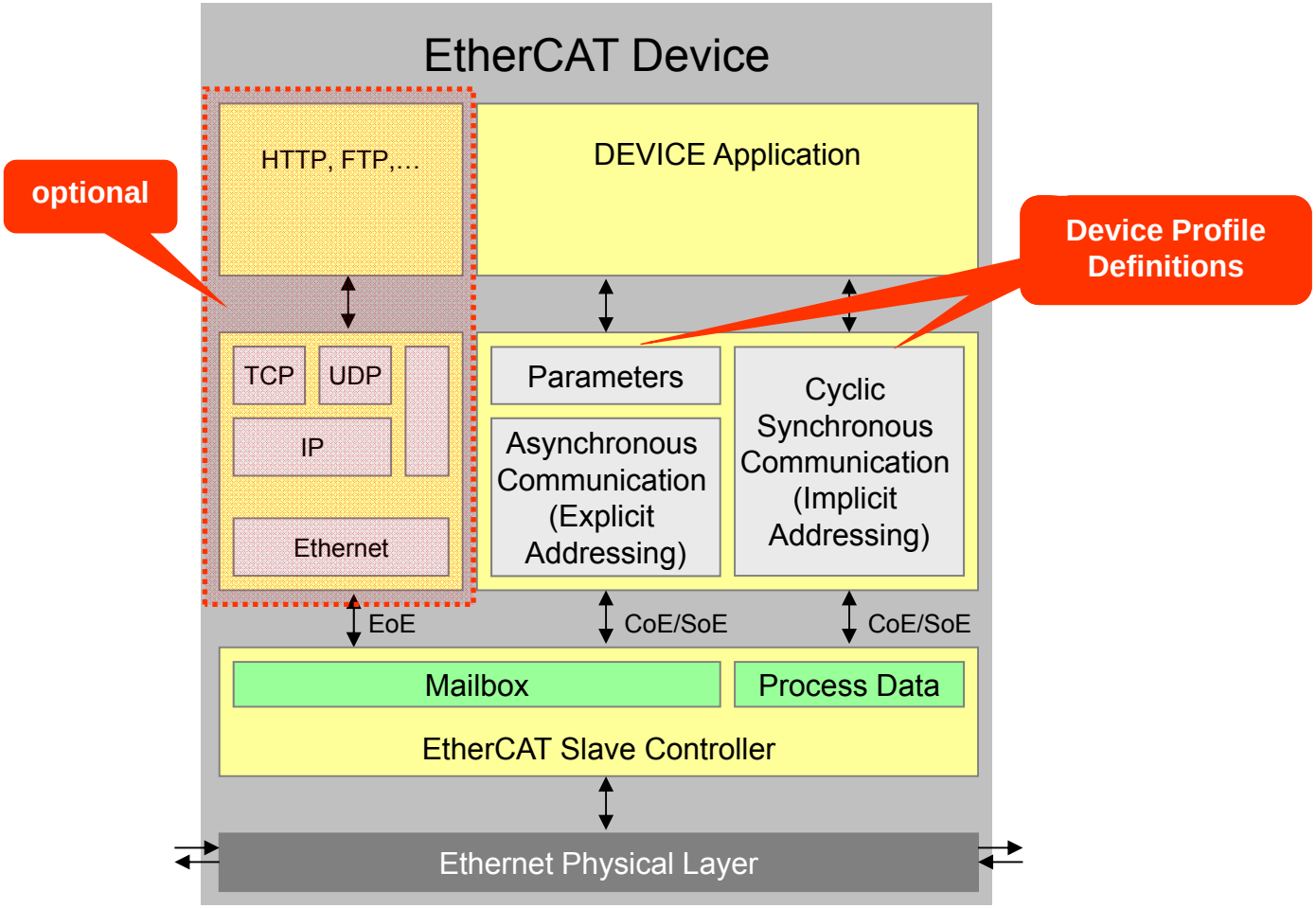

EtherCAT in IEC 61800-7

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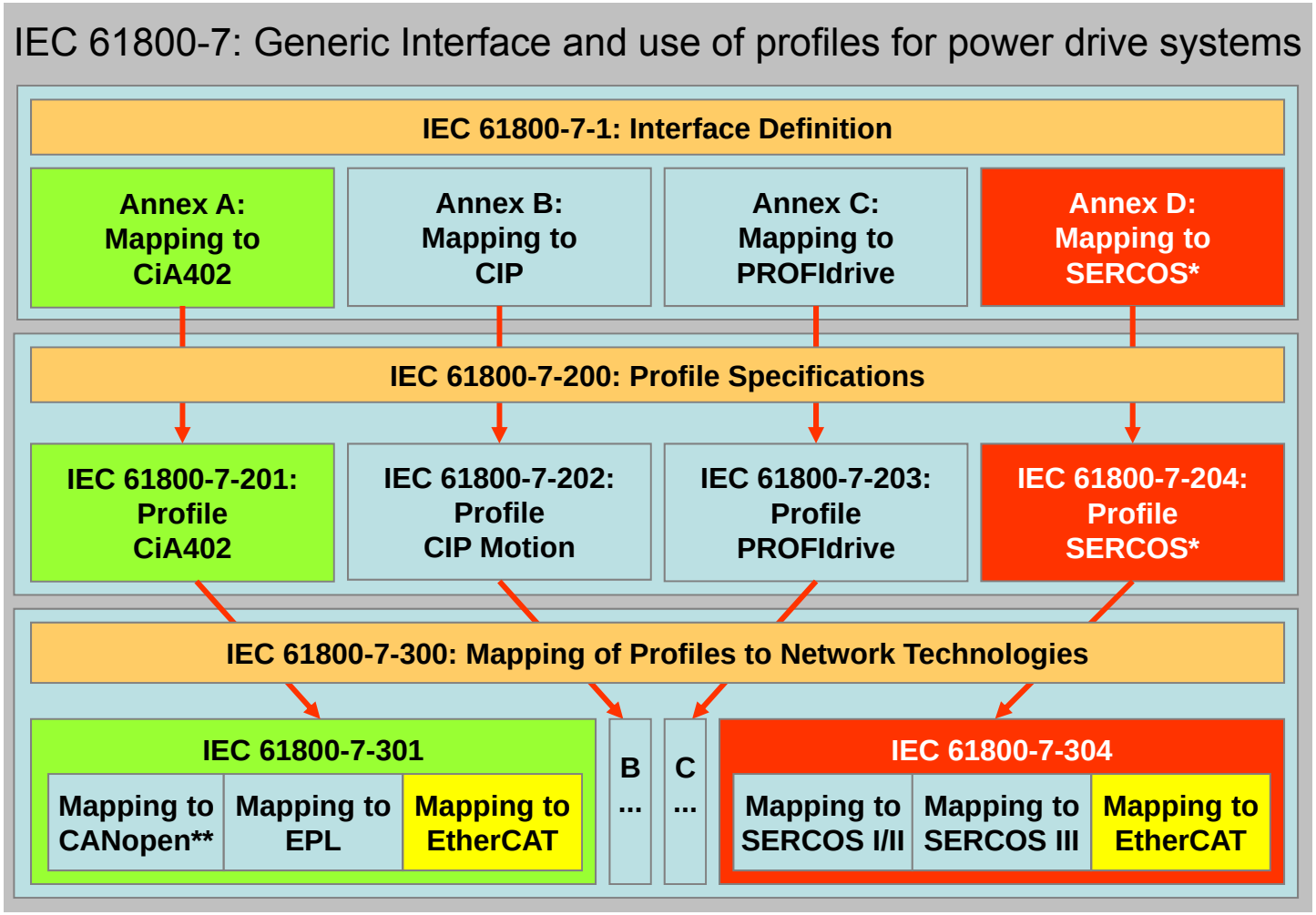

*SERCOS interface™ is a trademark of SI e.V.
**CANopen™ is a trademark of CAN in Automation e.V.

EtherCAT Architecture + Device Profiles

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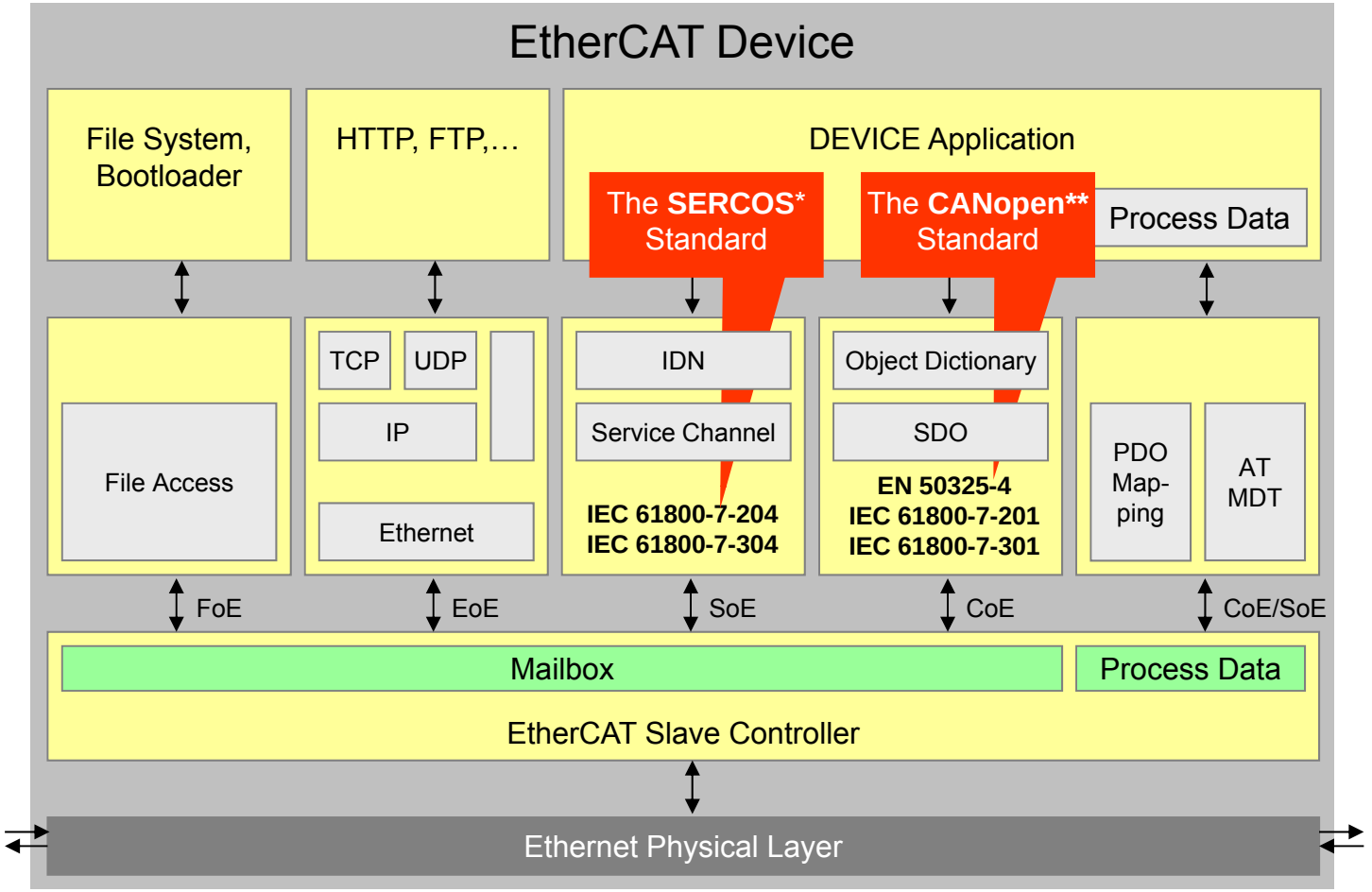

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EtherCAT is an open technology

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EtherCAT Masters implemented on wide range of RTOS*

- eCos
- Integrity
- Intime
- Linux with RT-Preempt
- MQX
- On Time RTOS-32
- OS-9
- PikeOS
- Proconos OS
- QNX
- Real-Time Java
- RMOS
- RT Kernel
- RT-Linux
- RTX
- RTXC
- RTAI Linux
- VxWin + CeWin+ RTOS32Win+LxWin
- VxWorks
- Windows CE
- Windows XP/XPE with CoDeSys SP RTE
- Windows XP/XPE with TwinCAT RT-Extension
- Windows Vista, 7
- XOberon
- XENOMAI Linux
- µC/OS II

*as of August 2011

EtherCAT is an open technology

EtherCAT is:

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- Industrial Ethernet ✓
- Flexible Topology ✓
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- Redundancy
- Versatile

- Foundation: November 2003
- Tasks: Support, Advancement and Promotion of EtherCAT
- The worlds largest fieldbus organization
- More than 1700* member companies from 52 countries in 6 continents:
  - Device Manufacturers
  - End Users
  - Technology Providers
- Membership is open to everybody

*as of August 2011

ETG Team Worldwide

EtherCAT is:

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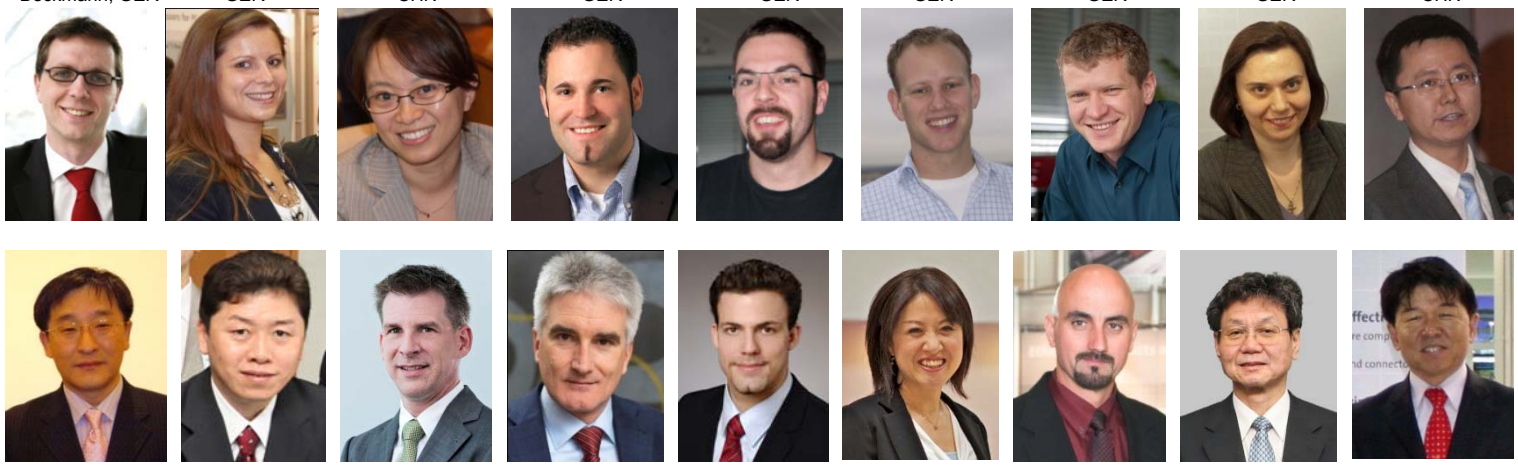

Dr. Guido Beckmann, GER | Andrea Bock, GER | Bin (Beryl) Fan, CHN | Oliver Fels, GER | Florian Hammel, GER | Florian Häfele, GER | Rainer Hoffmann, GER | Liliane Hügel, GER | Dr. YanQiang Liu, CHN

Prof Dr. Yong-Seon Moon, KOR | Masanori Obata, JPN | Thomas Rettig, GER | Martin Rostan, GER | Jakob Schmidt-Colinet, GER | Makiko Hori, JPN | Joseph P. Stubbs, USA | Yasuhiko Tabata, JPN | Key Yoo, KOR

EtherCAT Technology Group Structure

EtherCAT is:

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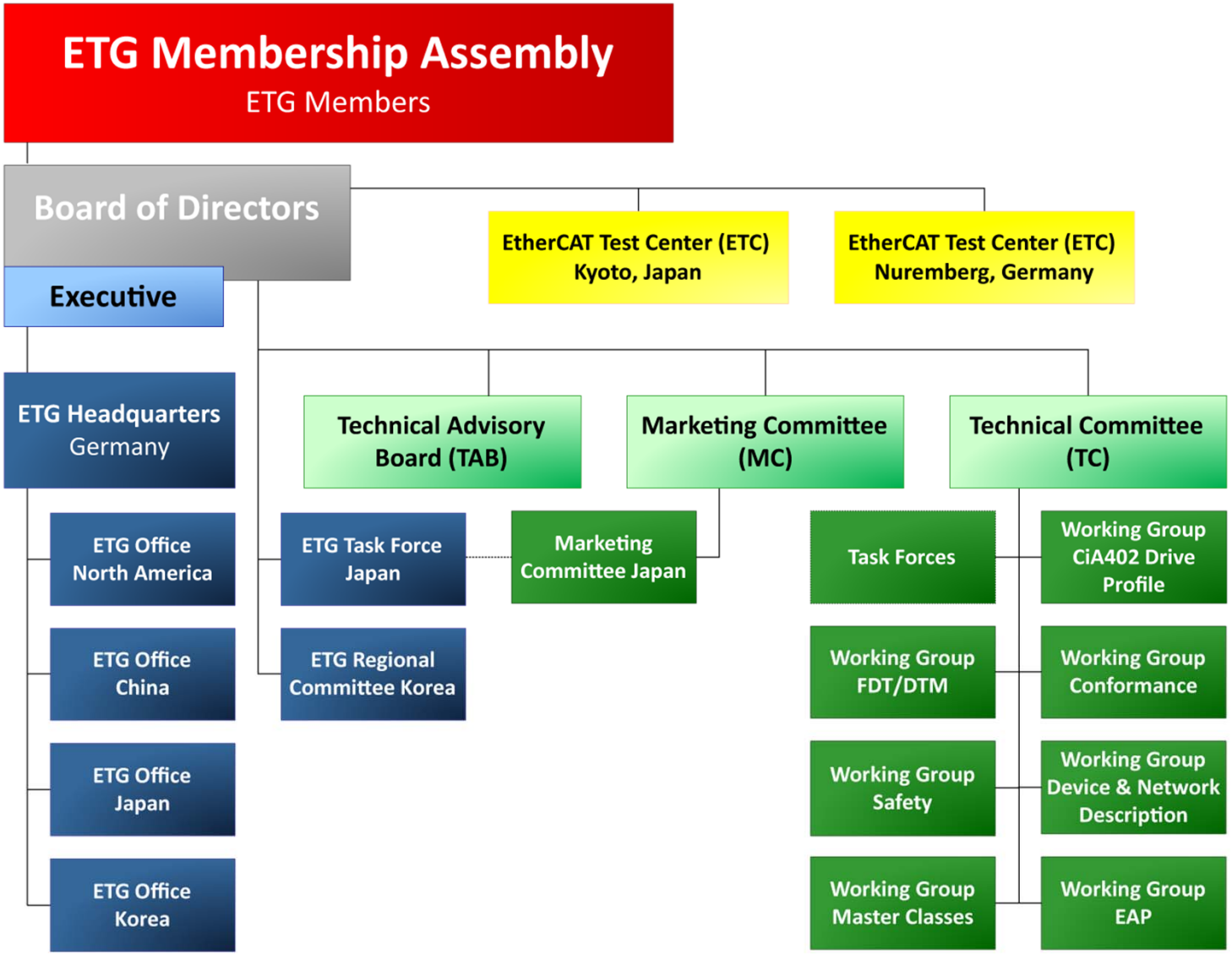

Conformance and Interoperability

EtherCAT is:

- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
- -Flexible Topology ✓
- Open ✓
- Conformance
- Safety
- Redundancy
- Versatile

EtherCAT Conformance tested

- Conformance and interoperability are very important factors for the success of a communication technology
  - Conformity to the specification is an obligation to all users of the EtherCAT technology
  - Therefore the **EtherCAT Conformance Test Tool** (CTT) is used
  - Test Cases for the CTT are provided by the Working Group “Conformance“ within the ETG community
  - The **EtherCAT Conformance Test** proves conformance with issuing a certificate after passing the test at an official **EtherCAT Test Center** (ETC)

Safety over EtherCAT: Features

EtherCAT is:

- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
- -Flexible Topology ✓
- Open ✓
- Conformance ✓
- Safety
- Redundancy
- Versatile

Safety over EtherCAT®

- Safety over EtherCAT (FSoE) defines a safety communication layer for the transportation of safety process data between Safety over EtherCAT devices.
- FSoE is an open technology within the EtherCAT Technology Group (ETG).
- The protocol is developed according to IEC 61508
  - It meets the Safety Integrity Level (SIL) 3
  - Residual Error Probability R(p) < 10^{-9}
- The protocol is approved by an independent Notified Body (TÜV)

Safety over EtherCAT: Features (2)

EtherCAT is:

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- Open ✓
- Conformance ✓
- Safety
- Redundancy
- Versatile

Safety over EtherCAT®

- FSoE Frame is mapped in the cyclic PDOs
  - Minimum FSoE Frame-Length: 6 Byte
  - Maximum FSoE Frame-Length: depending on the number of safe process data of the Slave Device
  - Therefore the protocol is suitable for safe I/O as well as for functional safe motion control
- Confirmed transfer from the FSoE Master to the FSoE Slave and vice versa.
- Safe Device Parameter can be downloaded from the Master to the Slave at Boot-Up of a FSoE Connection
- Certified products with Safety over EtherCAT are available since 2005.

Safety over EtherCAT: Features (3)

EtherCAT is:

- Faster ✓
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- Open ✓
- Conformance ✓
- Safety
- Redundancy
- Versatile

Safety over EtherCAT®

- The FSoE specification has no restrictions according to:
  - Communication layer and interface
    The communication layer is not part of the safety measures: black channel
    (assumed unsolved bit error rate: $p = 10^{-2}$)
  - Transmission speed
  - Length of safe process data
    (lenght of safe process data is arbitrary)
- Routing via non-safety certified gateways, fieldbus systems or backbones is possible

Safety over EtherCAT: Routing

EtherCAT is:

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- Conformance ✓
- Safety
- Redundancy
- Versatile

Safety over EtherCAT®

- Can be routed via non-safe gateways
- Can be routed via fieldbus systems
- One Safety technology for (almost) all bus systems

Safety over EtherCAT: Software Architecture

EtherCAT is:

- Faster ✓
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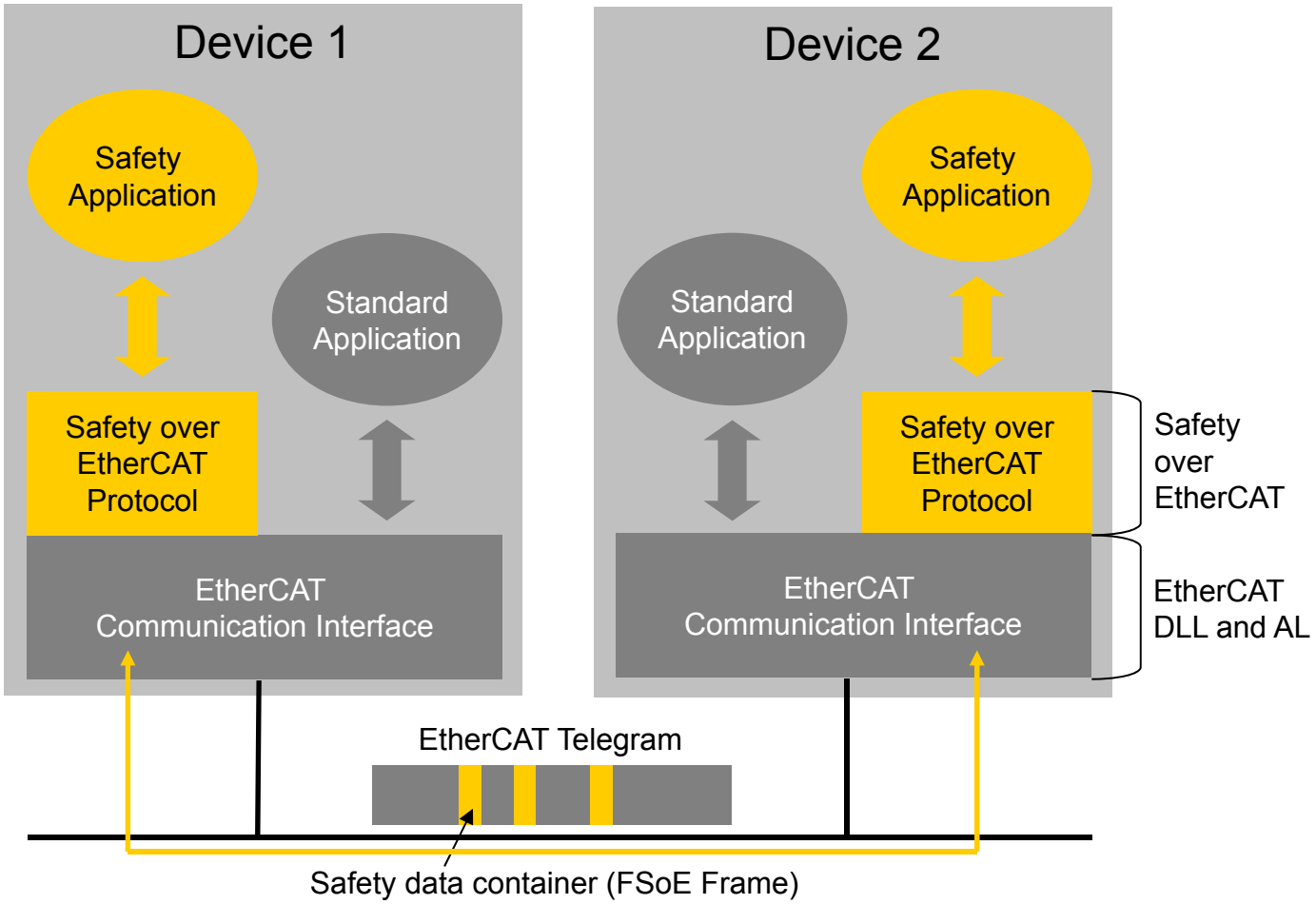
- Black channel approach
  - with safety and non-safety data on the same bus



Safety over EtherCAT: Hardware Architecture

EtherCAT is:

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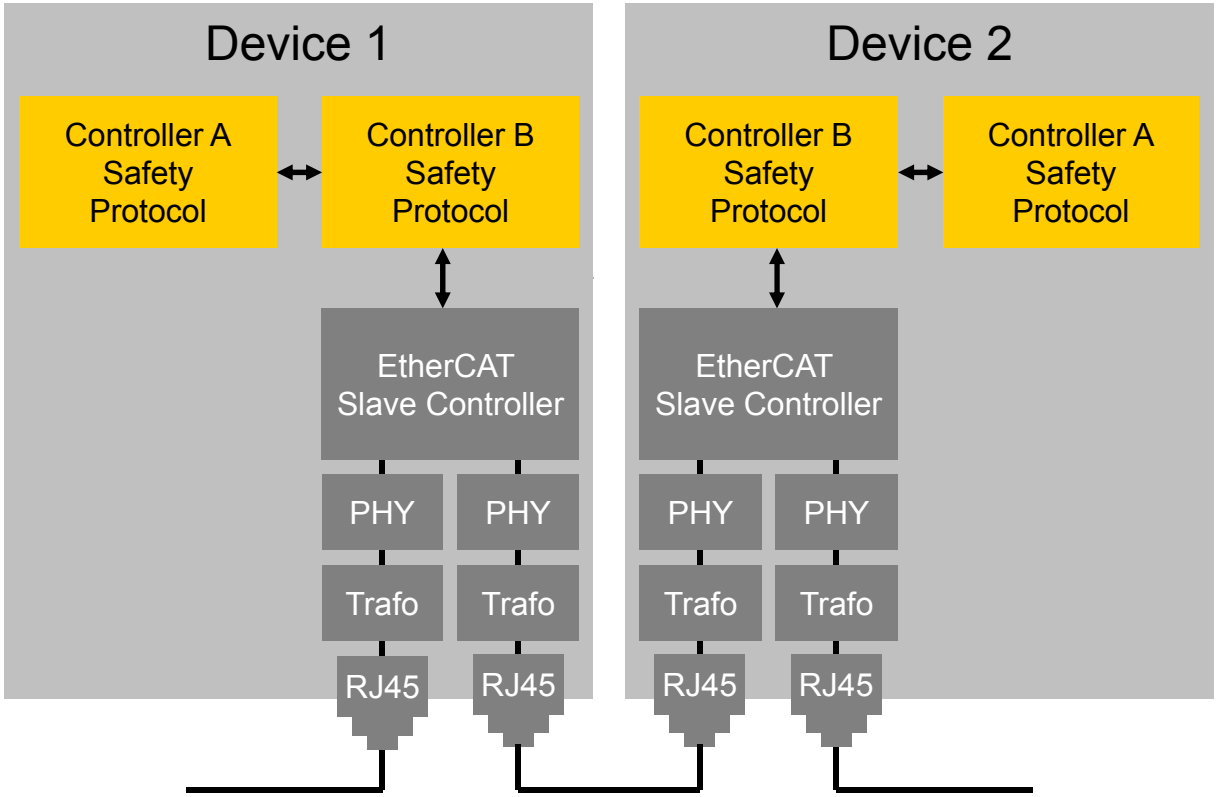
- One channel communication system
  - Model A according to IEC 61784-3 Annex A



Safety over EtherCAT: Frame Structure

EtherCAT is:

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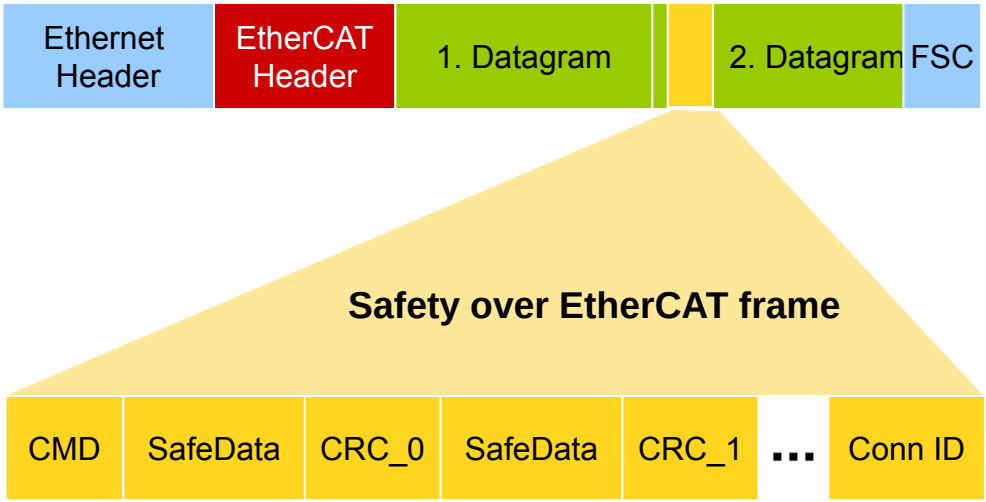
- Ethernet telegram



  - Safety over EtherCAT frame
    - The FSoE Frame is a data container mapped in the process data of the devices
    - A new FSoE Frame is recognized if at least one bit has changed according to the last frame
    - For every 2 Byte SafeData a 2 Byte CRC is calculated
    - Up to n Byte SafeData can be transmitted

Safety over EtherCAT: Safety Measures

EtherCAT is:

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Measure / Error	Sequence Number	Watchdog	Connection ID	CRC Calculation
Unintended repetition	☑			☑
Loss	☑	☑		☑
Insertion	☑			☑
Incorrect sequence	☑			☑
Corruption				☑
Unacceptable delay		☑		
Masquerade		☑		☑
Repeating memory errors in Switches	☑			☑
Incorrect forwarding between segments			☑	

Safety over EtherCAT: Implementation Example

EtherCAT is:

- Faster ✓
- Synchronization ✓
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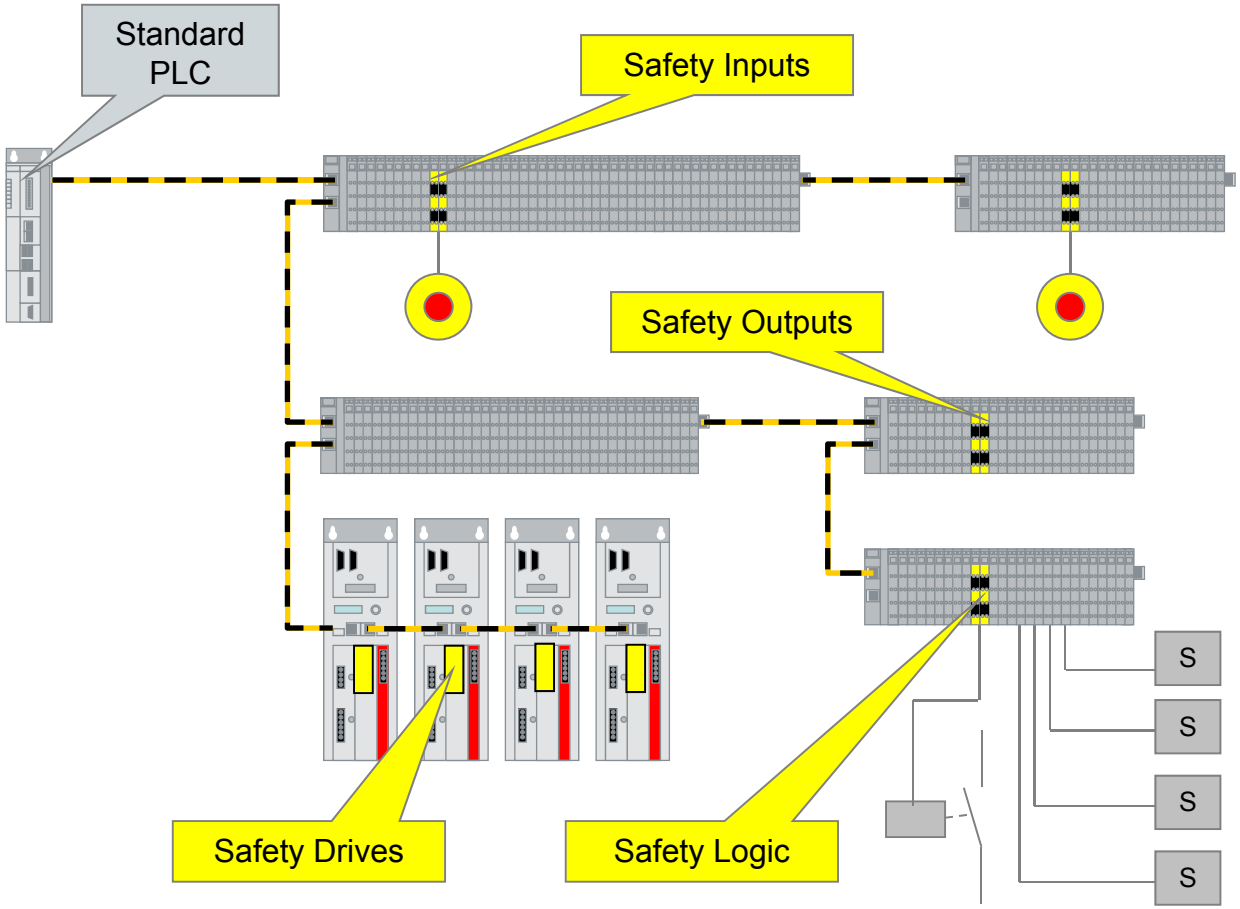
- Safety
- Redundancy
- Versatile

- Decentralized Safety-Logic
- Standard PLC routes the safety messages



Safety over EtherCAT: Advantages

EtherCAT is:

- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
- -Flexible Topology ✓
- Open ✓
- Conformance ✓
- Safety
- Redundancy
- Versatile

- Fully integrated solution:
  - safe and standard communication in one channel
- Reduction of the number of different fieldbuses and interfaces
- Central configuration, diagnosis and maintenance for safe and ‘unsafe‘ I/O in one tool
- Safety application makes full use of EtherCAT advantages:
  - Short reaction times
  - Almost unlimited number of nodes
  - Large network extensions
  - Cable redundancy options
  - High Flexibility with Hot Connect

Without Redundancy: Normal Operation

EtherCAT is:

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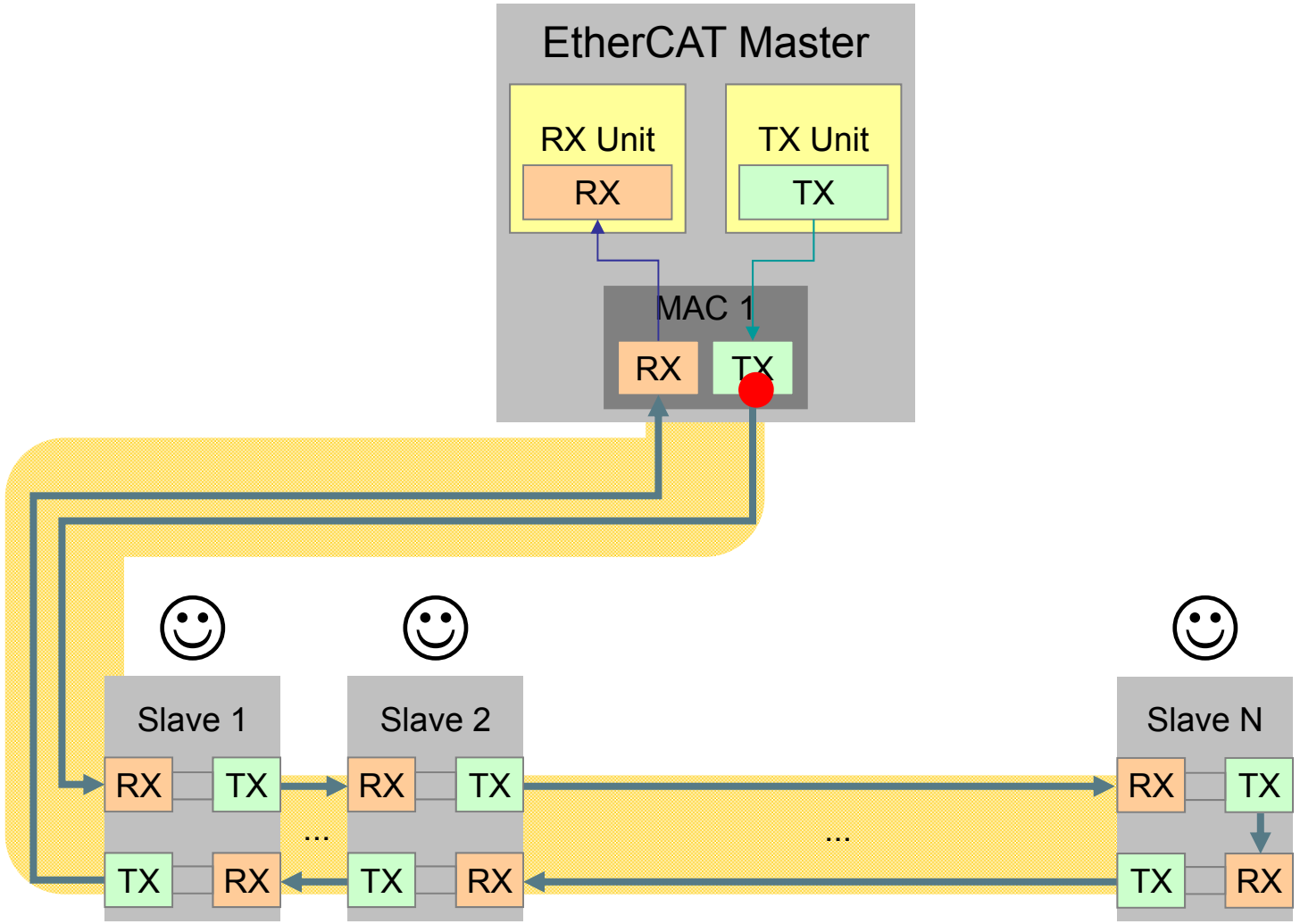

Without Redundancy: Cable Failure

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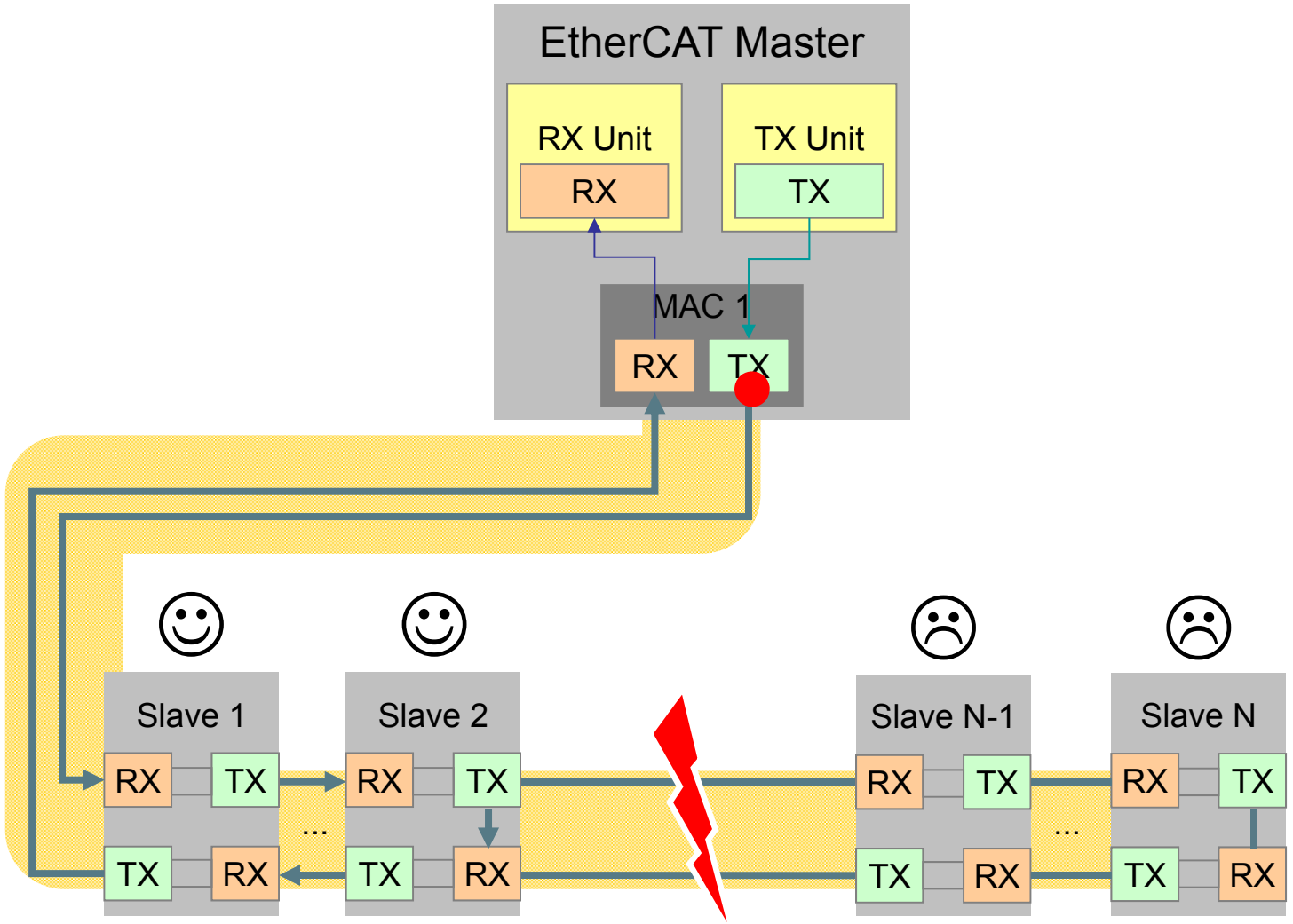

Without Redundancy: Node or Cable Failure

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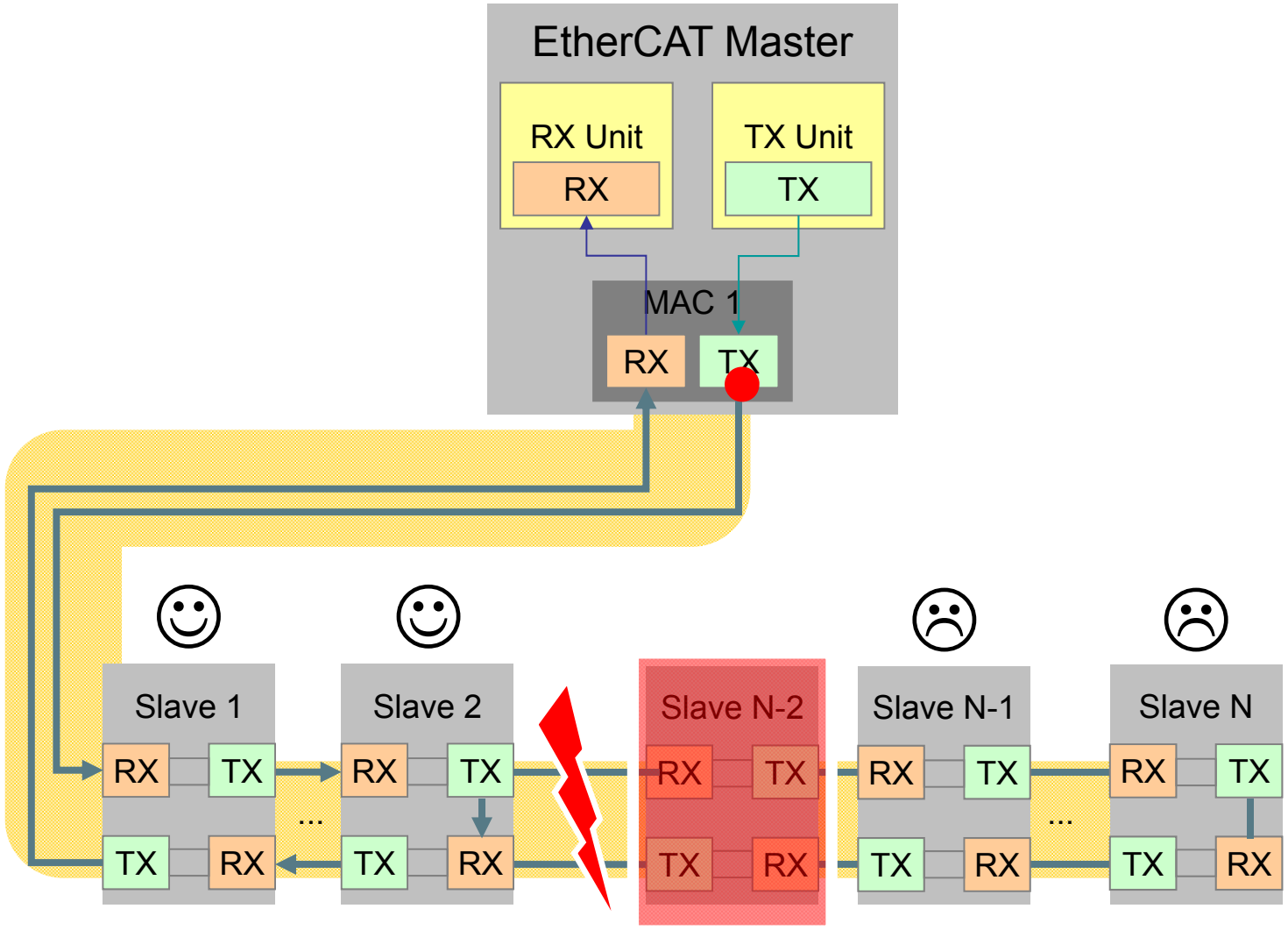
- Safety ✓
- Redundancy
- Versatile



With Redundancy: Normal Operation

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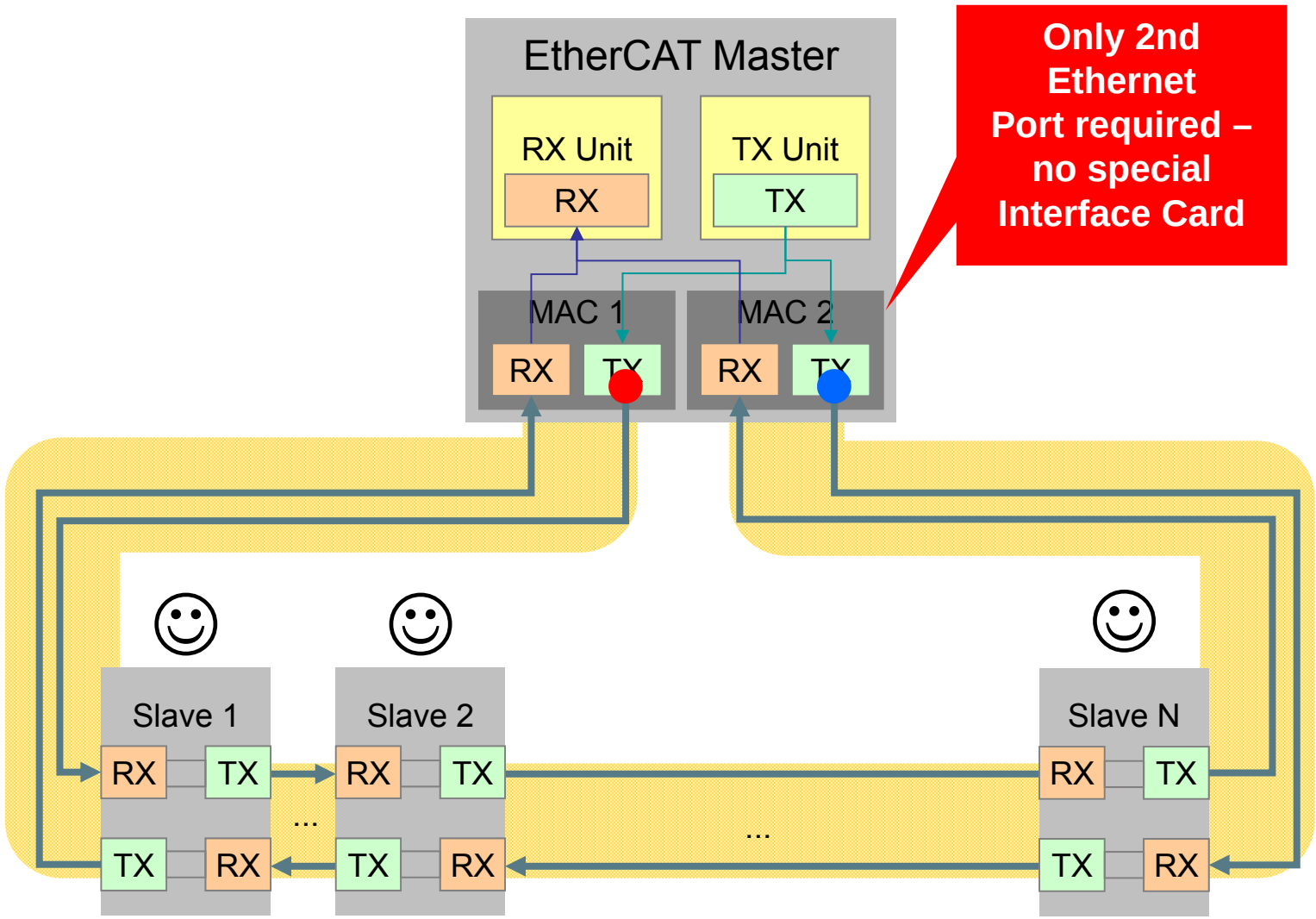

With Redundancy: Cable Failure

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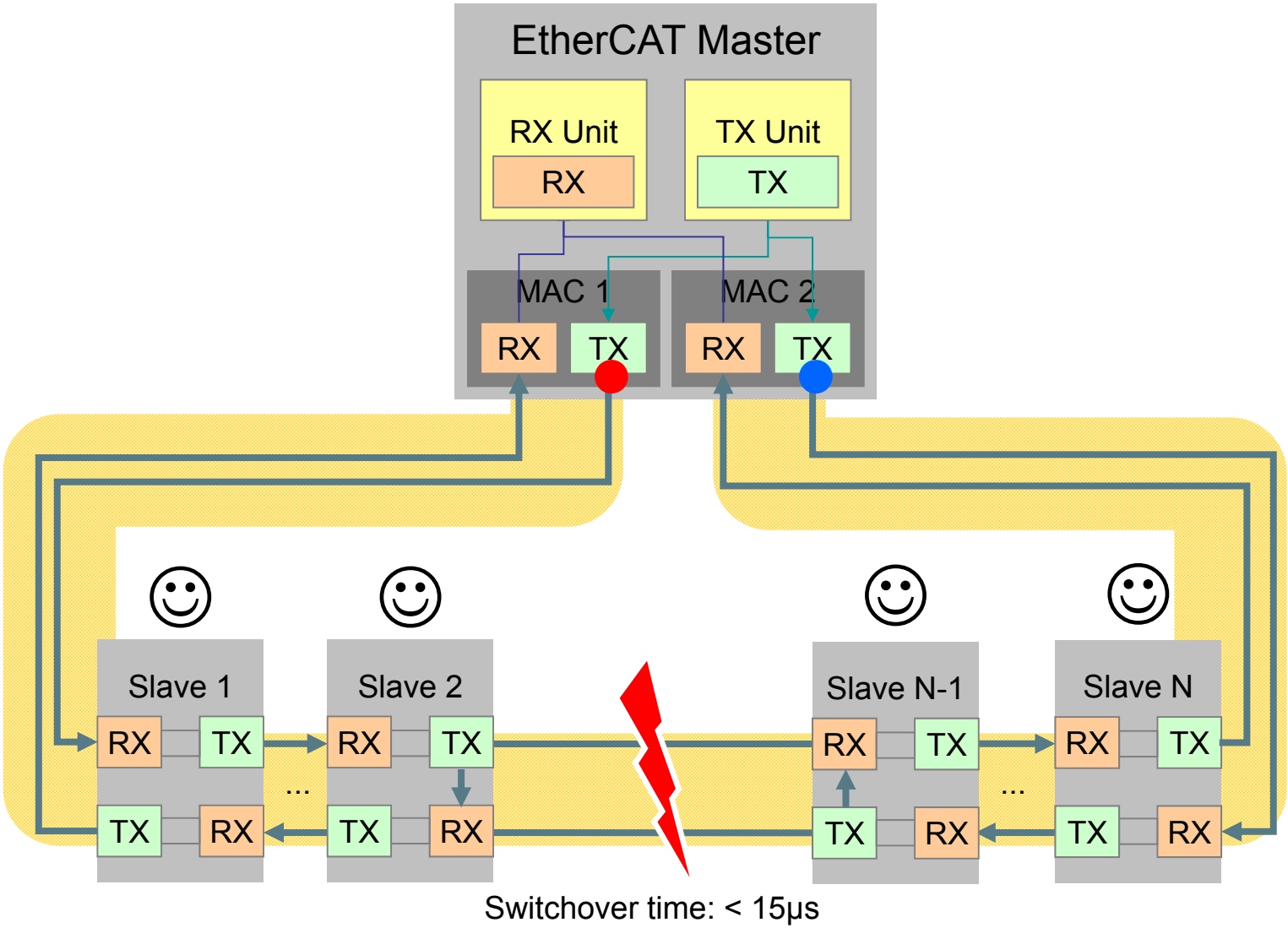

With Redundancy: Node or Cable Failure

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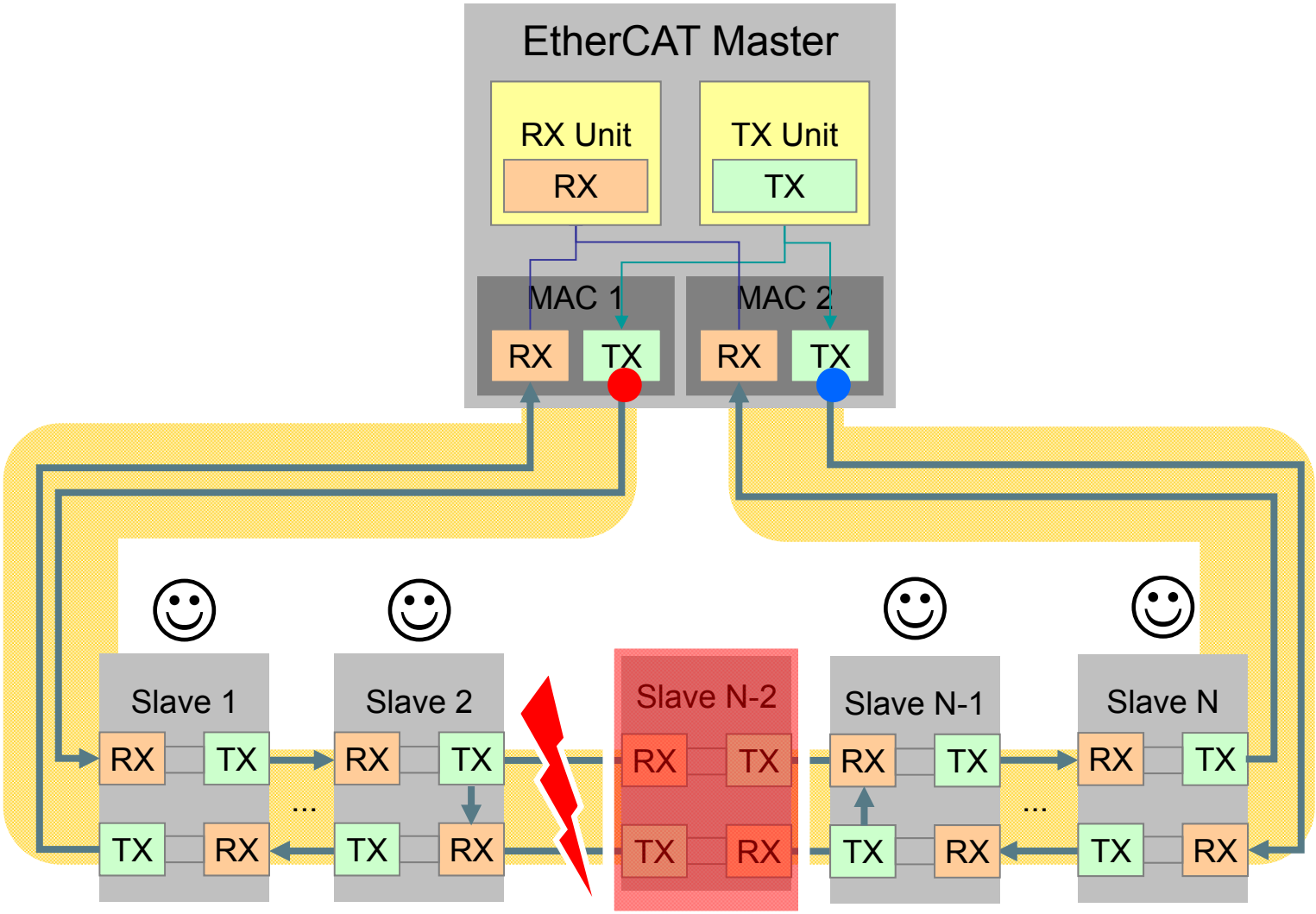

EtherCAT: High availability

EtherCAT is:

- Faster ✓
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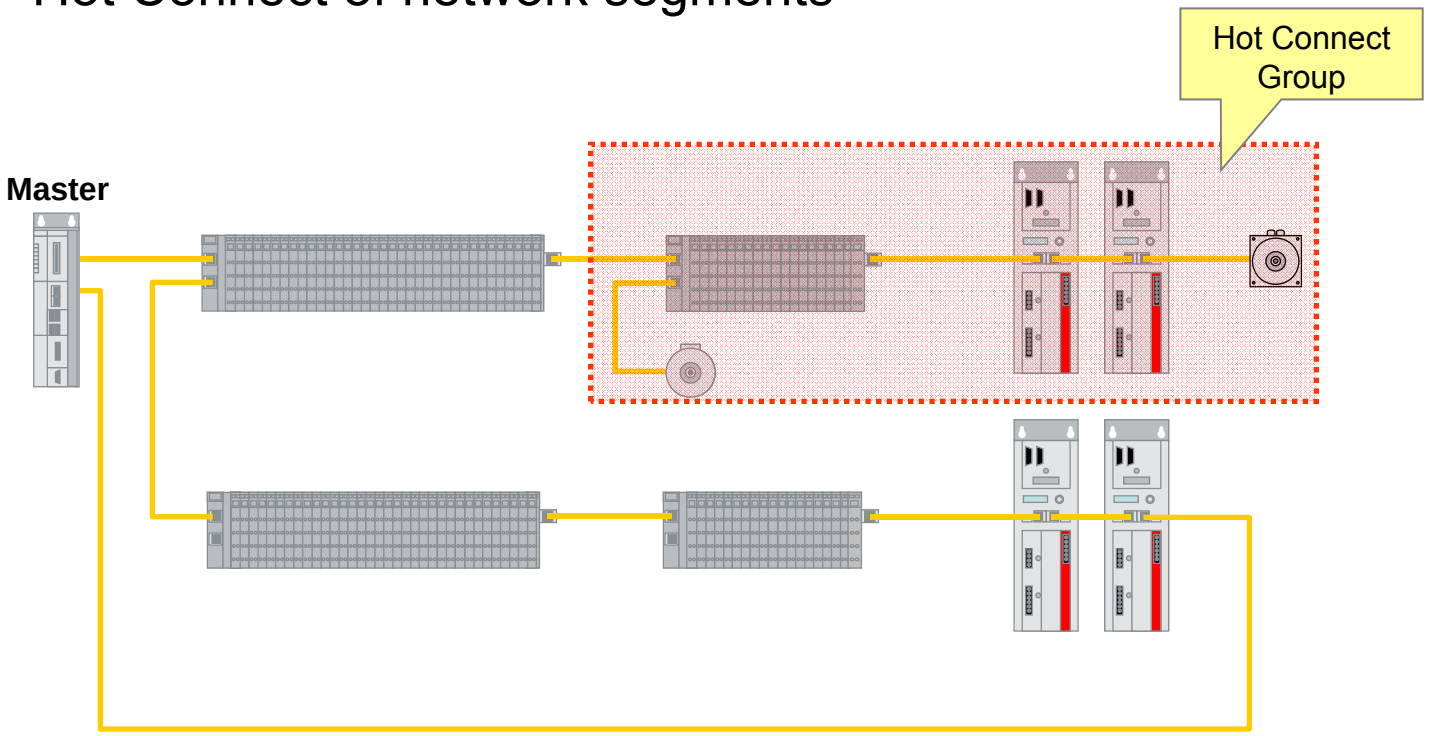
- Safety ✓
- Redundancy ✓
- Versatile

- Cabling redundancy
  - 2nd Ethernet port needed on master side only
- Hot Swap of devices
- Hot Connect of network segments



EtherCAT: versatile system architecture

EtherCAT is:

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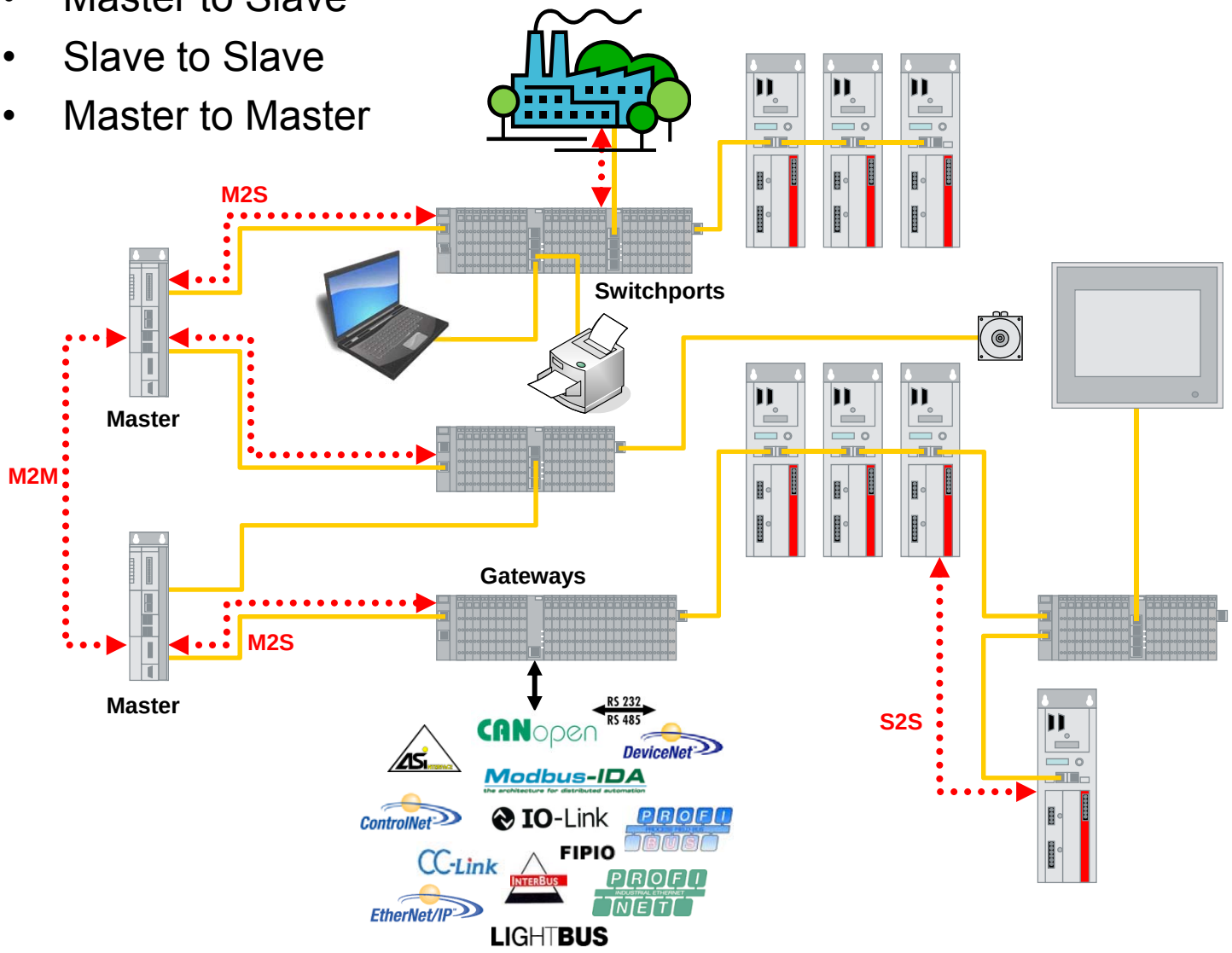
- Redundancy ✓
- Versatile

- Master to Slave
- Slave to Slave
- Master to Master



EtherCAT Automation Protocol

EtherCAT is:

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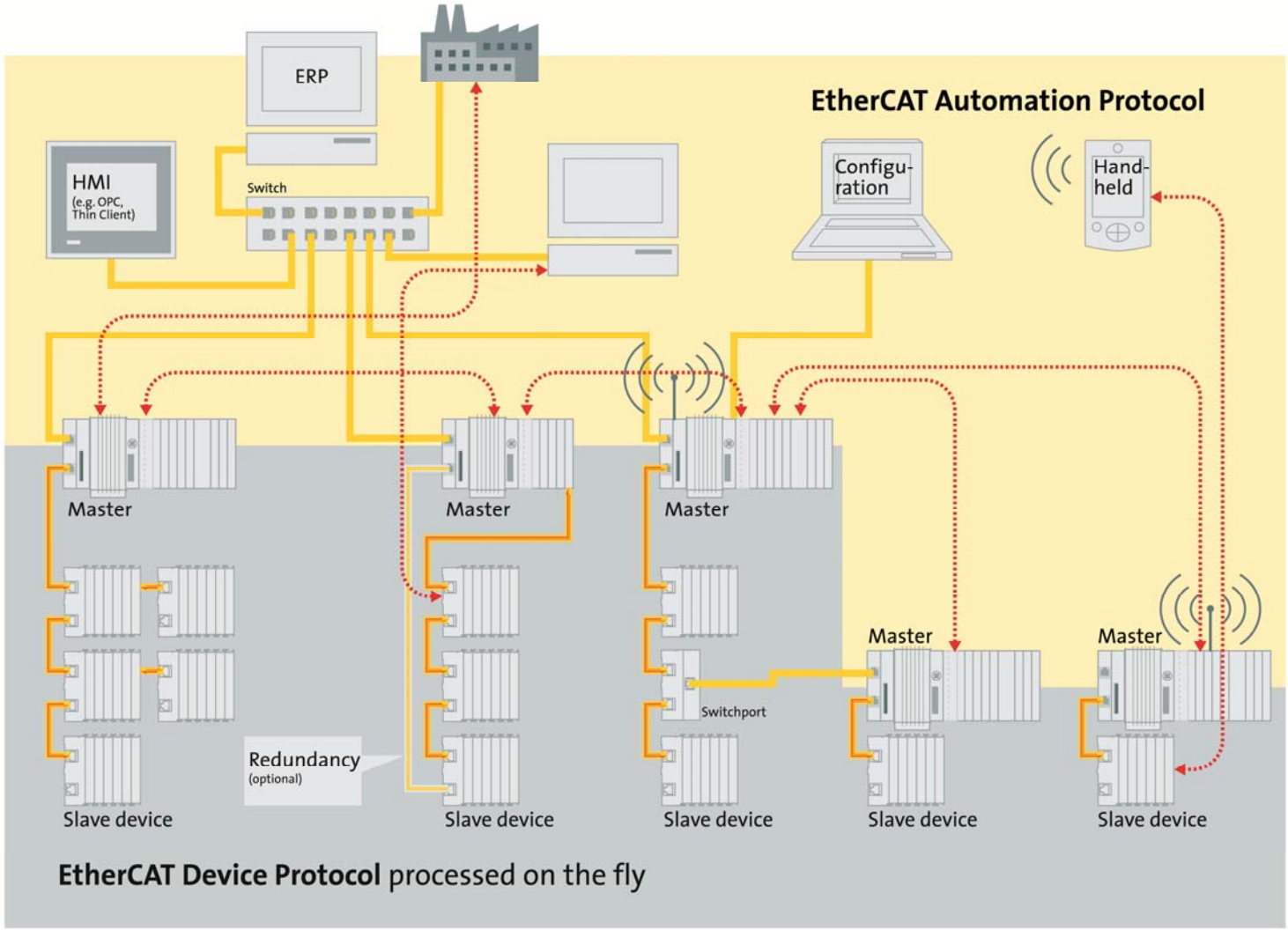

EtherCAT - The Ethernet Fieldbus.

EtherCAT is:

- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
-Flexible Topology ✓
- Open ✓
- Conformance ✓
- Safety ✓
- Redundancy ✓
- Versatile ✓

Why go for something slower, just because it is more expensive?

EtherCAT - *The* Ethernet Fieldbus

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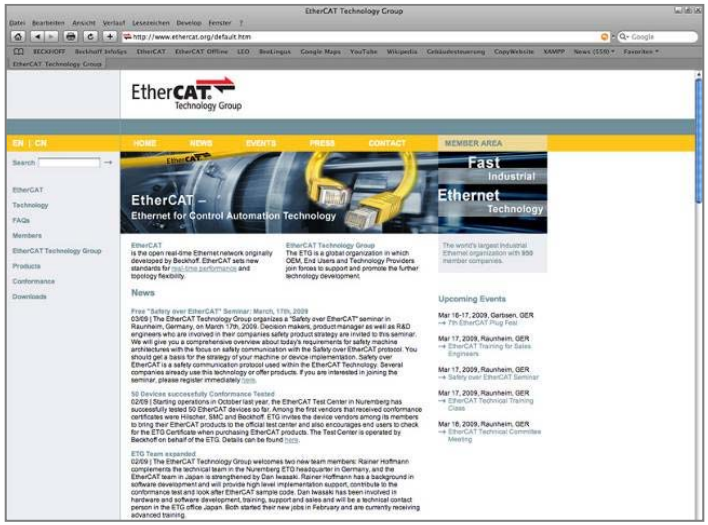
- Safety ✓
- Redundancy ✓
- Versatile ✓

Please visit

www.ethercat.org

for more information



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