



The slide features a title bar with a globe icon and the text "Industrial Ethernet Technologies: Overview". Below the title bar is a vertical navigation menu on the left side, listing various industrial Ethernet technologies. To the right of the menu is a large image showing a car on an assembly line with a complex network of cables and connectors. At the bottom of the slide, there is a footer with the date "February 2014" and the copyright notice "© EtherCAT Technology Group".

- > Classification
- > PROFINET
- > EtherNet/IP
- > CC-Link IE
- > Sercos III
- > Powerlink
- > Modbus/TCP
- > EtherCAT
- > Summary

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

### Editorial Preface:

This presentation intends to provide an overview over the most important Industrial Ethernet Technologies. Based on published material it shows the technical principles of the various approaches and tries to put these into perspective.

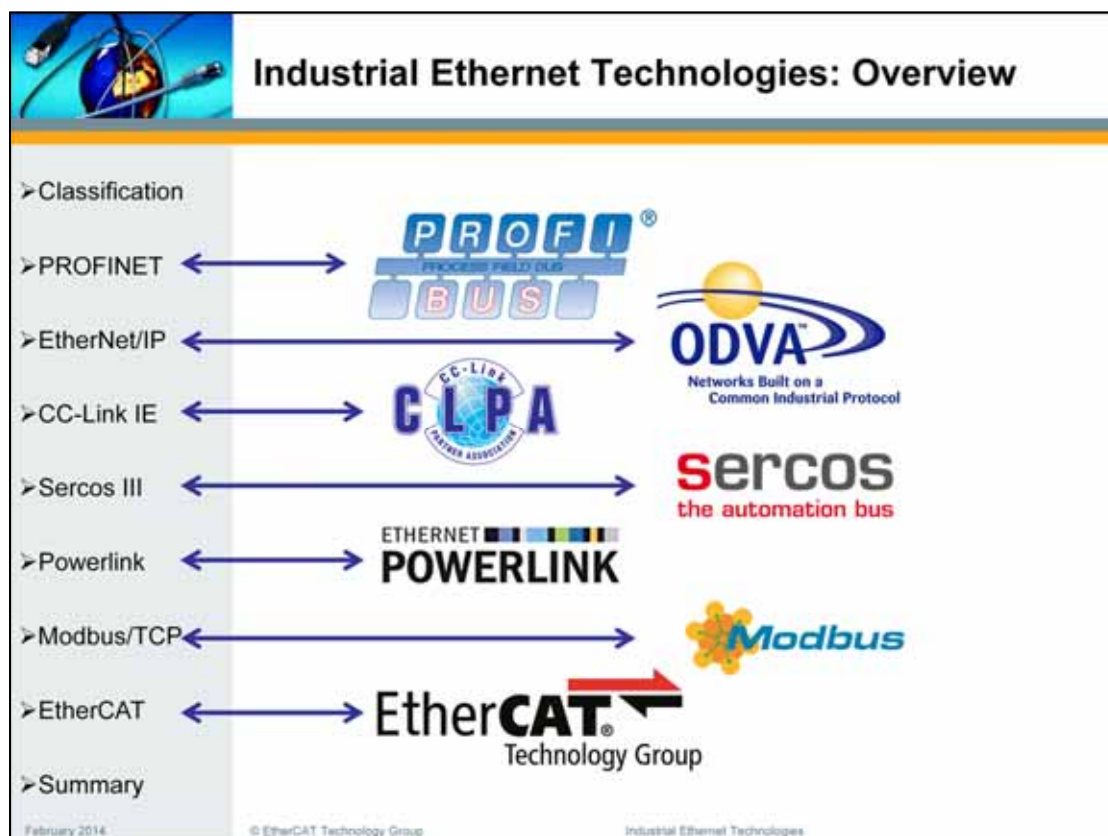
The content given represents my best knowledge of the systems introduced. Since the company I work for is member of all relevant fieldbus organizations and supports all important open fieldbus and Ethernet standards, you can assume a certain level of background information, too.

The slides were shown on ETG Industrial Ethernet Seminar Series in Europe, Asia and North America as well as on several other occasions, altogether attended by several thousand people. Among those were project engineers and developers that have implemented and/or applied Industrial Ethernet technologies as well as key representatives of some of the supporting vendor organizations. All of them have been encouraged and invited to provide feedback in case they disagree with statements given or have better, newer or more precise information about the systems introduced. All the feedback received so far was included in the slides.

You are invited to do the same: provide feedback and – if necessary – correction. Please help to serve the purpose of this slide set: a fair and technology driven comparison of Industrial Ethernet Technologies.

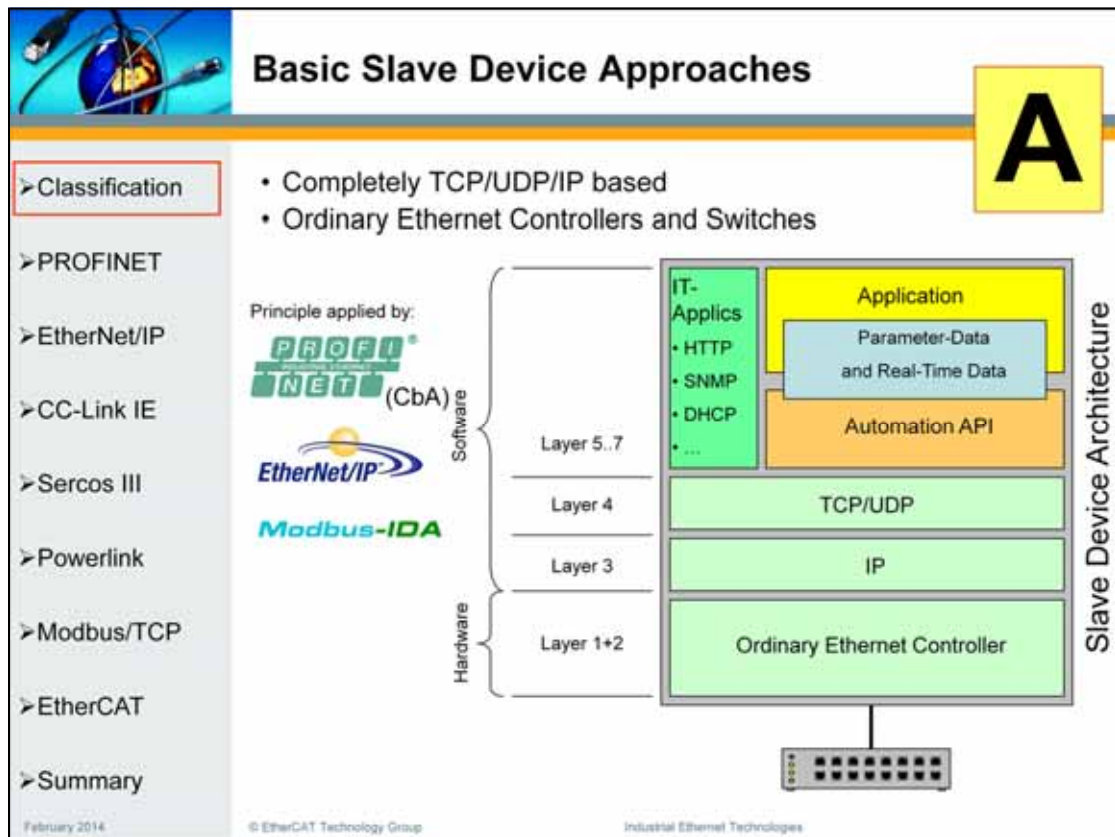
Nuremberg, February 2014

Martin Rostan, [m.rostan@ethercat.org](mailto:m.rostan@ethercat.org)



All Industrial Ethernet Technologies introduced in this presentation are supported by user and vendor organizations. EPSG and ETG are pure Industrial Ethernet organizations, whilst the others have a fieldbus background and thus members primarily interested in the respective fieldbus technology.

All technology names as well as the names of the organizations promoting and supporting those are trademarked. The trademarks are honored.



Depending on the real time and cost requirements, the technologies follow different principles or approaches. This comparison tries to group those approaches in three different classes by looking at the slave device implementations:

Class A uses standard, unmodified Ethernet hardware as well as standard TCP/IP software stacks for process communication. Of course some implementations may have modified „tuned“ TCP/IP stacks, which provide better performance.

Class A approaches are also referred to as „best effort“ approaches. The real time performance is limited by unpredictable delays in infrastructure components like switches – no just due to other traffic on the network. The by far largest obstacle to better real time performance however is provided by the software stacks (TCP/UDP/IP).

## Basic Slave Device Approaches

B

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Process Data: Parallel Channel to TCP/UDP/IP
- TCP/UDP/IP Timing Controlled by Process Data Driver
- Ordinary Ethernet Controllers and Switches (or Hubs)

Principle applied by:

(RT)

Software

Layer 5..7

Layer 4

Layer 3

Hardware

Layer 1+2

IT-Applics • HTTP • SNMP • DHCP • ...	Application Parameter Data Process Data Automation API
TCP/UDP	Process Data Protocol
IP	
Timing-Layer	
Ordinary Ethernet Controller	

Slave Device Architecture

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Class B approaches still use standard, unmodified hardware, but do not use TCP/IP for process data communication. A dedicated process data protocol is introduced, which is transported directly in the Ethernet frame. TCP/IP stacks may still exist, but typically their access to the Ethernet network is controlled and limited by what can be considered a timing layer. Of course this description is pretty generic – but more details are given in the technology specific sections.


## Basic Slave Device Approaches

C


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Process Data: Parallel Channel to TCP/UDP/IP
- TCP/UDP/IP Timing Controlled by Process Data Driver
- Special Realtime Ethernet Controllers or Switches


Principle applied by:




PROFINET  
NET (IRT)



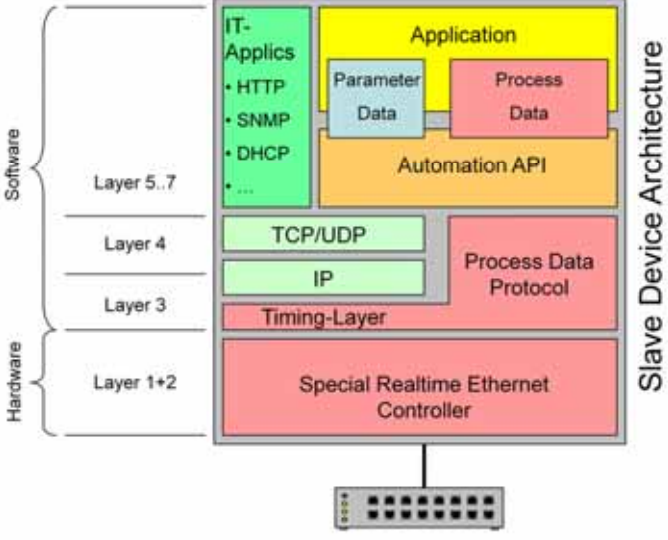
CC-Link IE



Sercos  
the automation bus



EtherCAT



February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Class C approaches aim even higher with regard to performance. In order to achieve these goals, dedicated hardware has to be used (at least on the slave device side).

In case of PROFINET IRT, the Special Real-time Ethernet Controller is more a Special Switch Device – but the result is the same: better performance due to better hardware integration.

This does not exclude the use of TCP/IP and the Internet Technologies.



**PROFINET Overview**

PROFINET – PI / Siemens Ethernet Solution

Three different varieties:

Version 1 (2001)	Version 2 (2004)	Version 3 (2005)
CbA: <b>A</b>	RT: <b>B</b>	IRT: <b>C</b>
„Component based Automation“	Soft Real Time (Software Based)	Isynchronous Real Time (Hardware Based)

Navigation menu:

- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

Diagram illustrating the network stack and process data flow:

- Factory automation (100ms) and Motion Control (10ms) are shown above the PROFINET layer.
- The PROFINET layer is connected to IT services (100ms) and TCP/IP (<1ms).
- The bottom layer shows Process data (100ms) and Real-time (<1ms).

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies Pictures sourced from PTO/PNO website

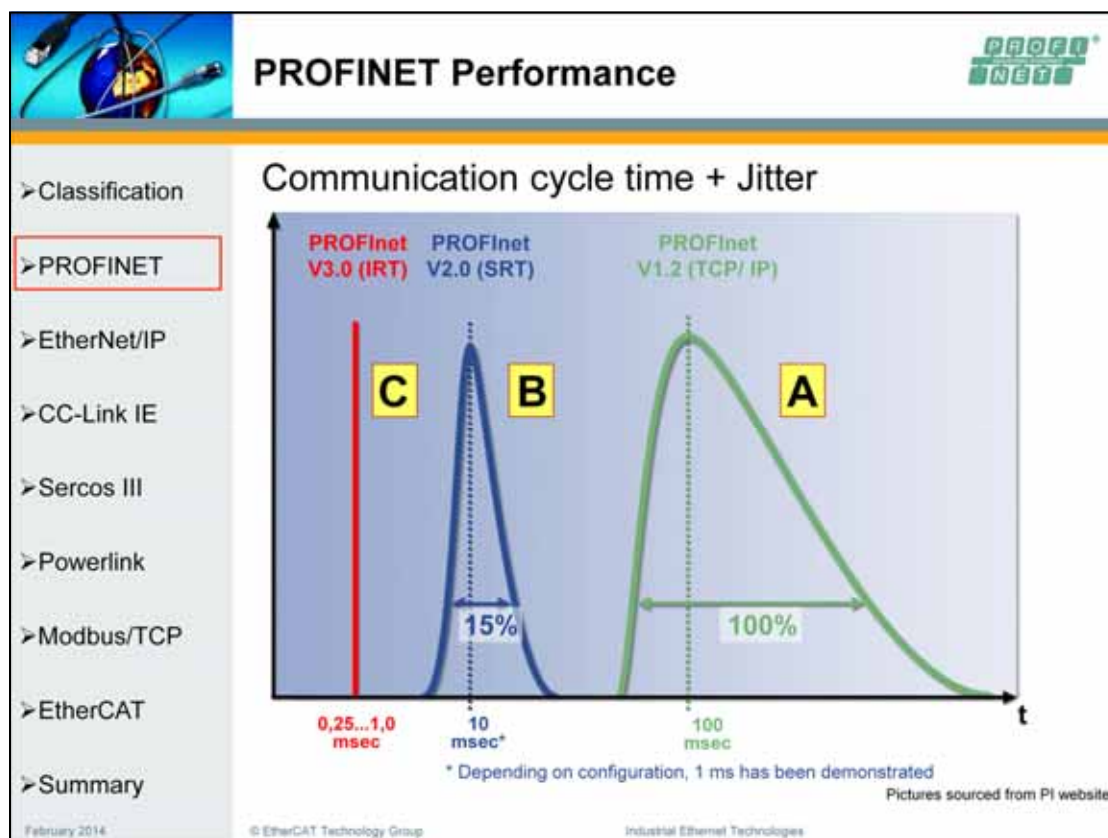
There are 3 PROFINET-Versions:

Version 1 („Component Based Automation“), a Class A approach

Version 2 ((Soft) Real Time“), a Class B approach


Version 3: („Isynchronous Real Time“), a Class C approach

Profibus International (PI) has moved away from the terms RT/IRT and introduced the term PROFINET IO for both RT and IRT...




Not all IRT devices support cycle times < 0.5 ms, e.g. Siemens Sinamics Controller.

The jitter shown in the graph above show the intended values for the end device – and do not necessarily cover the jitter caused by the network (e.g. forwarding jitter of the switches)

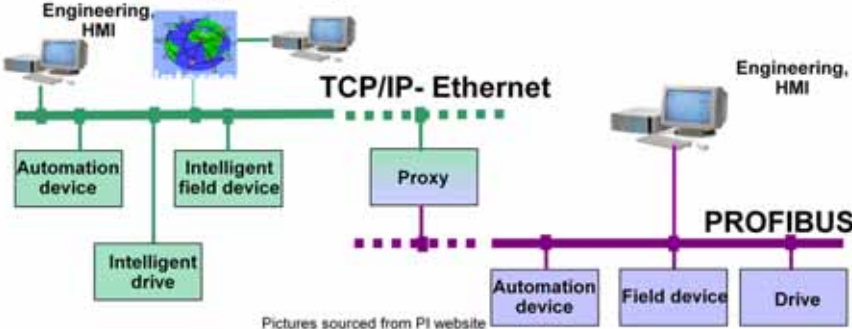


## PROFINET CbA (V1): Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Initial Profibus Answer to the Ethernet Hype: PROFINET V1
- Remote Procedure Calls on TCP/IP originally on DCOM
- Access to PROFIBUS Networks via Proxy Devices
- For Parameter Data only, not for Process Data
- since DCOM will not be advanced by Microsoft any more, PROFINET CbA V2 has SRT Protocol Adaptation
- few known Products
- No longer supported by Profibus International



Pictures sourced from PI website

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Initially the PNO/PTO message was: protect your investment and continue using Profibus, for Ethernet connectivity we provide a transparent gateway.

Work on the gateway (proxy) concept was started as early as 1999. First spec (V0.9) published in March 2001 (EtherNet/IP was first introduced in 2000).

Meanwhile CBA is not supported by Profibus International any more. The most recent document mentioning CBA on the PROFINET Website is from 2009.



## Component Based Programming Approach


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

The diagram illustrates the Component Based Programming Approach. At the top, an 'Engineering Interface' contains a 'Data Interface' and 'Information' flow. Below this, two vendors are shown: 'Vendor A Bottle Cleaning' and 'Vendor B Filling'. Each vendor has a 'PROFIBUS' interface. A red arrow labeled 'Information' points from the Data Interface to the vendors. Below the vendors are physical representations of the components: 'Bottle Cleaning' (purple) and 'Filling' (teal). A red arrow connects the two physical components. To the right, a screenshot of the 'PROFINET Connection Editor' software is shown, displaying a graphical mapping of variables and communication links.


- PROFINET CbA comprises more than just the communication
- Approach may be fine for 50 variables, but how do you handle 500 variables this way?

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies      Pictures sourced from PI website

PROFINET CbA (Component Based Automation) comprises more than just a communication protocol: the CbA programming approach with graphical mapping of variables to establish communication links.



## PROFINET RT (V2): Overview

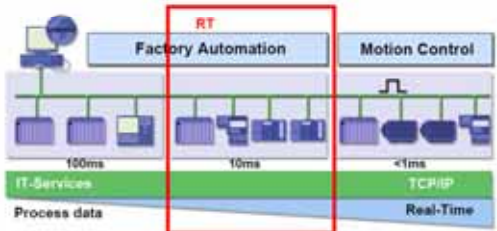


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Originally named „Soft Realtime“ (SRT)
- „Best Effort“ Protocol with 5..10 ms typical cycle time and 15% jitter\*
- Modified Stack bypasses TCP and IP for Realtime-(process)data
- Aimed at and suited for PLC type applications (including drive control, but not motion control)
- Requires substantial amount of software (Field device: ~ 1MByte)

Limitations:

- Soft Realtime Solution with
  - Influence by TCP traffic
  - Inpredictable Queue delays in switches
  - Stack delays
- Standard Controllers are sensitive for IP Multicast Traffic



• RT in PROFINET provides similar Real-Time properties like PROFIBUS  
 • Cycle times can be realized in the range of 5 to 10 ms

Pictures sourced from PI website

\*Jitter; end device jitter, not taking network delays and jitter into account  
Industrial Ethernet Technologies


February 2014
© EtherCAT Technology Group

PROFINET V2 was initially called SRT (Soft Real-time). The term „soft“ was later dropped for marketing reasons.


PROFINET RT is meanwhile mainly addressed as PROFINET I/O (together with IRT).

Siemens communicated that PROFINET RT provides performance similar to Profibus. Even though this is optimistic (typically Profibus is faster and provides better node synchronization), one can read this statement as follows:

If Profibus performance is sufficient, but Profibus is not expensive enough, PROFINET RT is an alternative.



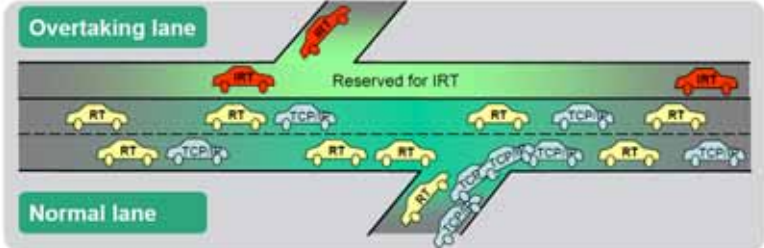
## PROFINET IRT (V3): Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Hard Real Time by Time Slicing
- Requires Special Switch Chips – within ALL device (Master, Slave + all Infrastructure Devices): Class C
- Aimed at Motion Control Applications
- Reservation of Time Slices for Non Real Time (NRT) + TCP/IP Traffic
- In spite of using special hardware, still requires substantial amount of software (Field device: ~ 1 MByte)

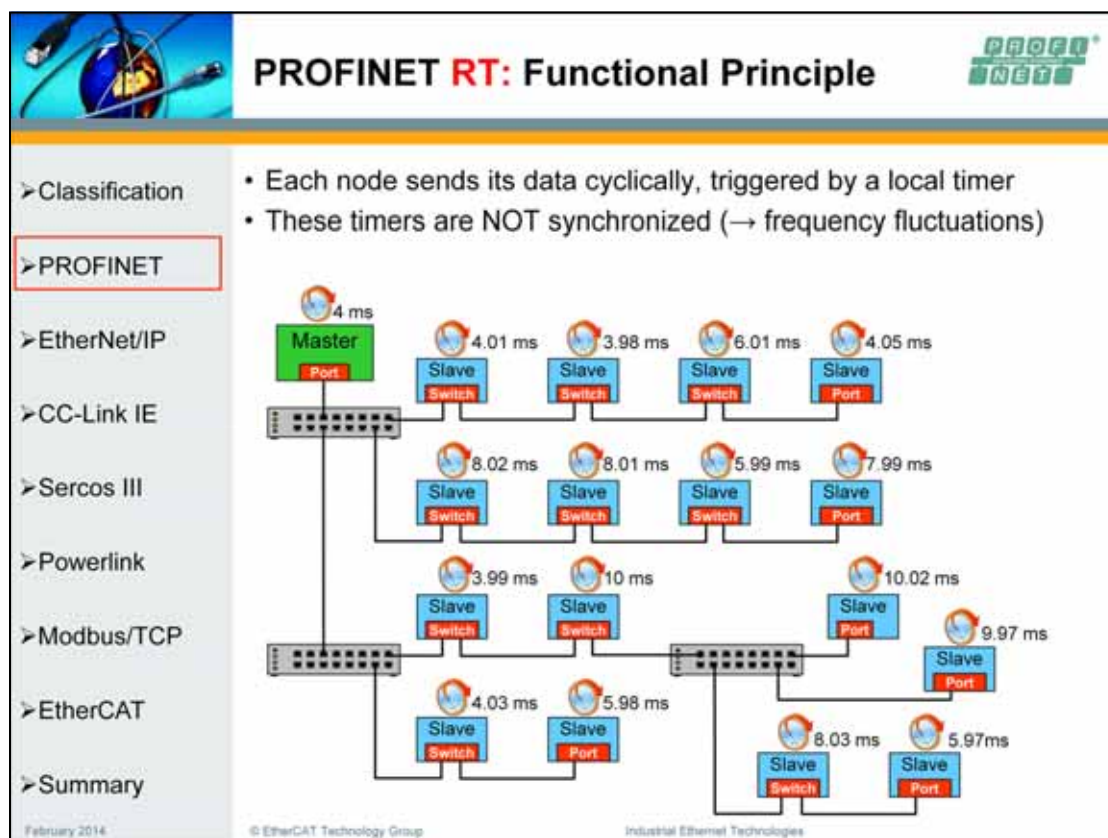
C




The diagram illustrates a highway with three lanes. The top lane is labeled 'Overtaking lane' and contains a red car labeled 'RT'. The middle lane is labeled 'Reserved for IRT' and contains a red car labeled 'RT'. The bottom lane is labeled 'Normal lane' and contains several yellow cars labeled 'RT' and blue cars labeled 'TCP'. The highway is shown with a perspective view, curving to the right.

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
Pictures sourced from PTO/PNO website


PROFINET IRT (V3) is a class C approach which introduces special hardware in order to achieve sufficient performance and synchronicity for motion control applications.



In PROFINET RT, cyclic data exchange is triggered by local timers, which are NOT synchronized (High Precision Time synchronization with PTP is only required in IRT = Conformance Class C). Hence in PROFINET RT there is no general support for sub-ms network wide synchronization, and there are frequency fluctuations.



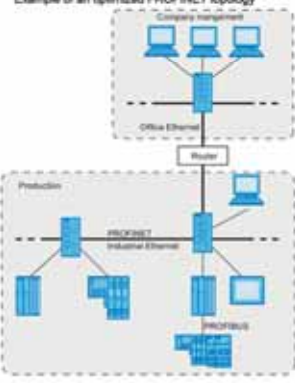
# PROFINET RT: Topology



---

- Line, Branch + Tree Topologies are supported
- Siemens recommends:  
*use star architecture and keep the cascade depth of switches low*
- Line Topology thus not recommended, due to cascaded switch issue

Example of an optimized PROFINET topology



PROFINET data exchange and communication  
4.6 Setup recommendations for optimizing PROFINET

### 4.6 Setup recommendations for optimizing PROFINET

**Optimizing PROFINET with RT**

PROFINET allows you to set up communication with both high-performance and a high degree of integration. By keeping to the following guidelines, you can further improve performance of your PROFINET IO system in RT mode.


1. Connect a router or a SCALANCE S between the office network and PROFINET system. Use the router to define access privileges for your PROFINET system.
2. Where useful, set up your PROFINET in a star architecture (in the control cabinet perhaps).
3. Keep the cascade depth of switches low. This increases clarity of your PROFINET system architecture.

Source: Siemens PROFINET System Description, System Manual 08/2008, A5E00298288-04, Page 75  
In the 2010 version of this document, item 3 was removed – the 2010 version contains the recommendation to use dedicated Siemens Switches only...


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Even though PROFINET marketing claims that line topology is supported, in fact this is not recommended by Siemens.



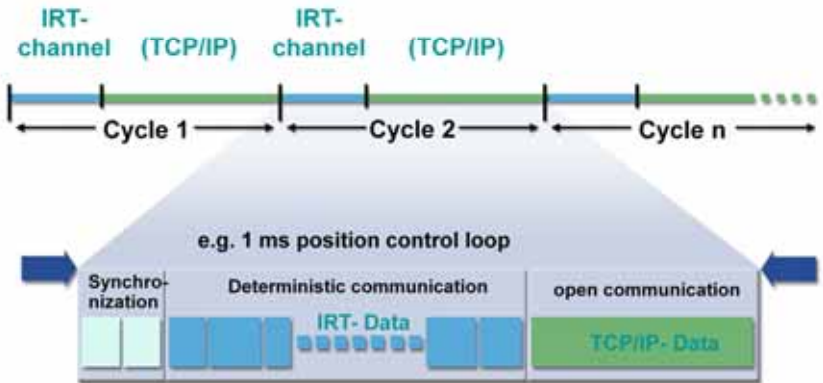


## PROFINET IRT: Functional Principle



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Timeslicing Approach by special Switch ASICs
- Switches can be integrated into devices
- Topologies: Line (up to 25 nodes), Branch, Tree supported
- Cycle Time 250  $\mu$ s to 4 ms, 1  $\mu$ s jitter.  
V 2.3 (Ed.1): Cycle time starting from 31.25  $\mu$ s (claimed)



Pictures sourced from PI website

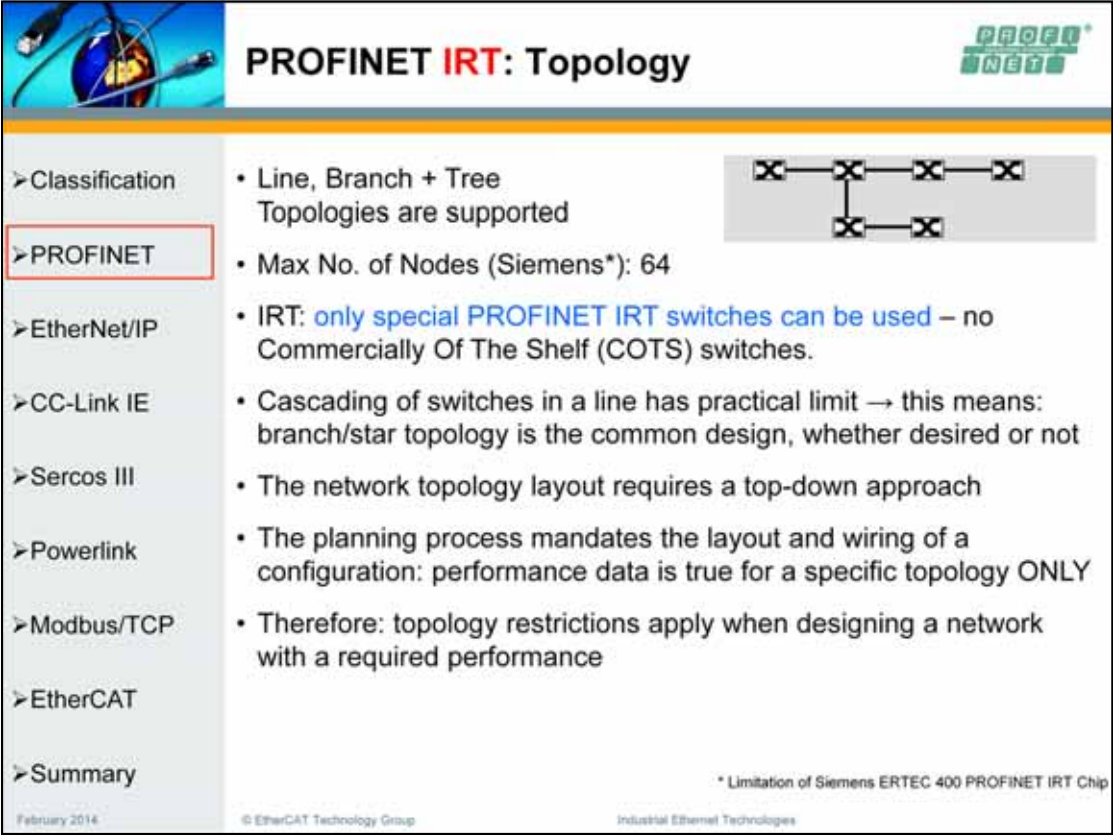
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

The minimum cycle time is determined by the approach to include generic TCP/IP traffic in a gap wide enough for the largest Ethernet frame.

This approach leads to limited bandwidth utilization, since even though most applications only have sporadic TCP/IP communication, the bandwidth remains reserved for this kind of traffic.

For cycle times below 250 $\mu$ s the so called High-Performance-Profile has to be implemented, which is an optional feature in V2.3.

As of Feb 2014, there are no master devices supporting this profile. The standard PROFINET masters from Siemens start at 250 $\mu$ s (Motion Controller) or at 1ms (e.g. PLC S7-315).



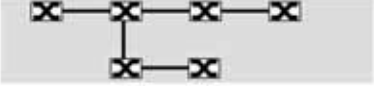
## PROFINET IRT: Topology

**PROFINET**


- Classification
  - Line, Branch + Tree Topologies are supported
- PROFINET
  - Max No. of Nodes (Siemens\*): 64
- EtherNet/IP
  - IRT: **only special PROFINET IRT switches can be used** – no Commercially Of The Shelf (COTS) switches.
- CC-Link IE
  - Cascading of switches in a line has practical limit → this means: branch/star topology is the common design, whether desired or not
- Sercos III
  - The network topology layout requires a top-down approach
- Powerlink
  - The planning process mandates the layout and wiring of a configuration: performance data is true for a specific topology ONLY
- Modbus/TCP
  - Therefore: topology restrictions apply when designing a network with a required performance
- EtherCAT
- Summary

\* Limitation of Siemens ERTEC 400 PROFINET IRT Chip


February 2014    © EtherCAT Technology Group    Industrial Ethernet Technologies



The non-linear and even unpredictable interdependency between topology and performance may require several iterations (or „try and error“ steps) when designing a network layout for a required performance.



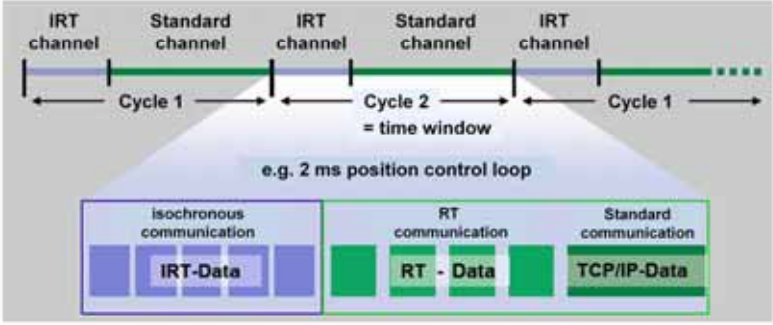
## PROFINET V2 (RT) and V3 (IRT)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**Both versions can be mixed, if**

- supported by master
- only IRT switches are used
- enough bandwidth available



e.g. 2 ms position control loop


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

In principle both varieties (RT+IRT) can be mixed. Since IRT switches have to be used then, one can say:


RT devices can be integrated in IRT networks, if there is sufficient bandwidth and if the master supports this.

Siemens recommends in the current System Manual\* to position the RT devices at the end of the PROFINET system, outside of the IRT sync domain. Synchronization between the RT and IRT devices is not possible (“if you want to synchronize with IRT, the respective PROFINET devices must support IRT communication”).

\* Source: Siemens PROFINET System Description, page 153, “Setting up PROFINET with IRT”, 07/2010, A5E00298288-05



## PROFINET IRT System Planning (I)



- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**Input** for planning/configuration of the network:

- the topology of the network
  - For every connected port of every device in the IRT network the partner port has to be configured – configuring the cable length or signal delay time is also recommended for better results
- and for every transmission the optimization algorithm needs:
  - the source- and the target node,
  - the amount of transmission data,
  - projected features of the connection path (e.g. Redundancy)

**Output** of the projection for every transmission and device respective switch:

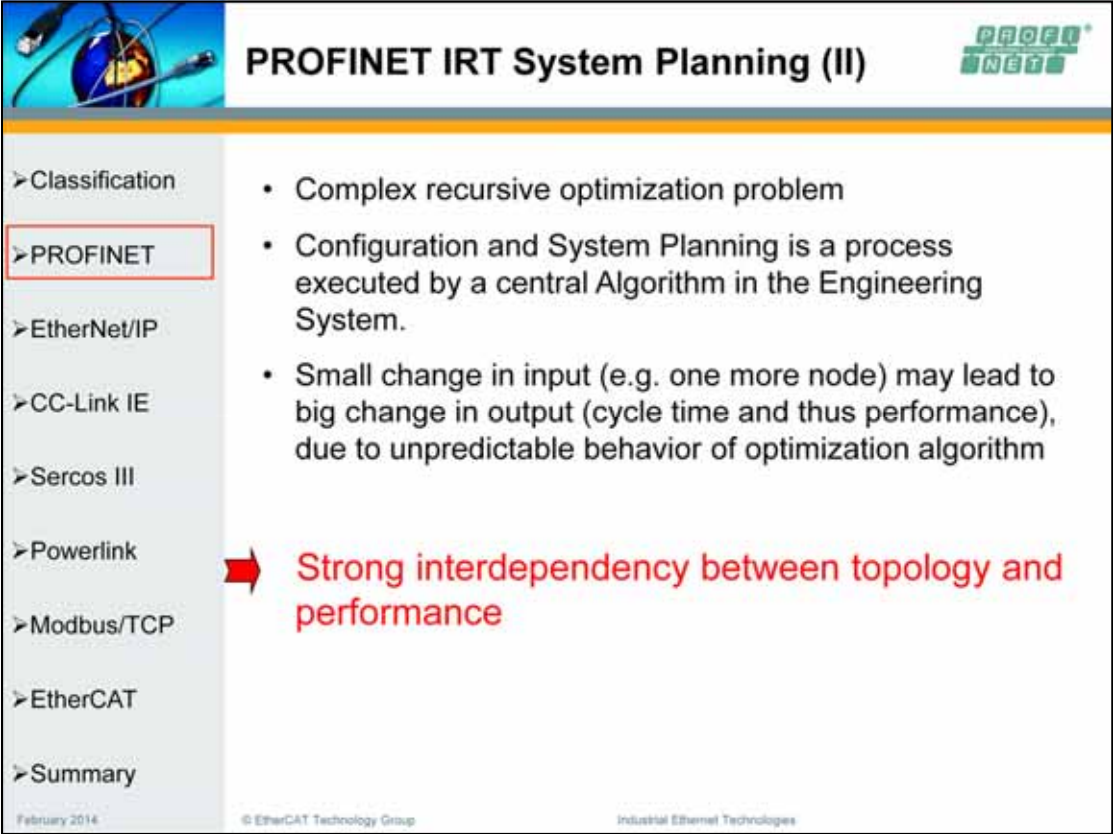
- Ports and exact transfer time timing for each frame

February 2014

© EtherCAT Technology Group

Industrial Ethernet Technologies

Besides hardware costs, the crucial issue of PROFINET IRT is the complex system planning.



The slide is titled "PROFINET IRT System Planning (II)" and features the PROFINET logo in the top right corner. On the left side, there is a vertical navigation menu with the following items: Classification, PROFINET (highlighted with a red box), EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. A red arrow points from the "Powerlink" item to the text "Strong interdependency between topology and performance" in red. The main content area contains three bullet points: "Complex recursive optimization problem", "Configuration and System Planning is a process executed by a central Algorithm in the Engineering System.", and "Small change in input (e.g. one more node) may lead to big change in output (cycle time and thus performance), due to unpredictable behavior of optimization algorithm". At the bottom of the slide, there is a footer with the date "February 2014" and the copyright notice "© EtherCAT Technology Group" and "Industrial Ethernet Technologies".

## PROFINET IRT System Planning (II)

- Classification
  - Complex recursive optimization problem
- PROFINET
  - Configuration and System Planning is a process executed by a central Algorithm in the Engineering System.
  - Small change in input (e.g. one more node) may lead to big change in output (cycle time and thus performance), due to unpredictable behavior of optimization algorithm
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
  - ➔ **Strong interdependency between topology and performance**
- Modbus/TCP
- EtherCAT
- Summary

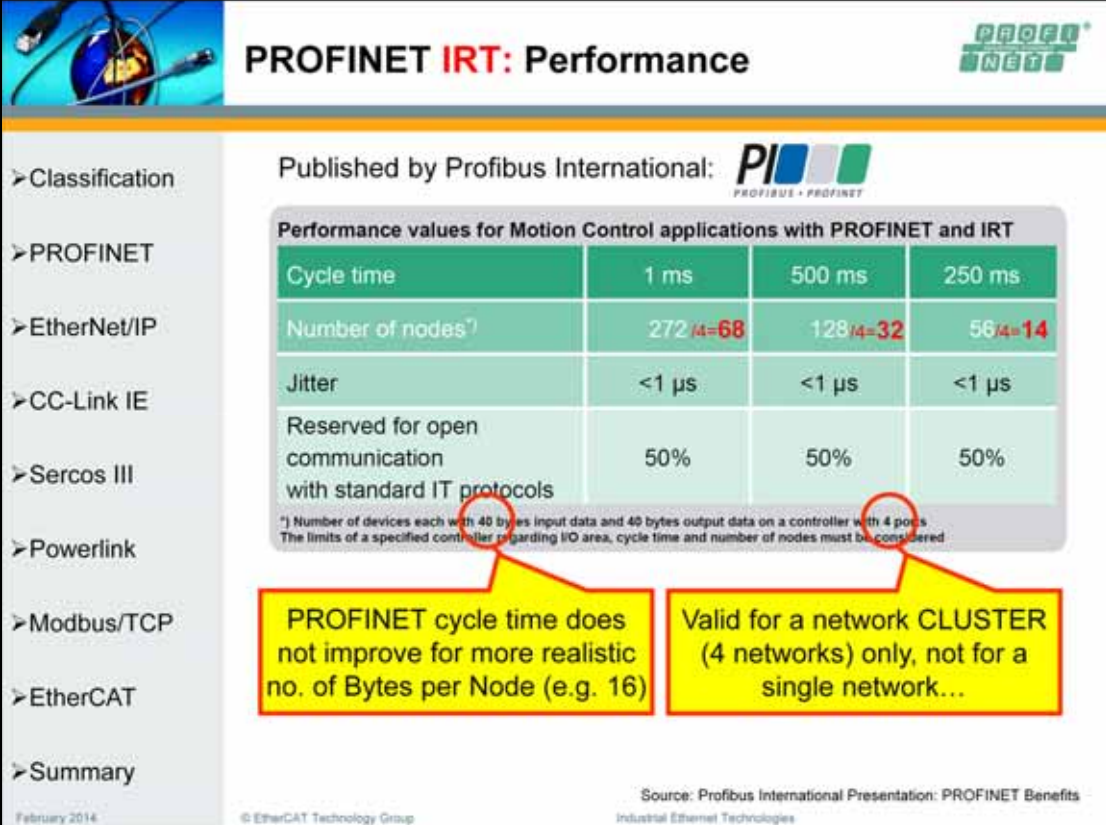
February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

For each node all communication relationships have to be known and scheduled. Of course there are strong interdependencies between the schedules. Therefore the system planning is a complex recursive optimization problem without a straightforward solution – even with fairly simple topologies.


Due to the complex nature of this problem the optimization algorithm may come up and be satisfied with a relative rather than the absolute optimum – which means, that a small change in the configuration (e.g. adding just one more node) may result in large changes in the network performance.

The algorithm was developed by Prof. Dr. Ulrich Lauther and has 23.000 lines of code, according to Siemens. A license for the planning algorithm (in dll format) can meanwhile be obtained by PI members – it remains a black box algorithm, however.





**PROFINET IRT: Performance**

Published by Profibus International: 

**Performance values for Motion Control applications with PROFINET and IRT**

Cycle time	1 ms	500 ms	250 ms
Number of nodes <sup>*)</sup>	272 /4=68	128 /4=32	56 /4=14
Jitter	<1 μs	<1 μs	<1 μs
Reserved for open communication with standard IT protocols	50%	50%	50%

\*) Number of devices each with 40 bytes input data and 40 bytes output data on a controller with 4 ports. The limits of a specified controller regarding I/O area, cycle time and number of nodes must be considered.

**PROFINET cycle time does not improve for more realistic no. of Bytes per Node (e.g. 16)**

**Valid for a network CLUSTER (4 networks) only, not for a single network...**

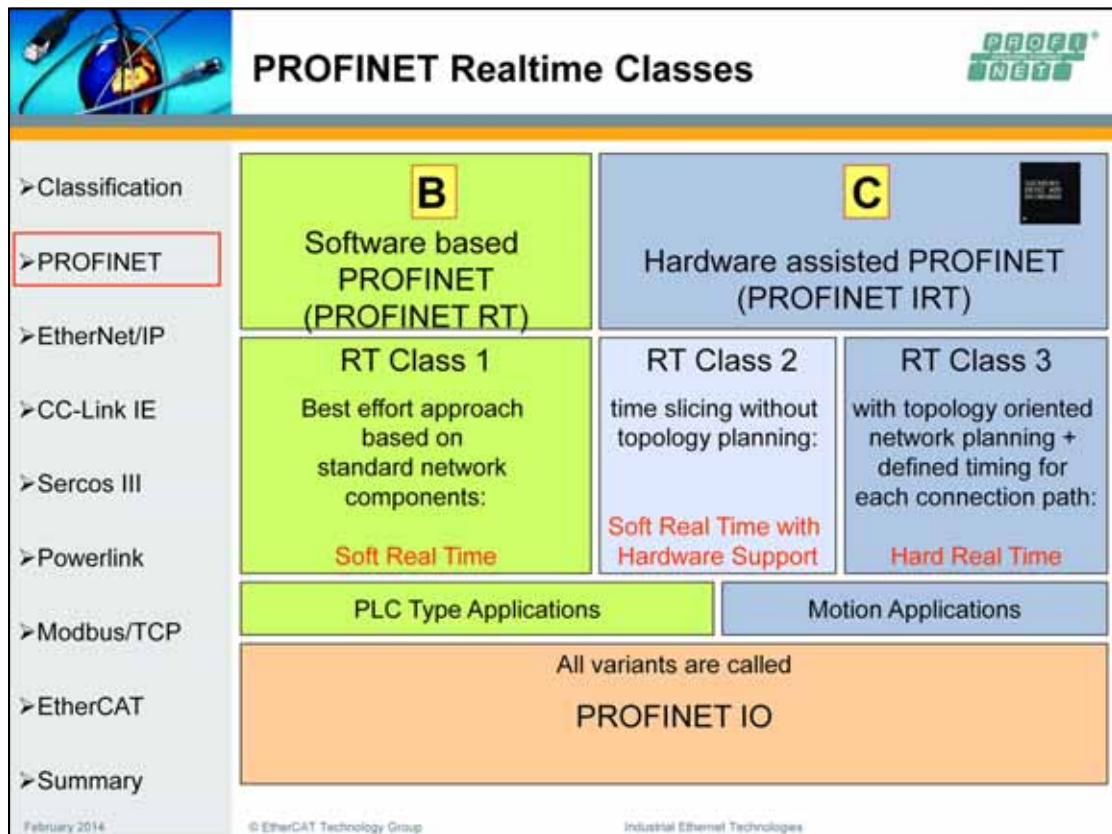
February 2014 © EtherCAT Technology Group Source: Profibus International Presentation: PROFINET Benefits Industrial Ethernet Technologies

This is the performance data table published for PROFINET IRT. However, the table is valid only for a cluster of networks: 272 nodes sharing 50% bandwidth at 1ms cycle time means  $500 \mu\text{s} / 272 = 1,84 \mu\text{s}$  per node. The shortest Ethernet frame takes  $7 \mu\text{s}$  to transmit.

Furthermore, most controllers using the Siemens ERTEC 400 chip have a limit of **64 IRT nodes – on all 4 ports combined**, due to resource limitations within the chip.

Controllers using the 2-port ERTEC 200P can only handle a much smaller number of nodes (~16)

This is not to state that PROFINET IRT was not fast enough for most applications...



In order to avoid the complex topology network planning process, an intermediate approach had been introduced: Realtime (RT) Class 2 (within Siemens also called IRT “Flex” or “IRT with high flexibility”) using PROFINET chips (e.g. ERTEC). High priority network traffic is sent in the IRT time slice, but without predefined timing for each connection. Low priority communication is handled in the NRT time slice. PROFINET chips have to be used throughout. Cyclic behavior can be achieved if the network load is low and the application tasks are synchronized with the communication cycle. The downside is that there is unused bandwidth that is exclusively reserved and cannot be used for other communication.

IRT Flex was intended as a simplified PROFINET IRT variety for PLC type applications that utilize ERTEC profinet chips (Siemens Simatic S7). However, due to incompatibility issues, IRT Flex is not promoted or recommended by Siemens any more. In the PROFINET Specification V2.3 IRT Flex is marked as “legacy”, thus not supported any more.

RT Class 3 (also called IRT “TOP” or “IRT with high performance”) is the variant formerly referred to as PROFINET IRT. This approach provides hard real time behavior but requires the detailed network planning (topology editor) and the optimization algorithm: the topological information from the configuration is used for planning the communication. Siemens is adopting this variant for PLCs as well.

PTO/PNO generally downplays the differences between the PROFINET variants, summarizing all of them with the term “PROFINET IO”.

**PROFINET IO: Conformance Classes**

- PROFINET defines 3 conformance classes: A+B = RT, C = IRT (+RT)
- For synchronized Motion Control, regardless of Cycle Time: Class C required

- Class C:**
  - Highest deterministic data transfer
  - Certified devices and network components
  - Topmost performance
- Class B:**
  - Certified devices and network components
  - Topology determination and upload
  - Comfortable Diagnostics, redundancy
- Class A:**
  - Standard Ethernet Network components
  - Certified Devices and Controller

# Application Class:	non isochronous	non isochronous	Non Iso. + Isochronous
# Communication Class:	TCP/IP, RT	TCP/IP, RT	TCP/IP, RT, IRT
# Redundancy:	RedClass 1 optional	RedClass 1 mandatory RedClass 2 optional	RedClass 1, 2, 3 mandatory

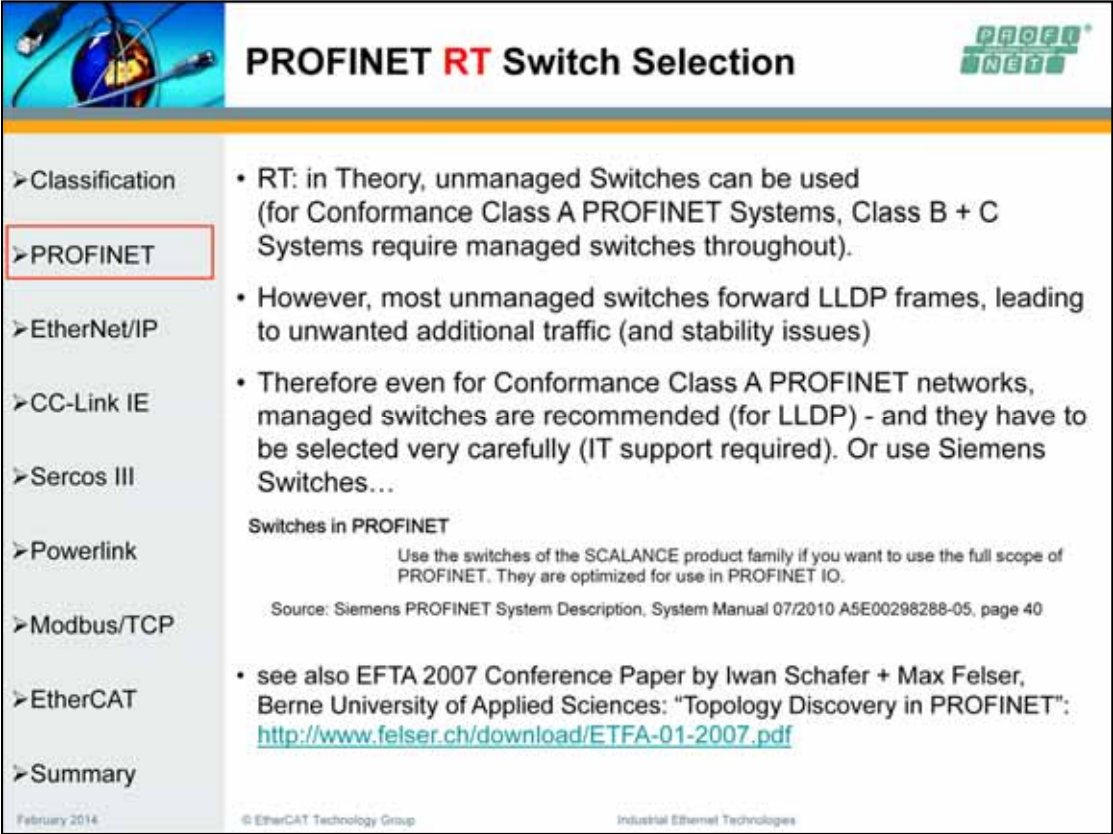
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies Source: PI PROFINET Technology Presentation

In addition to the RT classes, PROFINET has introduced (see IEC 61784-2) **Application Classes** (Isochronous for motion control, Non-isochronous for factory process + building automation),

**Redundancy Classes** (MRP: Media redundancy protocol; MRRT: Media redundancy for real-time (dropped in PROFINET V2.3); MRPD: media redundancy for planned duplication) and

**Conformance Classes.** The Conformance Classes predominantly define the support for the topology recognition features. Redundancy Classes and Conformance Classes are interlinked.

Topology Recognition originally was required for Conformance Class B + C, only; meanwhile this is required for Conformance Class A (but without LLDP-MIB).



The slide is titled "PROFINET RT Switch Selection" and features the PROFINET logo in the top right corner. On the left, there is a vertical navigation menu with the following items: Classification, PROFINET (highlighted with a red box), EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area contains the following text:

- RT: in Theory, unmanaged Switches can be used (for Conformance Class A PROFINET Systems, Class B + C Systems require managed switches throughout).
- However, most unmanaged switches forward LLDP frames, leading to unwanted additional traffic (and stability issues)
- Therefore even for Conformance Class A PROFINET networks, managed switches are recommended (for LLDP) - and they have to be selected very carefully (IT support required). Or use Siemens Switches...

**Switches in PROFINET**

Use the switches of the SCALANCE product family if you want to use the full scope of PROFINET. They are optimized for use in PROFINET IO.

Source: Siemens PROFINET System Description, System Manual 07/2010 A5E00298288-05, page 40

- see also EFTA 2007 Conference Paper by Iwan Schafer + Max Felser, Berne University of Applied Sciences: "Topology Discovery in PROFINET": <http://www.felser.ch/download/ETFA-01-2007.pdf>


February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

It was found that there are issues when using unmanaged switches with PROFINET Class A (in B managed switches are mandatory): common COTS switch chips forward LLDP (Link Layer Discovery Protocol) frames to all ports, which leads to substantial additional network traffic (the frames are handled like broadcast frames).


**Conclusion: even for Conformance Class A PROFINET networks, in reality managed switches have to be used (for LLDP) - and they have to be selected very carefully (IT support required).**

see also EFTA 2007 Conference Paper by Iwan Schafer + Max Felser, Berne University of Applied Sciences: "Topology Discovery in PROFINET": <http://www.felser.ch/download/ETFA-01-2007.pdf>






## PROFINET Robustness (I)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- PROFINET can be vulnerable if certain non-PN network traffic occurs, such as high density of (short) ARP requests
- This applies to RT as well as to IRT, since in IRT the NRT channel is used for supporting services, such as:
  - Synchronization (PROFINET PCTP, similar to IEEE1588 PCTP)
  - All acyclic services (which are used by some masters in a cyclic way).
  - Discovery protocol (LLDP)



- Therefore Profibus International has published a spec/guideline called „PROFINET IO Net load“
- **Thus the PROFINET user is now responsible to ensure that certain network load limits are not exceeded.**

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

PROFINET marketing has always claimed that PROFINET provides (quote from PI “PROFINET Benefits” presentation):

- “Unlimited IT communications parallel to real-time communications
- Easy use and integration of standard Ethernet applications”

However, since the PROFINET technology itself (unlike e.g. EtherCAT) has no means to control or restrict incoming “unlimited IT communications”, there can be rare overload situations that cause the network to fail. If the communication processor of a device is too busy to handle e.g. an occasional burst of broadcasted ARP frames and therefore cannot keep up with executing services such as IP communication, propagation delay measurement or synchronization, the communication times out and the master will recognize an error – the system stops.

One could consider this an implementation problem that can be avoided by providing sufficient processing resources throughout – but it is a problem that occurs in reality, especially in large networks. And adding resources such as processing power eases the problem, but does not resolve it reliably.

It can be challenging to ensure that certain network load limits are not exceeded. If e.g. a service notebook starts to scan the network for IP addresses at high pace, who knows what kind of load condition this generates?

By the way: Industrial Ethernet technologies that tunnel other Ethernet traffic - such as EtherCAT – remain in control of the additional network load and avoid such situations by design.



**PROFINET Robustness (II)**

PROFINET IO Security Level 1 - Netload

PROFINET User, Manufacturer

This area is for members only. Please login to access this download.

Descriptions

Because Security becomes more and more important for production networks, robustness and an adequate behavior in case of security incidents are necessary qualities of automation devices. The netload test helps to improve these qualities.

In order to achieve a common approach to evaluate the behavior of PROFINET IO nodes a netload test is used to provide common test conditions.

The document 7.302 describes the focus of the netload test and provides background information concerning the netload test as part of the PROF certification.

The document 2.302 describes how to get the information of the test Security Level 1 test for PROFINET IO. The test cases shall describe test frames and sequences that can be downloaded from [www.profibus.com](http://www.profibus.com).

February 2014

© EtherCAT Technology Group


Screenshot from Profibus International website:  
<http://www.profibus.com/nc/download/test-and-certification/downloads/profinet-io-net-load-1/ksplv/>

Regardless of the net load class, PROFINET IO devices are only required to handle 50 ARP request per second (in any density within that second). This means that things may go wrong if an average of one ARP request per 20 ms is exceeded. The latest draft version of the PROFINET IO Security Level 1 - Netload Guideline was published in Nov 2013. Now LLDP traffic exceeding 5% within one ms is suggested to be a “faulty” condition.




The screenshot shows the Industrial Ethernet Book website. The main header features the PROFINET logo and the title "PROFINET Robustness (III)". A navigation menu on the left lists various industrial Ethernet technologies, with "PROFINET" highlighted. The main content area displays a press release titled "Softing's PROFINET implementation passes testing for Net Load Class III". The article includes an image of a circuit board and text explaining that Softing's device passed the Class III category of the 'Net Load Test' performed by PROFIBUS & PROFINET International (PI). The text states that this performance objective ensures that PROFINET based devices that are based on Softing's protocol software will operate at the highest level of robustness and reliability even under high network load. It also mentions that Softing's off-the-shelf industrial Ethernet communications board FPGA ITEM CII served as the hardware platform for the Net Load Test. The article concludes by stating that the data security aspect in production networks is becoming more and more important, and that it is essential to ensure stable communication links and predictable device behavior even under extreme conditions such as the integration of production and company networks into one secure subnet. The PI Net Load Test is designed to evaluate the effects of extra network load on a PROFINET protocol implementation by introducing additional data traffic up to the total available network bandwidth. Depending on how well the PROFINET protocol software is able to sustain a reliable communication link, it determines its ranking into Net Load Classes I, II or III with Class III identifying the highest level of reliability. The article is dated February 2014 and is published by IEB Media GmbH. A footer note indicates the screenshot was taken from the Industrial Ethernet Book website at the URL: http://www.iebmedia.com/index.php?id=9934&parentid=1945&themeid=1945&showdetail=true&bb=1.

This press release shows that vendors take the net load specifications seriously: Softing is happy that their device passed (the preliminary) test cases for net load class III, but how does the user ensure that the net load is confined within a certain class?

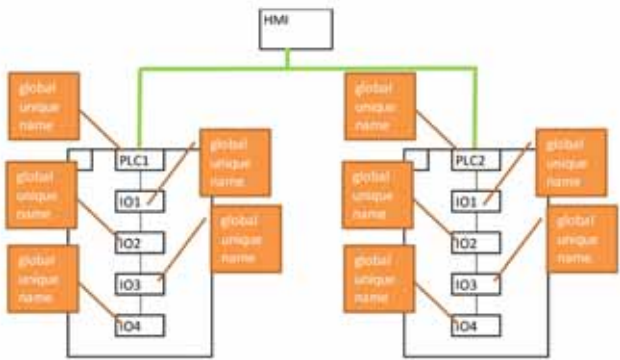


## PROFINET: Ease of Use



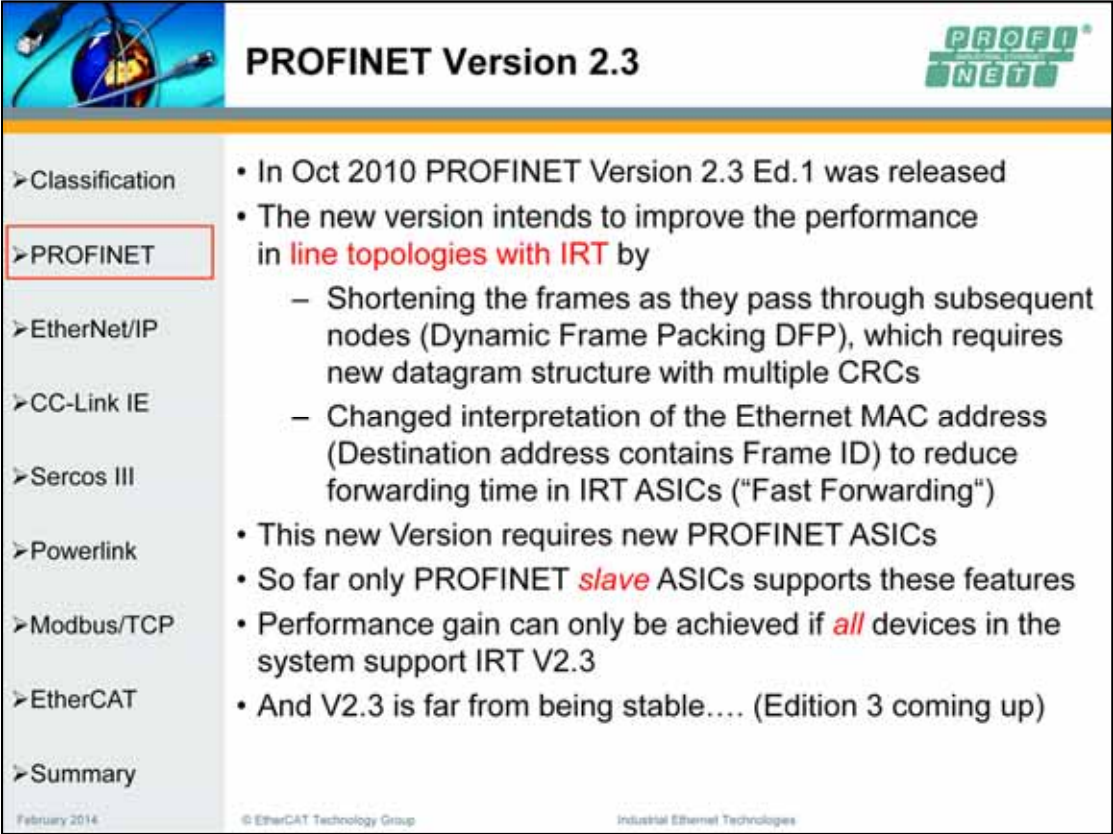
- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- PROFINET has no structuring concept (with isolated Ethernet segments), therefore Single Layer 2 network needed
- All modules or subsystems within one line require a common configuration!
- Setup of addresses difficult – each IO-module affected
- Setup cannot be done by the machinery supplier



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Since PROFINET has no structuring concept, all modules within reach of one PROFINET node (e.g. all machines and subsystems in an assembly line) have to have unique names/addresses. This means that the node address has to be assigned by the system integrator: the node addresses assigned by the machine or subsystem supplier may conflict with neighboring systems and may therefore have to be modified at the customer site.



The image shows a presentation slide titled "PROFINET Version 2.3". The slide features a navigation menu on the left with items: Classification, PROFINET (highlighted with a red box), EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area contains a bulleted list of key features and updates for the new version. The PROFINET logo is in the top right corner. At the bottom, there is a footer with the date "February 2014" and copyright information for "EtherCAT Technology Group" and "Industrial Ethernet Technologies".

## PROFINET Version 2.3

- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In Oct 2010 PROFINET Version 2.3 Ed.1 was released
- The new version intends to improve the performance in **line topologies with IRT** by
  - Shortening the frames as they pass through subsequent nodes (Dynamic Frame Packing DFP), which requires new datagram structure with multiple CRCs
  - Changed interpretation of the Ethernet MAC address (Destination address contains Frame ID) to reduce forwarding time in IRT ASICs ("Fast Forwarding")
- This new Version requires new PROFINET ASICs
- So far only PROFINET **slave** ASICs supports these features
- Performance gain can only be achieved if **all** devices in the system support IRT V2.3
- And V2.3 is far from being stable.... (Edition 3 coming up)

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Profibus organization PNO showed a PROFINET IRT+ demonstrator in April 2008 at Hannover Fair. According to a PNO press release of Nov 26, 2008, "The specifications will be finished in the second half of 2009".


Similar to RT and IRT version that are summarized as "PROFINET IO" in order to play down the many varieties of the technology, the PROFINET organization does not use the term IRT+ any more. The features of the new version which requires new chips are contained in the PROFINET specification V2.3, of which Ed. 1 was published in October 2010.

V2.3Ed.2 was published in December 2012.


The next version V2.3Ed.2MU1 was published in October 2013.

(substantial change log in Technical-editorial-Changes-d23Ed2MU1\_V1\_Oct13.pdf).

Currently PNO is working on Ed. 3.



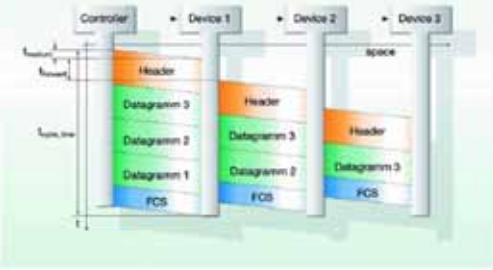
## IRT 2.3: Dynamic Frame Packing (DFP)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

DFP aims to enhance PROFINET IRT Performance in Line Topologies

- Frame Efficiency will be improved by shortening frames dynamically in node (only in line topology)



- In DFP-Lines, IP-Frames (other Ethernet Traffic) will be fragmented – just as with EtherCAT


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Picture: Phoenix Contact @ SPS/IPC/Drives Congress 2009

DFP will work in line topologies, only.

With DFP PROFINET introduces the layer 2 fragmentation of IP-Frames – another feature that EtherCAT has introduced and which PROFINET marketing used to condemn...





## PROFINET IRT 2.3: Fast Forwarding (FF)

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Fast Forwarding (FF) will reduce Cut-Through Forwarding Time by introducing Multicast MAC Addresses with integrated PROFINET Address
  - Cut Through Switch can decide („forward to which port?“) after reception of PROFINET destination address (FID, frame ID)

Header					Datagram	FCS
DA	SA	VLAN	ET	FID		
→						

Decision Time without FF

Header					Datagram	FCS	
FID	DA	SA	VLAN	ET			FID
→							

Decision Time with FF

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

For introducing Fast Forwarding the address usage had to be modified. The goal is to reduce the „per-node-delay“ of PROFINET. Since PROFINET Version 2.3 the FrameID is part of the OUI (Organizationally Unique Identifier) in the MAC address, with the first two bits set to “1” (= Locally Administered Group Address).


The MAC addresses used for Fast Forwarding are not protected and can be used by others as well – it is the responsibility of the user to ensure that there is no address conflict within his network.

Examples for systems with known address conflicts:


03:00:C7:00:00:EE HP (Compaq) ProLiant NIC teaming

03:00:FF:FF:FF:FF All-Stations-Address

03:BF:00:00:00:00 MS-NLB-VirtServer-Multicast





## PROFINET V2.3: 31.25 $\mu$ s?



- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- PI tries to imply that with IRT V2.3 PROFINET now supports 31.25 $\mu$ s cycle time
- However, there is no product supporting this yet
- And no Master chip available
- EtherCAT demonstrated 12.5 $\mu$ s cycle time with standard Commercially Off The Shelf Products and standard EtherCAT ...




February 2014


© EtherCAT Technology Group

Industrial Ethernet Technologies



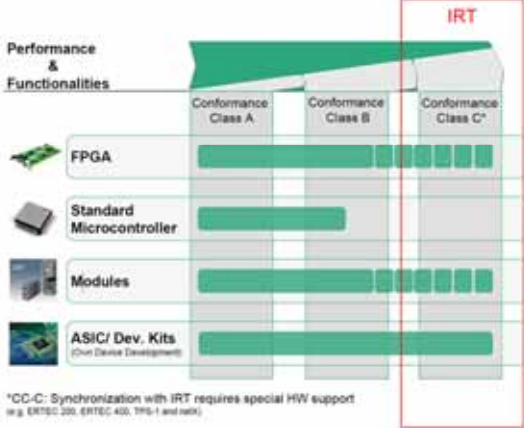


## PROFINET IRT: Implementation



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Master: Special PROFINET Chip (ERTEC 400)\*
- Slave: Special PROFINET Chip (ERTEC 200, 200P#, TPS-1, netX51/52/6#)



\*CC-C: Synchronization with IRT requires special HW support (e.g. ERTEC 200, ERTEC 400, TPS-1 and netX)

Source: Profibus International Presentation: PROFINET Benefits.

\* New Intel® Ethernet Controller I210 only for relaxed sync requirements

\* supports IRT V2.3 with DFP and FF

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies


Siemens/Renesas ERTEC400 chip is intended for master devices, has 4 ports and supports minimal cycle times of 250µs;

Siemens/Renesas ERTEC200 chip is intended for slave devices, has 2 ports and supports minimal cycle times of 250µs;


Siemens ERTEC200P chip is intended for slave devices, has 2 ports and claims to support minimal cycle times of 31,25µs (if there was a master supporting this).

In Feb 2013 The Intel Ethernet Controller I210 was introduced as breakthrough for low cost IRT Master implementations. However, according to reports the chip is only suitable for relaxed synchronization requirements.

There are considerably smaller PROFINET stacks that claim to be V2.3 compatible – however, these are PROFINET RT (Conformance Class A, Realtime Class 1) stacks, not supporting IRT.


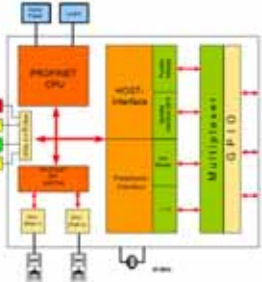


## PROFINET Chip TPS1 “Tiger”



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Developed by Phoenix Contact (+ inIT), distributed by Renesas, marketed by KW Software
- Goal: Simpler to integrate than Siemens ERTEC200
- DFP - Dynamic Frame Packing + FF - Fast Forwarding not (yet) supported
- PHYs + Protocol CPU integrated, but no Application  $\mu$ C
- Aimed at I/O and Drives
- Initially announced for 2009, first samples mid of 2011, series production 2012
- Marketing: “Joint Development of Phoenix and Siemens” in order to stress compatibility with ERTEC

Picture sourced from KW Software Website

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

TPS1 is also called “Tiger” chip, since it was planned to be released in the Year of the Tiger (2/2010 – 2/2011). Even though it will now be released in the Year of the Rabbit (or Hare), no plans are known to officially rename it the “Rabbit” chip.

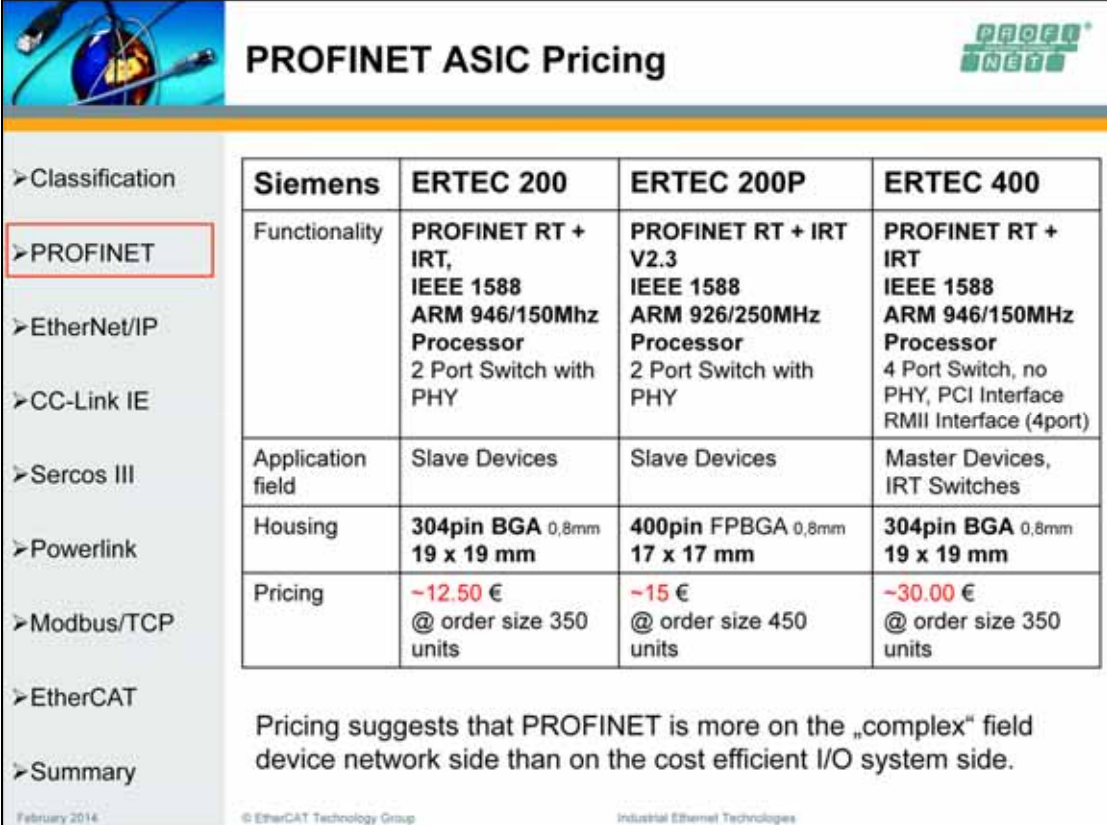
The Tiger aka TPS1 (aka Rabbit) chip is a Phoenix Contact development (subcontracted to the Institut Industrial IT (inIT) of the University of Applied Science Westfalen Lippe) – and Phoenix Contact (not Siemens) also was the driving force behind PROFINET V4 (IRT+). So the TPS1 was intended to be the first chip supporting the new PROFINET version.

But end of 2009 it looked that Siemens was unhappy about Phoenix trying to take the lead in PROFINET advancement and therefore forced Phoenix into a lengthy consensus building process within PNO in order to delay the availability of PROFINET V4. Later Siemens seemed to have recognized that this strategy backfired on PROFINET in general.

So in March 2010 PNO held a press conference where in total contrast to the statements of Nov 2009, where Siemens had denied any involvement in the TPS1 development, Siemens and Phoenix Contact called the TPS1 a joint development of both companies which they plan to use also in the future in devices of their own product portfolio.

Nevertheless, PNO committees changed the Fast Forwarding technology again in fall 2010 and thus too late for the first version of the TPS1 chip. So the TPS1 chip will initially not support the DFP and FF – which is not such a big problem, since there is no master in sight supporting these features anyhow. The Siemens next generation PROFINET chip (ERTEC 200P) thus has been the first one to support DFP and FF.

The TPS1 is for slave devices only. The integrated “PROFINET CPU” is an ARM core and executes the time critical parts of the PROFINET protocol. Digital I/O can be connected directly to the chip. For communication with the application (host) CPU the chip contains internal DPRAM, which can be accessed via serial or parallel interface. Since its cyclic process data image is limited to 340 bytes, it is hardly suitable for bus couplers of modular I/O devices or other more complex devices. KW Software claims that with this chip the interface hw costs can be reduced to 13€ (~19\$).



**PROFINET ASIC Pricing**

PROFINET

- Classification
- PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

Siemens	ERTEC 200	ERTEC 200P	ERTEC 400
Functionality	PROFINET RT + IRT, IEEE 1588 ARM 946/150Mhz Processor 2 Port Switch with PHY	PROFINET RT + IRT V2.3 IEEE 1588 ARM 926/250MHz Processor 2 Port Switch with PHY	PROFINET RT + IRT IEEE 1588 ARM 946/150MHz Processor 4 Port Switch, no PHY, PCI Interface RMII Interface (4port)
Application field	Slave Devices	Slave Devices	Master Devices, IRT Switches
Housing	304pin BGA 0,8mm 19 x 19 mm	400pin FPBGA 0,8mm 17 x 17 mm	304pin BGA 0,8mm 19 x 19 mm
Pricing	~12.50 € @ order size 350 units	~15 € @ order size 450 units	~30.00 € @ order size 350 units

Pricing suggests that PROFINET is more on the „complex“ field device network side than on the cost efficient I/O system side.

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies


First samples of the ERTEC 400 were shipped in May 2005, first samples of the ERTEC 200 were shipped in May 2006. The ERTEC 200P was released in April 2013.

Initially, the ERTEC 400 was sold for 38€ and the ERTEC 200 for 19 € per chip (@ 10.000 units/year). As of Oct 1<sup>st</sup>, 2007, Siemens lowered the prices substantially (-40%).


12.50€ respective 30€ per chip still exceeds fieldbus cost levels not only for simple devices, in particular if one considered the amount of memory needed:

A PROFINET slave device needs about 1-2 MByte of Code for the communication part. For implementation with ERTEC chips, a VxWorks license is required: the stack is provided as object code for this RTOS.





## PROFINET: Test and Certification



- PROFINET Conformance relates to
  - Version of the Standard /Version of the Test Spec
  - Version of the 2 different (RT/IRT) Test Cases
  - Version of the 2 different (RT/IRT) Test Tools
- Only **7** IRT Devices found as certified products in PNO Database!

Test Report Number: **PN109-1, IRT005-1**  
 Authorized Test Laboratory: **SIEMENS AG, Fürth, Germany**

The tests were executed in accordance with the following documents:  
 \*Test Specifications for PROFINET IO devices, Version 2.2.3 from September 2010\*  
 \*Test Cases for PN-Tester for PROFINET IO devices, Version 2.2.14.18\*

is certificate confirms that the product has successfully passed the certification tests with the IRT scope:  
 Hardware Fiber Optic  
 Conformance Class B, C RT\_CLASS\_1, RT\_CLASS\_2, RT\_CLASS\_3, RTA, LLDP, SNMP, MIB-II

Test Report Number: **PN212-1, IRT045-1**  
 Authorized Test Laboratory: **Siemens AG, Fürth, Germany**

The tests were executed in accordance with the following documents:  
 \*Test Specifications for PROFINET IO devices, Version 2.2.3 from December 2010\*,  
 \*Test Cases for PN-Tester for PROFINET IO devices, Version 2.2.14.16.21\*,  
 \*Test Specifications for PROFINET IO devices, Version V2.2.4 from December 2010\*,  
 \*PROFINET IO IRT Test Cases V2.2.3 from September 2010\*,  
 \*Test system V2.2.4.16.21 with annex Spieria 2.2.4.2.212\*  
 is certificate is granted according to the document: .....


Hardware Auto\_Negotiation, Auto\_Polarity, Auto\_Crossover  
 Conformance Class B, C RT\_CLASS\_1, RT\_CLASS\_2, RT\_CLASS\_3, RTA, LLDP, SNMP, MIB-II, LLDP-MIB

Test Report Number: **PN138-1, irt012-1**  
 Authorized Test Laboratory: **SIEMENS AG, Fürth, Germany**

The tests were executed in accordance with the following documents:  
 \*Test Specifications for PROFINET IO devices, Version 2.2.3 from Jan 2008\*,  
 \*Test Cases for PN-Tester for PROFINET IO devices, Version 2.2.14.18\*,  
 \*Test Specifications for PROFINET IO devices, Version 2.2.3 from September 2010\*,  
 \*PROFINET IO IRT Test Cases V2.2.3.1 from September 2010\*,  
 \*Test system V2.2.2.14.18 with annex Spieria 2.2.3.2.209\*

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

The PROFINET IO Varieties lead to corresponding test tool and test case varieties. So far no test for V2.3 available.  
 PROFINET International is working on an integrated test specification, though.



## PROFINET: **Versions** (IEC61158, PNO)

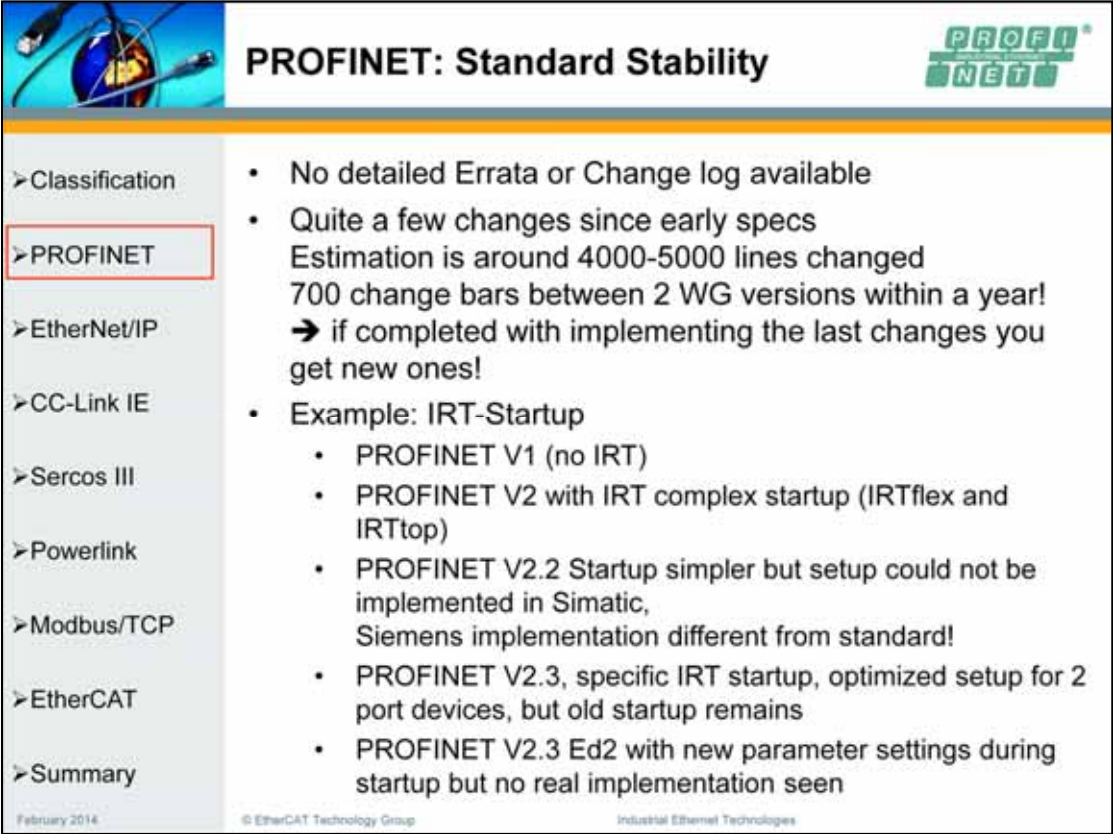
- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- 2003 V1: Initial IEC standard PROFINET CbA\*<sup>1</sup>
- 2005 V2.0: First IO specification IEC/PAS 62411\*<sup>2</sup>  
(about 600 pages includes some IRT material)
- 2007 IEC 61158-5/6-10 Ed.1\*<sup>3</sup>
- 2007 V2.2: PROFINET IO Specification
- 2010 IEC 61158-5/6-10Ed.2\*<sup>4</sup>
- 2010 V2.3 (Ed1): PROFINET IO Specification  
removed 270 pages inserted 300 pages, changes in >1000 places
- 2012 V2.3 (Ed2): PROFINET IO Specification  
changes in Annex part 6: 3 new normative 9 other Annex inserted/deleted

\*1 <http://www.dke.de/de/Service/Nachrichten/documents/typ10profinet.pdf>  
 \*2 [http://webstore.iec.ch/p-preview/info\\_iecpas62411%7Bed1.0%7Den.pdf](http://webstore.iec.ch/p-preview/info_iecpas62411%7Bed1.0%7Den.pdf)  
 \*3 [http://webstore.iec.ch/p-preview/info\\_iec61158-6-10%7Bed1.0%7Den.pdf](http://webstore.iec.ch/p-preview/info_iec61158-6-10%7Bed1.0%7Den.pdf)  
 \*4 [http://webstore.iec.ch/preview/info\\_iec61158-6-10%7Bed2.0%7Den.pdf](http://webstore.iec.ch/preview/info_iec61158-6-10%7Bed2.0%7Den.pdf)

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Many versions of PROFINET.



**PROFINET: Standard Stability**

PROFI  
NET

- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


- No detailed Errata or Change log available
- Quite a few changes since early specs  
Estimation is around 4000-5000 lines changed  
700 change bars between 2 WG versions within a year!  
➔ if completed with implementing the last changes you get new ones!
- Example: IRT-Startup
  - PROFINET V1 (no IRT)
  - PROFINET V2 with IRT complex startup (IRTflex and IRTtop)
  - PROFINET V2.2 Startup simpler but setup could not be implemented in Simatic, Siemens implementation different from standard!
  - PROFINET V2.3, specific IRT startup, optimized setup for 2 port devices, but old startup remains
  - PROFINET V2.3 Ed2 with new parameter settings during startup but no real implementation seen

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies


In October 2013 a document listing the Technical and editorial Changes of the PROFINET specs IEC 61158-5-10, 61158-6-10, 61784-2 was published. It contains a long list of changes, but no details.

There are even 3 completely different [Siemens](#) Implementations of PROFINET IO.

PROFINET remains a moving target...



## IRT and Siemens Motion Control

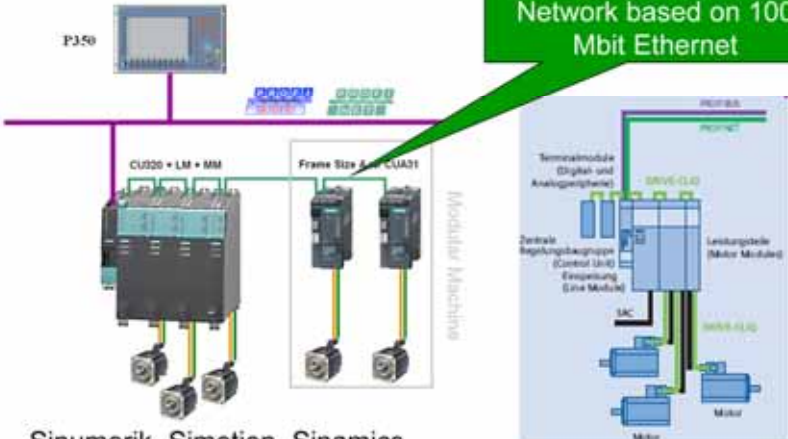


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

For closed loop motion control Siemens is using Drive-CLiQ, not PROFINET IRT...

**Innovative Machine Designs**

**Drive-CLiQ:**  
Siemens Motion Control Network based on 100 Mbit Ethernet



Sinumerik, Simotion, Sinamics favorite bus is Drive-CLiQ

Pictures sourced from Siemens website

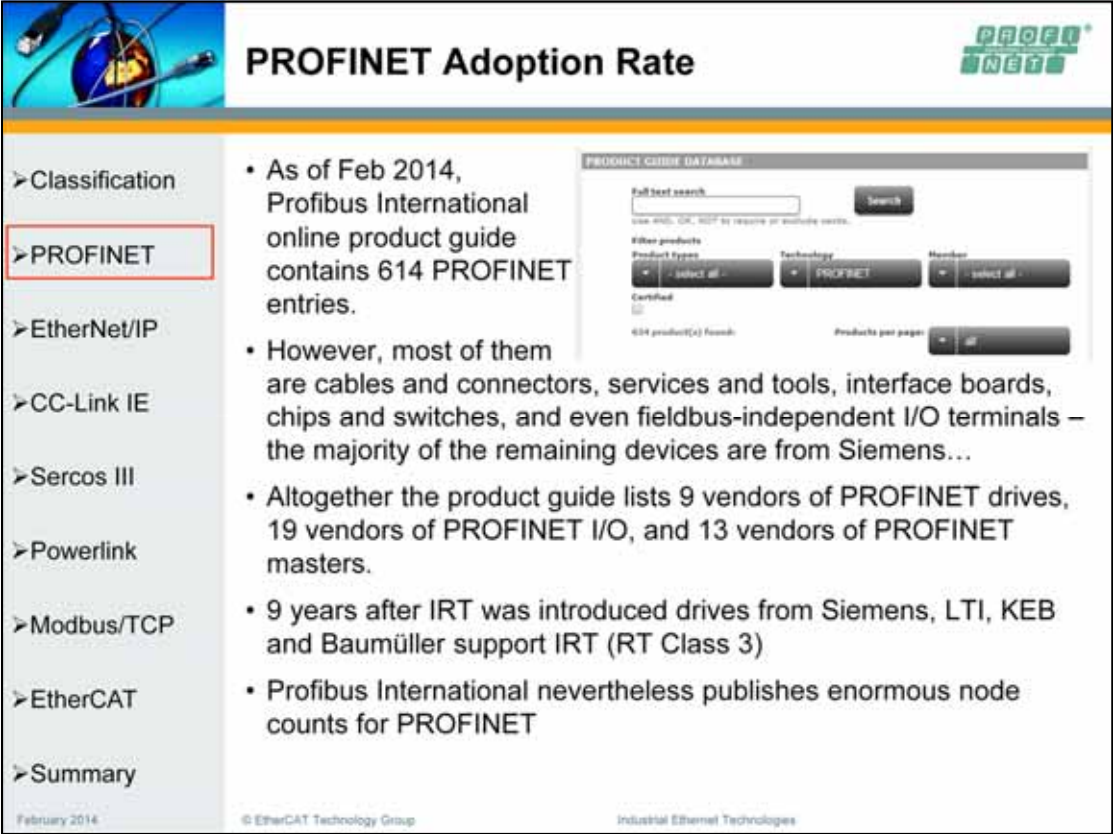
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Interesting enough, Siemens has also developed another Ethernet based motion control network: Drive-CLiQ.

Drive-CLiQ is used to connect the Sinamics motion controller containing the path planning algorithm (trajectory controller) with the drives, the position sensors (encoders, tachometers, resolver) and also with terminal modules (HMI).

PROFINET IRT and Profibus are used to network and synchronize several such motion controllers – so primarily for controller/controller communication.

End of November 2010 Siemens announced that they are is now even opening Drive-CLiQ to feedback sensor manufacturers who are invited to implement this interface in their encoders, resolvers, tachometers and linear position sensors. Siemens also provides a special chip for that purpose.



## PROFINET Adoption Rate

- Classification
- **PROFINET**
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- As of Feb 2014, Profibus International online product guide contains 614 PROFINET entries.
- However, most of them are cables and connectors, services and tools, interface boards, chips and switches, and even fieldbus-independent I/O terminals – the majority of the remaining devices are from Siemens...
- Altogether the product guide lists 9 vendors of PROFINET drives, 19 vendors of PROFINET I/O, and 13 vendors of PROFINET masters.
- 9 years after IRT was introduced drives from Siemens, LTI, KEB and Baumüller support IRT (RT Class 3)
- Profibus International nevertheless publishes enormous node counts for PROFINET


February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Given that the first version of PROFINET was introduced over 12 years ago, and that it is promoted by the market leading automation giant, the adoption rate of PROFINET is poor.


As of February 2014, there are still very few non-Siemens PROFINET masters – in particular non-Siemens IRT-masters are difficult to find. Also, there are very few known non-Siemens IRT drives, and if they support IRT, the usage can be very limited. E.g. the KEB F5 drive supports IRT, but only at 2000µs cycle time (not shorter).

The PROFINET Node Count has a very high Siemens share, but most of the nodes are the low cost S7 1200 controllers, which hardly use PROFINET.





# PROFIsafe



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- PROFIsafe was introduced in 1999 for PROFIBUS
- PROFIsafe is part of IEC 61784-3 as Functional Safety Communication Profile FSCP 3
- As of PROFIsafe Policy
  - „The right to implement PROFIsafe is granted free of charge for PI members *for use in conjunction with PROFIBUS and/or PROFINET systems.*
  - Because of the endpoint-to-endpoint principle of PROFIsafe (Black-Channel), the use of PROFIsafe in backplane busses and sub-system busses as not disclosed transmission channels is granted free of charge for PI members.*
  - The use of PROFIsafe in systems without any PROFIBUS and / or PROFINET communication paths has to be agreed by PI.*
  - The license conditions in these cases have to be negotiated with the patent holders.”*

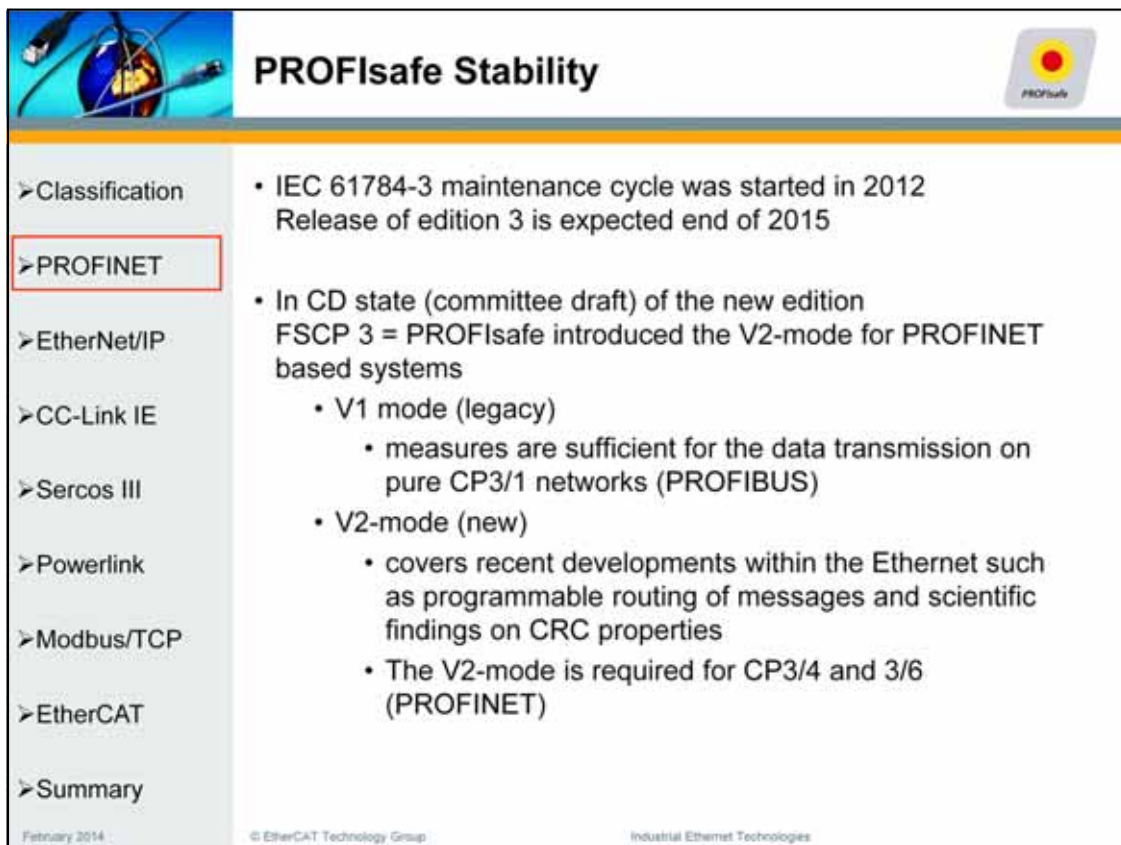
February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Even though PROFIsafe is based on a black channel approach, license conditions in the PROFIsafe Policy restrict the usage to PROFIBUS and PROFINET.

The PROFIsafe Policy explicitly prohibits to mention any Profisafe related problems in public:

*It says: “Negative statements to the public about problems without prior consultation or clarification with the PI Working Groups shall be avoided. Violators may be liable for any damage.”*

We hope that quoting from the Profisafe policy and describing the evolving Profisafe technology and its versions cannot be considered to be a “negative statement.”



## PROFIsafe Stability

- Classification
  - IEC 61784-3 maintenance cycle was started in 2012  
Release of edition 3 is expected end of 2015
- **PROFINET**
  - In CD state (committee draft) of the new edition  
FSCP 3 = PROFIsafe introduced the V2-mode for PROFINET based systems
    - V1 mode (legacy)
      - measures are sufficient for the data transmission on pure CP3/1 networks (PROFIBUS)
    - V2-mode (new)
      - covers recent developments within the Ethernet such as programmable routing of messages and scientific findings on CRC properties
      - The V2-mode is required for CP3/4 and 3/6 (PROFINET)
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

The PROFIsafe specification has passed through several changes to fulfill requirements of a black channel safety protocol which is capable to be used e.g. in Ethernet-based communication systems.

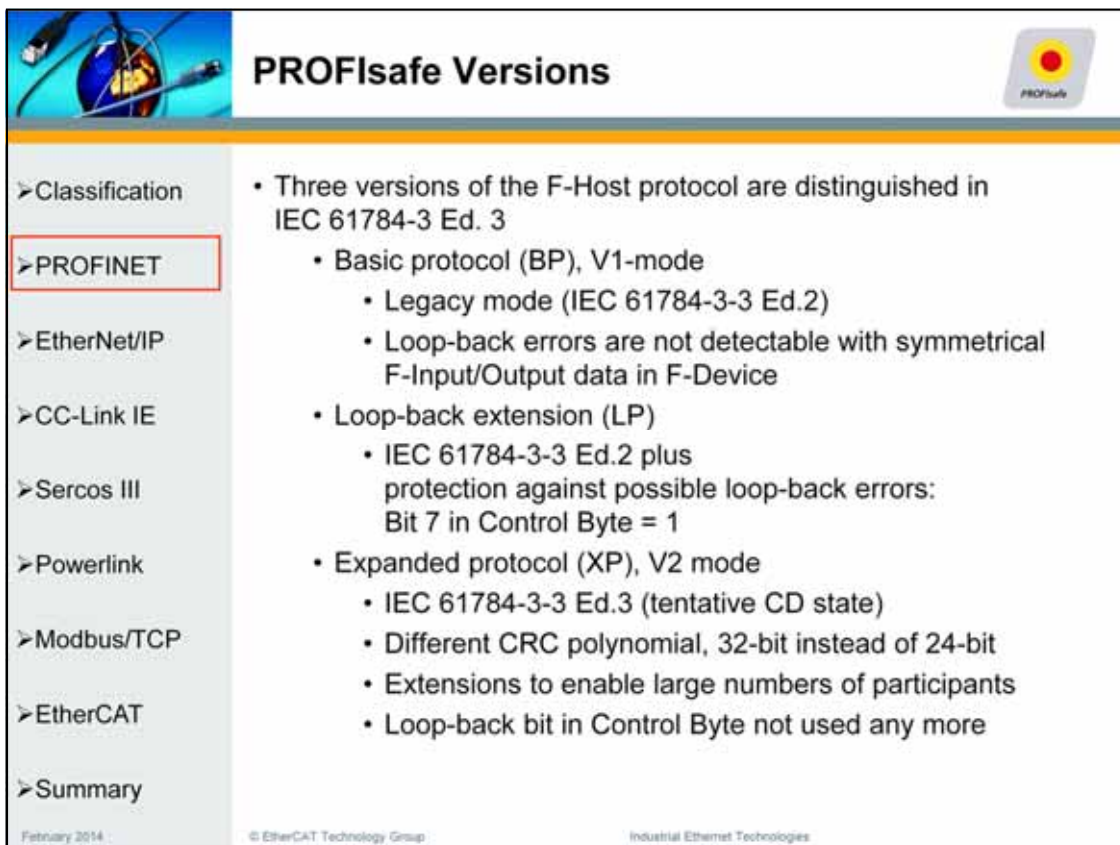
The new Profisafe specification V 2.6 was published within PROFINET International in October 2013, intended as input for the third edition of IEC 61784-3.

In the foreword it says:

*This third edition cancels and replaces the second edition published in 2010. This edition constitutes a technical revision. The main changes with respect to the previous edition are listed below:*

- Legacy V1-mode removed from this protocol edition;
- Protocol extensions to protect against possible loopbacks (LP extensions);
- Protocol extensions to keep SIL3 for safety networks with large numbers of participants (XP extensions) and subsequent new F-Parameter "F\_CRC\_Seed";
- Introduction of random and disjoint Codename based MonitoringNumbers (MNR) in addition to the previous Consecutive Numbers;
- Provisions for Channel Granular Passivation and subsequent new F-Parameter "F\_Passivation";
- GSD extensions due to new F-Parameters;

This suggests that Profisafe is currently undergoing another major change.



The image shows a presentation slide titled "PROFIsafe Versions". On the left is a navigation menu with items: Classification, PROFINET (highlighted with a red box), EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area lists three versions of the F-Host protocol distinguished in IEC 61784-3 Ed. 3:


- Basic protocol (BP), V1-mode
  - Legacy mode (IEC 61784-3-3 Ed.2)
  - Loop-back errors are not detectable with symmetrical F-Input/Output data in F-Device
- Loop-back extension (LP)
  - IEC 61784-3-3 Ed.2 plus protection against possible loop-back errors: Bit 7 in Control Byte = 1
- Expanded protocol (XP), V2 mode
  - IEC 61784-3-3 Ed.3 (tentative CD state)
  - Different CRC polynomial, 32-bit instead of 24-bit
  - Extensions to enable large numbers of participants
  - Loop-back bit in Control Byte not used any more

At the bottom of the slide, there is a footer with "February 2014", "© EtherCAT Technology Group", and "Industrial Ethernet Technologies".


In Basic protocol (BP) version a loop-back error may occur with symmetrical F-Input/Output data in an F-Device. **The user** has to consider certain features of his system to prevent this:

- Does the Black channel comprise programmable IO Data routers?
- Is there Symmetrical F-Input/Output data in F-Device?
- Furthermore, verification of each and every safety function shall be performed after any change within the programmable IO data router. In case of routing variants, this verification shall be performed for each variant.

In Expanded protocol (XP) the CRC polynomial has changed from 24-bit to a 32-bit.



# PROFIsafe



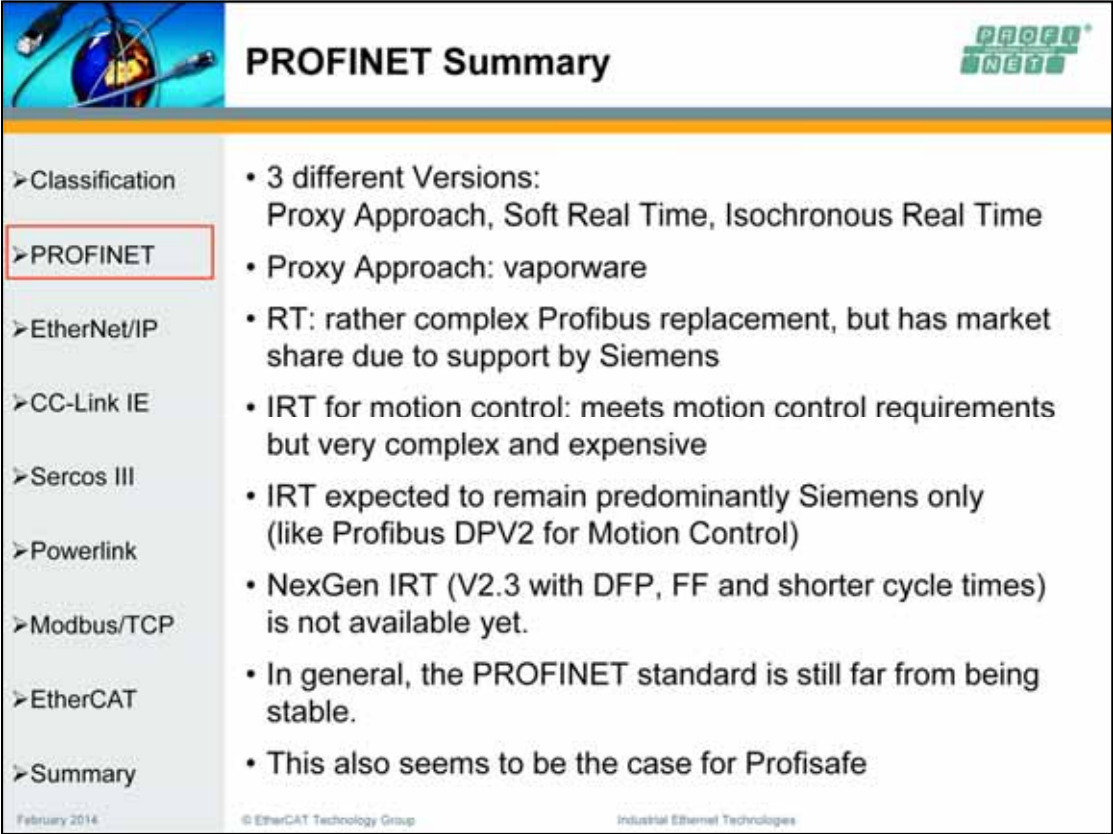
- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

• F-Host / F-Device conformance matrix

F-Host	F-Device / Module	
	according previous editions	according to IEC 61784-3-3 Ed. 3
according previous editions	Basic protocol (BP)	Basic protocol (BP)
according to IEC 61784-3-3 Ed. 3	Loop-back extension (LP)	Expanded protocol (XP)

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

The expanded protocol functions require conformance considerations between three F-Host protocol versions (BP, LP, XP) and F-Devices/F-Modules according to IEC 61784-3-3 Edition 2 and Edition 3.



The slide is titled "PROFINET Summary" and features a navigation menu on the left with the following items: Classification, PROFINET (highlighted with a red box), EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area lists three versions of PROFINET: Proxy Approach, Soft Real Time, and Isochronous Real Time. It provides details for each: Proxy Approach is vaporware; RT is a complex Profibus replacement supported by Siemens; IRT for motion control is complex and expensive, with Siemens being the primary provider; and NexGen IRT (V2.3) is not yet available. A general note states that the PROFINET standard is still far from being stable, and this also applies to Profisafe.

**PROFINET Summary**

- Classification
  - 3 different Versions: Proxy Approach, Soft Real Time, Isochronous Real Time
- **PROFINET**
  - Proxy Approach: vaporware
- EtherNet/IP
  - RT: rather complex Profibus replacement, but has market share due to support by Siemens
- CC-Link IE
  - IRT for motion control: meets motion control requirements but very complex and expensive
- Sercos III
  - IRT expected to remain predominantly Siemens only (like Profibus DPV2 for Motion Control)
- Powerlink
  - NexGen IRT (V2.3 with DFP, FF and shorter cycle times) is not available yet.
- Modbus/TCP
  - In general, the PROFINET standard is still far from being stable.
- EtherCAT
  - This also seems to be the case for Profisafe
- Summary

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

PROFINET RT is not low cost, requires a lot of code and is not high performance, but in the long run it will be a success – regardless of the technology, simply due to the Siemens (+ PNO/PTO) market position, just like Profibus.


The German car makers have announced to use PROFINET in car assembly lines „if it provides technological and economical advantages“ (quote). Daimler, e.g., has clearly stated that this announcement does not cover the power train business, where CNC and other motion control applications are in place.

The situation is different for PROFINET IRT: A solution with sufficient performance, but with rather expensive chips and a very complex network planning and configuration tool where the key algorithms are not open. IRT is positioned at servo motion control applications and will therefore be – just like Profibus MC – a Siemens motion control solution with limited support from third party vendors (just like PROFINET MC).

Plus, Siemens latest Motion Control product line prefers a different communication link for closed loop control: DriveCliqu, which uses Ethernet physical layer, only.



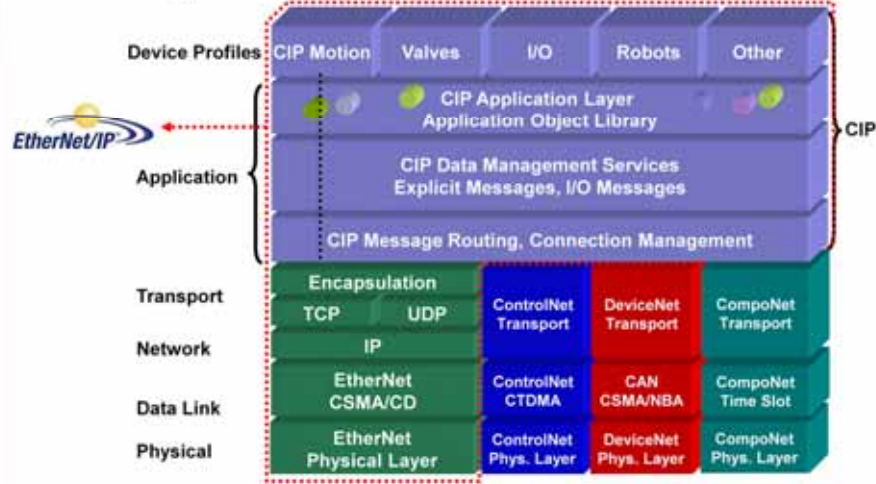
## EtherNet/IP: Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- ODVA (Rockwell) Approach: „IP“ stands for Industrial Protocol
- CIP (Common Industrial Protocol): common object library for EtherNet/IP, ControlNet, DeviceNet, CompoNet
- Follows Approach A.

A

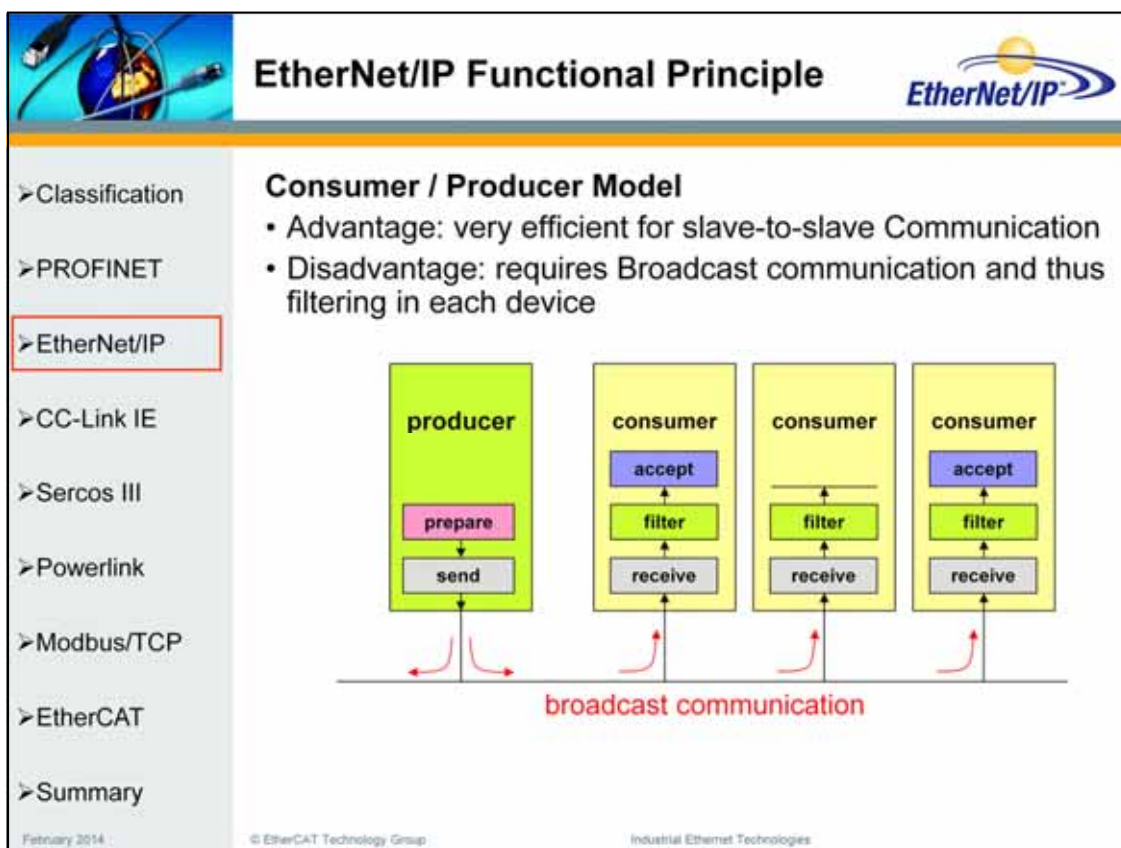


The diagram illustrates the EtherNet/IP protocol stack, which is based on the CIP (Common Industrial Protocol) architecture. It is divided into several layers:

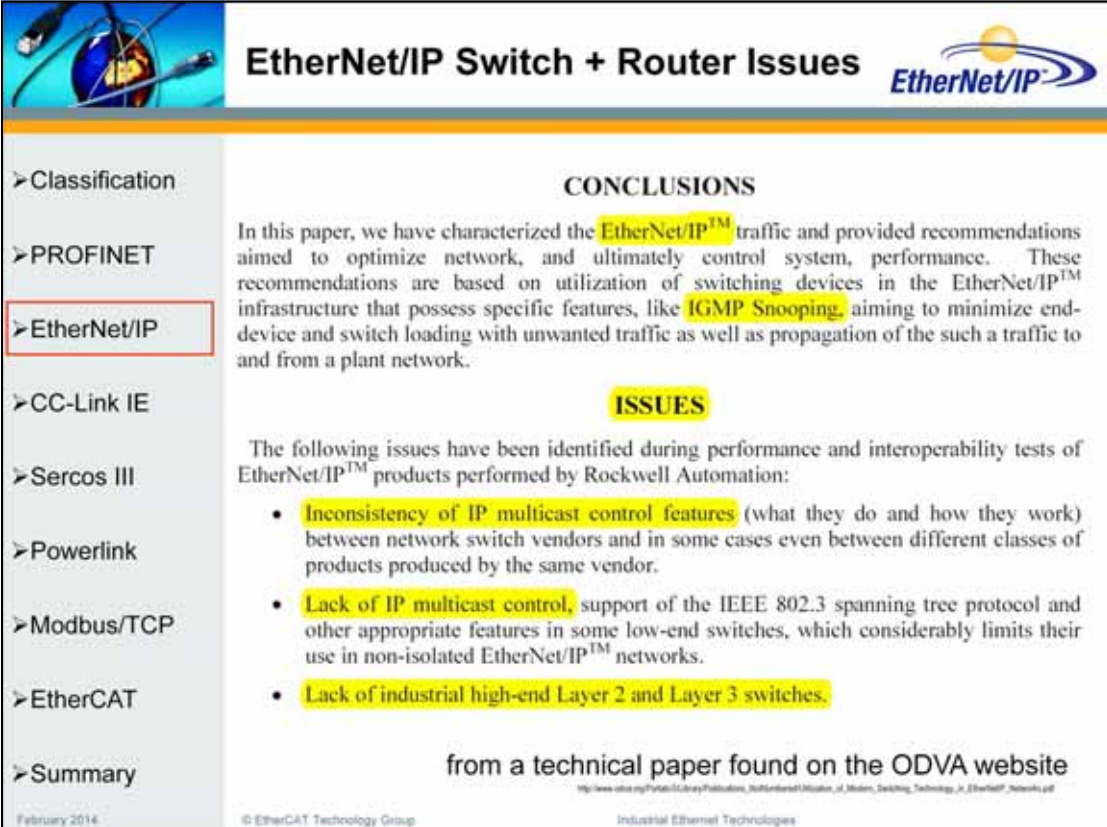
- Device Profiles:** CIP Motion, Valves, I/O, Robots, Other.
- Application Layer (CIP):**
  - CIP Application Layer (Application Object Library)
  - CIP Data Management Services (Explicit Messages, I/O Messages)
  - CIP Message Routing, Connection Management
- Transport Layer (Encapsulation):**
  - TCP, UDP
  - ControlNet Transport, DeviceNet Transport, CompoNet Transport
- Network Layer:** IP
- Data Link Layer:**
  - EtherNet CSMA/CD, ControlNet CTDMA, CAN CSMA/NBA, CompoNet Time Slot
- Physical Layer:**
  - EtherNet Physical Layer, ControlNet Phys. Layer, DeviceNet Phys. Layer, CompoNet Phys. Layer

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

EtherNet/IP claims to use the same application layer as Devicenet, Controlnet and CompoNet. This may be beneficial for those that are familiar with those fieldbus networks. However, taken from the experience when implementing Devicenet and Controlnet, the synergy effects are expected to be somehow limited, since the communication technologies and even the protocols differ substantially.



By applying broadcast or multicast communication, the switches cannot forward incoming frames to a single destination port only - so they act like (full-duplex) Hubs, but with larger delay.



**EtherNet/IP Switch + Router Issues**

**Classification**

- PROFINET
- **EtherNet/IP**
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**CONCLUSIONS**

In this paper, we have characterized the EtherNet/IP™ traffic and provided recommendations aimed to optimize network, and ultimately control system, performance. These recommendations are based on utilization of switching devices in the EtherNet/IP™ infrastructure that possess specific features, like IGMP Snooping, aiming to minimize end-device and switch loading with unwanted traffic as well as propagation of the such a traffic to and from a plant network.

**ISSUES**

The following issues have been identified during performance and interoperability tests of EtherNet/IP™ products performed by Rockwell Automation:

- Inconsistency of IP multicast control features (what they do and how they work) between network switch vendors and in some cases even between different classes of products produced by the same vendor.
- Lack of IP multicast control, support of the IEEE 802.3 spanning tree protocol and other appropriate features in some low-end switches, which considerably limits their use in non-isolated EtherNet/IP™ networks.
- Lack of industrial high-end Layer 2 and Layer 3 switches.

from a technical paper found on the ODVA website


February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

This paper by Anatoly Moldovansky, a well-respected senior engineer from Rockwell Automation, highlights some of the issues with EtherNet/IP: there is a need for routers with multicast/broadcast control features, and there is no standard way to implement or configure these.

IGMP snooping constrains the flooding of multicast traffic by dynamically configuring switch ports so that multicast traffic is forwarded only to ports associated with a particular IP multicast group.

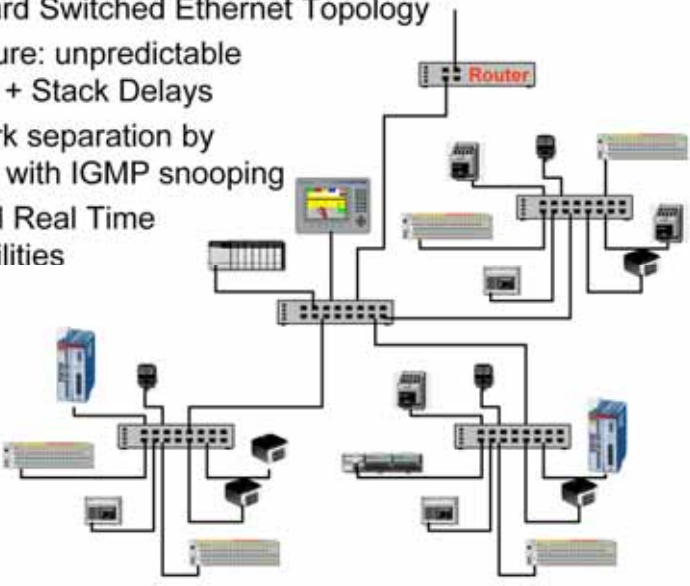
Furthermore, high-end switches typically have high-end prices. Rockwells documentation states that switches for EtherNet/IP have to support IGMP snooping as well as port mirroring (for troubleshooting). They should also support VLAN and SNMP – so manageable switches are required.

## EtherNet/IP Topology



- Classification
- PROFINET
- **EtherNet/IP**
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Standard Switched Ethernet Topology
- By nature: unpredictable Switch + Stack Delays
- Network separation by Router with IGMP snooping
- Limited Real Time Capabilities




February 2014


© EtherCAT Technology Group

Industrial Ethernet Technologies

Even though the switch delays are unpredictable by nature, the delays introduced by the software stacks are much more significant.



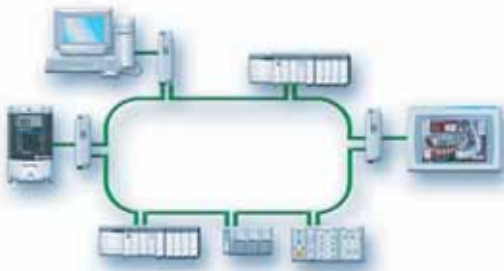
## EtherNet/IP Device Level Ring (DLR)



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Cable Redundancy Technology based on Ring topology
- Dedicated Ring Supervisor Node and DLR protocol for network management
- Devices with special embedded switches
- Introduced in 2008, first DLR products in 2009
- DLR unaware nodes should be connected through 3-port protocol aware switches



Picture: Rockwell Automation Press Release, Oct. 2009

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

DLR technology first published in Nov 2008 version of EtherNet/IP spec.  
First products in Q3 2009.

Requires special nodes who support the DLR protocols

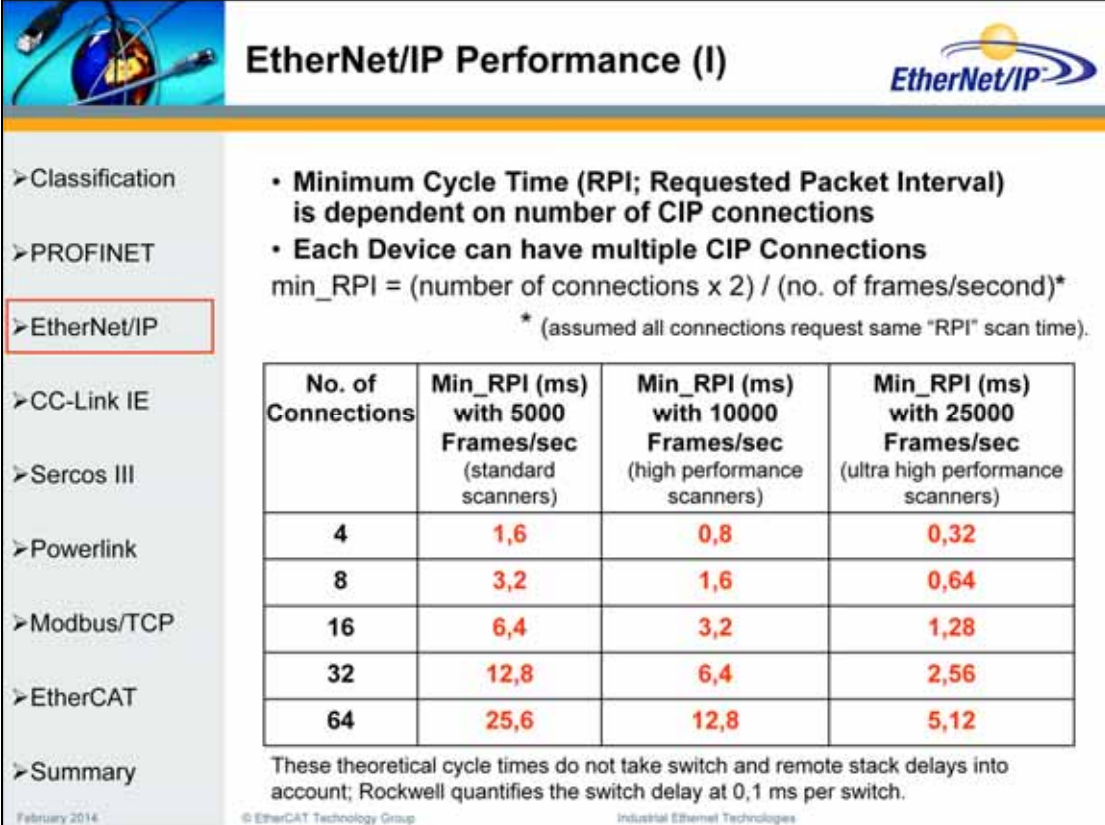
Ring supervisor node monitors network status with “Beacon frames”, per default every 400µs. In case of failure, ring supervisor actively reconfigures the network (e.g. by remotely opening or closing ports)


ODVA recommends to connect “DLR unaware nodes” through 3-port protocol aware switches.

Fault recovery time for a 50-node network: about 3 ms.


Enhances the EtherNet/IP topology options, also supports combinations of several rings and combinations of redundant rings with classical Ethernet star topologies – at the price of special nodes.







## EtherNet/IP Performance (I)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- **Minimum Cycle Time (RPI; Requested Packet Interval) is dependent on number of CIP connections**
- **Each Device can have multiple CIP Connections**

$\text{min\_RPI} = (\text{number of connections} \times 2) / (\text{no. of frames/second})^*$

\* (assumed all connections request same "RPI" scan time).

No. of Connections	Min_RPI (ms) with 5000 Frames/sec (standard scanners)	Min_RPI (ms) with 10000 Frames/sec (high performance scanners)	Min_RPI (ms) with 25000 Frames/sec (ultra high performance scanners)
4	1,6	0,8	0,32
8	3,2	1,6	0,64
16	6,4	3,2	1,28
32	12,8	6,4	2,56
64	25,6	12,8	5,12

These theoretical cycle times do not take switch and remote stack delays into account; Rockwell quantifies the switch delay at 0,1 ms per switch.

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

EtherNet/IP distinguishes CIP and TCP Connections. A CIP connection transfers data from an application running on one end-node to an application running on another end-node. A CIP connection is established over a TCP connection. A single TCP connection can support multiple CIP connections.

Most Rockwell EtherNet/IP devices support up to 64 TCP connections, the number of CIP connections differs from device to device (e.g. 1756-ENBT: 128 CIP connections, 1756-EN2T and later: 256 CIP connections). All Rockwell scanners support a maximum of 32 multicast tags (producer/consumer I/O connections).

For communication with an I/O device, typically more than one CIP connection is used (e.g. one for implicit messaging, one for explicit messaging).

The Rockwell Automation (RA) publication "Ethernet Design Considerations" (ENET-RM002A-EN-P, July 2011) shows the complex process of how to predict the network performance. There is also an "EtherNet/IP Capacity Tool" available.


Rockwell also recommends to add scanner cards to the controller and divide the scanning function between the cards if the throughput is not sufficient.

The Packet Rate Capacity (packets/second) of most Rockwell EtherNet/IP scanners is 5000 Frames/sec – with the exception of the ControlLogix series, where Rockwell is constantly increasing the scanner card performance. As of August 2011, the latest generation (firmware >3.6) scanners support up to 25.000 frames/second (see Table 9 of Rockwell Automation Publication ENET-RM002A-EN-P, July 2011). With these new high end scanners (1756-EN2xx, 1756-EN3xx) the right hand column of the cycle time table applies – and it is obvious that the system real time performance remains comparatively poor.


The standard ControlLogix Ethernet IP Bridge (1756-ENBT) still supports 5000 Frames/sec. The release notes (Publication 1756-RN591Q-EN-P - January 2008) of this device contain the following passage:

**Performance Considerations:** *In general, the 1756-ENBT module is capable of supporting 5,000 packets/seconds. However, it is possible in some applications, depending on the combination of connection count, RPI settings, and communication formats, that the product may be able to achieve only 4,000 packets/seconds.*

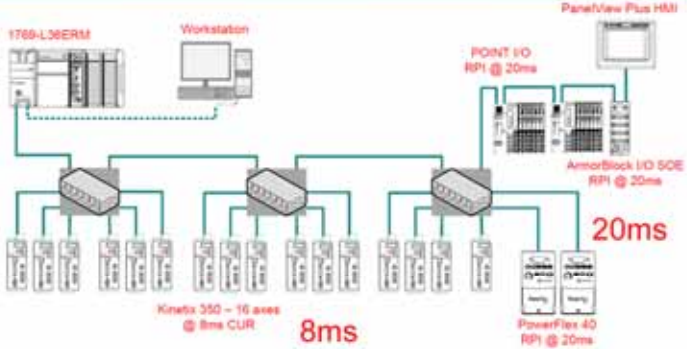
See also: Rockwell Automation (RA) publication "EtherNet/IP Performance" (ENET-AP001D-EN-P, released October 2004, according to RA website still valid in Aug 2011)



## EtherNet/IP Performance (II)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



**Quote: „When tested up to 80 percent network bandwidth utilization, using both managed and unmanaged switches, the system managed 16 position configured axes with an 8 ms coarse update rate. “**


Source: Rockwell Automation, White Paper:  
 “Scalability-The Best Approach to Change”, Aug 2012  
[http://literature.rockwellautomation.com/idc/groups/literature/documents/wpla-wp002\\_en-p.pdf](http://literature.rockwellautomation.com/idc/groups/literature/documents/wpla-wp002_en-p.pdf)

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies



16 Axes: 8ms update rate, I/O update rate: 20ms, all this at 80% bus load (and 100Mbit/s). And this with a star topology, which is favorable for EtherNet/IP.

Data from August 2012.

A properly configured DeviceNet system should achieve better performance (@ 500 kbit/s).

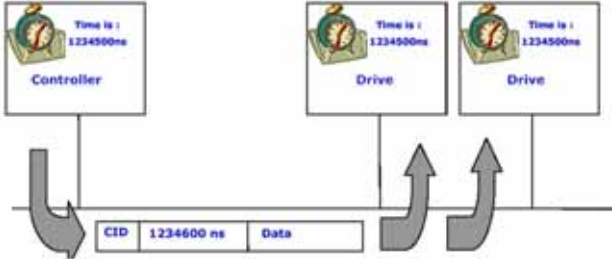


## EtherNet/IP + CIP Sync

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- EtherNet/IP has limited Real Time Capabilities:
  - limited Cycle Time Performance, limited Determinism
  - acceptable Throughput (for large Data Units)
- CIP Sync adds Time Synchronization, but does not reduce cycle time or process data performance
- Distributed Clock Protocol: IEEE 1588
- CIP Sync: announced April 2003, added to CIP spec in May 2006 (Version 3.0). First products shipping since 2009.




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

CIP sync was introduced to improve the real time behavior of the system.


The marketing message given by ODVA tries to tell that by adding synchronization the real time capability is achieved – but time synchronization does not improve cycle time, throughput or performance.

CIP sync was announced in April 2003, and included in Version 3.0 of the CIP spec in May 2006.

First CIP sync products from Rockwell Automation are the sequence of events (SOE) data capture modules that support timestamps. The version with CIP sync support is shipping since mid of 2009.

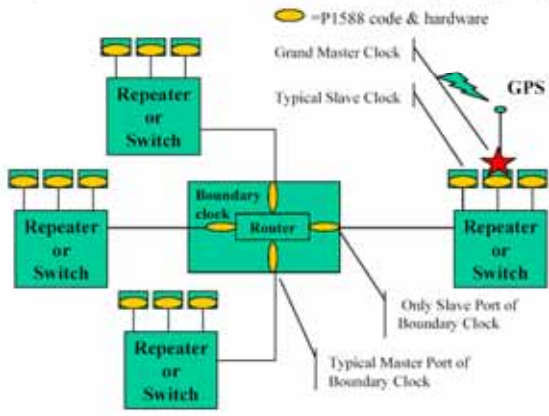


## What is IEEE 1588?



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- A method for precision time synchronisation tailored to requirements of distributed measurement and control systems. Widely independent of transport protocol.
- 1588 on Ethernet: Version 1 (2002) based on UDP/IP, Version 2 (2008) also with direct Ethernet (Layer2) option



Source: introduction\_to\_1588.pdf by IEEE


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

IEEE 1588, officially entitled "*Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*", is a technology for time synchronization that is or will be used by a variety of systems: EtherNet/IP, PROFINET, Powerlink,... EtherCAT also supports gateways to IEEE 1588 systems for *external* time synchronization.


The first version of IEEE1588 was published in November 2002. Version 2 (IEEE 1588-2008) followed in March 2008 and added various features, including the layer 2 transport option (embedded in the Ethernet frame without UPD/IP) and the "transparent clock" approach which improves the accuracy for linear systems (line topology) since it eliminates cascaded clocks.

V2 of the standard is not directly interoperable with V1.

IEEE supports an annual international symposium on 1588 technology. In conjunction with this symposium a plug fests for improving interoperability is held.

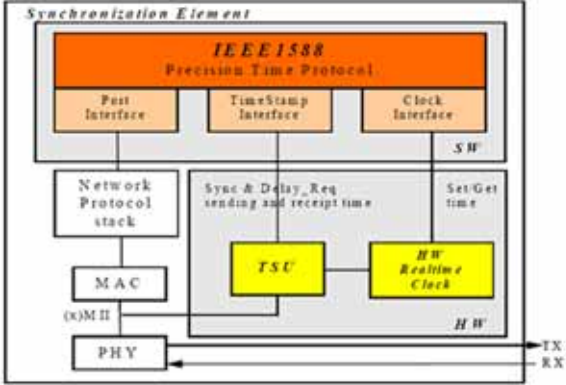


## IEEE 1588 Hardware Support



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In order to achieve good results hardware timestamping is required
- This functionality can be implemented in MACs, PHYs or integrated solutions.



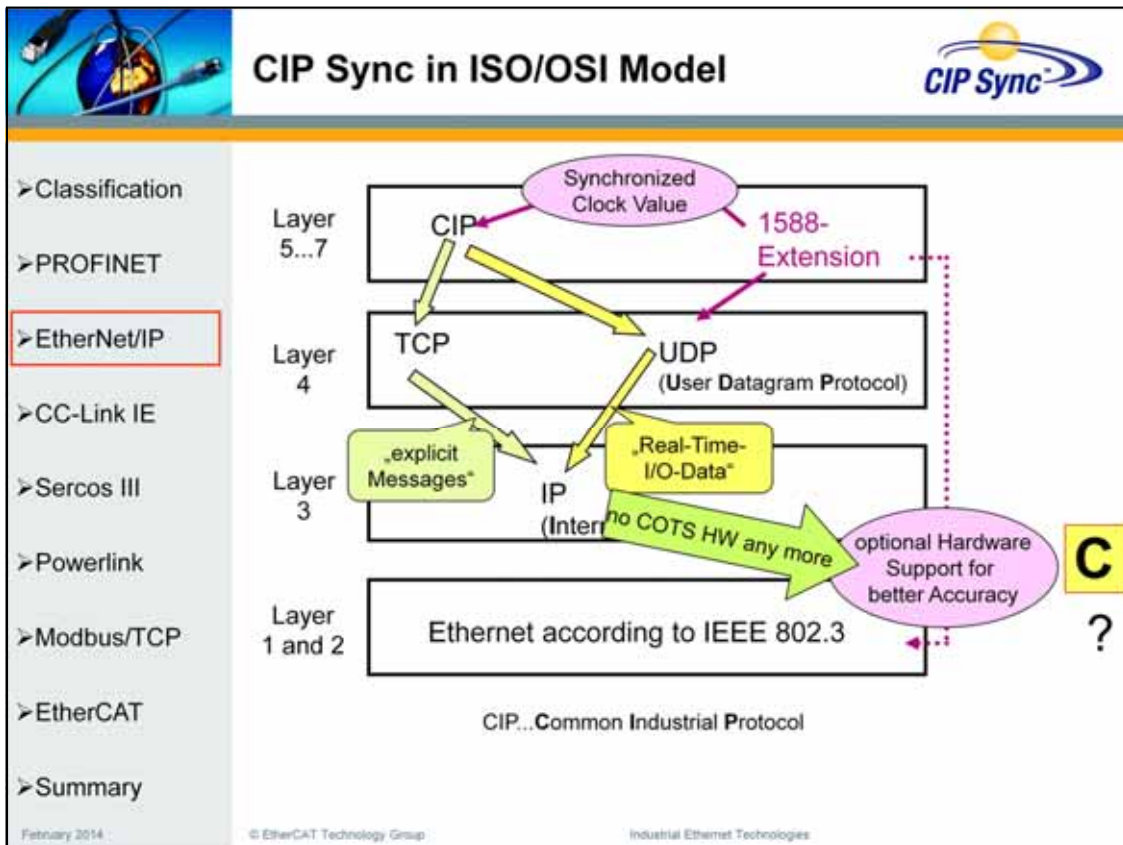
T S U - TimeStamp Unit

Source: Dirk Mohl, www.ieee1588.com

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies


In general the stack processing times limit the accuracy in case of pure software implementations. For good results hardware with built in IEEE1588 timestamp support has to be used – and the corresponding switches. First silicon was introduced by Intel and Hyperstone, meanwhile National Semiconductor, Freescale, Zarlink and others provide processors, MACs and PHYs with such features. FPGA-IP with IEEE1588 timestamp functionality is also available.







In order to make the time synchronization independent from software jitters and stack performance, at least the time stamp functionality had to be implemented in hardware (directly in or at the Ethernet MAC).

This turns the class A approach “EtherNet/IP” into the class C approach “EtherNet/IP with CIP Sync”, even though silicon with direct timestamp support may be considered COTS technology at some stage.



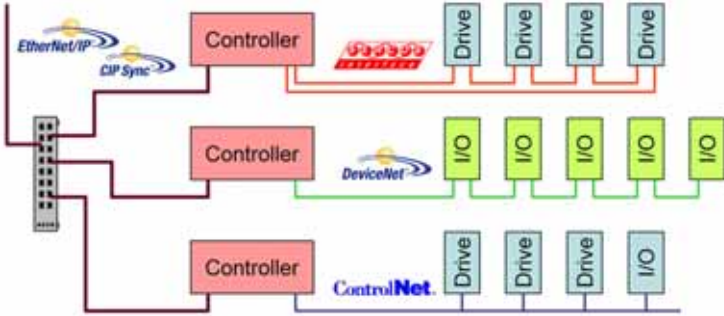
## EtherNet/IP + CIP Sync

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### Best suited and typically used as Controller to Controller network


- Limited No. of Connections
- Bus cycle time is typically 5 .. 10 ms
- Reaction time is typically 15 .. 30 ms
- Determinism is added via system-time-synchronized actions and timely non-deterministic communication.




Example EtherNet/IP Network

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Even though it is more and more used for I/O communication as well, the nature of EtherNet/IP clearly shows that this technology is aimed at the controller to controller level. The synchronization capabilities of CIP Sync are suitable for synchronizing motion controllers, but the communication performance is not sufficient for closed loop servo drive communication.



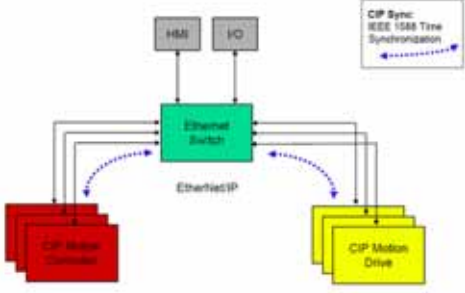
## CIP Motion + CIP Sync



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### Enhances CIP networks for motion control

- EtherNet/IP Premise: Full duplex, switched Ethernet with QoS Prioritization, IEEE 1588 Synchronization and time stamped data transmission is deterministic enough for motion control
- Motion Control Device Profile included in CIP Spec since 2006
- First products shown in fall 2009, started shipping in 2010
- Performance limitation of EtherNet/IP leads to trajectory generator in drive
- Same approach as with legacy non-motion fieldbus systems



February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Beginning of 2006, ODVA announced an initiative to enhance the CIP protocols by CIP Motion for motion control over EtherNet/IP.

ODVA acknowledges that three main ingredients are required:

Synchronization services: for this purpose IEEE1588 time synchronization (CIP Sync) will be employed

Timely Data Transfer: The goal is to use standard Mechanisms to ensure this:


- Full-Duplex 100-BaseT or 100BaseF “Fast” Ethernet.
- Ethernet switches to eliminate collisions.
- QoS frame prioritization to eliminate queuing delays

Motion Control Device Profiles: have been added in V3 of the CIP spec.


The goal is to achieve high-performance motion control over standard, unmodified, Ethernet.

Even though ODVA aims to achieve timely data transfer in the sub-millisecond cycle time range, this is in total contradiction to the “real life” EtherNet/IP performance. It may be possible to achieve sufficient results in very small, isolated and well engineered networks with carefully selected components. But real life applications will almost certainly be limited to open loop motion control with the trajectory generator in the drive – which is also possible with legacy fieldbus systems like DeviceNet. Whilst the CIP Motion Device Profile is mapped to EtherNet/IP only (and not to DeviceNet, ControlNet), most parameters and mechanisms of the profile clearly have been included to compensate for lack of short cycle times: they describe local trajectory generation. Compared to other drive profiles of IEC 61800-7, the profile is therefore rather complex.

Introducing CIP Motion products implies that Rockwell – a Sercos vendor in the past – has turned down Sercos-III and tries to push an own motion bus approach.



## CIP Motion + CIP Sync

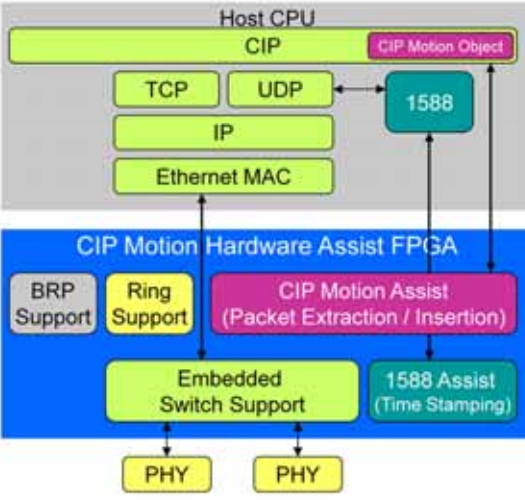


C

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### CIP Motion Profile: ongoing project

- At the ODVA general assembly in 2009, major changes in the CIP Motion Profile were announced, since the requested performance could not be achieved with the original version of the spec
- Among other changes, the Startup Procedure was modified
- The Drive-to-Controller Process Data assembly was reduced from 120(!) Bytes to 36 Bytes
- It is now recommended to use a „CIP Motion Hardware Assist FPGA“ for implementing a CIP Motion drive
- Thus CIP Motion now a Class C approach



The diagram illustrates the hardware architecture for CIP Motion. At the top is the Host CPU, which contains a CIP layer (with a CIP Motion Object) and network layers for TCP, UDP, IP, and Ethernet MAC. A 1588 interface connects the Host CPU to the CIP Motion Hardware Assist FPGA. The FPGA provides BRP Support, Ring Support, CIP Motion Assist (for Packet Extraction / Insertion), Embedded Switch Support, and 1588 Assist (Time Stamping). The FPGA is connected to two PHY (Physical) layers at the bottom.

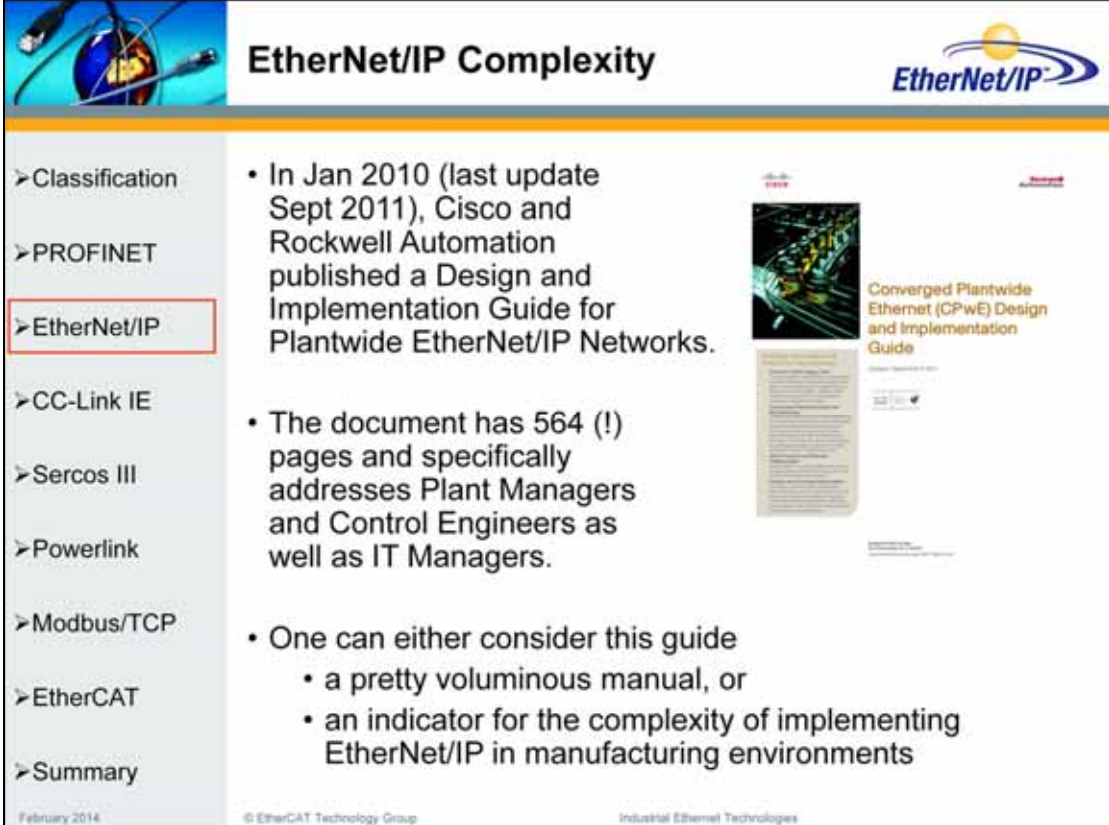
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

It is interesting that ODVA now recommends to use an FPGA for implementing the protocol: at the 2007 ODVA general assembly the presentation “Why CIP Motion, Why Now?” claimed that CIP Motion – unlike its competitors – was using “COTS Ethernet hardware, no proprietary ASICs or processors”.

First CIP Motion products were previewed at the Rockwell Automation Fair in November 2009 and became available in 2010. In September 2010, RA published a comprehensive CIP Motion Reference Manual (286 pages) and a CIP Motion Configuration and Startup user manual (298 pages).

See also:

[http://www.odva.org/Portals/0/Library/CIPConf\\_AGM2009/2009\\_CIP\\_Networks\\_Conference\\_Technical\\_Track\\_CIP\\_Motion\\_Implementation.pdf](http://www.odva.org/Portals/0/Library/CIPConf_AGM2009/2009_CIP_Networks_Conference_Technical_Track_CIP_Motion_Implementation.pdf)



The slide features a navigation menu on the left with 'EtherNet/IP' highlighted in a red box. The main content area contains a list of bullet points and an image of a document cover. The document cover is titled 'Converged Plantwide Ethernet (CPwE) Design and Implementation Guide' and shows a factory floor with green and yellow lighting.

## EtherNet/IP Complexity

**EtherNet/IP**

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In Jan 2010 (last update Sept 2011), Cisco and Rockwell Automation published a Design and Implementation Guide for Plantwide EtherNet/IP Networks.
- The document has 564 (!) pages and specifically addresses Plant Managers and Control Engineers as well as IT Managers.
- One can either consider this guide
  - a pretty voluminous manual, or
  - an indicator for the complexity of implementing EtherNet/IP in manufacturing environments

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

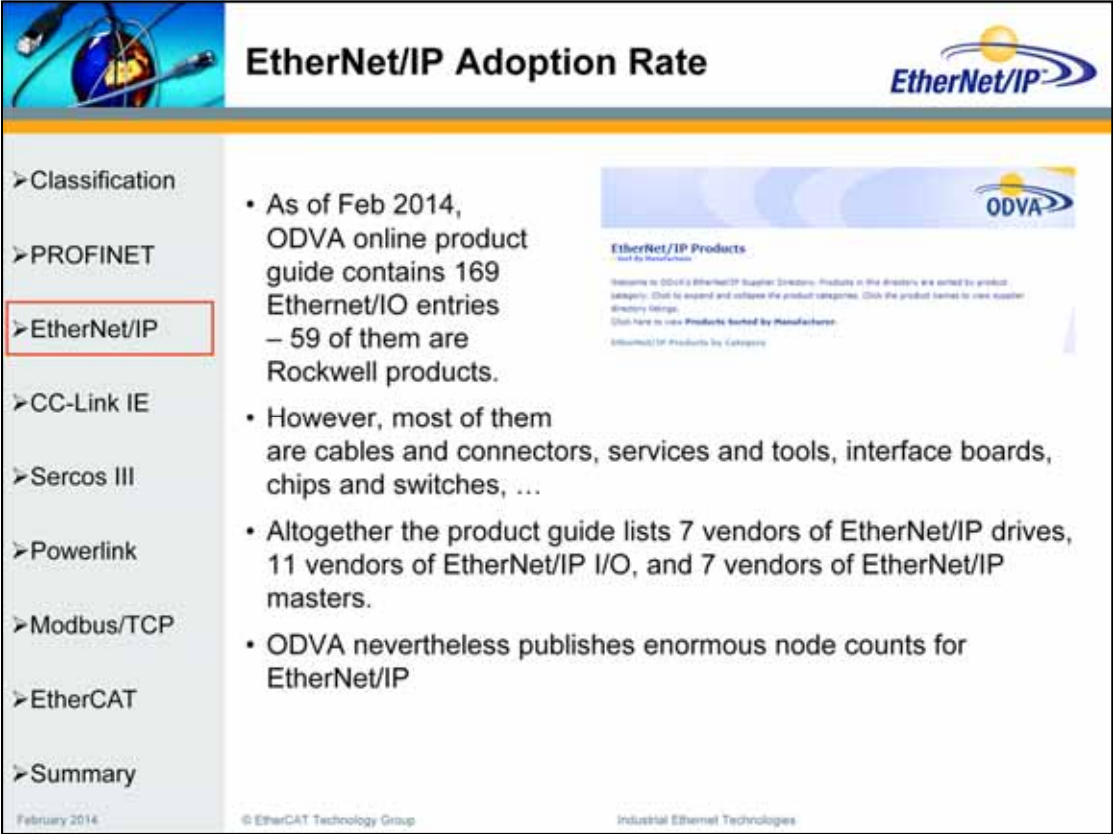
The guideline (ENET-TD001D-EN-P) can be found here:

[http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001\\_-en-p.pdf](http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf)

Or here:

[http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE\\_DIG.pdf](http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE_DIG.pdf)






## EtherNet/IP Adoption Rate

**EtherNet/IP**

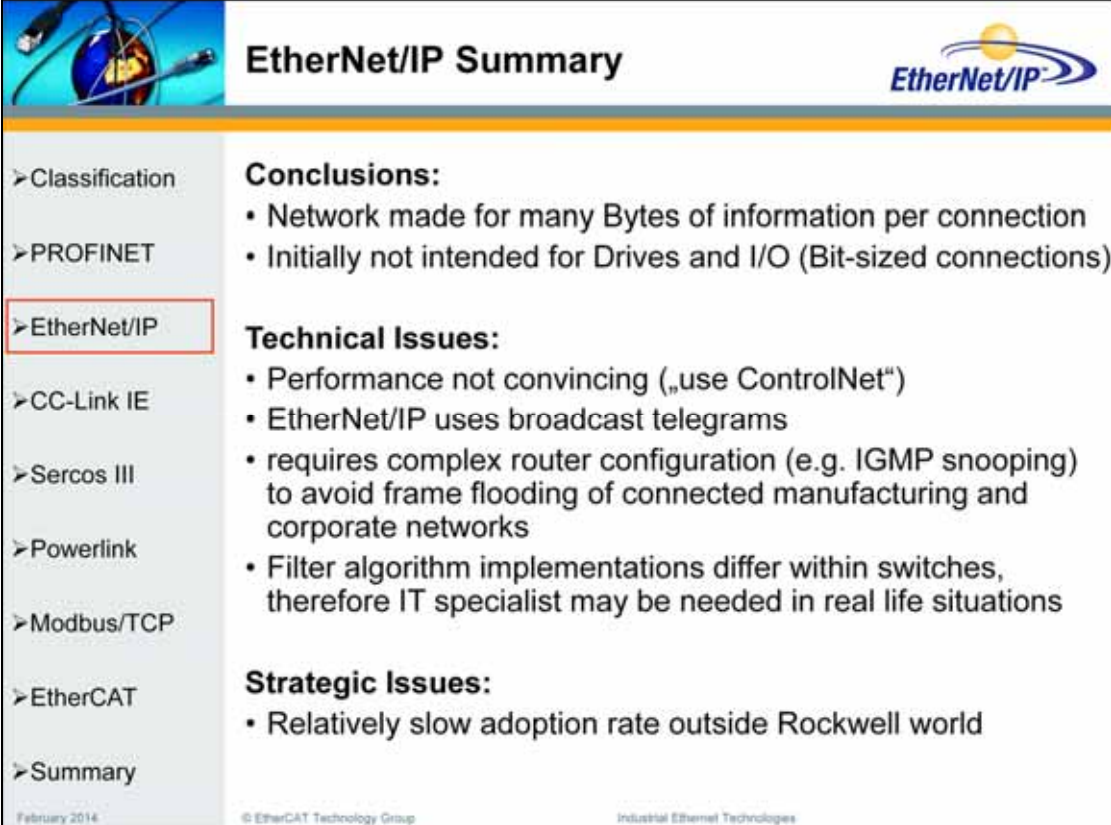
- Classification
- PROFINET
- **EtherNet/IP**
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- As of Feb 2014, ODVA online product guide contains 169 Ethernet/I/O entries – 59 of them are Rockwell products.
- However, most of them are cables and connectors, services and tools, interface boards, chips and switches, ...
- Altogether the product guide lists 7 vendors of EtherNet/IP drives, 11 vendors of EtherNet/IP I/O, and 7 vendors of EtherNet/IP masters.
- ODVA nevertheless publishes enormous node counts for EtherNet/IP

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies




As of February 2014, about 15 years after publication of the spec, the adoption rate is not really convincing – especially outside of the Rockwell/Allen Bradley world.



The slide is titled "EtherNet/IP Summary" and features the EtherNet/IP logo in the top right corner. On the left side, there is a vertical navigation menu with the following items: Classification, PROFINET, EtherNet/IP (highlighted with a red box), CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area is divided into three sections: "Conclusions:", "Technical Issues:", and "Strategic Issues:". The "Conclusions:" section lists two points: "Network made for many Bytes of information per connection" and "Initially not intended for Drives and I/O (Bit-sized connections)". The "Technical Issues:" section lists three points: "Performance not convincing („use ControlNet“)", "EtherNet/IP uses broadcast telegrams", and "requires complex router configuration (e.g. IGMP snooping) to avoid frame flooding of connected manufacturing and corporate networks". The "Strategic Issues:" section lists one point: "Relatively slow adoption rate outside Rockwell world". At the bottom of the slide, there is a footer with the date "February 2014" on the left, and "© EtherCAT Technology Group" and "Industrial Ethernet Technologies" on the right.

## EtherNet/IP Summary



- Classification
- PROFINET
- **EtherNet/IP**
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**Conclusions:**

- Network made for many Bytes of information per connection
- Initially not intended for Drives and I/O (Bit-sized connections)

**Technical Issues:**


- Performance not convincing („use ControlNet“)
- EtherNet/IP uses broadcast telegrams
- requires complex router configuration (e.g. IGMP snooping) to avoid frame flooding of connected manufacturing and corporate networks
- Filter algorithm implementations differ within switches, therefore IT specialist may be needed in real life situations

**Strategic Issues:**


- Relatively slow adoption rate outside Rockwell world

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

A quote from a Rockwell employee: if you need more performance, use Controlnet...



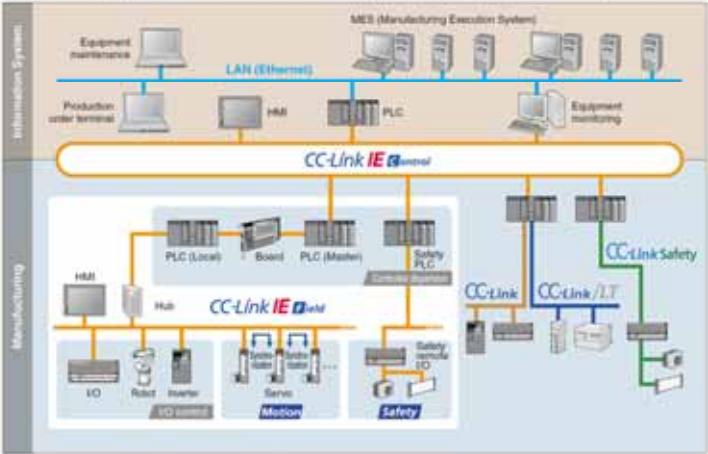
## CC-Link IE: Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- CC-Link is the legacy Fieldbus developed by Mitsubishi in 1997 and since 2000 promoted by CC-Link Partner Association (CLPA)
- CC-Link IE: „IE“ stands for Industrial Ethernet
- Follows Approach C – needs special interface chips.

C



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
Source: CLPA Brochure Nov 2013, www.cc-link.org

CC-Link is an RS485 based fieldbus technology introduced by Mitsubishi Electric in 1997. In 2000, the CC-Link Partner Association (CLPA) was founded, and since then CC-Link is promoted as an open technology. CC-Link is intended for I/O type communication – not for motion control (for this purpose Mitsubishi developed SSCNET).

CC-Link LT is the CLPA technology focusing on simplified wiring and intended for simple I/O devices; it competes with Comconet and AS-Interface.


CC-Link Safety is the CLPA network for functional safety. Unlike other functional safety protocols, CC-Link Safety is not making use of the “black-channel-approach” but requires a separate network: CC-Link Safety cannot be transported via CC-Link or CC-Link LT.

CC-Link IE is the Industrial Ethernet technology of CLPA.


There are two main versions:

1. CC-Link IE Control (also named CC-Link IE Controller) is intended for controller/controller communication.
2. CC-Link IE Field was originally intended for I/O type communication (similar to CC-Link). In Nov 2011 a Motion Control Profile was added.

Furthermore, since April 2011 there is also a Functional Safety Protocol for integration into CC-Link IE Field.




## CC-Link IE Control: Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- CC-Link IE Control: for Controller/Controller communication (CLPA: „in-factory backbone“)
- Media Access Control: Token Passing
- One Control Station, up to 119 Slave Stations
- Process Images exchanged by Shared Memory Approach



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
Source: CLPA Brochure Nov 2013, www.cc-link.org


### Token Passing Approach:

A CC-Link IE network consists of a single control station and multiple slave stations. As in standard token passing networks, the control station manages the network and starts the token passing sequence by sending the token to the first slave station on the network.


The slave station that receives the token performs its cyclic transmission, and then passes the token to the next station in the sequence.

After the last slave station completes the process, it passes the token back to the CC-Link IE control station where the entire sequence is started again.

A general problem of Token Passing is the error recovery: if the token frame is lost for any reason, the entire token passing system has to be reconfigured – of course the real time behavior is then gone temporarily.



## CC-Link IE Control: Protocol



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- CC-Link IE Frame is embedded in Ethernet Frame
- Frame layout is configured at boot up and fixed at run-time
- Token holder writes to pre-assigned area of the frame
- Frame Format is not published

User Application	
Application layer	Common object access Network-orientated common memory
Transport Layer	Transient Transmission Cyclic Transmission
Network Layer	
Data link Layer	IEEE 802.3
Physical Layer	IEEE 802.3z (1000BASE-SX)


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
Source: CLPA Brochure 2009, www.cc-link.org

The CC-Link IE Control frame is directly embedded in the Ethernet frame. In addition to the MAC address there is a node number and a network (in the CC-Link IE Header), which are primarily used for addressing.


Unfortunately the CLPA CC-Link IE Control specification does not cover the transport layer and the network layer, protocol details are not published.

According to an article published by CLPA Europe (IEB Issue 49, November 2008), "TCP/IP communications is supported by way of the transient/acyclic communication function." However, the specs do not mention this option – it seems that the authors refer to the SLMP over TCP/IP option (see below).



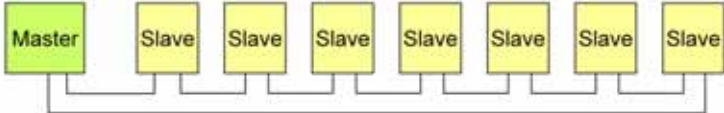


## CC-Link IE Control: Topology




- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Topology: Ring
- Ring Topology provides Cable Redundancy
- Physical Layer: 1000BASE-SX Multimode Optical Fiber 50/125µm (IEEE 802.3)
- Connectors: LC Connectors (Duplex)
- Max Distance between nodes: 550m
- Up to 120 nodes per network, multiple networks can be coupled



CC-Link IE Control cannot make use of existing Ethernet Backbone: requires separate Network



LC Duplex Connector

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
Picture: Wikimedia Commons

Unlike most other Industrial Ethernet technologies, which use a standard Ethernet network (which is in place in many factory automation environments already), CC-Link IE Control needs a dedicated and separate network of its own.

Only ring topology is supported – switches cannot (and may not) be used.

CC-Link IE Control products may limit the max. no of nodes. Example: as of 2/2014, the Mitsubishi CC-Link IE Control Interface supports 120 nodes only in conjunction with a specific PLC. With other controllers, 64 nodes are supported.

**CC-Link IE Control: Implementation**

CC-Link IE Control

- Classification
- PROFINET
- EtherNet/IP
- **CC-Link IE**
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- CC-Link IE Control requires special interface ASIC by Mitsubishi, standard Ethernet MACs cannot be used.
- ASIC is not mentioned on CLPA or Mitsubishi Websites and Brochures
- CC-Link IE Control Specification is available for CLPA Members on request:
  - Spec is very „lean“, data link layer is missing, interface ASIC not mentioned

**For third parties, implementation of CC-Link IE Control obviously is not encouraged**

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

The information about the special ASIC is difficult to find: neither the CC-Link IE website, nor the brochures nor the spec provide any information about this fact. Also, detailed information regarding the CC-Link IE Control chip – which is NOT the same as the CC-Link IE Field chip CP220 - itself is not available.

### „Lean“ Specification

(as of February 2014, CLPA distributes the first version of the spec, dated Dec 2007):

- Device Profile Spec: 1 page
- Implementation Rules Spec: 3 pages
- Application Layer Service Definition: 41 pages
- Application Layer Protocol Definition: 115 pages (+ 10 pages description of ‘Transmission Point Extended Mode’ added in Oct 2010)
- Communication Profile Specification: 2 pages

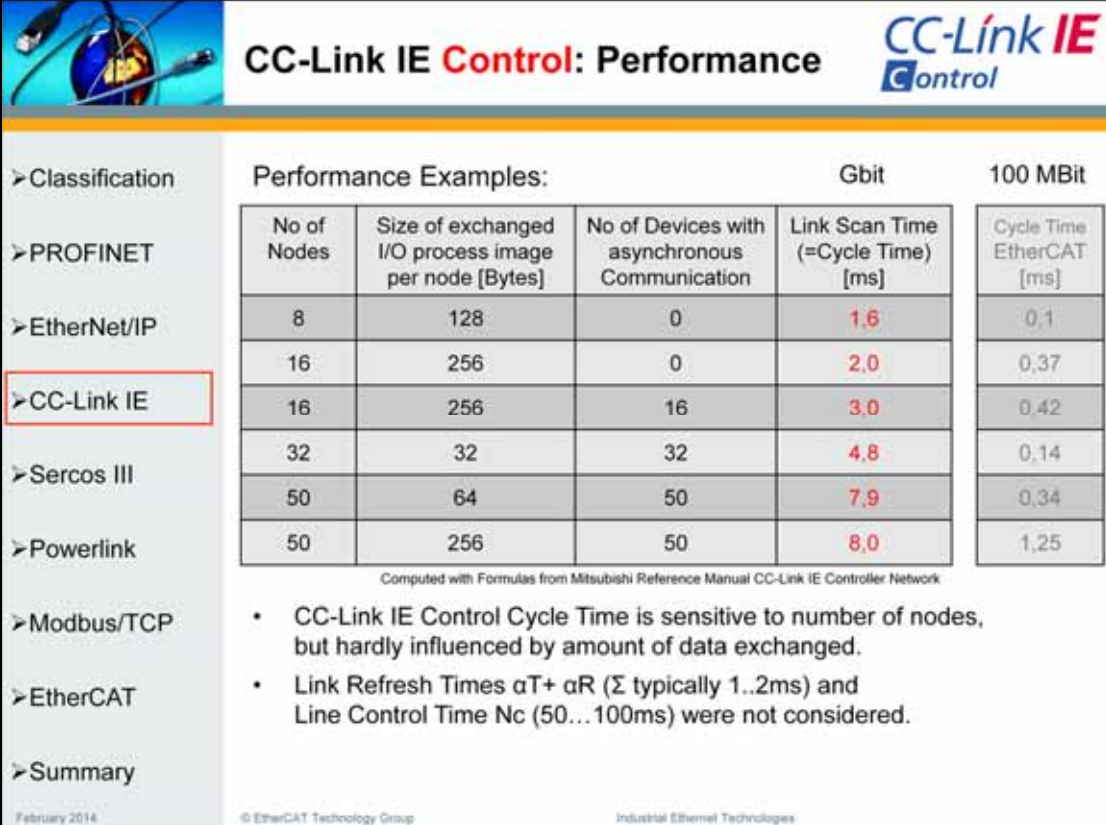
The application layer specs are relatively comprehensive as they have been prepared for inclusion in IEC61158 – CC-Link IE is type 23. Publication of the edition of this standard containing CC-Link IE is expected for April 2014.

Data link layer/transport layer/network layer with key features such as boot-up, network management and error control are not specified. The Implementation Rules Spec, the Device Profile Spec and the Communication Profile Specs are not sufficient for implementing the technology, the chip seems not to be available outside Mitsubishi.

The “CC-Link Product Development Guidebook“, 12/2013 of CLPA Europe includes CC-Link IE Control, but does not mention the corresponding chip. The only implementation possibility listed in this brochure is a Mitsubishi PC board, for which software drivers are mentioned. So it remains impossible for a PLC vendor to implement CC-Link Control.

Thus the conclusion is that, six years after the introduction of CC-Link IE Control as open network technology, the implementation of CC-Link IE Control is not encouraged – if not impossible – for third parties, at least not outside Japan.

**CC-Link IE Control thus cannot be considered an open technology.**



**CC-Link IE Control: Performance**

CC-Link IE Control

Classification	Performance Examples:				Gbit	100 MBit
	No of Nodes	Size of exchanged I/O process image per node [Bytes]	No of Devices with asynchronous Communication	Link Scan Time (=Cycle Time) [ms]		Cycle Time EtherCAT [ms]
PROFINET						
EtherNet/IP	8	128	0	1,6		0,1
<b>CC-Link IE</b>	16	256	0	2,0		0,37
	16	256	16	3,0		0,42
	32	32	32	4,8		0,14
Sercos III	50	64	50	7,9		0,34
Powerlink	50	256	50	8,0		1,25

Computed with Formulas from Mitsubishi Reference Manual CC-Link IE Controller Network

- CC-Link IE Control Cycle Time is sensitive to number of nodes, but hardly influenced by amount of data exchanged.
- Link Refresh Times  $\alpha T + \alpha R$  ( $\Sigma$  typically 1..2ms) and Line Control Time  $N_c$  (50...100ms) were not considered.


February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Due to using Gigabit Ethernet physical layer, CC-Link IE Control cycle time is hardly influenced by the amount of data exchanged. In contrast, due to its functional principle, EtherCAT is hardly influenced by the number of nodes – and is much faster anyhow, in spite of using 100Mbit technology.

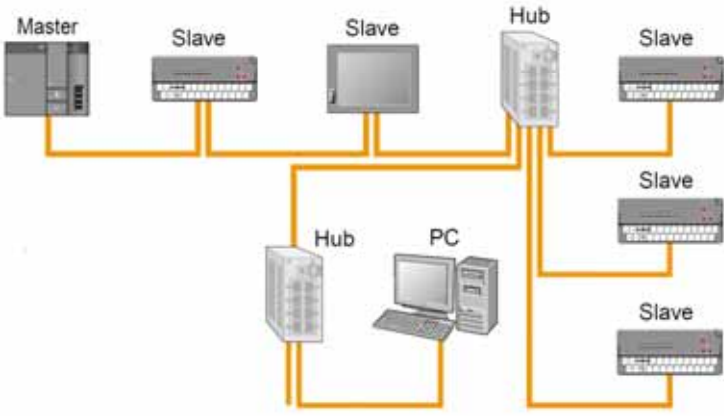
In order to have a fair comparison, the dedicated and separated CC-Link IE Control network was compared with a dedicated and separated EtherCAT (Device Protocol) network, which can also be used for controller/controller communication. However, in many cases the EtherCAT Automation Protocol (EAP) will be used for that purpose, since EAP can be transmitted via an already existing Ethernet backbone (which is of course not limited to 100Mbit/s). Since EAP is making use of standard Ethernet switch technology, the EtherCAT cycle times listed above are not achieved with the EAP option, though.

The Link Scan Time (=Cycle Time) formula used was taken from Chapter 7.1 (Link Scan Time) of the “MELSEC Q series CC-Link IE Controller Network Reference Manual” SH(NA)-080668ENG-I of May 2012 (as of Feb 2014, this is the latest version available). We used formula (1) with  $LY=0$ ,  $T=2$  (default value) and the Line Control Time  $N_c$  (Time required for reconfiguring the data link when network is disconnected and reconnected)  $=0$ . Usual values for  $N_c$  given in that manual are 50ms (Normal) and 100ms (Worst). For error case considerations this time has to be added. For Cyclic Transmission Delay Time the Link Refresh Times have to be taken into account as well.

## CC-Link IE Field: Overview



- Classification
  - CC-Link IE Field: for I/O type communication
  - Media Access Control: Token Passing
  - All Frames are broadcasted (Switches act like Hubs)
  - One Control Station, up to 120 Slave Stations
- PROFINET
- EtherNet/IP
- **CC-Link IE**
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary




February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies Source: CLPA Brochure Nov 2010, www.cc-link.org

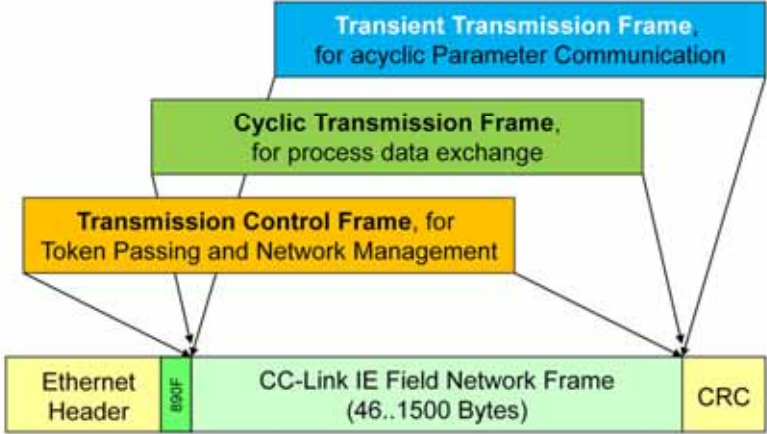
CC-Link IE Field is the adaptation of CC-Link IE Control to the field level. The functional principle – token passing - is shared by both variants. CC-Link IE Field uses copper based Gigabit Ethernet, and supports non-ring topologies such as star and line.

120 Slave stations: the specification allows for up to 253 slave devices; however, as of Feb 2014 implementations only support 120 slave devices.

## CC-Link IE Field: Frame Types



- Classification
  - CC-Link IE Frames are directly embedded in Ethernet Frame
  - There are three basic frame types
- PROFINET
- EtherNet/IP
- **CC-Link IE**
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



Transient Transmission Frame, for acyclic Parameter Communication

Cyclic Transmission Frame, for process data exchange

Transmission Control Frame, for Token Passing and Network Management

Ethernet Header

800F

CC-Link IE Field Network Frame (46..1500 Bytes)

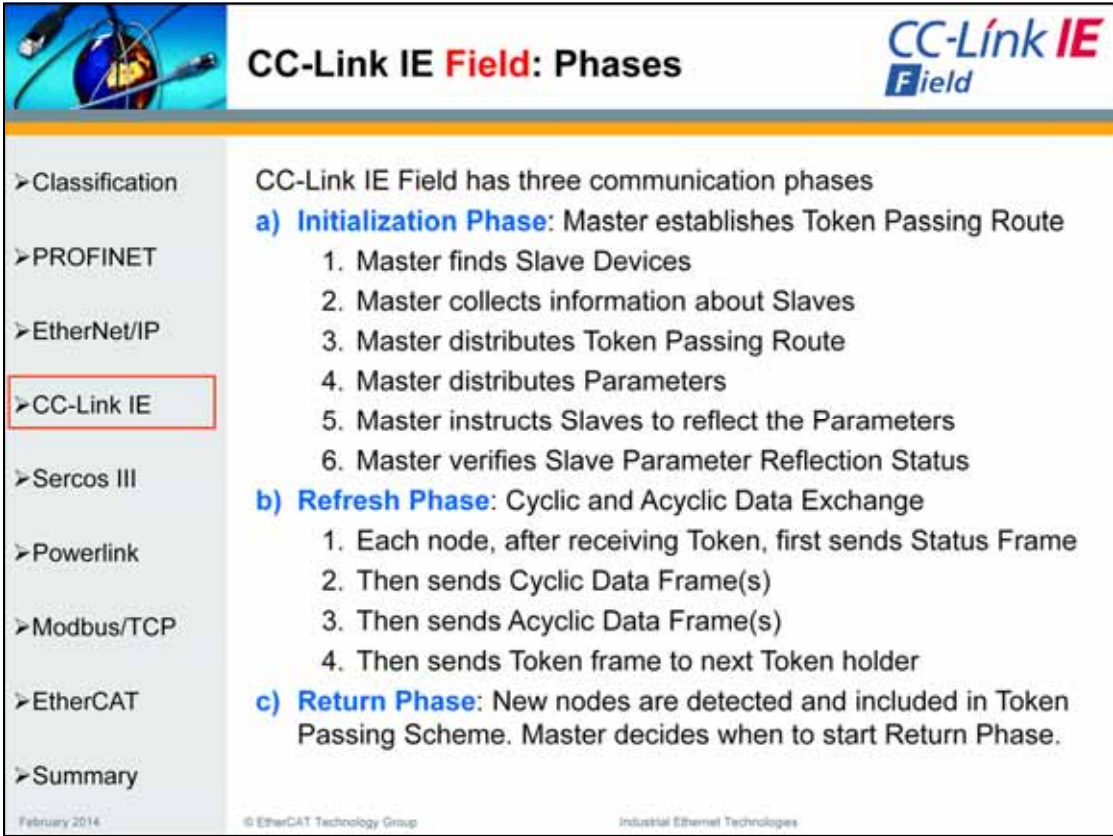
CRC

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

CC-Link IE Field uses Ethernet frames according to IEEE 803.2 and the Ethertype 0x890F.

As of February 2014, the CC-Link IE Field Data Link Layer specification contains no further information than this. The format of the transmission control frame, of the transient transmission control frame and the cyclic transmission control frame are not published.





The image shows a presentation slide titled "CC-Link IE Field: Phases". The slide is divided into a left sidebar and a main content area. The sidebar contains a list of navigation items: Classification, PROFINET, EtherNet/IP, CC-Link IE (highlighted with a red box), Sercos III, Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area is titled "CC-Link IE Field: Phases" and features the CC-Link IE Field logo. The text describes the three communication phases of CC-Link IE Field: a) Initialization Phase, b) Refresh Phase, and c) Return Phase. Each phase is followed by a numbered list of steps. The slide also includes a footer with the date "February 2014" and copyright information for EtherCAT Technology Group and Industrial Ethernet Technologies.

## CC-Link IE Field: Phases

CC-Link IE Field has three communication phases

- Classification
- PROFINET
- EtherNet/IP
- **CC-Link IE**
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**a) Initialization Phase:** Master establishes Token Passing Route

1. Master finds Slave Devices
2. Master collects information about Slaves
3. Master distributes Token Passing Route
4. Master distributes Parameters
5. Master instructs Slaves to reflect the Parameters
6. Master verifies Slave Parameter Reflection Status

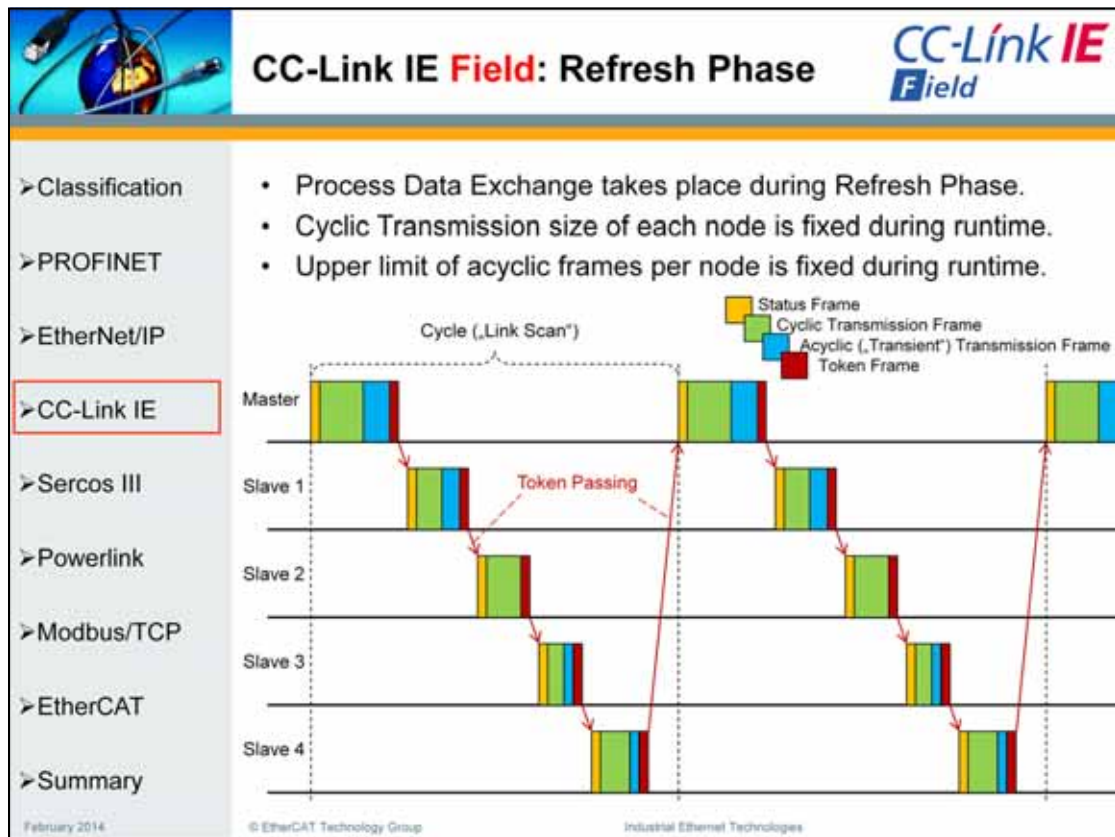
**b) Refresh Phase:** Cyclic and Acyclic Data Exchange

1. Each node, after receiving Token, first sends Status Frame
2. Then sends Cyclic Data Frame(s)
3. Then sends Acyclic Data Frame(s)
4. Then sends Token frame to next Token holder

**c) Return Phase:** New nodes are detected and included in Token Passing Scheme. Master decides when to start Return Phase.

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

The CC-Link IE Field specification describes the phases in general and also shows the sequence of frames that are exchanged – but it does not contain the frame formats itself.




After receiving the token, the slave device first sends its status frame, then one or more cyclic transmission frames, optionally followed by acyclic frames (for the so called transient communication). The number of acyclic frames per node and cycle can be limited in order to avoid cycle time violations. Lastly, the node sends the Token Frame to the next token holder.

All Frames are broadcasted: nodes with two ports send all frames to both ports, and switches are used like hubs (making use of broadcast MAC addresses).


CC-Link IE distinguishes different node types, which differ by maximum process data size as well as features such as support of acyclic communication:

e.g.:

- “Remote Device Stations” are limited to 128 bits of cyclic I/O data (+ register data) and do not support client functionality in acyclic communication.
- “Remote I/O stations” are limited to 64 bits of cyclic I/O data (no register data) and do not support acyclic communication at all.

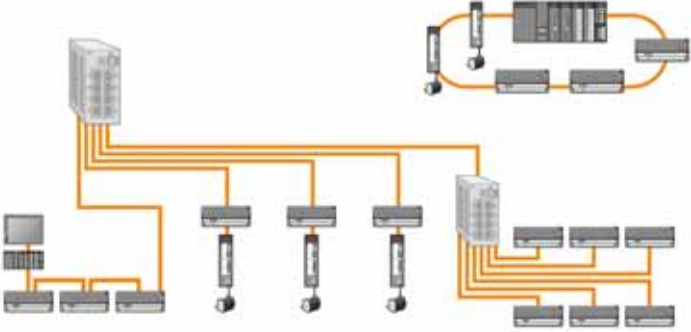


## CC-Link IE Field: Topology




- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Topology: Combination of Line and Star Topology, or Ring
- Physical Layer: 1000BASE-T (IEEE 802.3)
- Connectors: Shielded RJ-45
- Max Distance between nodes: 100m
- Up to 120 nodes per network, multiple networks can be coupled




February 2014© EtherCAT Technology GroupIndustrial Ethernet TechnologiesSource: CLPA Brochure Nov 2009, www.cc-link.org

The topology of CC-Link IE Field is more flexible than the CC-Link IE Control topology. 120 nodes: spec allows for up to 254, but as of Feb 2014 we could not find any products supporting more than 120 nodes.



## CC-Link IE Field: Implementation

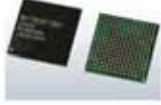





---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- CC-Link IE Field also requires special interface  
Standard Ethernet MACs cannot be used.
- ASIC by Mitsubishi: CP220 (BGA256, 17x17mm)  
ASIC seems not (yet) available in Europe
- IP Core for Altera Cyclone IV FPGA by Altime
- ASIC by Renesas: R-IN32M3-CL
- Embedded Interface Board by HMS anybus
- CC-Link IE Field Specification is available for CLPA Members:
  - Spec is pretty „lean“, but more comprehensive than CC-Link IE Control spec.

**For third parties, only implementation of CC-Link IE Field slaves seems feasible**

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies
CP220 Picture: Mitsubishi Japan Website

According to Mitsubishi Electric Germany in Feb 2014, the CC-Link IE Field chip CP220 is not (yet) available in Europe.


### “Lean” Specification

(as of Feb 2014, the latest version is BAP 1605 of Nov 2011):


- Device Profile Spec: 23 pages
- Implementation Rules Spec: 8 pages
- Data Link Layer Spec: 2 lines (not pages)
- Application Layer Service Definition: 69 pages
- Application Layer Protocol Definition: 197 pages

The application layer specs are relatively comprehensive as they have been prepared for inclusion in IEC61158 – CC-Link IE is going to be type 23. Publication of the edition of this standard containing CC-Link IE is expected for 4 / 2014.

While it looks feasible meanwhile to implement a slave device, it looks as if the master device cannot be implemented by third parties as of now: there is no information about the Data Link Layer and there are no chips supporting a master.



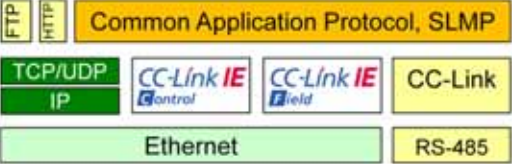
## CC-Link IE: SLMP



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- SLMP stands for **S**eamless **M**essage **P**rotocol

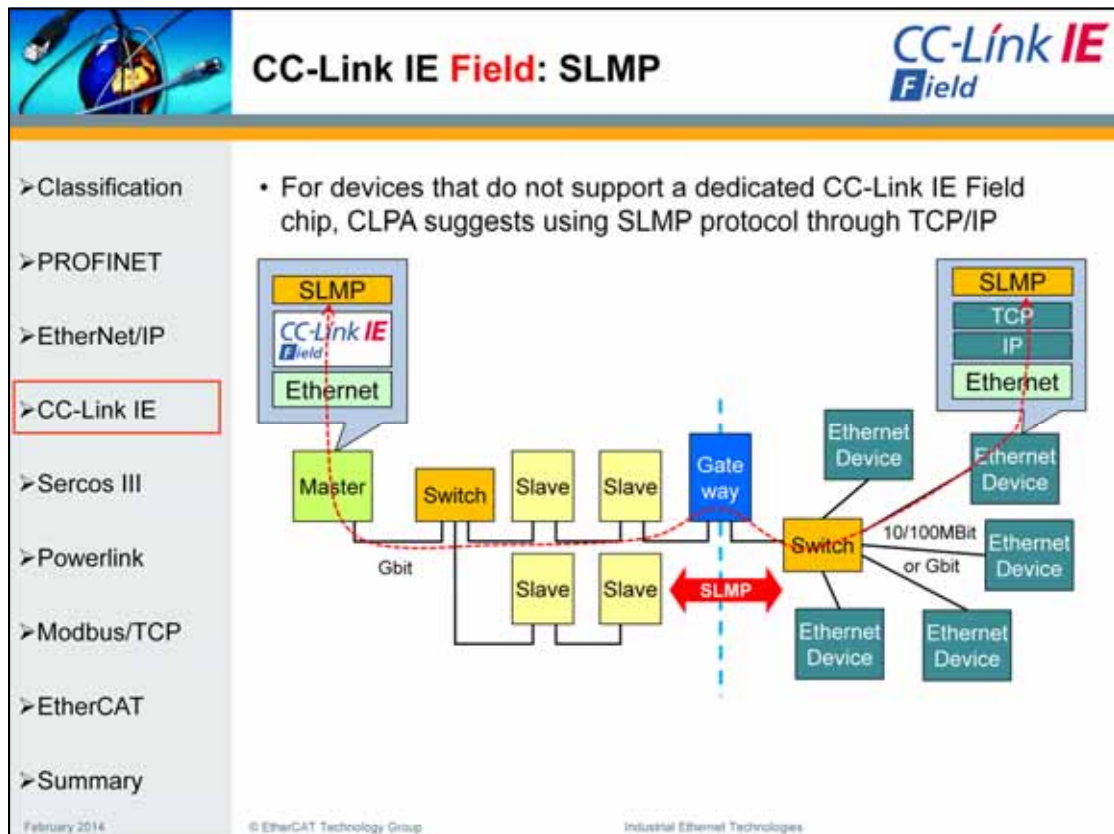


- SLMP is independent of the data link layer and can be implemented on CC-Link IE and TCP(UDP)/IP
- According to CPLA, legacy CC-Link also supports a similar protocol
- SLMP supports
  - Client/Server communication: for remote access to parameters or status information
  - Remote Control of Devices
  - Event driven communication („on-demand communication“)

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

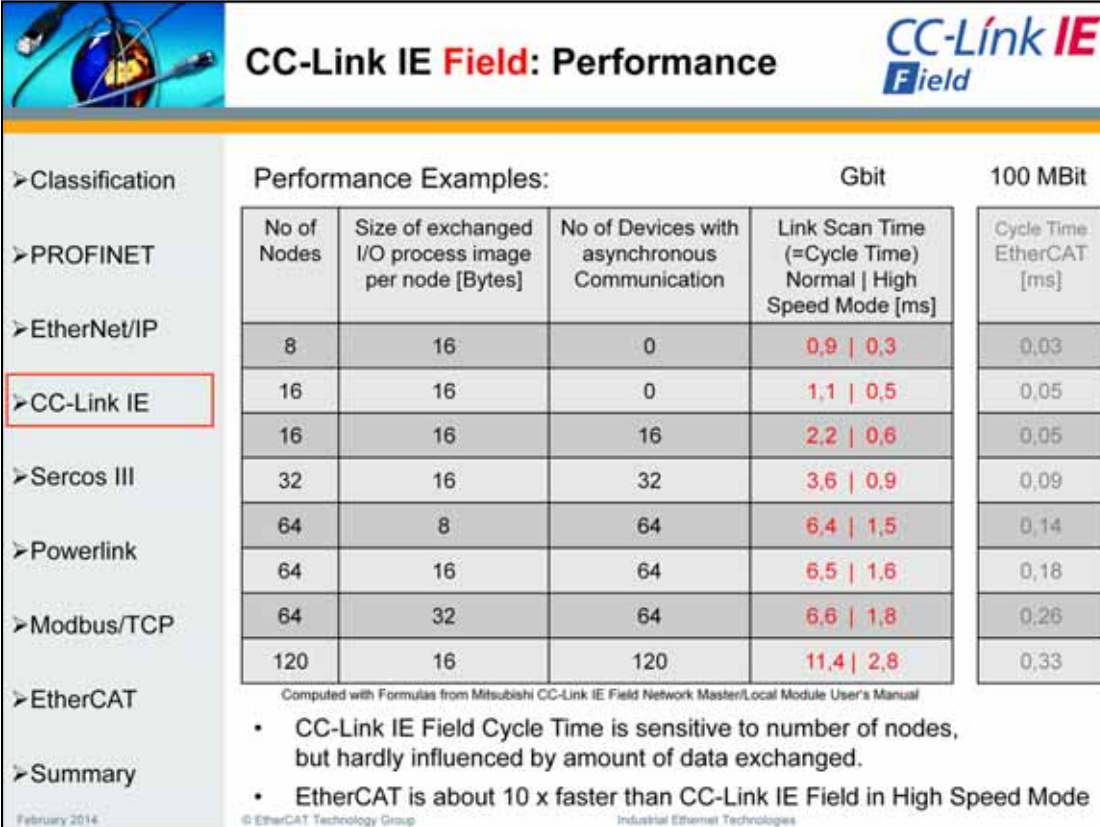
By introducing SLMP, CLPA aims to install a common protocol layer and thus a “cross-media” communication option for all CC-Link technologies. This can be seen as the attempt to provide an approach similar to CIP (ODVA) – however, SLMP does not contain device profiles. Thus, it may provide a common “how to communicate” protocol, but lacks a “what to communicate” definition.





CLPA suggests to use the SLMP via TCP/IP approach for devices such as RFID controllers, HMI, Barcode readers or Vision Sensors. Of course this approach is non-real time.

To make this very clear: According to the available specifications, CC-Link IE Field cannot transport other Ethernet traffic such as TCP/IP. The SLMP via TCP/IP approach simply means that the SLMP protocol of CC-Link IE can also be transported via TCP/IP, and Ethernet TCP/IP devices also supporting the SLMP protocol can exchange information with a CC-Link IE network via a gateway.



**CC-Link IE Field: Performance**

CC-Link IE Field

Classification	Performance Examples:			Gbit	100 MBit
	No of Nodes	Size of exchanged I/O process image per node [Bytes]	No of Devices with asynchronous Communication	Link Scan Time (=Cycle Time) Normal   High Speed Mode [ms]	Cycle Time EtherCAT [ms]
PROFINET					
EtherNet/IP					
<b>CC-Link IE</b>	8	16	0	0,9   0,3	0,03
	16	16	0	1,1   0,5	0,05
	16	16	16	2,2   0,6	0,05
Sercos III	32	16	32	3,6   0,9	0,09
	64	8	64	6,4   1,5	0,14
Powerlink	64	16	64	6,5   1,6	0,18
Modbus/TCP	64	32	64	6,6   1,8	0,26
	120	16	120	11,4   2,8	0,33

Computed with Formulas from Mitsubishi CC-Link IE Field Network Master/Local Module User's Manual

- CC-Link IE Field Cycle Time is sensitive to number of nodes, but hardly influenced by amount of data exchanged.
- EtherCAT is about 10 x faster than CC-Link IE Field in High Speed Mode

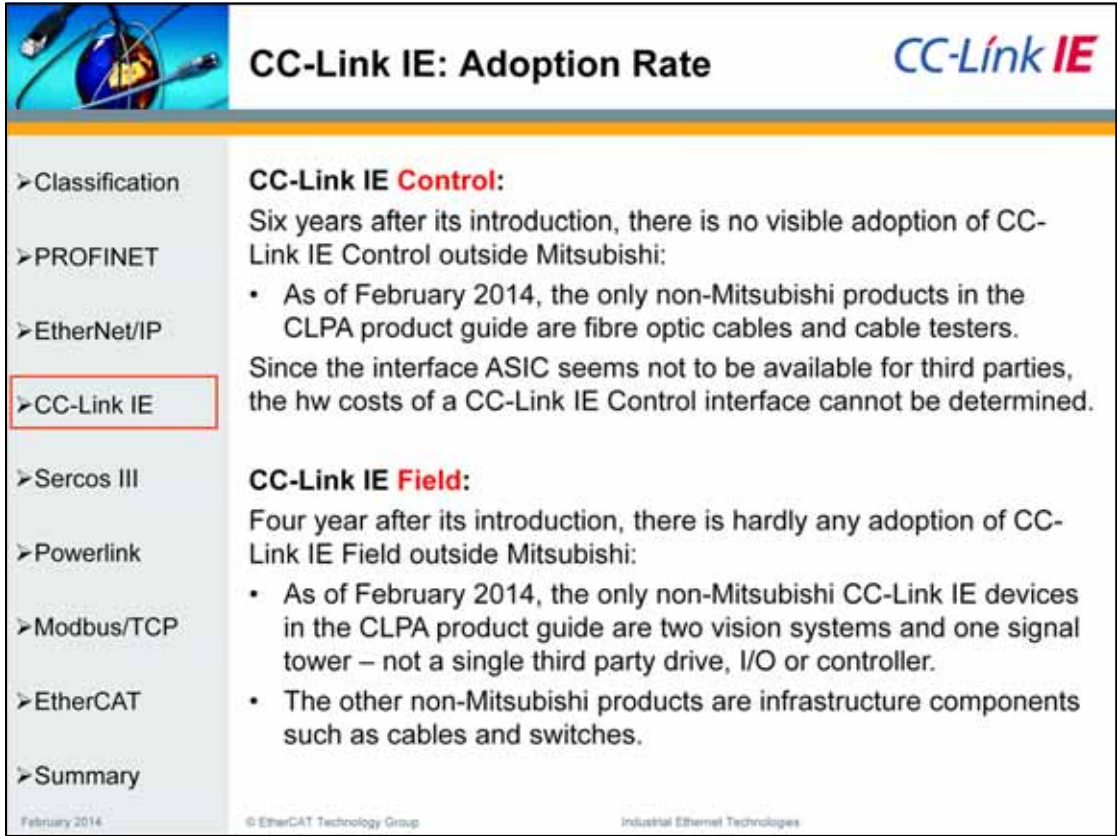
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

The Mitsubishi CC-Link IE Field Master supports two modes: Normal Mode – which is the default - performs both cyclic and acyclic (transient) transmission without losing their inherent speed performance, while High Speed Mode preferentially performs cyclic transmission for high-speed communications and reduces processing speed for transient transmissions. In High Speed Mode the maximum data size for register communication is reduced.

Similar to CC-Link IE Control, the cycle time of CC-Link IE Field is hardly influenced by the amount of data exchanged. In contrast, due to its functional principle, EtherCAT is hardly influenced by the number of nodes – and is much faster anyhow, in spite of using 100Mbit technology.

The Link Scan Time (=Cycle Time) formula used was taken from Appendix 5.2 (Link Scan Time) of the “MELSEC Q CC-Link IE Field Network Master/Local Module User’s Manual” SH(NA)-080917ENG-H of July 2012, found in Feb 2014 on [www.meau.com](http://www.meau.com) (Mitsubishi Electric Automation Inc, USA). CC-Link IE manuals are not available on the European website of Mitsubishi Electric – their CC-Link IE products are not offered in Europe.

We used the link scan time formula with  $K_a=25,8$  (Normal Mode)| $18,5$  (High Speed),  $K_b=655$  (NM)| $168$  (HS),  $K_c=160+60*(no\_of\_nodes\_with\_acyclic\_comm)$ (NM)| $80$ (HS),  $N_i=0$  and  $K_d$  (Maximum data link processing time when the station is disconnected from or returned to the network) =0. Using recommended values for  $K_d$  leads to additional ~20ms cycle time. For error case considerations this time has to be added. For Cyclic Transmission Delay Time the Link Refresh Times have to be taken into account as well.



The slide features a header with a globe icon and the title "CC-Link IE: Adoption Rate" in bold black text, with the "CC-Link IE" logo in blue and red to the right. A left-hand navigation menu lists various industrial protocols, with "CC-Link IE" highlighted by a red rectangular box. The main content area is divided into two sections: "CC-Link IE Control" and "CC-Link IE Field". The "Control" section states that six years after introduction, there is no visible adoption outside Mitsubishi, with a bullet point noting that as of February 2014, only fibre optic cables and cable testers are non-Mitsubishi products in the CLPA product guide. It also mentions that the interface ASIC is not available for third parties, making hardware costs undetermined. The "Field" section states that four years after introduction, there is hardly any adoption outside Mitsubishi, with two bullet points: one noting that as of February 2014, only two vision systems and one signal tower are non-Mitsubishi devices in the CLPA product guide, and another noting that other non-Mitsubishi products are infrastructure components like cables and switches. The footer contains the date "February 2014" and two copyright notices: "© EtherCAT Technology Group" and "Industrial Ethernet Technologies".

## CC-Link IE: Adoption Rate

**CC-Link IE Control:**

Six years after its introduction, there is no visible adoption of CC-Link IE Control outside Mitsubishi:

- As of February 2014, the only non-Mitsubishi products in the CLPA product guide are fibre optic cables and cable testers.

Since the interface ASIC seems not to be available for third parties, the hw costs of a CC-Link IE Control interface cannot be determined.

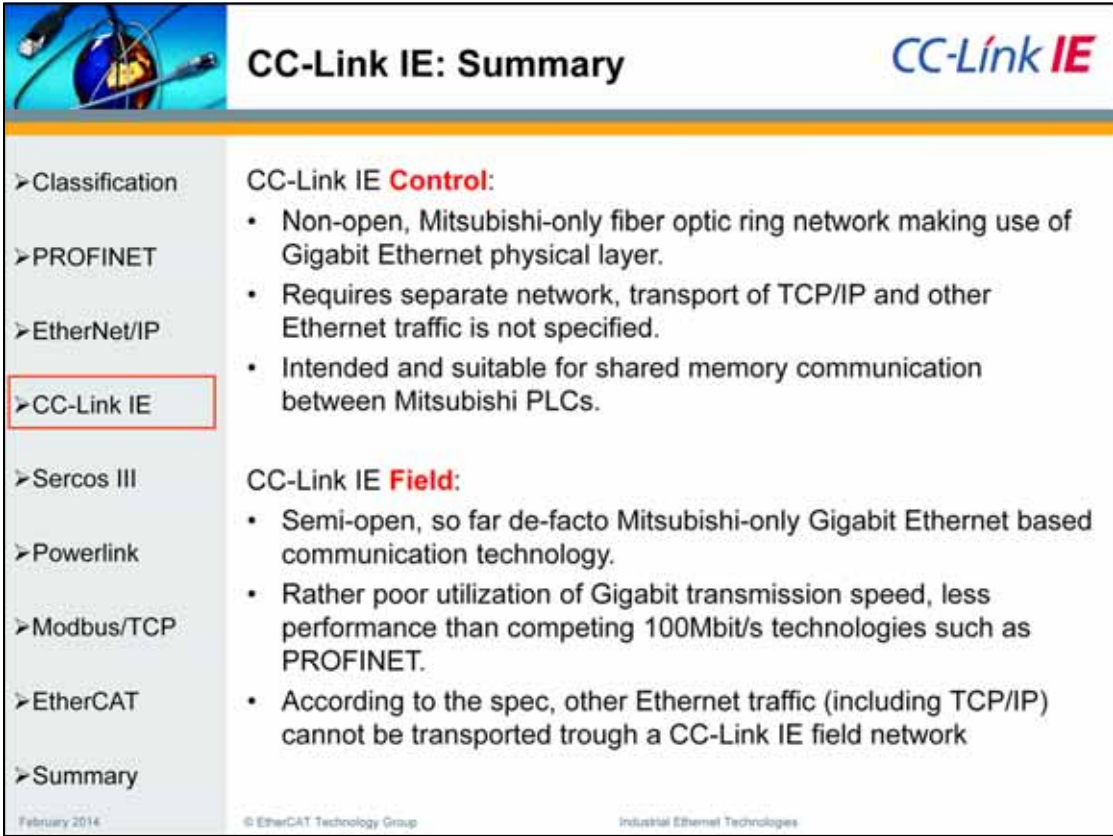
**CC-Link IE Field:**

Four year after its introduction, there is hardly any adoption of CC-Link IE Field outside Mitsubishi:

- As of February 2014, the only non-Mitsubishi CC-Link IE devices in the CLPA product guide are two vision systems and one signal tower – not a single third party drive, I/O or controller.
- The other non-Mitsubishi products are infrastructure components such as cables and switches.

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

The adoption rate is exceptional.



The slide features a header with a globe icon and the title 'CC-Link IE: Summary' on the left, and the 'CC-Link IE' logo on the right. A navigation menu on the left lists various industrial Ethernet technologies, with 'CC-Link IE' highlighted by a red box. The main content area is divided into two sections: 'CC-Link IE Control' and 'CC-Link IE Field', each with a bulleted list of characteristics. The footer contains the date 'February 2014' and copyright information for the EtherCAT Technology Group and Industrial Ethernet Technologies.

## CC-Link IE: Summary

**CC-Link IE**

- Classification
- PROFINET
- EtherNet/IP
- **CC-Link IE**
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**CC-Link IE Control:**

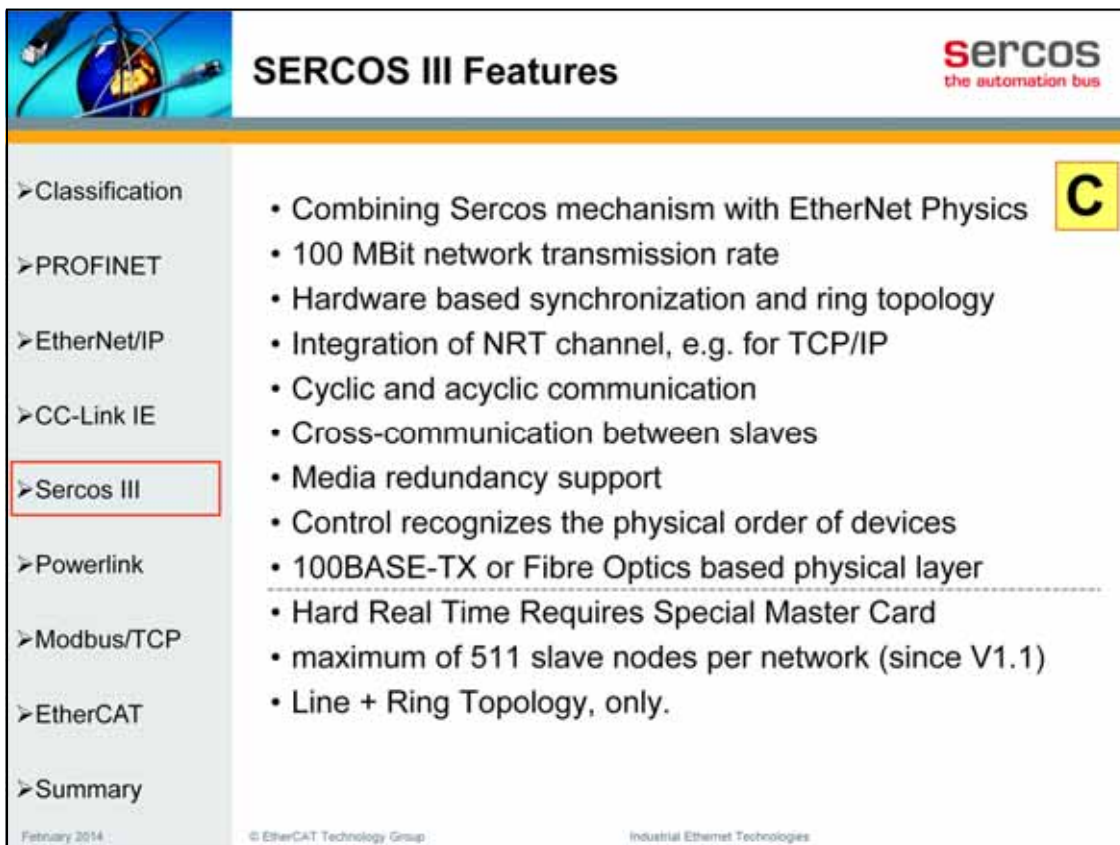
- Non-open, Mitsubishi-only fiber optic ring network making use of Gigabit Ethernet physical layer.
- Requires separate network, transport of TCP/IP and other Ethernet traffic is not specified.
- Intended and suitable for shared memory communication between Mitsubishi PLCs.

**CC-Link IE Field:**

- Semi-open, so far de-facto Mitsubishi-only Gigabit Ethernet based communication technology.
- Rather poor utilization of Gigabit transmission speed, less performance than competing 100Mbit/s technologies such as PROFINET.
- According to the spec, other Ethernet traffic (including TCP/IP) cannot be transported through a CC-Link IE field network

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Seems difficult to find a convincing reason why an automation vendor should adopt any CC-Link IE variant – it will be challenging to position CC-Link IE as an alternative to existing Industrial Ethernet Technologies.



The slide is titled "SERCOS III Features" and includes the Sercos logo "sercos the automation bus" in the top right. A yellow box with a black letter "C" is in the top right corner. A left sidebar contains a list of categories: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III (highlighted with a red border), Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content area lists features for Sercos III, including combining Sercos with EtherNet Physics, 100 MBit transmission rate, hardware-based synchronization, NRT channel integration, cyclic/acyclic communication, cross-communication, media redundancy, device order recognition, 100BASE-TX or Fibre Optics physical layer, a hard real-time requirement for a special master card, a maximum of 511 slave nodes, and Line + Ring Topology only. A dashed line separates the physical layer from the real-time requirements. Footer text at the bottom includes "February 2014", "© EtherCAT Technology Group", and "Industrial Ethernet Technologies".

## SERCOS III Features

**sercos**  
the automation bus

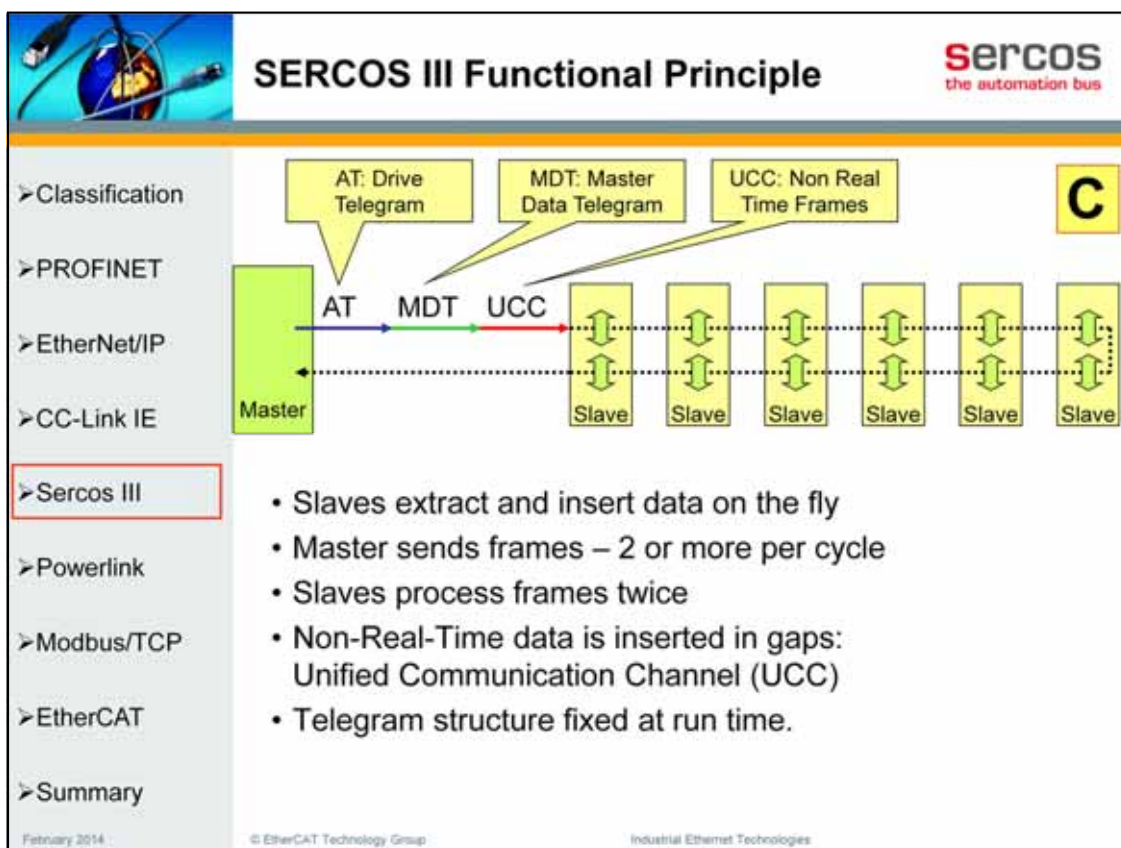
**C**

- Classification
  - Combining Sercos mechanism with EtherNet Physics
- PROFINET
  - 100 MBit network transmission rate
- EtherNet/IP
  - Hardware based synchronization and ring topology
- CC-Link IE
  - Integration of NRT channel, e.g. for TCP/IP
- Sercos III
  - Cyclic and acyclic communication
  - Cross-communication between slaves
  - Media redundancy support
  - Control recognizes the physical order of devices
- Powerlink
  - 100BASE-TX or Fibre Optics based physical layer
- Modbus/TCP
  - Hard Real Time Requires Special Master Card
- EtherCAT
  - maximum of 511 slave nodes per network (since V1.1)
- Summary
  - Line + Ring Topology, only.

February 2014    © EtherCAT Technology Group    Industrial Ethernet Technologies

The list of features of SERCOS-III reads like the list of features of EtherCAT – except the last three items.



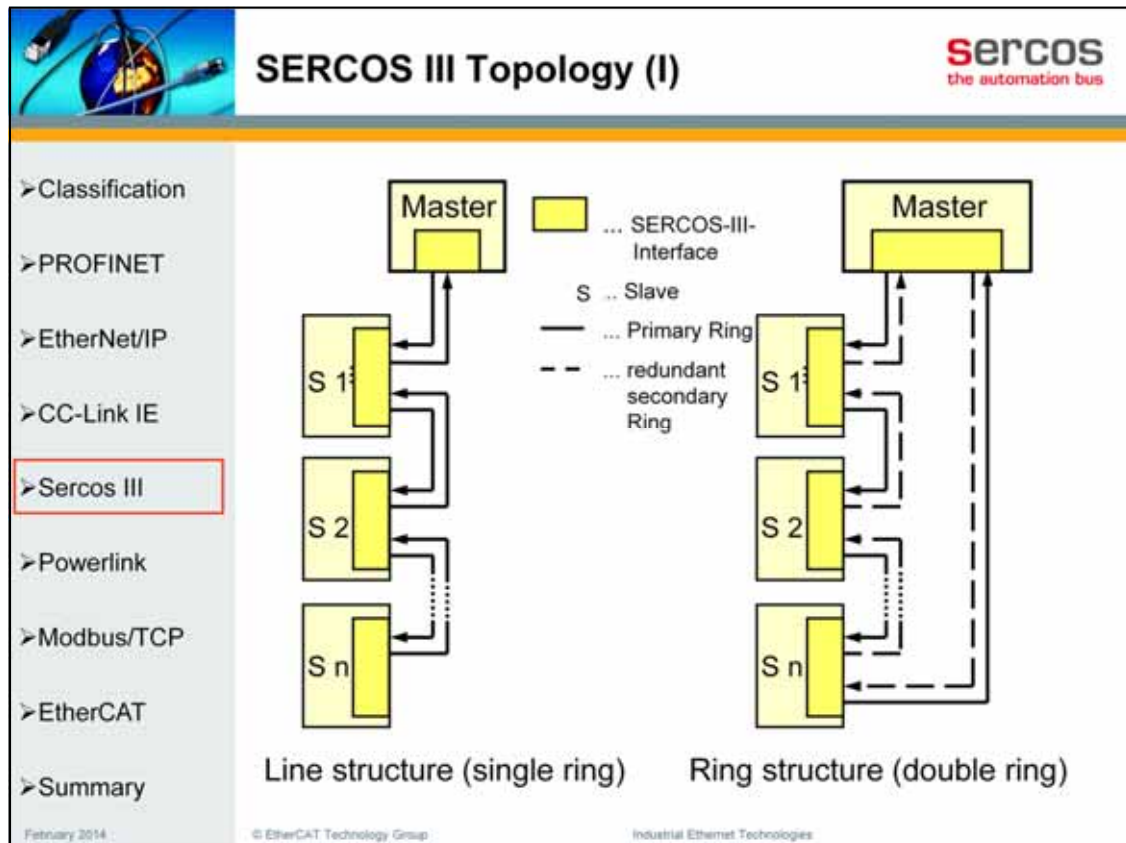


SERCOS-III has adopted the EtherCAT functional principle: processing Ethernet frames on the fly. There are some main differences, though:


1. SERCOS-III separates input and output data in two frames – so there are at minimum two frames per cycle
2. The slaves process the data twice: on the way out and on the way back
3. Very rigid frame layout – no changes at runtime, no bit-wise mapping.
4. Non Realtime Data (such as TCP/IP) is inserted in gaps between the frames.

These differences have the following impact – compared with EtherCAT:


1. Bandwidth utilization is lower. Dual processing in the slave devices. Therefore in average 2-3 times slower than EtherCAT.
2. Separating input and output data and processing twice allows for topology independent slave-to-slave communication within the same cycle. For topology independent slave-to-slave communication, EtherCAT has to relay the data through the master (performance implementation dependent, can also be done with 2nd frame within in the same cycle). However, since Servos III overall cycle time is higher, slave-to-slave performance is not better than with EtherCAT.
3. Due to the „processing twice“ principle, only line topology (+ ring for redundancy) are possible: no drop lines, tree configuration etc.
4. No flexibility in process data communication: same update rate for all nodes and data.
5. If the IP gap is shorter than the maximum Ethernet frame length ( $< 122 \mu\text{s}$ ), the MTU (Ethernet Maximum Transmission Unit) has to be adapted accordingly: the device interfacing Ethernet to Sercos III has to handle the fragmentation, similar to an EtherCAT switchport.



SERCOS-III originally supported line and ring topology, only.  
Ring structure: Recovery time in case of cable failure <math>< 25\mu\text{s}</math>.

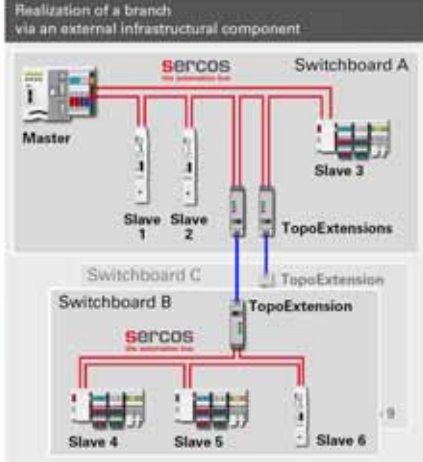


## SERCOS III Topology (II)

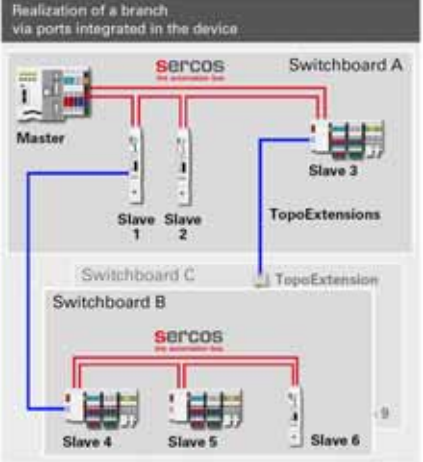


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

Realization of a branch via an external infrastructural component



Realization of a branch via ports integrated in the device

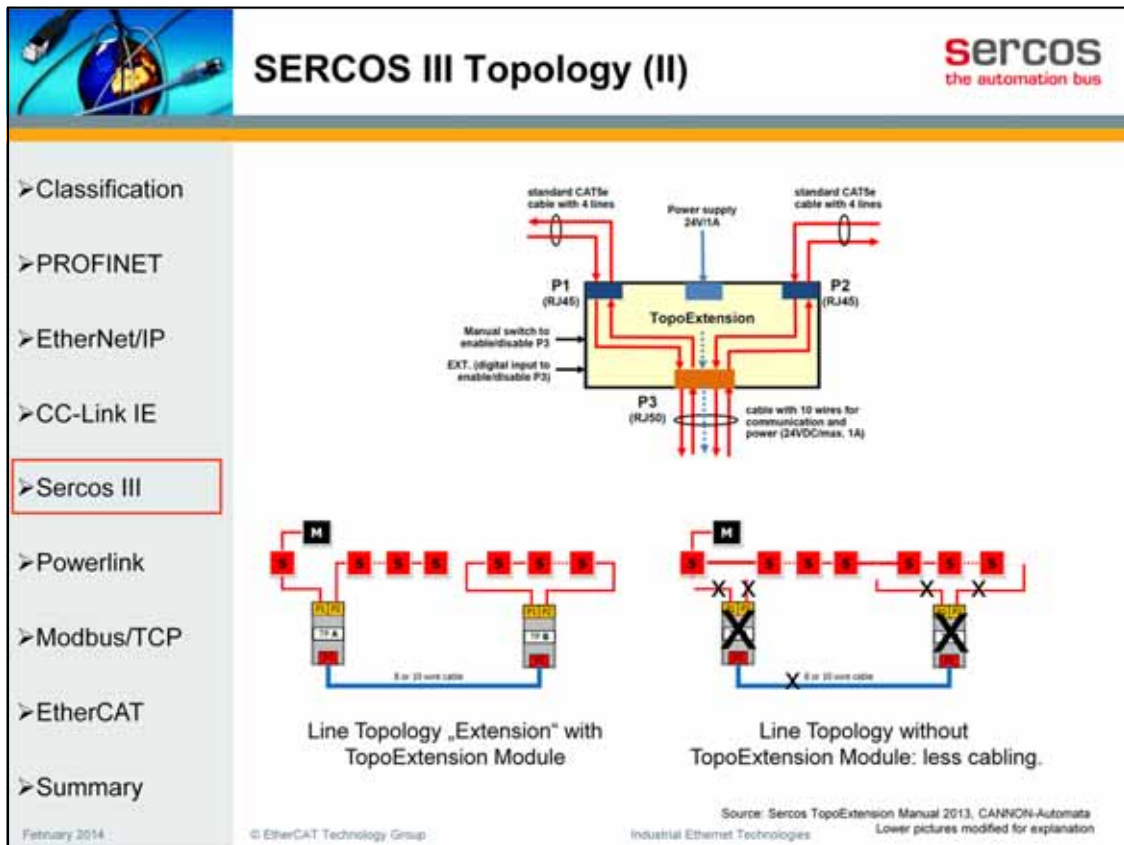


— Sercos-III Ethernet Cable, 4 wire

— Sercos-III Topo Extension, 8 or 10 wire: 2 x Ethernet + optional Power

February 2014 © EtherCAT Technology Group Source: Sercos III Brochure, Sercos International, Edition 1/2014  
Industrial Ethernet Technologies

In November 2012 the so called TopoExtension Module was announced. It allows one to extend the ring topology using one cable instead of two. In theory, the same functionality could be included into a slave device as well.



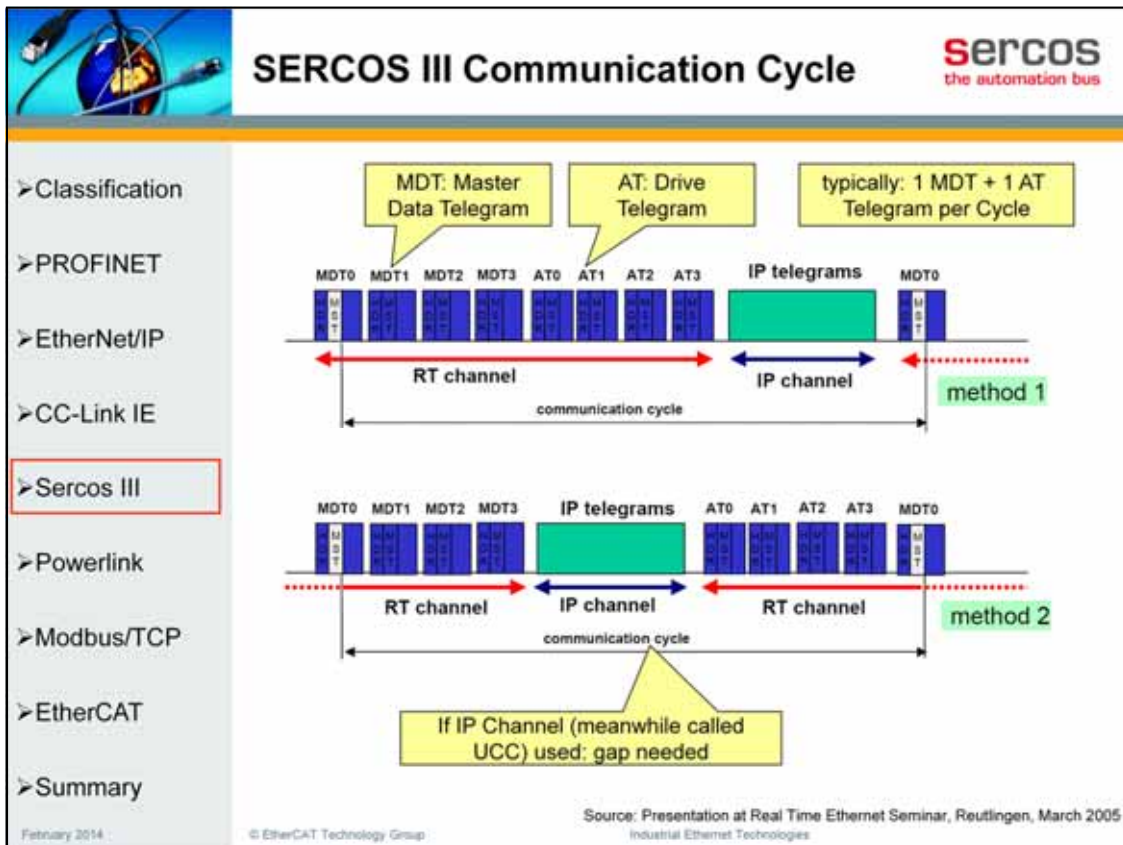
The TopoExtension Module combines two Ethernet lines into one (+ optional power).

At first glance it looks as if the TopoExtension adds drop line and tree topology support to Sercos-III; however, this is not really the case, since standard Sercos-III devices cannot be directly connected to the TopoExtension cable.

So one can replace two standard cables with two TopoExtension modules and a special cable (RJ50).

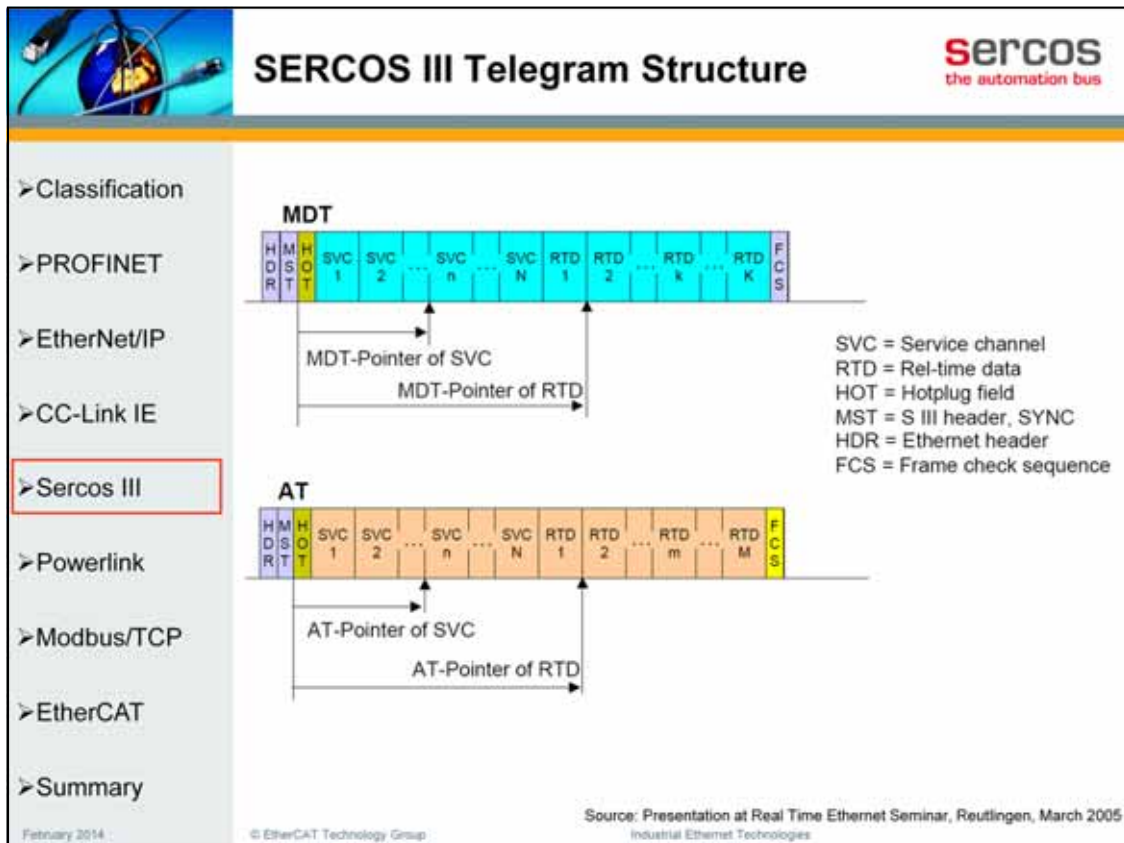
Conclusion: the main advantage/purpose of the Sercos TopoExtension is the ability to actively switch off a sub-ring.

Therefore we think it is appropriate to maintain the following statement: Sercos-III supports line and ring topology.



IP data is inserted in a gap (originally named IP channel, now called Unified Communication Channel UCC). The gap can either be after the input and output frames (method 1) or in between (method 2). Typically method 1 is used.







Once in real time mode, Sercos-III uses the same frame structure in every cycle. Therefore there is no flexibility in process data communication: each node and each process data part is updated at the same rate.

It is thus not possible to e.g. cyclically read a status bit of a device and request data only if this status bit indicates new data.

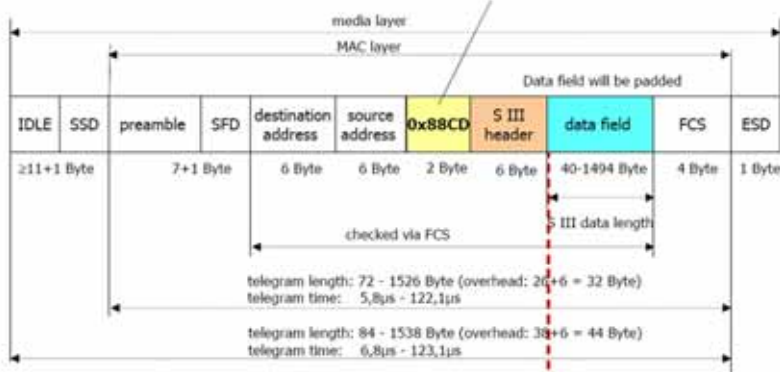
Furthermore, since the process data length per node is fixed to either 2,4 or 8 bytes (+ 4 bytes status per device), this approach is not ideal for devices with very small process data images (like digital I/O).



## SERCOS III Synchronization



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



**Synchronization Trigger**


Synchronization Accuracy depends on Master Accuracy: hardware support required

Source: Presentation at Automation Summit, Beijing, June 2007  
Source: Prof. Schwager, FH Reutlingen


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Just like with SERCOS-II, synchronization in SERCOS-III is based on cyclic, deterministic and jitter-free communication. This requires special hardware support in the master: a special dedicated SERCOS master card.

IEEE1588 support may be added later, but will as well need hw support for accuracy.




# SERCOS III Synchronization



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

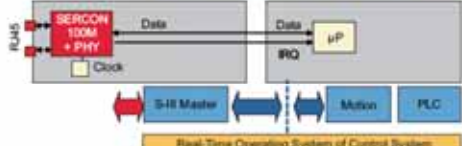
Soft-Master

**SERCOS III Master using Standard Ethernet Hardware**



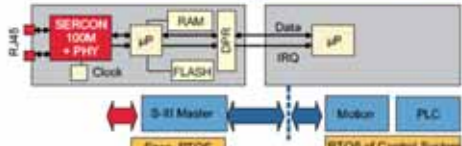
Hard-Master

**SERCOS III Master with passive SERCOS III interface board**



Hard-Master

**SERCOS III Master with active SERCOS III interface board**




Announced in April 2007:  
Soft-Master, suitable if RTOS-Jitter is sufficient for Node Synchronization

Source: Presentation at Automation Summit, Beijing, June 2007


In April 2007, Sercos International announced the development of a Sercos-III “Soft-Master”, implementing the master functionality using software (+ a standard Ethernet Port). According to the press release (quote), “The achievable synchronization accuracy of a SERCOS III real-time network using a soft master is depending on the performance of the hardware and the characteristic of the used operating system”.

Sercos International:

- special hardware support for 1µs jitter
- soft master for up to 50µs jitter



## SERCOS III Implementation



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



### 1. FPGA solution






### 2. Integrating SERCOS III interface into universal communication controllers

Cost effective  
Makes "single-chip devices" possible  
Multi-Protocol capability



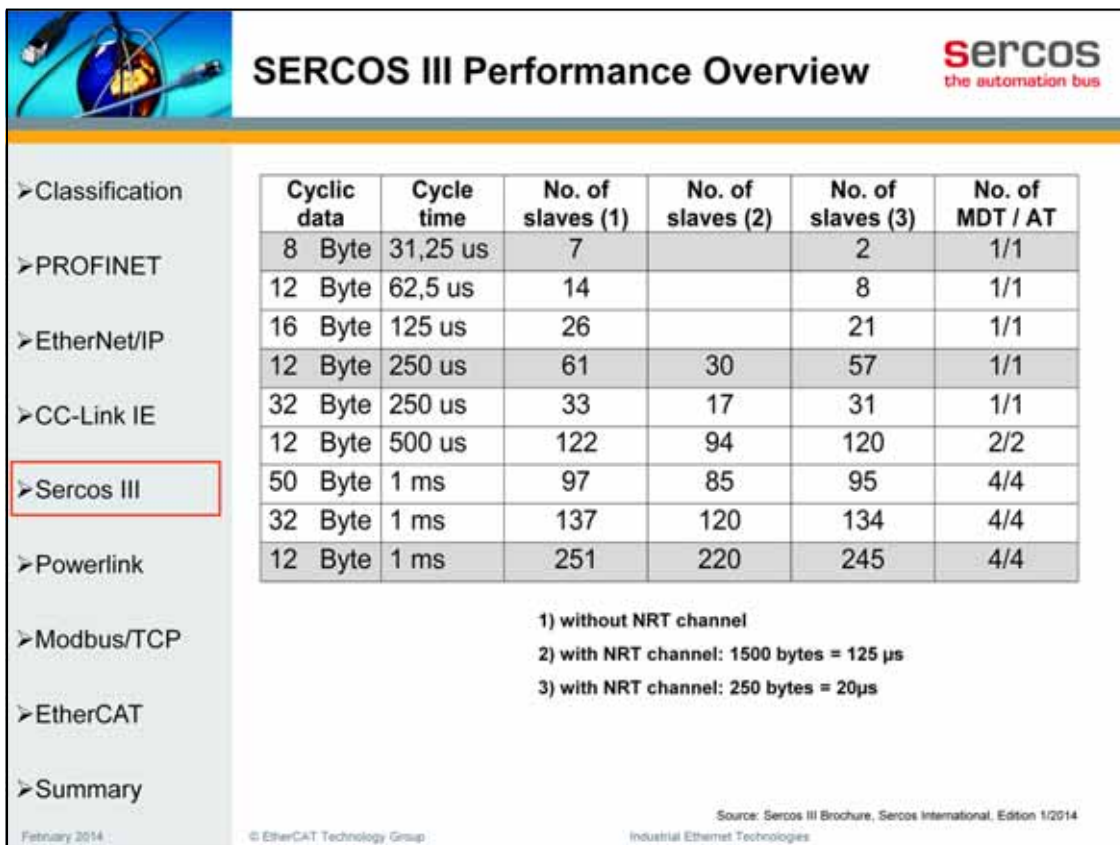
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

SERCOS-III Controllers are either FPGA based, or the Hilscher netX chip family can be used, which also supports EtherCAT + PROFINET. Furthermore, the TI Sitara Chip Family can also be equipped with a Sercos-III Slave Core.

In order to push the adoption of the SERCOS I/O profile (which was published in Nov 2006), Sercos launched Easy-I/O in April 2007), a free IP Core for the Xilinx Spartan-3 XC3S250E FPGA. This code is limited to 64 Byte I/O data, and targeted at encoders, measuring sensors, valve clusters, 24V digital I/O and analog I/O. It is not suitable for Sercos-III drive implementation.

For Sercos International (SI) members, a commercial IP core for Sercos-III is available for a one time fee. For non members of Sercos International an annual license fee for this IP core applies. Alternatively, run-time licenses are available (non members pay double runtime fees).

In April 2009, Sercos International announced to publish a Sercos-III master API under GPL license. The API only supports the SERCON100M Master IP Core (no generic Ethernet MAC).



The slide features a header with the SERCOS logo (the automation bus) and the title 'SERCOS III Performance Overview'. On the left, a vertical navigation menu lists various protocols: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III (highlighted with a red box), Powerlink, Modbus/TCP, EtherCAT, and Summary. The main content is a table with 7 columns: Cyclic data, Cycle time, No. of slaves (1), No. of slaves (2), No. of slaves (3), and No. of MDT / AT. Below the table, three footnotes explain the conditions for the slave counts. The source is cited as 'Sercos III Brochure, Sercos International, Edition 1/2014'.

	Cyclic data	Cycle time	No. of slaves (1)	No. of slaves (2)	No. of slaves (3)	No. of MDT / AT
>Classification	8 Byte	31,25 us	7		2	1/1
>PROFINET	12 Byte	62,5 us	14		8	1/1
>EtherNet/IP	16 Byte	125 us	26		21	1/1
>CC-Link IE	12 Byte	250 us	61	30	57	1/1
>Sercos III	32 Byte	250 us	33	17	31	1/1
>Powerlink	12 Byte	500 us	122	94	120	2/2
>Modbus/TCP	50 Byte	1 ms	97	85	95	4/4
>EtherCAT	32 Byte	1 ms	137	120	134	4/4
>Summary	12 Byte	1 ms	251	220	245	4/4

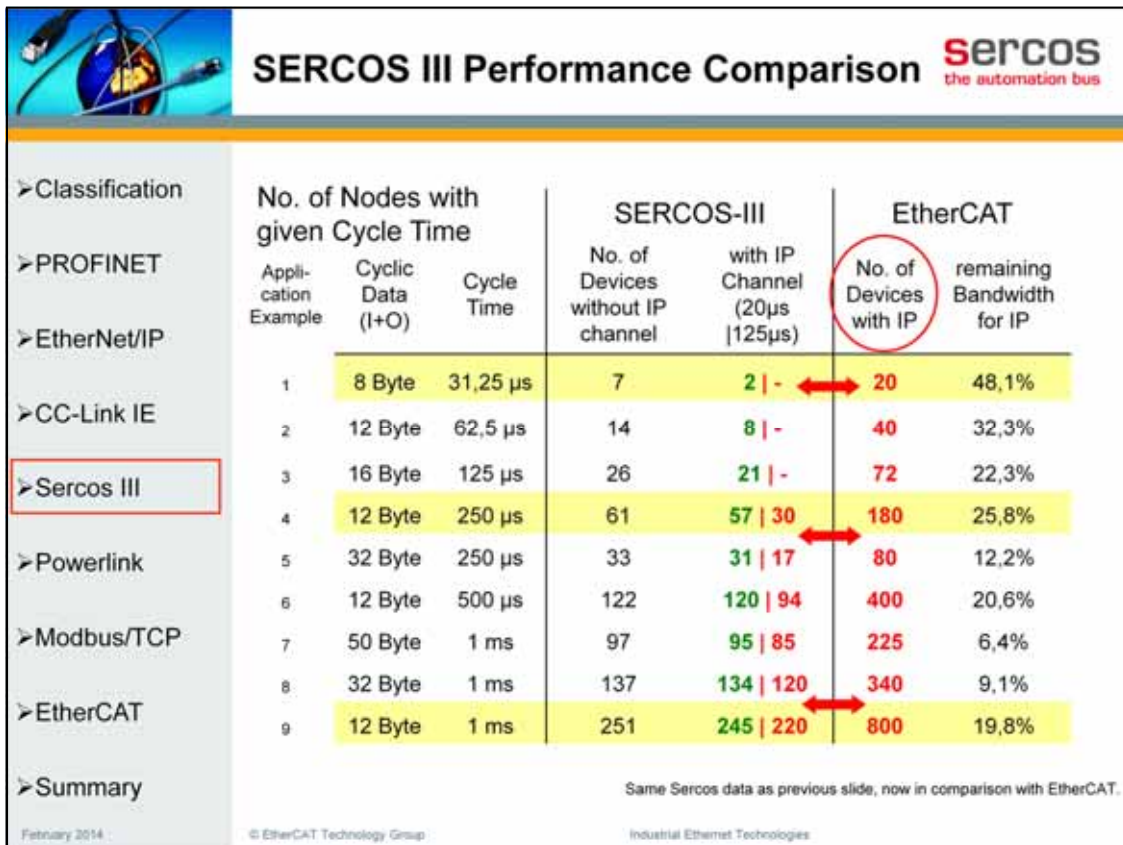
1) without NRT channel  
 2) with NRT channel: 1500 bytes = 125 µs  
 3) with NRT channel: 250 bytes = 20µs


February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies Source: Sercos III Brochure, Sercos International, Edition 1/2014

This performance data is taken from the Sercos-III brochure published by Sercos International, Edition 1/2014. At cycle times below 250µs the IP channel is shorter than a maximum frame length, and thus IP traffic is fragmented: MTU (Ethernet Maximum Transmission Unit) has to be adapted accordingly by the gateway.

This MTU adaptation is not supported by the Ethernet/Sercos-III gateways as of Feb 2014.





**SERCOS III Performance Comparison** 

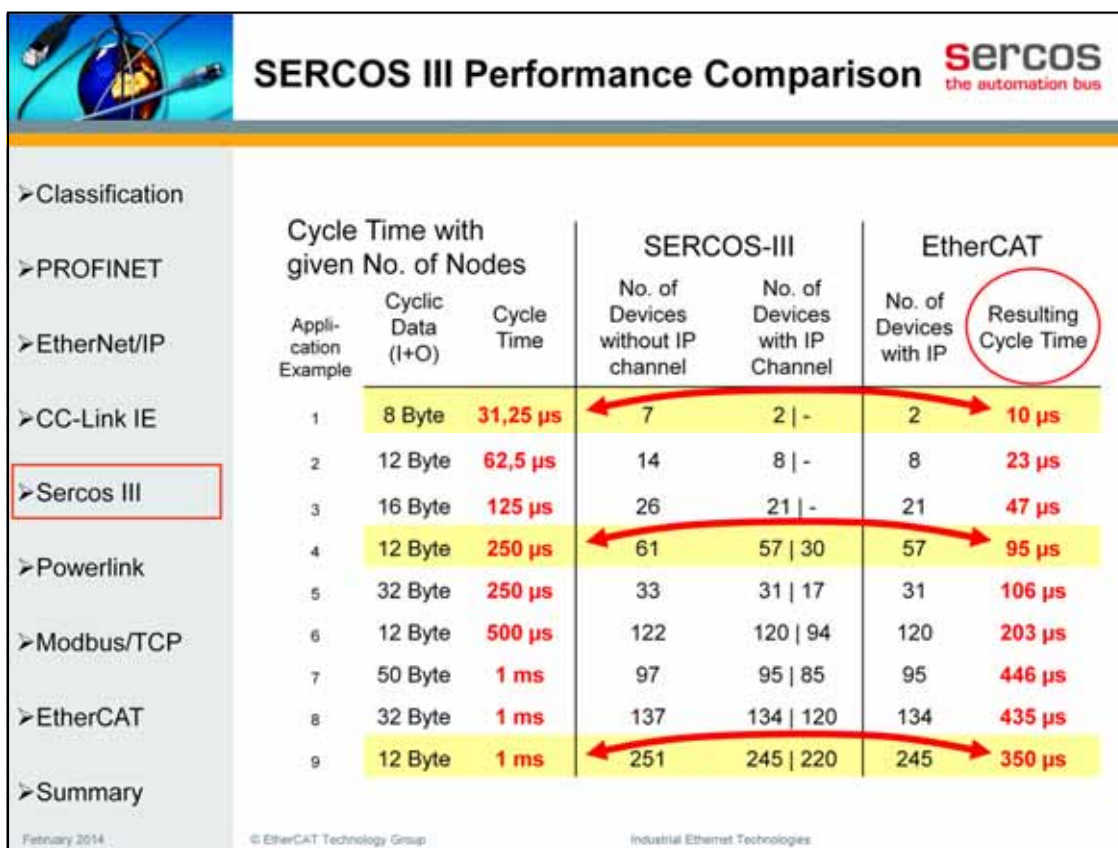
Classification	No. of Nodes with given Cycle Time			SERCOS-III		EtherCAT	
	Applica-tion Example	Cyclic Data (I+O)	Cycle Time	No. of Devices without IP channel	with IP Channel (20µs   125µs)	No. of Devices with IP	remaining Bandwidth for IP
>PROFINET							
>EtherNet/IP							
>CC-Link IE							
>Sercos III							
>Powerlink							
>Modbus/TCP							
>EtherCAT							
>Summary							


Same Sercos data as previous slide, now in comparison with EtherCAT.

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Comparing SERCOS-III and EtherCAT performance: at given cycle times and amount of data per slave, the maximum number of nodes is given for both technologies.

Please note that as of Feb 2014, we could not find a gateway supporting the shortened IP channel (which would lead to the values marked in green)

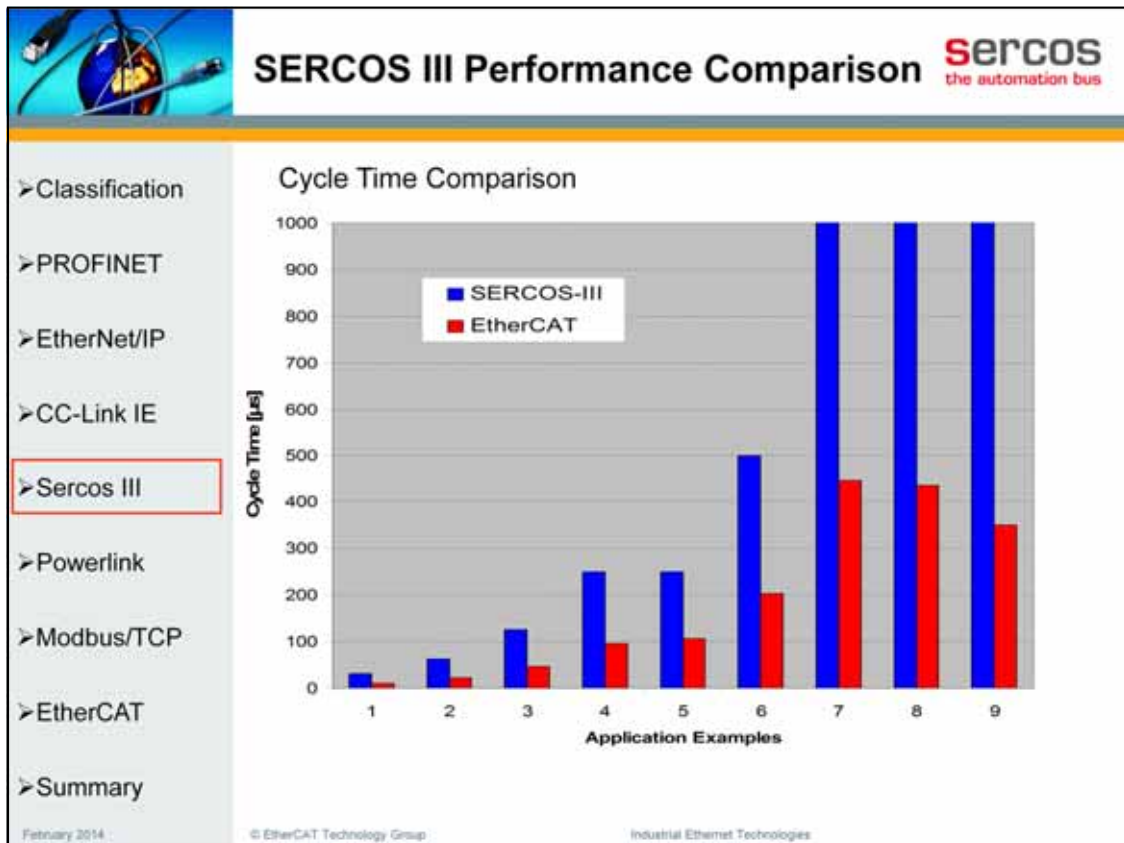


**SERCOS III Performance Comparison** 

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies


Classification	Cycle Time with given No. of Nodes			SERCOS-III		EtherCAT	
	Application Example	Cyclic Data (I+O)	Cycle Time	No. of Devices without IP channel	No. of Devices with IP Channel	No. of Devices with IP	Resulting Cycle Time
>PROFINET	1	8 Byte	31,25 µs	7	2   -	2	10 µs
>EtherNet/IP	2	12 Byte	62,5 µs	14	8   -	8	23 µs
>CC-Link IE	3	16 Byte	125 µs	26	21   -	21	47 µs
>Sercos III	4	12 Byte	250 µs	61	57   30	57	95 µs
>Powerlink	5	32 Byte	250 µs	33	31   17	31	106 µs
>Modbus/TCP	6	12 Byte	500 µs	122	120   94	120	203 µs
>EtherCAT	7	50 Byte	1 ms	97	95   85	95	446 µs
>Summary	8	32 Byte	1 ms	137	134   120	134	435 µs
	9	12 Byte	1 ms	251	245   220	245	350 µs

Another view for the comparison: now the number of nodes and the amount of data per slave is fixed, and the resulting cycle time is compared.




A graphical view for the previous table.

In average (over 9 different application scenarios), EtherCAT is 2,7 times faster.



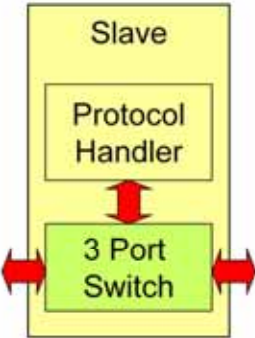
## SERCOS III IP-Handling (I)



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


- At Boot-Up, Slaves are in NRT (Non Real Time) Mode until they see first RT Frame
- In NRT Mode, Slave Chips behave like 3-port Switches
- Each node needs a MAC Address
- The internal Switches are implemented with "Store and Forward" or with "Cut Through" methodology
- Forwarding Delay depends on No. of Nodes, size of IP or NRT slot, frame size and switch methodology (may differ from node to node)
- Typical Store and Forward Delay per Node and Direction: 10...125µs, depending on Frame Length




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Sercos-III implementations either follow the “store and forward” approach for the switch (NRT) mode, which in case of Sercos-III means that the NRT frame is only forwarded in the next cycle, or they follow the “cut through” methodology, which means that they forward the frame only within the same cycle if after the analysis of the destination address the remaining IP-Slot is able to carry the maximum frame length.

It will be interesting to see how the IP communication over a large number of cascaded switches behaves.



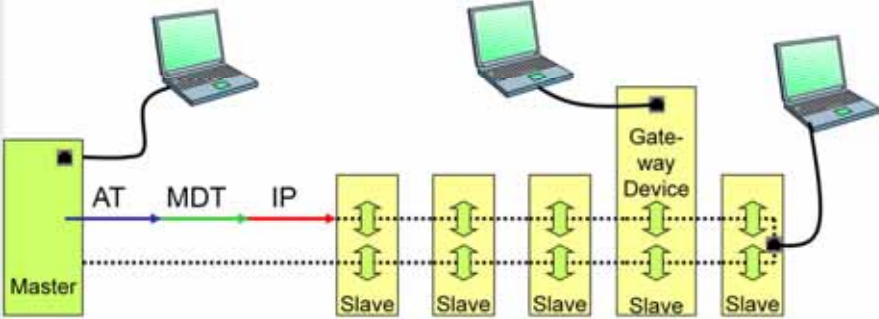
## SERCOS III IP-Handling (II)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

for IP Access to Slave Devices via TCP/IP:

- Gateway Device or Master with Gateway Functionality Required
- or access through open port @ last node in line



The diagram illustrates a Sercos III line topology. On the left is a green 'Master' device. A blue arrow labeled 'AT' points from the Master to the first 'Slave' device. A green arrow labeled 'MDT' points from the Master to the second 'Slave'. A red arrow labeled 'IP' points from the Master to the 'Gateway Device' (Slave 4). The 'Gateway Device' is connected to the last 'Slave' in the line. A laptop is connected to the Master, and another laptop is connected to the Gateway Device. Dotted lines represent the Sercos III bus connecting all devices in the line.


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

In order to allow for IP access to slave devices at run-time, either routing through the master or a special gateway device have to be used.


This is the same if IP access (e.g. for remote diagnosis) shall be supported without the need to physically connect the link first.

If an unused port is available, this can be used alternatively. Since Sercos-III Devices have two ports, in line topology there is one unused port at the last node in the line (no unused port in ring topology)



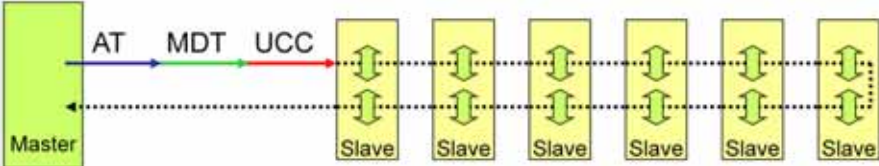


## SERCOS III IP-Handling (III)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In RT Mode, IP Traffic is inserted in Unified Comm. Channel
- During UCC Phase, Slave is in Switch Mode

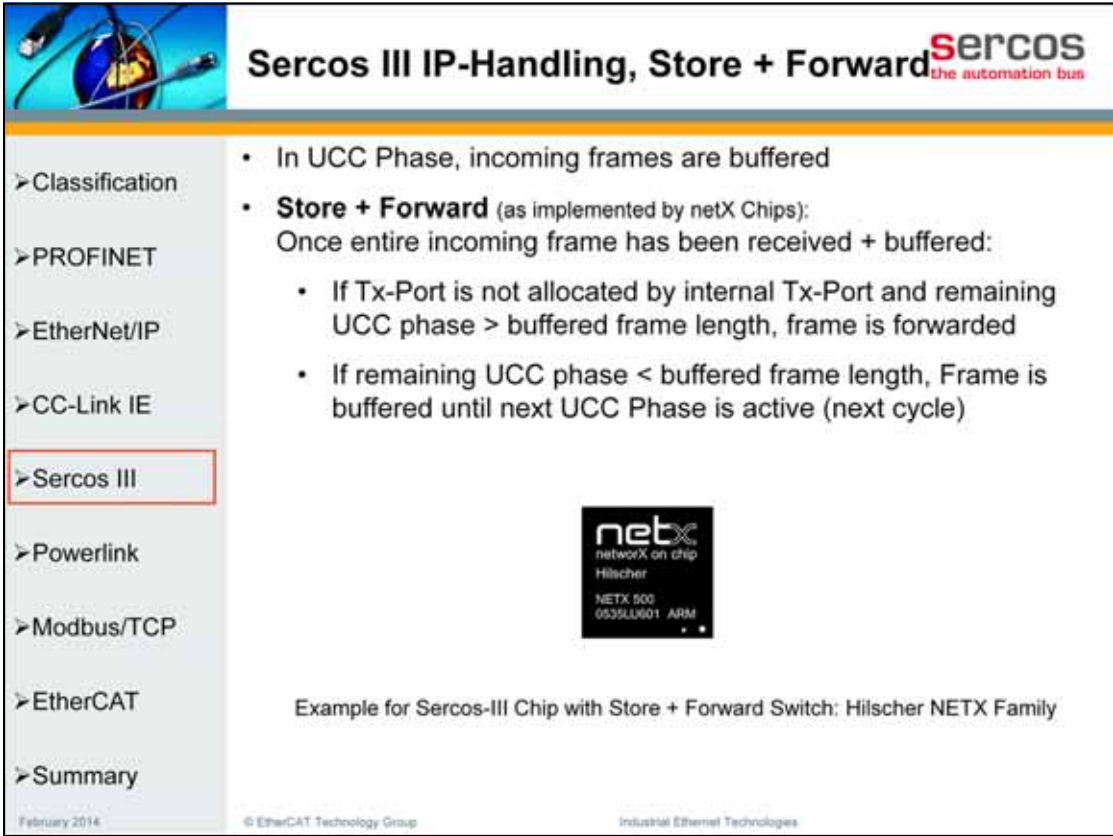



- If UCC slot is short or slave controller chip works with store and forward methodology, forwarding of larger frames is delayed to the next cycle – in this case sending a frame e.g. to node 50 takes 50 cycles, response frame accordingly (TCP/IP handshake).
- UCC performance strongly depends on No. of Nodes
- Within one cycle only one frame can be handled, regardless of Unified Communication Channel Size

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

In each RT cycle, the slave controllers switch between “processing on the fly-mode” for process data and “switch-mode” for IP data.


The forwarding behavior of IP frames in the IP slot depends on the slave device capabilities and on the network configuration



**Sercos III IP-Handling, Store + Forward**  the automation bus

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- **Sercos III**
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


- In UCC Phase, incoming frames are buffered
- **Store + Forward** (as implemented by netX Chips):  
Once entire incoming frame has been received + buffered:
  - If Tx-Port is not allocated by internal Tx-Port and remaining UCC phase > buffered frame length, frame is forwarded
  - If remaining UCC phase < buffered frame length, Frame is buffered until next UCC Phase is active (next cycle)




Example for Sercos-III Chip with Store + Forward Switch: Hilscher NETX Family

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

Most current Sercos-III implementations support Store and Forward, which means that within one Sercos-III cycle an IP frame moves from node n to node n+1, if frame sending takes longer than half of the UCC phase.



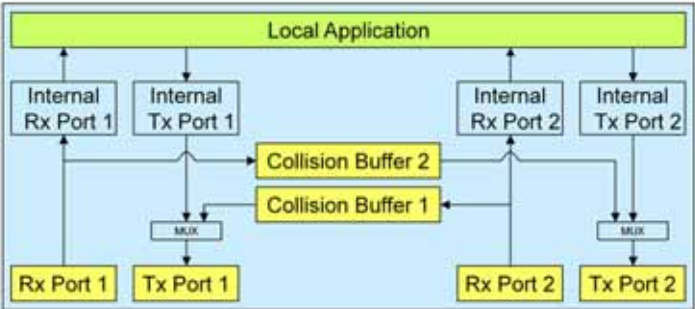
## Sercos III IP-Handling, Cut-Through



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In UCC Phase, incoming frames are buffered (Collision buffer)
- **Cut Through:** Once destination address is received:
  - If Tx-Port is not allocated by internal Tx-Port and remaining UCC Phase is  $> 122\mu\text{s}$  (max. frame length), frame is forwarded
  - Otherwise: frame is buffered until next IP-Channel is active

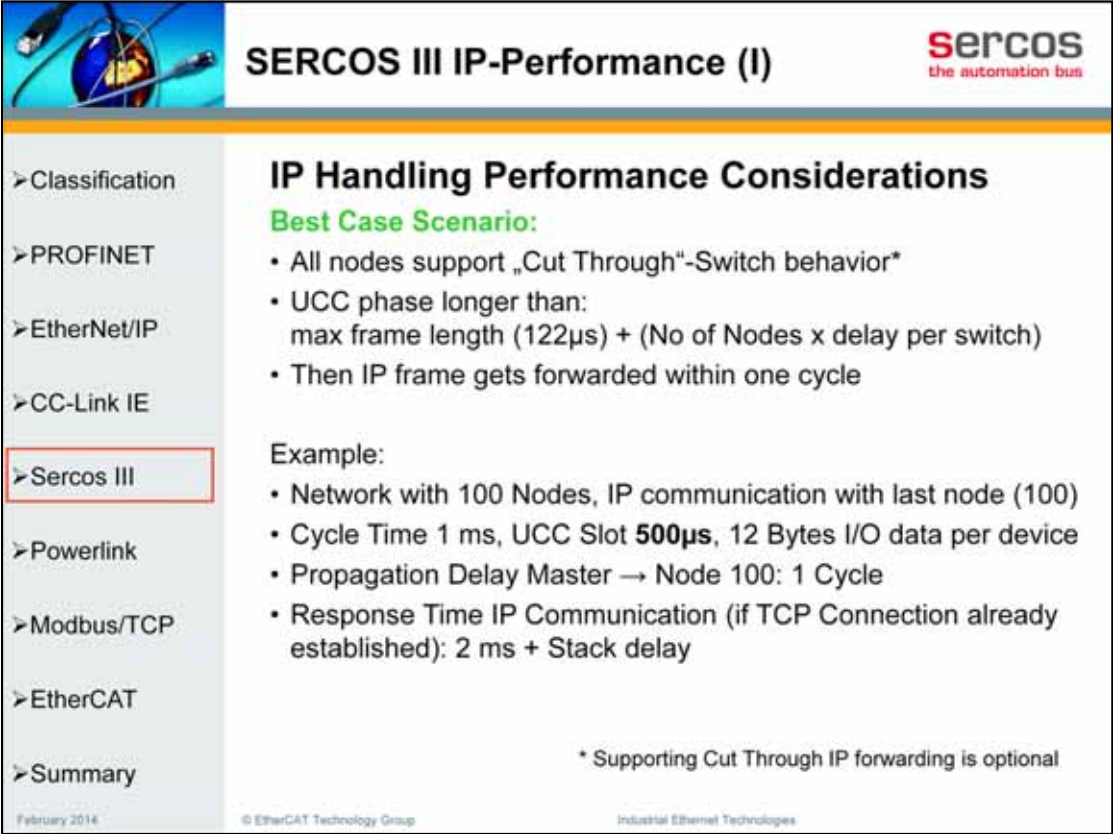


Example for Sercos-III Chip with Store + Forward Switch: SERCON-FPGA

- If IP slot is  $\leq 125\mu\text{s}$ , Cut-through forwards in next cycle

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

If Cut-Through behavior in NRT mode is supported, an IP frame can move several nodes before it is stored for the next cycle. However, if the IP slot is shorter than  $125\mu\text{s}$ , the only Cut-Through Sercos-III slave controller (SERCON FPGA) buffers the frame for the next cycle.



The slide features a header with a globe icon on the left, the title "SERCOS III IP-Performance (I)" in the center, and the "sercos the automation bus" logo on the right. A vertical navigation menu on the left lists various protocols, with "Sercos III" highlighted in a red box. The main content area is titled "IP Handling Performance Considerations" and includes a "Best Case Scenario" section with a bulleted list of conditions and an "Example" section with specific network parameters. A footnote at the bottom right states that supporting cut-through IP forwarding is optional. The footer contains the date "February 2014" and copyright information for EtherCAT Technology Group and Industrial Ethernet Technologies.

## SERCOS III IP-Performance (I)

**sercos**  
the automation bus

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- **Sercos III**
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### IP Handling Performance Considerations

**Best Case Scenario:**

- All nodes support „Cut Through“-Switch behavior\*
- UCC phase longer than:  
max frame length (122μs) + (No of Nodes x delay per switch)
- Then IP frame gets forwarded within one cycle

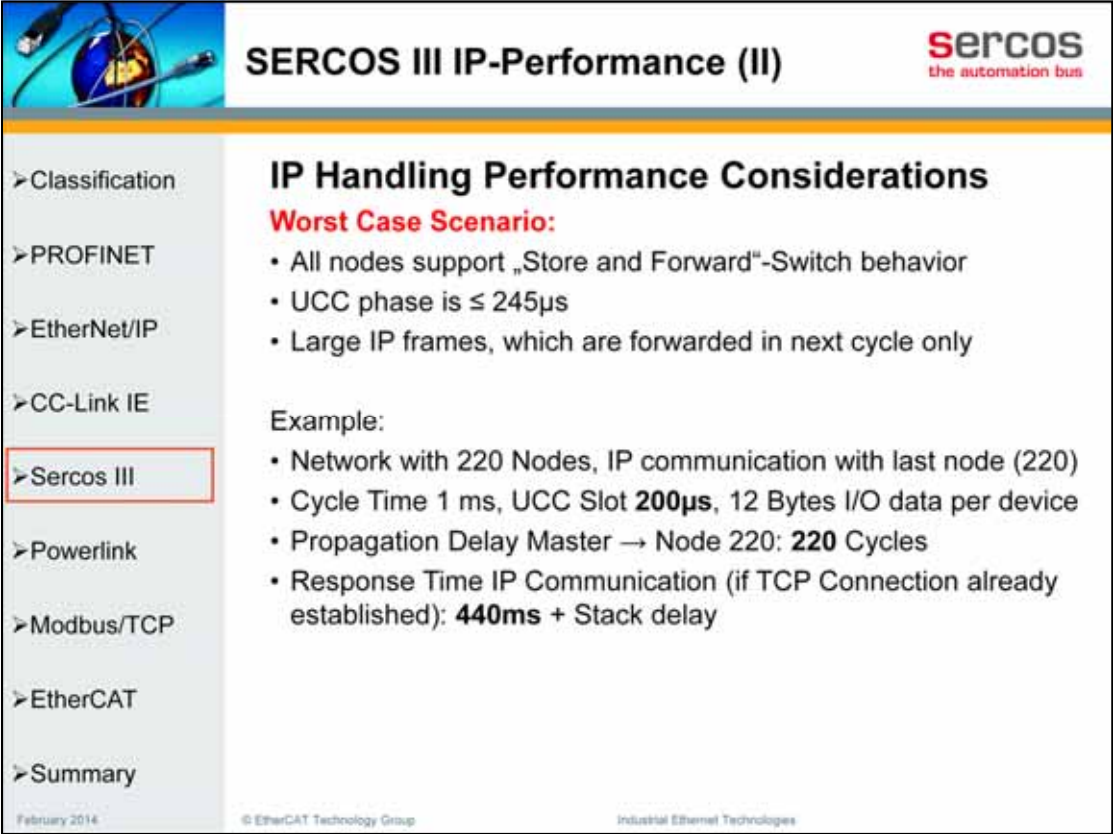
Example:

- Network with 100 Nodes, IP communication with last node (100)
- Cycle Time 1 ms, UCC Slot **500μs**, 12 Bytes I/O data per device
- Propagation Delay Master → Node 100: 1 Cycle
- Response Time IP Communication (if TCP Connection already established): 2 ms + Stack delay

\* Supporting Cut Through IP forwarding is optional

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

If UCC phase is long enough ( $\gg 125\mu\text{s}$ ) and cut-through is supported throughout, the performance of the IP communication looks sufficient.



The slide features a header with a globe icon and the title "SERCOS III IP-Performance (II)". The SERCOS logo is in the top right. A left sidebar lists various protocols, with "Sercos III" highlighted. The main content area discusses IP handling performance, including a "Worst Case Scenario" with three bullet points and an "Example" with four bullet points. The footer contains the date "February 2014" and copyright information for EtherCAT Technology Group and Industrial Ethernet Technologies.

## SERCOS III IP-Performance (II)

**SERCOS**  
the automation bus

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### IP Handling Performance Considerations

**Worst Case Scenario:**

- All nodes support „Store and Forward“-Switch behavior
- UCC phase is  $\leq 245\mu\text{s}$
- Large IP frames, which are forwarded in next cycle only

Example:

- Network with 220 Nodes, IP communication with last node (220)
- Cycle Time 1 ms, UCC Slot **200 $\mu\text{s}$** , 12 Bytes I/O data per device
- Propagation Delay Master → Node 220: **220 Cycles**
- Response Time IP Communication (if TCP Connection already established): **440ms** + Stack delay


February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

If UCC phase is short IP communication performance may deteriorate substantially – especially in larger networks.


This can be avoided by smart configuration tools, which take the node behavior and network size into account and adjust the IP slot time accordingly.

It is obvious, though, that the IP handling mechanism of SERCOS III works best in small networks.

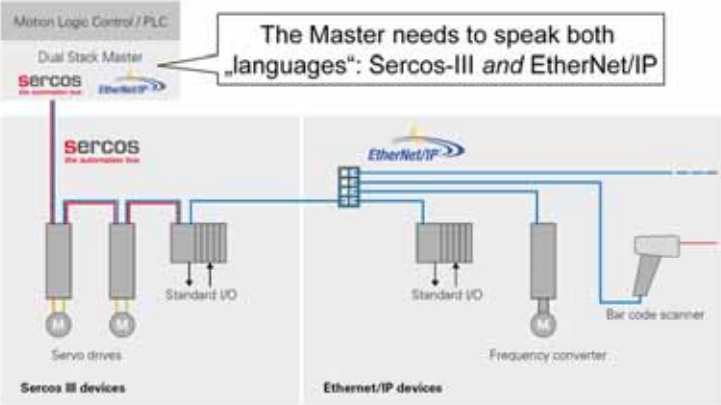




## SERCOS III and EtherNet/IP



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



The Master needs to speak both „languages“: Sercos-III and EtherNet/IP


- Following Bosch Rexroths move towards ODVA in 2011, Sercos International started to promote EtherNet/IP for Standard I/O and other non-motion-control devices.
- The topology is a little awkward, though: EtherNet/IP and Sercos-III devices cannot be mixed – the EtherNet/IP segment is connected e.g. to the end of the Sercos Line.

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

In February 2011 Bosch Rexroth became a “Principal Member” of ODVA. It is understood that the goal of this move was to get better access to the US market, especially to market segments dominated by Rockwell Automation. So Bosch Rexroth followed the example of Schneider Electric from 2007, even though it seems not to have really worked out for Schneider. Whereas many had expected that the Bosch Rexroth move towards ODVA would pave the way for ODVA accepting Sercos-III as official motion network, this did not happen. Unlike for Modbus TCP, for which an integration into the ODVA architecture was build after Schneider Electric became a principal member, similar activities were not started for Sercos-III.

However, Sercos International had to integrate EtherNet/IP instead, which raised some eyebrows: one of the fastest motion control bus systems adopts the slowest available Industrial Ethernet technology for I/O integration. This can also be seen as the confession of failure for Sercos-III as general automation bus. If Sercos-III would have been successful in integrating generic I/O, sensors and other non-motion control components, why promote EtherNet/IP as the solution for such devices?

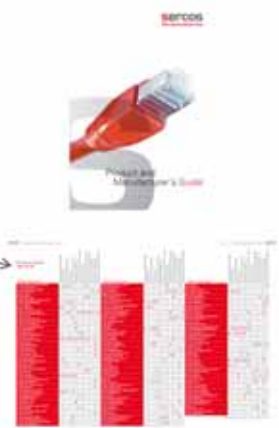
As of Feb 2014, no master product with dual stack capabilities can be found in the Sercos Product Guide.



## SERCOS III Adoption Rate

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

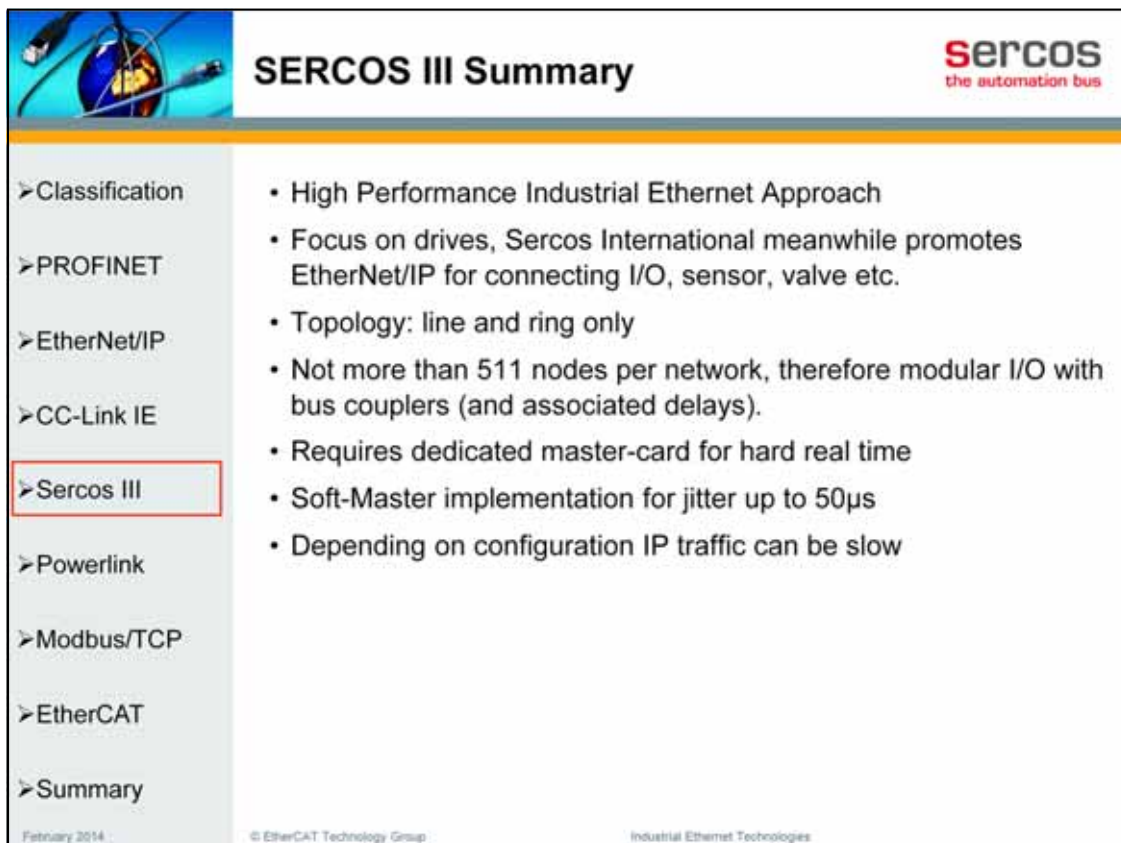
- As of Feb 2014, the Sercos International product guide contains 192 Sercos entries.
- However, most of them are Sercos-II products.
- Altogether the product guide overview matrix table shows 23 vendors of Sercos-III drives, 10 vendors of Sercos-III I/O, and 18 vendors of Sercos-III masters.
- The detailed product listing shows 12 vendors of Sercos-III drives, 7 vendors of Sercos-III I/O, and 12 vendors of Sercos-III masters.



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Whilst the SERCOS technology has a good reputation for servo drive control, similar reputation as general bus system I/O, sensors, or other devices has not been achieved.

With only very few exceptions, all drive and I/O products supporting Sercos-III also also available with EtherCAT interface, since EtherCAT can be implemented on the same FPGAs that are used for Sercos-III.



The slide features a header with a blue and yellow graphic of a globe and cables on the left, the title "SERCOS III Summary" in the center, and the "sercos the automation bus" logo on the right. A vertical navigation menu on the left lists various industrial protocols, with "Sercos III" highlighted by a red box. The main content area contains a bulleted list of characteristics for Sercos III. At the bottom, there are three small text elements: "February 2014", "© EtherCAT Technology Group", and "Industrial Ethernet Technologies".

## SERCOS III Summary


**sercos**  
the automation bus

- Classification
  - High Performance Industrial Ethernet Approach
- PROFINET
  - Focus on drives, Sercos International meanwhile promotes EtherNet/IP for connecting I/O, sensor, valve etc.
- EtherNet/IP
  - Topology: line and ring only
- CC-Link IE
  - Not more than 511 nodes per network, therefore modular I/O with bus couplers (and associated delays).
- Sercos III
  - Requires dedicated master-card for hard real time
  - Soft-Master implementation for jitter up to 50µs
  - Depending on configuration IP traffic can be slow
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

SERCOS-III achieves a performance comparable with PROFINET IRT – and thus sufficient for most applications.

Whilst the SERCOS technology has a good reputation for servo drive control, SERCOS-III has not been able to establish itself as generic automation bus with seamless integration of I/O, sensors and other devices.



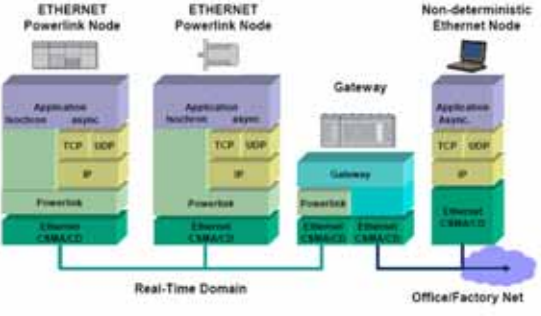
## Powerlink: Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Ethernet Approach originally introduced by B+R
- Medium Access Control by Polling (similar to Profibus)
- TCP/IP for Parameters, separate Process Data Protocol
- uses Hubs
- active Master Plug-in-Card required, no Standard NICs

B



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies


Powerlink replaces the Ethernet CSMA/CD Media Access Control Method by Polling: The master (called managing node) sends a poll request to each slave (called controlled node) which then answers with a response.

Hubs (no switches): the Powerlink Spec states: „To fit EPL jitter requirements it is recommended to use hubs“\*.


Protected real time mode: Since the Powerlink topology (up to 10 nodes in line configuration) violates IEEE802.3 roundtrip delay rules, CSMA/CD does not work in this configuration – so a network designed for protected mode cannot be accessed with standard Ethernet interfaces (not even in non-realtime mode).

\* In theory switches can be used, but due to the additional latency the network performance would be unacceptable. All performance calculations in the Powerlink spec assume a Hub Delay Time of 500ns – „store and forward“-switches have a delay time of >10µs (for short frames), „cut through“-switches have a delay time of ~5µs. If hubs were replaced by switches with 10µs delay, the cycle time of example 4 in the Powerlink Spec would be increased from 2,34 ms to 19,44 ms.

In September 2005, EPSG announced that Micrel's new 3-Port switch chip is endorsed for Ethernet Powerlink implementations. However, in Powerlink applications this switch chip is operated in half duplex repeater mode, only. Thus it is a switch chip that supports a hub mode, too.



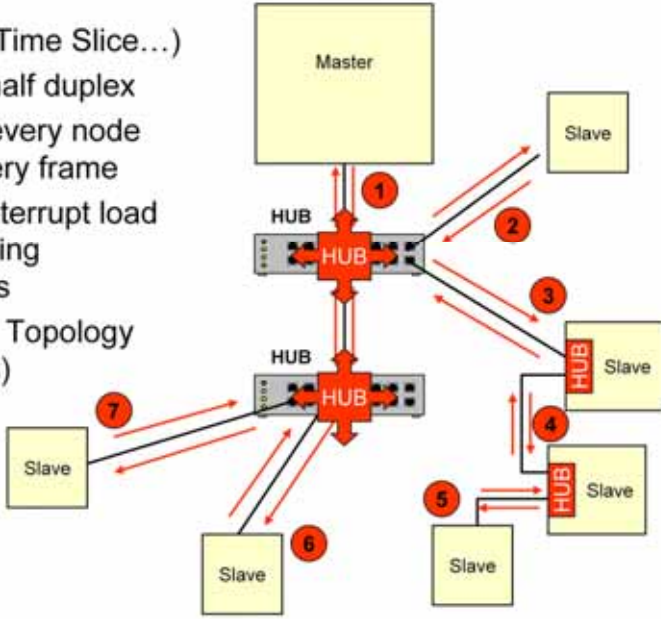
## Powerlink: Functional Principle



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Polling (Marketing: Time Slice...)
- Hubs only, half duplex
- Broadcast: every node receives every frame
- Thus high Interrupt load and processing requirements
- Limited Line Topology (Hub Delays)



The diagram illustrates a Powerlink network topology. A Master node is connected to a chain of HUBs. The first HUB is connected to a Slave. The second HUB is connected to a Slave and another HUB. The third HUB is connected to a Slave and another HUB. The fourth HUB is connected to a Slave. Red arrows indicate the flow of data, numbered 1 through 7, showing the sequence of communication from the Master through the HUBs to the Slaves.

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

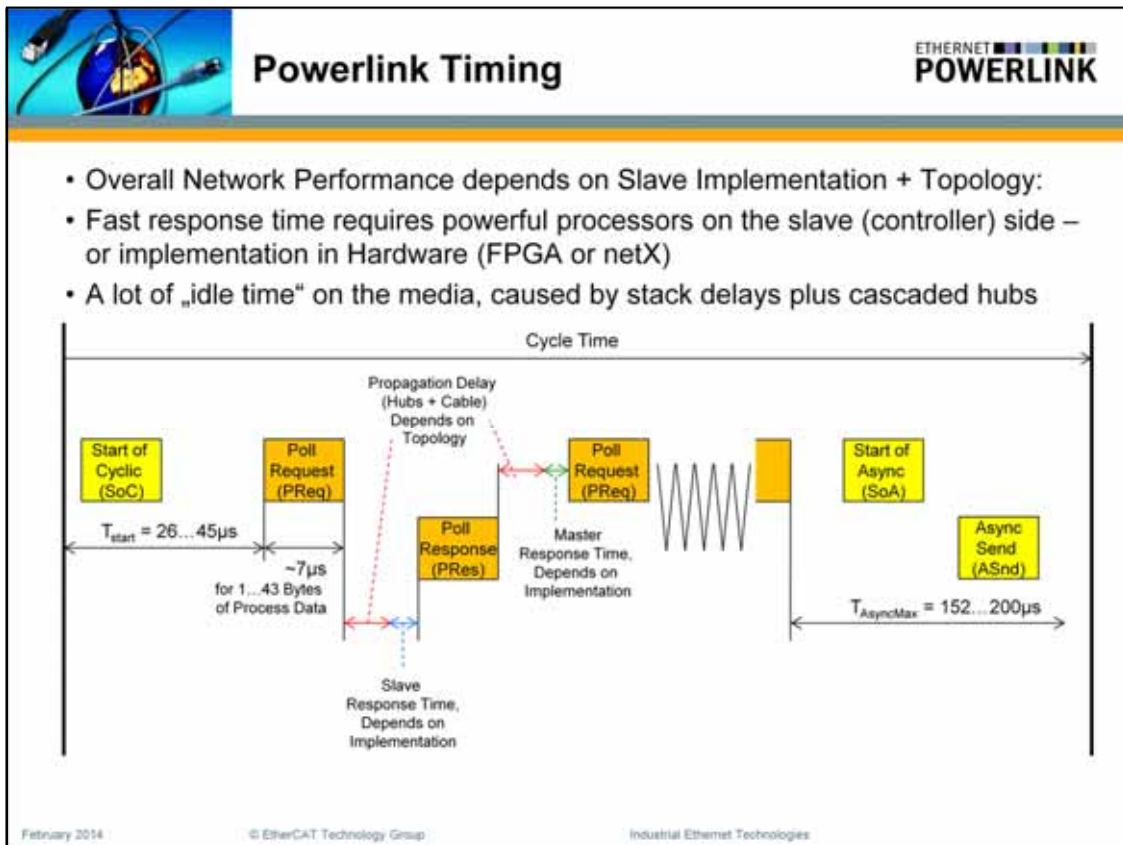
Powerlink Marketing calls the Media Access Method „Time Slicing“ or „Slot Communication Network Management“. The principle nevertheless is polling – the controlled device only „speaks“ after it was „asked“.

Due to the broadcast nature of hubs, all nodes receive all frames. Therefore the nodes have to filter each frame.

The broadcast mechanism can be used for slave to slave communication (consumer/producer principle). However, performance of slave to slave communication cannot be better than the cycle time...


The accumulation of the hub delays limits the number of nodes in a line topology.






The timing (and thus the performance) of a Powerlink network is mainly determined by the topology and the node response times: each poll request first has to get from the master through all hubs (both the external ones and the integrated ones in a daisy chain or line topology) to the destination node, then the node has to process the request, send the response, which then again goes through all hubs back to the master. Only after the master has received the response, he can issue the next poll request.

At the end of the cycle there is the asynchronous phase.

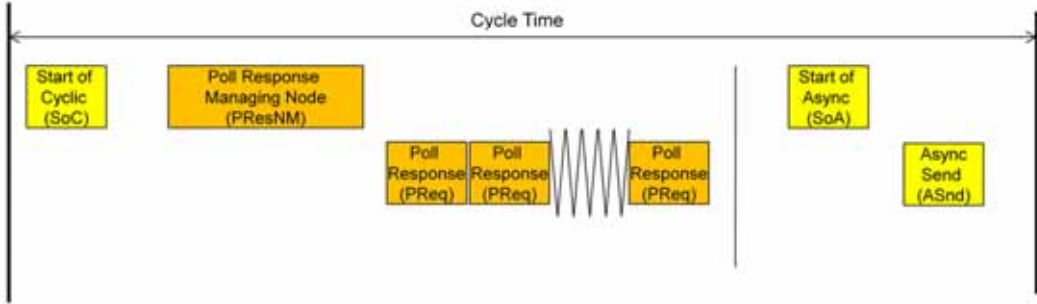


## Powerlink PollResponse Chaining



---

- In 2012 EPSG introduced another Powerlink Version: PollResponse Chaining.
- Master (=Managing Node) sends output data in one broadcast frame.
- Slaves reply with their Poll Response frames, triggered by pre-configured response times. These times are set so that slave tries to send while still receiving previous frame; Ethernet carrier sense mechanism delays actual sending until end of reception of previous frame.



- Increases performance, but adds substantial complexity: master has to determine the propagation delays between all nodes and set the timing accordingly
- Furthermore, system is sensitive to timing violations of any participating node.

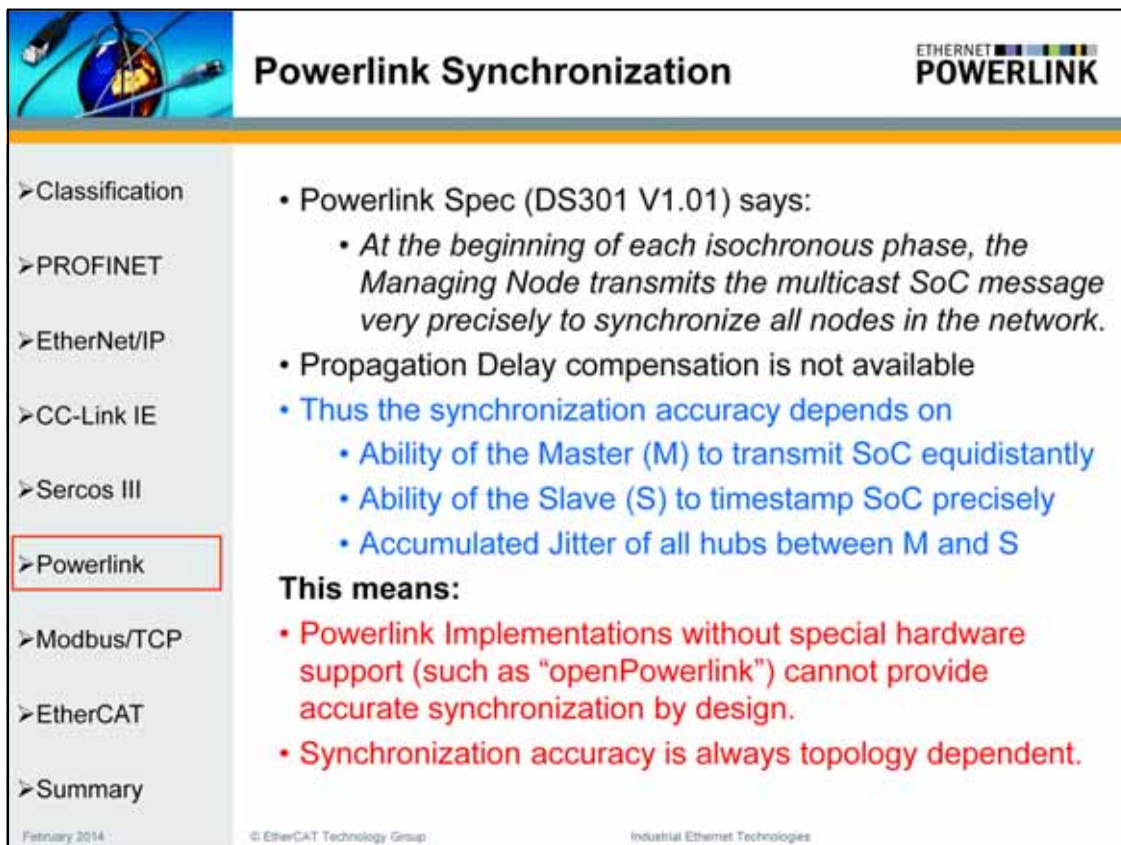
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

The PollResponse Chaining mode increases the performance of Powerlink but also increases the complexity and vulnerability. Boot-up and error handling become complex since collisions are not avoided by the polling mechanism any more. If a device responds just slightly too late collisions happen and the system becomes instable.

In previous versions of Powerlink the topology already had a substantial influence on the network performance. With PollResponse Chaining not only the topology, but also the sequence of node addresses influences the network performance: the timing depends not only on the sum of the propagation delays between master and slave devices, but also on the propagation delays of the subsequent node addresses. Overall, it becomes even more difficult to predict the performance of Powerlink for any given scenario.

PollResponse Chaining requires implementation of master and slave controller in Hardware (FPGA or netX)

The PollResponse Chaining Specification can be downloaded from the EPSG website. In particular the very “lean” error handling sections leave lots of implementation freedom, which is probably not such an issue since there are no non-B&R masters supporting this version.



The slide is titled "Powerlink Synchronization" and features the EtherCAT Technology Group logo in the top right corner. On the left side, there is a vertical navigation menu with the following items: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III, Powerlink (highlighted with a red box), Modbus/TCP, EtherCAT, and Summary. The main content area contains the following text:

- Powerlink Spec (DS301 V1.01) says:
  - *At the beginning of each isochronous phase, the Managing Node transmits the multicast SoC message very precisely to synchronize all nodes in the network.*
- Propagation Delay compensation is not available
- Thus the synchronization accuracy depends on
  - Ability of the Master (M) to transmit SoC equidistantly
  - Ability of the Slave (S) to timestamp SoC precisely
  - Accumulated Jitter of all hubs between M and S

**This means:**


- Powerlink Implementations without special hardware support (such as "openPowerlink") cannot provide accurate synchronization by design.
- Synchronization accuracy is always topology dependent.

At the bottom of the slide, there are three small text elements: "February 2014" on the left, "© EtherCAT Technology Group" in the center, and "Industrial Ethernet Technologies" on the right.

Furthermore, the cycle time setting must provide sufficient leeway for accumulated response jitter of all nodes and for repeating corrupt messages.

EPSG announced several times (also in the V2.0 spec of 2006) that precise synchronization using IEEE1588 time precision protocol will be added in Version 3.0.

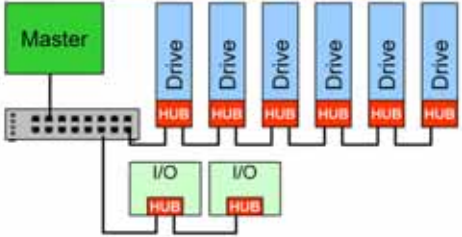
However, in order to downplay the Powerlink versioning issue V2.0 of the specification was later renamed in DS301 V 1.0. In Feb 2014 the 2008 version (Ds301 V1.01) of the spec is still valid, which contains no such synchronization.



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

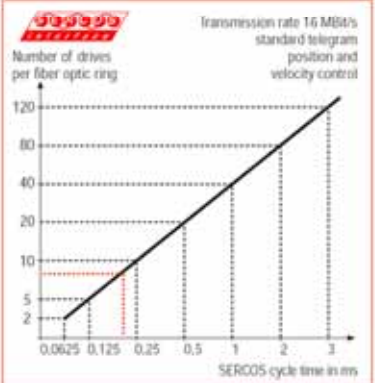
### Application Example:

- 6 Drives
- 2 I/O Nodes
- 400 m Cable Length
- Cycle Time: **291 μs**



### For Comparison:

- Sercos II (16 Mbaud): < 250 μs
- EtherCAT: **17 μs.**



February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

This performance example is taken from the Powerlink V 2.0 specification, Version 0.1.0. In this version of the spec, the

- slave response time = 8μs; master response time = 1μs (!)
  - $T_{\text{AsyncMax}} = 90\mu\text{s}$ ;  $T_{\text{Start}} = 45\mu\text{s}$ ;  $T_{\text{HubDelay}} = 0,5\mu\text{s}$
- and the resulting Cycle Time is **291 μs**.

In Powerlink V 2.0 specification Version **1.0.0**, this performance example is not available any more. However, the performance examples in this version assume

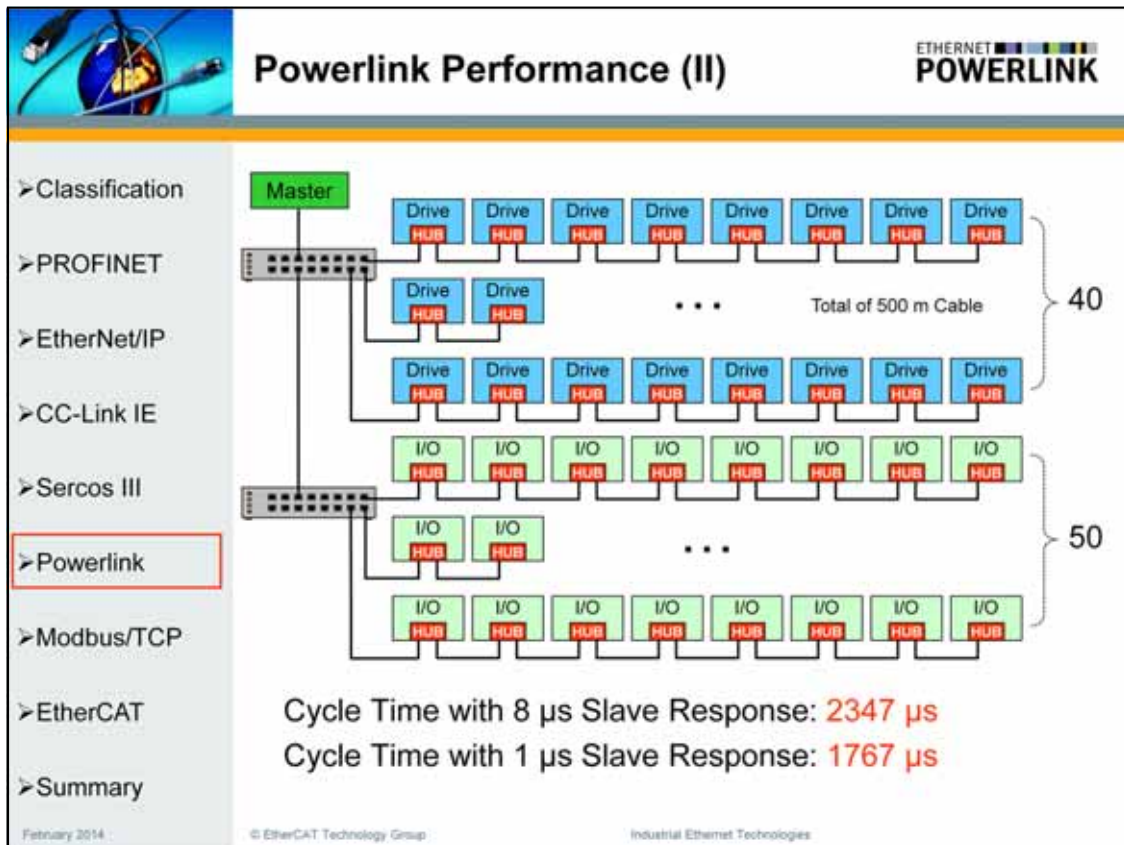
- slave response time = 1μs (!); master response time = 1μs (!)
- $T_{\text{AsyncMax}} = 120+32 (=152)\mu\text{s}$  + maximum signal propagation;  $T_{\text{Start}} = 26\mu\text{s}$ ;  $T_{\text{HubDelay}} = 0,5\mu\text{s}$

Applying these values to the performance example shown above leads to a Cycle Time of **281 μs**.

The Powerlink DS 301 V1.01 specification (which is the current one as of Feb 2014) does not contain any performance example any more.

However, the Powerlink Spec does not demand any specific slave response time, and manuals or data sheets of Powerlink products typically do not provide that value. Meanwhile most B&R Powerlink products are FPGA based and thus provide a short response time – since there are few “non-B&R” Powerlink products, such a short response time may be assumed. However, we have seen Powerlink drives in a multivendor motion control demonstrator (equipped with a network analyzer tool) on an EPSG booth with a response time of 10..20μs.





This performance example is referenced in the EtherCAT introductory presentation, it is taken from the Powerlink V 2.0 specification, Version 0.1.0.

In this version of the spec, the

- slave response time = 8 $\mu\text{s}$ ; master response time = 1 $\mu\text{s}$  (!)
- $T_{\text{AsyncMax}} = 90\mu\text{s}$ ;  $T_{\text{Start}} = 45\mu\text{s}$ ;  $T_{\text{HubDelay}} = 0,5\mu\text{s}$

and the resulting Cycle Time is **2347  $\mu\text{s}$** .

In Powerlink V 2.0 specification Version 1.0.0, this performance example is not available any more. However, the performance examples in this version assume


- slave response time = 1 $\mu\text{s}$  (!); master response time = 1 $\mu\text{s}$  (!)
- $T_{\text{AsyncMax}} = 120+32 (=152)\mu\text{s}$  + maximum signal propagation;  $T_{\text{Start}} = 26\mu\text{s}$
- $T_{\text{HubDelay}} = 0,5\mu\text{s}$

Applying these values to the performance example shown above leads to a Cycle Time of **1767  $\mu\text{s}$** .


The Powerlink DS 301 V1.01 specification (which is the current one) does not contain any performance example any more.

EtherCAT cycle time for this setup would be **276 $\mu\text{s}$**  if one waits for the frame to return before the next one is sent out, or **125 $\mu\text{s}$**  if one does not wait (unlike Powerlink, EtherCAT is full-duplex)





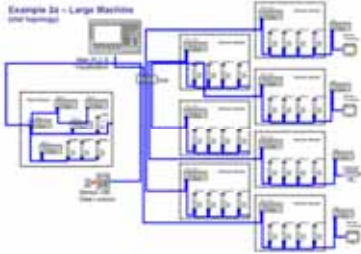
## Powerlink Performance (III)



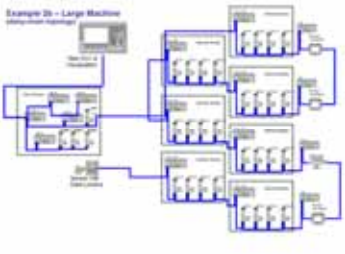
- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### Topology Dependency of Powerlink Performance

Performance Example 2 in the current Powerlink Spec comes in two topology options: star and daisy chain



**Star Topology,**  
53 nodes:  
Cycle Time **999 μs**




**Daisy Chain Topology,**  
53 nodes:  
Cycle Time **1967 μs**

Source: ETHERNET Powerlink V2.0 Communication Profile Specification Version 1.0.0


February 2014© EtherCAT Technology GroupIndustrial Ethernet Technologies

This performance example assumes a slave response time of  $1\mu\text{s}$  (!) and a master response time of  $1\mu\text{s}$  (!)

With EtherCAT the topology influence on the cycle time is negligible, the cycle time for separate 53 nodes with the same amount of data is  **$149\mu\text{s}$**  (@50% bus load).

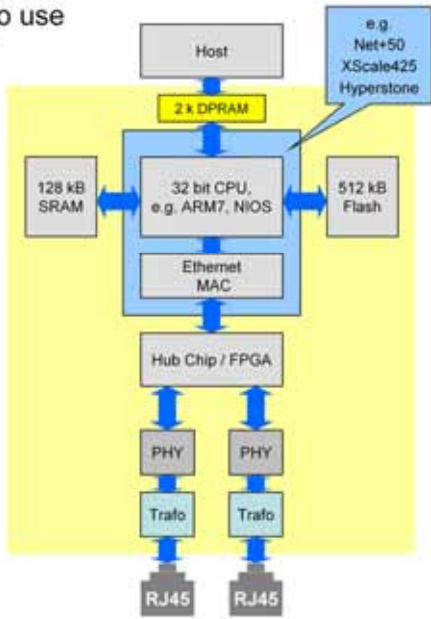


## Powerlink Interface Costs (I)




- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Originally, Powerlink claimed to use „standard Ethernet chips only“
- But: Performance of Software implemented Protocol-Stack unsatisfactory
- Nodes need a 32 bit CPU and infrastructure
- Furthermore, Hub Chips became obsolete -> ASIC or FPGA required




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

This hardware block diagram was drawn by an EPSG member company and shows the hardware effort for a Powerlink interface based on standard chips. The discrete design of a Powerlink slave interface is not a very cost efficient approach.




## Powerlink Interface Costs (II)



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

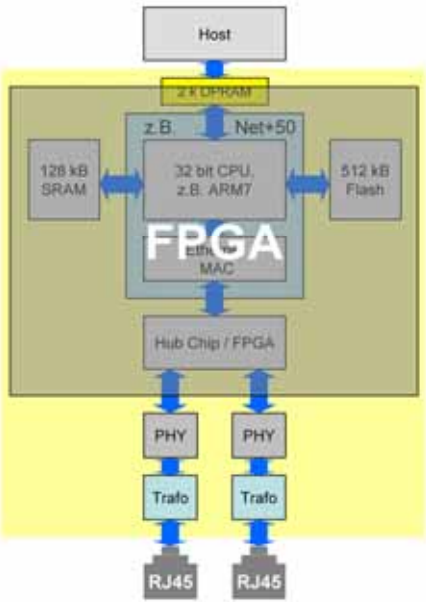
- Since discrete Interface is
  - too slow
  - too unpredictable
  - way too expensive
- Powerlink moved to FPGA implementation
- so: now HW-Situation similar to PROFINET, SERCOS III and EtherCAT



B

➔

C




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

EPSC is now supporting different implementation possibilities – the most cost effective is the FPGA solution. It uses the same Altera FPGA that is used for EtherCAT as well, but requires additional 10ns 256k x 16 SRAM.

In November 2007, IXXAT, B&R + Lenze announced that the master (managing node) is now also implemented in an FPGA.

The rationale is, according to a press statement\*: *“Until now on the control side there were only solutions which had limited performance and which were not suitable or too expensive for extremely demanding applications such as highly dynamic motion systems, since very powerful CPUs are used.”*

\* Translated from the Article “Master-FPGA für Powerlink”, Computer&Automation Magazine 12/2007, p.17



Classification	Version	Feature	Availability
PROFINET	Powerlink Version 1	<ul style="list-style-type: none"> <li>Protected mode only</li> <li>Half Duplex Polling (Hubs)</li> </ul>	Available by B&R only
EtherNet/IP	Powerlink Version 2	<ul style="list-style-type: none"> <li>Network Management</li> <li>New Frame Structure</li> <li>MAC-Addressing</li> <li>Asynchronous Channel</li> <li>TCP/IP Support</li> <li>Bridge / Router Support</li> <li>Profile Support (CANopen)</li> </ul>	Spec: 2003 <ul style="list-style-type: none"> <li>Devices Shipping: 2007</li> </ul>
CC-Link IE			
Sercos III			
<b>Powerlink</b>	Powerlink Version 3	<ul style="list-style-type: none"> <li>New protocol principle: Burst Polling</li> <li>Switched Gbit Ethernet Based</li> <li>IEEE1588 synchronization</li> </ul>	Announced 2006 First outline 2009 Spec: ??? <ul style="list-style-type: none"> <li>Devices Shipping: ??</li> </ul>
Modbus/TCP			
EtherCAT	Powerlink Version 4	<ul style="list-style-type: none"> <li>Poll Response Chaining</li> <li>Still half duplex, 100 Mbit/s</li> </ul>	Spec: 2012 <ul style="list-style-type: none"> <li>Devices Shipping (B&amp;R)</li> </ul>
Summary			

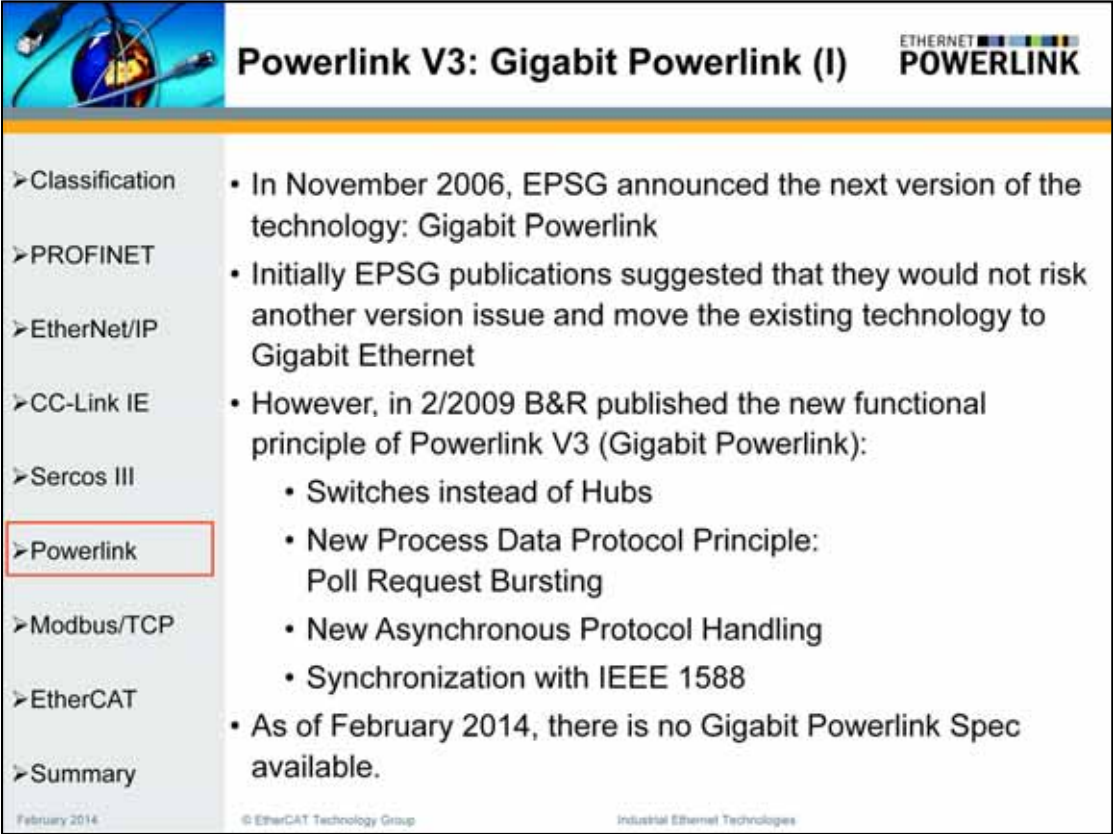
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies


Powerlink Version 1 products are available from B&R only.

Powerlink Version 2: Lenze Drives (founding member of Ethernet Powerlink Standardization Group and driving force behind V2) started shipping first Powerlink Products End of 2006. Lenze has meanwhile moved to EtherCAT as system bus (Powerlink may remain in use for applications in which there is no controller, just networked drives)

Powerlink Version 3 (Gigabit Powerlink) was announced in November 2006. Lenze is not contributing to Powerlink V3, which seems to be B&R driven. In 2009 B&R published an article describing the functional principle (see next slides) and announced products for 2011. As of February 2014, no Gigabit Powerlink specification has been published (neither within EPSG nor externally), and the most recent publication mentioning Gigabit Powerlink on the EPSG Website is from 2008.

In 2012 the Powerlink Version 4 (PollResponse Chaining) was published. EPSG will not consider this a new version, but since the entire communication mechanism is changed dramatically it should be considered to be one.



**Powerlink V3: Gigabit Powerlink (I)** ETHERNET  POWERLINK

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In November 2006, EPSG announced the next version of the technology: Gigabit Powerlink
- Initially EPSG publications suggested that they would not risk another version issue and move the existing technology to Gigabit Ethernet
- However, in 2/2009 B&R published the new functional principle of Powerlink V3 (Gigabit Powerlink):
  - Switches instead of Hubs
  - New Process Data Protocol Principle: Poll Request Bursting
  - New Asynchronous Protocol Handling
  - Synchronization with IEEE 1588
- As of February 2014, there is no Gigabit Powerlink Spec available.

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

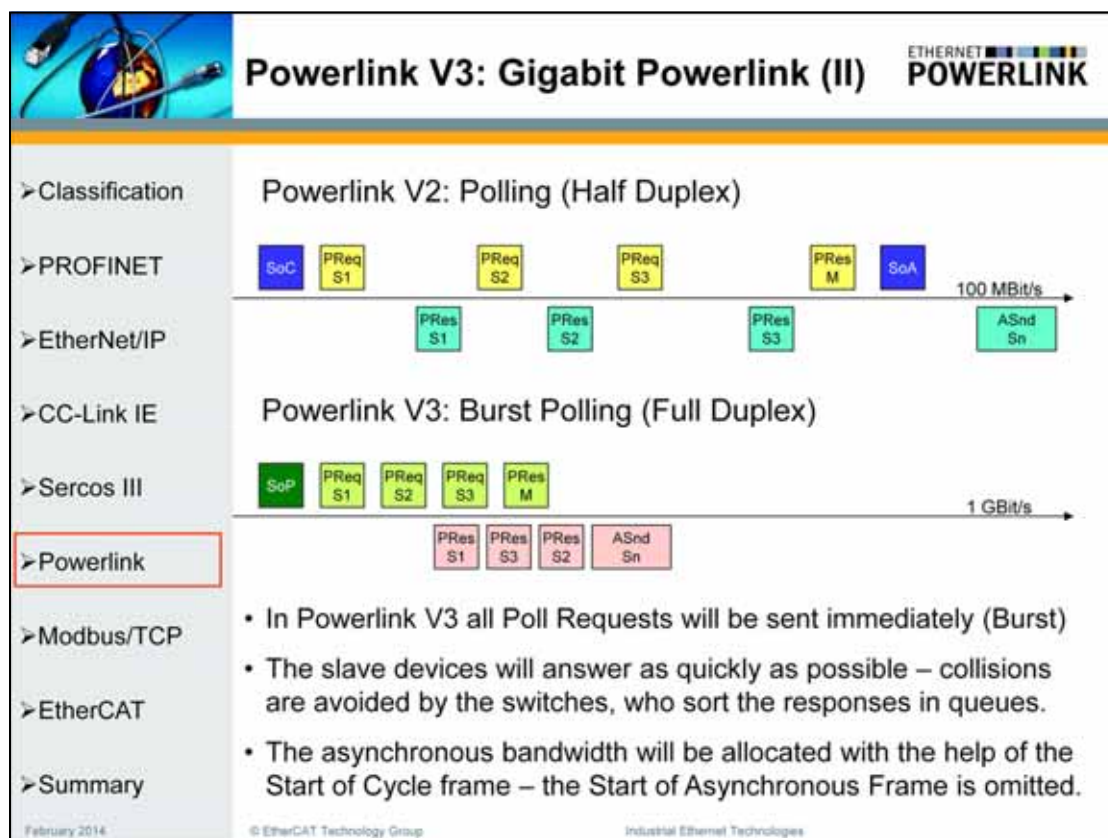
In November 2006, EPSG announced Gbit Powerlink as a simple hardware modification (Quote from Powerlink “Facts” 1/2007: *“POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer must do, resulting only in a somewhat different list of components to be fitted onto an otherwise identical PCB.”*)

However, this approach was later abandoned: Doing the math's shows that the performance gain would have been minimal. Depending on the configuration, a factor of 1.38...2 was to be expected, since most of the Powerlink cycle time is made up by stack delays which are not influenced by bandwidth increase. Furthermore, moving on to switches increases the forwarding delay within the infrastructure substantially, which would have over-compensated the bandwidth increase.

So in 2/2009 it was announced that Powerlink V3 will be based on a new functional principle (see next slide).

Many device vendors postponed their Powerlink implementation plans since V2 was already outdated in 2006/2007, and Gigabit Powerlink not yet specified.





As with the change from Powerlink V1 to V2, the announced version V3 will change both the protocol and the cyclic behavior of the network. Hence downwards compatibility cannot be expected.

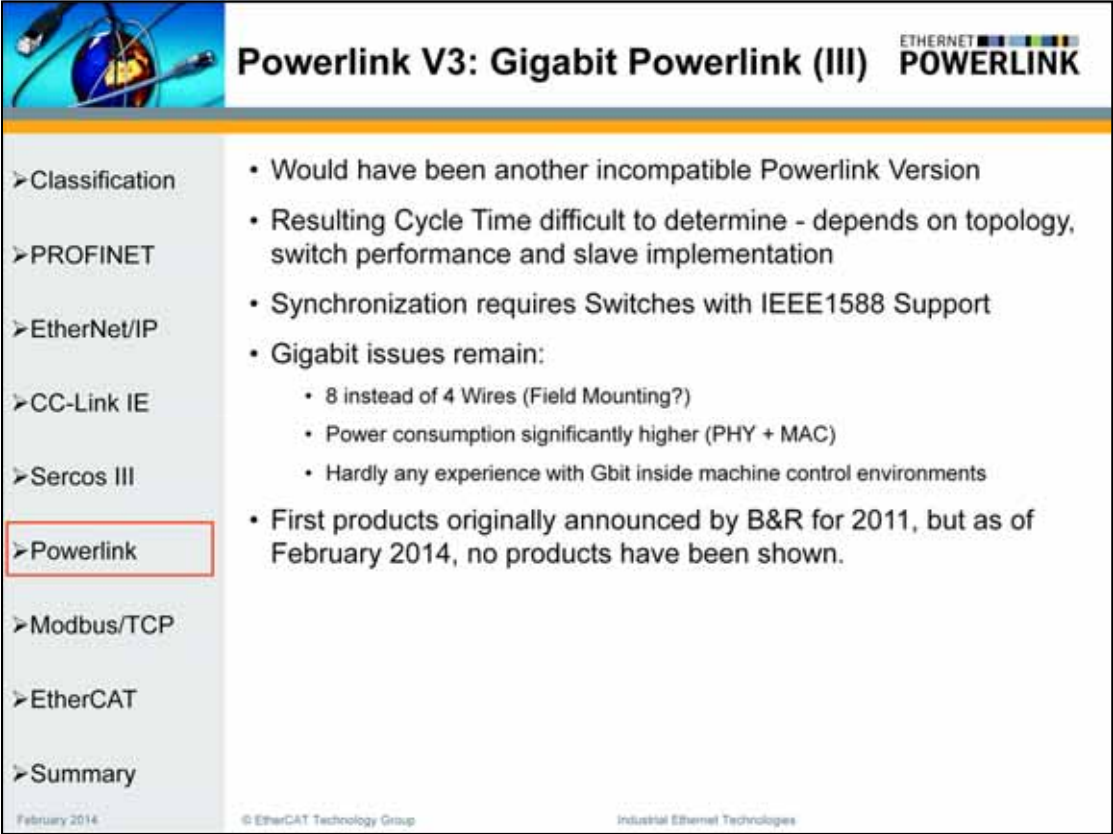
Hubs will be replaced by switches, and instead of individual polling a “burst polling” approach will be introduced.

The “Start of Asynchronous” Frame will be abandoned, its functionality will be included in the “Start of Protocol” (SoP) Frame, which replaces the “Start of Cycle” frame of Powerlink V2. A node that wants to send an asynchronous frame informs the master by flagging this in its poll response frame. With the next SoP frame the master then allows the node to send such a frame. Other than with Powerlink V2, asynchronous frames are thus postponed to the next cycle.

The “poll response” frames are going to be sent with broadcast MAC addresses –this preserves the slave-to-slave communication but puts substantial load on all devices, which have to filter all poll responses. Furthermore, this means that for half of the traffic the switches sacrifice their routing capabilities and become “slower hubs”.

For synchronization with IEEE 1588, the sync frame of the 1588 protocol is included in the SoP frame. All switches have to support the IEEE 1588 peer-to-peer, one-step transparent clocks in hardware. Thus special switches are required.

The shortest cycle time is either determined by the sum of frames sent by the master, or by the sum of frames sent by the slaves, or by response time and the overall propagation delay of the farthest slave device (including the switch delays). It is thus still difficult to predict and influenced by protocol stack performances, topology and the performance of the infrastructure components.



**Powerlink V3: Gigabit Powerlink (III)** ETHERNET **POWERLINK**

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- **Powerlink**
- Modbus/TCP
- EtherCAT
- Summary


- Would have been another incompatible Powerlink Version
- Resulting Cycle Time difficult to determine - depends on topology, switch performance and slave implementation
- Synchronization requires Switches with IEEE1588 Support
- Gigabit issues remain:
  - 8 instead of 4 Wires (Field Mounting?)
  - Power consumption significantly higher (PHY + MAC)
  - Hardly any experience with Gbit inside machine control environments
- First products originally announced by B&R for 2011, but as of February 2014, no products have been shown.

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

According to a B&R customer presentation (July 2008), the R&D phase for Powerlink V3 (Gigabit Powerlink) products is scheduled for 2009/2010, and first products are planned for 2011. However, since the B&R Powerlink Day in May 2011, Gigabit Powerlink was not even mentioned any more.

So meanwhile many people assume that Gigabit Powerlink died before it was really born....


By the way: the functional principle of Gigabit Powerlink was introduced in 2001 by Beckhoff („RT-Ethernet“ – a predecessor of EtherCAT)




## Ethernet Powerlink Standardization Group

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- EPSG originally hosted by Institute of Embedded Systems, Zurich University Winterthur (Switzerland)
- In 2006, EPSG Office moved to marketing agency in Aachen, Germany
- In 2007, EPSG Office moved to advertising agency in Berlin, Germany
- 2007: New Logo and CI
- Recent Membership Development: from 69 members in 5/2006 to 71 members in 11/2006 to 71 members in 4/2007 to 65 members in 11/2007\*





Date	Membership Count
Mai 06	69
Nov 06	71
Feb 07	71
Nov 07	65

\* Source: Powerlink Facts May/Nov 2006/April/Nov 2007, published by EPSG; EPSG website

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Ethernet Powerlink Standardization Group is managed and hosted by an advertising agency. Technical and implementation support is available by the advertising agency and by technology providers, who charge for these services.

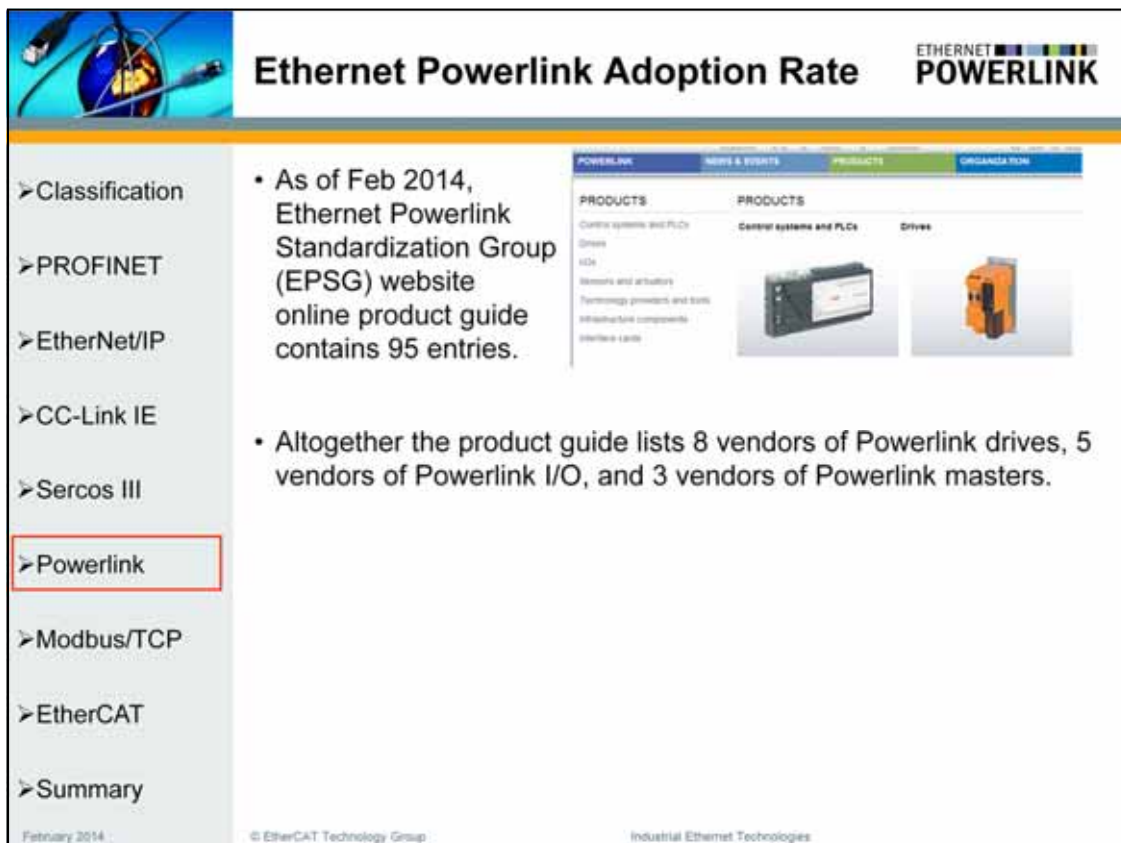
Obviously membership figures of EPSG and ETG cannot be compared directly: EPSG charges between 500€ and 5000€ per annum for membership, while e.g. ETG has adopted the philosophy that charging for access to a technology is not a sign of openness.


Therefore in small print: (Between 5/2006 and 11/2007, ETG grew from 315 to 634 members, exceeding 2600 members in Jan 2014).

The figures discussed above were taken from the EPSG publication “Powerlink Facts”, which was published until 2010 and is available for download from the EPSG website. Until end of 2007, there all members were listed; the June 2008 and all later editions do not list members any more.

Please note that EPSG typically uses the term “members, supporters and users” when referring to membership levels, and accumulates those to over 400\* (as of 5/2007). As of 02/2014, the website lists 170 “members and users”.

\* The EPSG website e.g. lists Tetra Pak in the members and users list. According to a Tetra Pak R&D manager, they used Powerlink in one R&D project which was later cancelled, never delivered a Powerlink equipped system and also terminated their EPSG membership.



**Ethernet Powerlink Adoption Rate** ETHERNET  POWERLINK

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- As of Feb 2014, Ethernet Powerlink Standardization Group (EPSG) website online product guide contains 95 entries.
- Altogether the product guide lists 8 vendors of Powerlink drives, 5 vendors of Powerlink I/O, and 3 vendors of Powerlink masters.

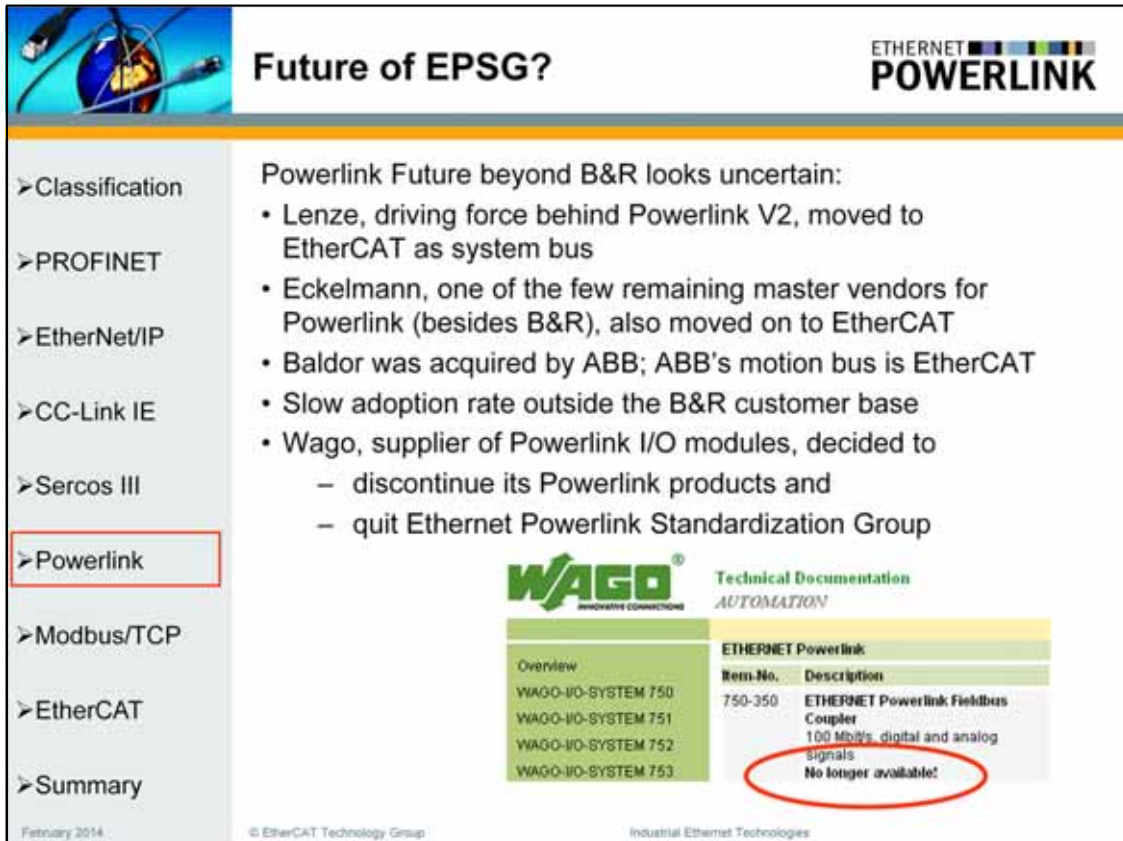
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

95 entries, out of which 32 are tools and services.


Third party (“non-B&R”) Powerlink products are typically complementary to the B&R products – so for B&R’s own products there are few third party alternatives available, if at all.

For many of the complementary products B&R either implemented the Powerlink interface or paid for the implementation.

3 master vendors: besides B&R, the product guide lists Baldor Motion and IXXAT. Baldor Motion was acquired by ABB in 2011, and ABB’s motion system bus is EtherCAT – it looks like Powerlink is being phased out (no new Powerlink products since the acquisition, but several EtherCAT products). For IXXAT, a PCI interface card and the “Econ 100” embedded Controller are listed: as of Feb 2014, the IXXAT website advertises the Econ 100 with EtherCAT, only: [http://www.ixxat.com/embedded-controller\\_en.html](http://www.ixxat.com/embedded-controller_en.html).




## Future of EPSG?



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

Powerlink Future beyond B&R looks uncertain:

- Lenze, driving force behind Powerlink V2, moved to EtherCAT as system bus
- Eckelmann, one of the few remaining master vendors for Powerlink (besides B&R), also moved on to EtherCAT
- Baldor was acquired by ABB; ABB's motion bus is EtherCAT
- Slow adoption rate outside the B&R customer base
- Wago, supplier of Powerlink I/O modules, decided to
  - discontinue its Powerlink products and
  - quit Ethernet Powerlink Standardization Group



ETHERNET Powerlink	
Item-No.	Description
750-350	ETHERNET Powerlink Fieldbus Coupler 100 Mb/s: digital and analog signals <b>No longer available!</b>

The Wago Powerlink Bus Coupler was featured in the “product news” section of the “Powerlink Facts” brochure 1/2006 (May 2006), 2/2006 (Nov 2006) and 1/2007 (April 2007).

For many of the few new Powerlink Products introduced since 2007, B&R either implemented the Powerlink interface or paid for the implementation.

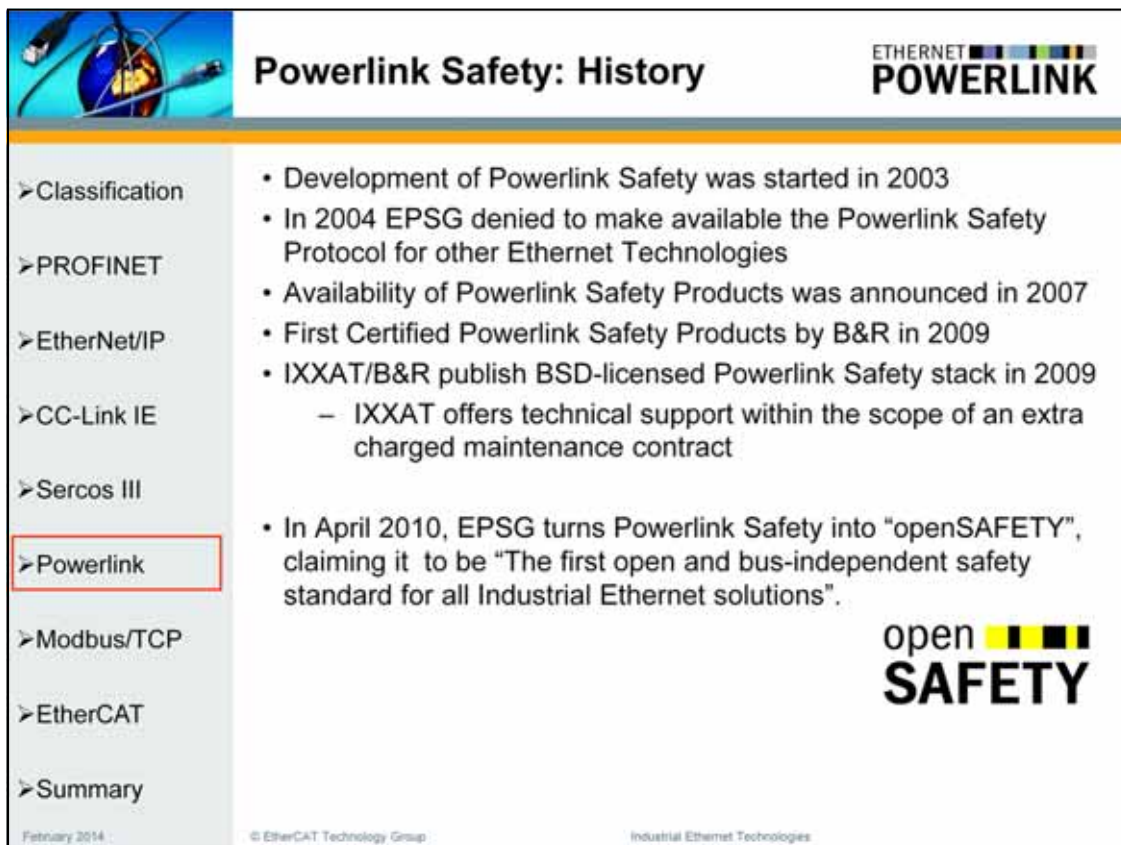
At SPS/IPC/Drives Show in November 2009, B&R introduced EtherCAT products.

At SPS/IPC/Drives Show in November 2013, ABB/Baldors booth did not show any Powerlink products any more.

<http://www.eckelmann.de/nc/en/presse/latest/detail/date/2013/04/09/eexc-66-mit-ethercatR>


[http://www.baldormotion.com/pdf/ABB%20literature/16124%20Motion\\_control\\_brochure\\_3AUA0000068580\\_RevD.pdf](http://www.baldormotion.com/pdf/ABB%20literature/16124%20Motion_control_brochure_3AUA0000068580_RevD.pdf)






The slide is titled "Powerlink Safety: History" and features a navigation menu on the left with the "Powerlink" item highlighted. The main content area contains a bulleted list of historical events. The "open SAFETY" logo is positioned in the bottom right corner of the slide content.

## Powerlink Safety: History

ETHERNET   
**POWERLINK**


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- **Powerlink**
- Modbus/TCP
- EtherCAT
- Summary

- Development of Powerlink Safety was started in 2003
- In 2004 EPSG denied to make available the Powerlink Safety Protocol for other Ethernet Technologies
- Availability of Powerlink Safety Products was announced in 2007
- First Certified Powerlink Safety Products by B&R in 2009
- IXXAT/B&R publish BSD-licensed Powerlink Safety stack in 2009
  - IXXAT offers technical support within the scope of an extra charged maintenance contract
- In April 2010, EPSG turns Powerlink Safety into "openSAFETY", claiming it to be "The first open and bus-independent safety standard for all Industrial Ethernet solutions".


**open SAFETY** 

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

- In 2004 IAONA asked EPSG to make available Powerlink Safety for other Ethernet Technologies; this was turned down by EPSG.
- Also in 2004, innotec GmbH (a German Safety Consultancy company) filed several patents regarding Powerlink Safety / openSAFETY. These were granted in 2006.  
It is unclear how a license is granted for the usage of the technology
- Since the BSD-licensed safety stack needs to be modified for integration, the certification has to be started from scratch.
  - E.g. CRC calculation routines are not part of the code




## Powerlink Safety / openSAFETY



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Announcement of Powerlink Safety (openSAFETY) in 04/2010 as Safety Protocol for EtherNet/IP and SERCOS-III takes ODVA and Sercos International by surprise:
  - Neither Sercos International nor ODVA have authorized the use of their intellectual property in conjunction with openSAFETY
- Tunneling of Powerlink Safety via other communication protocols is defined on asynchronous services
  - Limited real-time capabilities require large time-out values
- In fact, Powerlink Safety has substantial technical limitations which make the protocol not suitable to be used independent of the underlying communication system



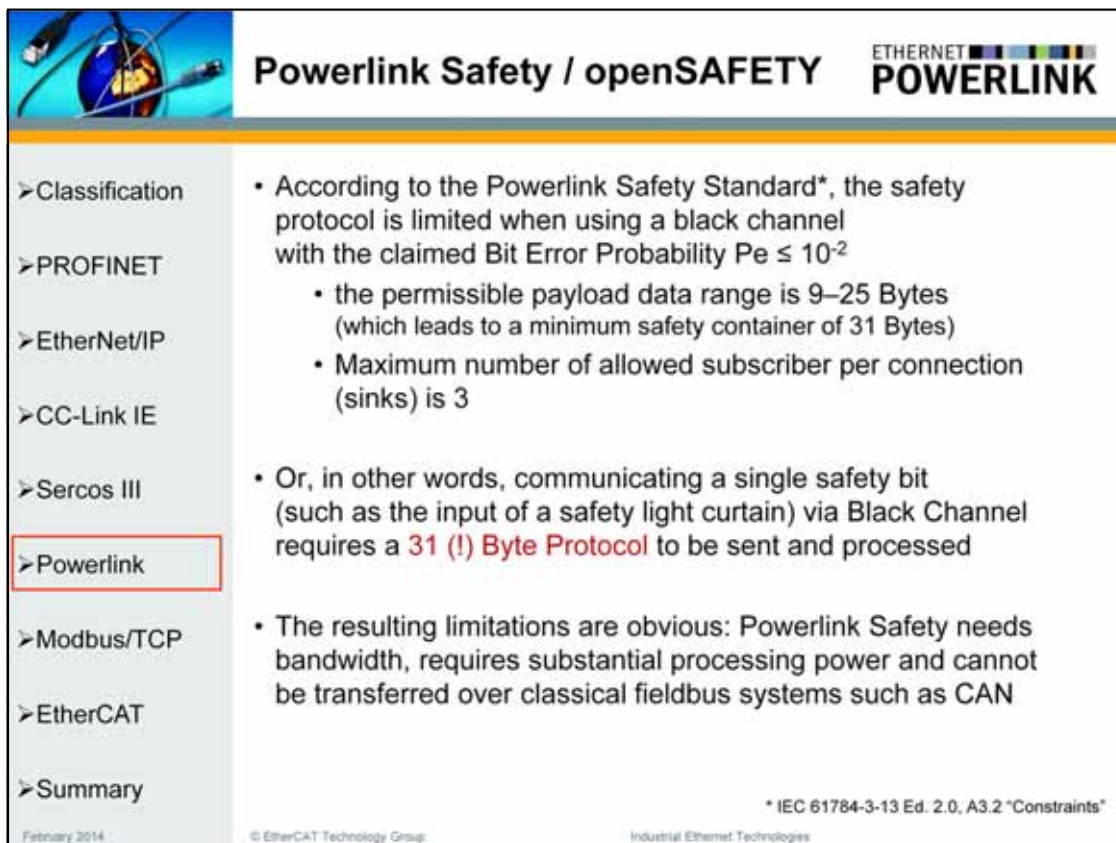
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Statement# of Katherine Voss, Executive Director ODVA: *“ODVA and Sercos International are cooperating on the adaptation of CIP Safety to their respective industrial Ethernet networks, EtherNet/IP and Sercos III. At this time, ODVA does not have a similar cooperation arrangement with any other organization. ... CIP Safety on EtherNet/IP is the only network configuration for functional safety that is authorized by ODVA to run on EtherNet/IP.”*

Statement# of Peter Lutz, Managing Director Sercos International: *“We were surprised by the unauthorized usage of our registered Sercos trademark in publications and displays on the Ethernet Powerlink Standardization Group (EPSG) booth at Hannover fair. This might imply that the announced concept and the combination of “openSafety” (Powerlink Safety) and Sercos III is approved and supported by Sercos International. We would like to clearly state that no discussions have been held and that no formal agreements are in place between SERCOS International (SI) and either EPSG or B&R. ... The introduction of an additional – incompatible – safety protocol is not helpful as the complexity for manufacturers and users is significantly increased and the acceptance is diminished to the same degree.”*

In Nov 2010, EPSG announced an openSAFETY solution for PROFINET.

Technical limitations are described on the next slides.



The slide features a header with a globe icon, the title "Powerlink Safety / openSAFETY", and the "ETHERNET POWERLINK" logo. A left-hand navigation menu lists various protocols, with "Powerlink" highlighted in a red box. The main content area contains a list of constraints for the Powerlink Safety protocol. A footnote at the bottom right references IEC 61784-3-13 Ed. 2.0, A3.2 "Constraints".

## Powerlink Safety / openSAFETY

ETHERNET POWERLINK

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- **Powerlink**
- Modbus/TCP
- EtherCAT
- Summary

- According to the Powerlink Safety Standard\*, the safety protocol is limited when using a black channel with the claimed Bit Error Probability  $P_e \leq 10^{-2}$ 
  - the permissible payload data range is 9–25 Bytes (which leads to a minimum safety container of 31 Bytes)
  - Maximum number of allowed subscriber per connection (sinks) is 3
- Or, in other words, communicating a single safety bit (such as the input of a safety light curtain) via Black Channel requires a **31 (!) Byte Protocol** to be sent and processed
- The resulting limitations are obvious: Powerlink Safety needs bandwidth, requires substantial processing power and cannot be transferred over classical fieldbus systems such as CAN


\* IEC 61784-3-13 Ed. 2.0, A3.2 "Constraints"

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Powerlink Safety, as do most safety protocols, uses the “black channel approach”, which means that the transporting communication channel does not have to be included in the safety considerations. The “black channel approach” is the pre-requisite for bus independence of the safety technology.

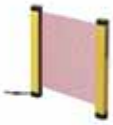
However, with Powerlink Safety the black channel approach is only valid within the constraints listed above which lead to a minimum safety container of 31 Bytes.

For comparison: the minimum safety container of Safety over EtherCAT (FSoE) is 6 bytes (for 1 Byte payload), thus FSoE is suitable e.g. for CAN as well.

**Powerlink Safety / openSAFETY** ETHERNET  POWERLINK

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

I



Safety Input

```

I00II0I00I0I000I
I00II0I0I00II0I0
0I0II000I0I00I0I
00I0III000I0I00I
0000IIII0I0III00
I00I00IIII00II0I
IIIII00III0IIII0
00II00III00I00I0
0I0I0I00I0I000I0
0II0I0I0I000I0II
I0000I00III0I0I0
0I0I0I00I0I0I000
I0I0I0I0I0III0I0
II0000I000000I00
000I0I00I0II0I0I
I0I0I0I0
                    
```

Safety Input in minimum  
openSAFETY  
container

```

00II00III00I00I0
0I0I0I00I0I000I0
0II0I0I0I000I0II
                    
```

Safety Input in minimum  
Safety over EtherCAT  
container

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

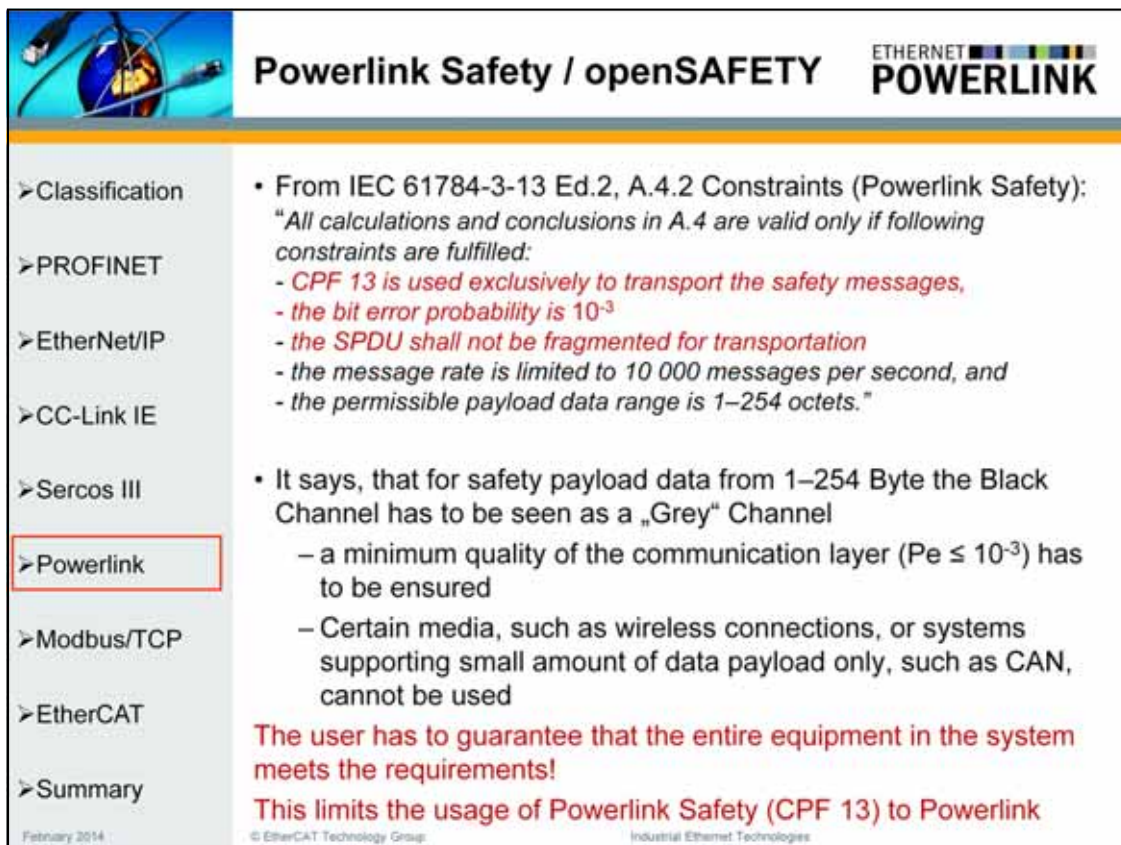
A Safety Input device often has only a few Bit of SafeData. For a safe light curtain for example only 1 Bit SafeData can be sufficient.

Container length for 1 Bit SafeData

Powerlink Safety:            31 Bytes

Safety over EtherCAT:    6 Byte





The image shows a presentation slide titled "Powerlink Safety / openSAFETY" with the "ETHERNET POWERLINK" logo. The slide contains a table of contents on the left and detailed text on the right. The "Powerlink" item in the table of contents is highlighted with a red box. The text on the right discusses constraints from IEC 61784-3-13 Ed.2, A.4.2, and lists requirements for safety payload data (1-254 bytes) and communication quality ( $P_e \leq 10^{-3}$ ). It also states that certain media like wireless connections or CAN cannot be used, and that the user must guarantee the entire equipment meets the requirements.

Classification	From IEC 61784-3-13 Ed.2, A.4.2 Constraints (Powerlink Safety): "All calculations and conclusions in A.4 are valid only if following constraints are fulfilled:
PROFINET	- CPF 13 is used exclusively to transport the safety messages, - the bit error probability is $10^{-3}$
EtherNet/IP	- the SPDU shall not be fragmented for transportation - the message rate is limited to 10 000 messages per second, and - the permissible payload data range is 1–254 octets."
CC-Link IE	
Sercos III	• It says, that for safety payload data from 1–254 Byte the Black Channel has to be seen as a „Grey“ Channel
<b>Powerlink</b>	- a minimum quality of the communication layer ( $P_e \leq 10^{-3}$ ) has to be ensured - Certain media, such as wireless connections, or systems supporting small amount of data payload only, such as CAN, cannot be used
Modbus/TCP	<b>The user has to guarantee that the entire equipment in the system meets the requirements!</b>
EtherCAT	<b>This limits the usage of Powerlink Safety (CPF 13) to Powerlink</b>
Summary	

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Powerlink Safety requires a proven communication channel for safety payload data 1..8, 26...254 Byte.

Bit Error Probability  $P_e \leq 10^{-3}$  can be assumed for 100BASE-TX Ethernet-based Powerlink based communication,...

... but the Black channel may also consist of

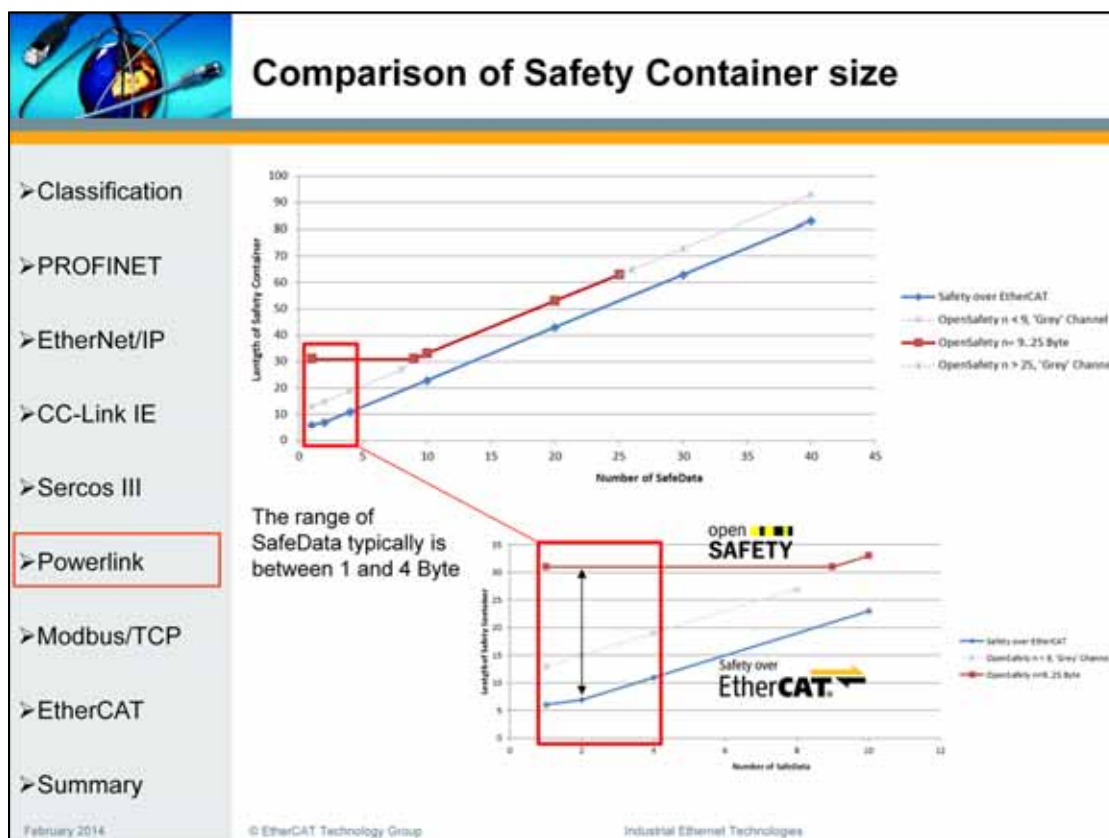
- internal backbone communication,
- other physical layers for Ethernet,
- infrastructure devices like switches or gateway devices,
- Routing of safety containers via software within the standard master or infrastructure devices (switches, router)
- ...

With Powerlink Safety the user has to ensure that the „Grey“ Channel does not exceed these limitations and in fact is a Black Channel.

For any other equipment in the system, next to the Powerlink communication, this assumption has to be approved!

As of now we are not aware of any standard covering non-Powerlink based openSafety.

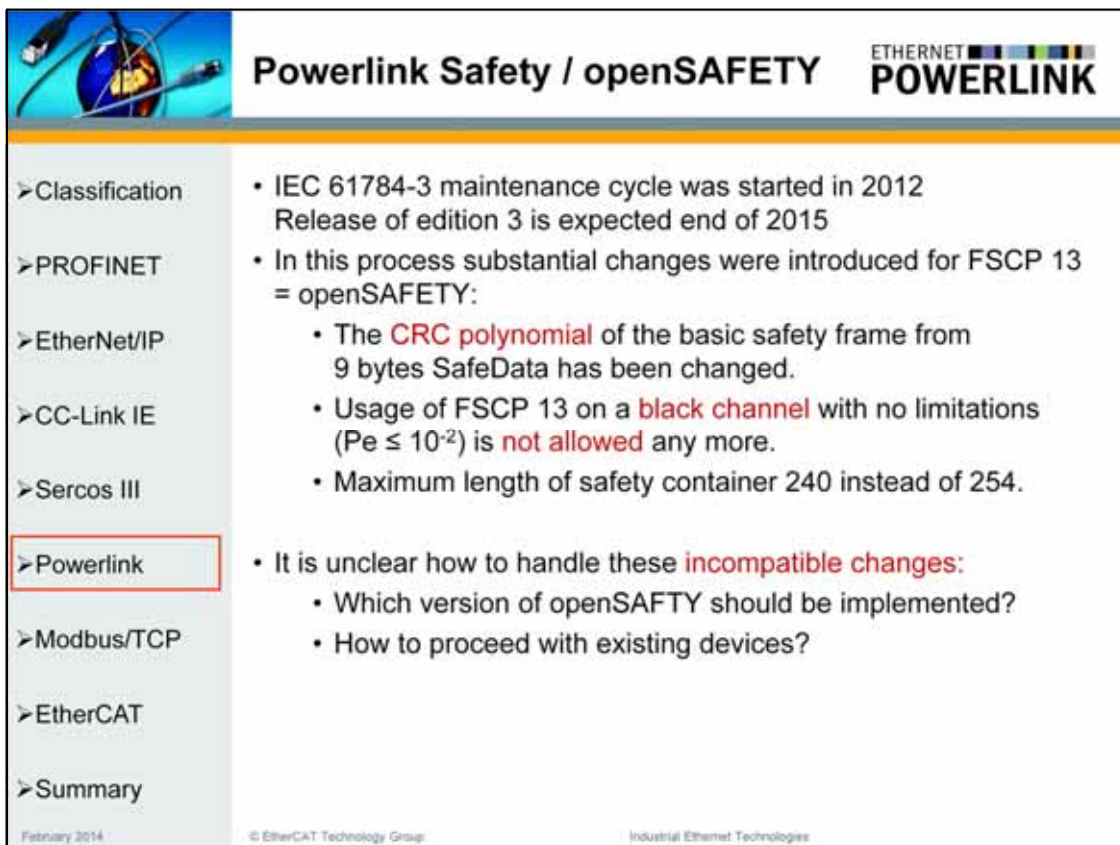




The typical number of safety payload data per connection is small, e.g. in the range of 1...4 Bytes.

With 2 Byte of SafeData for example

- a 16 channel Safety Input device can be handled or
- 16 different drive integrated safety functions can be activated



The slide features a header with a globe icon and the text "Powerlink Safety / openSAFETY" and "ETHERNET POWERLINK". A left sidebar lists various industrial protocols, with "Powerlink" highlighted in a red box. The main content area contains a bulleted list of updates and questions regarding IEC 61784-3 maintenance cycles and openSAFETY changes.


## Powerlink Safety / openSAFETY

ETHERNET POWERLINK


- Classification
  - IEC 61784-3 maintenance cycle was started in 2012
  - Release of edition 3 is expected end of 2015
- PROFINET
  - In this process substantial changes were introduced for FSCP 13 = openSAFETY:
    - The **CRC polynomial** of the basic safety frame from 9 bytes SafeData has been changed.
    - Usage of FSCP 13 on a **black channel** with no limitations ( $P_e \leq 10^{-2}$ ) is **not allowed** any more.
    - Maximum length of safety container 240 instead of 254.
- EtherNet/IP
- CC-Link IE
- Sercos III
- **Powerlink**
  - It is unclear how to handle these **incompatible changes**:
    - Which version of openSAFETY should be implemented?
    - How to proceed with existing devices?
- Modbus/TCP
- EtherCAT
- Summary

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Incompatible changes for openSAFETY have been introduced for the next edition of IEC 61784-3-13.

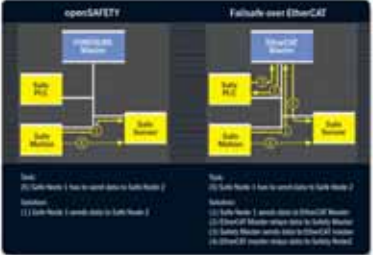


## Powerlink Safety / openSAFETY



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- In "Powerlink Facts" 01/10 EPSG compares openSAFETY with Safety over EtherCAT and concludes that openSAFETY is 4 x faster.



This comparison is misleading, since

- In most safety architectures the safe PLC is not bypassed (as shown in the openSAFETY example)
- If such an architecture is chosen, the network management configuration effort and the resulting traffic is enormous, since the actuators and the safe PLC have to independently monitor all safety communication links with cyclic frames
- The safety stack performance (31 byte minimum container size!) is not taken into account
- EtherCAT cycles are much faster than Powerlink cycles
- Last but not least: decentralized safe PLC is optional

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Multicast messaging increases the complexity of device implementation and of configuration effort.

Time synchronization in Powerlink Safety:

In order to avoid a delay of data the Consumer must query all connected Producer for their relative time. That means each Producer/Consumer connection needs a bidirectional communication channel on the underlying fieldbus to synchronize the time information.

Configuration effort:

Within a Producer/Consumer network such as Powerlink the number of communication relations is a multiplication of the number of Producer (n) and the number of Consumer (m). In a Master/Slave network such as EtherCAT the number is a summation.

Example: 10 Emergency stop buttons acting on 10 drives

Powerlink Safety                     $10 * 10 = \mathbf{100}$  communication relations  
 Safety over EtherCAT             $10 + 10 = \mathbf{20}$  communication relations

Complexity of each device:

For Powerlink Safety each Consumer device (e.g. Safety related Drive) must provide several safe connections if it supports several Producer Inputs. The Input information must be combined within the device (Safe Logic functionality).

With Safety over EtherCAT a single connection per FSoE Slave device to the FSoE Master is sufficient. The logical combination of Safety Inputs is done in the FSoE Master device.

**openSAFETY adoption rate**

ETHERNET **POWERLINK**

**open SAFETY**

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink**
- Modbus/TCP
- EtherCAT
- Summary

- The product guide on the Powerlink Website contains no safety products
- There is no product guide on the dedicated openSafety website
- The B&R website shows a number of Powerlink based safety products
- In 12/2011 B&R announced a safety controller with "openSafety over PROFINET"
- As of 2/2014 no such product can be found on the B&R website
- 4 years after launching openSafety no "non-Powerlink" openSafety products could be found.

**Smart Safe Reaction with openSAFETY for Profinet**  
12.06.2011

Now that B&R's SafetyDOC safety network, Smart Safe Reaction has integrated into Profinet automation openSAFETY, B&R's Smart Safe Reaction safety system that can react 10 times faster than openSAFETY real-time safety has a solution and can be used on all our network systems up to S5.2.

In industries where Profinet has not penetrated network, there is a technology: With the innovative and Smart Safe Reaction technology, openSAFETY, can requirements of automated machines and systems!

Product set for Profinet

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

Safety rated products have to be certified by a “notified body” (such as e.g. TÜV). For the safety certificate not only the safety layer has to be tested, but also the (non-safe) communication protocol layer: the notified bodies request a conformance certificate for this layer as well.

However, we are not aware of any fieldbus organization with an own (native) safety protocol, that would be prepared to issue a protocol conformance certificate for a safety device that uses an alien (non-native) safety protocol layer.

In 2011 EPSG and published press releases with suggested that Nestlé selected openSafety as their safety standard (quote: “Nestlé chooses openSAFETY as the safety standard for packaging machines”). According to Nestlé, this is not the case. Nestlé is in favor of an open safety standard, but did **not** select the openSafety protocol.

Language | Contact | Login

ETHERNET **POWERLINK**  
Standardization Group

POWERLINK THE POWER OF CONNECTIONS.

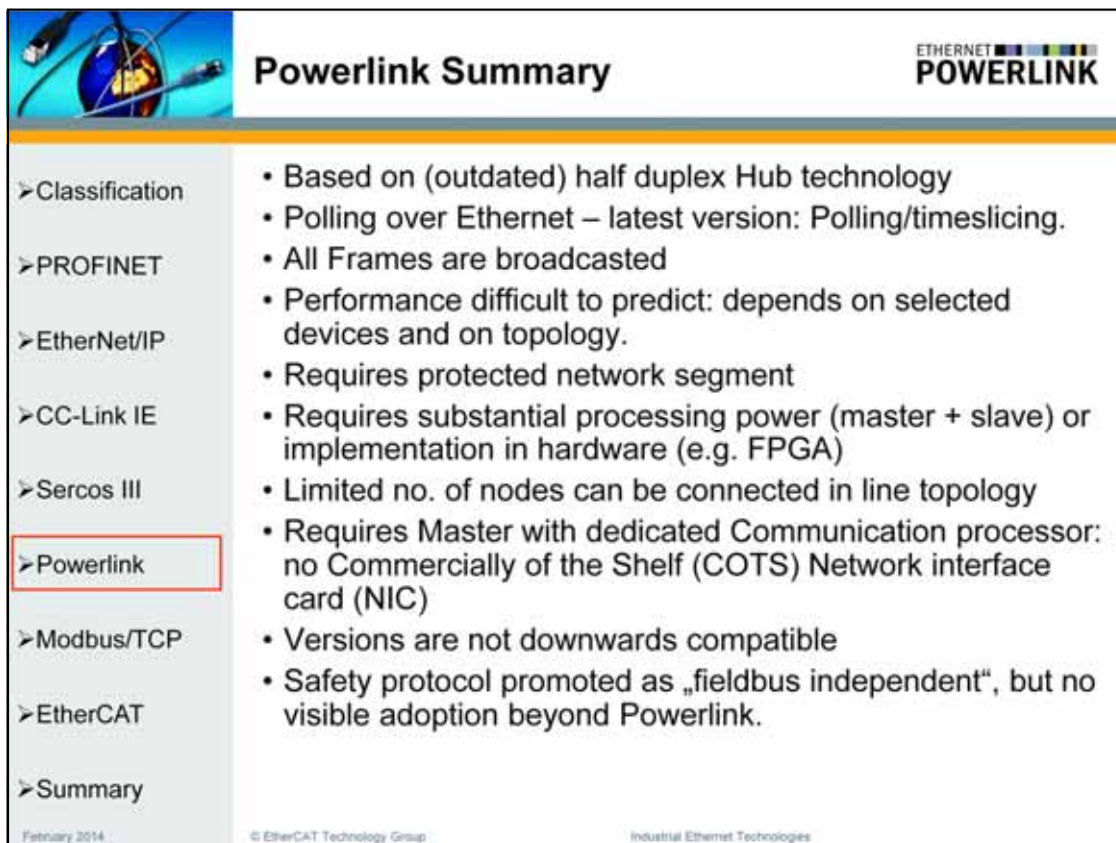
**POWERLINK** NEWS & EVENTS PRODUCTS ORGANIZATION DOWNLOADS

**NEWS & EVENTS** NEWS

**News** 23.06.2011 | Age: 3 yrs  
**Nestlé chooses openSAFETY as the safety standard for packaging machines**

On the one hand, large international companies such as Nestlé rely on a flexible choice of machines from various manufacturers. On the other hand, most machine producers have chosen one specific automation platform, which means that users who install different machine types need

Fairs  
Events  
Newsletter



The slide is titled "Powerlink Summary" and features the EtherCAT Technology Group logo in the top right corner. On the left side, there is a vertical navigation menu with the following items: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III, Powerlink (highlighted with a red box), Modbus/TCP, EtherCAT, and Summary. The main content area on the right lists several characteristics of Powerlink:

- Based on (outdated) half duplex Hub technology
- Polling over Ethernet – latest version: Polling/timeslicing.
- All Frames are broadcasted
- Performance difficult to predict: depends on selected devices and on topology.
- Requires protected network segment
- Requires substantial processing power (master + slave) or implementation in hardware (e.g. FPGA)
- Limited no. of nodes can be connected in line topology
- Requires Master with dedicated Communication processor: no Commercially of the Shelf (COTS) Network interface card (NIC)
- Versions are not downwards compatible
- Safety protocol promoted as „fieldbus independent“, but no visible adoption beyond Powerlink.

At the bottom of the slide, there is a footer with the text: February 2014, © EtherCAT Technology Group, and Industrial Ethernet Technologies.

Due to the polling principle, the master has to wait for the response of each slave before he can send the next request – or has to wait for the timeout.


The response time of each slave device depends

- on its individual implementation:
  - if implemented with standard components: processor performance, software stack implementation quality, varying local CPU load due to application etc.
  - or: implemented with FPGAs
- and on the topology (number and performance of the hubs in between).

Thus it is difficult to determine the performance of the network without measuring it.

Performance limitations require complex bandwidth optimization in more demanding applications.

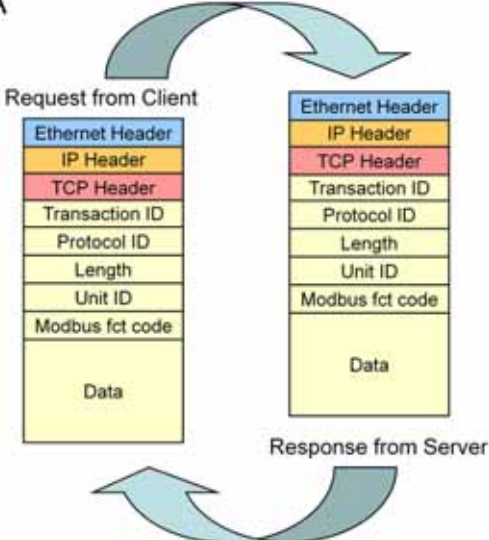




## Modbus/TCP: Overview

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Schneider Electric Approach: serial Modbus on TCP/IP
- Follows Approach A
- Few Services, simple to implement
- Widely used
- Many Products available
- Non-Real-Time Approach.

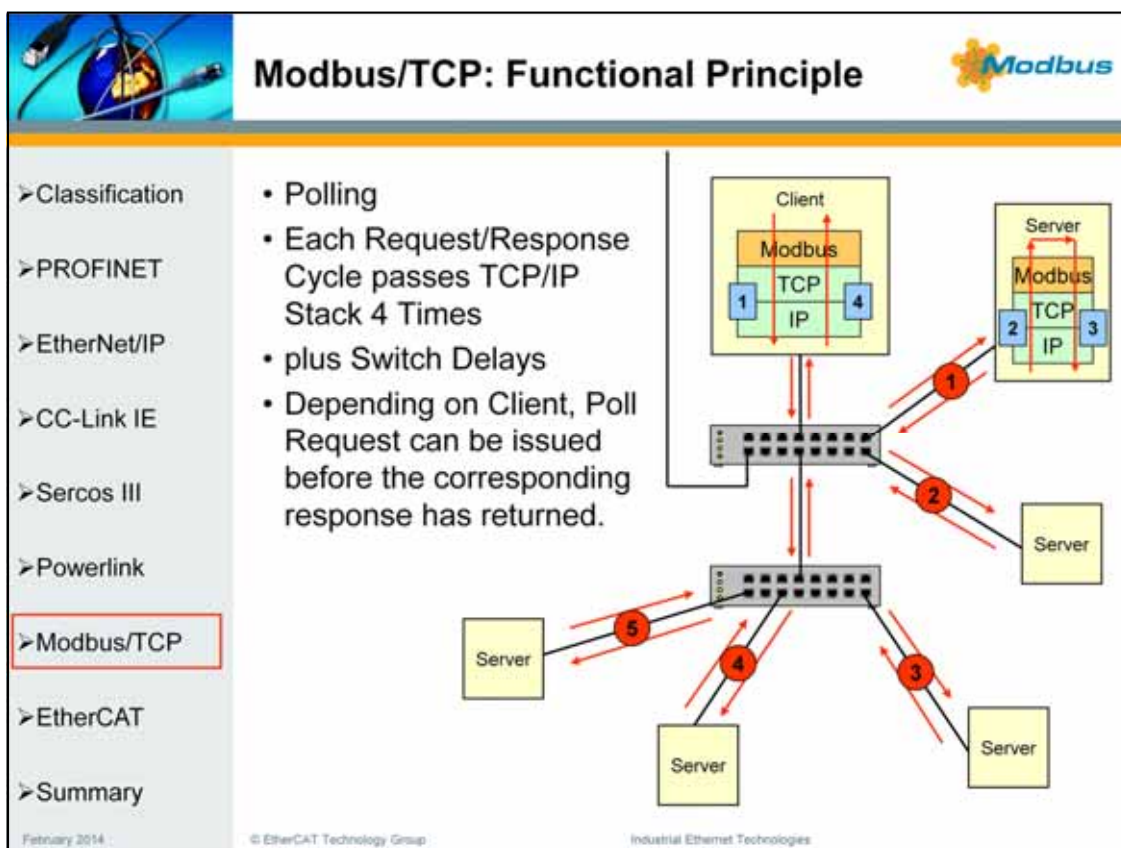


February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

Modbus/TCP is very widely used, since it is simple to implement.

Non-real-time approach: Due to its operating principle, Modbus/TCP cannot guarantee delivery times or cycle times or provide precise synchronization. Strongly depending on the stack implementation, response times of a few milliseconds can be achieved, which may be sufficient for certain applications.

Apart from the basic data exchange mechanisms, there is hardly any additional feature. Network management, device profiles, etc. have to be handled by the application program, the network layer does not provide solutions.



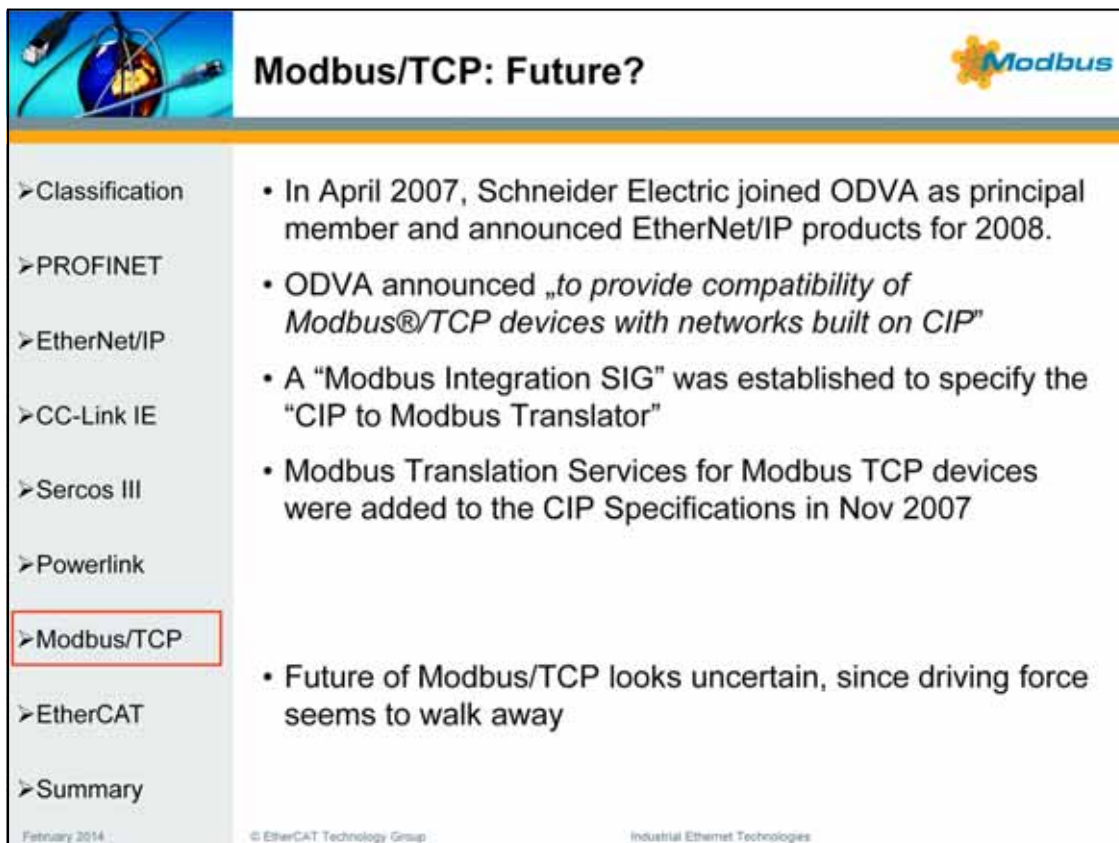
Modbus/TCP client/master implementations can either wait for each response to return before the next request is issued, or send several requests at once in order to allow for parallel processing in the server/slave devices. In the later case the overall performance is improved.

Since the performance is primarily determined by the stack performances, it very much depends on the implementation of the client (master) and server (slave) devices – which is difficult to assess.

If a client is implemented on a standard socket interface of a Windows OS, typical response times (per server) are in the order of 10-20ms with a worst case (e.g. moving a Window) of well over 250ms (We have tested this. The reason is that the OS processes the TCP/IP stack with low priority). Of course it is possible to implement a client/master with an RTOS and/or using a dedicated communication CPU and achieve better results.

A server/slave device with sufficient processing power and an optimized (=functionally reduced) TCP/IP stack may typically reply within 1-4 ms (and in worst case, depending on the load, within 10-15ms). Standard TCP/IP stacks on  $\mu$ C may have typical response times of >5ms.

Critical can be the retry times of the TCP/IP stacks – in case a frame was lost. These retry times can be in the order of seconds – and typically are not user definable nor mentioned in the product manuals.



The image shows a presentation slide titled "Modbus/TCP: Future?". The slide features a navigation menu on the left with items: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP (highlighted with a red box), EtherCAT, and Summary. The main content area contains a list of bullet points:

- In April 2007, Schneider Electric joined ODVA as principal member and announced EtherNet/IP products for 2008.
- ODVA announced „to provide compatibility of Modbus®/TCP devices with networks built on CIP”
- A “Modbus Integration SIG” was established to specify the “CIP to Modbus Translator”
- Modbus Translation Services for Modbus TCP devices were added to the CIP Specifications in Nov 2007
- Future of Modbus/TCP looks uncertain, since driving force seems to walk away

At the bottom of the slide, there is a footer with the text: February 2014, © EtherCAT Technology Group, and Industrial Ethernet Technologies.

Schneider replaced one non-real-time protocol by another one.


Details regarding the integration of Modbus TCP into CIP can be found here:

[http://www.modbus.org/docs/CIP%20Modbus%20Integration%20Hanover%20Fair\\_0408.pdf](http://www.modbus.org/docs/CIP%20Modbus%20Integration%20Hanover%20Fair_0408.pdf)


Modbus/TCP will certainly not vanish any time soon, but this move of Schneider suggests that there will not be any further enhancements of the protocol.

The most recent Modbus Application Protocol Specification V1.1b3 (April 2012) is a slightly reformatted update of the previous version (V1.1, June 2004). It corrected some acronym misnomers, contains some clarifications, and replaces the traditional master/slave language with the client/server construct. With regards to Modbus/TCP it refers to the MODBUS MESSAGING ON TCP/IP IMPLEMENTATION GUIDE V1.0b of October 2006.

By the way: in 2009 the former “Modbus-IDA” organization (IDA meaning Interface for Distributed Automation) changed its name (and logo) to Modbus, and the web-address to [www.modbus.org](http://www.modbus.org). [www.modbus-ida.org](http://www.modbus-ida.org) was abandoned and is now used by a whirlpool company.



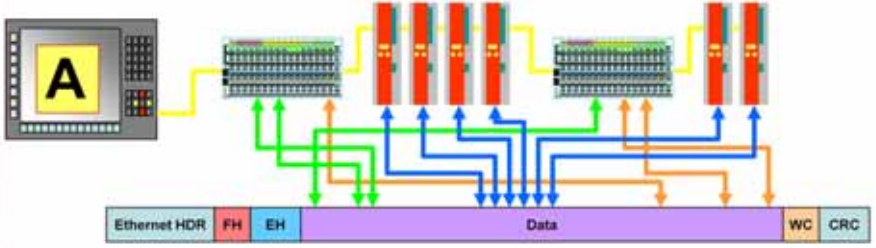
# EtherCAT Overview



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- EtherCAT is:
  - Industrial Ethernet down to the I/O Level
  - Flexible Wiring and simple Configuration
  - lower cost
  - well proven
  - an open technology
- Key Principle: Frame Processing on the Fly
- Master uses Standard Ethernet Controllers

C




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies


The Slave implementation of EtherCAT is a class C approach: the „processing on the fly“ technology requires dedicated slave controllers.

The EtherCAT Slave Controllers can be implemented as FPGA, ASIC or with standard  $\mu$ Controller with EtherCAT Slave Controller interface option – all solutions meet or undercut the cost levels of the other technologies discussed in this presentation. It is not required to buy an ASIC, and there are a variety of sources for EtherCAT Slave Controllers.

On the master side, EtherCAT does not require a dedicated master card: any standard Ethernet Controller is sufficient, the master functionality is implemented in software running on the host CPU that also runs the application program. It was found that the master code adds less load on the host CPU than servicing the DPRAM of an intelligent plug in card. There is a wide range of master stacks available.



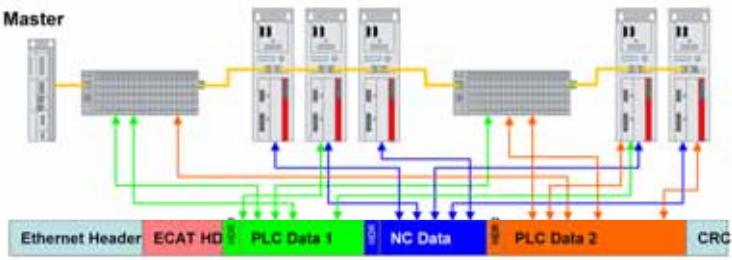
## EtherCAT: Ethernet “on the Fly”



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

### Minimal protocol overhead via implicit addressing



- Optimized telegram structure for decentralized I/O
- Communication completely in hardware: maximum performance
- no switches needed if only EtherCAT devices in the network
- Outstanding diagnostic features
- Ethernet-compatibility maintained

February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

EtherCAT is very effective even with small amounts of data per slave device, since it is not necessary to send an individual Ethernet frame for each data unit.

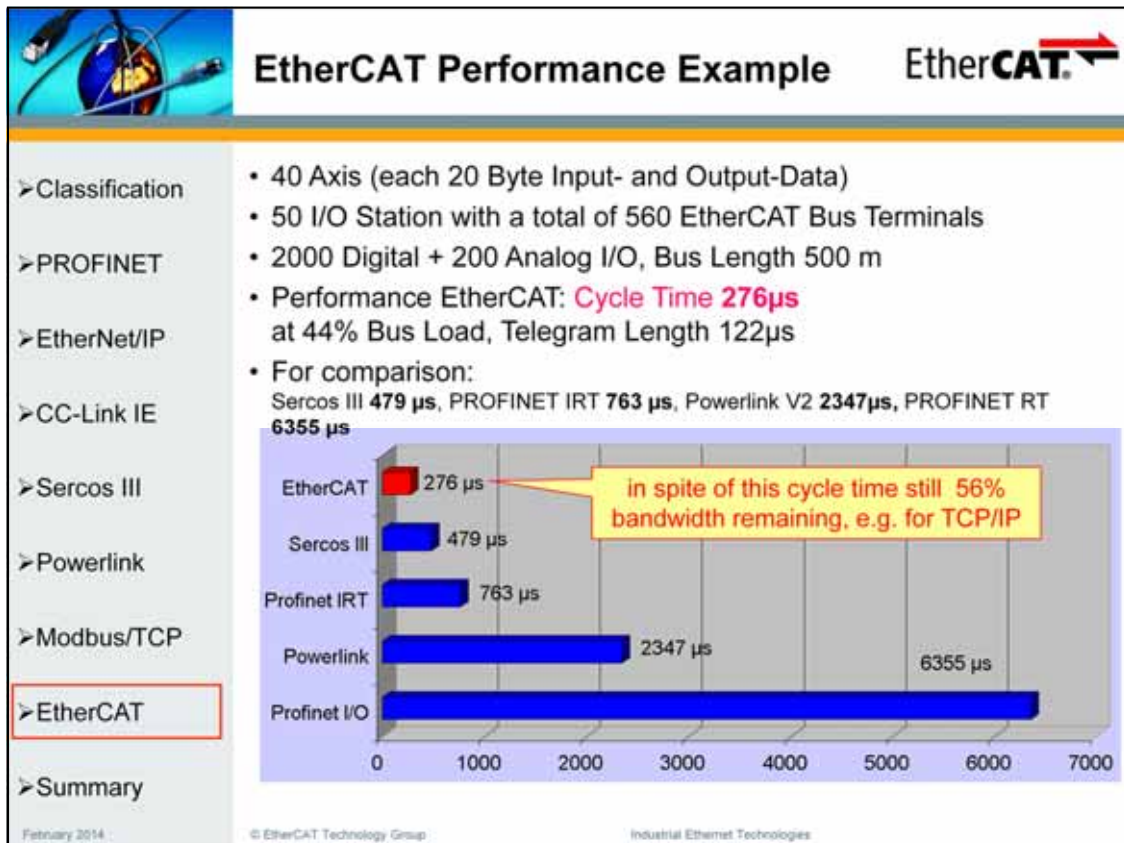
Since process data communication is handled completely in hardware (EtherCAT Slave Controller), the network performance does not depend on the  $\mu$ C performance of the slave devices – and is thus predictable.

Switches are not necessary and thus optional. Hence there are no costs related to switches, their power supply, mounting, wiring, configuration and so on.

Since the CRC is checked by each device - regardless if the frame is intended for this node – bit errors are not only detected immediately, but can be also located exactly by checking the error counters.

The EtherCAT approach is Ethernet compatible: in the master commercially off the shelf Ethernet MACs are sufficient, since only standard Ethernet frames are used.






The cycle time figures of the competing technologies were determined as follows:


PROFINET: Computations based on the specification (done by a well known PROFINET expert). The *configurable* cycle time for this example would be 1ms (IRT) resp. 8ms (RT).

Powerlink: see Powerlink section of this presentation. With Powerlink at this cycle time there is no remaining bandwidth for asynchronous communication.

For EtherCAT the Update Time (276 µs) is given: after this period of time all output data and all input data was transferred from or to the master – an entire cycle was finished. The telegram time is only 122µs – thus one could communicate even faster (e.g. new data every 125µs).



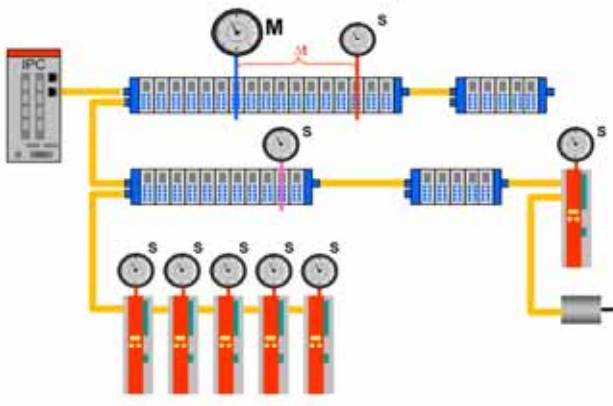
# EtherCAT Synchronization



- > Classification
- > PROFINET
- > EtherNet/IP
- > CC-Link IE
- > Sercos III
- > Powerlink
- > Modbus/TCP
- > EtherCAT
- > Summary

## Precise Synchronization ( $\ll 1 \mu\text{s}$ ) by exact adjustment of distributed clocks.

Advantage: Accuracy does not depend on master precision, small communication jitter and thus implementation in software only is acceptable and does not deteriorate synchronization




February 2014

© EtherCAT Technology Group


Industrial Ethernet Technologies

Since EtherCAT used precisely adjusted distributed clocks (a feature of the EtherCAT Slave Controller chips), the communication cycle itself does not have to be absolutely equidistant – a small jitter is allowed. Therefore EtherCAT masters do not need a special hardware (like a communication co-processor) and can be implemented in software, only – all that is needed is an Ethernet MAC, like the one that comes with most PC motherboards anyhow.

Measurements showed a synchronization accuracy of  $\sim 20\text{ns}$  with 300 distributed nodes and 120m (350 ft) cable length. Since the maximum jitter depends on many boundary conditions (e.g. no. of nodes, network length, temperature changes etc.), its value is given conservatively with  $\ll 1\mu\text{s}$ .

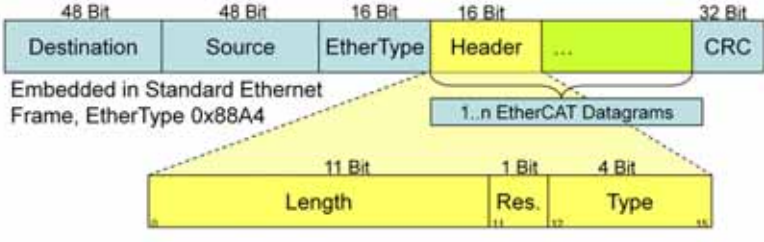


# EtherCAT is Industrial Ethernet



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- EtherCAT: only Standard Ethernet Frames (IEEE 802.3)
- Master: Ethernet MAC without co-processor or special HW
- Fully transparent for other Ethernet protocols
- Internet Technologies (TCP/IP, FTP, Web server etc.) without restricting the real time capabilities, even with 100µs cycle time – no large time gaps for rare traffic needed
- Full Tool-Access to devices at real time operation – with and without TCP/IP



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies


EtherCAT used only standard frames. Any other Ethernet Protocols are tunneled fully transparently – EtherCAT thus uses a method that is common with Ethernet itself and with many Internet technologies: every modem tunnels Ethernet frames as does WLAN, VPN uses this approach as well as TCP/IP itself.

By using this approach EtherCAT can transport any Ethernet protocol (not only TCP/IP) at shortest cycle times (even if they are shorter than the longest possible Ethernet frame).


In addition, it is not necessary to keep a large gap in the data stream – like most other approaches have to.

The protocol used is named “Ethernet over EtherCAT”.

Many EtherCAT masters support tool access from outside: a tool can communicate via Ethernet e.g. by TCP/IP or UDP/IP with the master, who inserts this data into the EtherCAT communication in such a way, that a fully transparent access to EtherCAT devices is possible without restricting the real time capabilities.

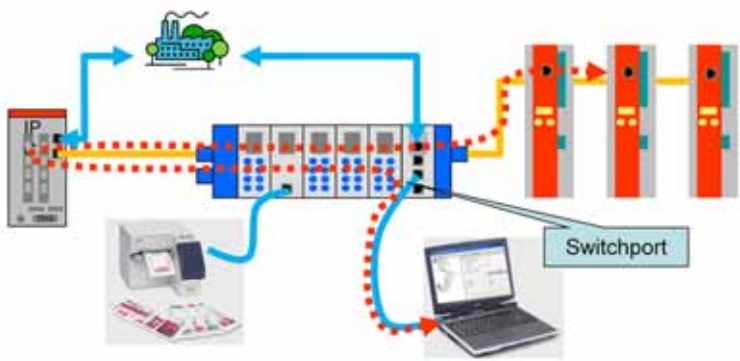


## EtherCAT is Industrial Ethernet



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


- Connection to any Ethernet device via Switchport
- Access to web server with standard browser
- Switchport can be implemented as device feature, separate device or software functionality in master
- Switchport allows for hard real time capability with parallel Ethernet communication of any kind




Switchport

February 2014© EtherCAT Technology GroupIndustrial Ethernet Technologies

The “tunnel entrance” (Switchport) for any Ethernet protocol can be implemented in a variety of ways: as separate device, as feature of a slave device or as software feature of the EtherCAT master.

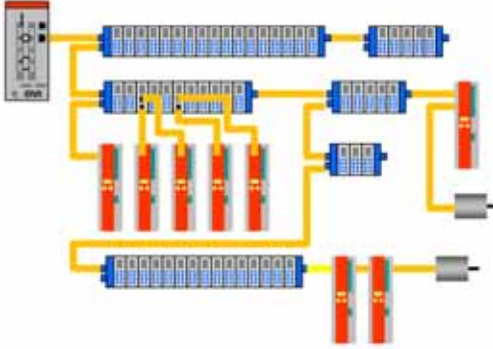


## EtherCAT: Most flexible Topology



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

- Flexible tree structures – arbitrarily extendable
- Line without limitations through cascaded switches or hubs
- 100 m between two nodes, up to 65535 nodes in one segment
- branches can be connected/removed at run time ("Hot Connect")
- Straight or crossed cables – automatic detection




The diagram illustrates a complex EtherCAT network topology. It features a central controller (a grey box with a red top) connected to a main backbone of blue nodes. From this backbone, several branches lead to various types of nodes, including red vertical modules and smaller blue units. The connections are shown as yellow lines, representing the flexible and extendable nature of the EtherCAT protocol.


February 2014© EtherCAT Technology GroupIndustrial Ethernet Technologies

With EtherCAT almost any number of devices (up to 65535) can be wired in a line structure – there are no restrictions due to cascaded switches or hubs. Any number of drop lines or branches are possible, too, providing the most flexible topology.



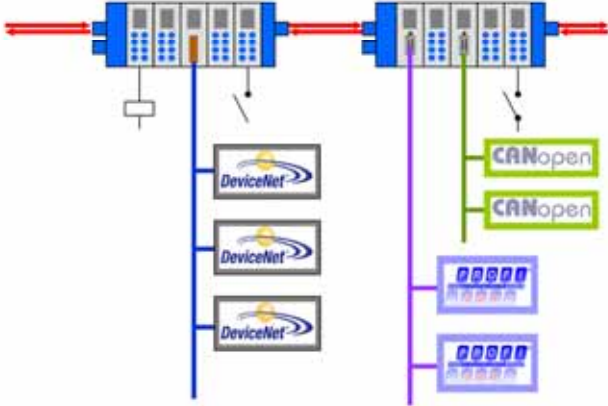


## EtherCAT Gateways



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

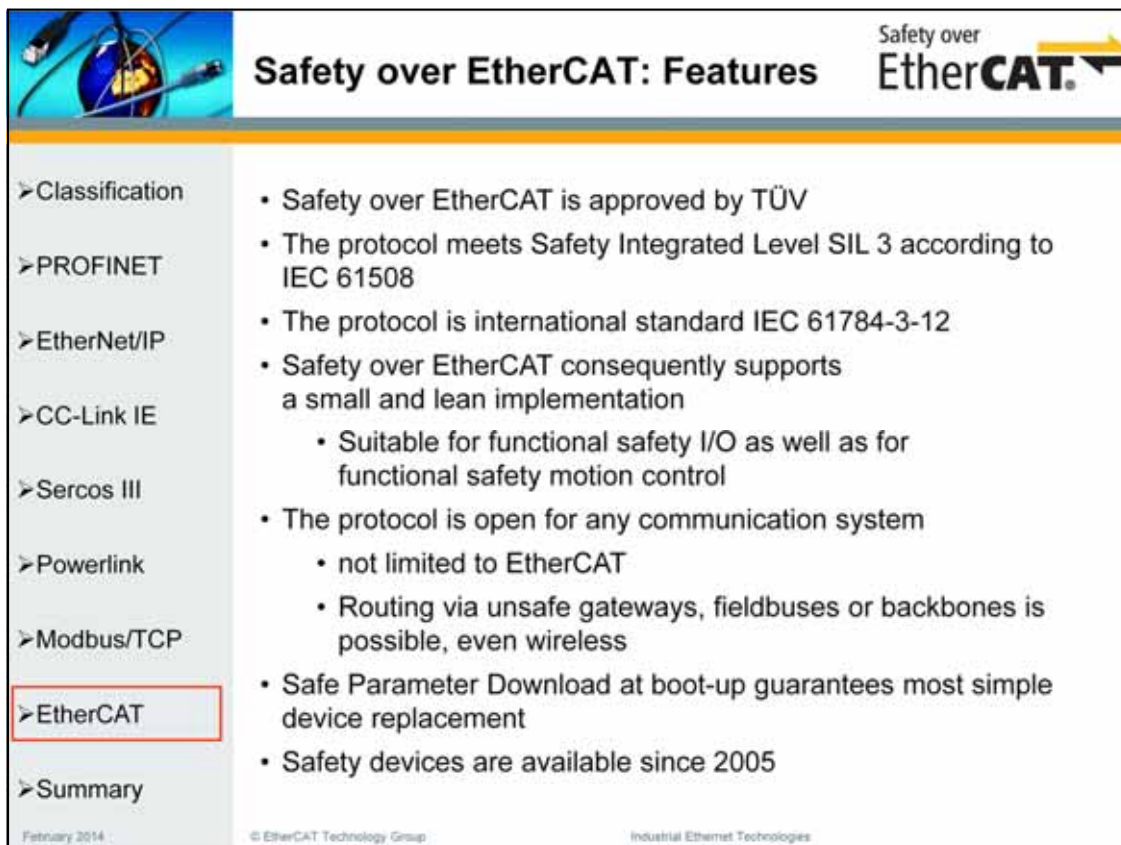
- EtherCAT Performance allows for: EtherCAT instead of PCI
- no card slots required any more
- maximum system expandability with low cost fieldbus gateways
- seamless integration of fieldbus devices protects your investment
- smooth migration path from fieldbus to EtherCAT



February 2014© EtherCAT Technology GroupIndustrial Ethernet Technologies

EtherCAT is so fast that it can replace the PCI bus (and thus the PCI slots) in almost all applications. Fieldbus master and slave card can be moved into the EtherCAT network. EtherCAT control computers can thus be very compact, without restricting the expandability.

In addition, this feature provides a very elegant and smooth migration path: Devices which are not (yet) available with EtherCAT interface, can be integrated via underlying fieldbus systems – typically without restricting the performance compared with the PCI solution.



The slide features a header with a globe icon, the title "Safety over EtherCAT: Features", and the EtherCAT logo with the slogan "Safety over EtherCAT". A left-hand navigation menu lists various protocols, with "EtherCAT" highlighted in a red box. The main content area contains a bulleted list of features for Safety over EtherCAT.

## Safety over EtherCAT: Features

- Classification
  - Safety over EtherCAT is approved by TÜV
- PROFINET
  - The protocol meets Safety Integrated Level SIL 3 according to IEC 61508
- EtherNet/IP
  - The protocol is international standard IEC 61784-3-12
- CC-Link IE
  - Safety over EtherCAT consequently supports a small and lean implementation
    - Suitable for functional safety I/O as well as for functional safety motion control
- Sercos III
  - The protocol is open for any communication system
- Powerlink
  - not limited to EtherCAT
  - Routing via unsafe gateways, fieldbuses or backbones is possible, even wireless
- Modbus/TCP
  - Safe Parameter Download at boot-up guarantees most simple device replacement
- EtherCAT
  - Safety devices are available since 2005
- Summary

February 2014 | © EtherCAT Technology Group | Industrial Ethernet Technologies

The open protocol Safety over EtherCAT (abbreviated with FSoE "FailSafe over EtherCAT") defines a safety related communication layer for EtherCAT. Safety over EtherCAT meets the requirements of IEC 61508 SIL 3 and enables the transfer of safe and standard information on the same communication system without limitations with regard to transfer speed and cycle time.

Its usage is not limited to EtherCAT based communication systems – it may be used on any fieldbus or Industrial Ethernet technology. However, ETG refrains from proactively promoting FSoE as universal fieldbus

independent safety protocol. We do not believe that a safety protocol that is alien to the system can displace the native safety protocol promoted by the corresponding fieldbus user organization. And if the alien protocol has to be implemented and maintained in addition to the native safety protocol (if such a product can be certified at all), it would add substantial non-justifiable costs.

**Safety over EtherCAT: Technology Approach**

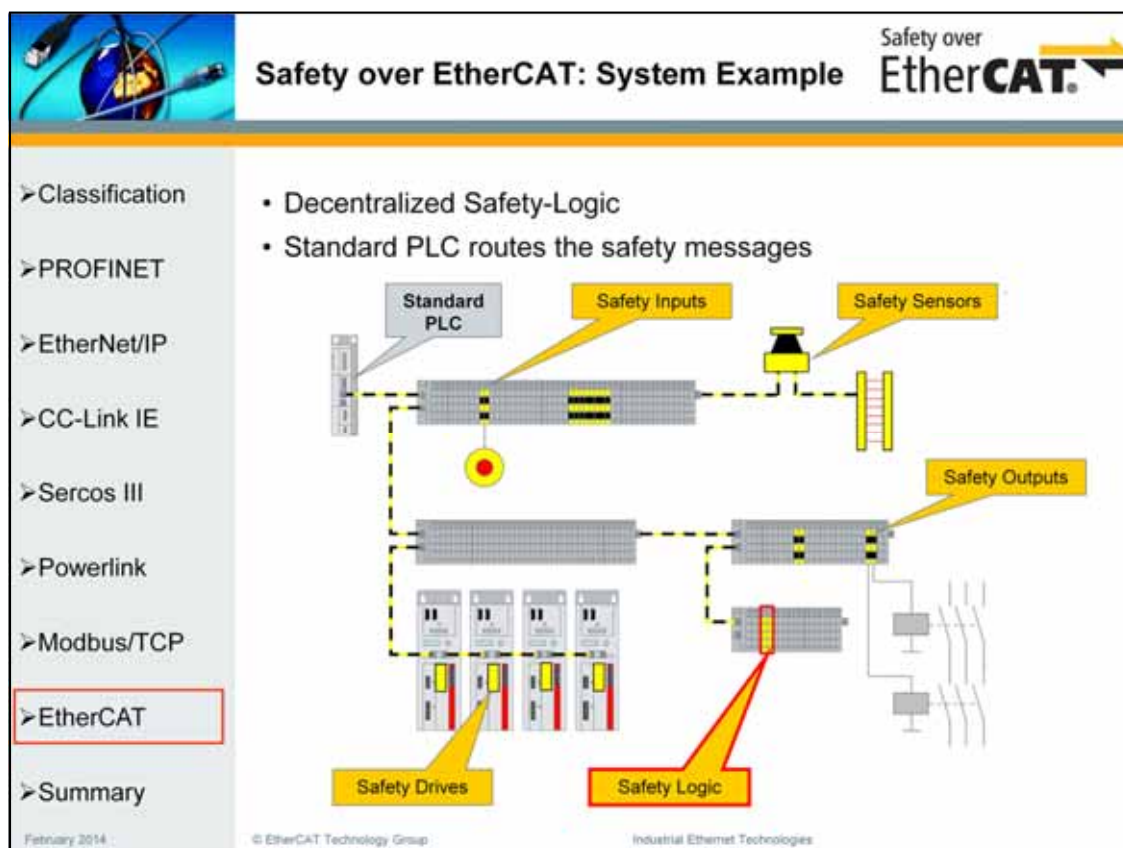
- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- **EtherCAT**
- Summary

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

The diagram illustrates the 'Black channel approach' where safety and non-safety data share the same bus. It shows two devices, Device 1 and Device 2, each containing a Safety Application and a Standard Application. Both applications communicate with an EtherCAT Communication Interface. The Safety Application uses the Safety over EtherCAT Protocol, while the Standard Application uses the EtherCAT DLL and AL. The communication interface connects to an EtherCAT Telegram on the bus, which is encapsulated in a Safety data container (FSoE Frame).

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies


With Safety over EtherCAT the communication channel is really “black” (or irrelevant for the safety analysis), and not “grey”. Therefore e.g. no SIL monitor is required to check the current error rate on the network.



With Safety over EtherCAT a decentralized safety PLC (“Safety Logic”) can be combined with a non-safe standard main controller. With this approach functional safety can be added to existing control systems without the need to replace the main controller with a functional safety PLC.

Of course FSoE also supports the classical approach (PLC also contains the safety controller).






## Safety over EtherCAT: Adoption Rate

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- **EtherCAT**
- Summary

- As of 2/2014, the EtherCAT product guide shows safety products from 6 vendors
- In total 6 vendors of FSoE masters, 9 vendors of FSoE drives, 7 vendors of FSoE I/O and sensors have shown their products e.g. on trade shows.

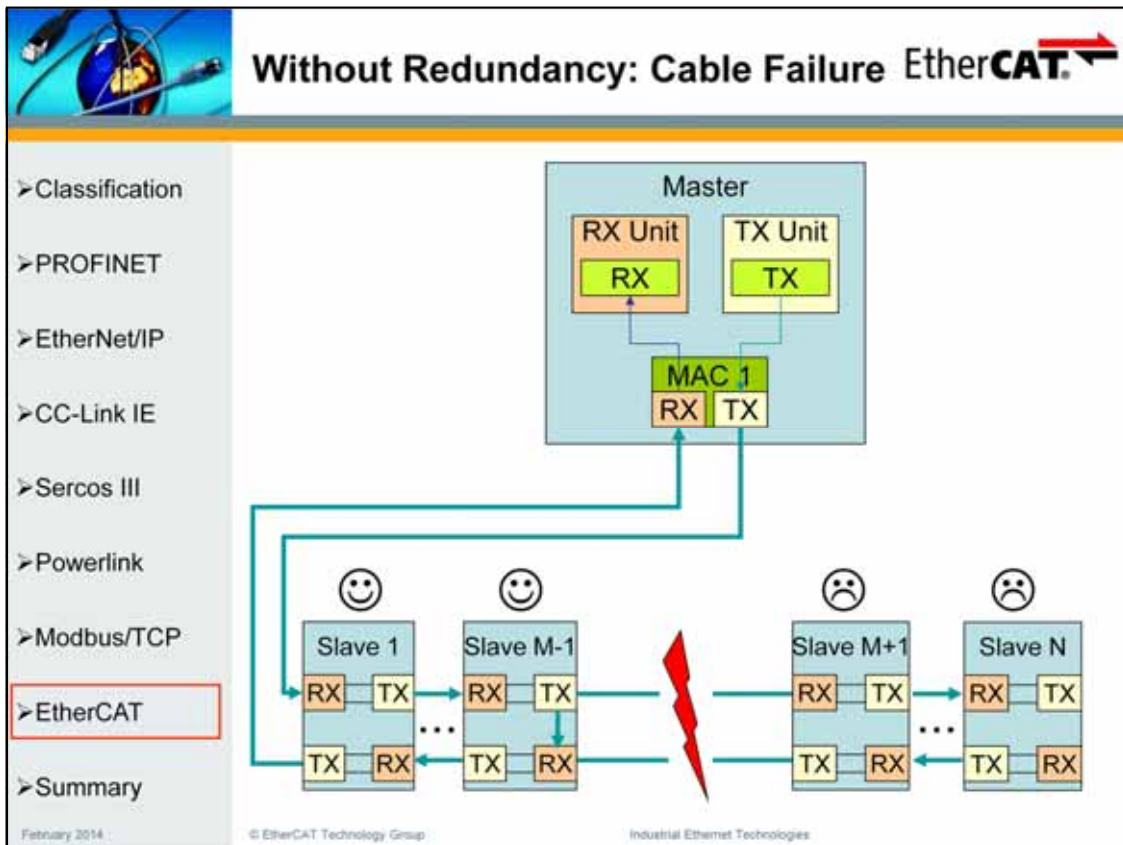


Multi-Vendor FSoE Demo @ SPS/IPC/Drives Trade Show 2013

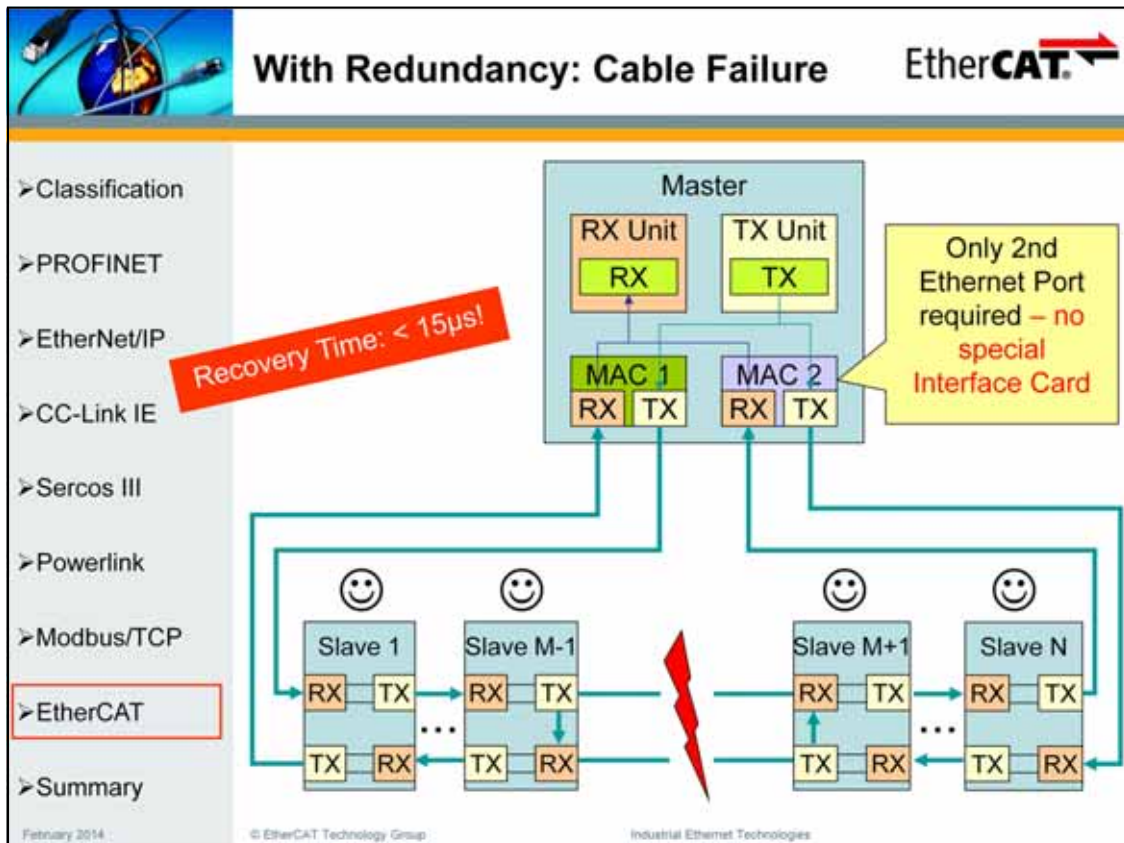
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

The FSoE license is provided free of charge.

The entire “eco-system” for implementing FSoE is available, including TÜV certified tests.



EtherCAT is – even when wired in line topology – a ring structure, with two channels in one cable (Ethernet full duplex feature). Whilst device located before a cable or device failure can continue to operate (the EtherCAT Slave Controller closes the ring automatically), devices behind the cable failure are naturally not accessible any more.




If the line is turned into a ring, there are two communication paths to each device: cable redundancy.


With EtherCAT even without special hardware in the master: a second Ethernet port is sufficient. All slave devices with two (or more) EtherCAT ports support the cable redundancy feature anyhow.

The recovery time in case of cable failure is shorter than  $15\mu\text{s}$ . The initial switchover to the redundant line does not require any reconfiguration by the master.

By using this feature it is feasible to exchange device exchange at run time (hot swap).




## EtherCAT is simpler to configure



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT**
- Summary

**Addressing:**

- No manual address setting required
- Addresses can be kept – no new addressing if nodes are added



**Topology:**

- Automatic topology target/actual comparison possible

**Diagnosis:**

- Diagnosis information with exact localization

**Network planning:**

- Performance independent of slave implementation (e.g. stack features,  $\mu$ C performance)
- Performance widely independent from topology (no switches/hubs)
- Performance more than sufficient - therefore no „tuning“ required any more, default settings do the job

February 2014

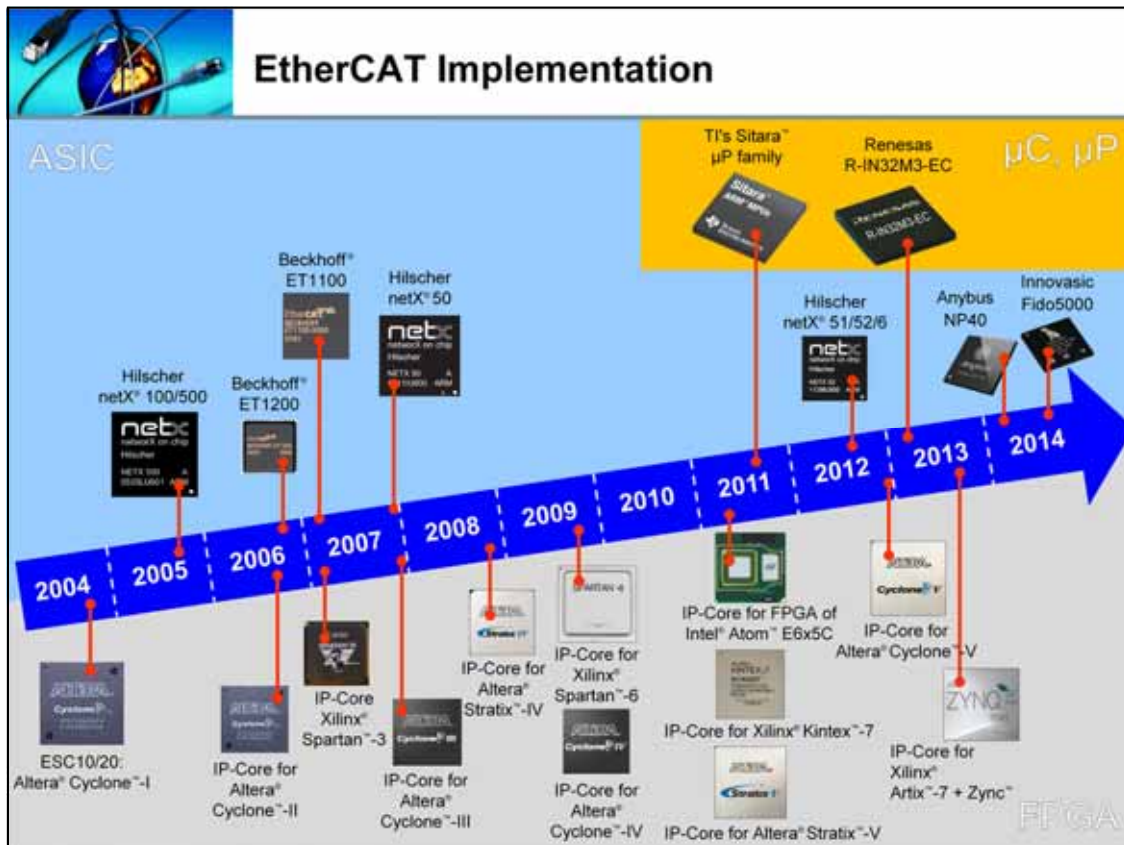
© EtherCAT Technology Group

Industrial Ethernet Technologies

The configuration of an EtherCAT network is very simple.


This is in particular the case for the network planning: since the process data performance does not depend on the devices that were selected (and their  $\mu$ C and stack performance) and since the topology has almost no influence at all, hardly anything has to be considered.

Also the network tuning, which has been necessary with many fieldbus and industrial Ethernet solutions, is hardly needed at all: even with default settings Ethernet is more than fast enough.




Like all Industrial Ethernet technologies that support hard real time, EtherCAT requires a dedicated hardware interface – unlike its competition EtherCAT requires such hardware only on the slave side. This provides both maximum and predictable performance of the network, since software stack delays do not have any influence any more. In addition this leads to lower costs. The first EtherCAT Slave Controller (ESC) back in 2004 was FPGA based, released by the originator of the technology, the German company Beckhoff Automation. In 2005 – 2007 EtherCAT ASICs were introduced by Beckhoff and Hilscher. Many EtherCAT device vendors also make use of the configurable EtherCAT IP-Cores for Altera and Xilinx FPGAs. The Texas Instruments and the Renesas microcontroller and microprocessor families also support EtherCAT Slave Controller Interfaces. And more chips from a number of other vendors are in the pipeline (not yet announced as of Feb 2014).






## EtherCAT is lower costs



---


- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

**Master:**  
*no dedicated plug in card (co-processor), on-board Ethernet Port is fine*




**Slave:**

- low cost Slave Controller
- FPGA or ASIC
- no powerful  $\mu$ C needed



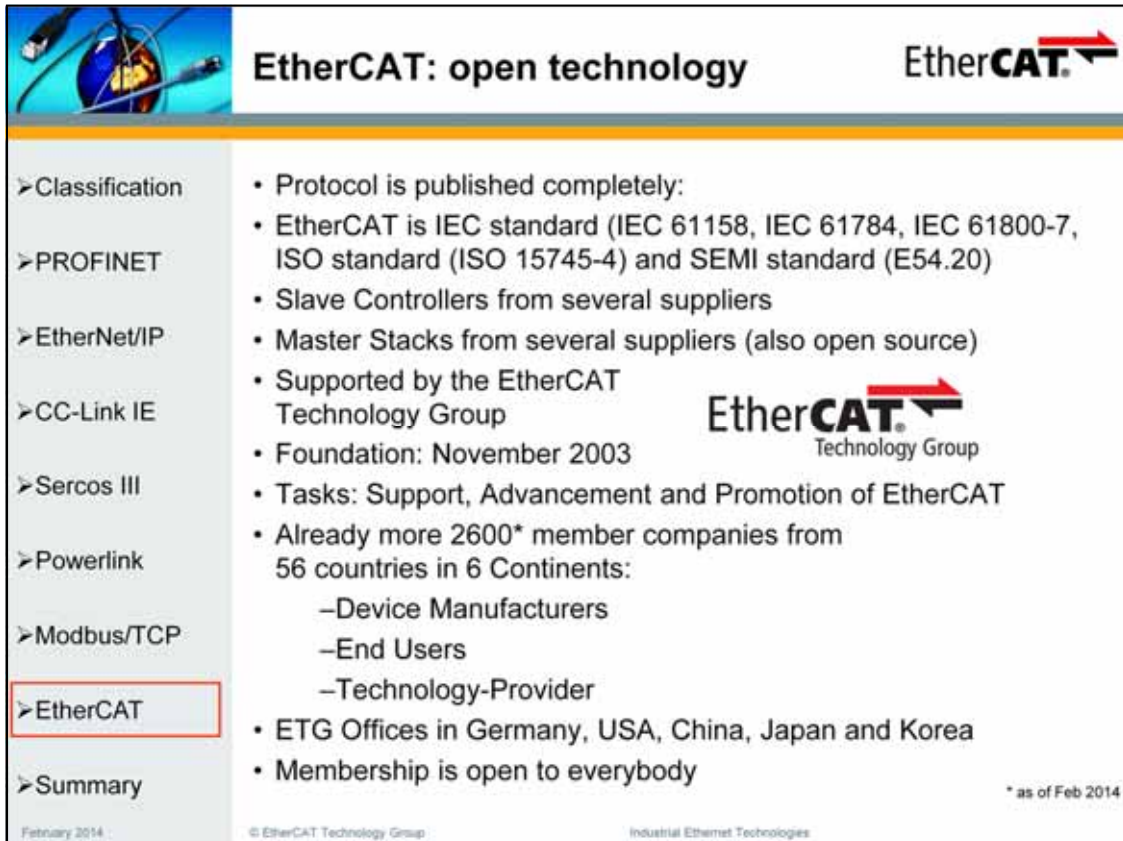
**Infrastructure:**


- no Switches/Hubs required
- Standard Ethernet Cabling




February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

EtherCAT intends to even undercut the fieldbus cost levels – in spite of the much better performance and many additional features.



**EtherCAT: open technology** 

- Classification
  - Protocol is published completely:
  - EtherCAT is IEC standard (IEC 61158, IEC 61784, IEC 61800-7, ISO standard (ISO 15745-4) and SEMI standard (E54.20)
  - Slave Controllers from several suppliers
- PROFINET
- EtherNet/IP
  - Master Stacks from several suppliers (also open source)
- CC-Link IE
  - Supported by the EtherCAT Technology Group 
  - Foundation: November 2003
- Sercos III
  - Tasks: Support, Advancement and Promotion of EtherCAT
- Powerlink
  - Already more 2600\* member companies from 56 countries in 6 Continents:
    - Device Manufacturers
    - End Users
    - Technology-Provider
- Modbus/TCP
- EtherCAT
  - ETG Offices in Germany, USA, China, Japan and Korea
  - Membership is open to everybody
- Summary

\* as of Feb 2014

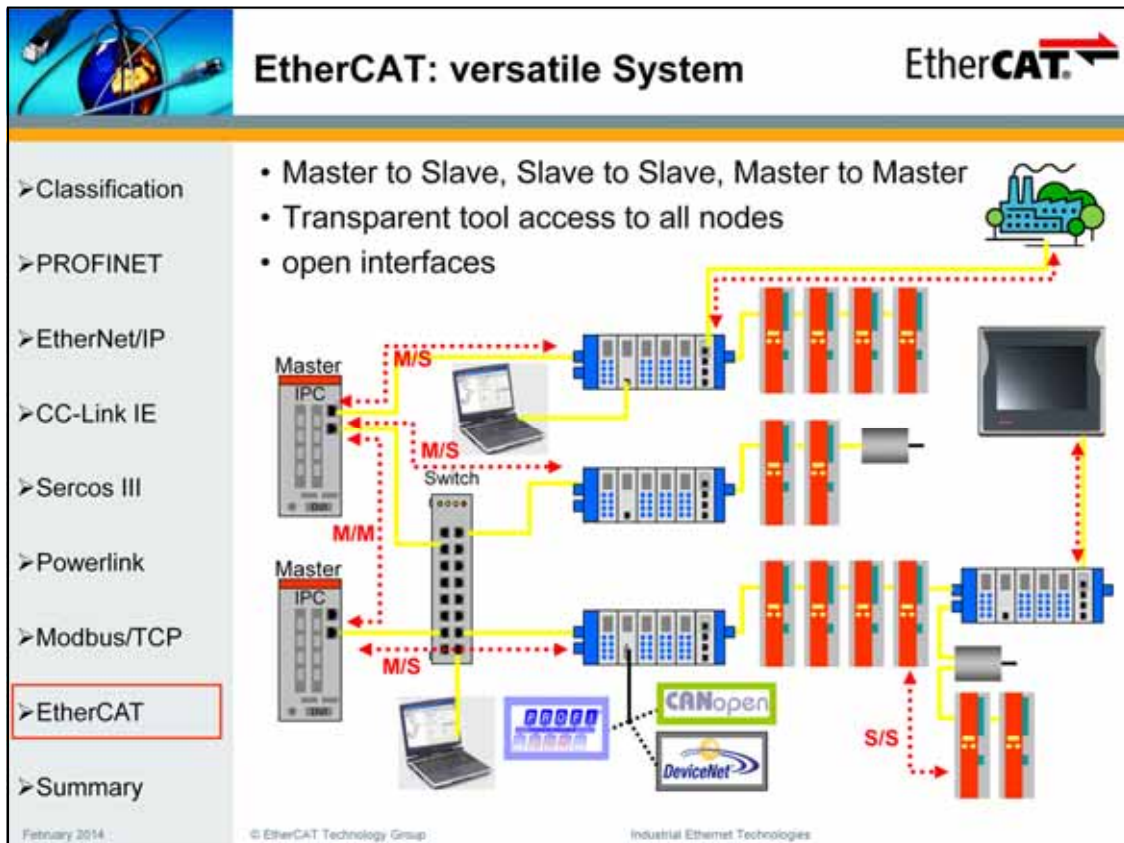
February 2014    © EtherCAT Technology Group    Industrial Ethernet Technologies

The EtherCAT Technology Group is official standardization partner of the IEC: the ETG nominates experts for the international standardization committees and may submit standard proposals.

Since beginning of 2005 EtherCAT is an official IEC specification: IEC/PAS 62407. Since Oct. 2007 EtherCAT is part of the standards IEC 61158 (Digital data communication for measurement and control – Fieldbus for use in industrial control systems), IEC 61784-2 (Digital data communication for measurement and control –Part 2: Additional profiles for ISO/IEC 8802-3-based communication networks in real-time applications) and IEC 61800-7 (Profiles for motion control systems). The latter is particularly important for motion control applications, since it makes EtherCAT a standardized communication technology for the SERCOS and CANopen drive profiles, on an equal footing with SERCOS I-III and CANopen respectively. The drive parameters and state machines as well as the process data layout of the device profiles remain untouched when mapped to EtherCAT. Hence the user interface does not change when moving from SERCOS and CANopen to EtherCAT, and device manufacturers can re-use major parts of their firmware.

Safety over EtherCAT has been standardized in IEC 61784-3-12 (Industrial communication networks - Profiles - Part 3-12: Functional safety fieldbuses), and cables, connectors etc. for EtherCAT are specified in the installation profile IEC 61785-5 -12 (Industrial communication networks - Profiles - Part 5-12: Installation of fieldbuses - Installation profiles for CPF 12). EtherCAT is also part of ISO 15745-4 (device description profiles)

The EtherCAT Technology Group (ETG) is an organization in which key user companies from various industries and leading automation suppliers join forces to support, promote and advance the EtherCAT technology. With over 2600 members, the EtherCAT Technology Group has become the largest fieldbus organization in the world. Founded in November 2003, it is also the fastest growing fieldbus organization.

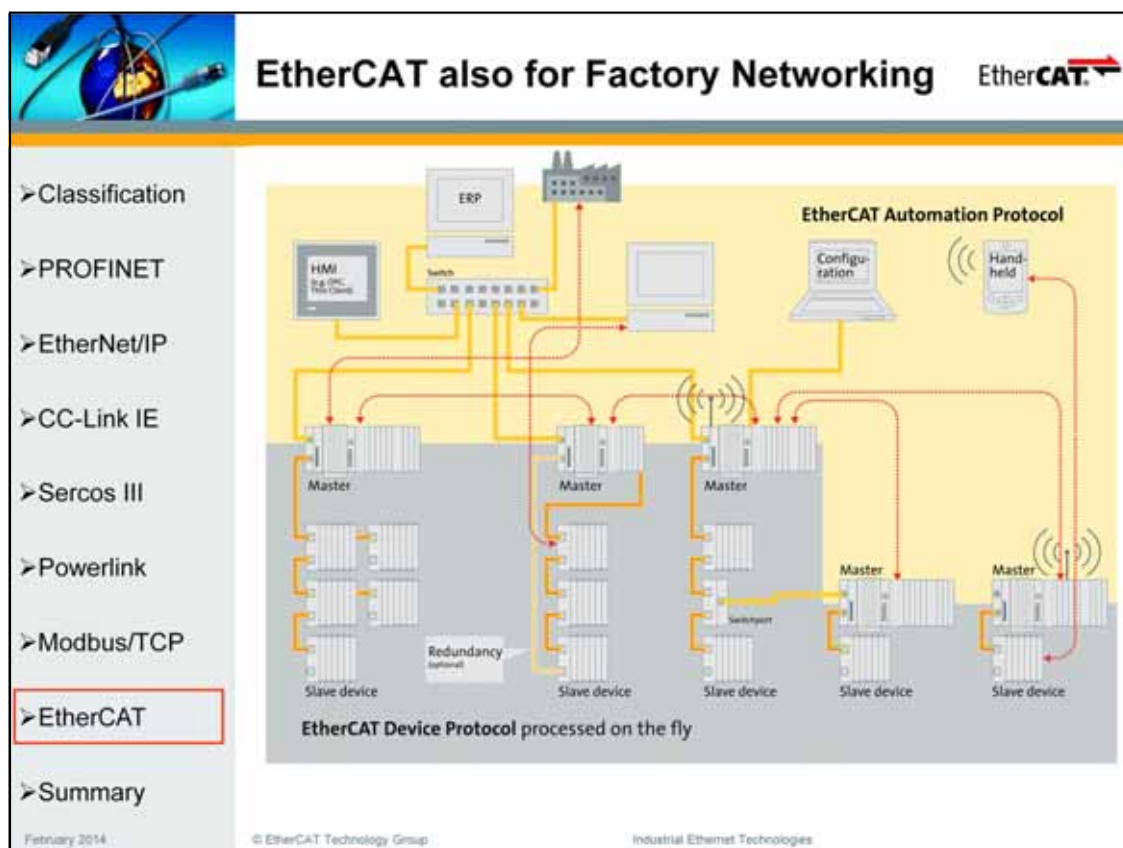


Besides the master/slave communication EtherCAT provides further possibilities: masters can communicate among each other as well as slave devices.

For slave to slave communication there are two varieties:

Topology dependent slaves can insert data “upstream” which can be read “downstream” by all other slaves. In many applications that require slave to slave communication these relationships are known at network planning stage and thus can be handled accordingly. Wherever this is not possible, the second variant can be applied:

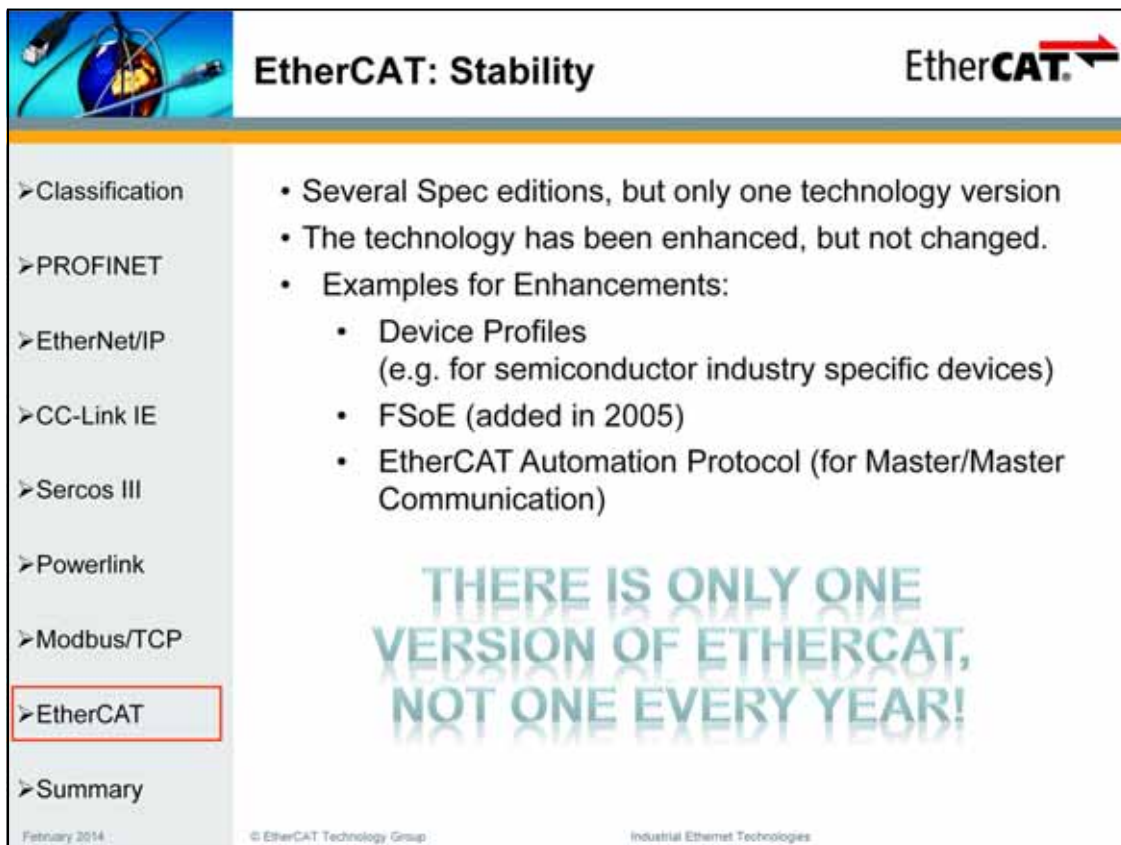
Topology independent two cycles are used for slave to slave communication. In most cases the corresponding delay time is not critical at all – in particular if one considers that EtherCAT is even at twice the cycle time still faster than any other solution....



In 2009 the EtherCAT protocol portfolio was enhanced by the EtherCAT Automation Protocol (EAP). As a result, EtherCAT also comprises the Ethernet communication between control systems, as well as to the supervisory systems. EAP simplifies the direct access of process data from field devices at the sensor / actuator level and also supports the integration of wireless devices.


For the factory level, the base protocols for process data communication have been part of the EtherCAT specification from the very beginning. In 2009 ETG enhanced those with services for the parameter communication between control systems and for routing across system boundaries. Uniform diagnostic and configuration interfaces are also part of the EAP. It can be used in switch-based Ethernet topologies as well as via wireless Ethernet. Process data is communicated like network variables, either cyclically or event-driven. Both the classic EtherCAT Device Protocol, which utilizes the special EtherCAT functional principle of "processing on the fly," and the new EAP make use of the same data structures and facilitate vertical integration to supervisory control systems and networked controllers.

While EAP handles the communication in the millisecond range on the process control level and between control systems, the EtherCAT Device Protocol handles I/O and motion control communication in the field level in the microsecond range.



The slide features a header with an image of a globe and network cables on the left, the title "EtherCAT: Stability" in the center, and the EtherCAT logo on the right. A navigation menu on the left lists various industrial Ethernet technologies, with "EtherCAT" highlighted in a red box. The main content area contains a bulleted list of points about the technology's stability and enhancements. A large, stylized text graphic in the center reads "THERE IS ONLY ONE VERSION OF ETHERCAT, NOT ONE EVERY YEAR!". The footer includes the date "February 2014" and copyright information for the EtherCAT Technology Group and Industrial Ethernet Technologies.

## EtherCAT: Stability



- Classification
  - Several Spec editions, but only one technology version
  - The technology has been enhanced, but not changed.
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- **EtherCAT**
- Summary

- Examples for Enhancements:
  - Device Profiles (e.g. for semiconductor industry specific devices)
  - FSoE (added in 2005)
  - EtherCAT Automation Protocol (for Master/Master Communication)

**THERE IS ONLY ONE  
VERSION OF ETHERCAT,  
NOT ONE EVERY YEAR!**

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

EtherCAT devices made in 2004 are interoperable with devices made in 2014 – the new devices may support additional features or may have implemented a device profile that had not been available in 2004, but the basic communication protocol has not been changed ever since.

The outstanding stability of EtherCAT has been a major asset of the technology: vendors of EtherCAT devices do not have to fear that their implementation is obsolete any time soon.



**EtherCAT Adoption Rate**

**EtherCAT**

Classification

PROFINET

EtherNet/IP

CC-Link IE

Sercos III

Powerlink

Modbus/TCP

**EtherCAT**

Summary

- As of Feb 2014, ETG online product guide contains 523 EtherCAT entries.
- Altogether 124 vendors of EtherCAT drives, 90 vendors of EtherCAT I/O and 159 vendors of EtherCAT masters.
- ETG does not publish node counts for EtherCAT

EtherCAT Products

EtherCAT Product Guide

The EtherCAT Product Guide lists EtherCAT products and services as submitted to ETG member companies. Even though the guide already contains over 500 entries there are more items which have not been entered yet. Please contact the vendor directly for any input or question. Technical information is provided as well to help you selecting the suitable product. Many entries are referenced to other corresponding device description files and documents.

Filter

Year Introduced: All

Industry: All

Company: All

EtherCAT I/O Vendors: 90

EtherCAT Drive Vendors: 124

EtherCAT Master (Controller) Vendors: 159

February 2014

© EtherCAT Technology Group


Industrial Ethernet Technologies

The adoption rate of EtherCAT is outstanding. In particular the adoption rate among master vendors underlines the wide spread support as well as the openness of the technology: it makes a difference if a vendor “just” support another fieldbus interface for his (slave) components such as drives or I/O, or if he adopts the fieldbus as own system bus and implements a master.


For two reasons ETG does not publish node counts:

1. ETG does not know the numbers, since sales do not have to be reported and since the EtherCAT Slave Controller sales cannot be monitored do to the “buy-out” licensing of the IP Core.
2. It is obvious that the other organizations do not know their numbers either....

So ETG has to live with the fact that most market research organizations underestimate the EtherCAT market share.



# EtherCAT Performance



---

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary


EtherCAT is the fastest Industrial Ethernet Technology:

Transmission Rate: 2 x 100 Mbaud (Voll-Duplex)

**Update Times:**

- 256 digital I/O in 11  $\mu$ s
- **1000 digital I/O** distributed to 100 nodes **in 30  $\mu$ s = 0.03 ms**
- 200 analog I/O (16 bit) in 50  $\mu$ s, 20 kHz Sampling Rate
- **100 Servo-Axis** (each 8 Byte I+O) **every 100  $\mu$ s = 0.1 ms**
- 12000 digital I/O in 350  $\mu$ s

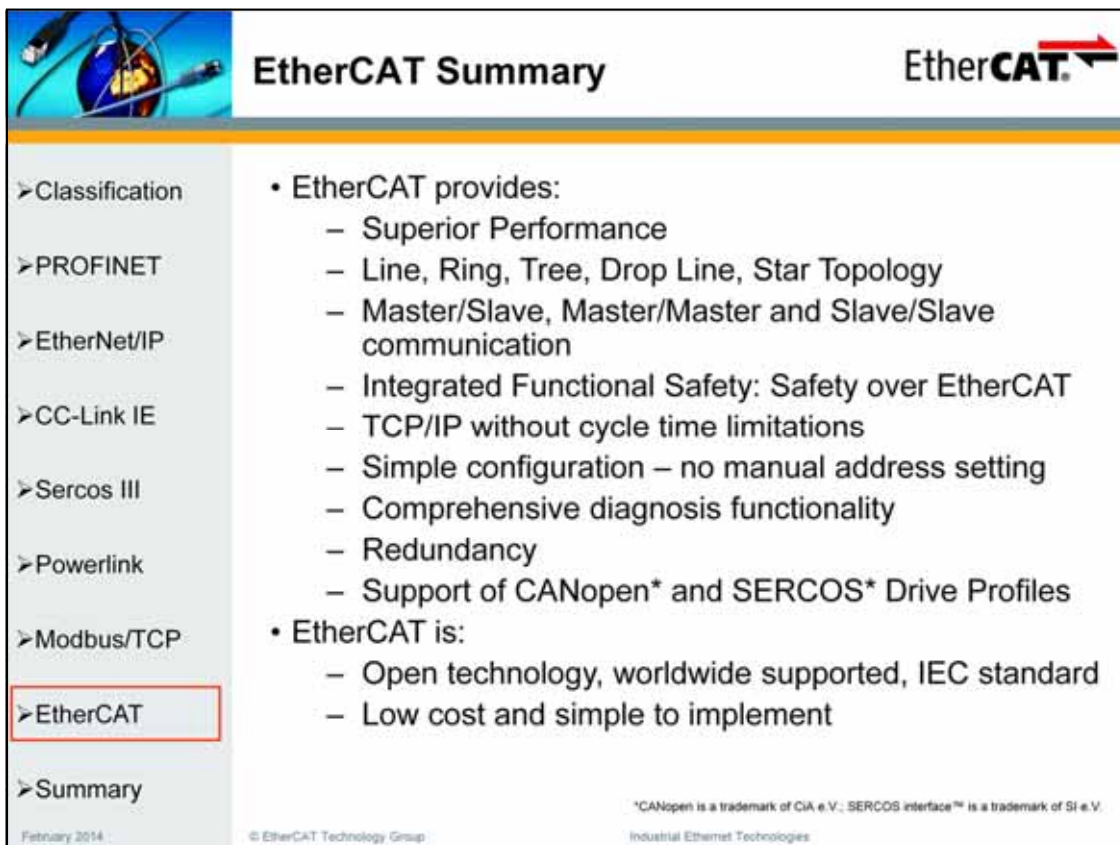
More details ?  
..... see EtherCAT Presentation  
or EtherCAT website  
[www.ethercat.org](http://www.ethercat.org)



February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

The performance figures have been determined with a mix of physical layers, thus representing typical installations.

A comprehensive EtherCAT introduction can be found at the EtherCAT website.



The slide is titled "EtherCAT Summary" and features the EtherCAT logo in the top right corner. On the left side, there is a vertical navigation menu with the following items: Classification, PROFINET, EtherNet/IP, CC-Link IE, Sercos III, Powerlink, Modbus/TCP, EtherCAT (highlighted with a red box), and Summary. The main content area lists the features and characteristics of EtherCAT.

## EtherCAT Summary

- Classification
  - PROFINET
  - EtherNet/IP
  - CC-Link IE
  - Sercos III
  - Powerlink
  - Modbus/TCP
  - **EtherCAT**
  - Summary
- EtherCAT provides:
  - Superior Performance
  - Line, Ring, Tree, Drop Line, Star Topology
  - Master/Slave, Master/Master and Slave/Slave communication
  - Integrated Functional Safety: Safety over EtherCAT
  - TCP/IP without cycle time limitations
  - Simple configuration – no manual address setting
  - Comprehensive diagnosis functionality
  - Redundancy
  - Support of CANopen\* and SERCOS\* Drive Profiles
- EtherCAT is:
  - Open technology, worldwide supported, IEC standard
  - Low cost and simple to implement

\*CANopen is a trademark of CIA e.V.; SERCOS interface™ is a trademark of SI e.V.

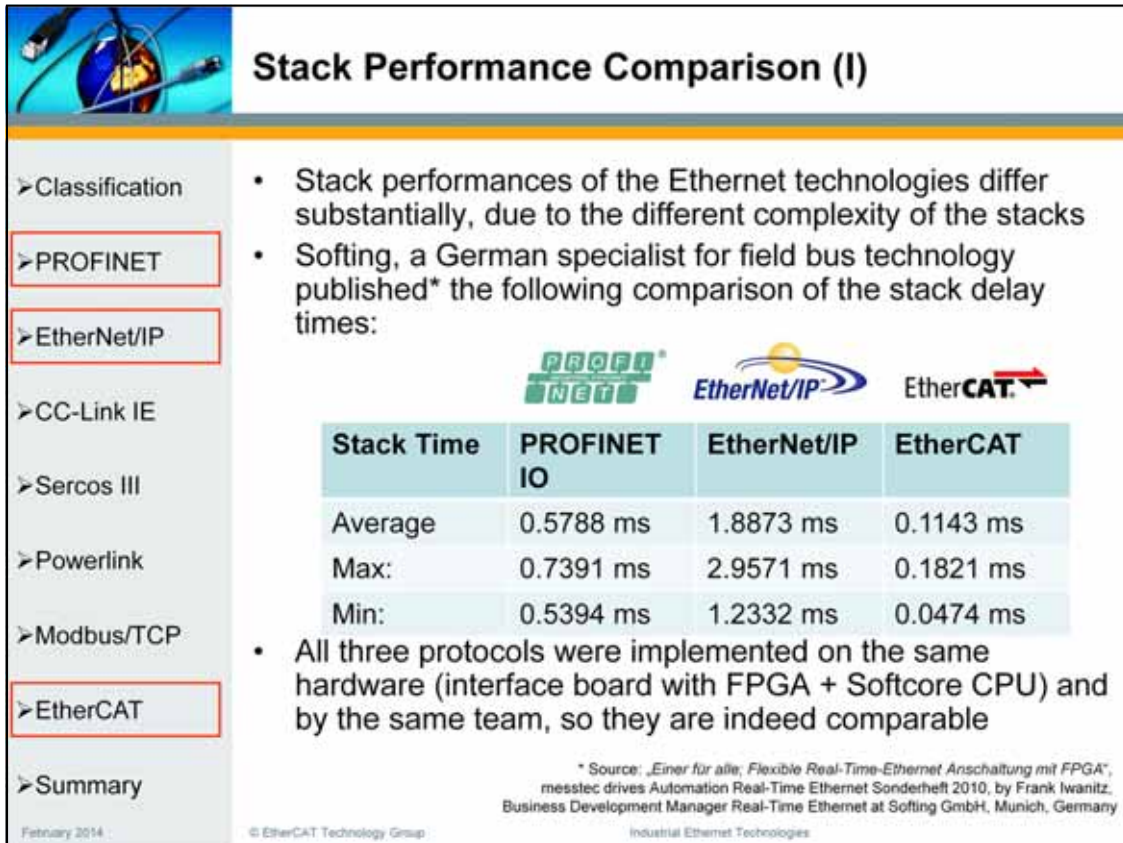
February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

EtherCAT typically is chosen for one or more of these three reasons:

- superior performance
- flexible topology – even at large distances
- low costs

For more information regarding EtherCAT please go to

**[www.ethercat.org](http://www.ethercat.org)**



## Stack Performance Comparison (I)

- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary

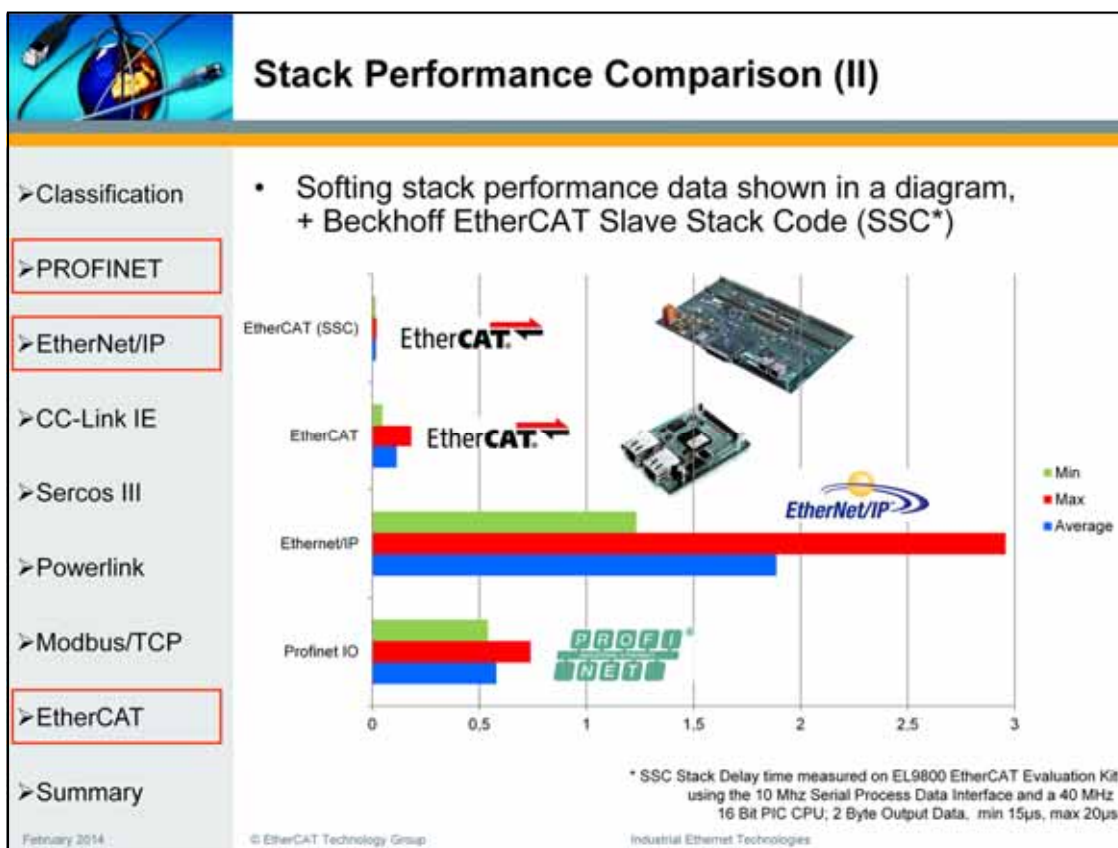
- Stack performances of the Ethernet technologies differ substantially, due to the different complexity of the stacks
- Softing, a German specialist for field bus technology published\* the following comparison of the stack delay times:
 

Stack Time	PROFINET IO	EtherNet/IP	EtherCAT
Average	0.5788 ms	1.8873 ms	0.1143 ms
Max:	0.7391 ms	2.9571 ms	0.1821 ms
Min:	0.5394 ms	1.2332 ms	0.0474 ms
- All three protocols were implemented on the same hardware (interface board with FPGA + Softcore CPU) and by the same team, so they are indeed comparable

\* Source: „Einer für alle; Flexible Real-Time-Ethernet Anschaltung mit FPGA“, messtec drives Automation Real-Time Ethernet Sonderheft 2010, by Frank Iwanitz, Business Development Manager Real-Time Ethernet at Softing GmbH, Munich, Germany

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

- Most performance comparisons only look at the network itself up to the slave controller chips, and neglect the stack performances.
- However, the stack performance is crucial when looking at the overall network system performance
- Softing is using the eCos RTOS on the Softcore CPU that runs the stacks
- The stack times were measured from the interrupt that is generated at the reception of the Ethernet frame at the IP core until the data is made available to the application at the application interface (stack API).



- Most performance comparisons only look at the network itself up to the slave controller chips, and neglect the stack performances.
- However, the stack performance is crucial when looking at the overall network system performance



	Modbus /TCP	Ethernet /IP	Profinet RT	Powerlink	Profinet IRT	CC-Link IE	Sercos III	EtherCAT
<b>Performance</b>	Modbus /TCP	Ethernet /IP	Profinet RT	Powerlink	Profinet IRT	CC-Link IE	Sercos III	EtherCAT
<b>Cycle Time</b>	--	--	-	○	+	○	+	++
<b>Synchronicity</b>	--	-- + (CIP sync)	--	- ○ (with special interface hw)	+	+	+	++
<b>Throughput of IP Data</b>	++	++	++	○ (half duplex)	+	--	-	○

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

In principle, one should not compare technologies in such an overview table: since the ratings are based on figures, assumptions and assessments that cannot be given in full detail, one may come to a different conclusion. However, some like this and ask for these tables.

In order to provide a better transparency, comments for each row are provided.

**Cycle Time:** EtherCAT is about 3 times faster than PROFINET IRT and Sercos-III, and about 10-15 times faster than Powerlink or CC-Link IE. Due to TCP/IP usage for process data communication and the related stack delays, the Modbus cycle time in principle is longer than with PROFINET I/O – but this is widely implementation dependent.

**Synchronicity:** The EtherCAT distributed clock mechanism provides jitter-values of <<1µs. With Sercos-III, Powerlink and CC-Link IE the jitter depends on the communication jitter of the master, with PROFINET-IRT, Powerlink and CC-Link IE Field it (also) depends on the number of cascaded switches resp. hubs. All four technologies claim a jitter of <1µs – as does CIPsync.

**Throughput of IP data:** with the „best effort“ approaches Modbus, EtherNet/IP and PROFINET RT the throughput of IP data is basically limited by the stack performance. Since PROFINET IRT and EtherCAT reserve bandwidth for Real-time communication, the remaining throughput for IP data is reduced by the protocol – but typically it remains higher than the stack performance of an embedded TCP/IP stack. With IRT the user has to ensure that certain load limits are not exceeded. Powerlink suffers from half duplex communication and overall poor bandwidth utilization due to polling. CC-Link IE does not transport other Ethernet traffic (the SLMP option is the other way round: SLMP via TCP/IP in external Ethernet networks). Sercos-III suffers from the delay introduced by large no. of cascaded switches (in Realtime Mode).

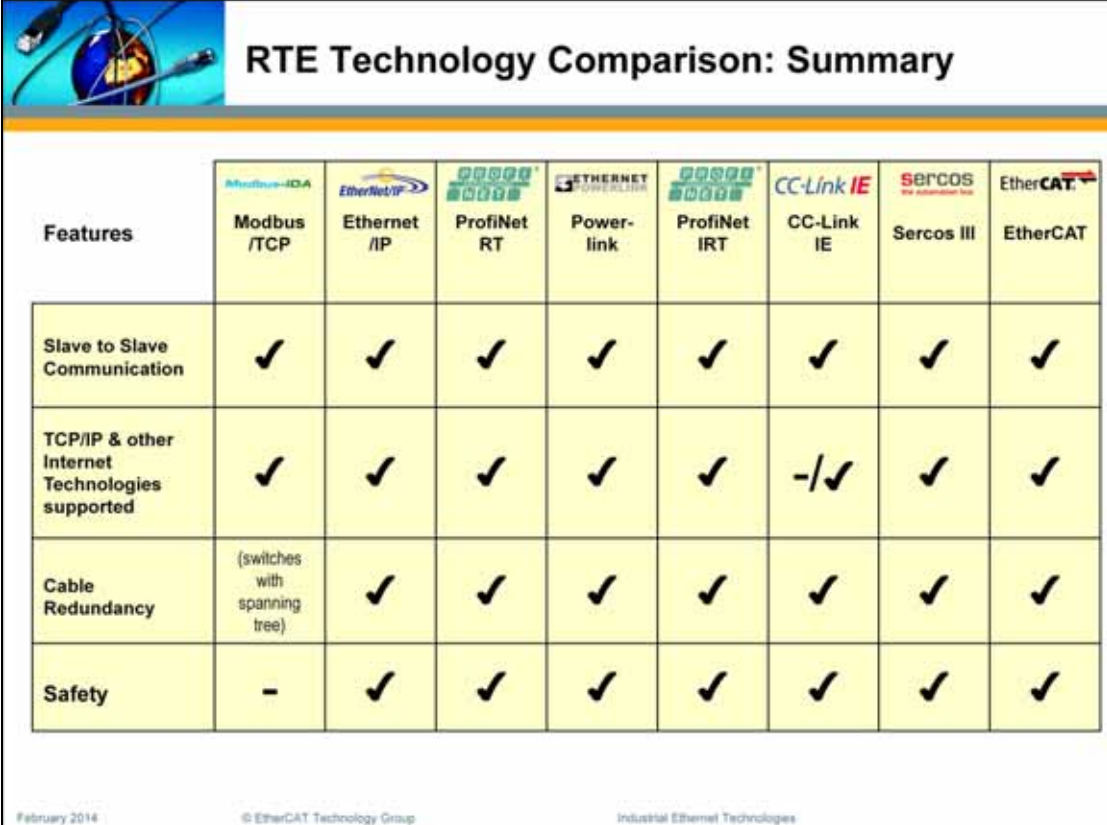
Topology + Wiring	Modbus /TCP	Ethernet /IP	ProfiNet RT	Powerlink	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Topology Flexibility	--	-	-	+	+	-- (Control) + (Field)	-	++
Line Structure	--	-	-	○ (10)	○ (~25)	-- (Control) + (Field)	+ (511)	++ (65535)
COTS Infrastructure Components (Switch, Router, Connector etc.)	++	+	○	○ (no Switch)	--	-- (Control) + (Field)	-	+

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies




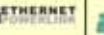


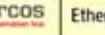

**Topology Flexibility:** EtherCAT supports line, tree, star, ring, drop lines without practical limitations on number of nodes and hardly any influence on performance. PROFINET IRT: line, tree, star, drop lines, but limited no. of nodes and strong interdependency between topology and performance. CC-Link IE Control: ring only; CC-Link IE Field: star + line, ring announced. Powerlink: line, tree, star, drop lines, but strong limitation due to hub delays. Sercos-III: line and ring only.

**Line Structure:** ModbusTCP, EtherNet/IP + PROFINET RT only support line topology with device integrated switches – and of course, the switch delays accumulate. With Powerlink, only few nodes in line, due to hub delays. According to B&R user manual, a maximum of 10 hubs is allowed between master and slave – so only 10 nodes in line. With PROFINET IRT, accumulated jitter due to cascaded switches limits the no. of nodes in line topology. CC-Link IE Field: up to 121 nodes in line, Sercos-III specifies up to 511 nodes in line, EtherCAT supports up to 65535.

**Commercially Off The Shelf (COTS) Infrastructure Components:** EtherNet/IP asks for manageable switches with IGMP support. Hubs with 100 MBit/s (Powerlink) cannot be considered COTS technology, since the chips are obsolete. PROFINET RT requires a careful switch selection. PROFINET IRT requires special switches throughout, Sercos-III does not allow switches, EtherCAT can be used with switches (between masters and EtherCAT segments). If required, EtherCAT networks can be further extended e.g. by inserting fiber optic segments using standard infrastructure devices. CC-link IE Control: no COTS devices possible; CC-Link IE Field: Switches can be used.



**RTE Technology Comparison: Summary**

Features	 Modbus /TCP	 Ethernet /IP	 ProfiNet RT	 Power-link	 ProfiNet IRT	 CC-Link IE	 Sercos III	 EtherCAT
	Slave to Slave Communication	✓	✓	✓	✓	✓	✓	✓
TCP/IP & other Internet Technologies supported	✓	✓	✓	✓	✓	-/✓	✓	✓
Cable Redundancy	(switches with spanning tree)	✓	✓	✓	✓	✓	✓	✓
Safety	-	✓	✓	✓	✓	✓	✓	✓

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies

**Slave to Slave Communication:** supported by all technologies. Via Master only: Modbus/TCP. Directly between slaves, but initiated by master: all others (EtherCAT: depending on topology). Topology independent slave-to-slave communication with EtherCAT requires 2 frames (which can be sent within the same cycle), so performance of this communication type may be degraded to Sercos-III or PROFINET IRT levels.

**TCP/IP & other Internet Technologies supported:** almost all technologies allow for TCP/IP communication and Internet Technologies. Modbus/TCP, EtherNet/IP and PROFINET I/O have no scheduling for this communication, all others do. Powerlink, PROFINET-IRT, Sercos-III and EtherCAT connect generic Ethernet devices (e.g. Service notebooks) via Gateways or special switchports. CC-Link IE Field can connect external SLMP/TCP/IP devices via Gateway, but cannot transport generic TCP/IP or Ethernet traffic.

**Cable Redundancy:** For Modbus/TCP switches with spanning tree protocol can be used to establish cable redundancy (between the switches only). EtherNet/IP has introduced the DLR protocol (and the corresponding devices). For PROFINET RT there is the Media Redundancy Protocol (MRP). For Powerlink, redundancy requires doubling of all infrastructure components plus additional redundancy interface devices (or special redundancy slaves). For PROFINET IRT there is Media Redundancy for Planned Duplication (MRPD). Sercos-III and EtherCAT support cabling redundancy, for EtherCAT with very little additional hw effort (only a 2nd Ethernet port in the master, no special card).

**Safety:** There is no Modbus/TCP safety protocol. The safety approaches of the other technologies differ regarding stability: Safety over EtherCAT products are shipping since end of 2005.

	Modbus /TCP	Ethernet /IP	ProfiNet RT	Powerlink	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
<b>Node Interface Costs</b>	○	○	○	○ + (w. FPGA)	- ERTEC400 ○ ERTEC200	?	+ (w. FPGA)	++ +(w. FPGA)
<b>Development Effort</b>	++	-	--	○	--	?	+	+
<b>Master Costs</b>	+	+	+	-*	-*	-*	-*	++
<b>Infrastructure Costs</b>	- (Switch)	-- (Switch)	-- (Switch) ○ (Switch integrated)	○ (Hubs integr.)	○ (Switch integr.)	○ (Switch integr.)	++ (no Switch)	++ (no Switch)

February 2014      © EtherCAT Technology Group      Industrial Ethernet Technologies      \* Requires Special Master Card with Co-Processor

**Node Costs:** Whilst Modbus/TCP – due to limited real time claims – can be implemented on 16bit  $\mu$ C, EtherNet/IP, PROFINET I/O and Powerlink require substantial processing power and memory. Using FPGAs, Powerlink, Sercos and EtherCAT achieve comparable cost levels, the ASIC implementation of EtherCAT reaches or undercuts fieldbus cost levels. Node costs for CC-Link IE Field are difficult to determine, since the ASICs are not available (at least not in Europe). CC-Link IE Control ASICs are not available at all.

**Development effort:** Assuming the TCP/IP stack is present, Modbus/TCP can be implemented with very low effort. PROFINET I/O requires about 1 MByte (!) of code. PROFINET IRT is very complex – not only but in particular the master. EtherCAT slaves can be implemented with very little effort, since all time critical functions are provided in hardware. EtherCAT masters range from very simple (e.g. with one process image) or more complex (e.g. with dynamic scheduling). Sercos development effort for slave devices is assumed to be similar to EtherCAT, since real time part is handled in hw, too. Development Effort for CC-Link IE Field are difficult to determine, since the ASIC manuals are not available (at least not in Europe).

**Master Costs:** Modbus/TCP, EtherNet/IP, PROFINET I/O and EtherCAT masters do not require a dedicated plug in card. Since EtherCAT masters typically only send one frame per cycle, the additional CPU load on the master is much lower than with the others in this group. For hard real time applications, PROFINET IRT, CC-Link IE, Powerlink and Sercos-III require special dedicated master cards with communication co-processors. For soft realtime requirements, Powerlink and Sercos-III can also be implemented with SoftMaster.

**Infrastructure Costs:** Whilst Modbus uses switches (but no special ones), EtherNet/IP (+ typically PROFINET RT) require manageable switches (EtherNet/IP with IGMP support). Depending on the topology, the integrated hubs (Powerlink) or switches (PROFINET-RT) or special switches (PROFINET-IRT, CC-Link IE) are sufficient - if not, external hubs or special switches are required. Sercos-III and EtherCAT do not require switches or any other active infrastructure components.



Strategic Topics (I)	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Size of supporting organization	++	+*	+*	○	+*	+*	○	++
Worldwide User Group	++	++	++	○	++	+	+	++
Worldwide Vendor Group	++	+	+	-	--	--	--	++
Technology Stability	++	+	○	-	--	-	○	++

\* Not all ODVA or PTO/PNO or CLPA members support Ethernet

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

**User Group Size:** No. of members in the user group is not crucial, but may serve as an indicator for the acceptance. As of Feb 2014, the EtherCAT Technology Group has 2662 member companies (membership free of charge\*), Sercos International has 58 member companies\*\*. EPSG (Powerlink) has 66 member companies\*\*\*. ODVA has 304 member companies\*\*\*\*. Profibus International (PI) consists of 25 regional organizations with a total of over 1400 members (Siemens is 25 x member), and CLPA\*\*\*\*\* has 1548 members, but their membership is predominantly fieldbus (Profibus, CC-Link) related. ModbusTCP is so widely used that the Modbus membership of 82 members\*\*\*\*\* only does not reflect its acceptance.

**Worldwide User Group:** ODVA, PI and CLPA are present worldwide – as is ETG, with offices in Europe, North America, China, Korea and Japan. Sercos has offices in Europe, North America and Japan.

**Worldwide Acceptance:** Modbus/TCP vendors exist worldwide. EtherNet/IP vendors are mainly from North America, some in Asia and Europe. Hardly and PROFINET RT products in Japan. Powerlink mainly implemented in Europe and China (open source). No non-German PROFINET IRT products known. No non-Mitsubishi CC-Link IE Control products, hardly any non-Japanese CC-Link IE Field products. No Non-European Sercos-III products known. EtherCAT has been implemented by vendors in 6 continents, and it widely accepted in Europe, NA, and Asia (including Japan).

**Technology stability:** Has the basic technology reached a stable state or are there still major changes?

\* since ETG membership is free of charge, membership figures should not be compared 1:1 with the other organizations.

\*\* according to website [www.sercos.de/www.sercos.com](http://www.sercos.de/www.sercos.com). + 9 Chinese Members of Sercos Asia + 8 Members of Sercos North America; all as of Feb 2014

\*\*\*according to EPSG Publication “PowerlinkFACTS” published in November 2007. In April 2007, there were 71 member companies. Since then now new membership figures published.

\*\*\*\* according to [www.odva.org](http://www.odva.org) as of Feb 2014

\*\*\*\*\* CLPA website claims 1900 members as of 2013, but in Feb 2014 lists only 313. There used to be a free of charge membership option – maybe this is the reason for the difference.

\*\*\*\*\* according to [www.modbus.org](http://www.modbus.org) as of Feb 2014



Strategic Topics (II)	Modbus /TCP	Ethernet /IP	Profinet RT	Powerlink	Profinet IRT	CC-Link IE	Sercos III	EtherCAT
	Special Hardware used?	++	++ - (CIP Sync)	++	○ (FPGA)	- (M+S)	- (M+S)	○ (FPGA)
Adoption Rate?	++	+ - (CIP Sync)	+	-	- (IRT) -- (IRT2.3)	--	○	++
International Standardization	+	+	+	+	+	(+)	+	+

February 2014 © EtherCAT Technology Group Industrial Ethernet Technologies

**Special Hardware Used:** Modbus/TCP, EtherNet/IP (not: CIPsync) + PROFINET RT can be implemented with standard hardware chips. For Powerlink, recommended implementation is with FPGA. PROFINET IRT, CC-Link require special chips in master and slave, Sercos-III need special chips (e.g. FPGA) in aster and slave, EtherCAT requires an EtherCAT Slave Controller (FPGA or ASIC) but no special chips, cards or co-processors in the master.

**Adoption Rate:** Modbus TCP has been used for many years. EtherNet/IP, PROFINET RT are spreading. Since 2007: hardly any new Powerlink products. Potential PROFINET IRT vendors wait for technology stability (IRT+). CC-Link IE Control: only Mitsubishi products (except cable + connectors), CC-Link IE Field: very few non-Mitsubishi products so far. Sercos-III 1.1 started shipping in December 2007. EtherCAT: large selection of master and slave devices from large variety of vendors (e.g. over 90 different servo drive vendors, 60 I/O device vendors, over 120 master vendors); more than 1200 implementation kits sold, many more devices expected soon.

**International Standardization:** As far as international standardization is concerned, all are part of IEC 61158 and IEC 61784-2 since Oct 2007 – the only exception is CC-Link IE, which is expected to become an IEC standard in 2013 (only the application layer, though)

Modbus-TCP: Communication Profile Family (CPF) 15, IEC 61158 Type 15

EtherNet/IP: CPF 2, IEC 61158 Type 2


PROFINET: CPF 3, IEC 61158 Type 10

Powerlink: CPF 13, IEC 61158 Type 13


CC-Link IE: CPF 8, IEC 61158 Type 23 (expected to be published in 2014)

Sercos-III: CPF 16, IEC 61158 Type 19

EtherCAT: CPF 12, IEC 61158 Type 12



- Classification
- PROFINET
- EtherNet/IP
- CC-Link IE
- Sercos III
- Powerlink
- Modbus/TCP
- EtherCAT
- Summary



Thank you!

February 2014

© EtherCAT Technology Group

Industrial Ethernet Technologies