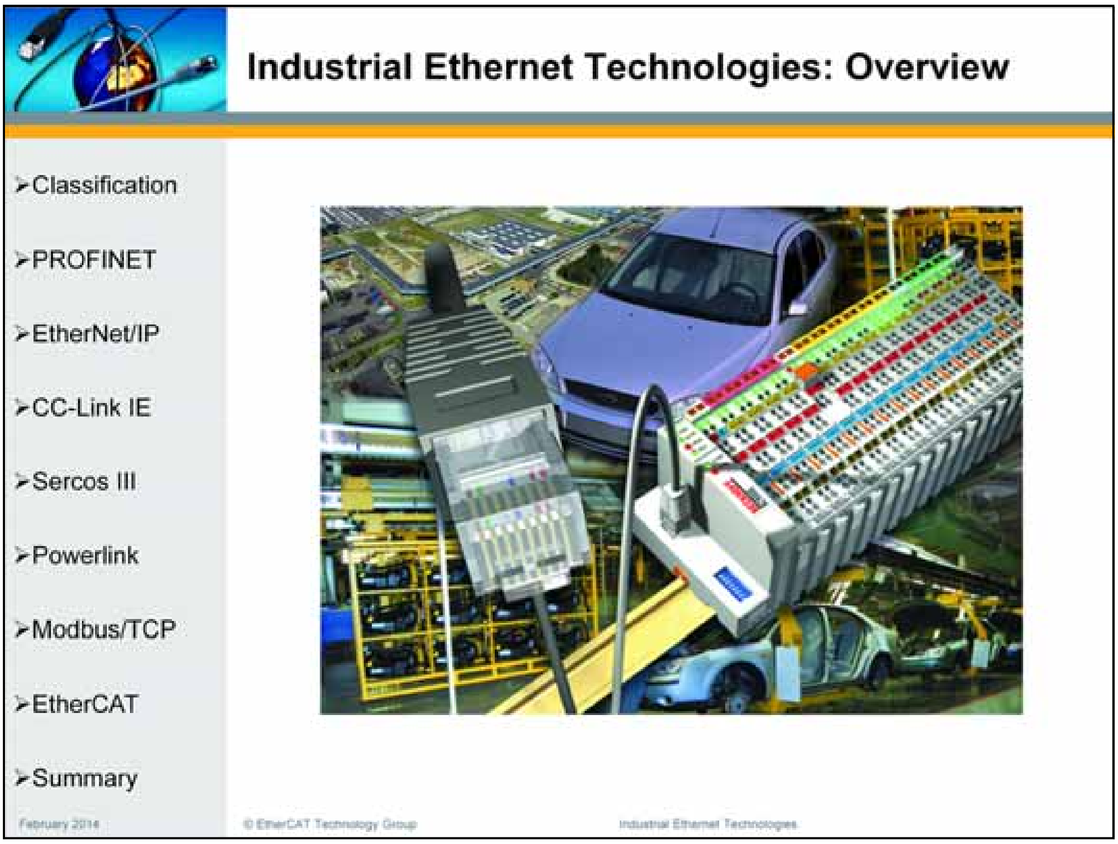


Editorial Preface:

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.

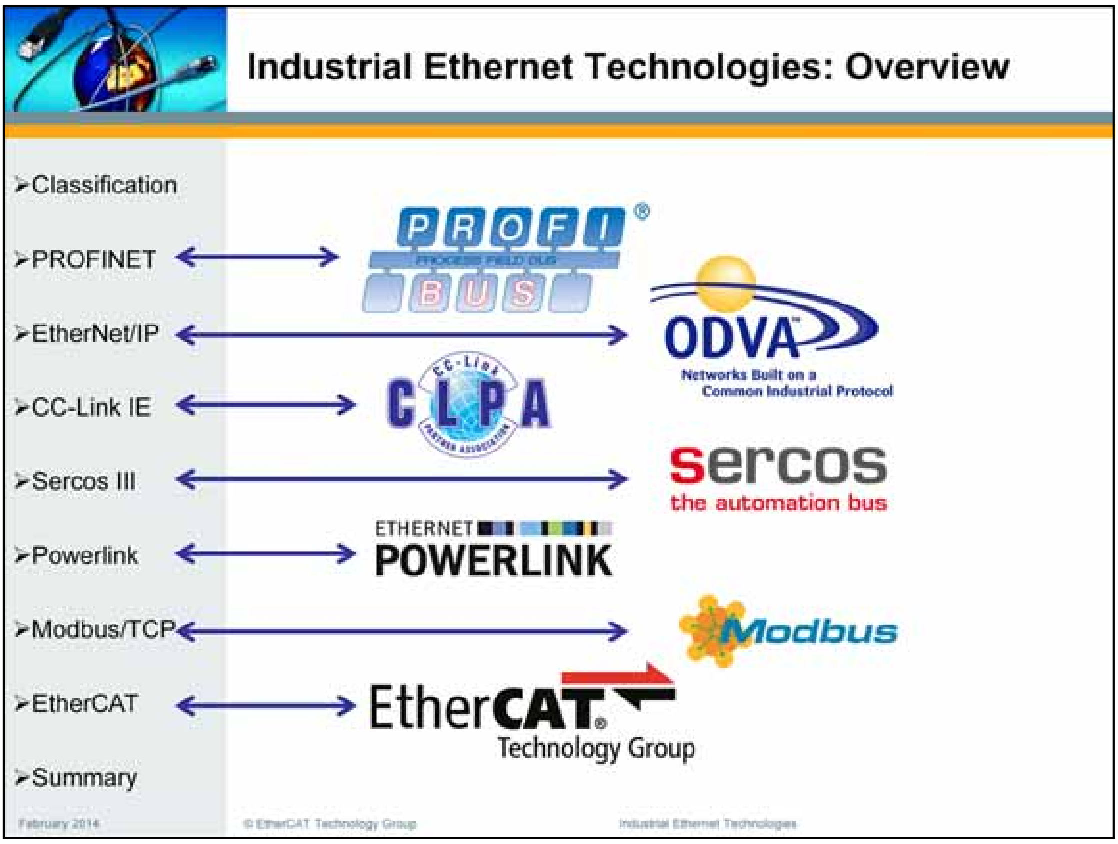
The content given represents my best knowledge of the systems introduced. Since the company I work for is member of all relevant fieldbus organizations and supports all important open fieldbus and Ethernet standards, you can assume a certain level of background information, too.

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.

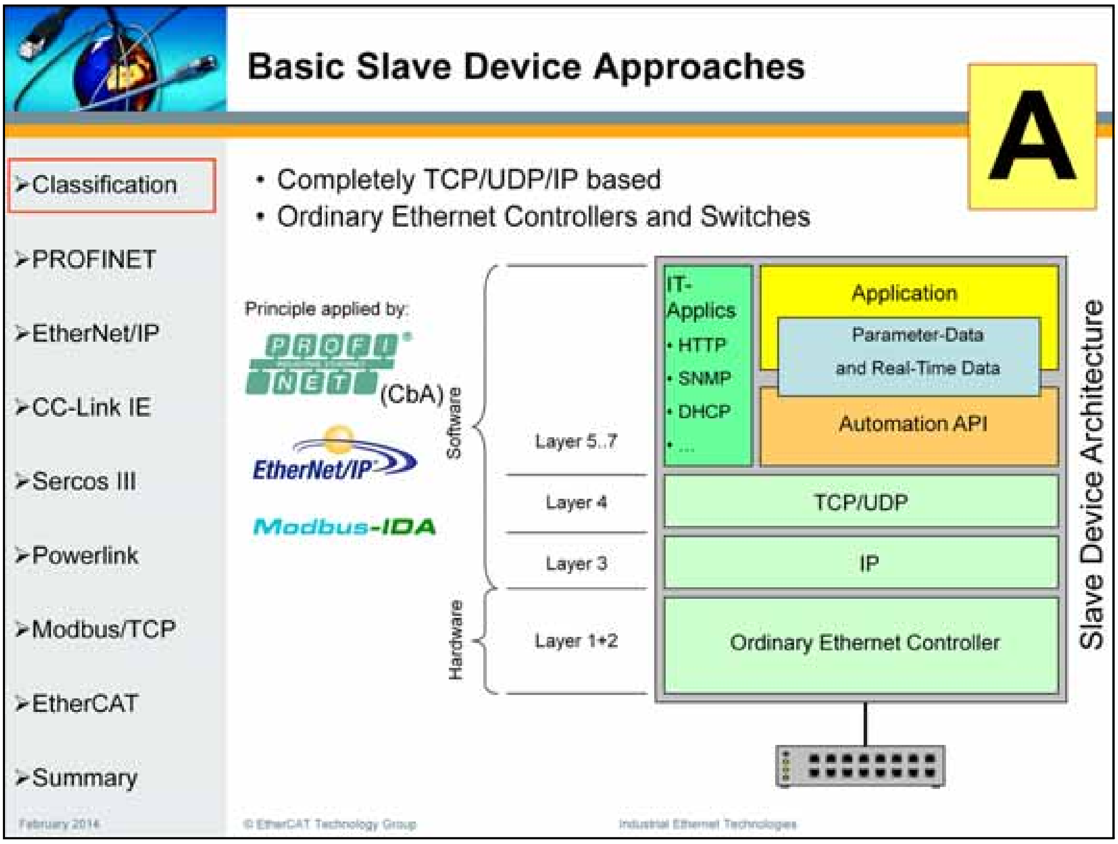
Nuremberg, February 2014

Martin Rostan, m.rostan@ethercat.org



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.

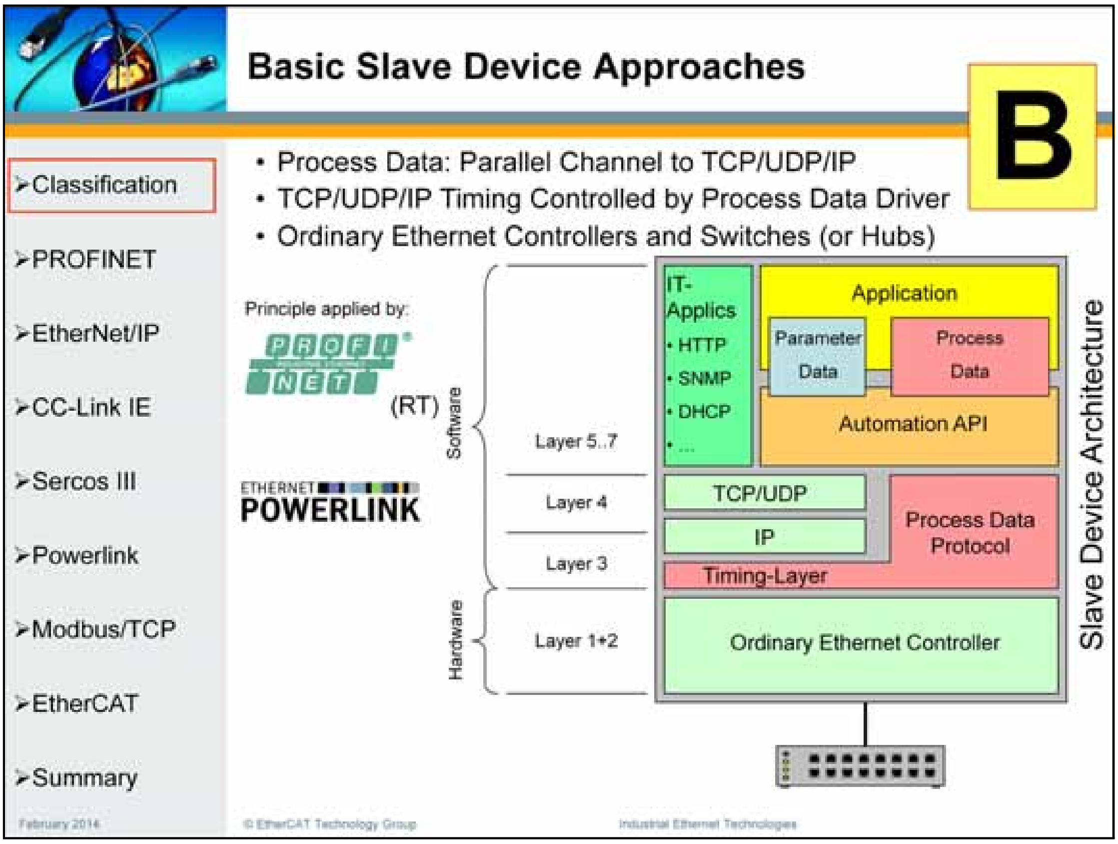
All technology names as well as the names of the organizations promoting and supporting those are trademarked. The trademarks are honored.



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.

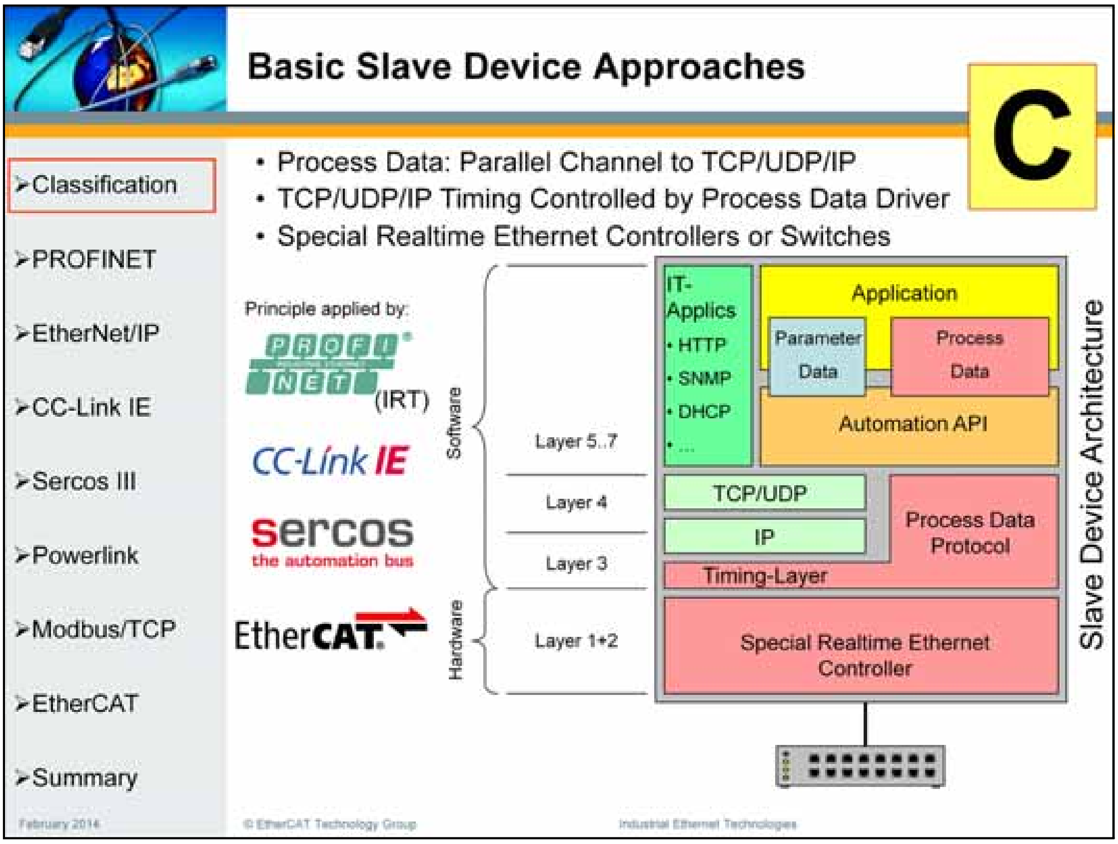
Class A approaches are also referred to as „best effort“ approaches. The real time performance is limited by unpredictable delays in infrastructure components like switches – no just due to other traffic on the network. The by far largest obstacle to better real time performance however is provided by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



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.

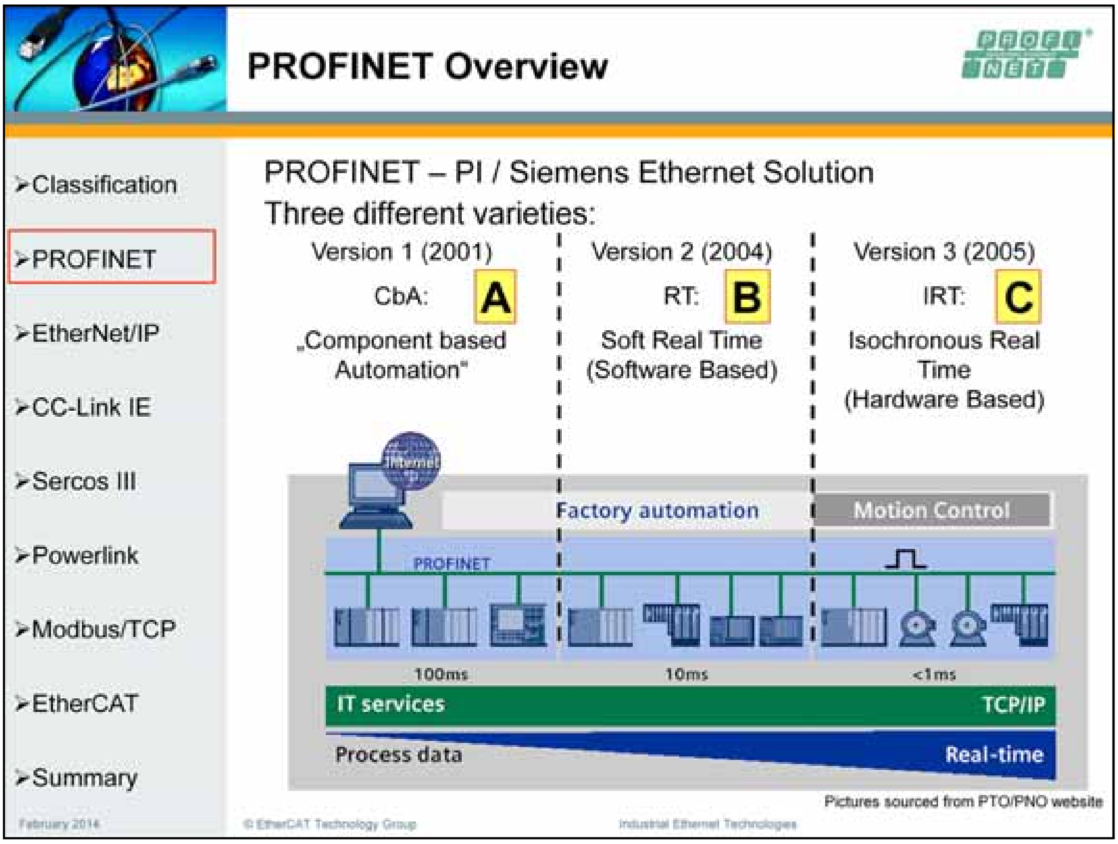
Of course this description is pretty generic – but more details are given in the technology specific sections.



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.



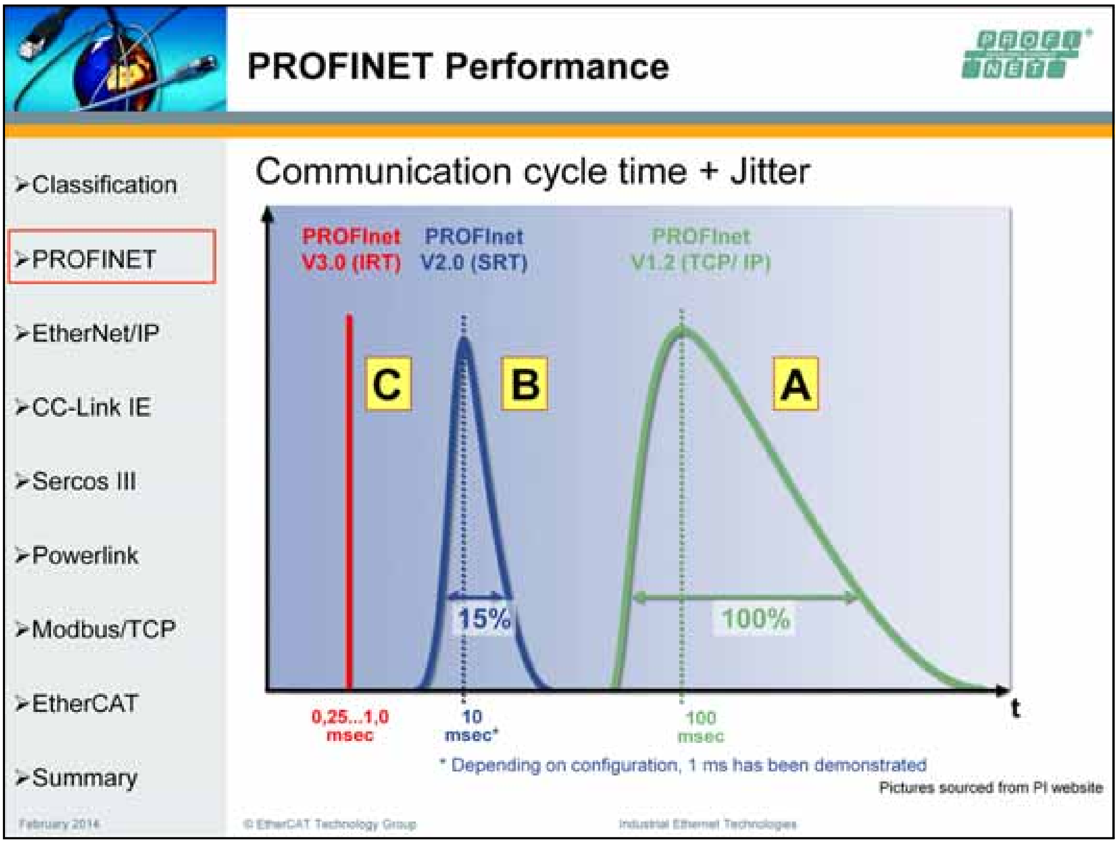
There are 3 PROFINET-Versions:

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

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

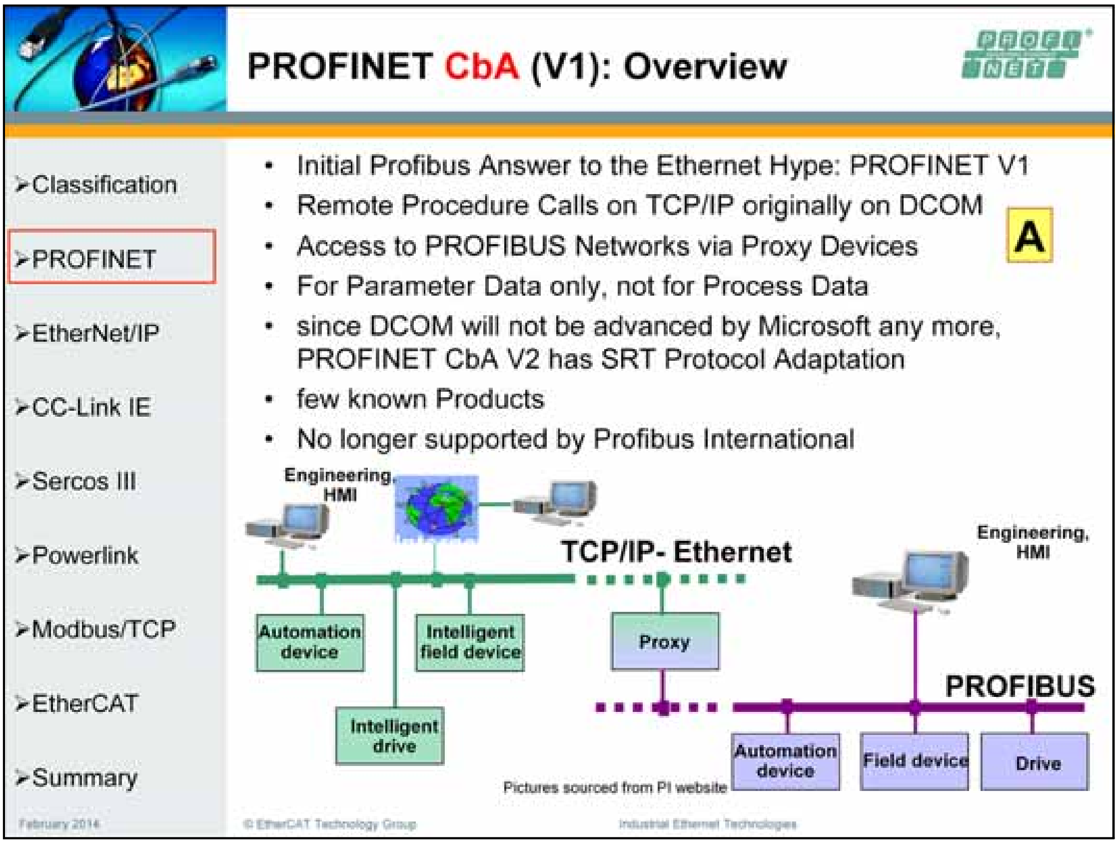
Version 3: („Isochronous Real Time"), a Class C approach

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.

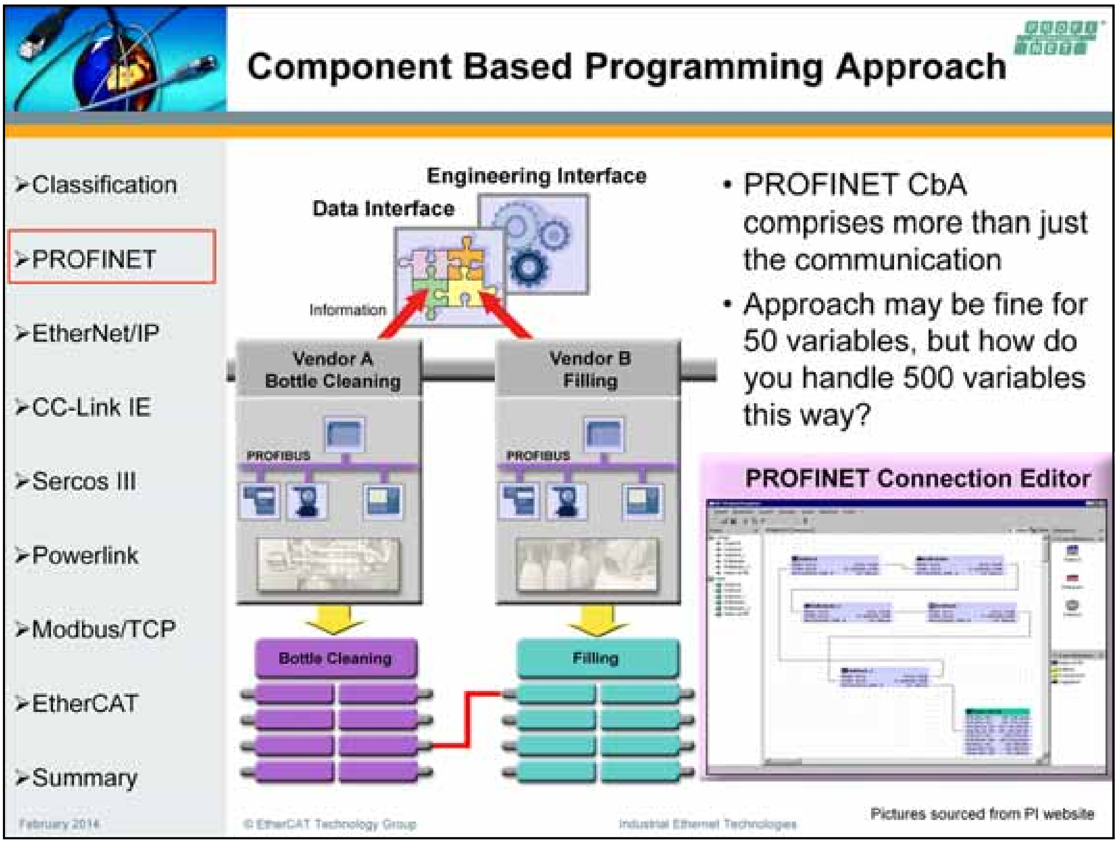
The jitter shown in the graph above show the intended values for the end device – and do not necessarily cover the jitter caused by the network (e.g. forwarding jitter of the switches)



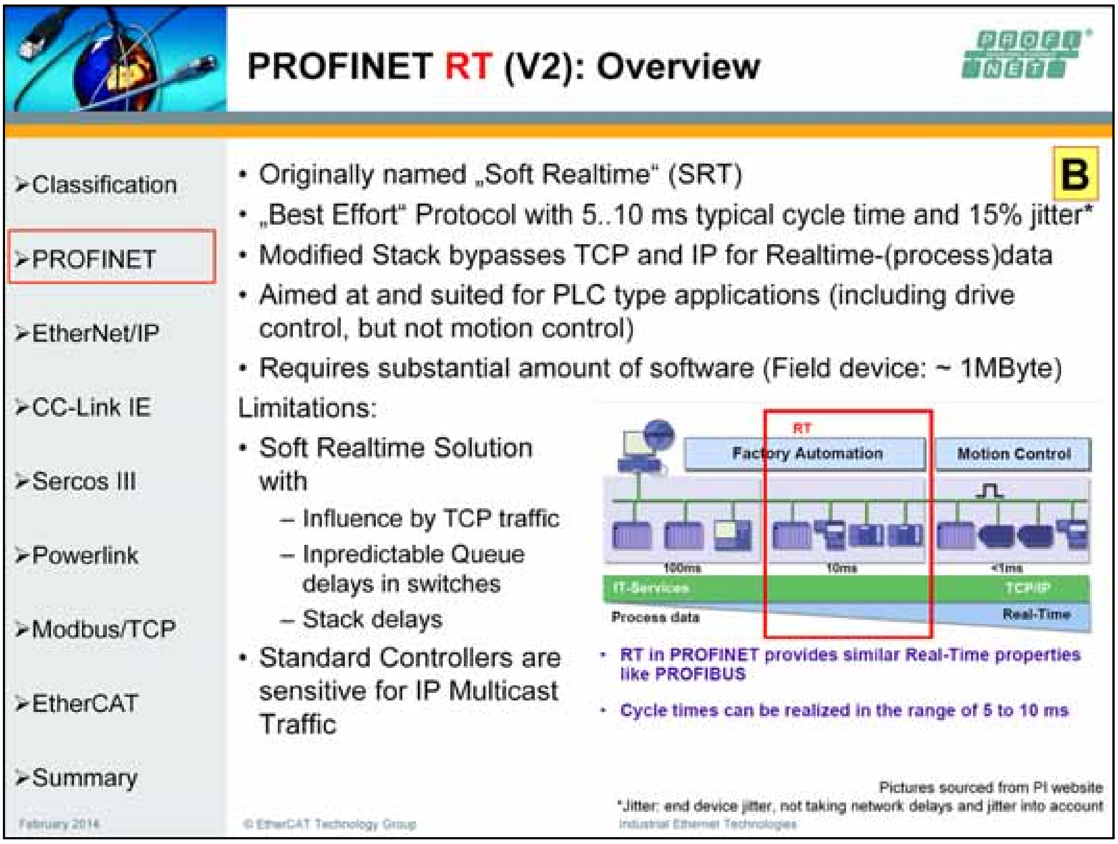
Initially the PNO/PTO message was: protect your investment and continue using Profibus, for Ethernet connectivity we provide a transparent gateway.

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.



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.

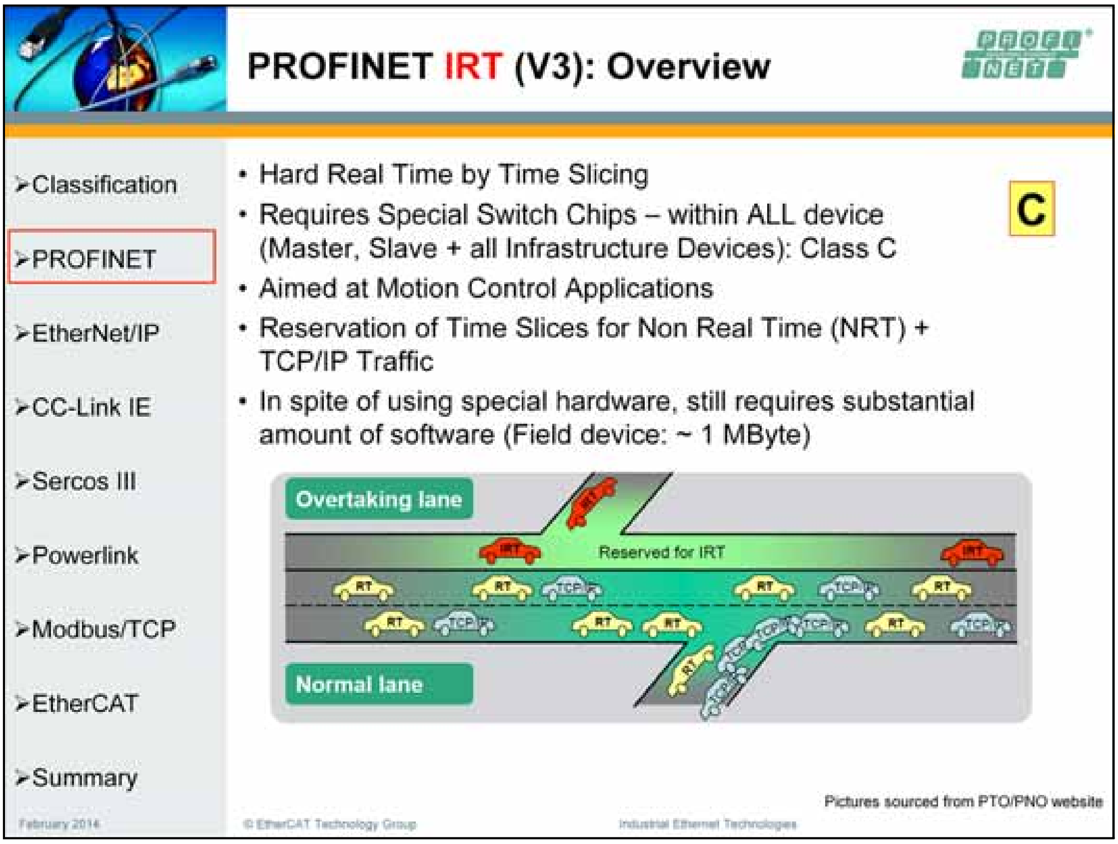


PROFINET V2 was initially called SRT (Soft Real-time). The term „soft“ was later dropped for marketing reasons.

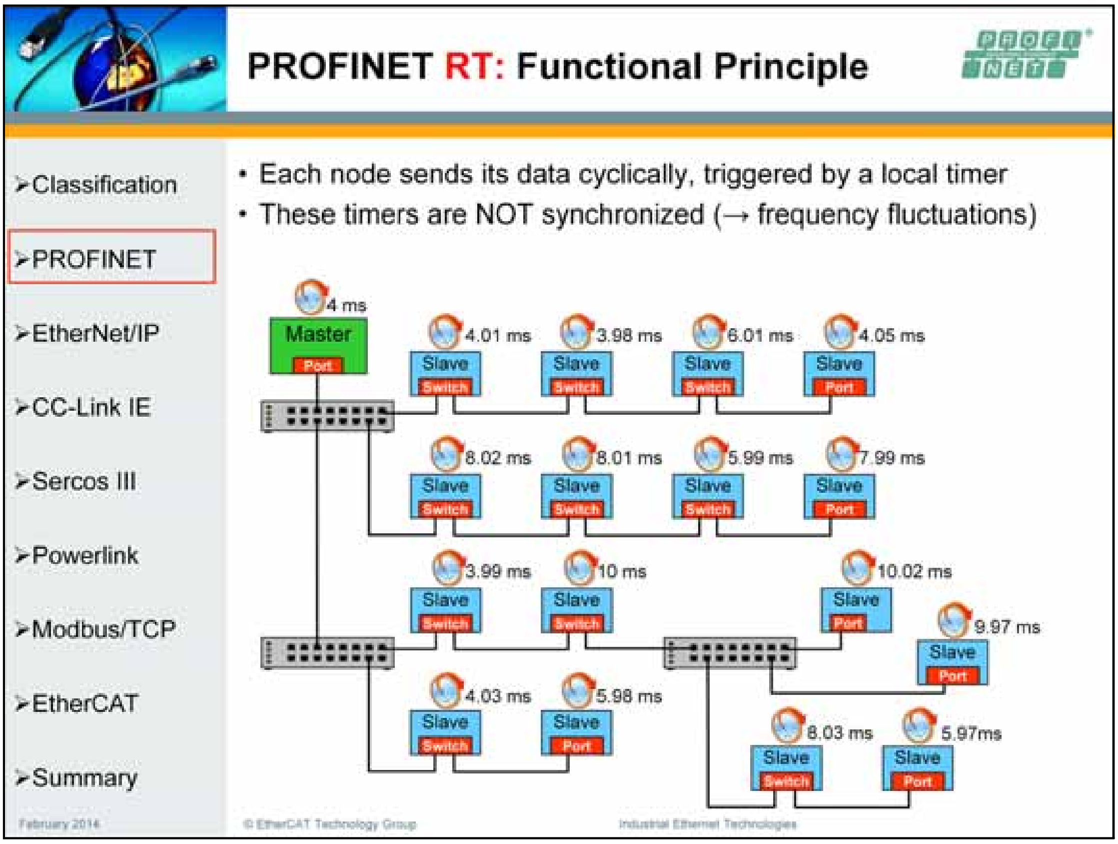
PROFINET RT is meanwhile mainly addressed as PROFINET I/O (together with IRT).

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:

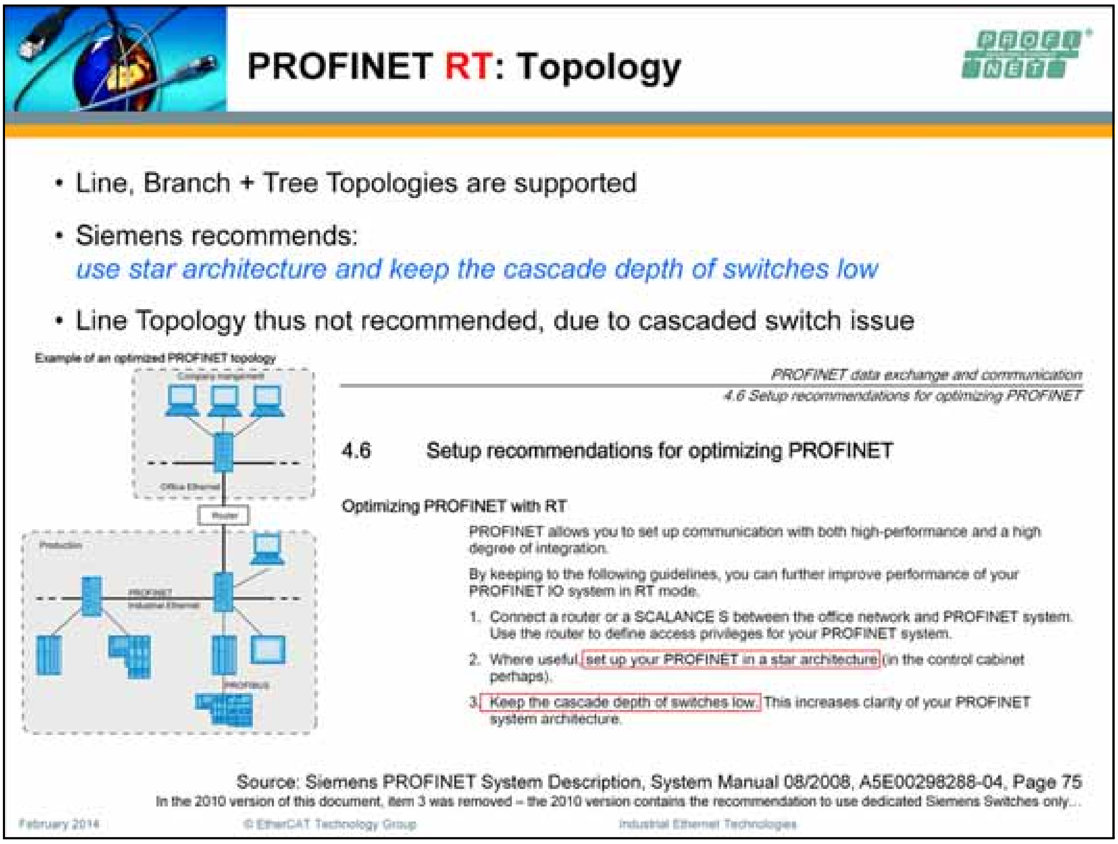
If Profibus performance is sufficient, but Profibus is not expensive enough, PROFINET RT is an alternative.



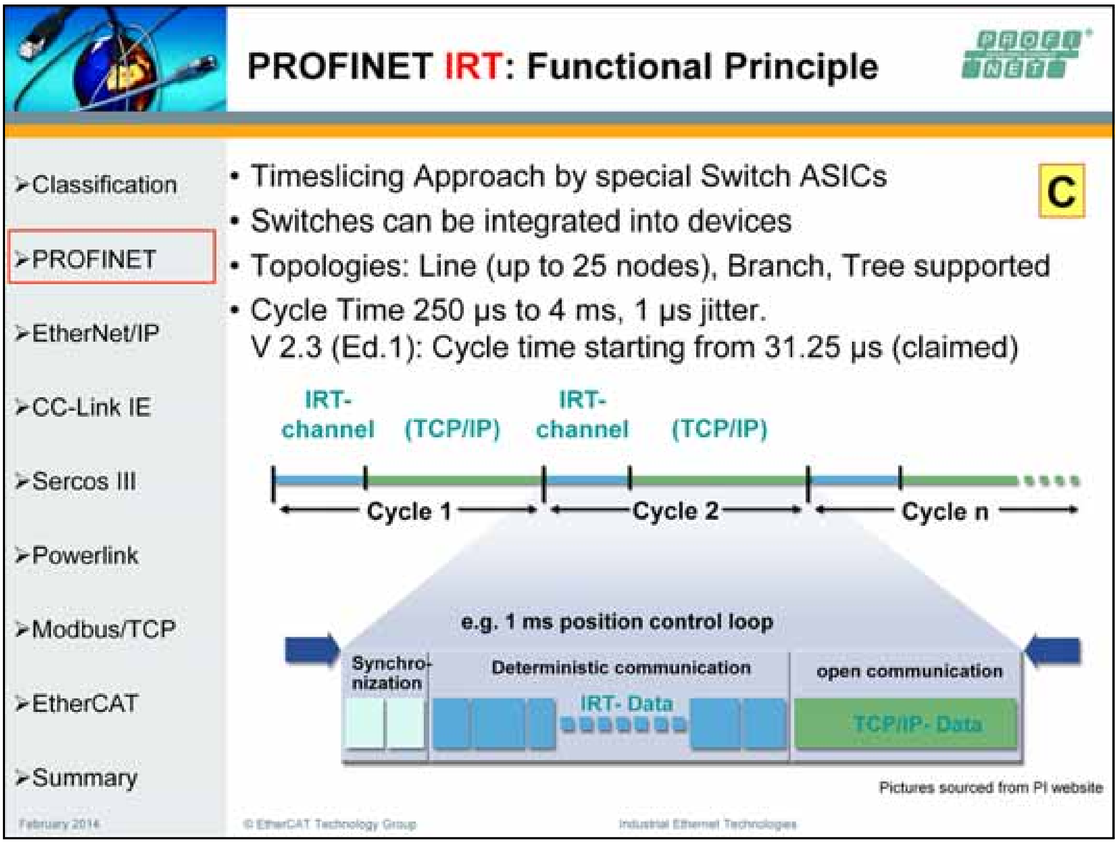
PROFINET IRT (V3) is a class C approach which introduces special hardware in order to achieve sufficient performance and synchronicity for motion control applications.



In PROFINET RT, cyclic data exchange is triggered by local timers, which are NOT synchronized (High Precision Time synchronization with PTCP 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.



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

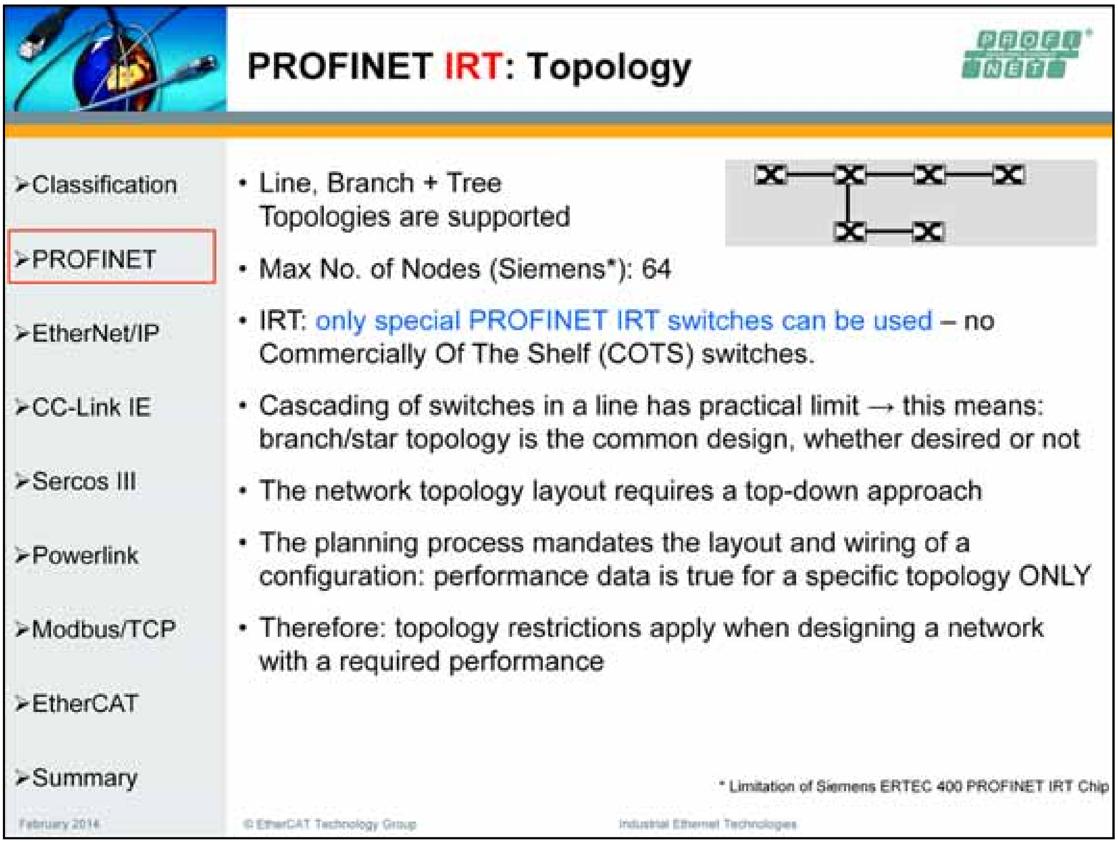


The minimum cycle time is determined by the approach to include generic TCP/IP traffic in a gap wide enough for the largest Ethernet frame.

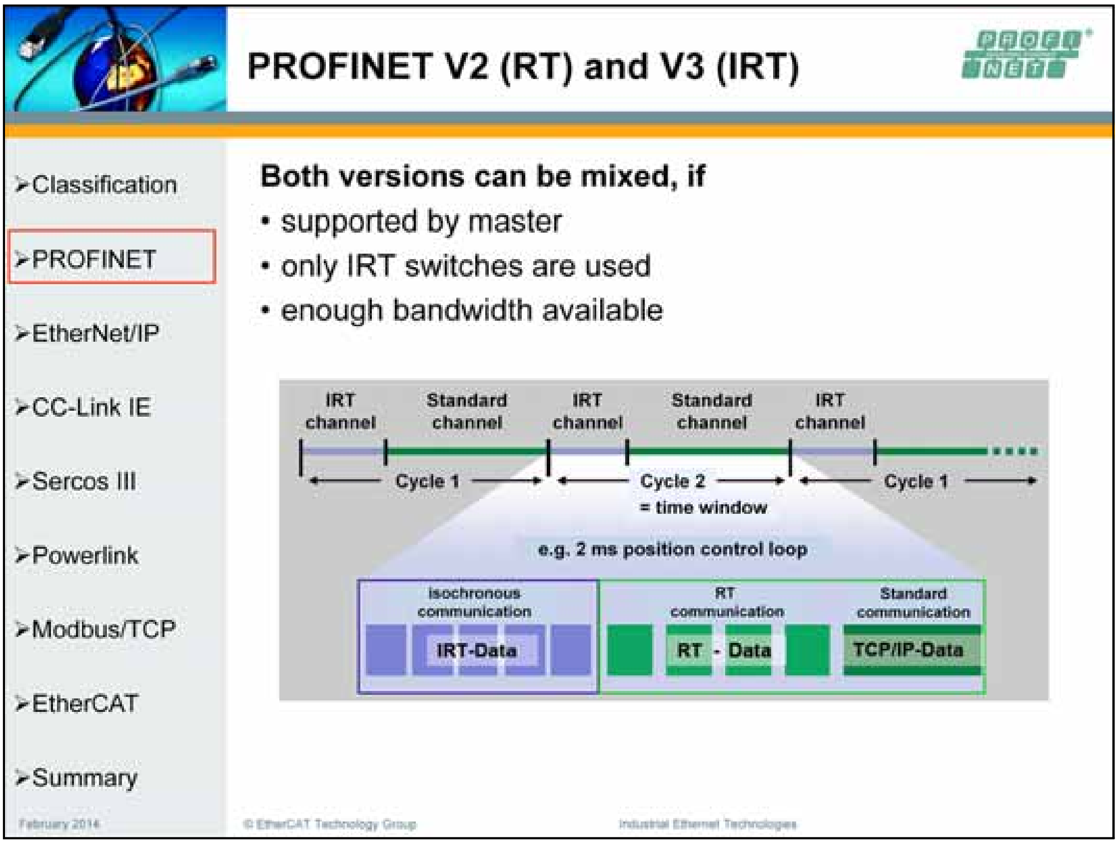
This approach leads to limited bandwidth utilization, since even though most applications only have sporadic TCP/IP communication, the bandwidth remains reserved for this kind of traffic.

For cycle times below 250µs 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 250µs (Motion Controller) or at 1ms (e.g. PLC S7-315).



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.

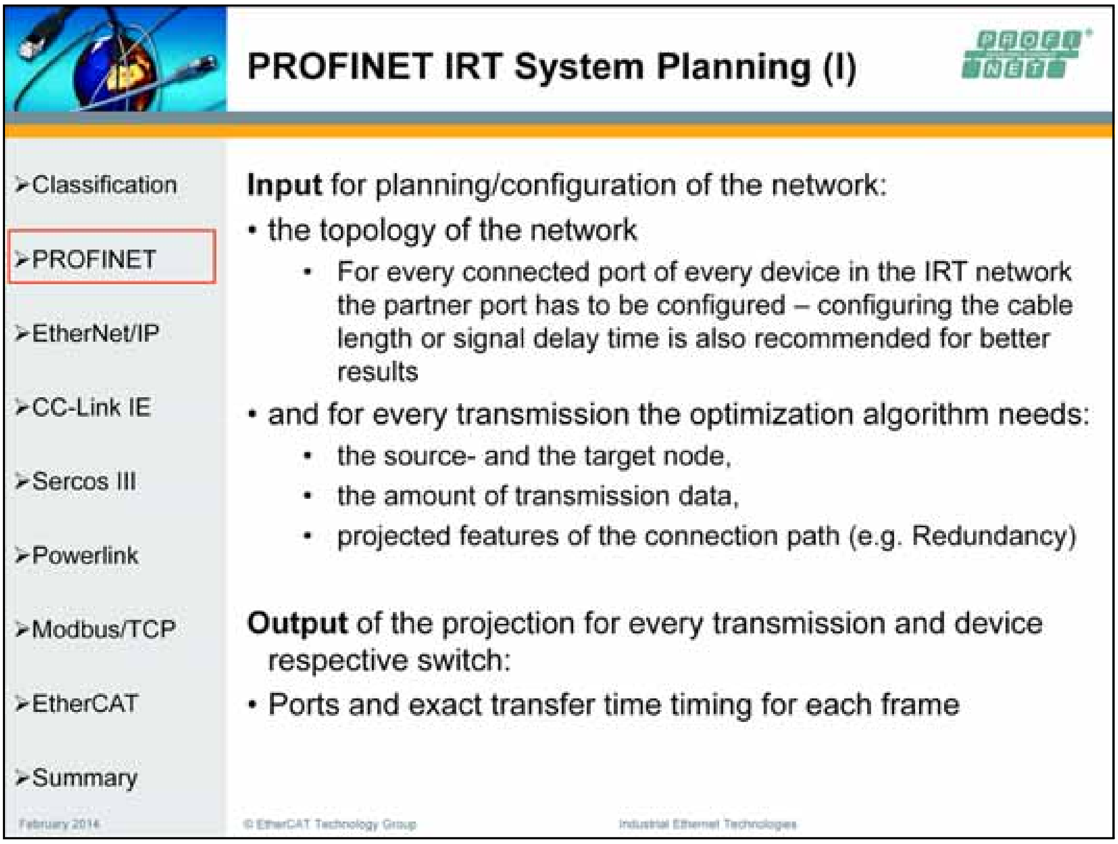


In principle both varieties (RT+IRT) can be mixed. Since IRT switches have to be used then, one can say:

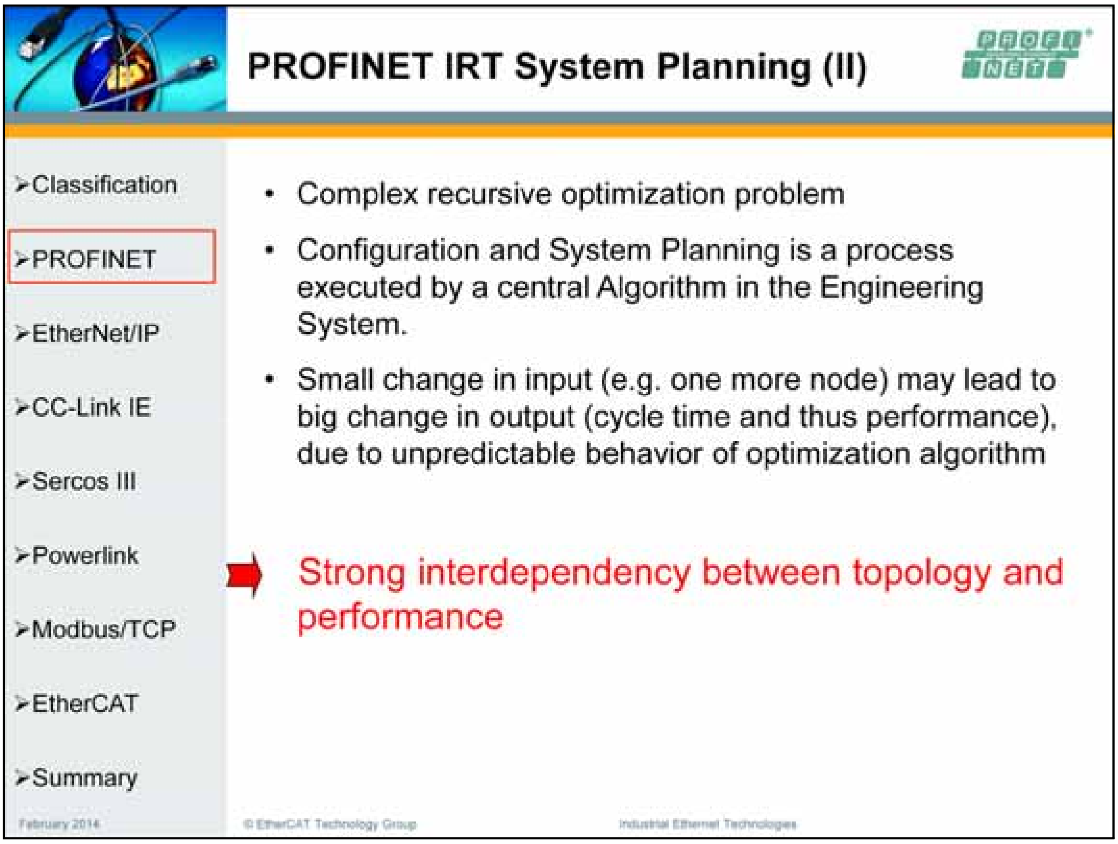
RT devices can be integrated in IRT networks, if there is sufficient bandwidth and if the master supports this.

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



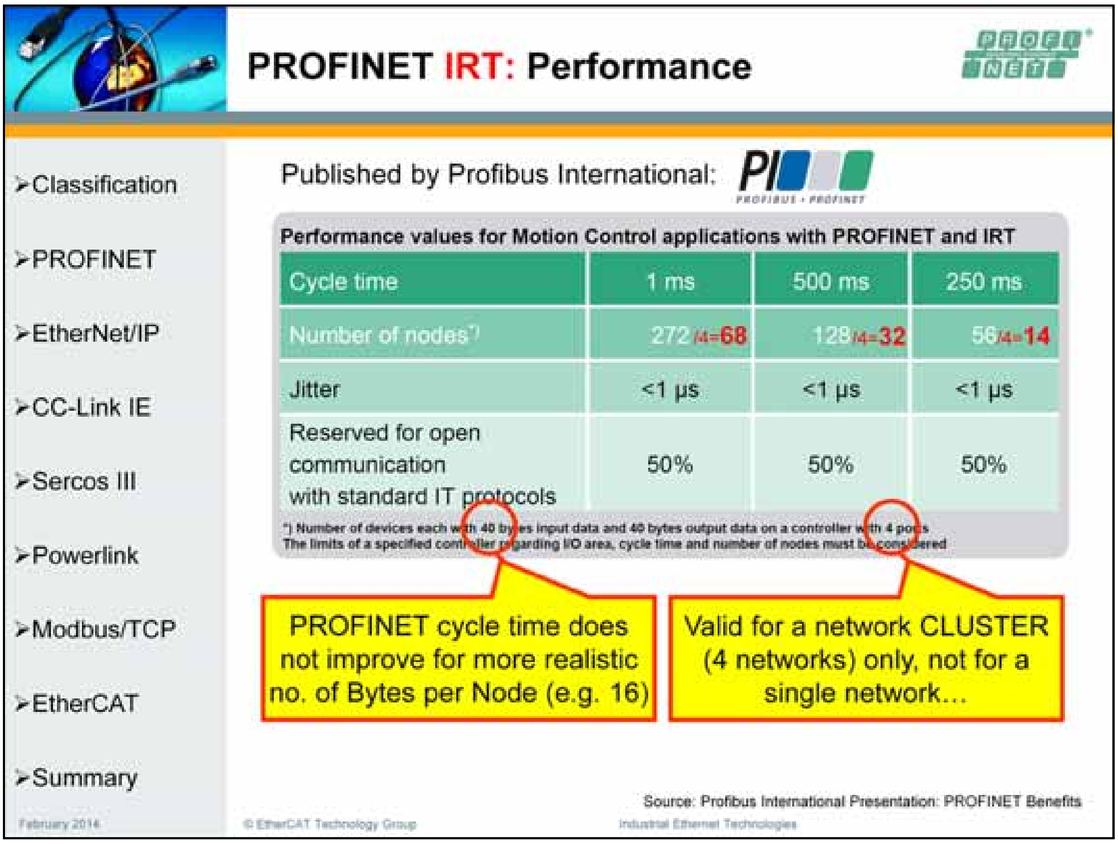
Besides hardware costs, the crucial issue of PROFINET IRT is the complex system planning.



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.

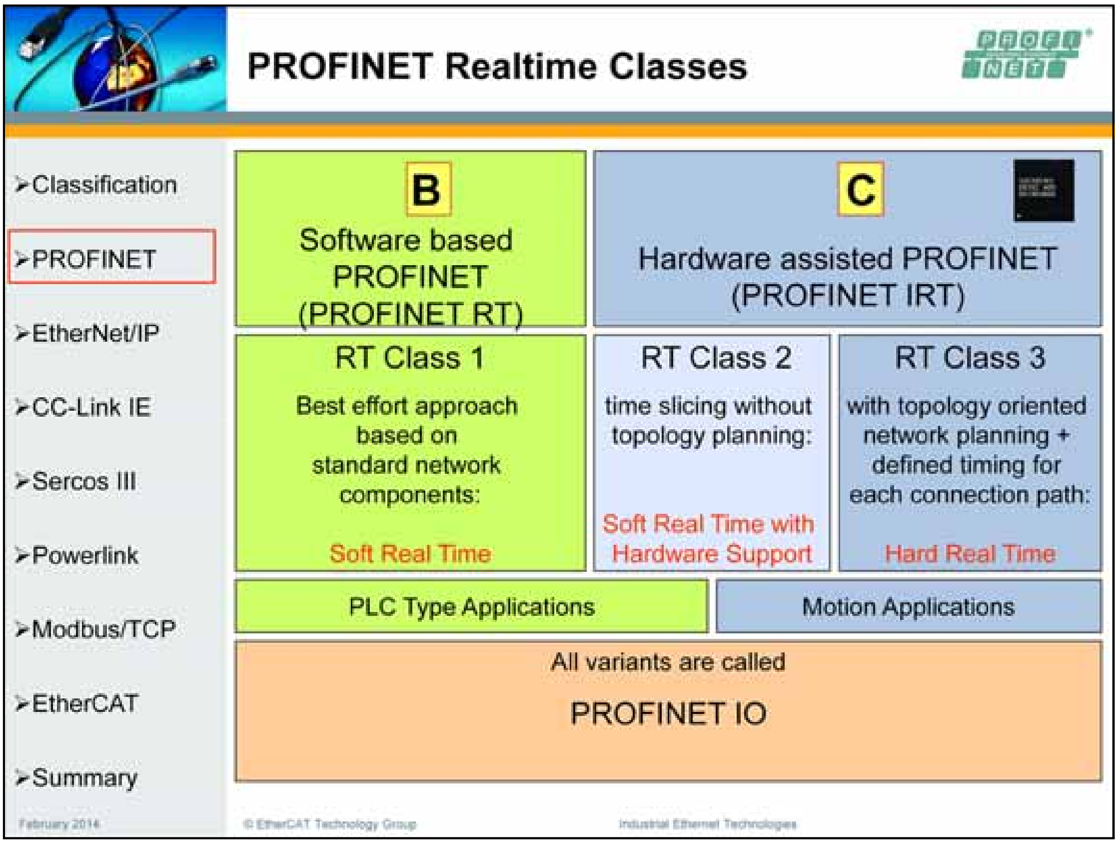


This is the performance data table published for PROFINET IRT. However, the table is valid only for a cluster of networks: 272 nodes sharing 50% bandwidth at 1ms cycle time means 500 µs / 272 = 1,84 µs per node. The shortest Ethernet frame takes 7µs to transmit.

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...

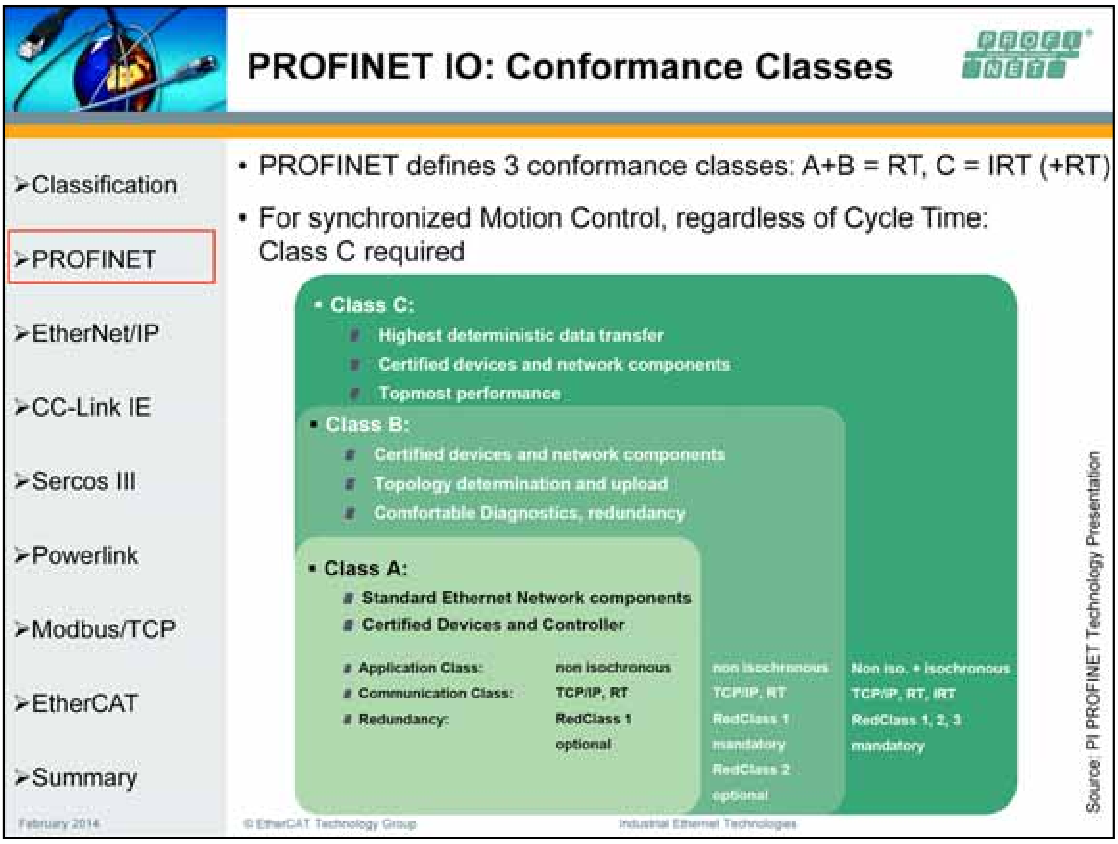


In order to avoid the complex topology network planning process, an intermediate approach had been introduced: Realtime (RT) Class 2 (within Siemens also called IRT "Flex" or "IRT with high flexibility") using PROFINET chips (e.g. ERTEC). High priority network traffic is sent in the IRT time slice, but 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".

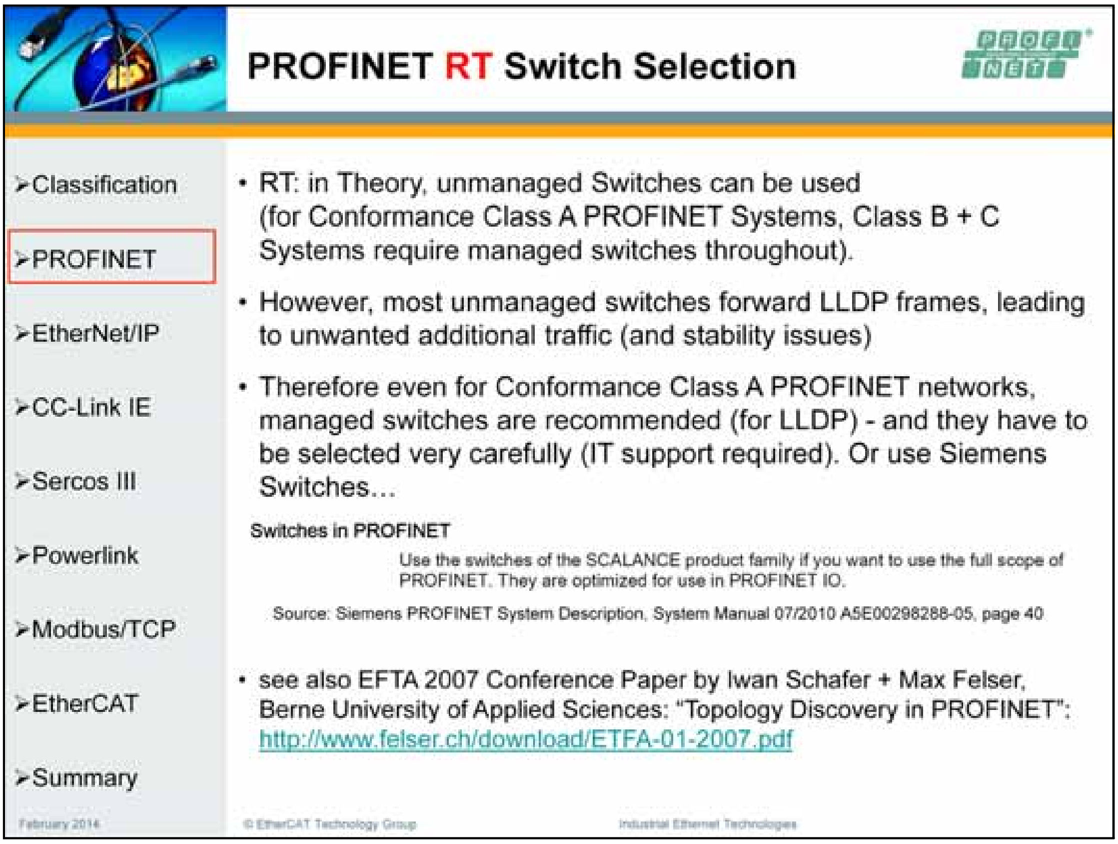


In addition to the RT classes, PROFINET has introduced (see IEC 61784-2) **Application Classes** (Isochronous for motion control, Non-isochronous for factory process + building automation),

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.

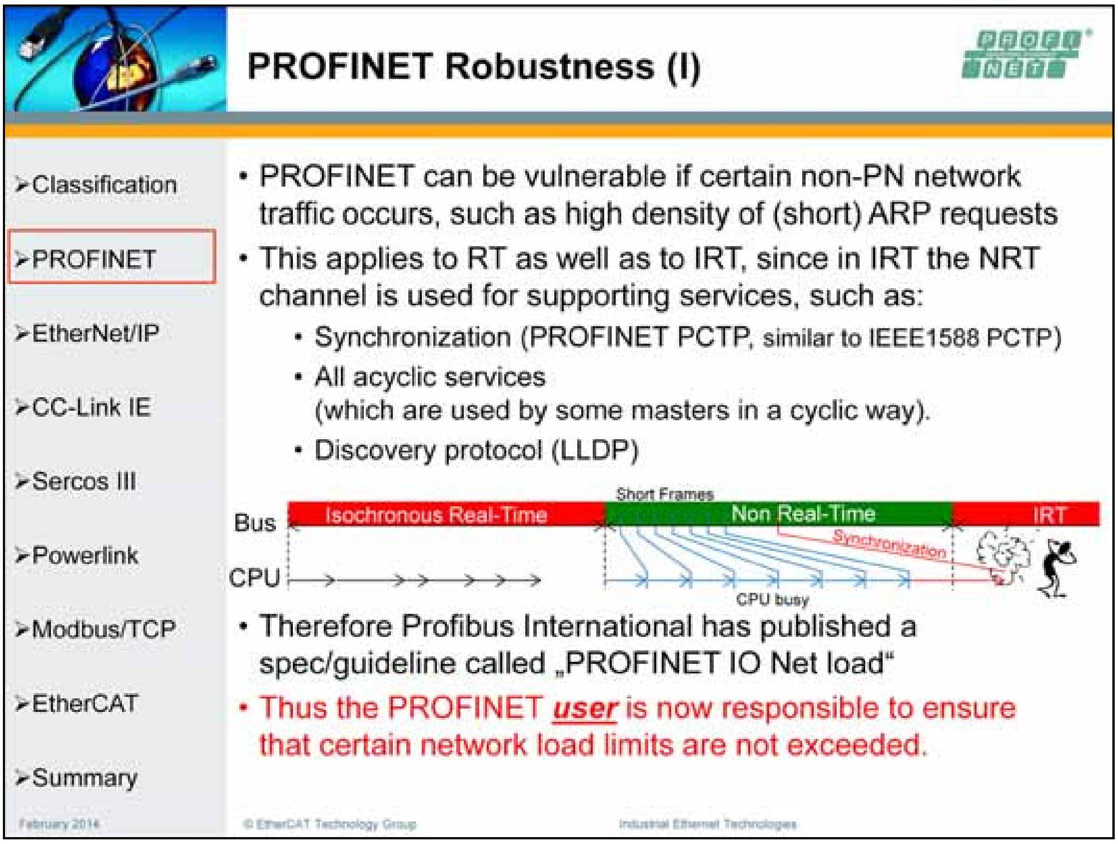
Topology Recognition originally was required for Conformance Class B + C, only; meanwhile this is required for Conformance Class A (but without LLDP-MIB).



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

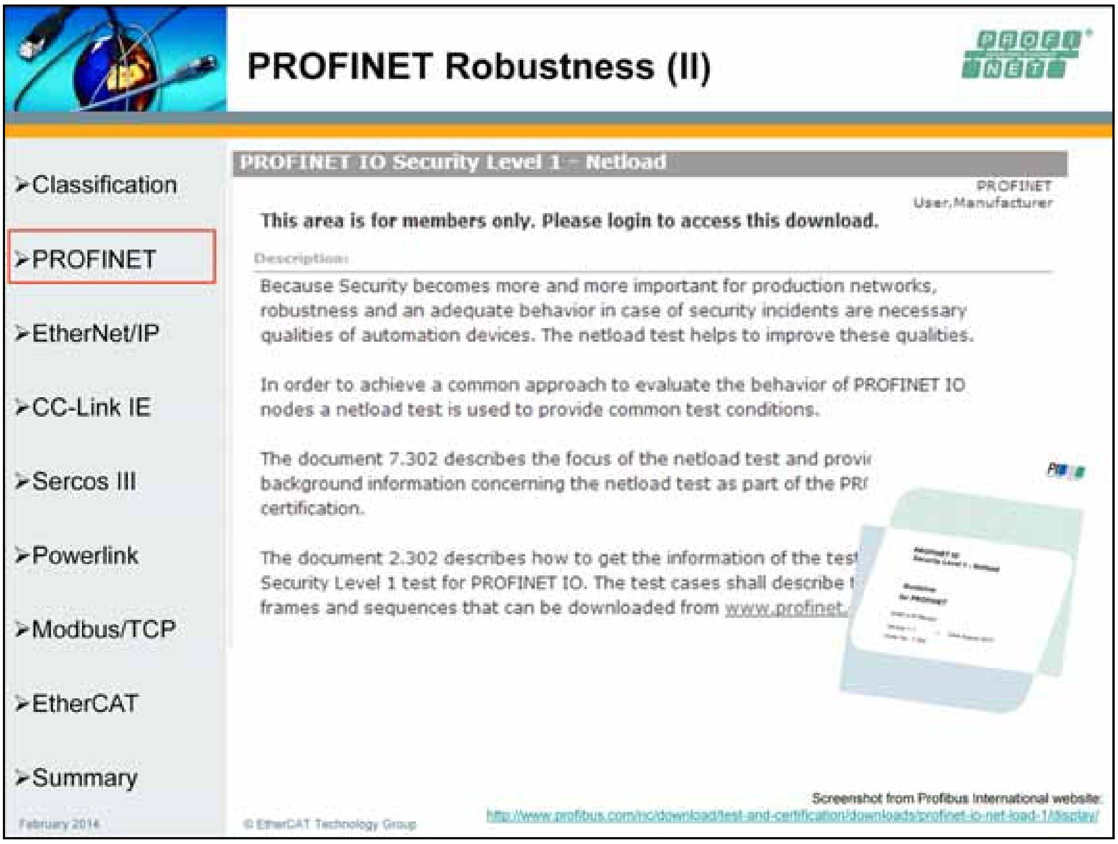
- "Unlimited IT communications parallel to real-time communications
- Easy use and integration of standard Ethernet applications"

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.

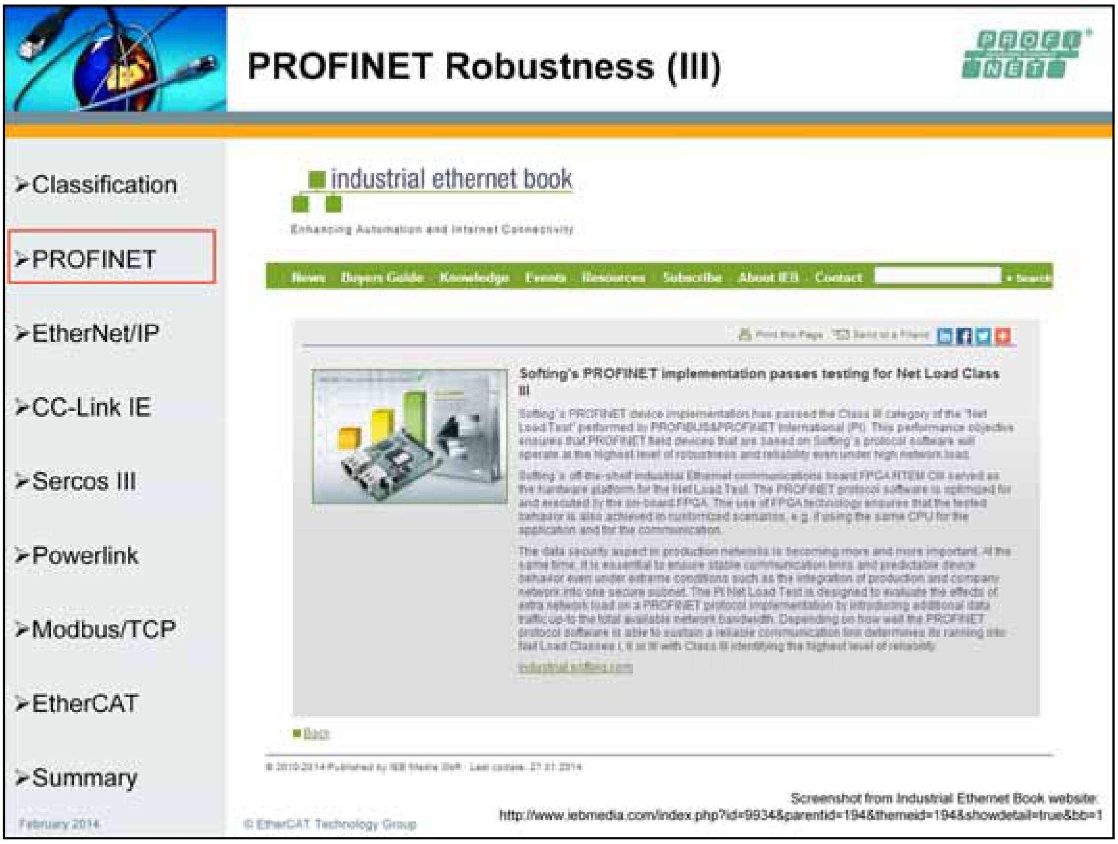
One could consider this an implementation problem that can be avoided by providing sufficient processing resources throughout – but it is a problem that occurs in reality, especially in large networks. And adding resources such as processing power eases the problem, but does not resolve it reliably.

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?

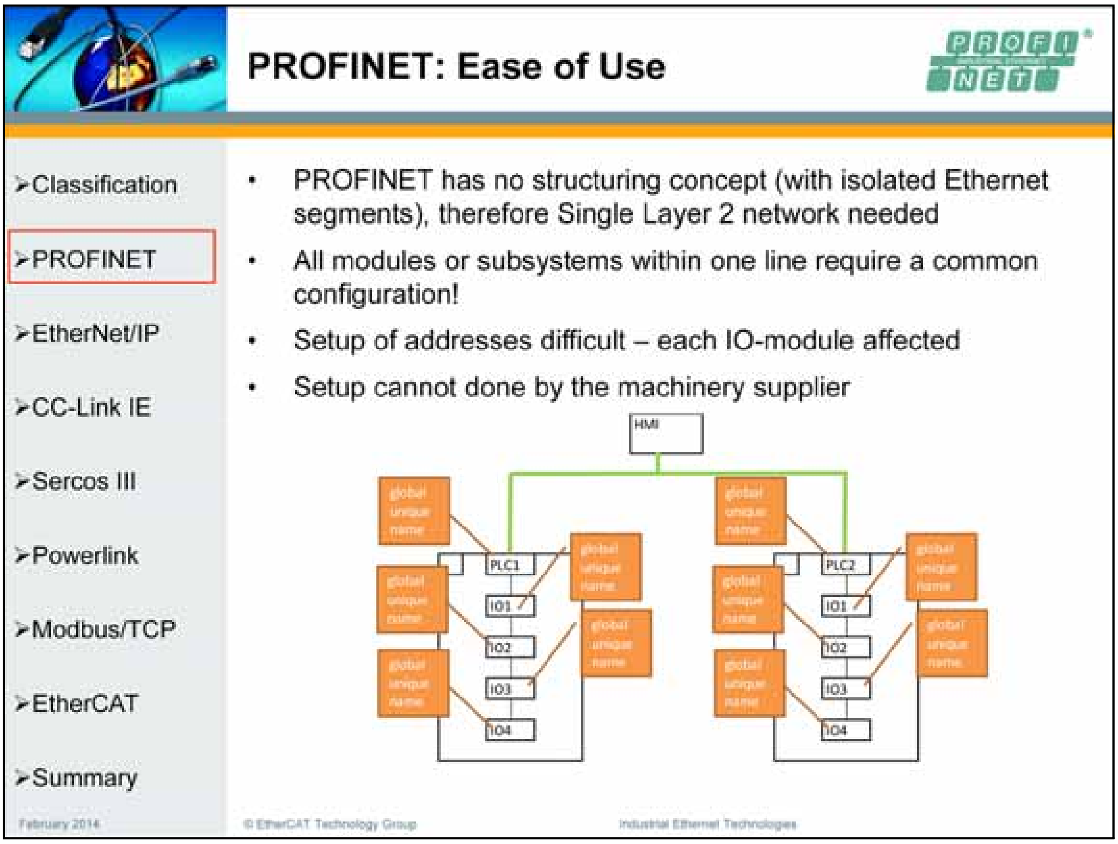
By the way: Industrial Ethernet technologies that tunnel other Ethernet traffic - such as EtherCAT – remain in control of the additional network load and avoid such situations by design.



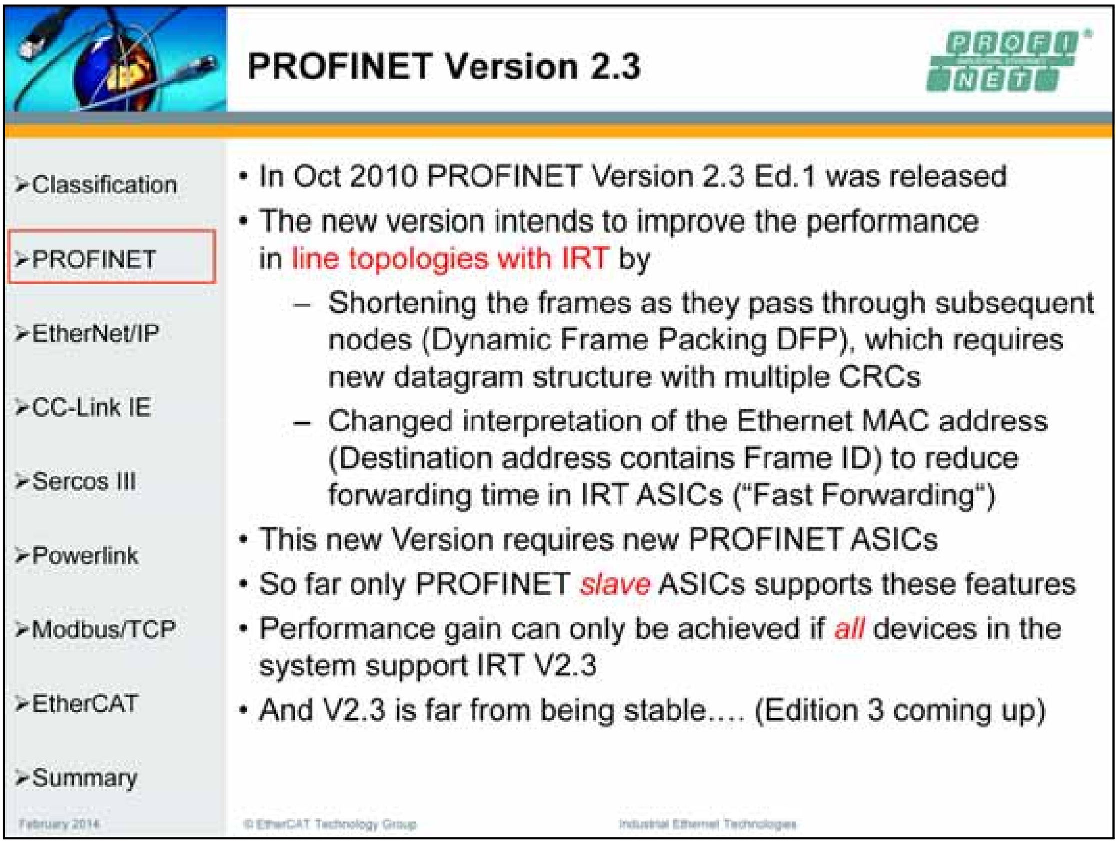
Regardless of the net load class, PROFINET IO devices are only required to handle 50 ARP request per second (in any density within that second). This means that things may go wrong if an average of one ARP request per 20 ms is exeeded. The latest draft version of the PROFINET IO Security Level 1 - Netload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



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?



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.



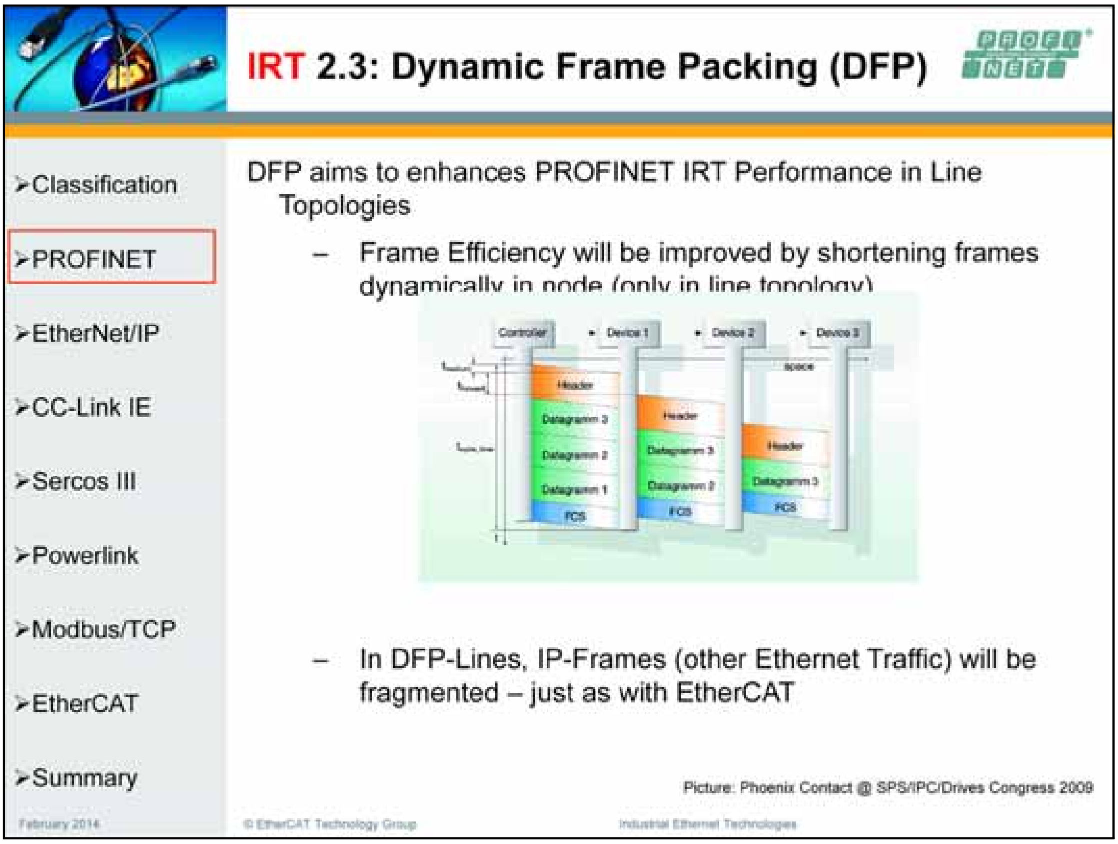
Profibus organization PNO showed a PROFINET IRT+ demonstrator in April 2008 at Hannover Fair. According to a PNO press release of Nov 26, 2008, *"The specifications will be finished in the second half of 2009*".

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.

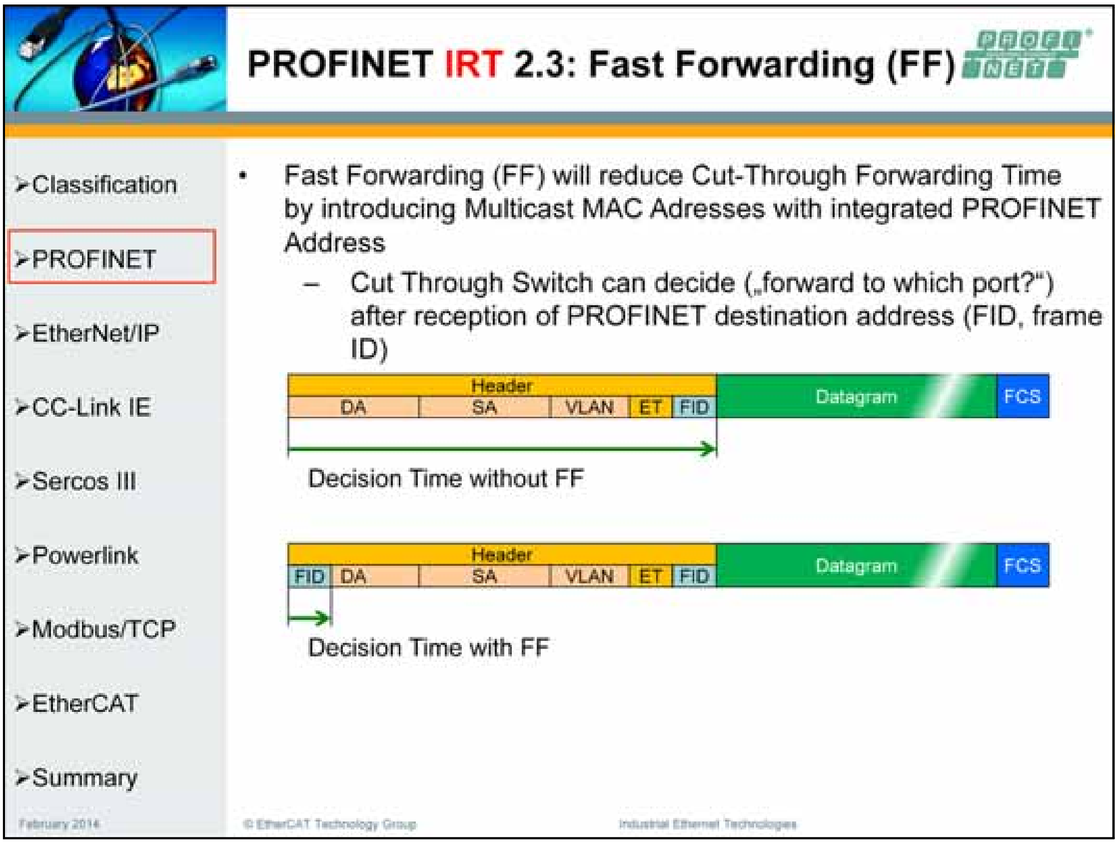
The next version V2.3Ed.2MU1 was published in October 2013.
(substantial change log in Technical-editorial-Changes-d23Ed2MU1_V1_Oct13.pdf).

Currently PNO is working on Ed. 3.



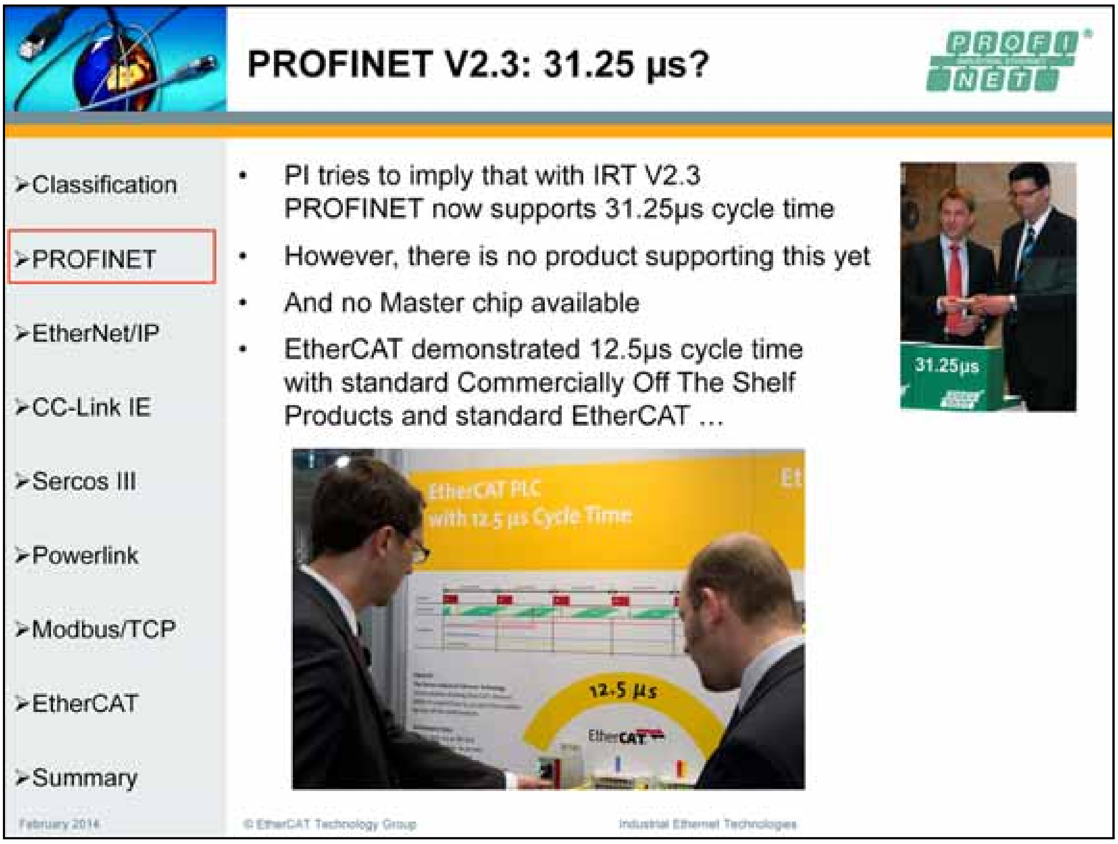
DFP will work in line topologies, only.

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



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 µs?
PROFINET
➢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 31.25µs cycle time
• However, there is no product supporting this yet
• And no Master chip available
• EtherCAT demonstrated 12.5µs cycle time with standard Commercially Off The Shelf Products and standard EtherCAT …
31.25µs
EtherCAT PLC
with 12.5 µs Cycle Time
12.5 µs
EtherCAT
February 2014
© EtherCAT Technology Group
Industrial Ethernet Technologies

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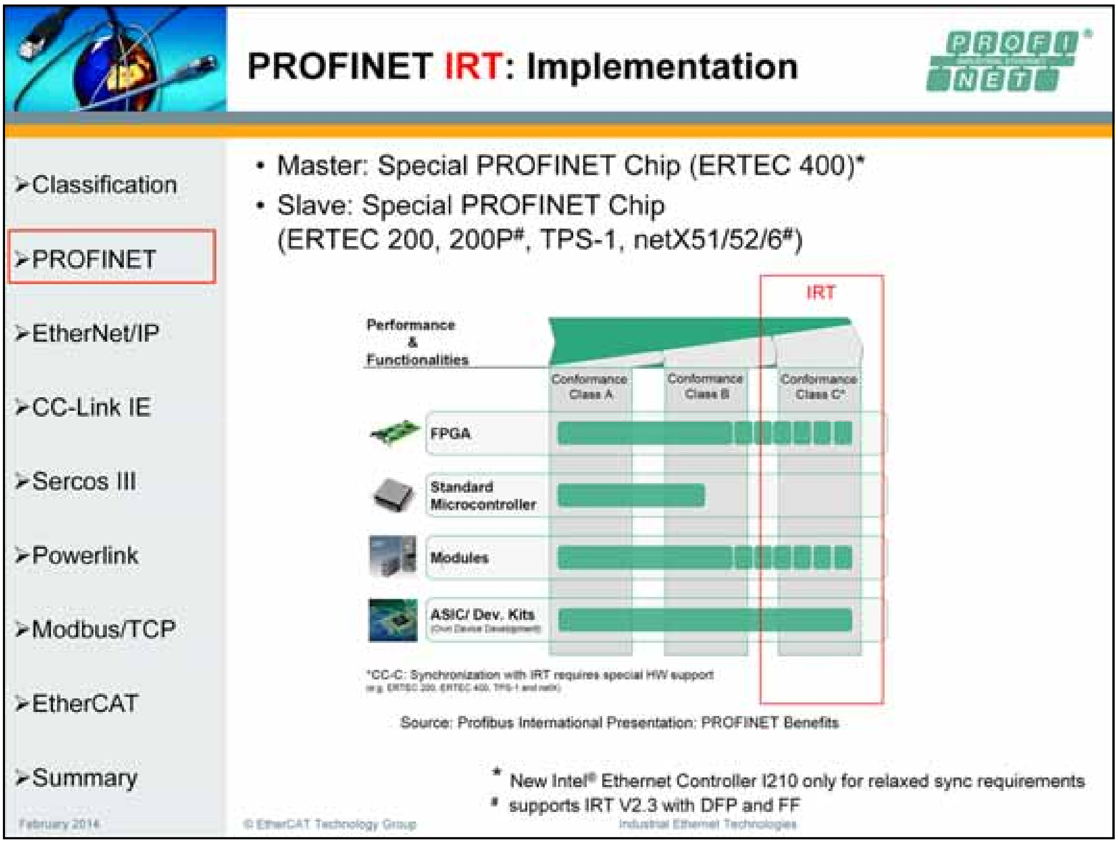
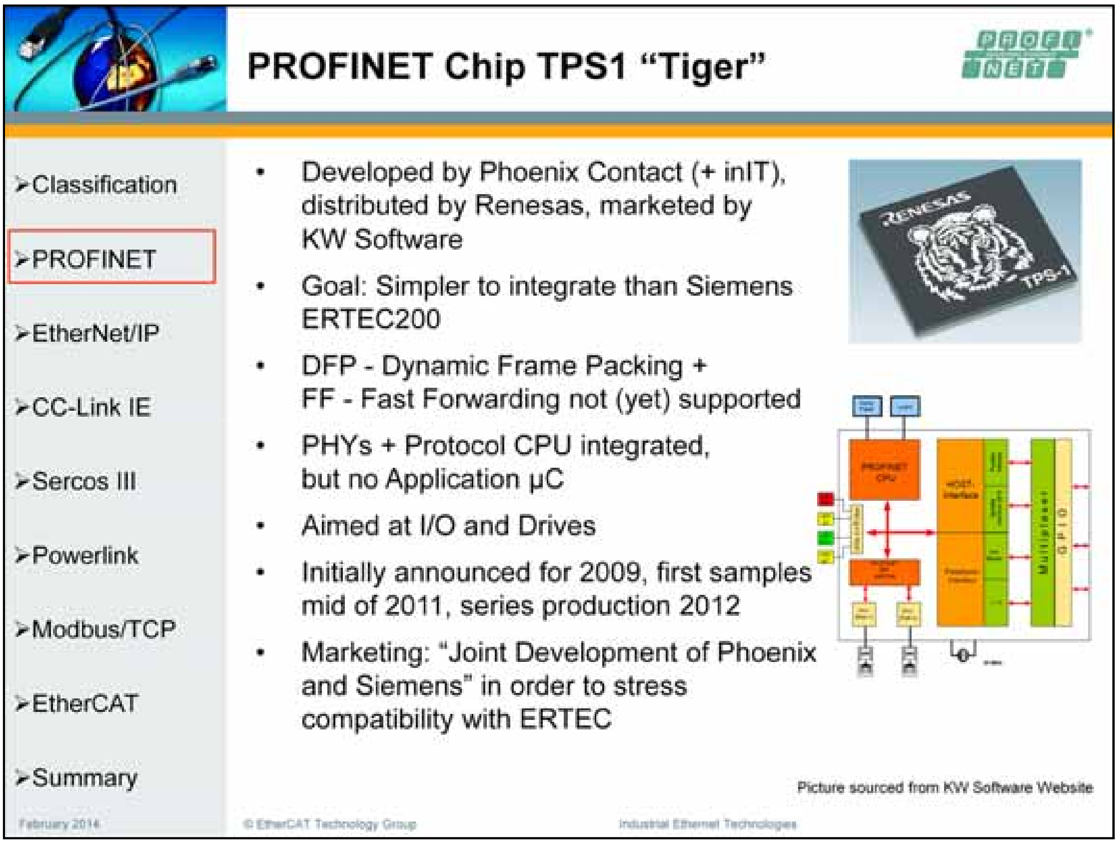


Siemens/Renesas ERTEC400 chip is intended for master devices, has 4 ports and supports minimal cycle times of 250µs;
Siemens/Renesas ERTEC200 chip is intended for slave devices, has 2 ports and supports minimal cycle times of 250µs;

Siemens ERTEC200P chip is intended for slave devices, has 2 ports and claims to supports 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.



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.

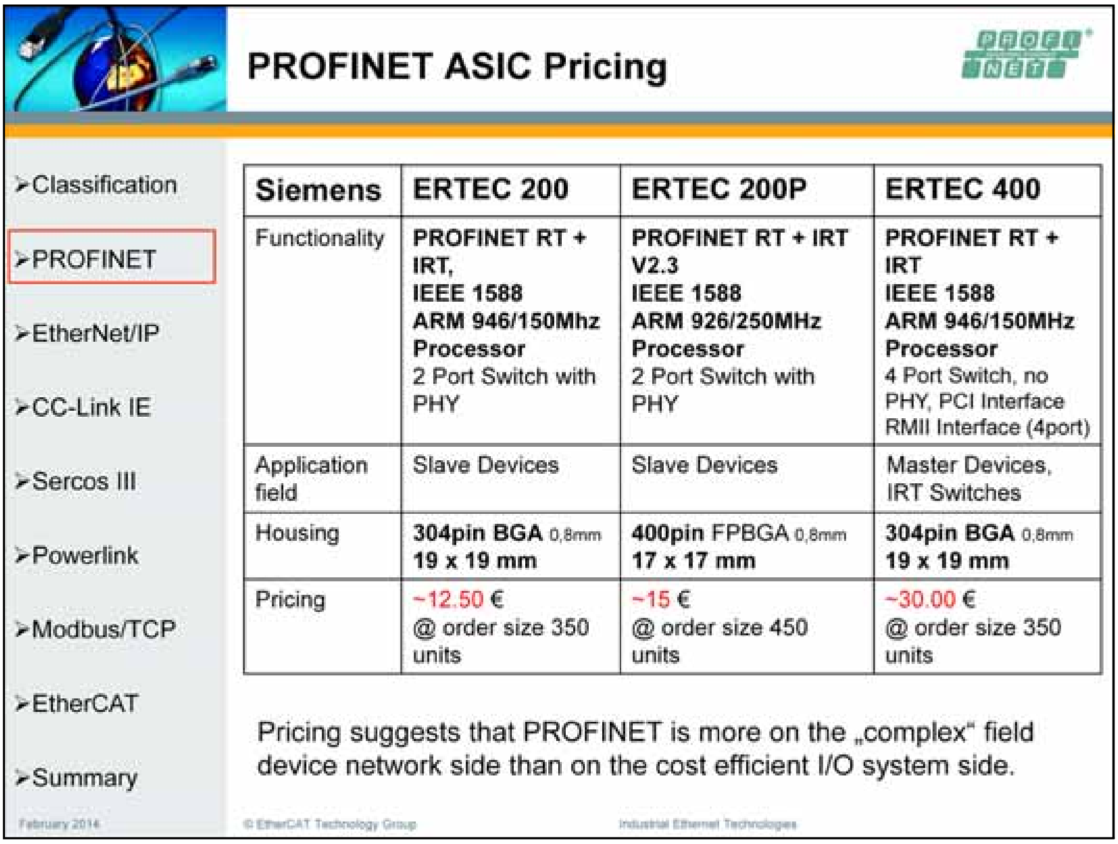
The Tiger aka TPS1 (aka Rabbit) chip is a Phoenix Contact development (subcontracted to the Institut Industrial IT (inIT) of the University of Applied Science Westfalen Lippe) – and Phoenix Contact (not Siemens) also was the driving force behind PROFINET V4 (IRT+). So the TPS1 was intended to be the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



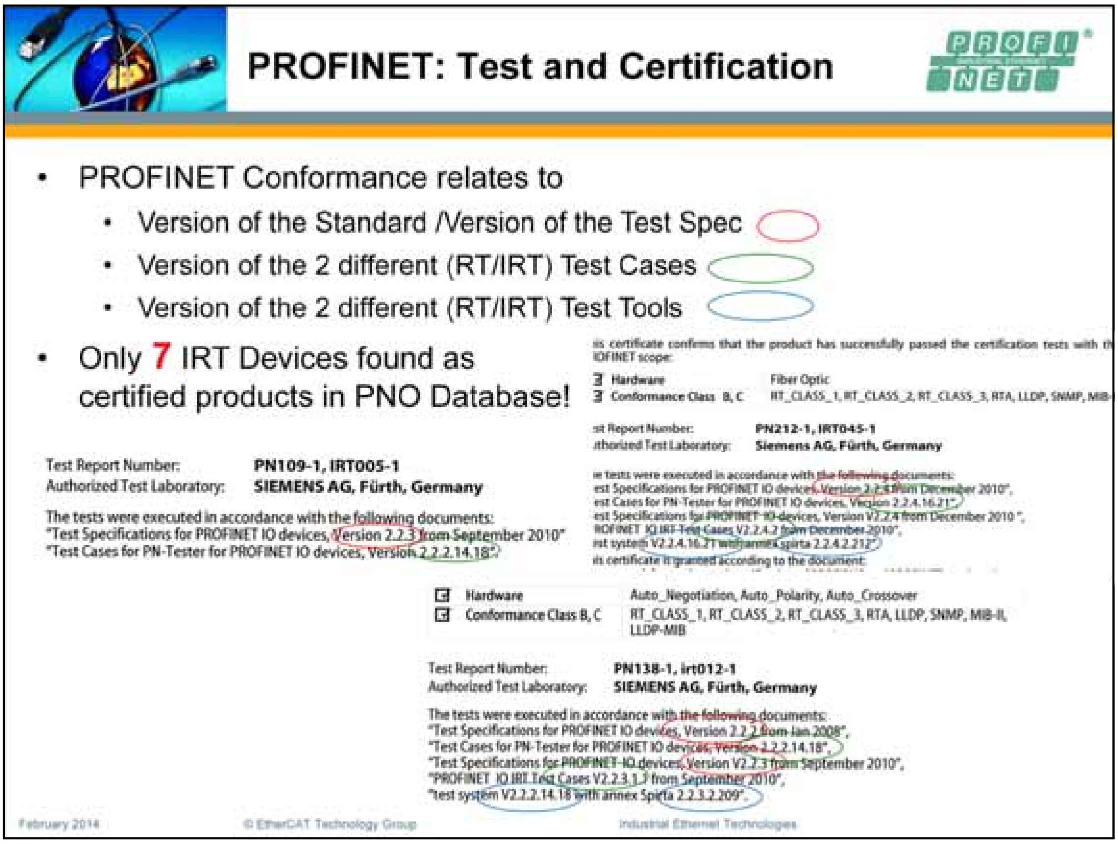
Siemens	ERTEC 200	ERTEC 200P	ERTEC 400
Functionality	**PROFINET RT + IRT, IEEE 1588 ARM 946/150Mhz Processor** 2 Port Switch with PHY	**PROFINET RT + IRT V2.3 IEEE 1588 ARM 926/250MHz Processor** 2 Port Switch with PHY	**PROFINET RT + IRT IEEE 1588 ARM 946/150MHz Processor** 4 Port Switch, no PHY, PCI 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

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 1st, 2007, Siemens lowered the prices substantially (-40%).

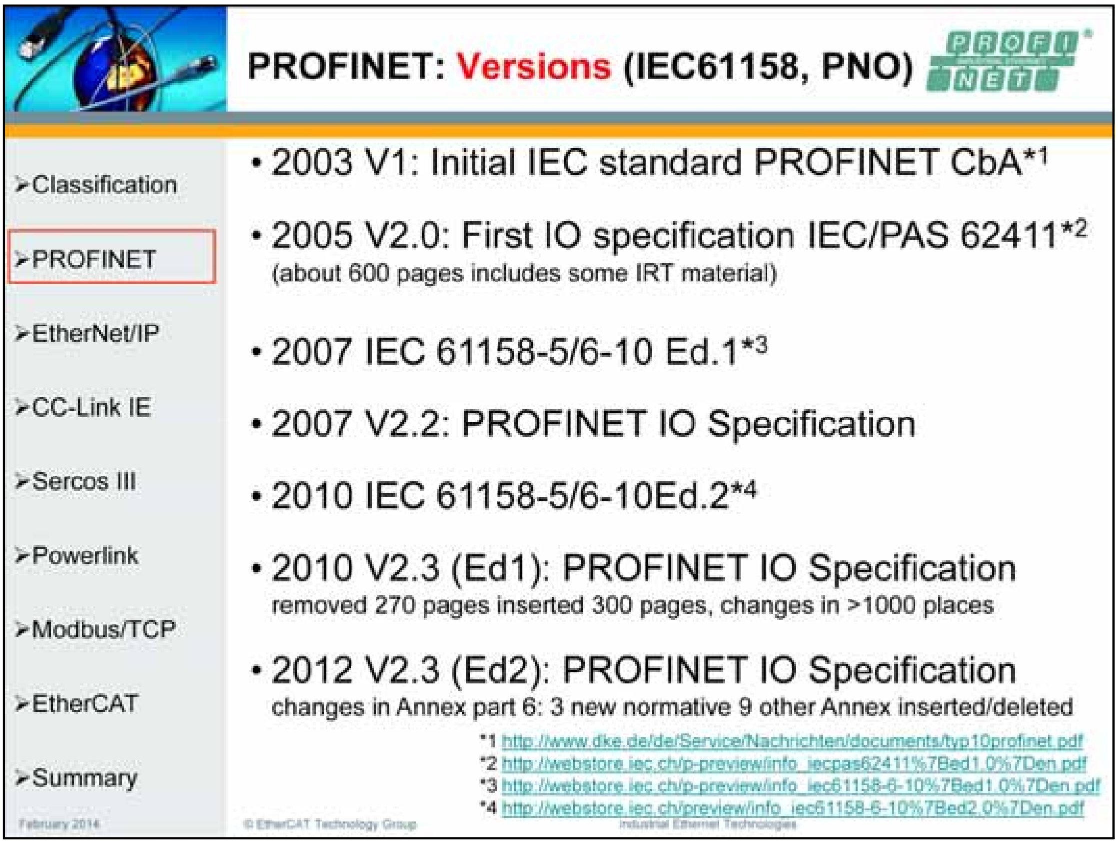
12.50€ respective 30€ per chip still exceeds fieldbus cost levels not only for simple devices, in particular if one considered the amount of memory needed:

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.

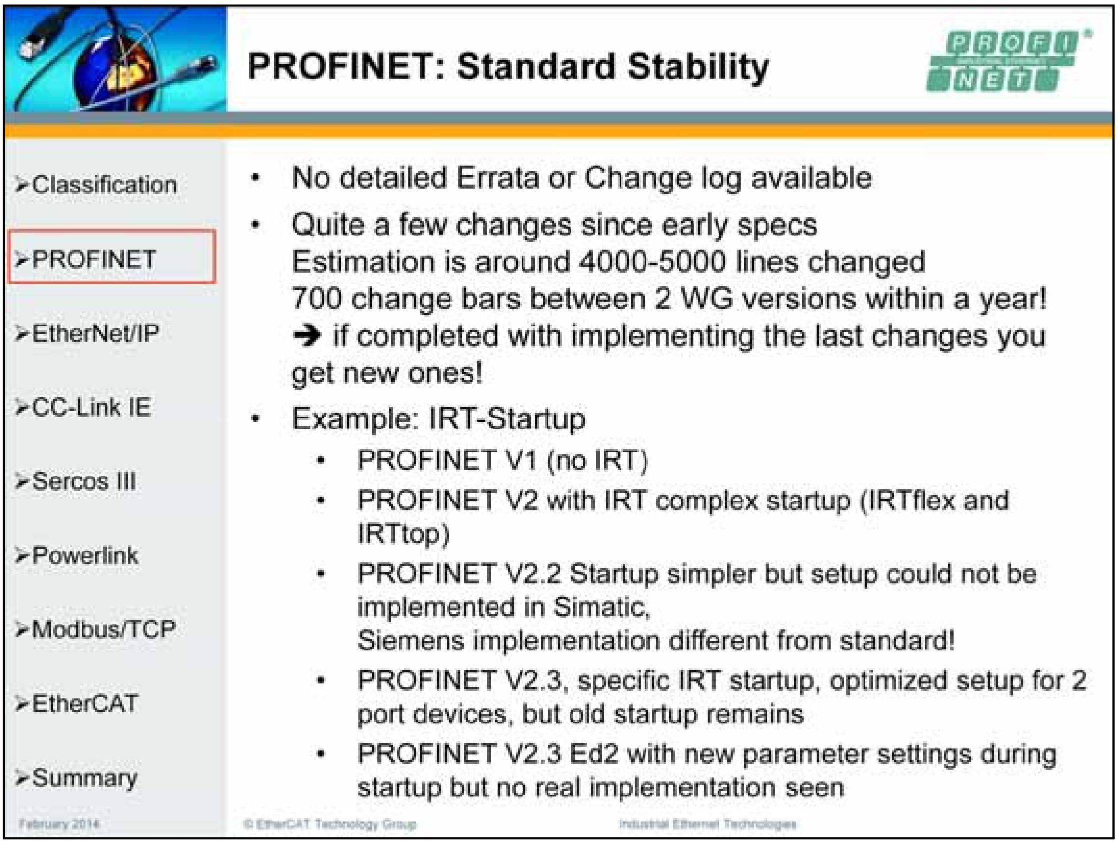


The PROFINET IO Varieties lead to corresponding test tool and test case varieties. So far no test for V2.3 available.

PROFINET International is working on an integrated test specification, though.



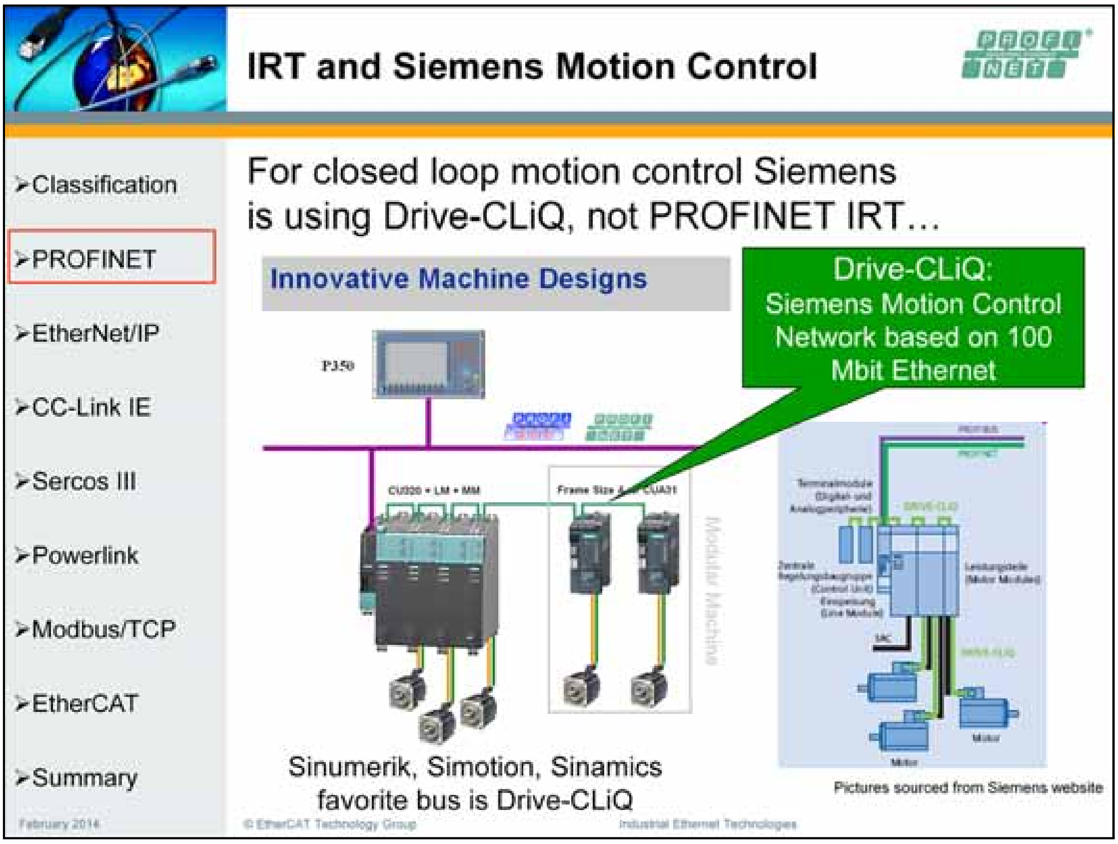
Many versions of PROFINET.



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…

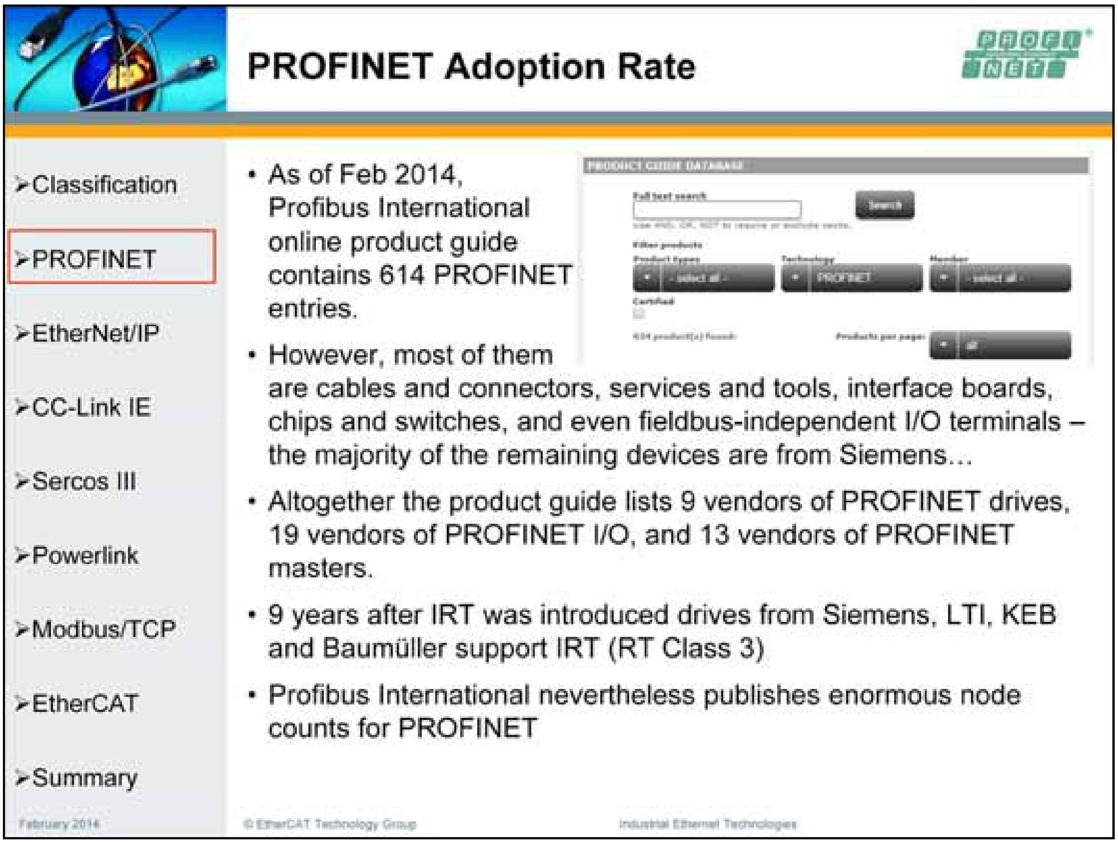


Interesting enough, Siemens has also developed another Ethernet based motion control network: Drive-CLiQ.

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.

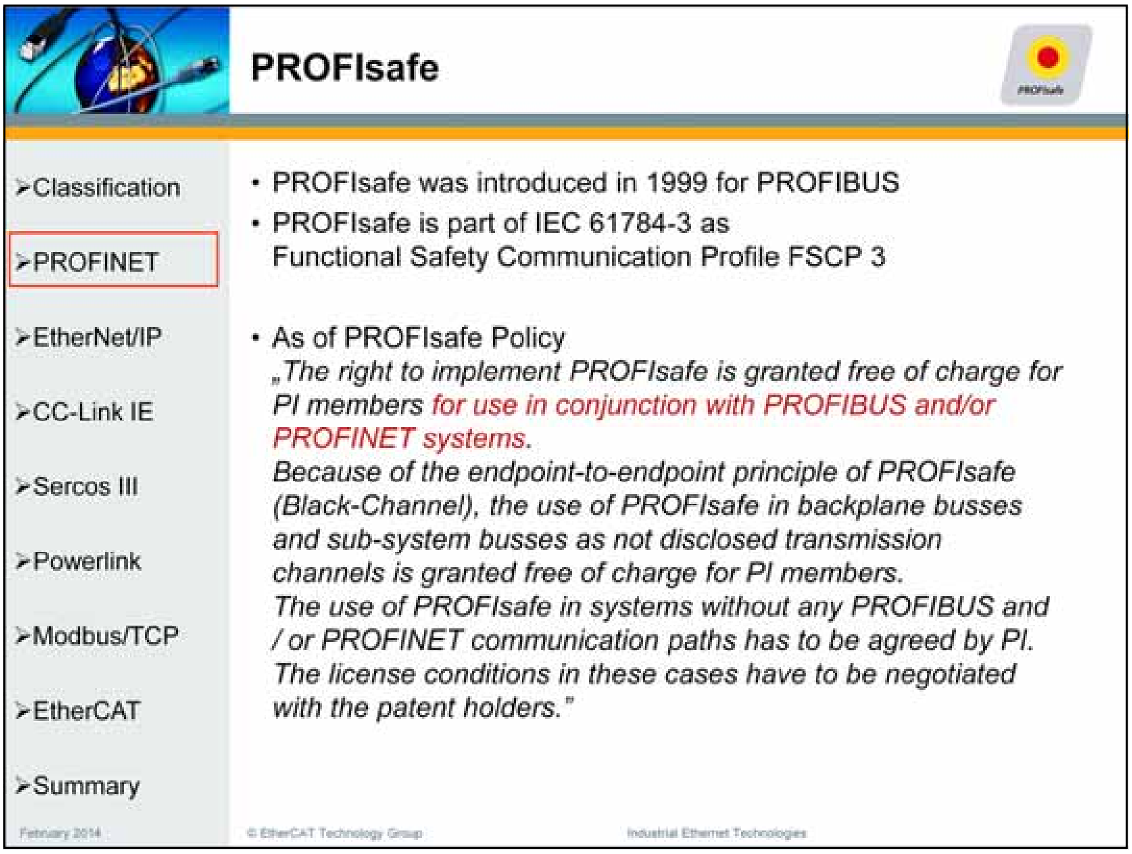
End of November 2010 Siemens announced that they are is now even opening Drive-CLiQ to feedback sensor manufacturers who are invited to implement this interface in their encoders, resolvers, tachometers and linear position sensors. Siemens also provides a special chip for that purpose.



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.

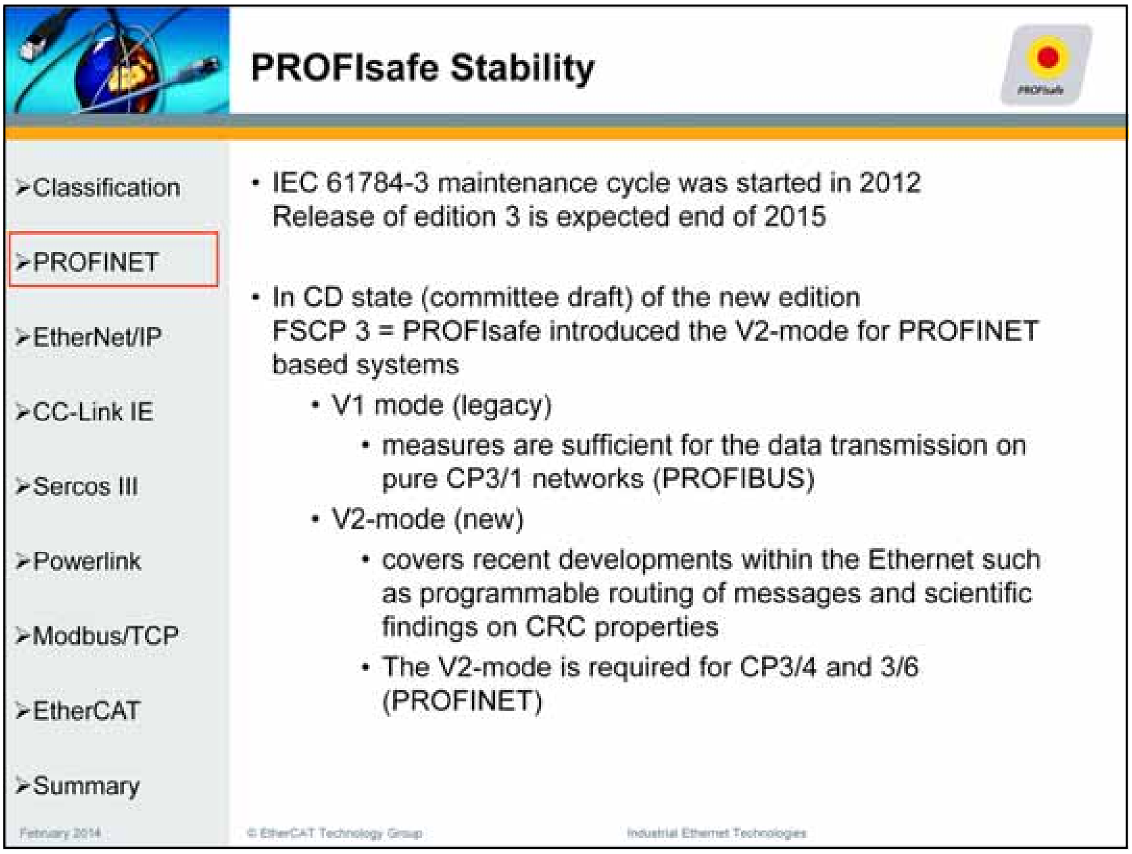


Even though PROFIsafe is based on a black channel approach, license conditions in the PROFIsafe Policy restrict the usage to PROFIBUS and PROFINET.

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."



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);

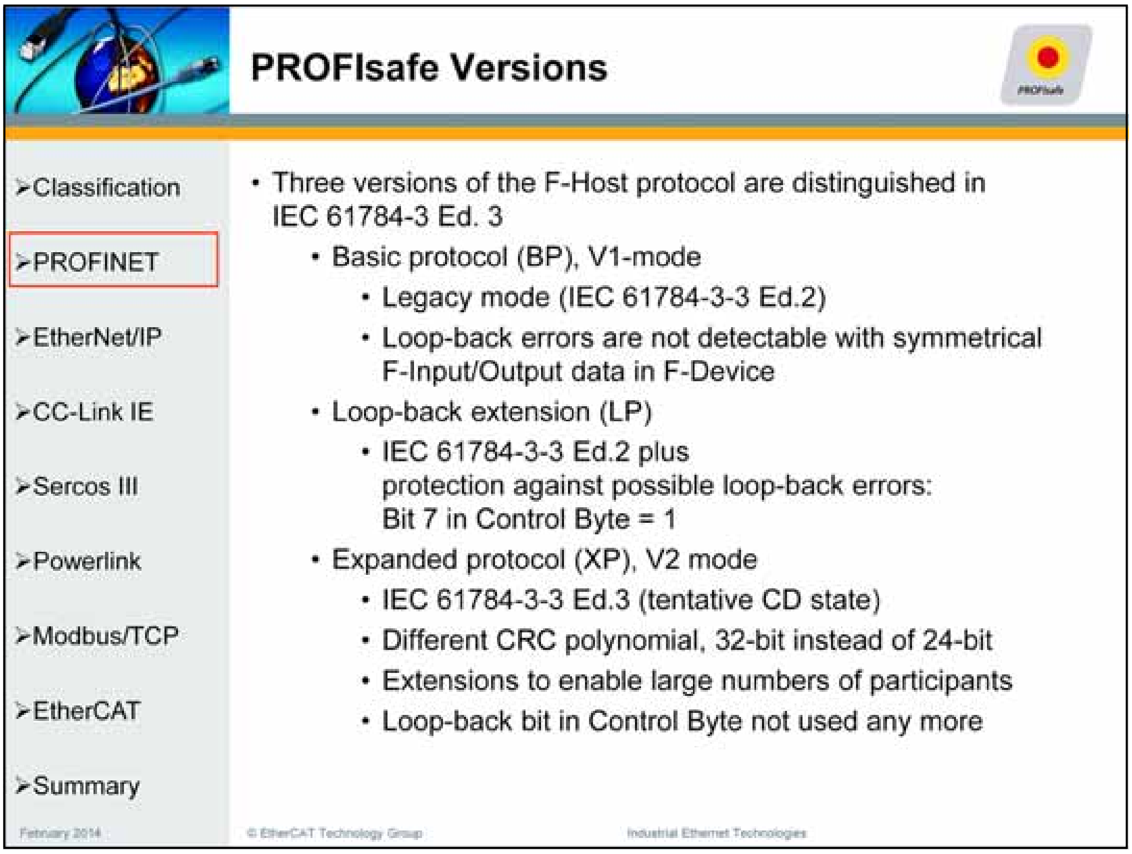
– Protocol extensions to keep SIL3 for safety networks with large numbers of participants (XP extensions) and subsequent new F-Parameter "F_CRC_Seed";

– 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;

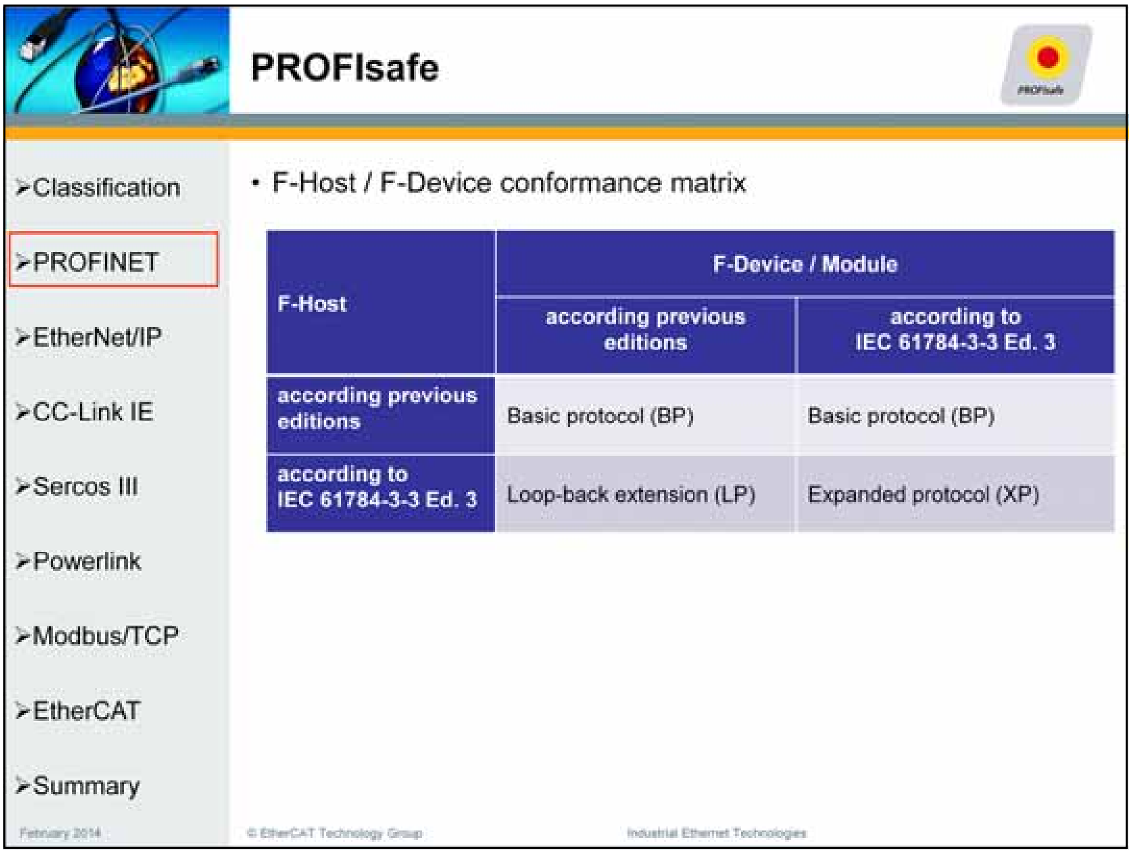
This suggests that Profisafe is currently undergoing another major change.



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:

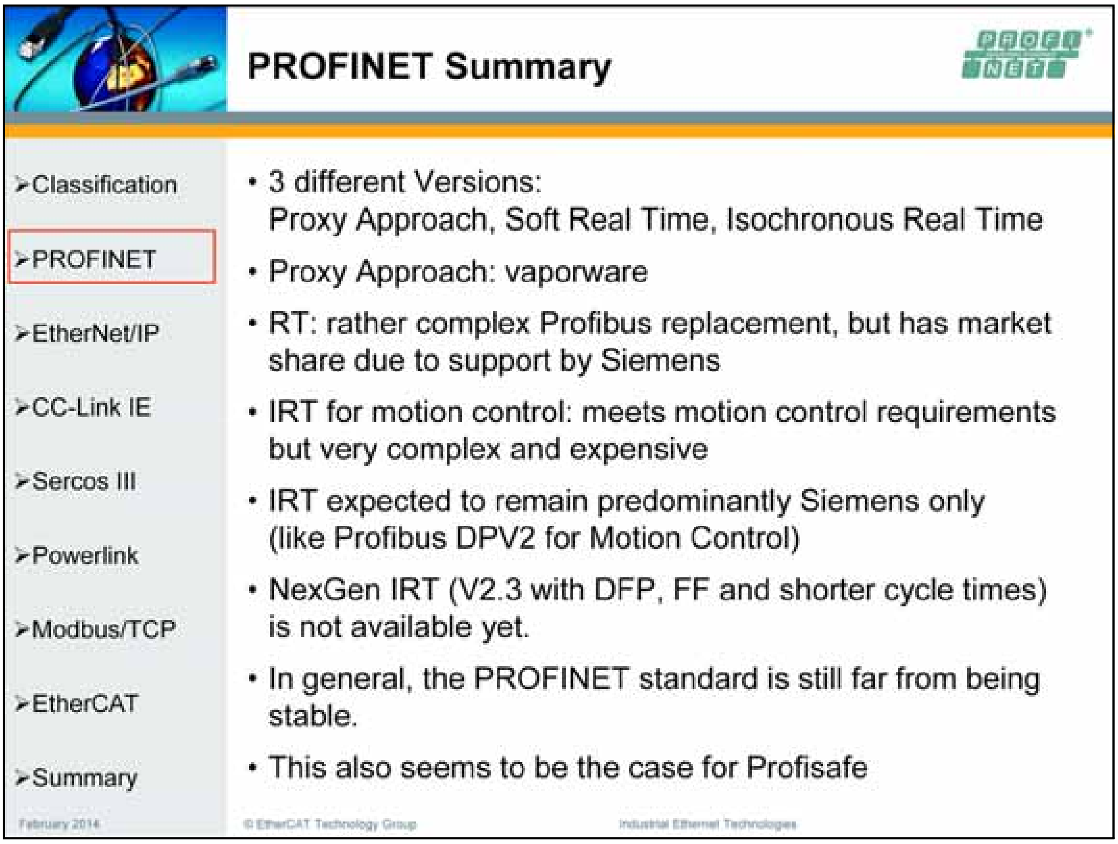
- Does the Black channel comprise programmable IO Data routers?
- Is there Symmetrical F-Input/Output data in F-Device?
- Furthermore, verification of each and every safety function shall be performed after any change within the programmable IO data router. In case of routing variants, this verification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

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



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)

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.

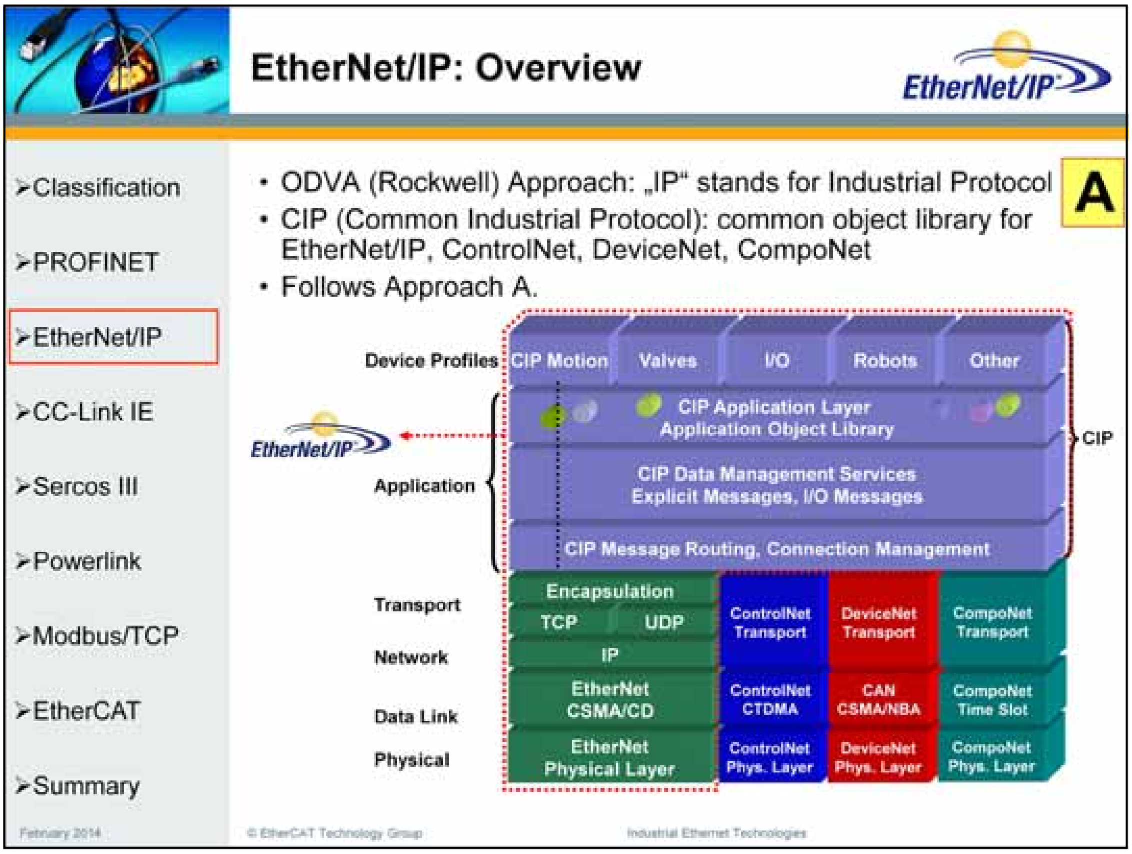


PROFINET RT is not low cost, requires a lot of code and is not high performance, but in the long run it will be a success – regardless of the technology, simply due to the Siemens (+ PNO/PTO) market position, just like Profibus.

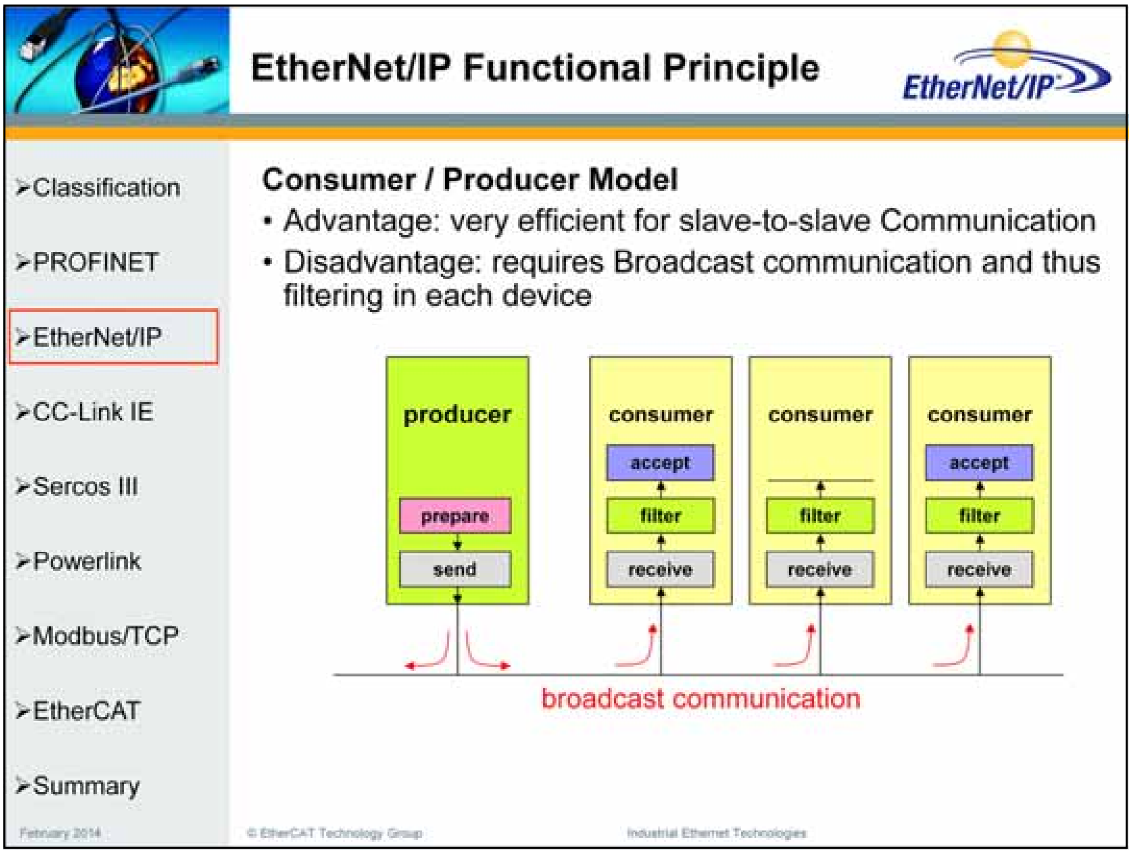
The German car makers have announced to use PROFINET in car assembly lines „if it provides technological and economical advantages“ (quote). Daimler, e.g., has clearly stated that this announcement does not cover the power train business, where CNC and other motion control applications are in place.

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).

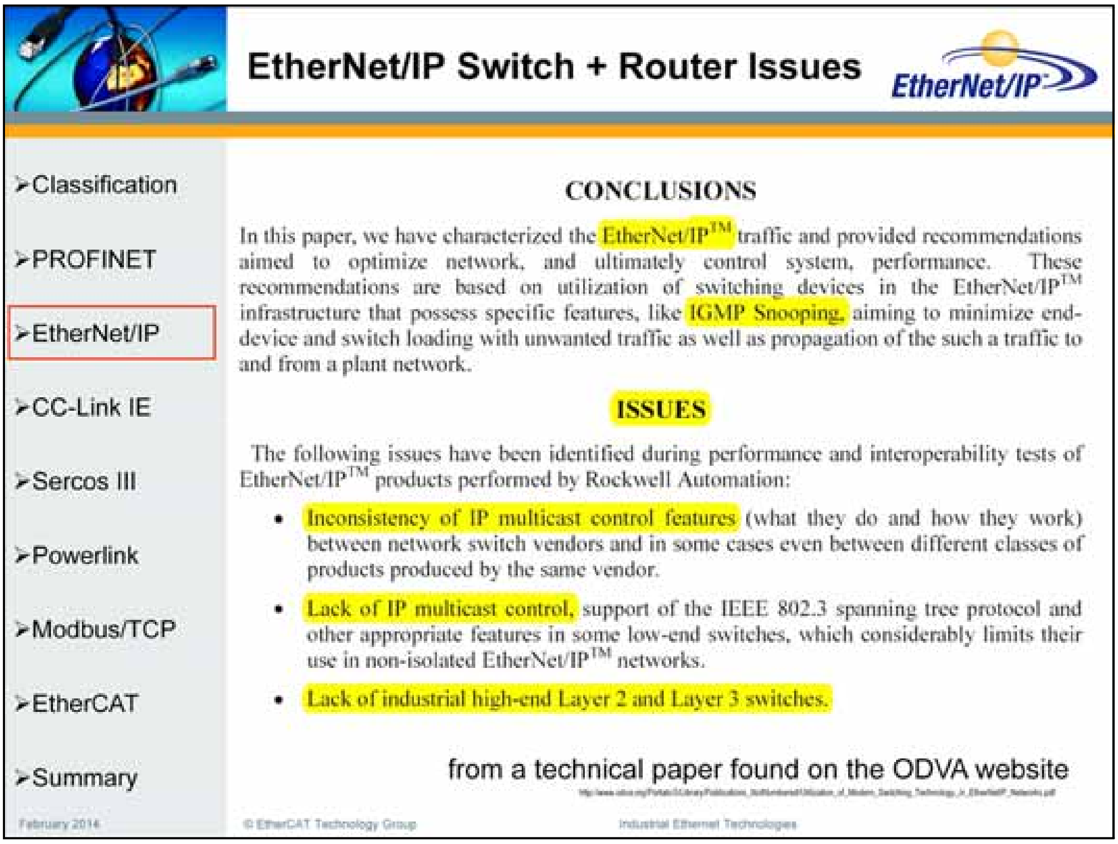
Plus, Siemens latest Motion Control product line prefers a different communication link for closed loop control: DriveCliq, which uses Ethernet physical layer, only.



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.



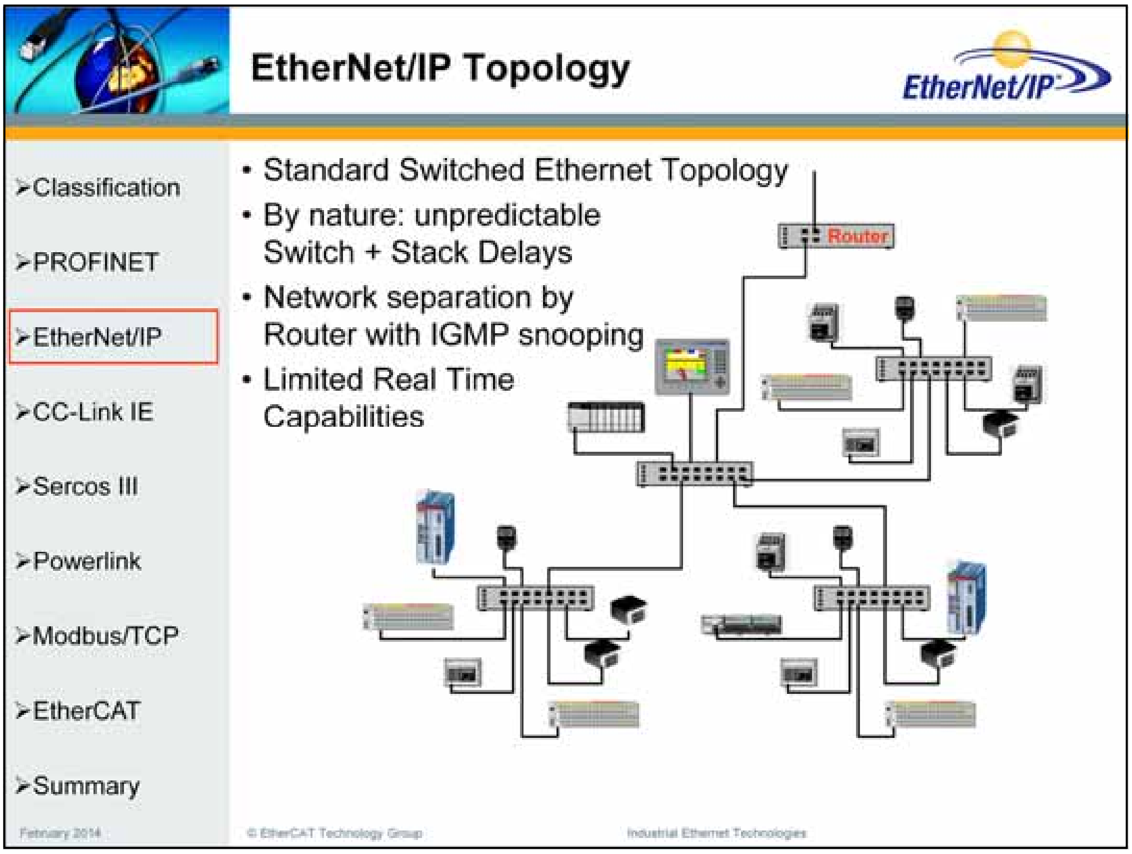
By applying broadcast or multicast communication, the switches cannot forward incoming frames to a single destination port only - so they act like (full-duplex) Hubs, but with larger delay.



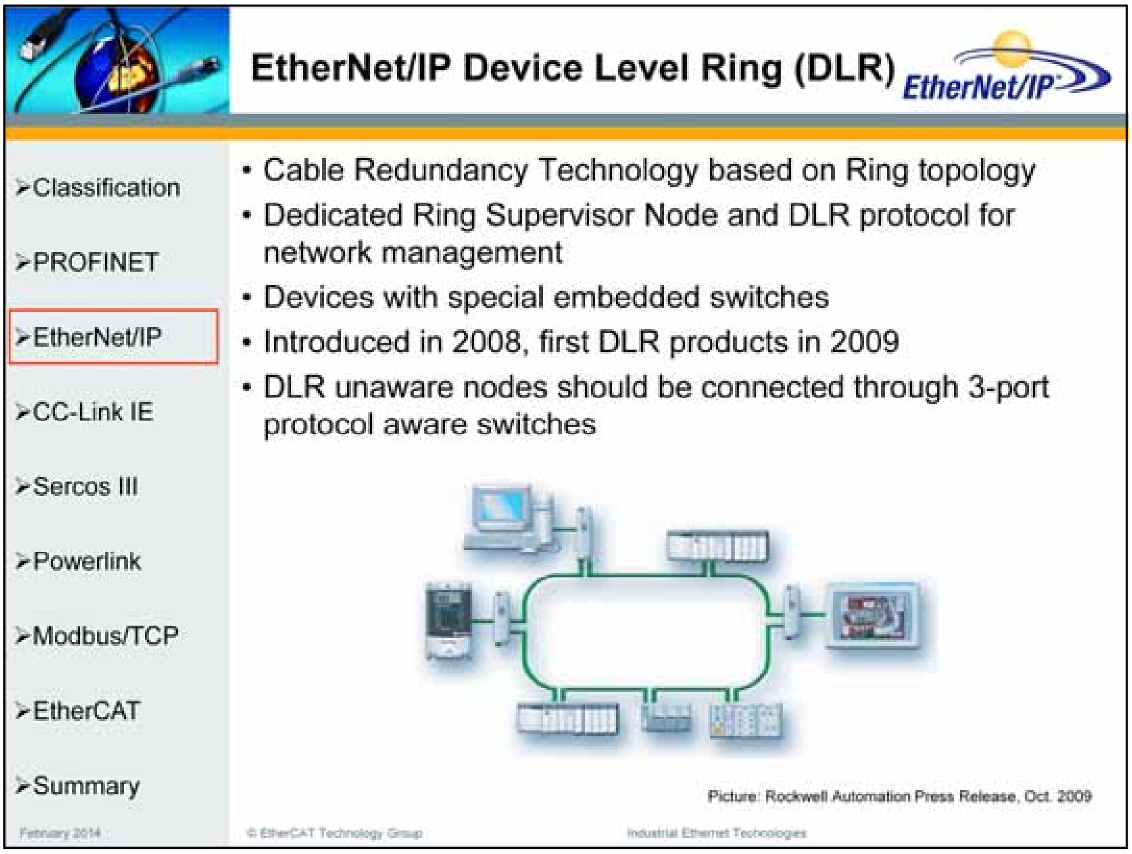
This paper by Anatoly Moldovansky, a well-respected senior engineer from Rockwell Automation, highlights some of the issues with EtherNet/IP: there is a need for routers with multicast/broadcast control features, and there is no standard way to implement or configure these.

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.



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



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

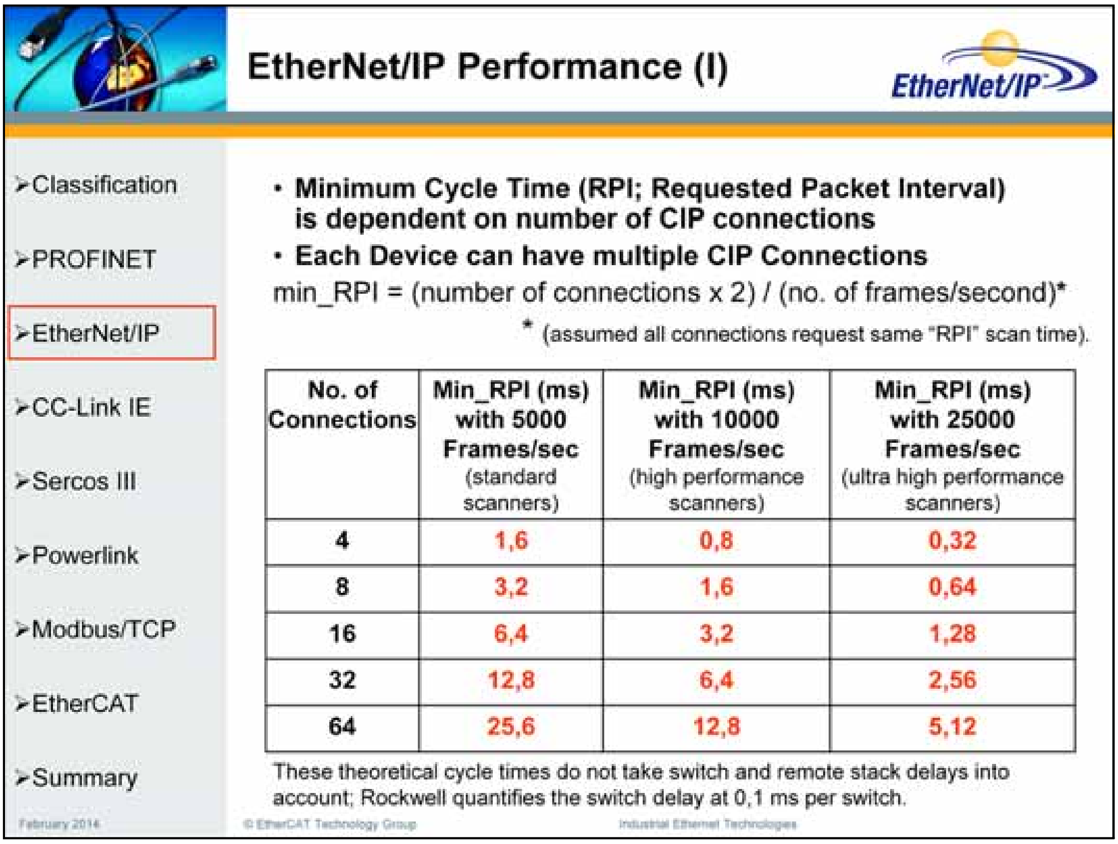
Requires special nodes who support the DLR protocols

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 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.

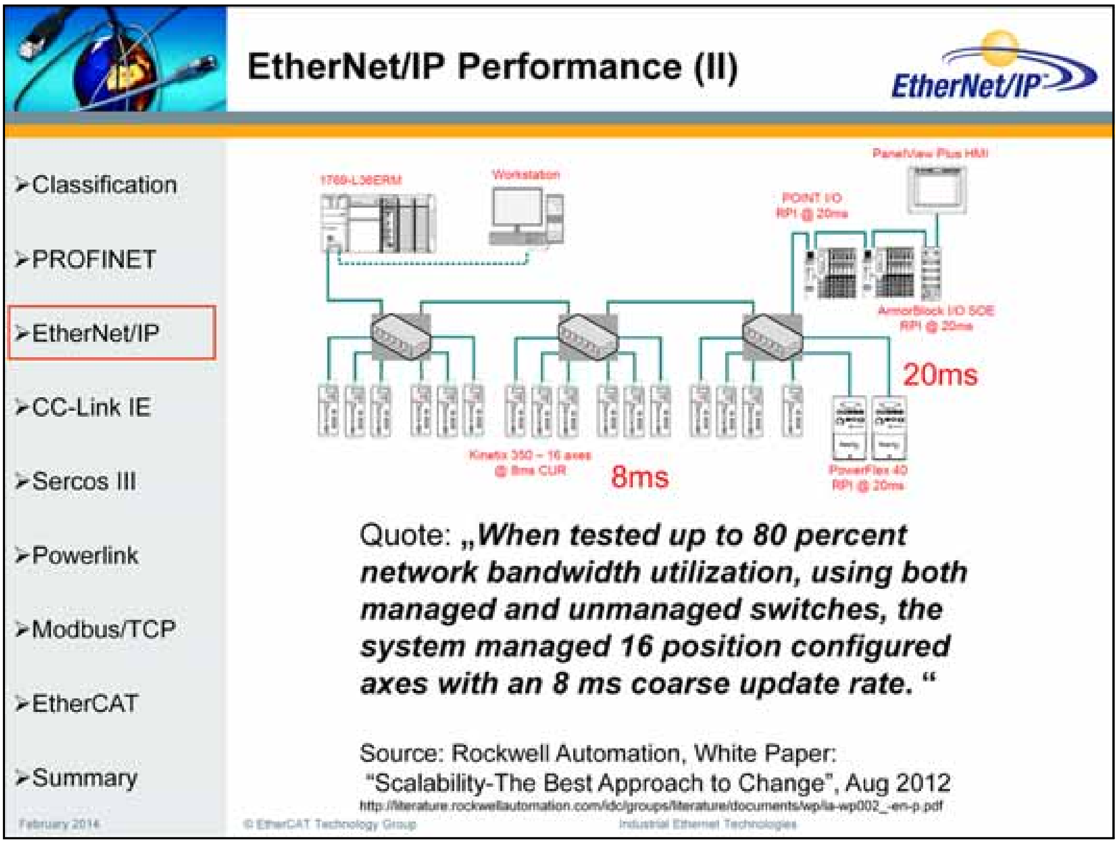
Rockwell also recommends to add scanner cards to the controller and divide the scanning function between the cards if the throughput is not sufficient.

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.*

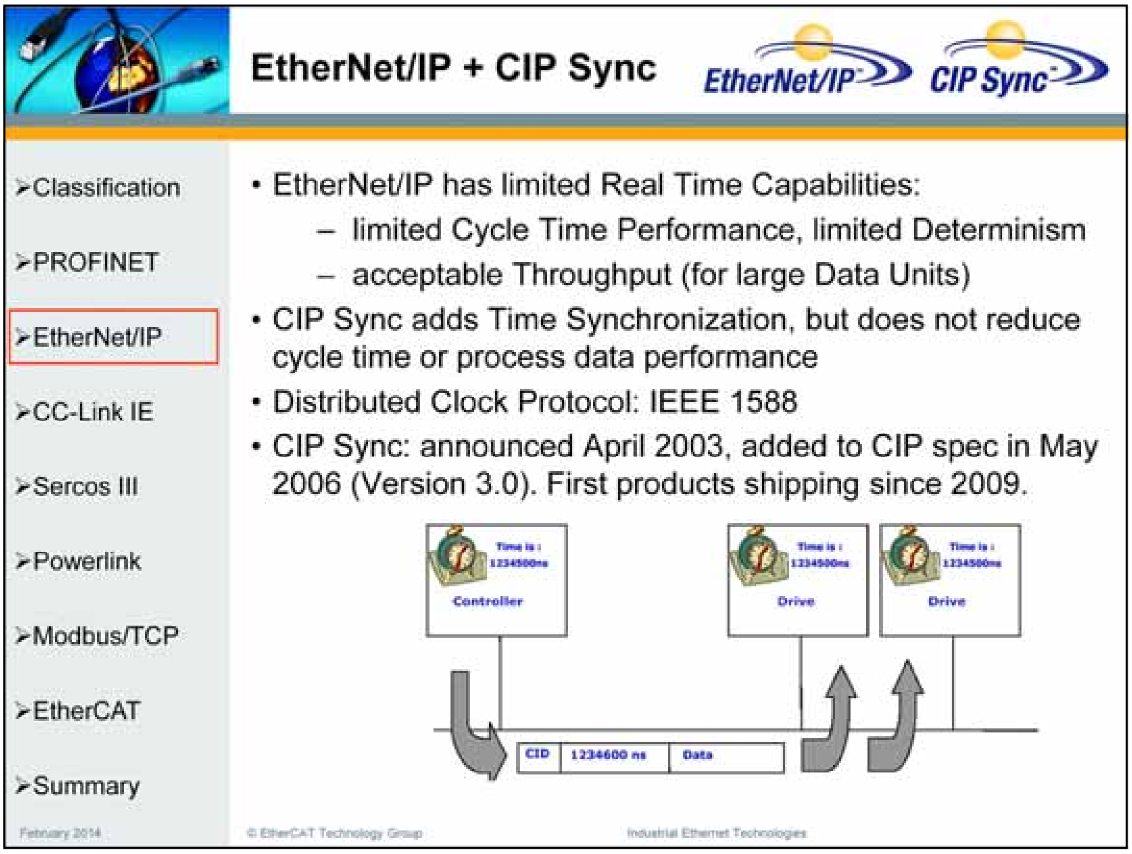
See also: Rockwell Automation (RA) publication "EtherNet/IP Performance" (ENET-AP001D-EN-P, released October 2004, according to RA website still valid in Aug 2011)



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).

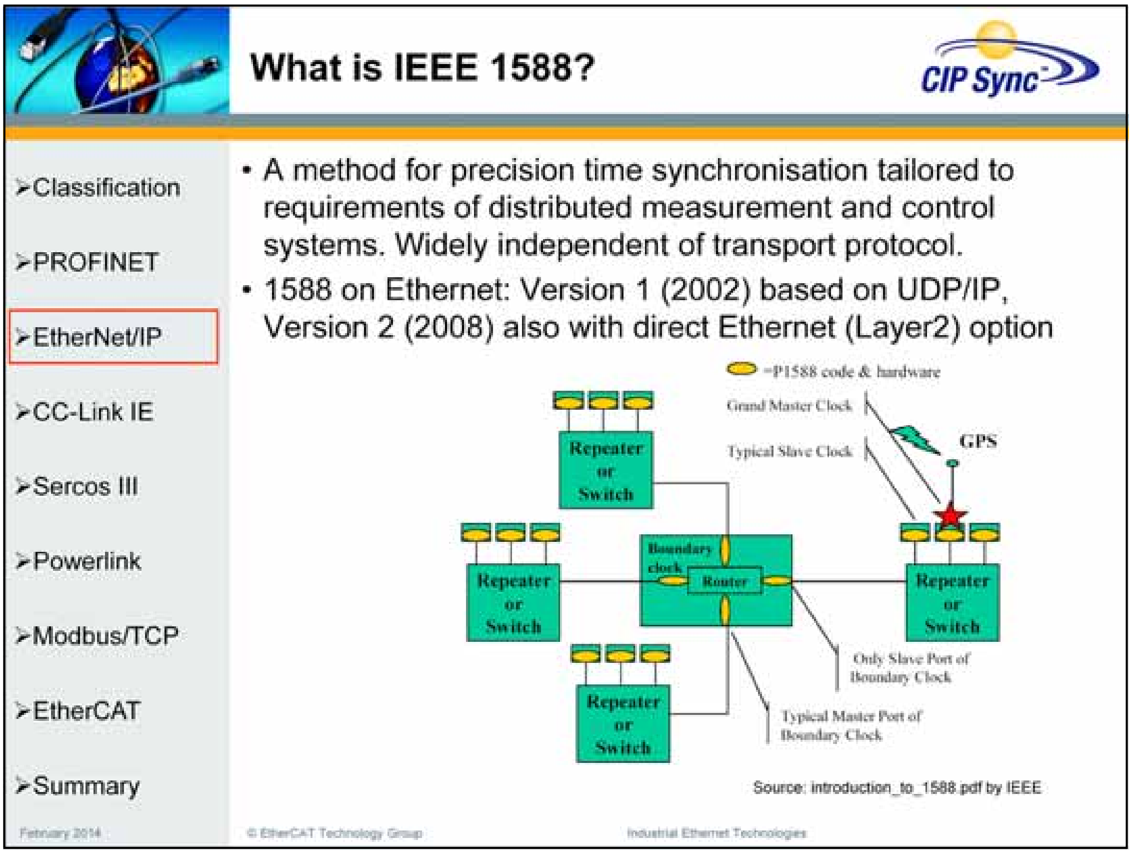


CIP sync was introduced to improve the real time behavior of the system.

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, throughout 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.

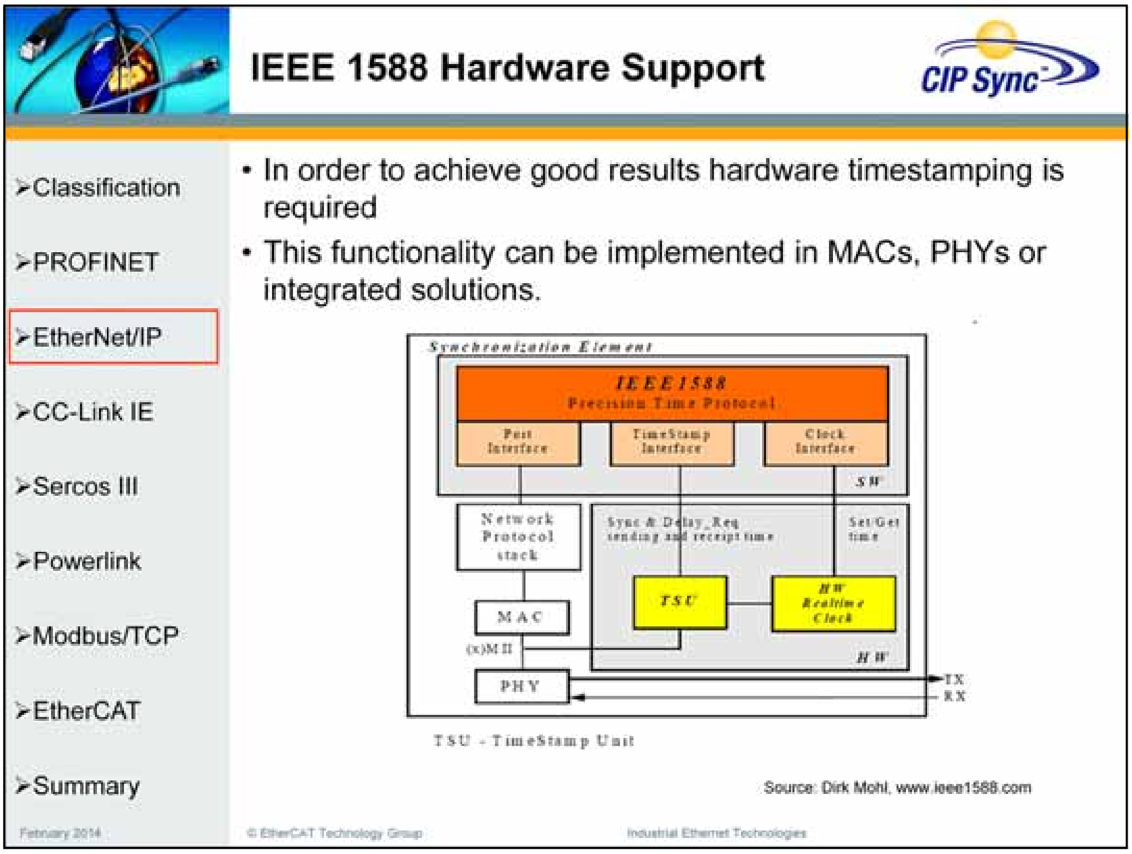


IEEE 1588, officially entitled *"Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems"* , is a technology for time synchronization that is or will be used by a variety of systems: EtherNet/IP, PROFINET, Powerlink,... EtherCAT also supports gateways to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

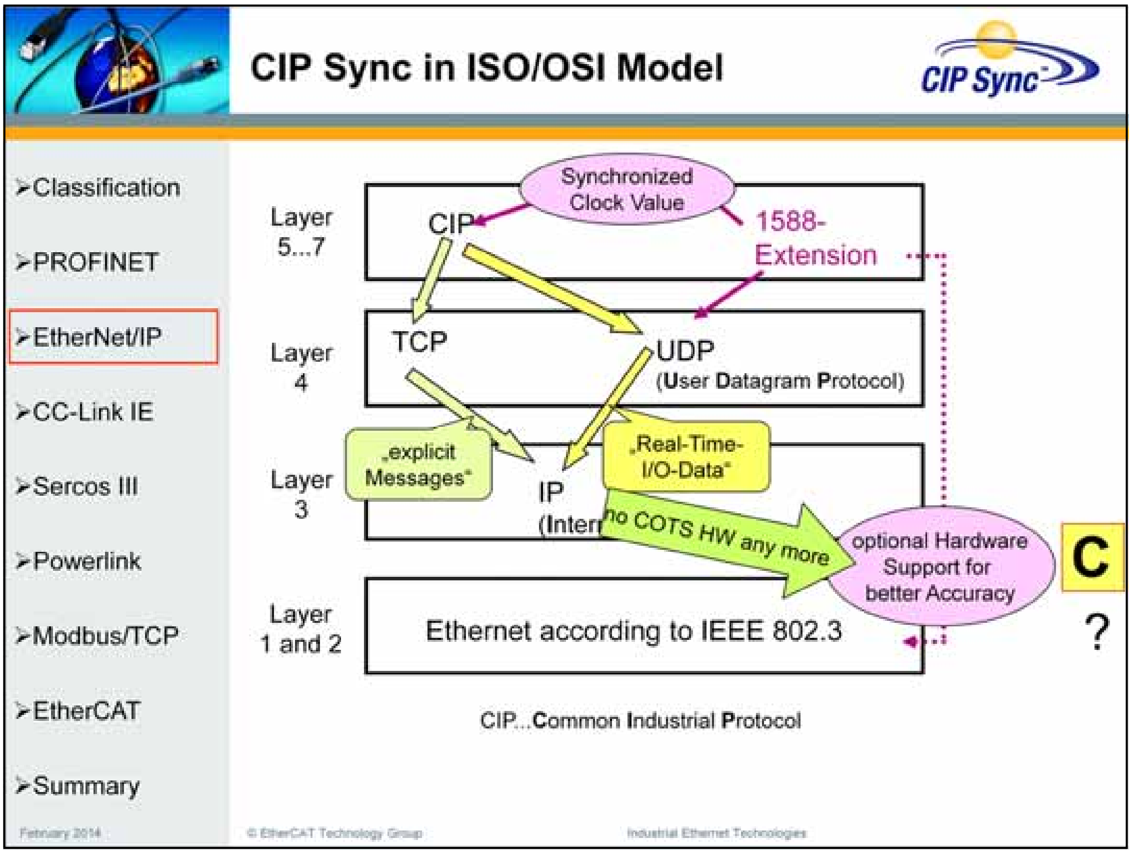
The first version of IEEE1588 was published in November 2002. Version 2 (IEEE 1588-2008) followed in March 2008 and added various features, including the layer 2 transport option (embedded in the Ethernet frame without UPD/IP) and the “transparent clock” approach which improves the accuracy for linear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

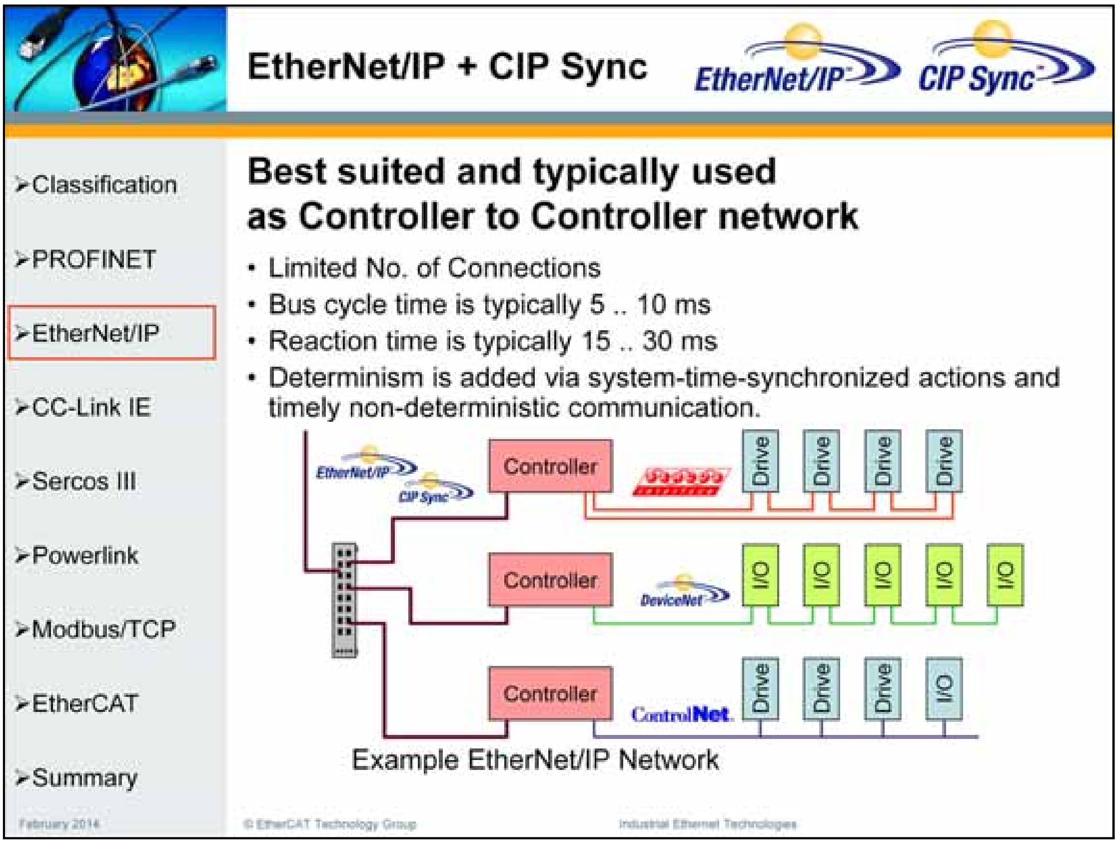


In general the stack processing times limit the accuracy in case of pure software implementations. For good results hardware with built in IEEE1588 timestamp support has to be used – and the corresponding switches. First silicon was introduced by Intel and Hyperstone, meanwhile National Semiconductor,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

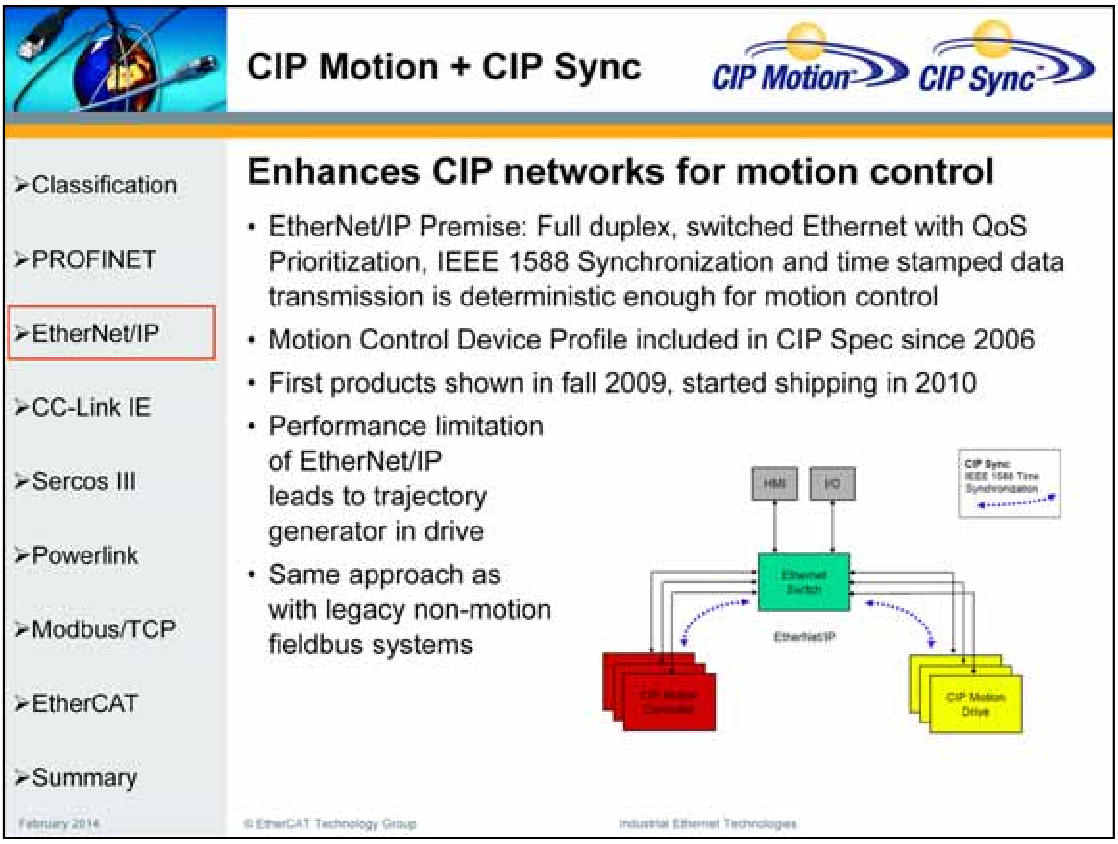


In order to make the time synchronization independent from software jitters and stack performance, at least the time stamp functionality had to be implemented in hardware (directly in or at the Ethernet MAC).

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.



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.



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

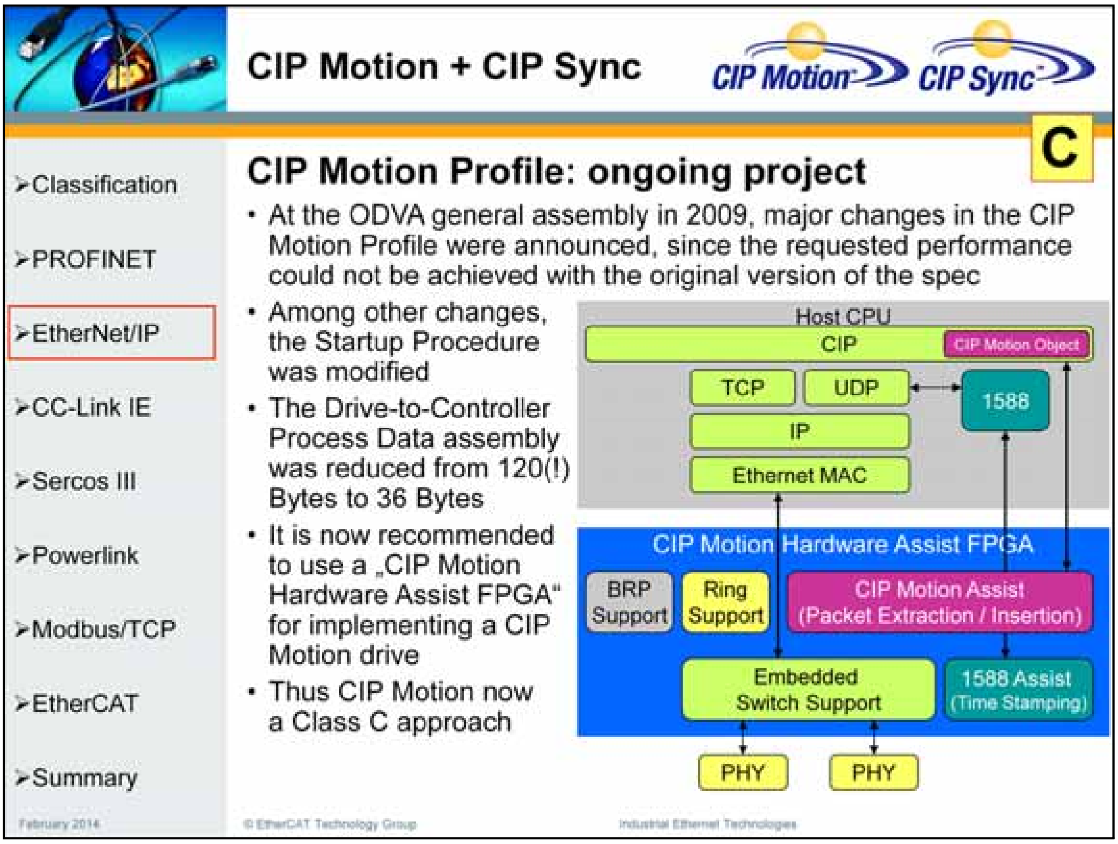
Timely Data Transfer: The goal is to use standard Mechanisms to ensure this:
- Full-Duplex 100-BaseT or 100BaseF "Fast" Ethernet.
- Ethernet switches to eliminate collisions.
- QoS frame prioritization to eliminate queuing delays

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.

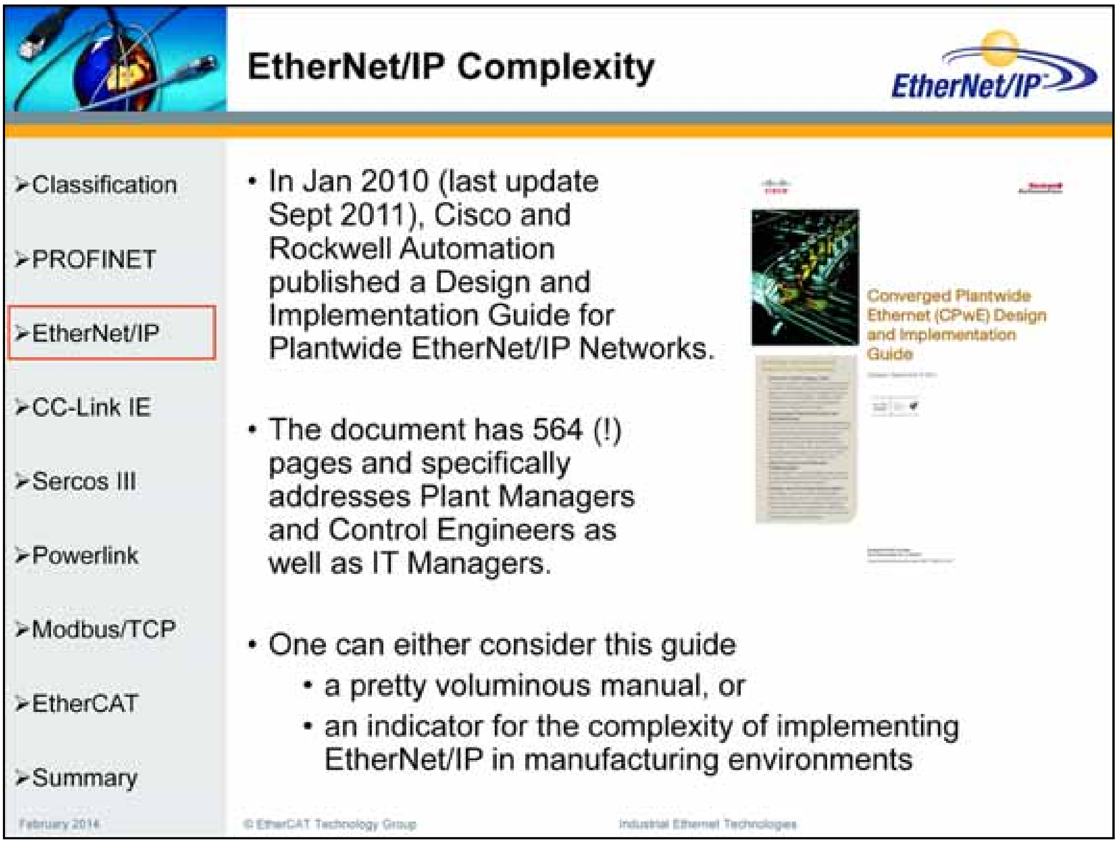
Introducing CIP Motion products implies that Rockwell – a Sercos vendor in the past – has turned down Sercos-III and tries to push an own motion bus approach.



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”.

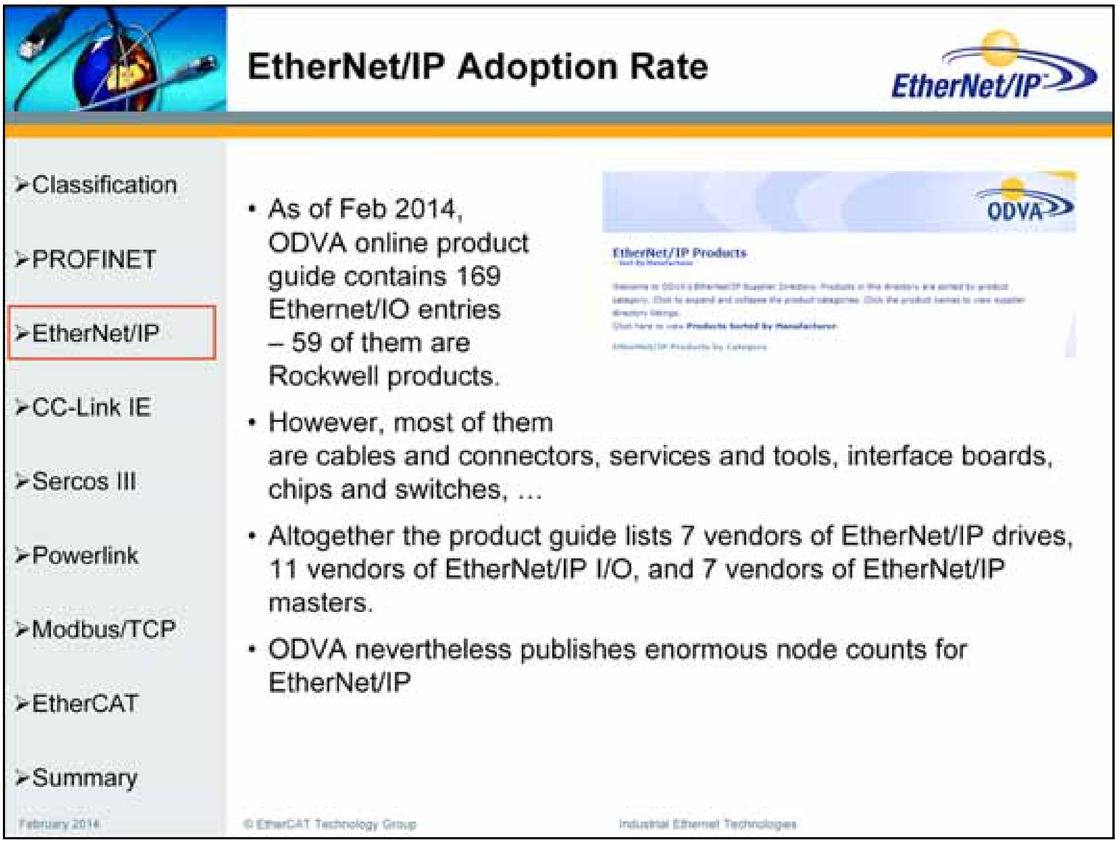
First CIP Motion products were previewed at the Rockwell Automation Fair in November 2009 and became available in 2010. In September 2010, RA published a comprehensive CIP Motion Reference Manual (286 pages) and a CIP Motion Configuration and Startup user manual (298 pages).

See also:
http://www.odva.org/Portals/0/Library/CIPConf_AGM2009/2009_CIP_Networks_Conference_Technical_Track_CIP_Motion_Implementation.pdf

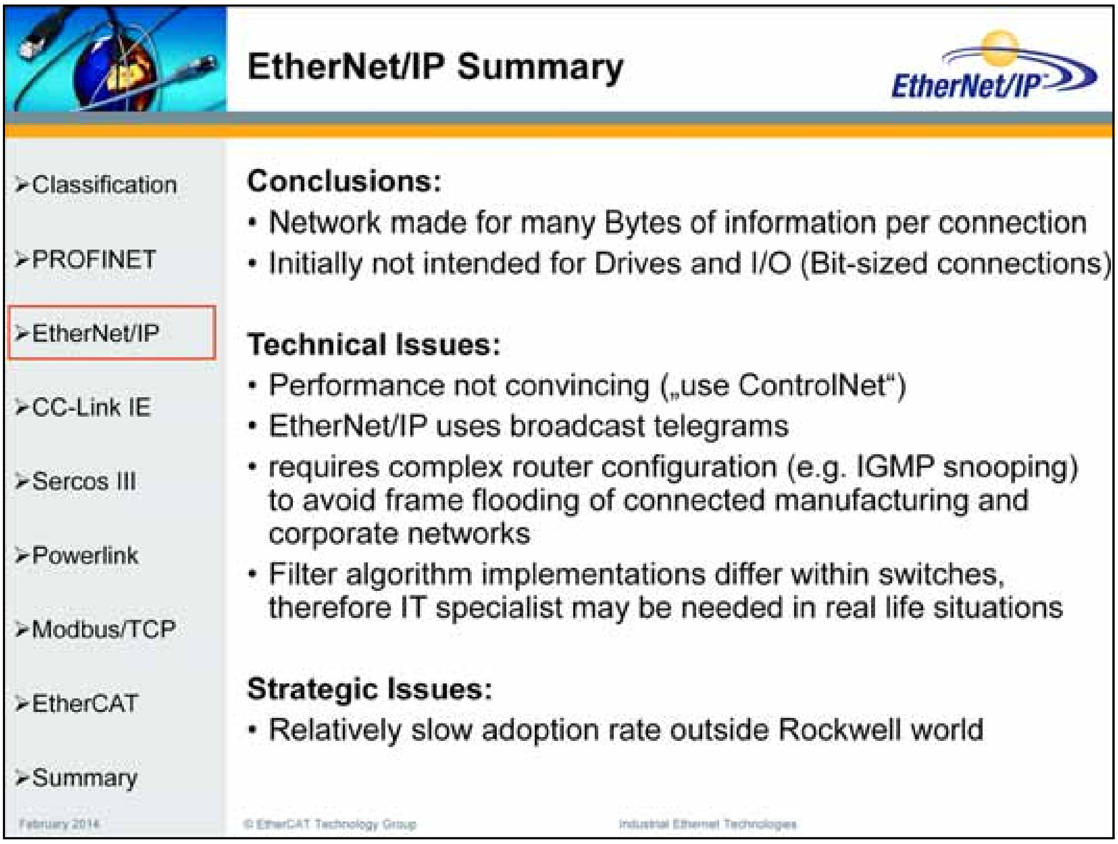


The guideline (ENET-TD001D-EN-P) can be found here:
http://literature.rockwellautomation.com/idc/groups/literature/documents/td/enet-td001_-en-p.pdf

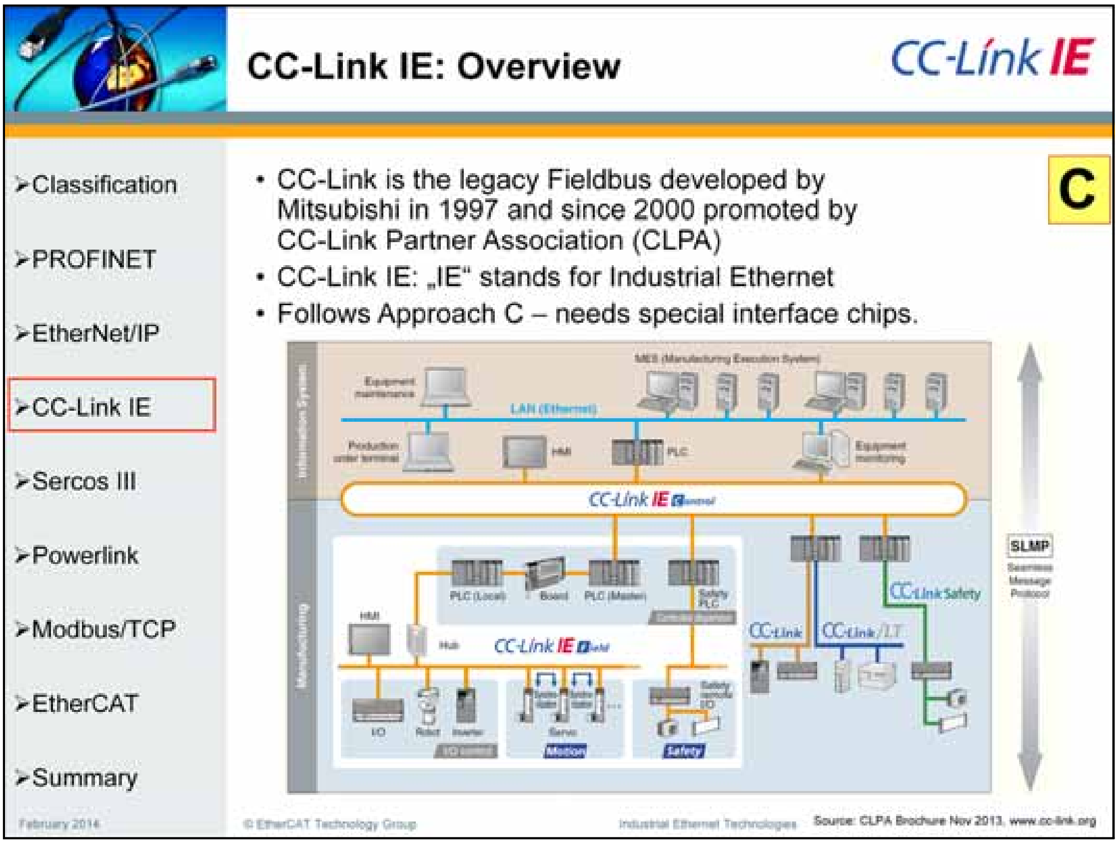
Or here:
http://www.cisco.com/en/US/docs/solutions/Verticals/CPwE/CPwE_DIG.pdf



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.



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



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).

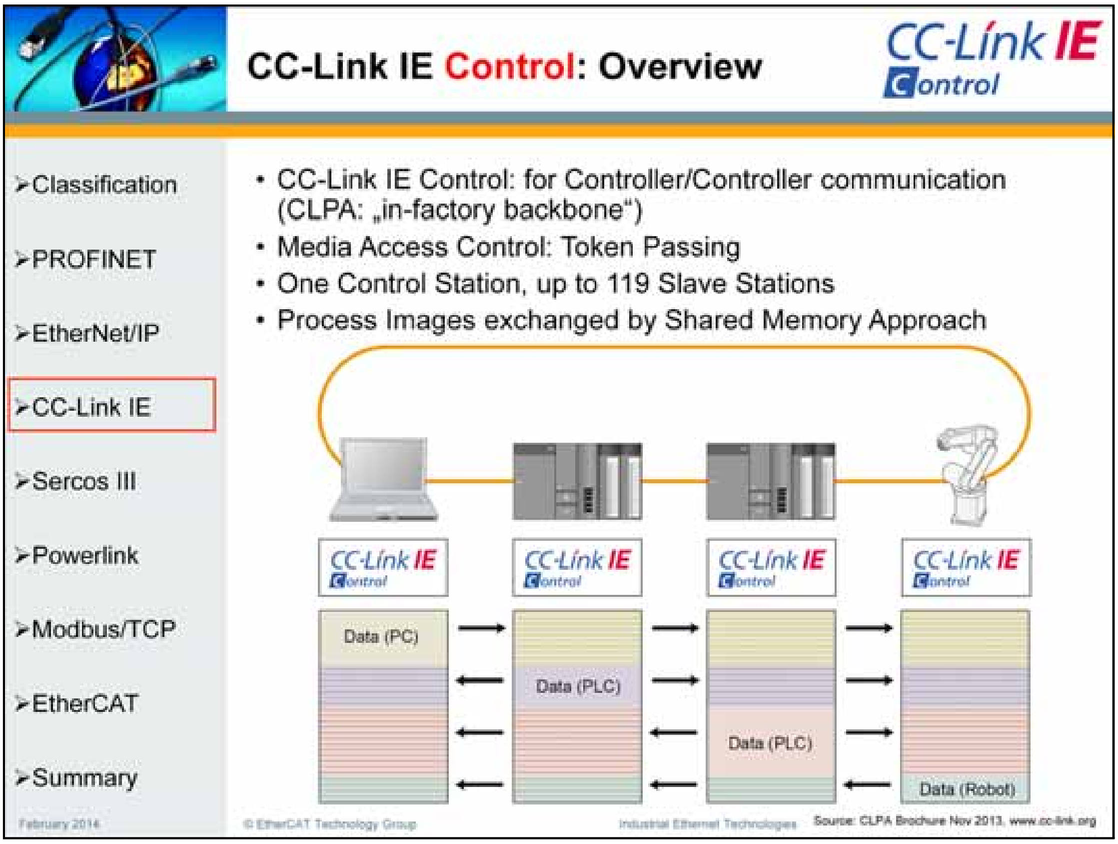
CC-Link LT is the CLPA technology focusing on simplified wiring and intended for simple I/O devices; it competes with Componet and AS-Interface.

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.



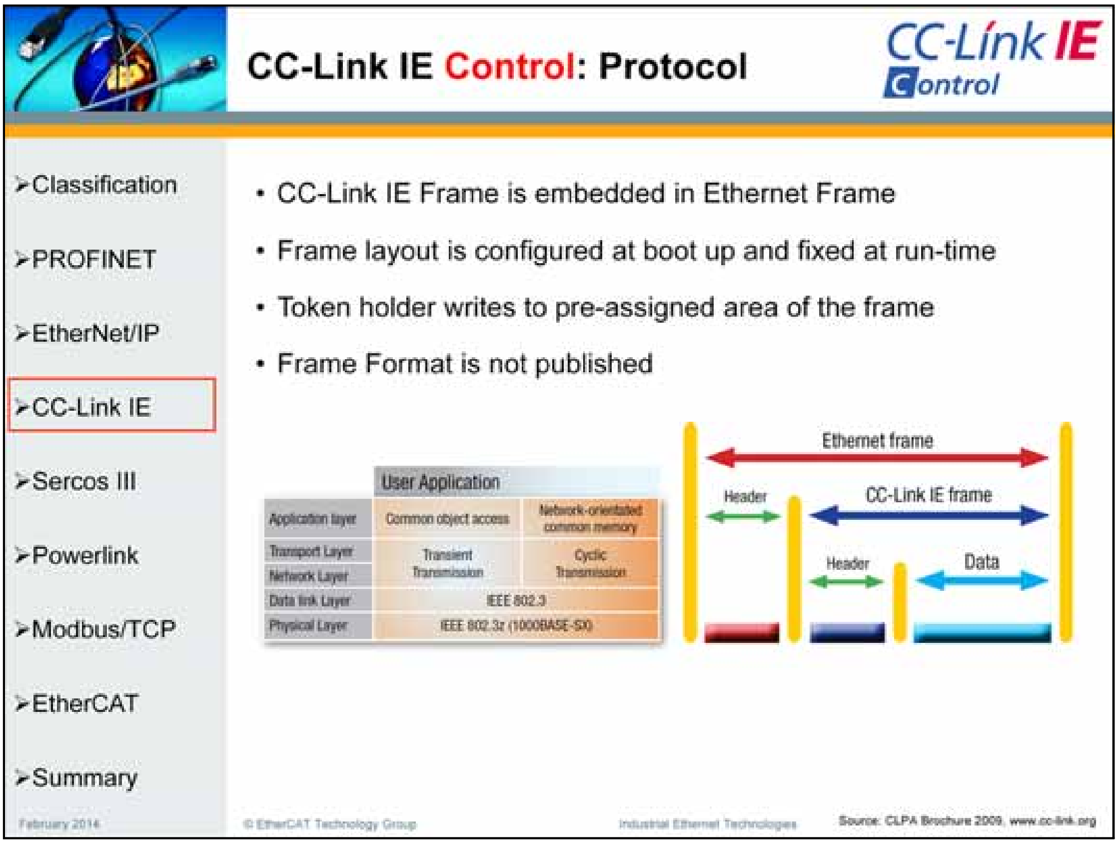
Token Passing Approach:

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.

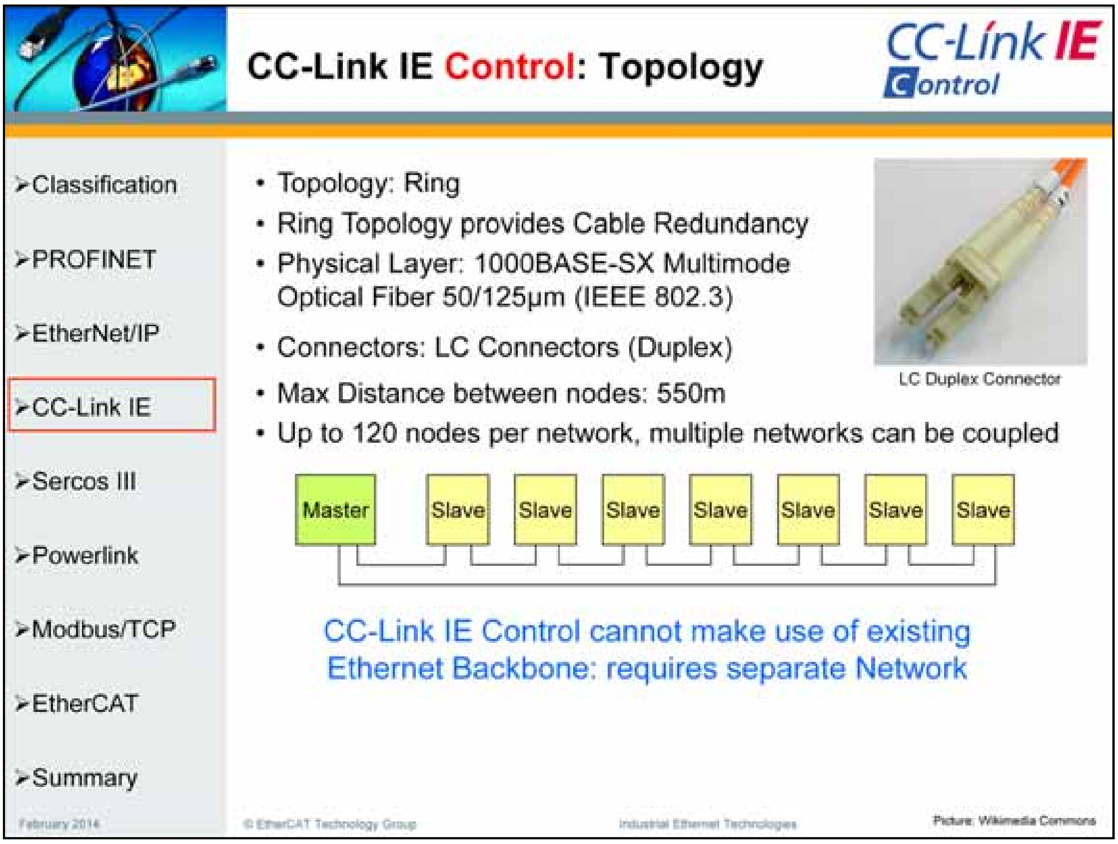


The CC-Link IE Control frame is directly embedded in the Ethernet frame.

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.

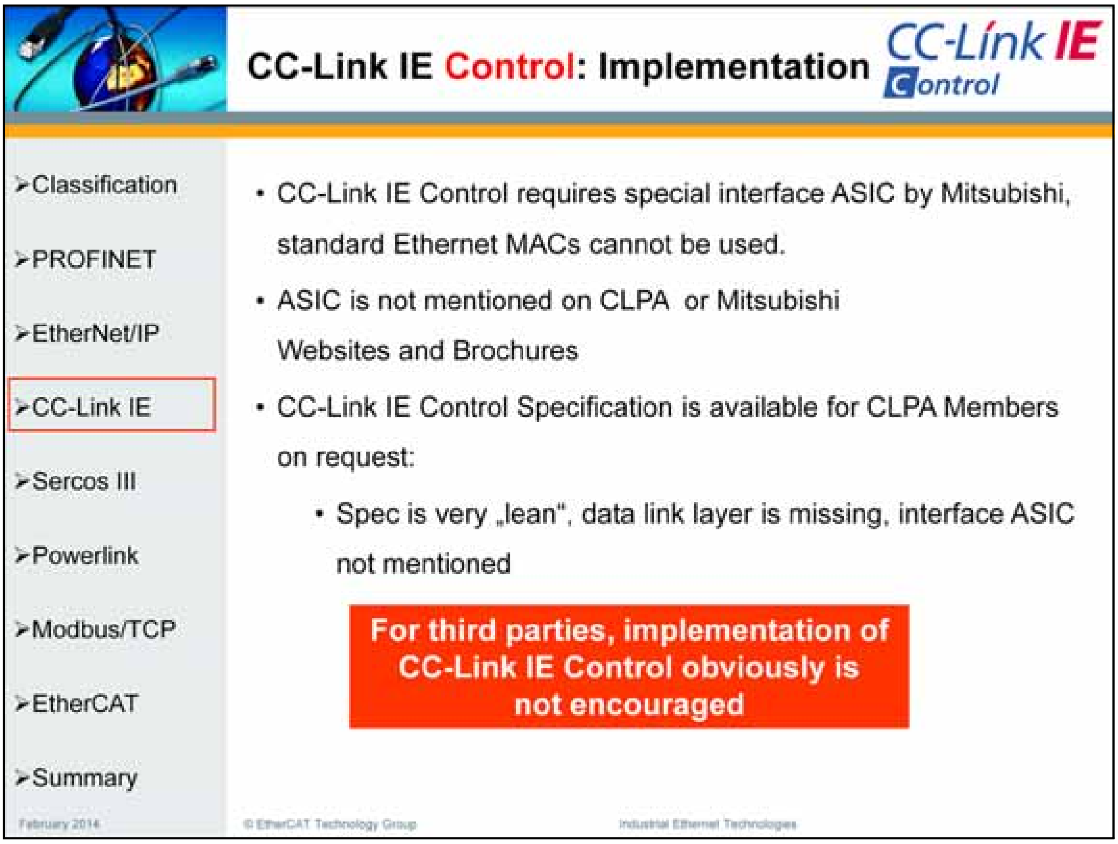
According to an article published by CLPA Europe (IEB Issue 49, November 2008), “TCP/IP communications is supported by way of the transient/acyclic communication function.” However, the specs do not mention this option – it seems that the authors refer to the SLMP over TCP/IP option (see below).



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.



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

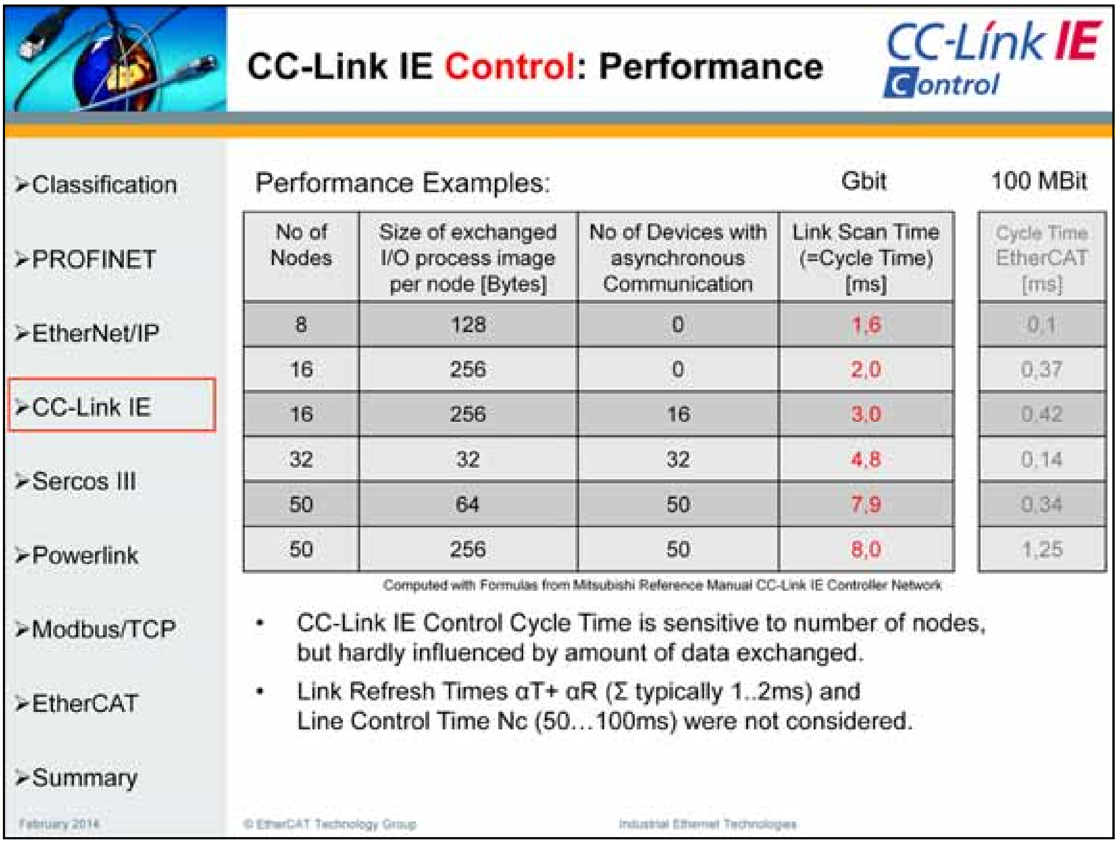
The application layer specs are relatively comprehensive as they have been prepared for inclusion in IEC61158 – CC-Link IE is type 23. Publication of the edition of this standard containing CC-Link IE is expected for April 2014.

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.

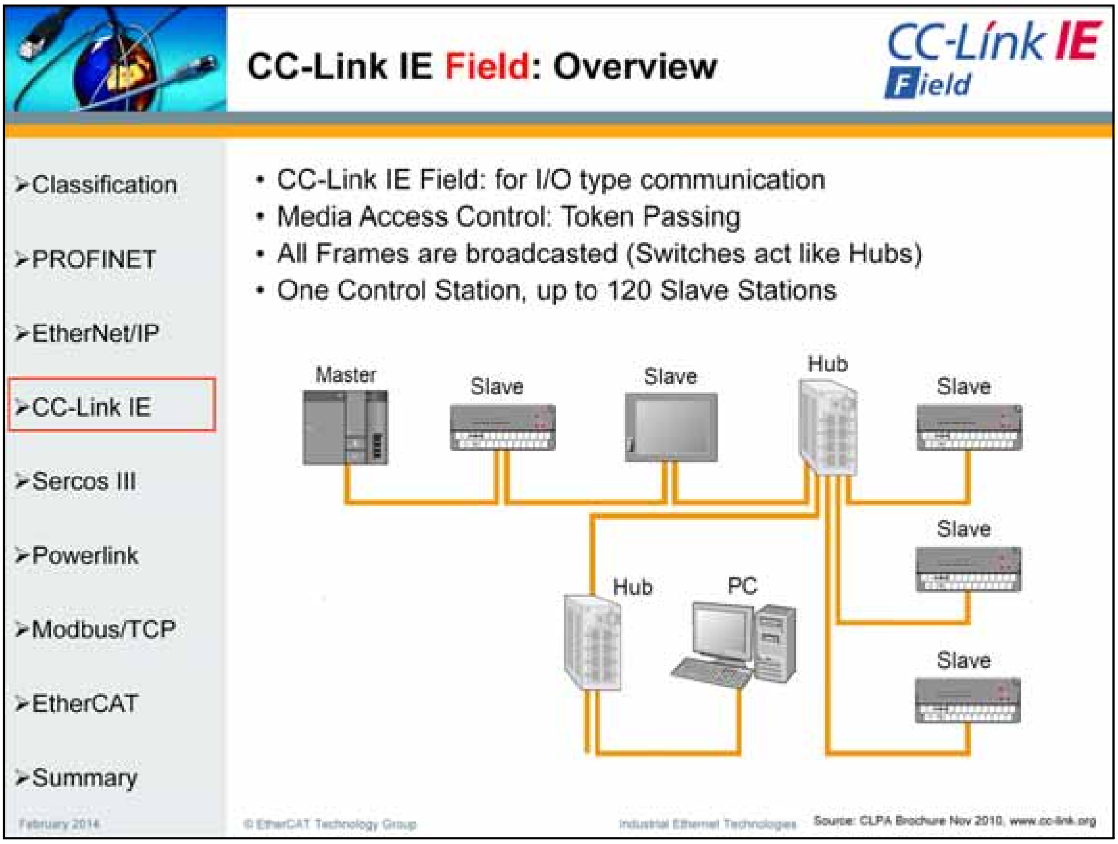


No of Nodes	Size of exchanged I/O process image per node [Bytes]	No of Devices with asynchronous Communication	Link Scan Time (=Cycle Time) [ms]	Cycle Time EtherCAT [ms]
8	128	0	1,6	0,1
16	256	0	2,0	0,37
16	256	16	3,0	0,42
32	32	32	4,8	0,14
50	64	50	7,9	0,34
50	256	50	8,0	1,25

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.

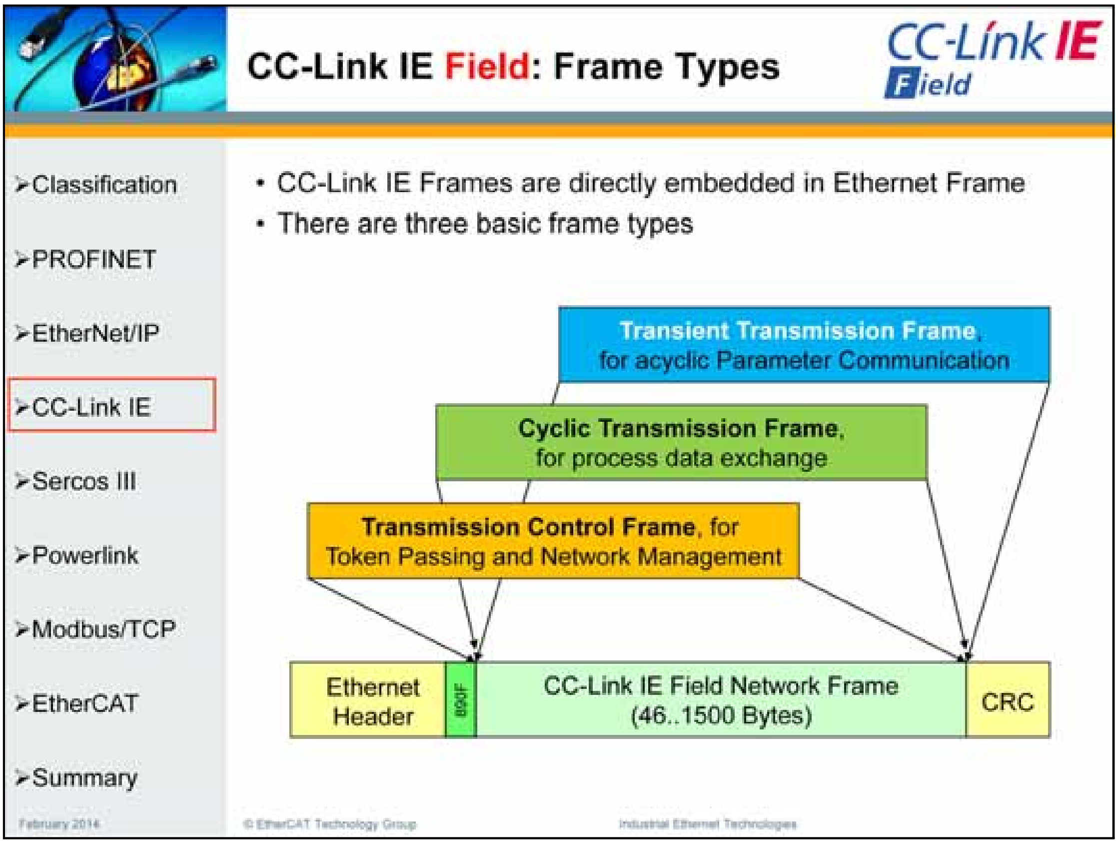
In order to have a fair comparison, the dedicated and separated CC-Link IE Control network was compared with a dedicated and separated EtherCAT (Device Protocol) network, which can also be used for controller/controller communication. However, in many cases the EtherCAT Automation Protocol (EAP) will 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 Nc (Time required for reconfiguring the data link when network is disconnected and reconnected) =0. Usual values for Nc 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.



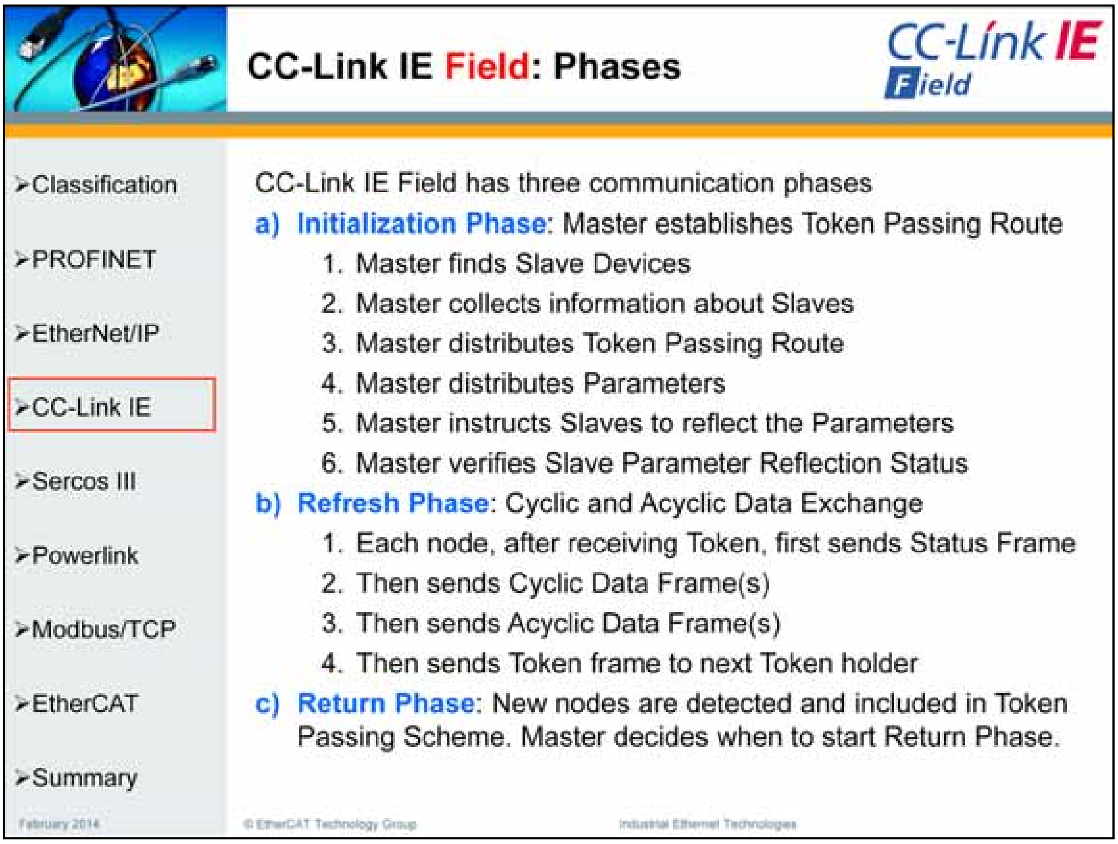
CC-Link IE Field is the adaptation of CC-Link IE Control to the field level. The functional principle – token passing - is shared by both variants. CC-Link IE Field uses copper based Gigabit Ethernet, and supports non-ring topologies such as star and line.

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

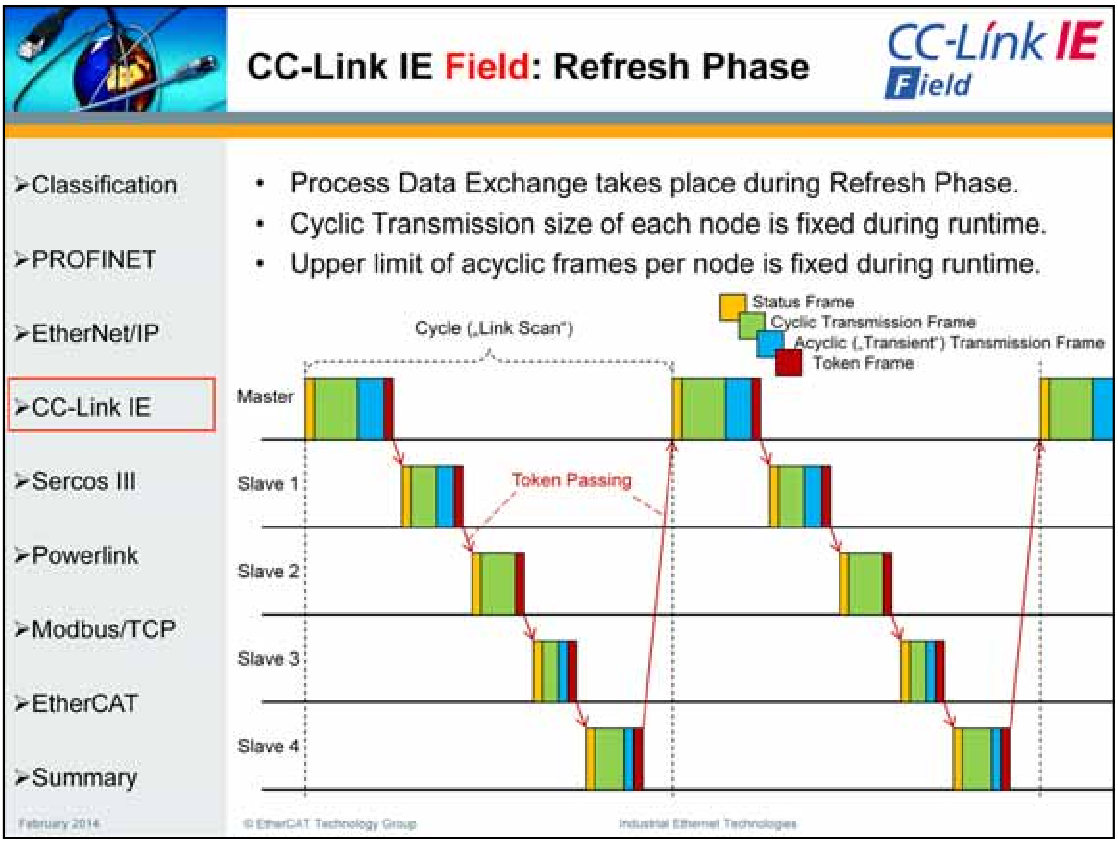


CC-Link IE Field uses Ethernet frames according to IEEE 802.2 and the Ethertype 0x890F.

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 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.



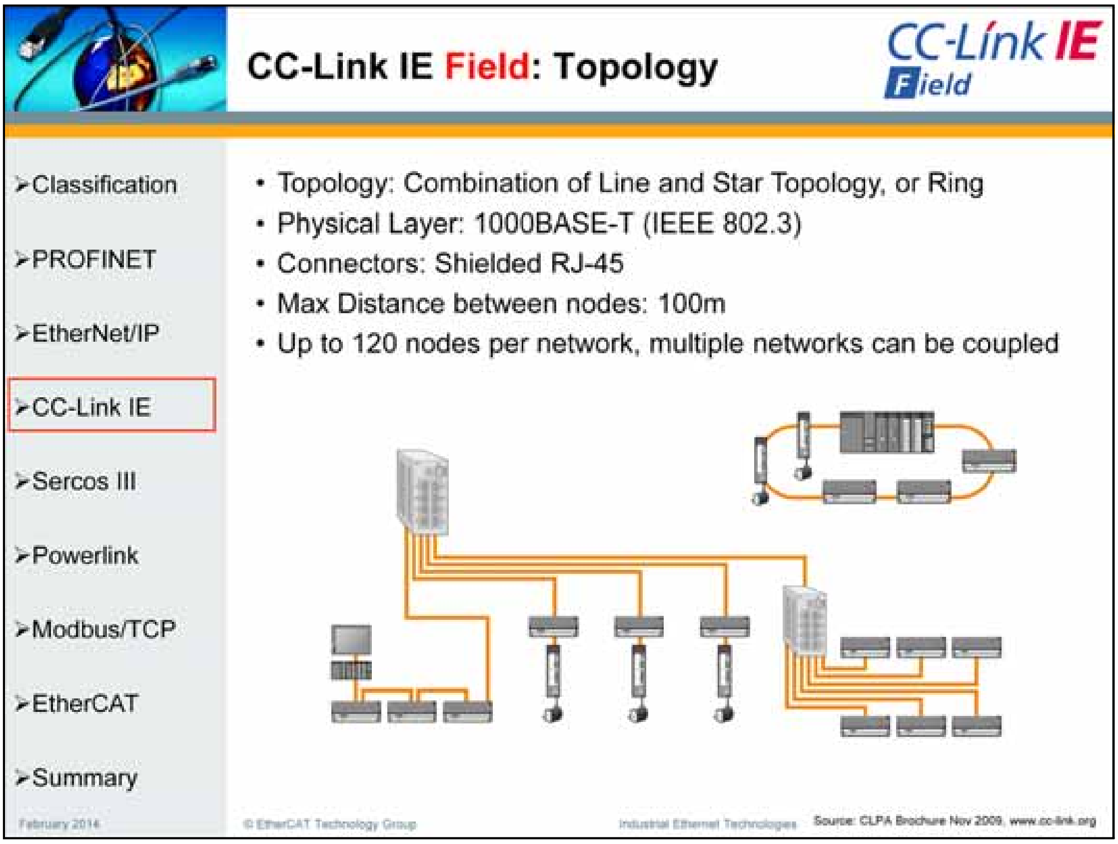
After receiving the token, the slave device first sends its status frame, then one or more cyclic transmission frames, optionally followed by acyclic frames (for the so called transient communication). The number of acyclic frames per node and cycle can be limited in order to avoid cycle time violations.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

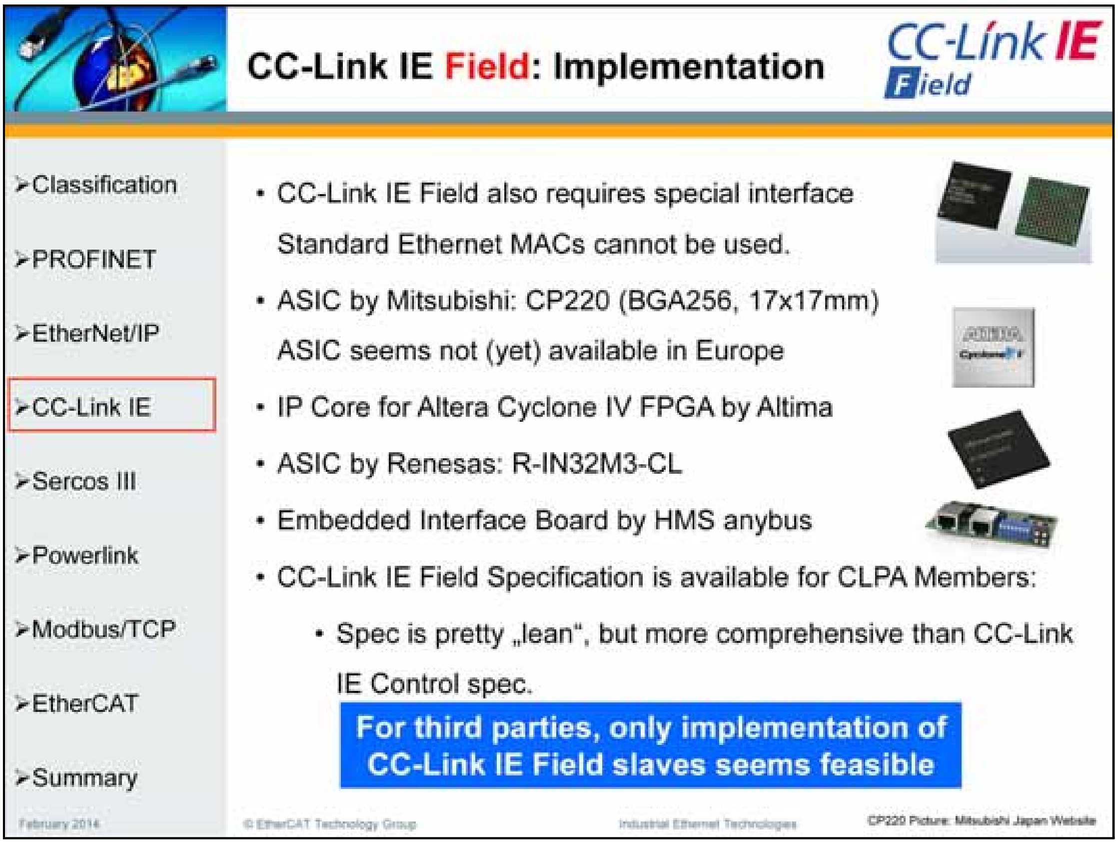
CC-Link IE distinguishes different node types, which differ by maximum process data size as well as features such as support of acyclic communication:

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.



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.



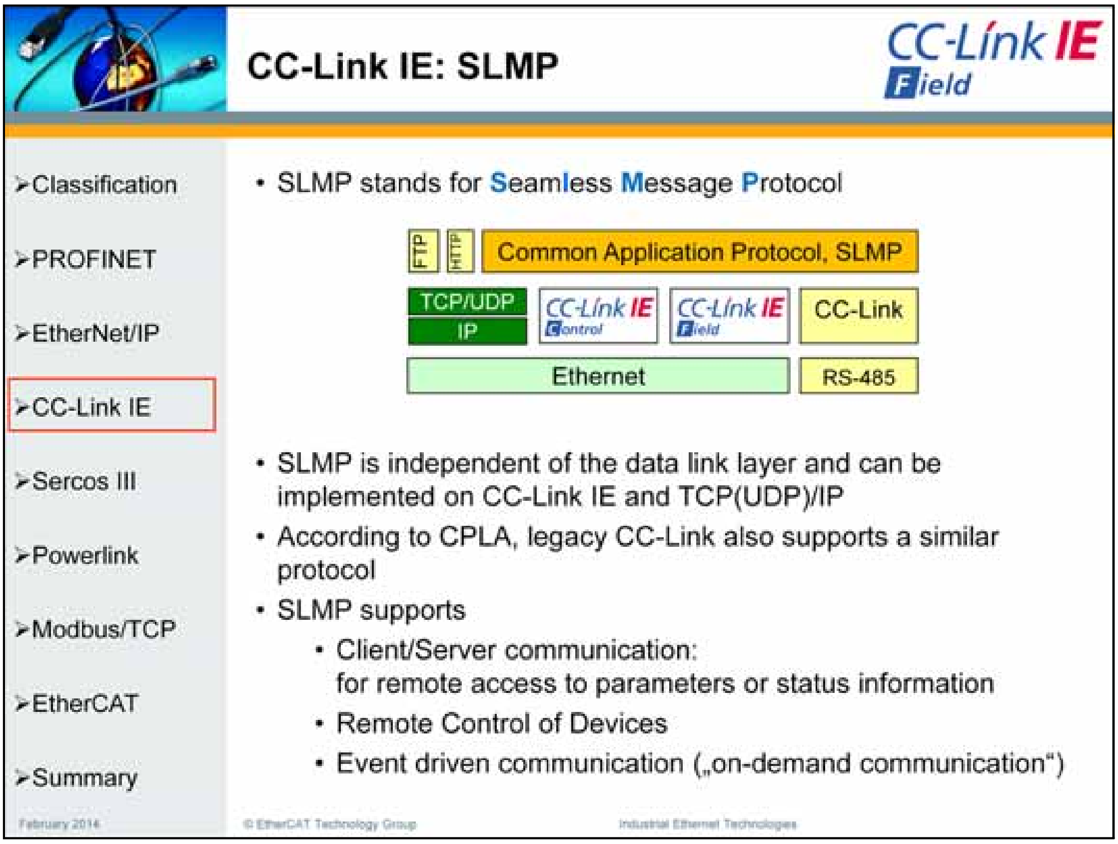
According to Mitsubishi Electric Germany in Feb 2014, the CC-Link IE Field chip CP220 is not (yet) available in Europe.

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

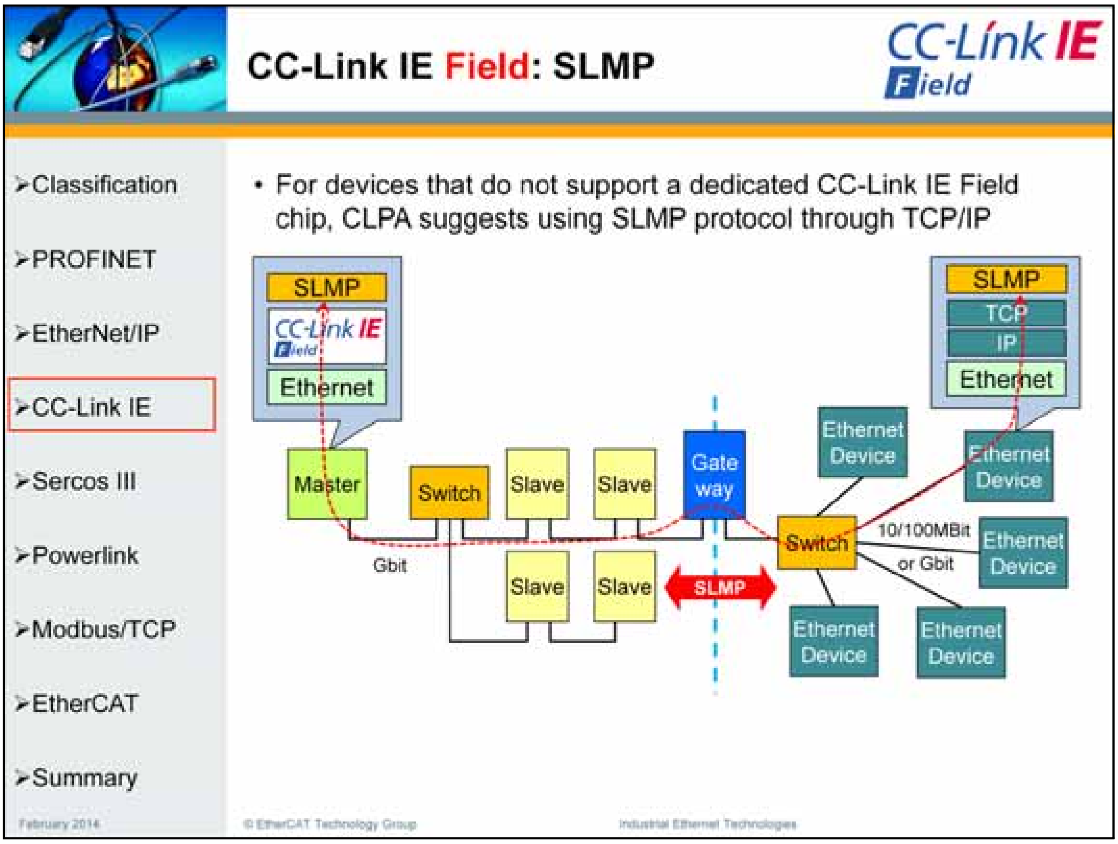
• Device Profile Spec:	23 pages
• Implementation Rules Spec:	8 pages
• Data Link Layer Spec:	2 lines (not pages)
• Application Layer Service Definition:	69 pages
• Application Layer Protocol Definition:	197 pages

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.

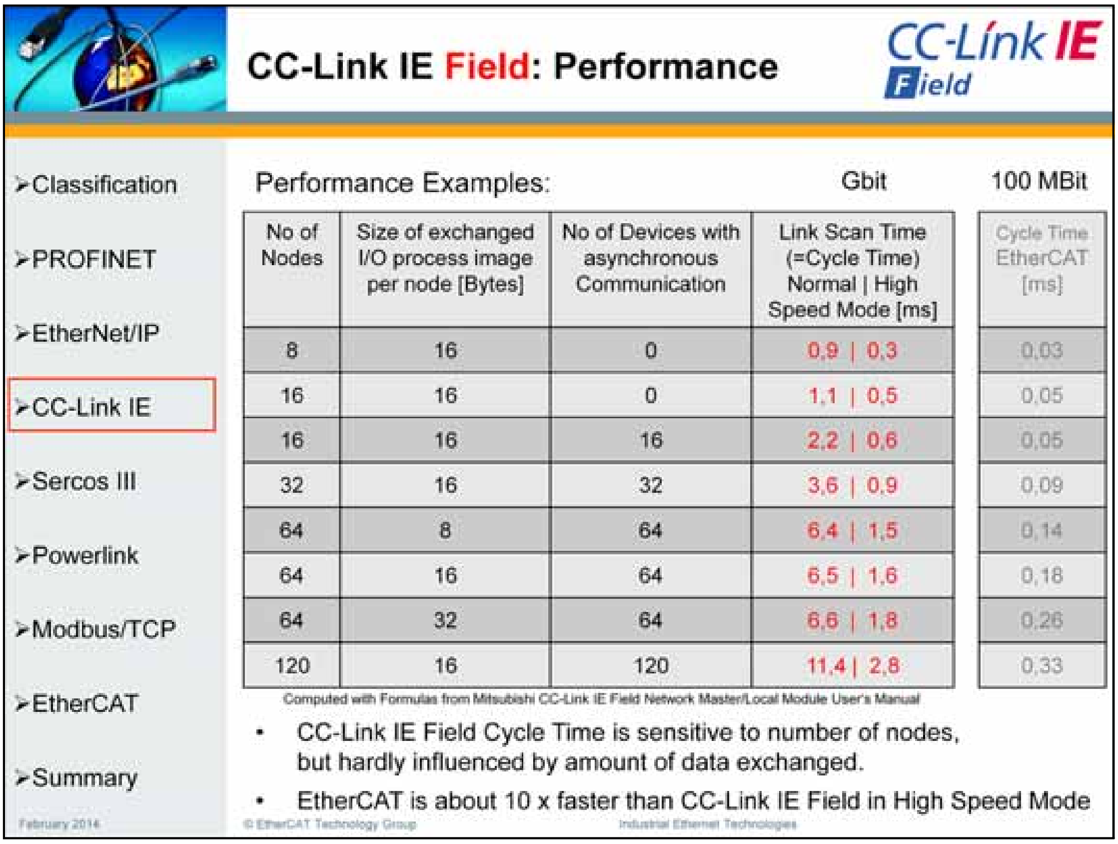


By introducing SLMP, CLPA aims to install a common protocol layer and thus a “cross-media” communication option for all CC-Link technologies. This can be seen as the attempt to provide an approach similar to CIP (ODVA) – however, SLMP does not contain device profiles. Thus, it may provide a common “how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



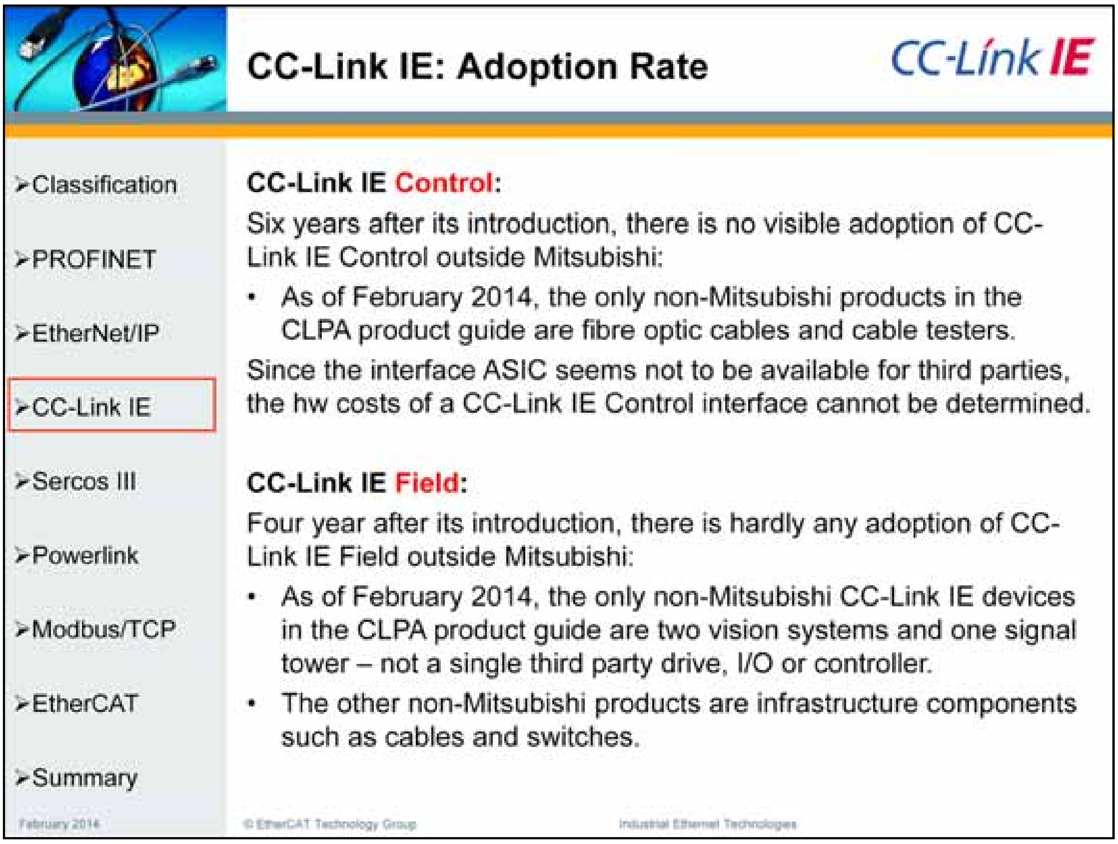
No of Nodes	Size of exchanged I/O process image per node [Bytes]	No of Devices with asynchronous Communication	Link Scan Time (=Cycle Time) Normal | High Speed Mode [ms]	Cycle Time EtherCAT [ms]
8	16	0	0,9 | 0,3	0,03
16	16	0	1,1 | 0,5	0,05
16	16	16	2,2 | 0,6	0,05
32	16	32	3,6 | 0,9	0,09
64	8	64	6,4 | 1,5	0,14
64	16	64	6,5 | 1,6	0,18
64	32	64	6,6 | 1,8	0,26
120	16	120	11,4 | 2,8	0,33

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.

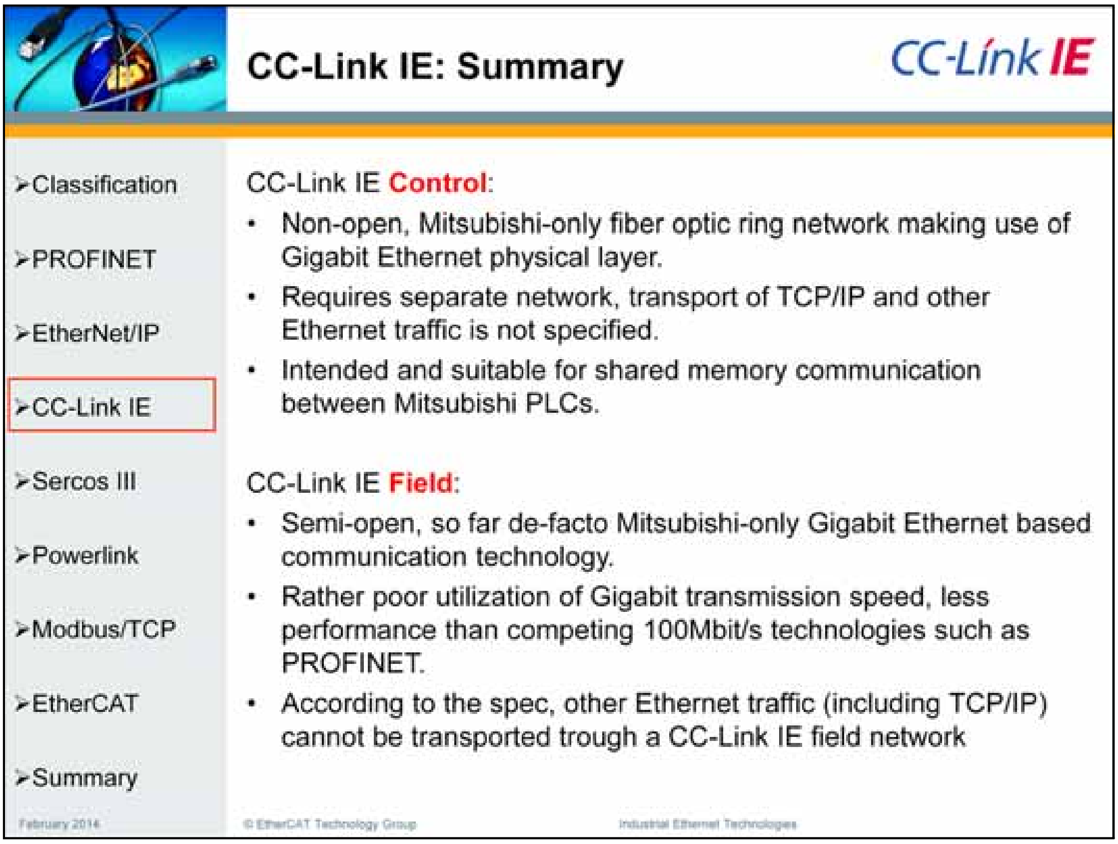
Similar to CC-Link IE Control, the cycle time of CC-Link IE Field is hardly influenced by the amount of data exchanged. In contrast, due to its functional principle, EtherCAT is hardly influenced by the number of nodes – and is much faster anyhow, in spite of using 100Mbit technology.

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 (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.

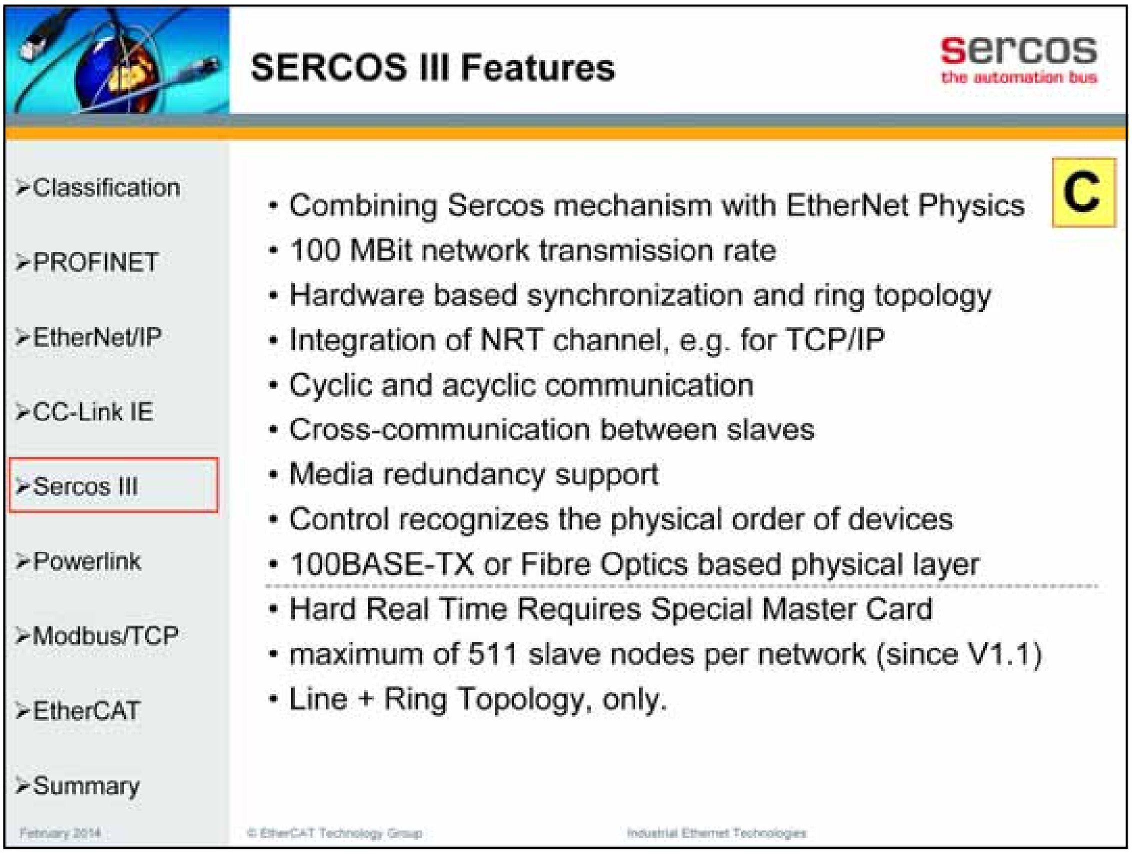
We used the link scan time formula with Ka=25,8 (Normal Mode)|18,5 (High Speed), Kb=655 (NM)|168(HS), Kc=160+60*(no_of_nodes_with_acyclic_comm)(NM)|80(HS), Ni=0 and Kd (Maximum data link processing time when the station is disconnected from or returned to the network) =0. Using recommended values for Kd 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.



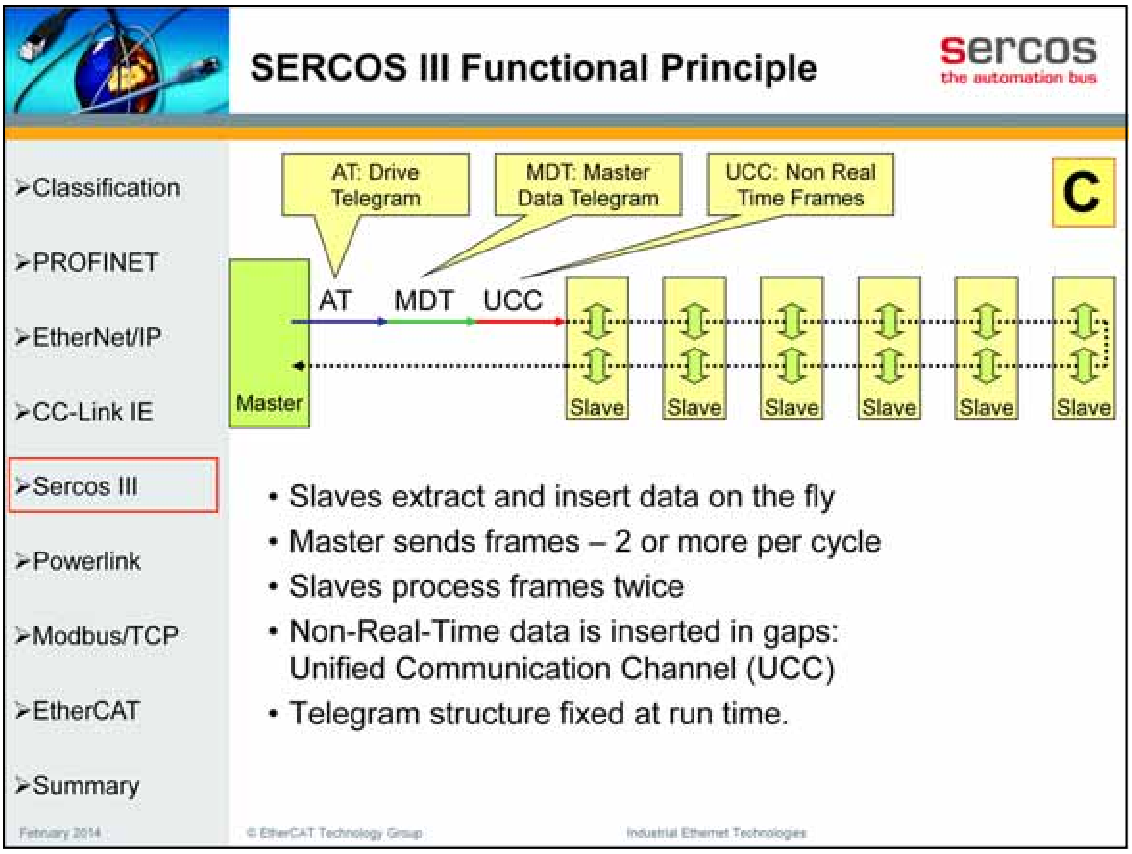
The adoption rate is exceptional.



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

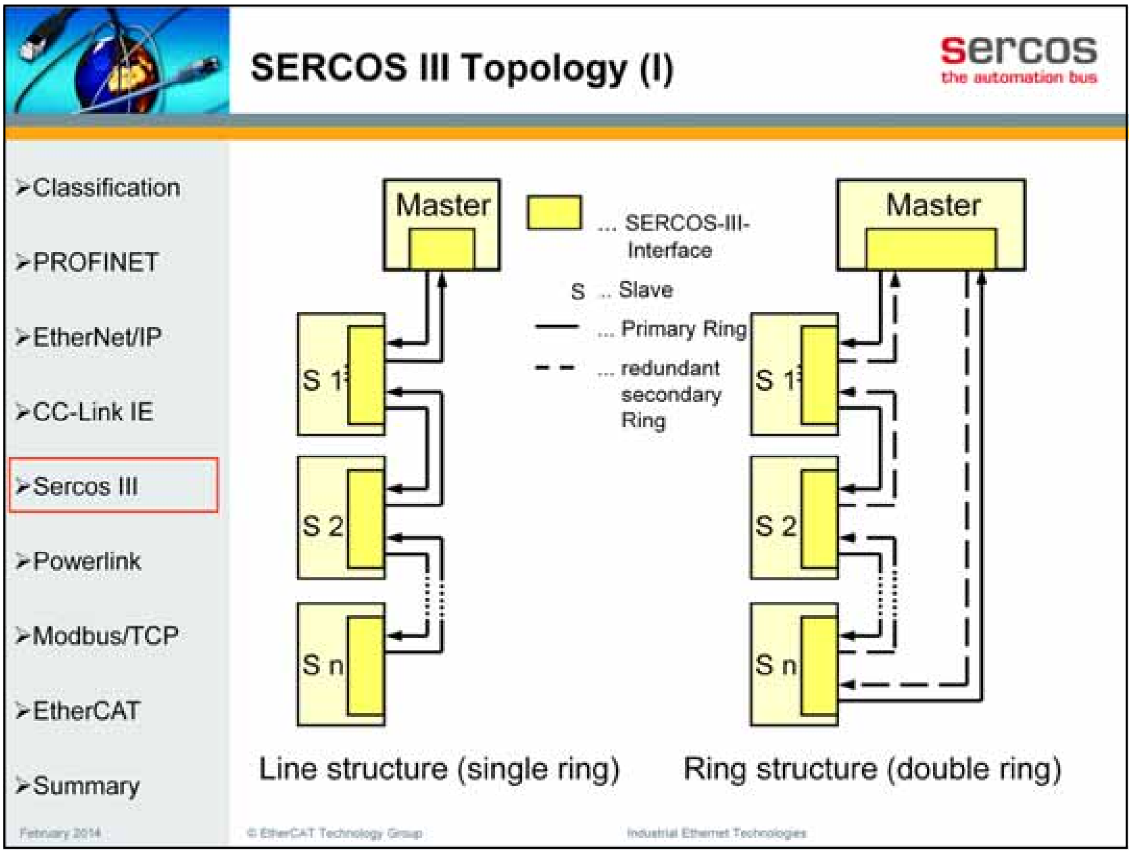


SERCOS-III has adopted the EtherCAT functional principle: processing Ethernet frames on the fly. There are some main differences, though:

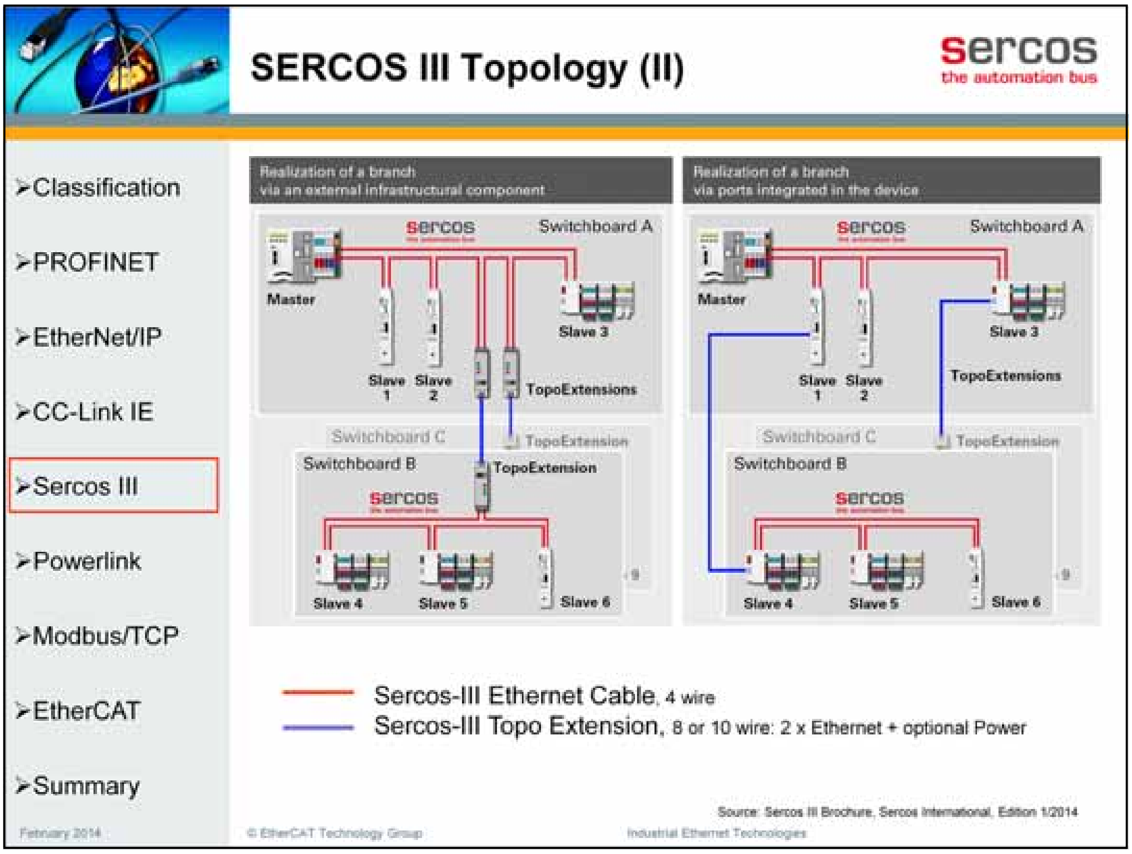
1. SERCOS-III separates input and output data in two frames – so there are at minimum two frames per cycle
2. The slaves process the data twice: on the way out and on the way back
3. Very rigid frame layout – no changes at runtime, no bit-wise mapping.
4. Non Realtime Data (such as TCP/IP) is inserted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

These differences have the following impact – compared with EtherCAT:

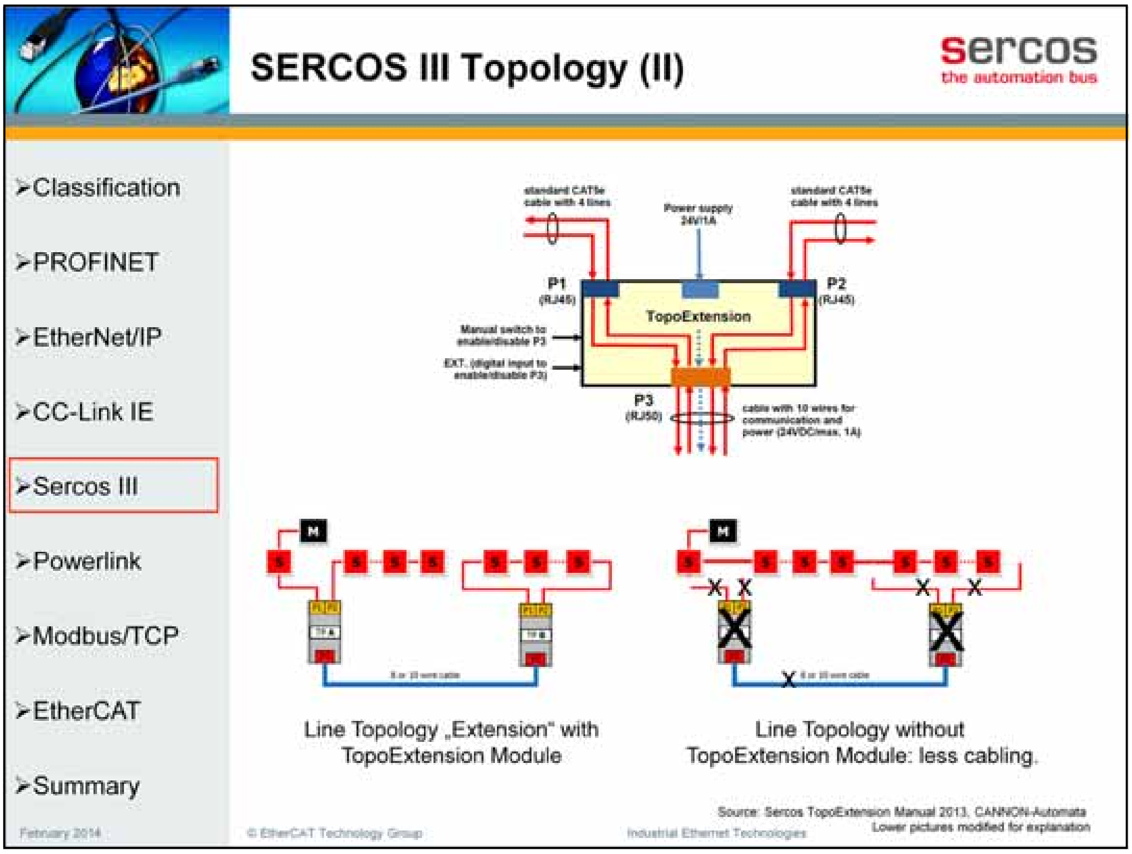
1. Bandwidth utilization is lower. Dual processing in the slave devices. Therefore in average 2-3 times slower than EtherCAT.
2. Separating input and output data and processing twice allows for topology independent slave-to-slave communication within the same cycle. For topology independent slave-to-slave 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 µs), 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 < 25µs.



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.



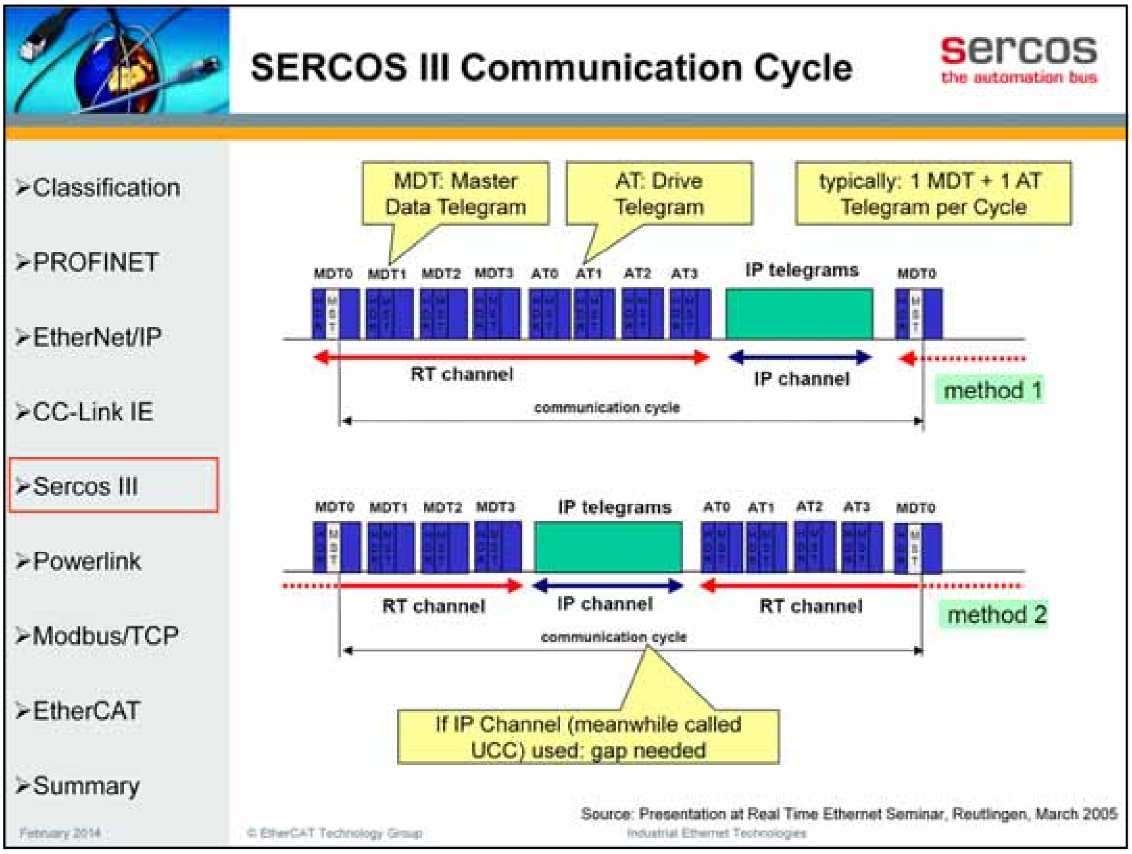
The TopoExtension Module combines two Ethernet lines into one (+ optional power).

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.

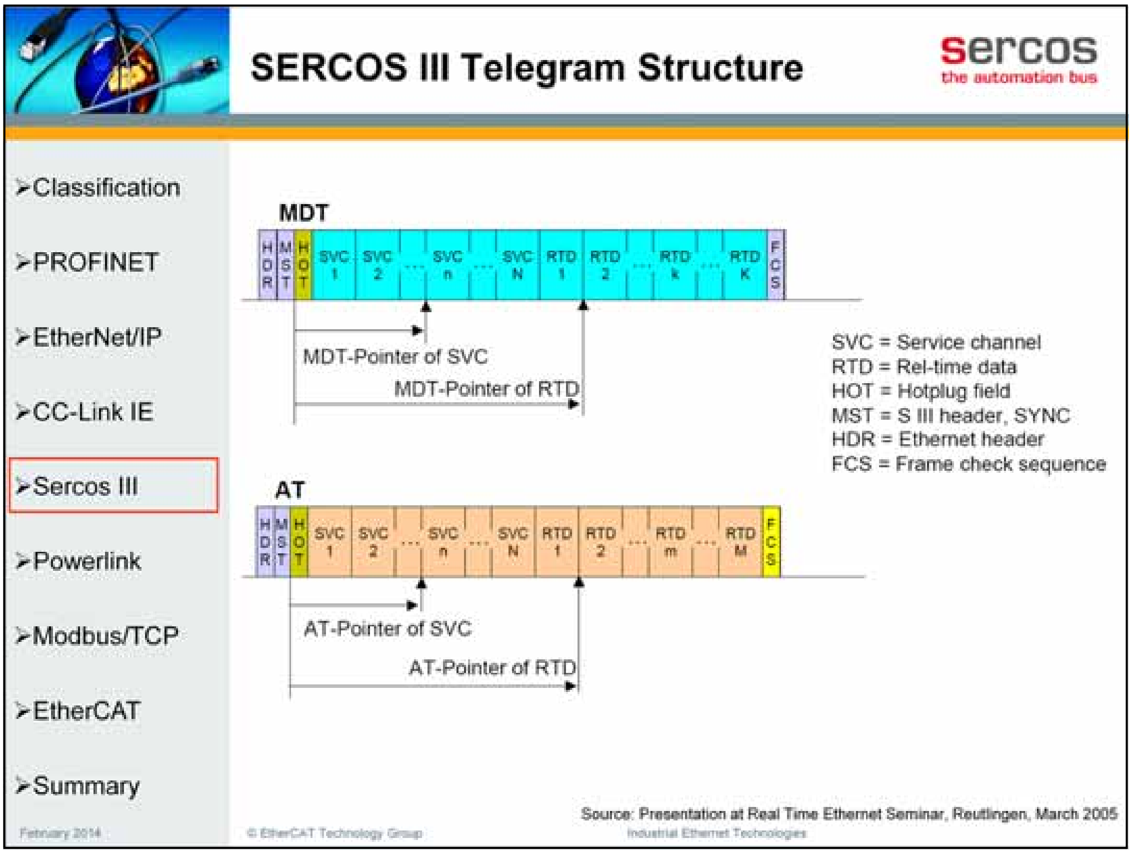
So one can replace two standard cables with two TopoExtension modules and a special cable (RJ50).

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.



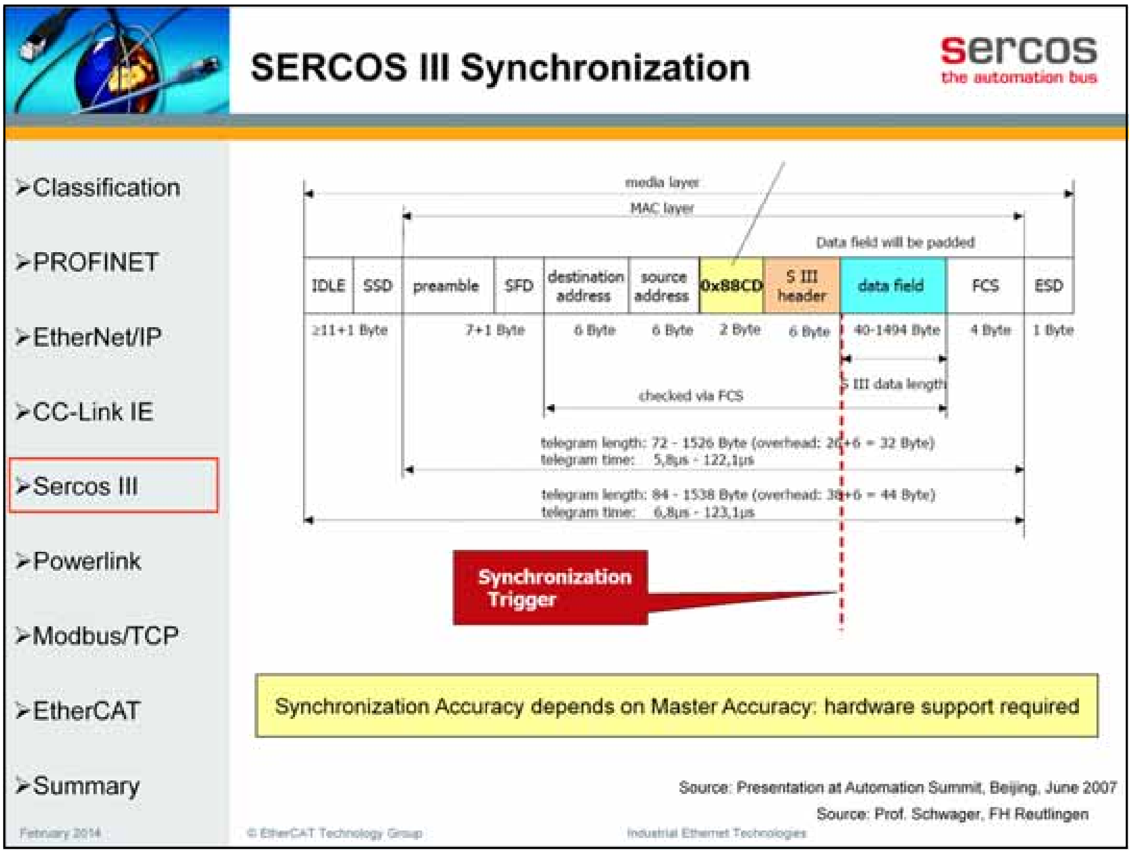
IP data is inserted in a gap (originally named IP channel, now called Unified Communication Channel UCC).The gap can either be after the input and output frames (method 1) or in between (method 2). Typically method 1 is used.



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.

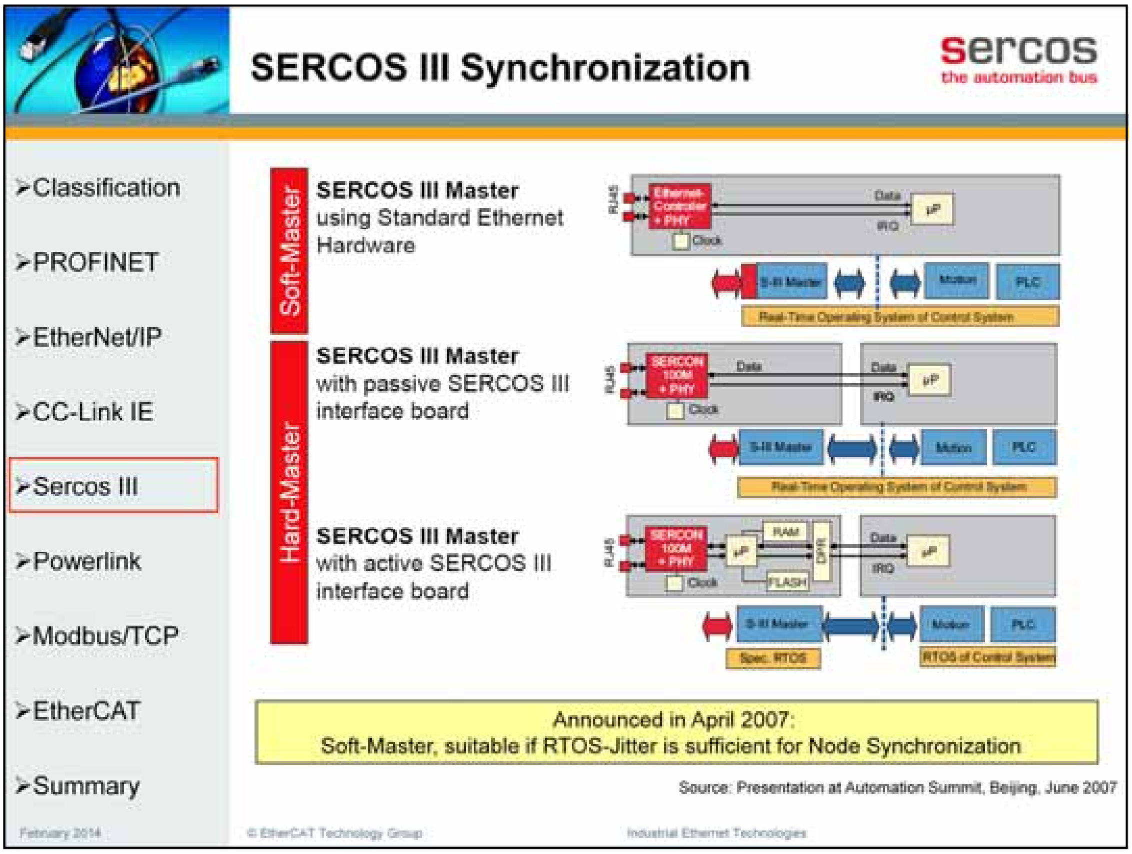
It is thus not possible to e.g. cyclically read a status bit of a device and request data only if this status bit indicates new data.

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).



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.

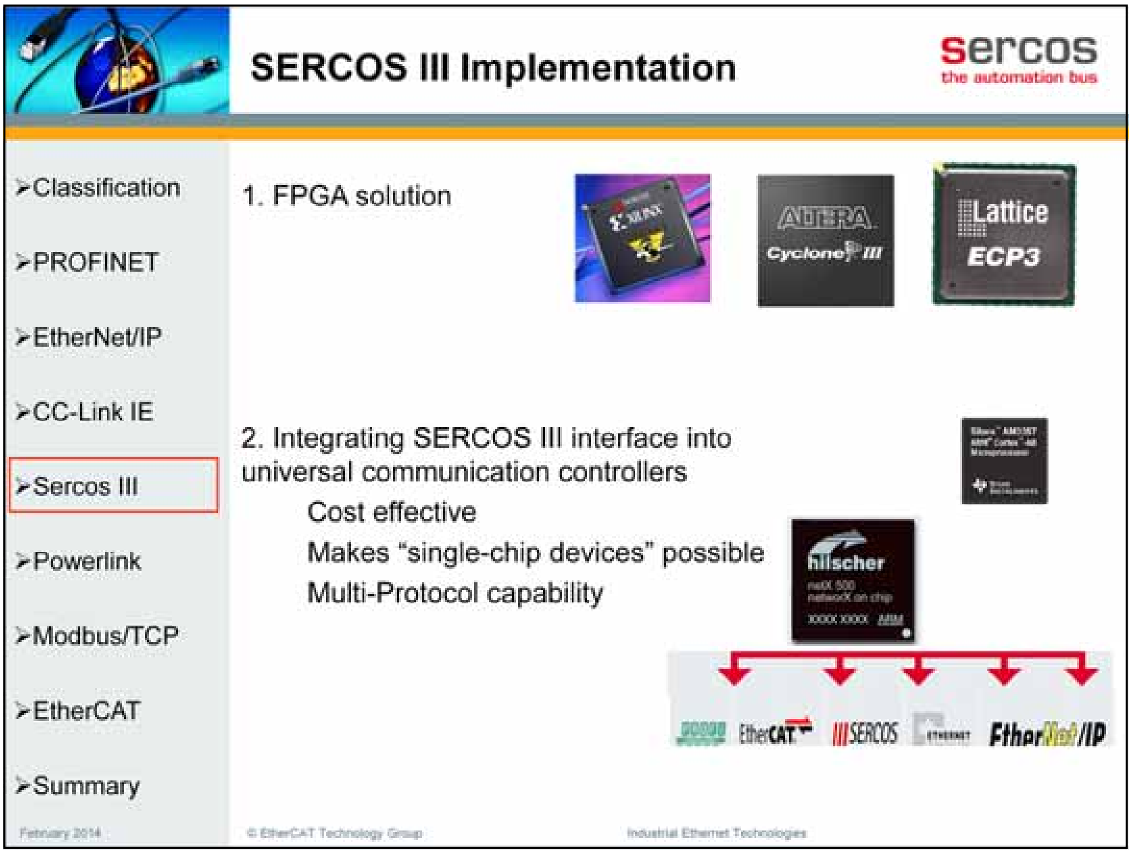


In April 2007, Sercos International announced the development of a Sercos-III “Soft-Master”, implementing the master functionality using software (+ a standard Ethernet Port). According to the press release (quote), ”The achievable synchronization accuracy of a SERCOS III real-time network using a soft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

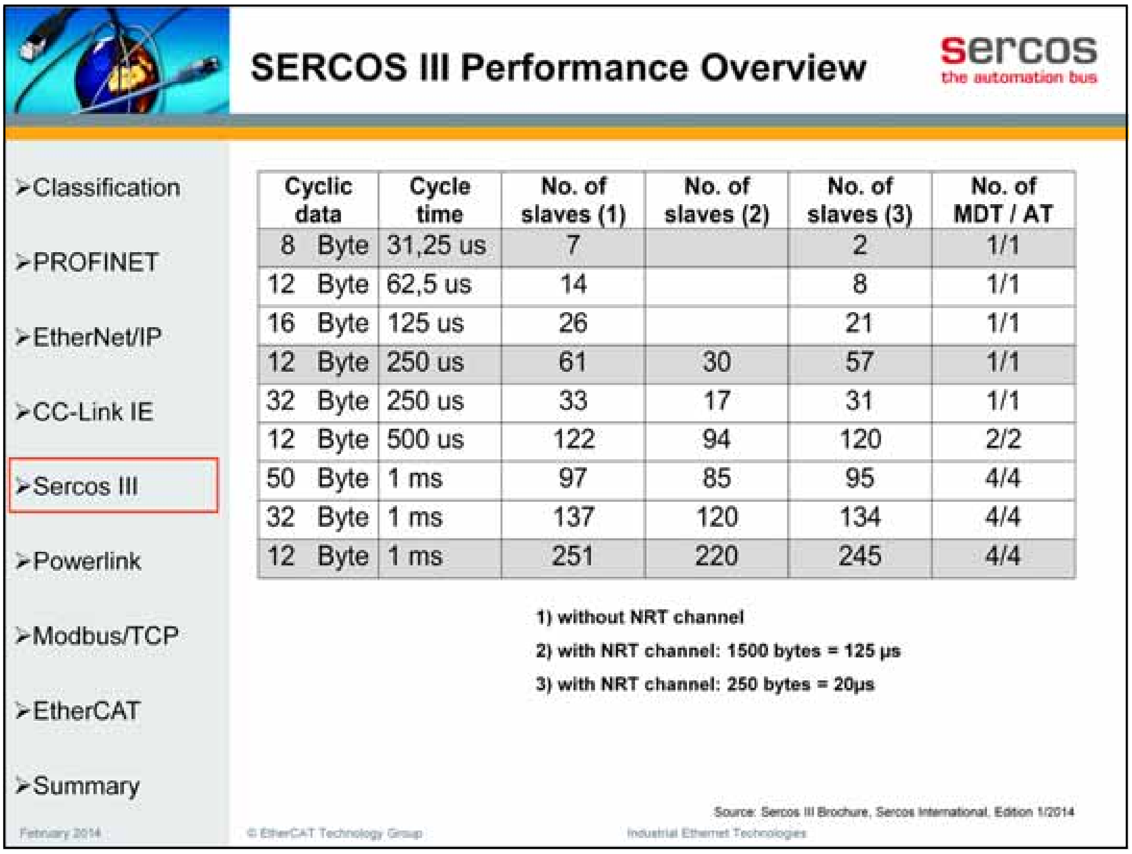


SERCOS-III Controllers are either FPGA based, or the Hilscher netX chip family can be used, which also supports EtherCAT + PROFINET. Furthermore, the TI Sitara Chip Family can also be equipped with a Sercos-III Slave Core.

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).



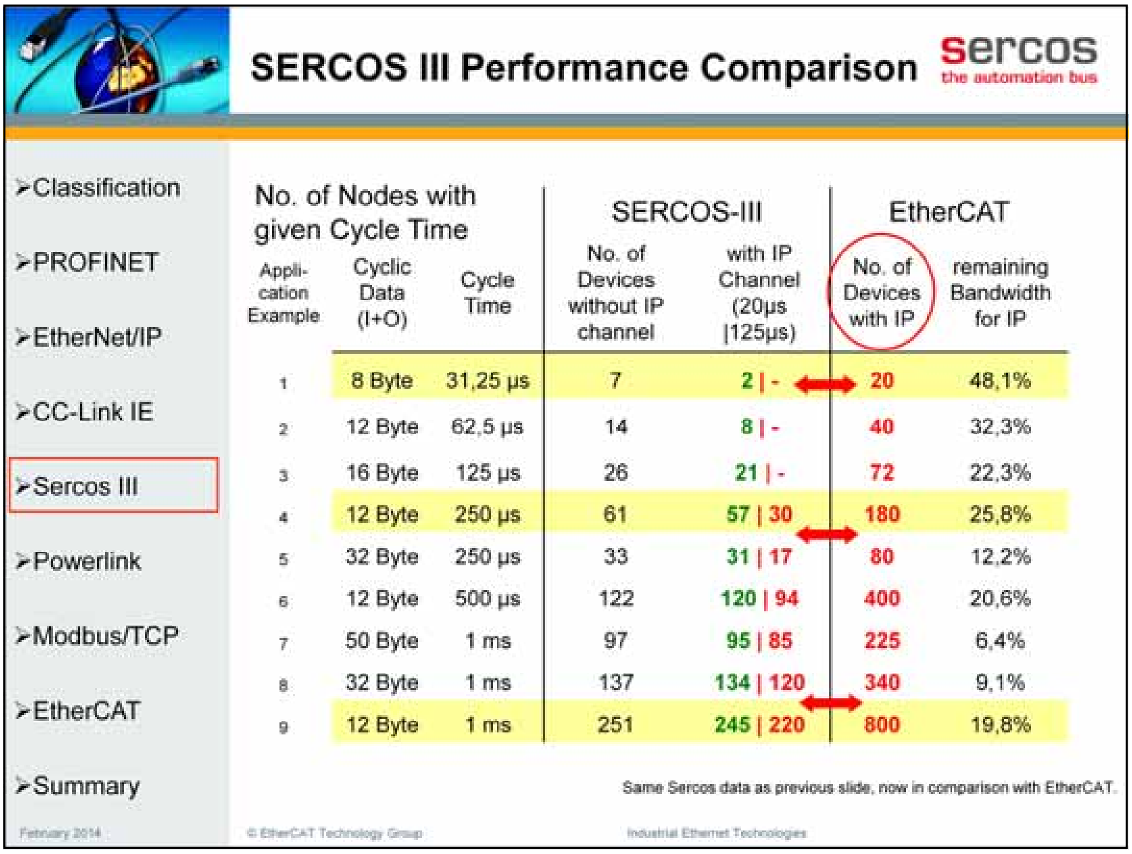
Cyclic data	Cycle time	No. of slaves (1)	No. of slaves (2)	No. of slaves (3)	No. of MDT / AT
8 Byte	31,25 us	7		2	1/1
12 Byte	62,5 us	14		8	1/1
16 Byte	125 us	26		21	1/1
12 Byte	250 us	61	30	57	1/1
32 Byte	250 us	33	17	31	1/1
12 Byte	500 us	122	94	120	2/2
50 Byte	1 ms	97	85	95	4/4
32 Byte	1 ms	137	120	134	4/4
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

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

sercos the automation bus

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

No. of Nodes with given Cycle Time			SERCOS-III		EtherCAT	
Application 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
1	8 Byte	31,25 µs	7	2 | -	20	48,1%
2	12 Byte	62,5 µs	14	8 | -	40	32,3%
3	16 Byte	125 µs	26	21 | -	72	22,3%
4	12 Byte	250 µs	61	57 | 30	180	25,8%
5	32 Byte	250 µs	33	31 | 17	80	12,2%
6	12 Byte	500 µs	122	120 | 94	400	20,6%
7	50 Byte	1 ms	97	95 | 85	225	6,4%
8	32 Byte	1 ms	137	134 | 120	340	9,1%
9	12 Byte	1 ms	251	245 | 220	800	19,8%

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

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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

sercos
the automation bus

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

Cycle Time with given No. of Nodes

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

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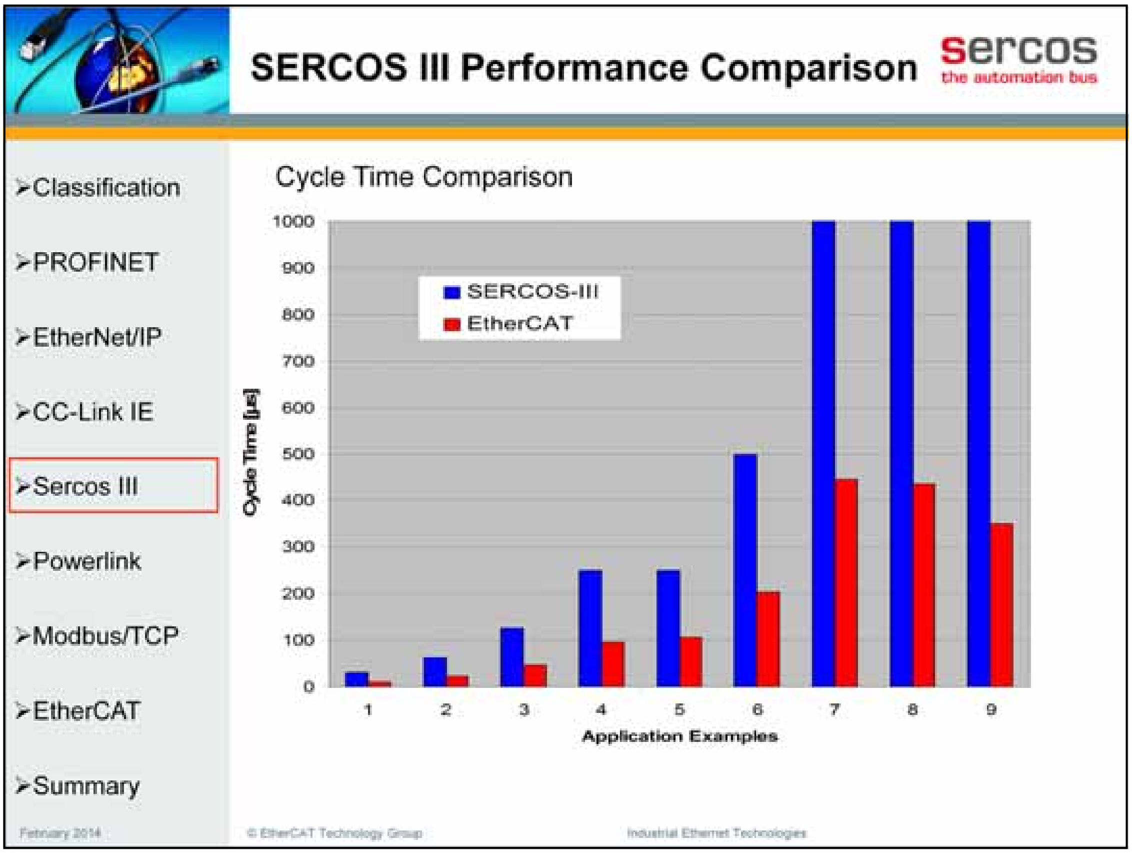
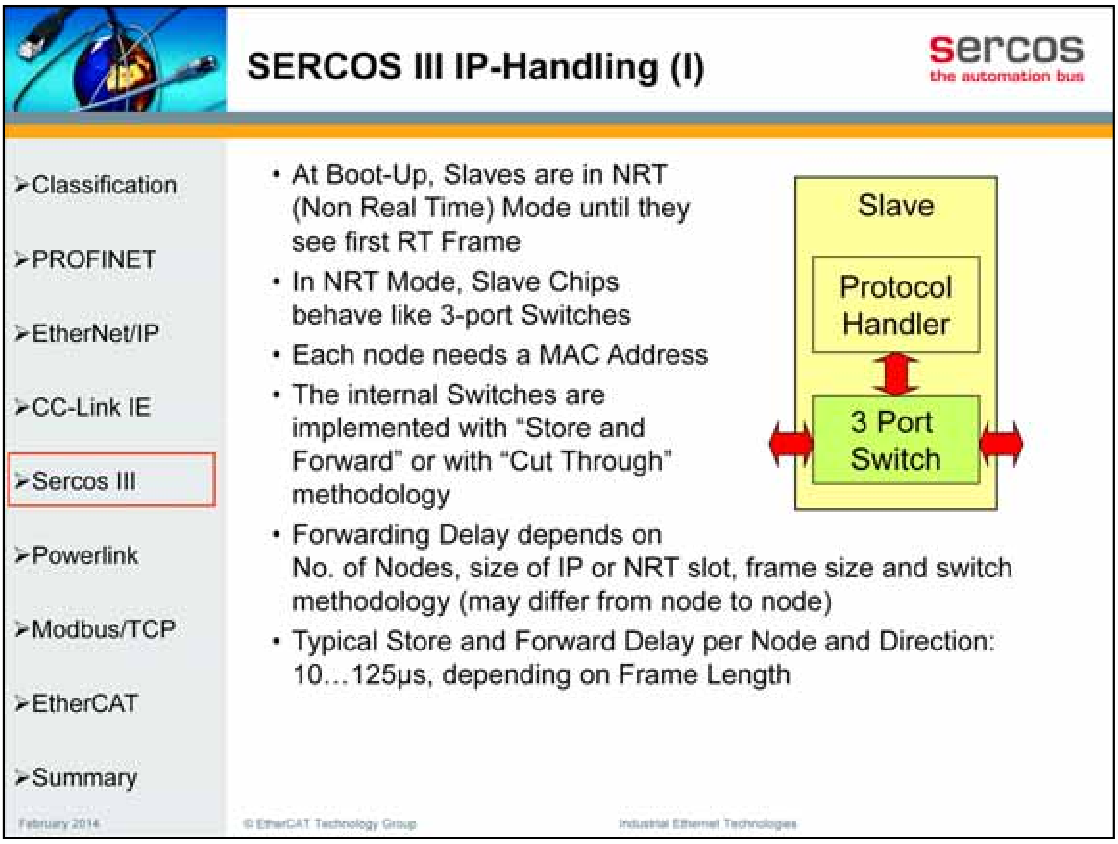
Another view for the comparison: now the number of nodes and the amount of data per slave is fixed, and the resulting cycle time is compared.



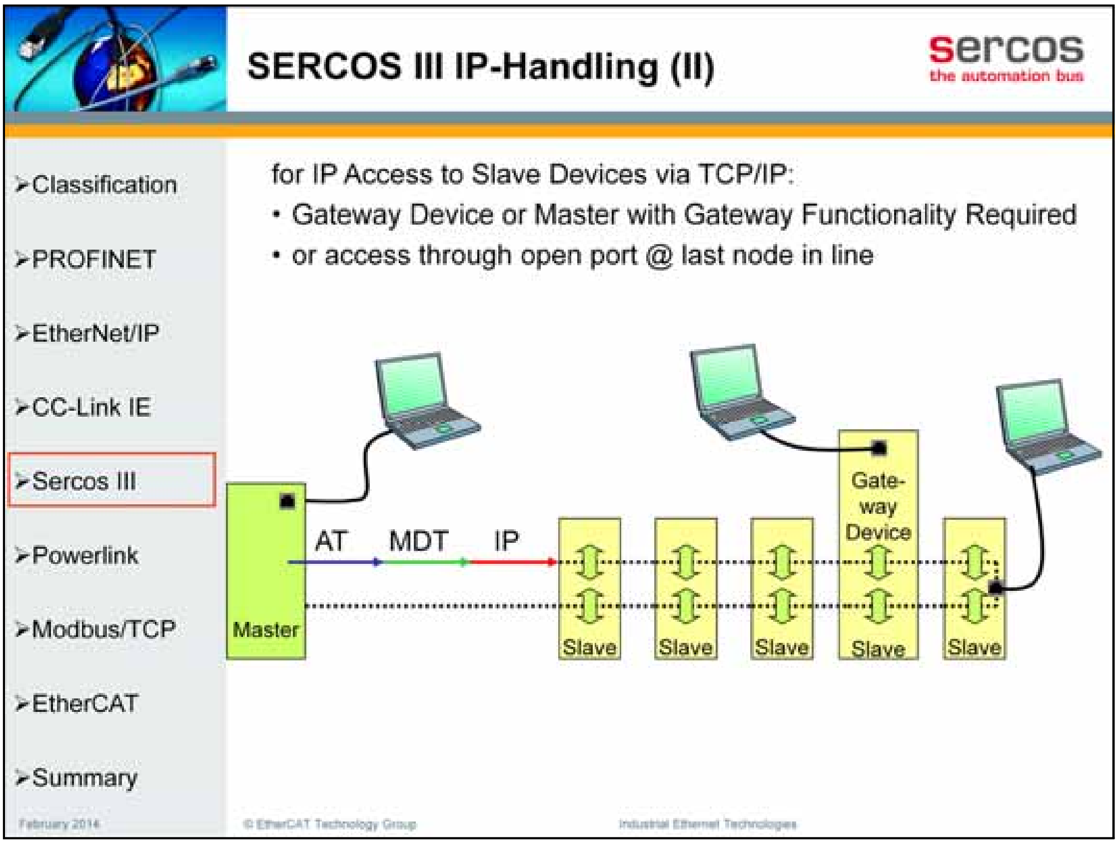
A graphical view for the previous table.

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



Sercos-III 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 the 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.

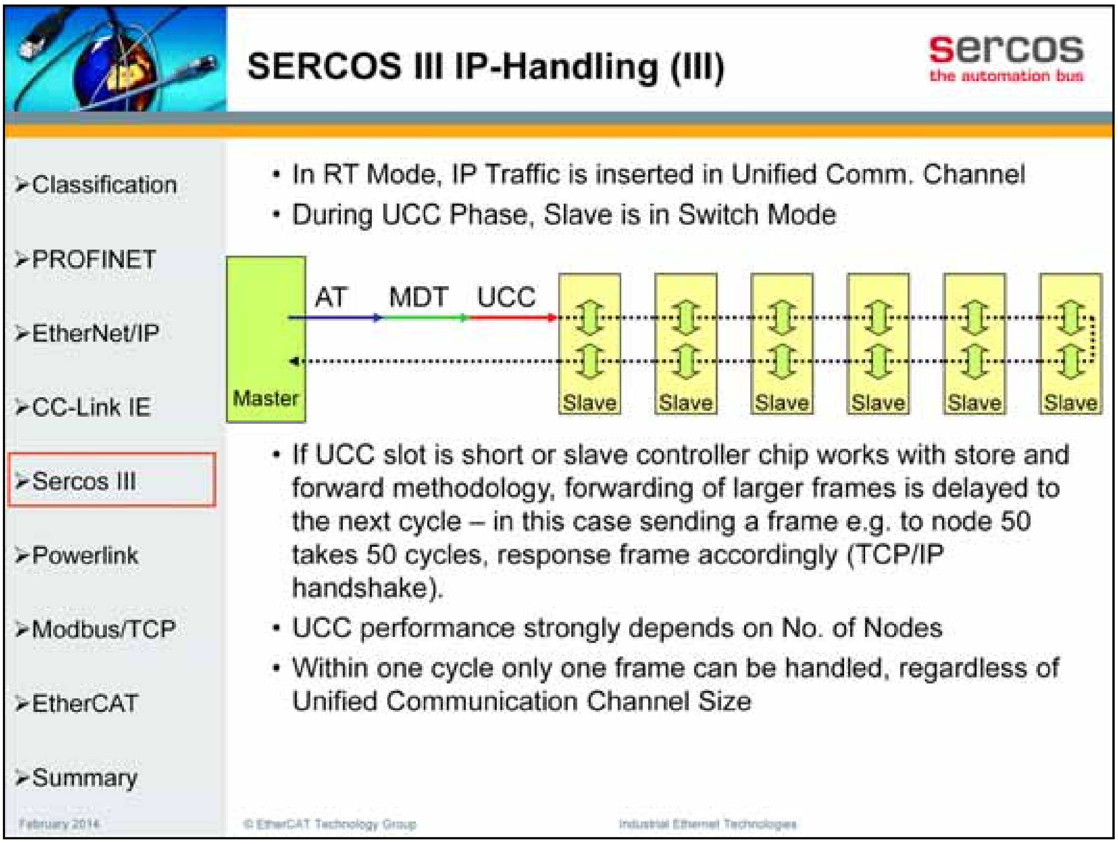
It will be interesting to see how the IP communication over a large number of cascaded switches behaves.



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.

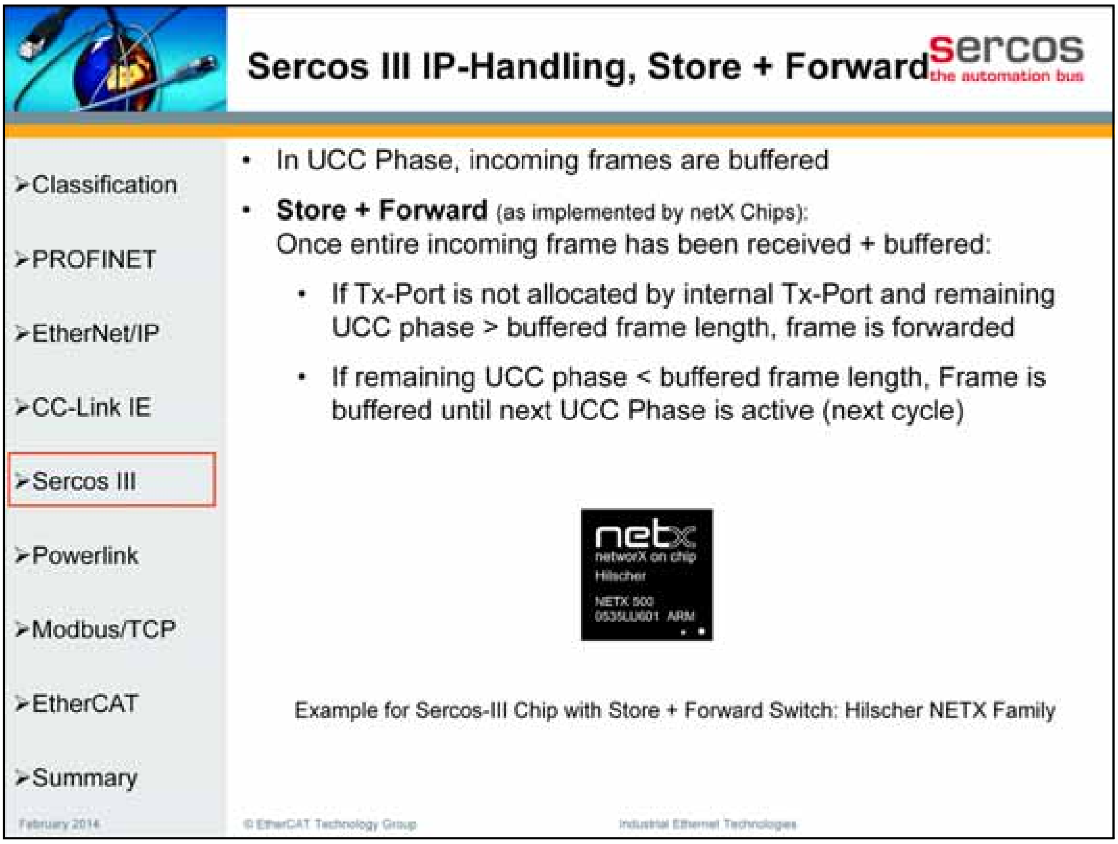
This is the same if IP access (e.g. for remote diagnosis) shall be supported without the need to physically connect the link first.

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)

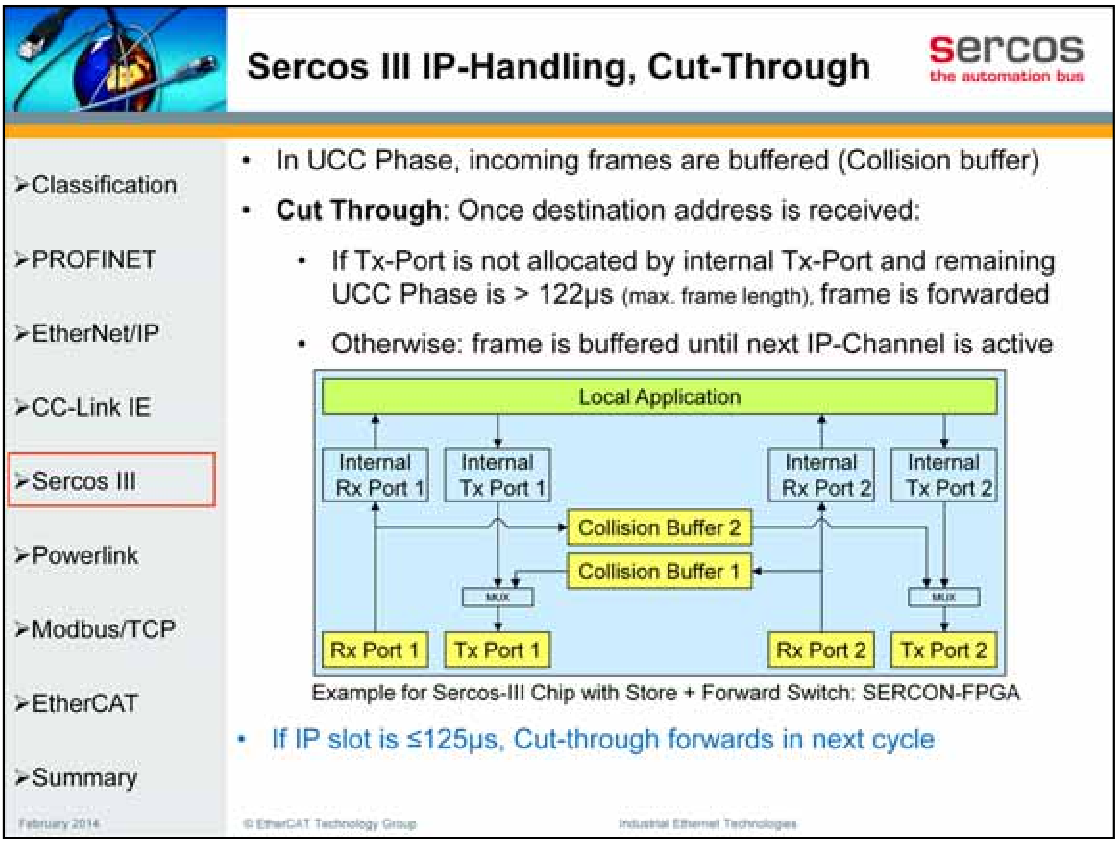


In each RT cycle, the slave controllers switch between “processing on the fly-mode” for process data and “switch-mode” for IP data.

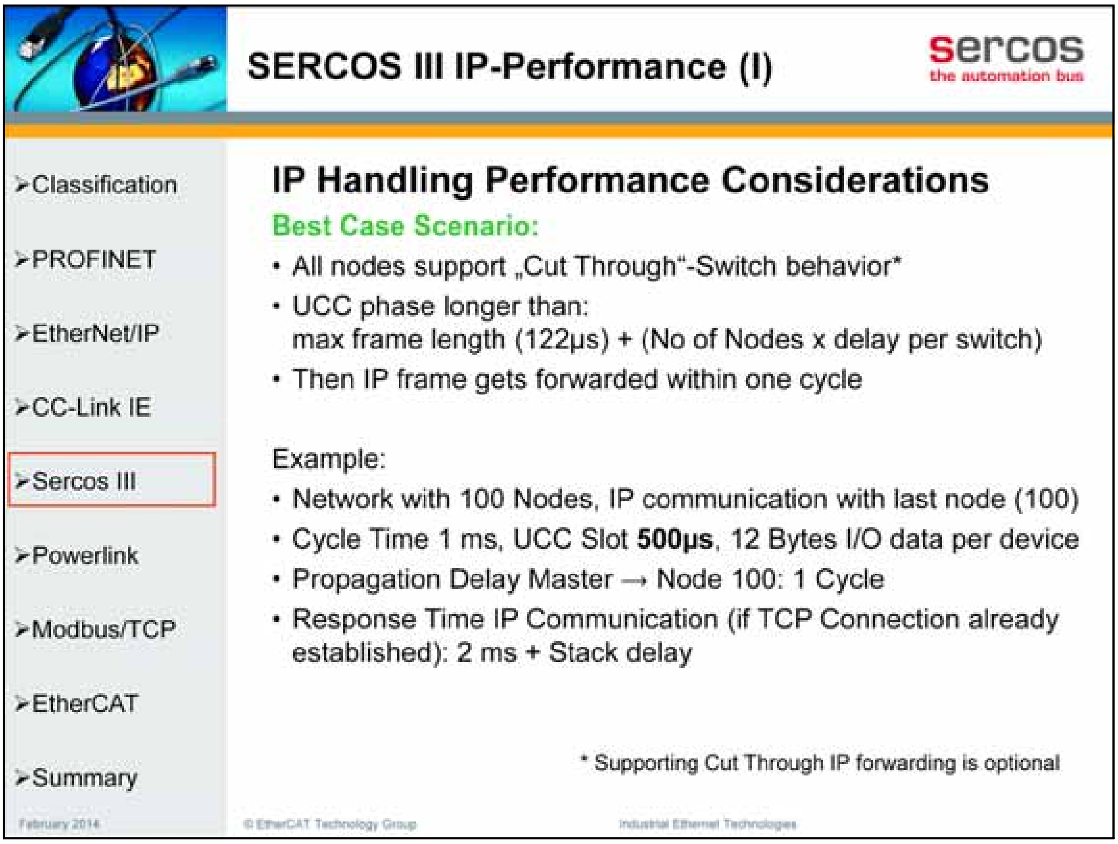
The forwarding behavior of IP frames in the IP slot depends on the slave device capabilities and on the network configuration



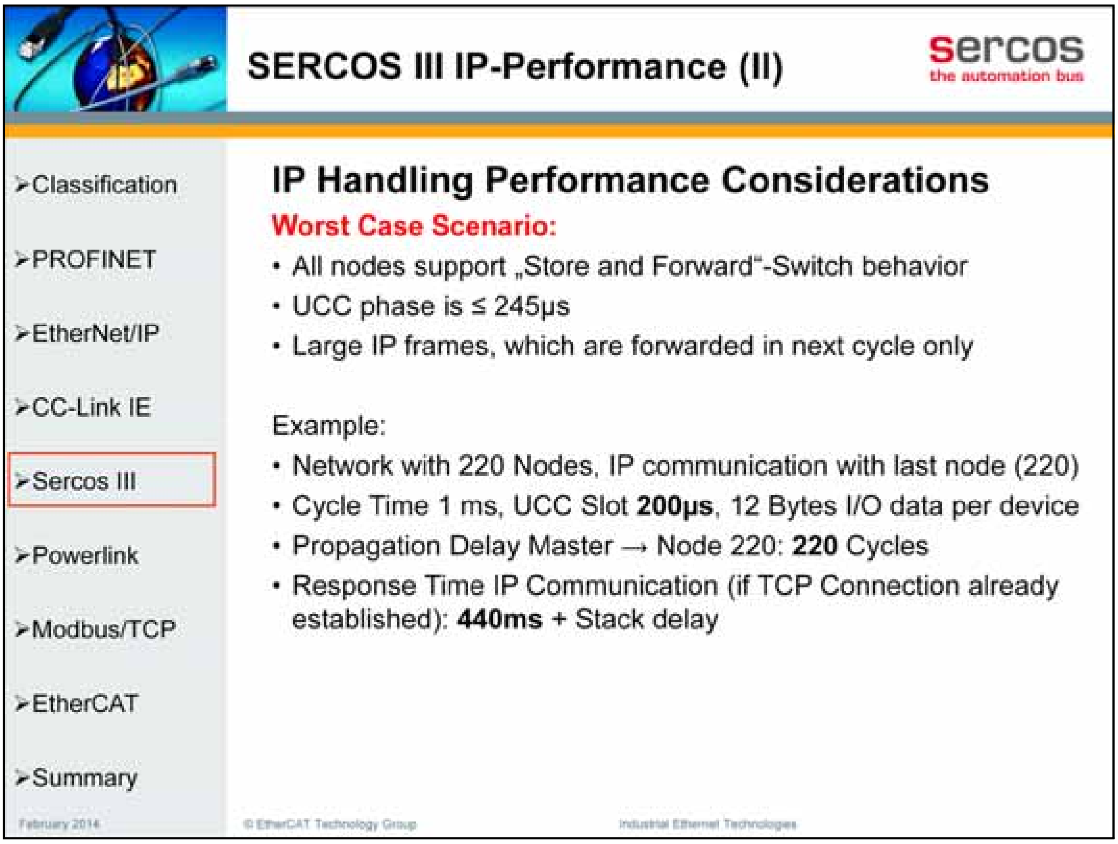
Most current Sercos-III implementations support Store and Forward, which means that within one Sercos-III cycle an IP frame moves from node n to node n+1, if frame sending takes longer than half of the UCC phase.



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 125µs, the only Cut-Through Sercos-III slave controller (SERCON FPGA) buffers the frame for the next cycle.



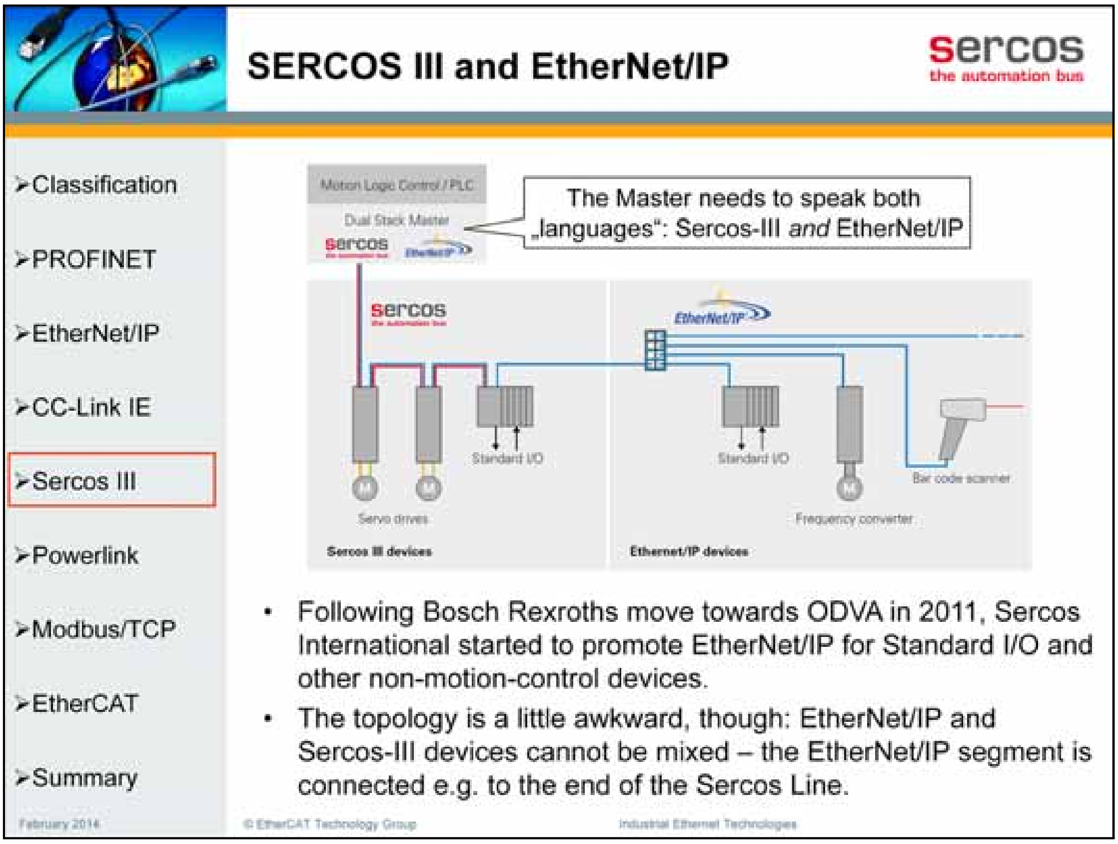
If UCC phase is long enough (>>125µs) and cut-through is supported throughout, the performance of the IP communication looks sufficient.



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.

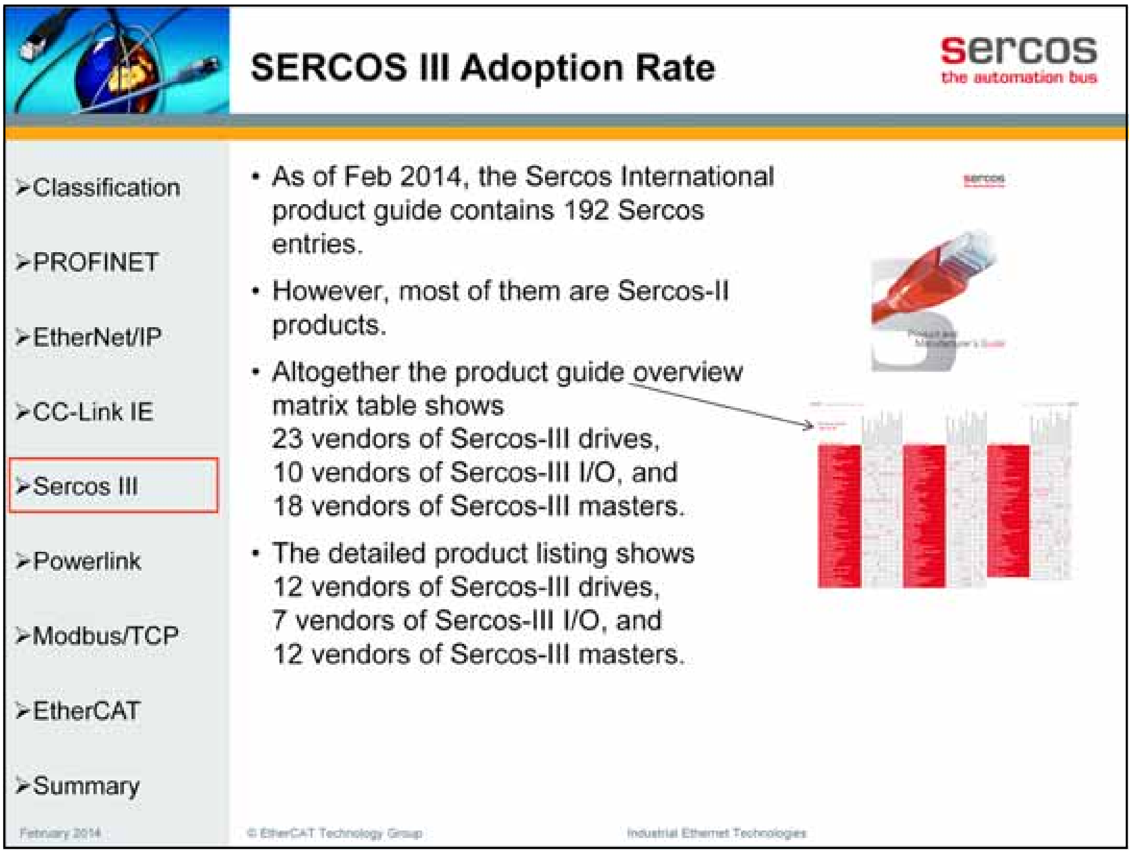
It is obvious, though, that the IP handling mechanism of SERCOS III works best in small networks.



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.

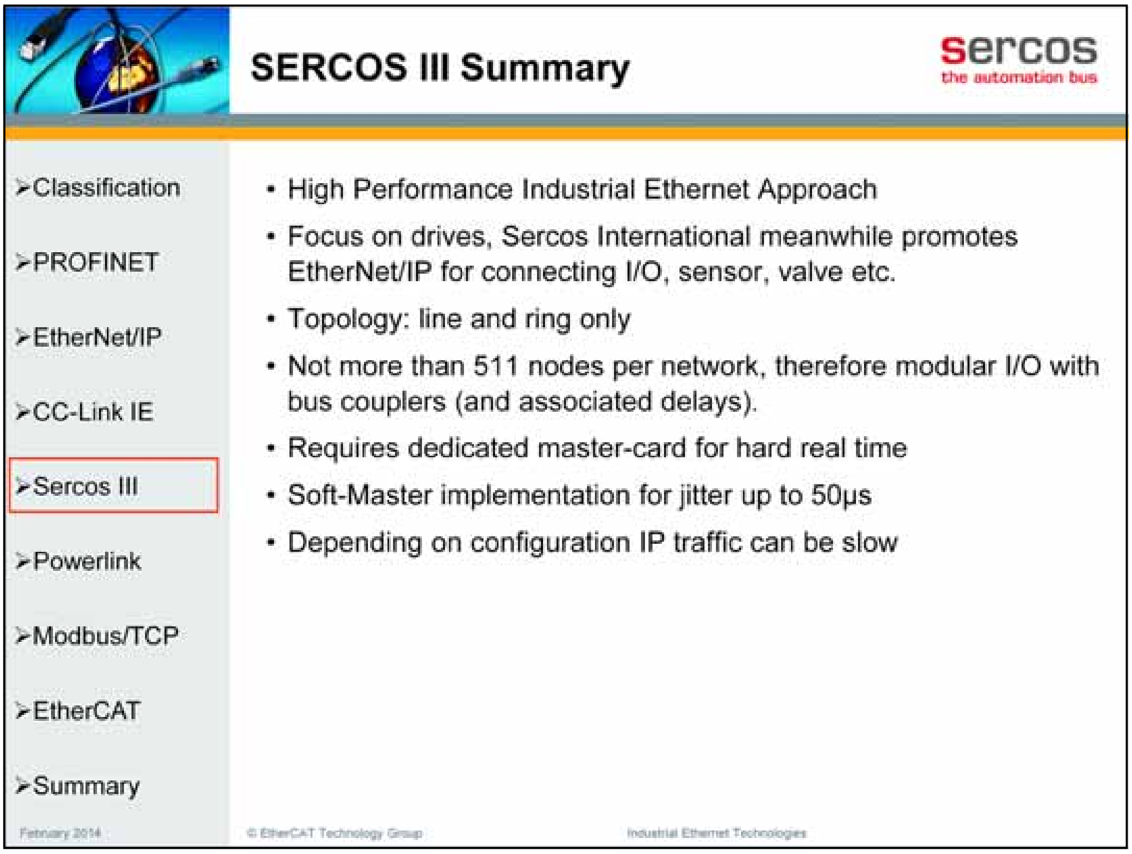
However, Sercos International had to integrate EtherNet/IP instead, which raised some eyebrows: one of the fastest motion control bus systems adopts the slowest available Industrial Ethernet technology for I/O integration. This can also be seen as the confession of failure for Sercos-III as general automation 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.



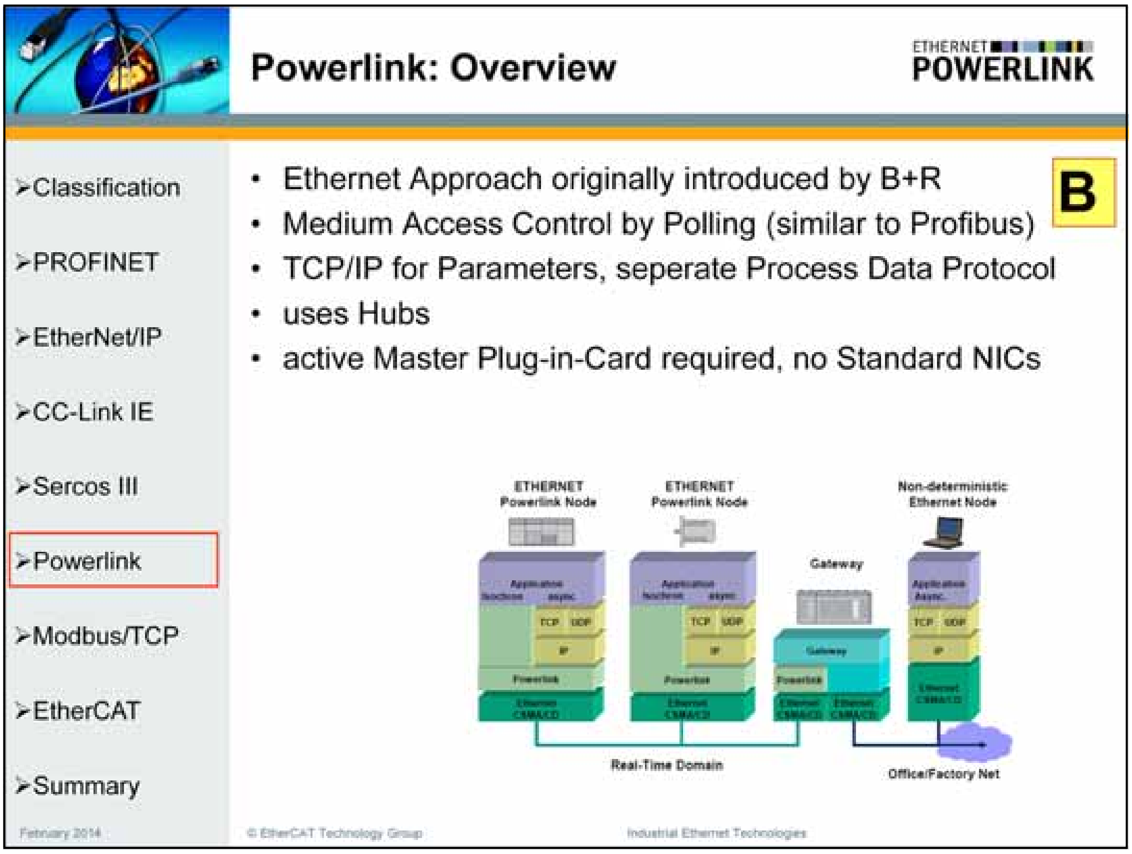
Whilst the SERCOS technology has a good reputation for servo drive control, similar reputation as general bus system I/O, sensors, or other devices has not been achieved.

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



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.



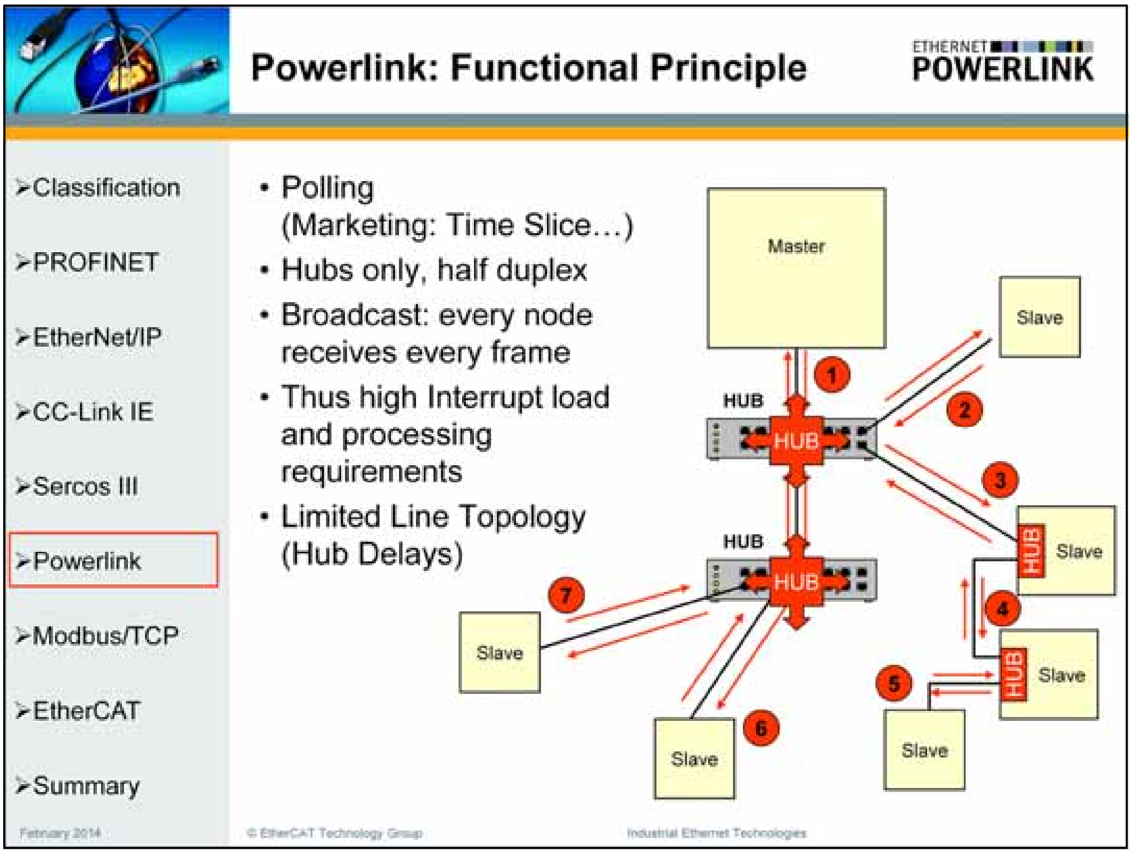
Powerlink replaces the Ethernet CSMA/CD Media Access Control Method by Polling: The master (called managing node) sends a poll request to each slave (called controlled node) which then answers with a response.

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 Micrels 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.

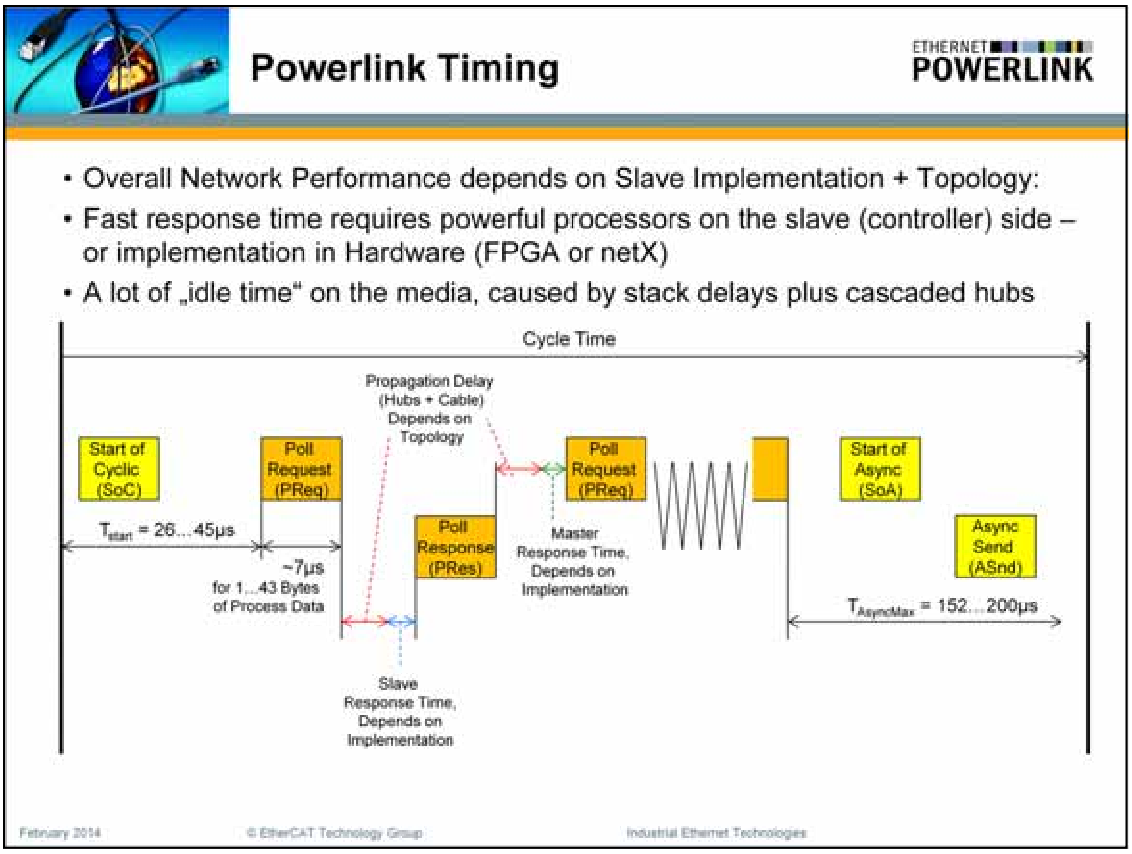


Powerlink Marketing calls the Media Access Method „Time Slicing“ or „Slot Communication Network Management“. The principle nevertheless is polling – the controlled device only „speaks“ after it was „asked“.

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

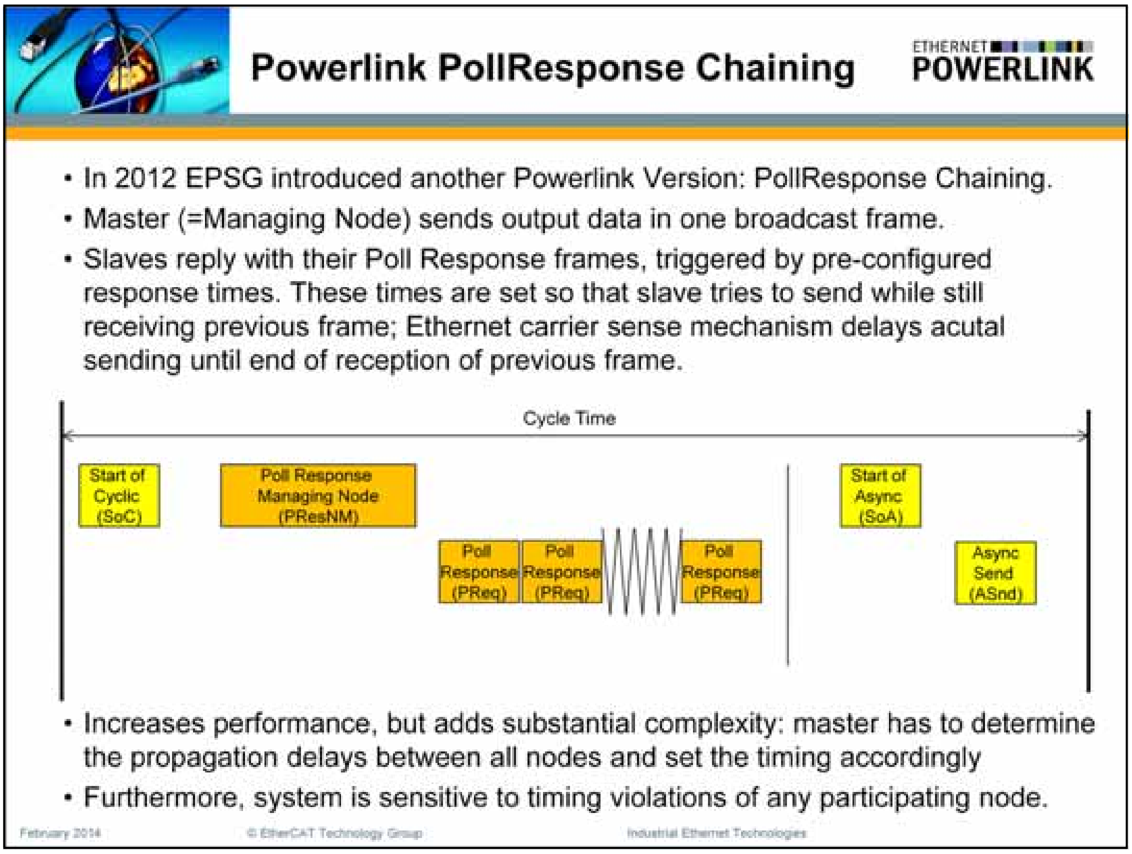
The broadcast mechanism can be used for slave to slave communication (consumer/producer principle). However, performance of slave to slave communication cannot be better than the cycle time...

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.

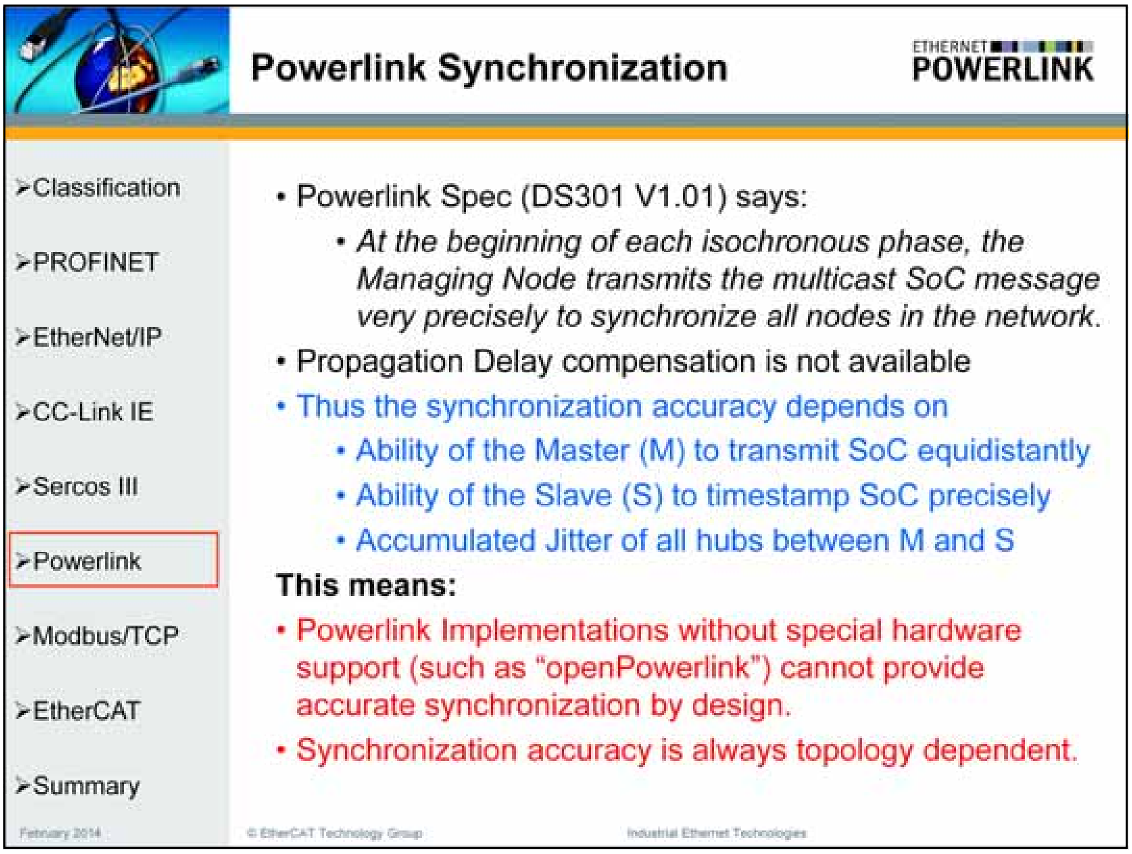


The PollResponse Chaining mode increases the performance of Powerlink but also increases the complexity and vulnerability. Boot-up and error handling become complex since collisions are not avoided by the polling mechanism any more. If a device responds just slightly too late collisions happen and the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

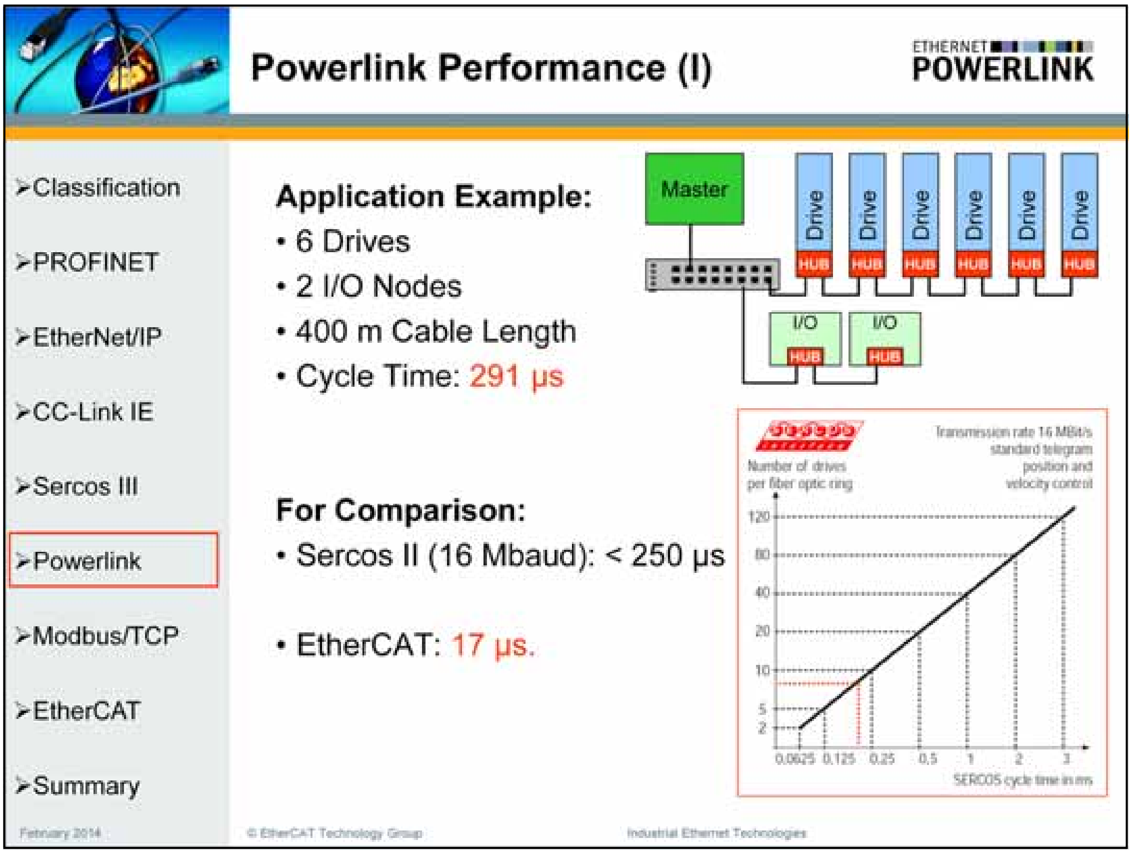
The PollResponse Chaining Specification can be downloaded from the EPSG website. In particular the very “lean” error handling sections leave lots of implementation freedom, which is probably not such an issue since there are no non-B&R masters supporting this version.



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.



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 (!)
- $T_{AsyncMax}$ = 90µs; T_{Start} = 45µs; $T_{HubDelay}$ = 0,5µs

and the resulting Cycle Time is **291 µs**.

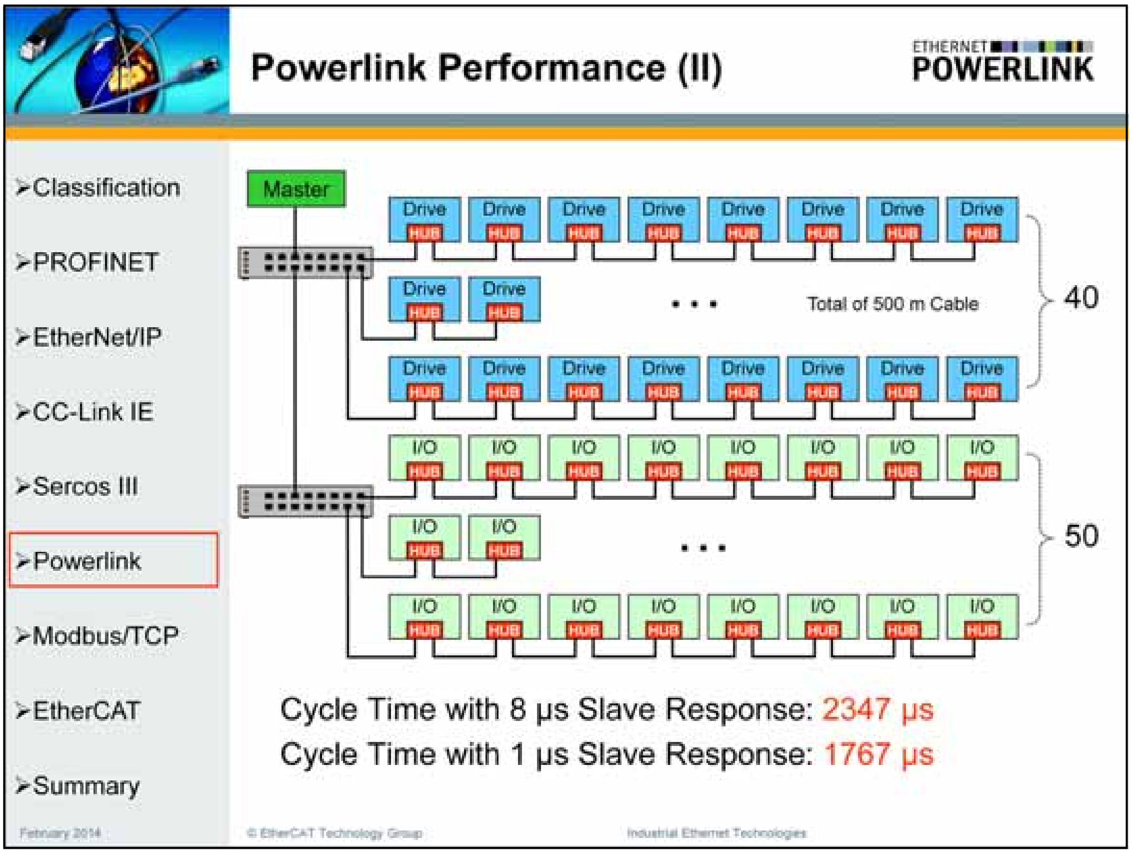
In Powerlink V 2.0 specification Version **1.0.0**, this performance example is not available any more. However, the performance examples in this version assume

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

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 = 8µs; master response time = 1µs (!)
- $T_{AsyncMax}$ = 90µs; T_{Start} = 45µs; $T_{HubDelay}$ = 0,5µs

and the resulting Cycle Time is **2347 µs.**

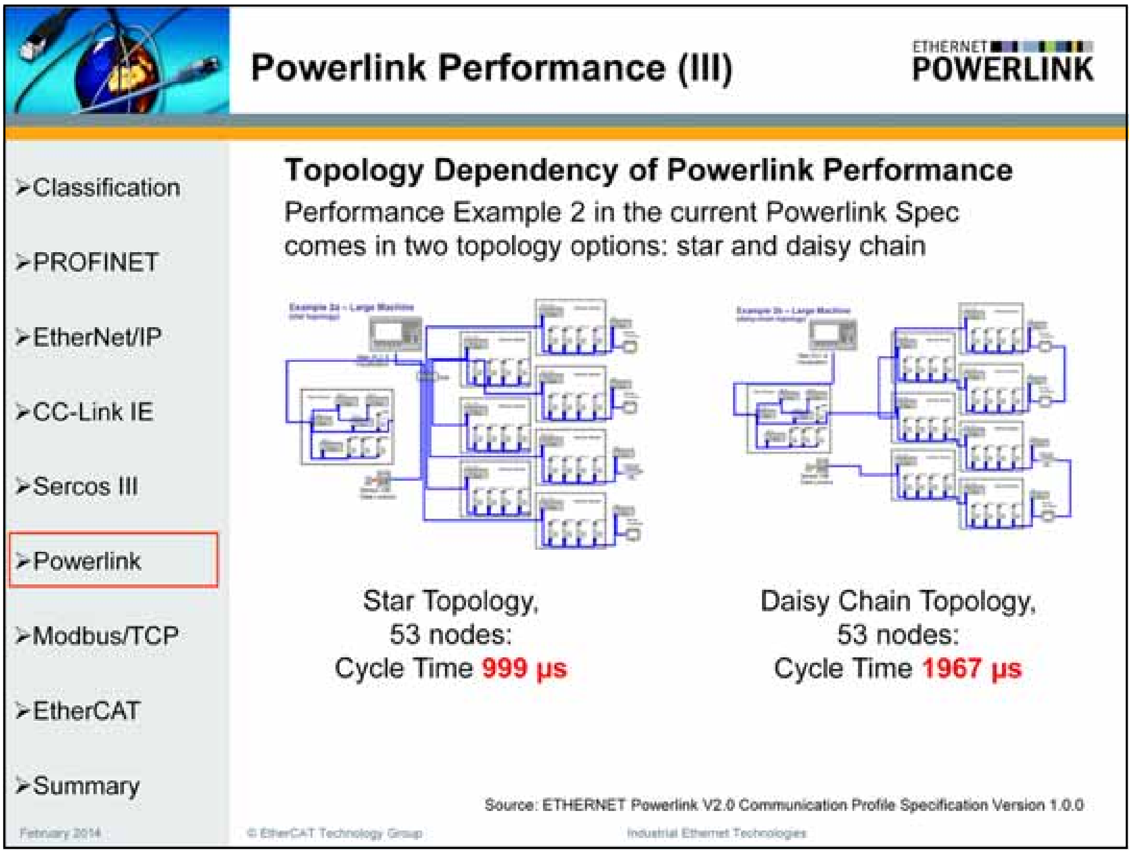
In Powerlink V 2.0 specification Version 1.0.0, this performance example is not available any more. However, the performance examples in this version assume

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

Applying these values to the performance example shown above leads to a Cycle Time of **1767 µs**.

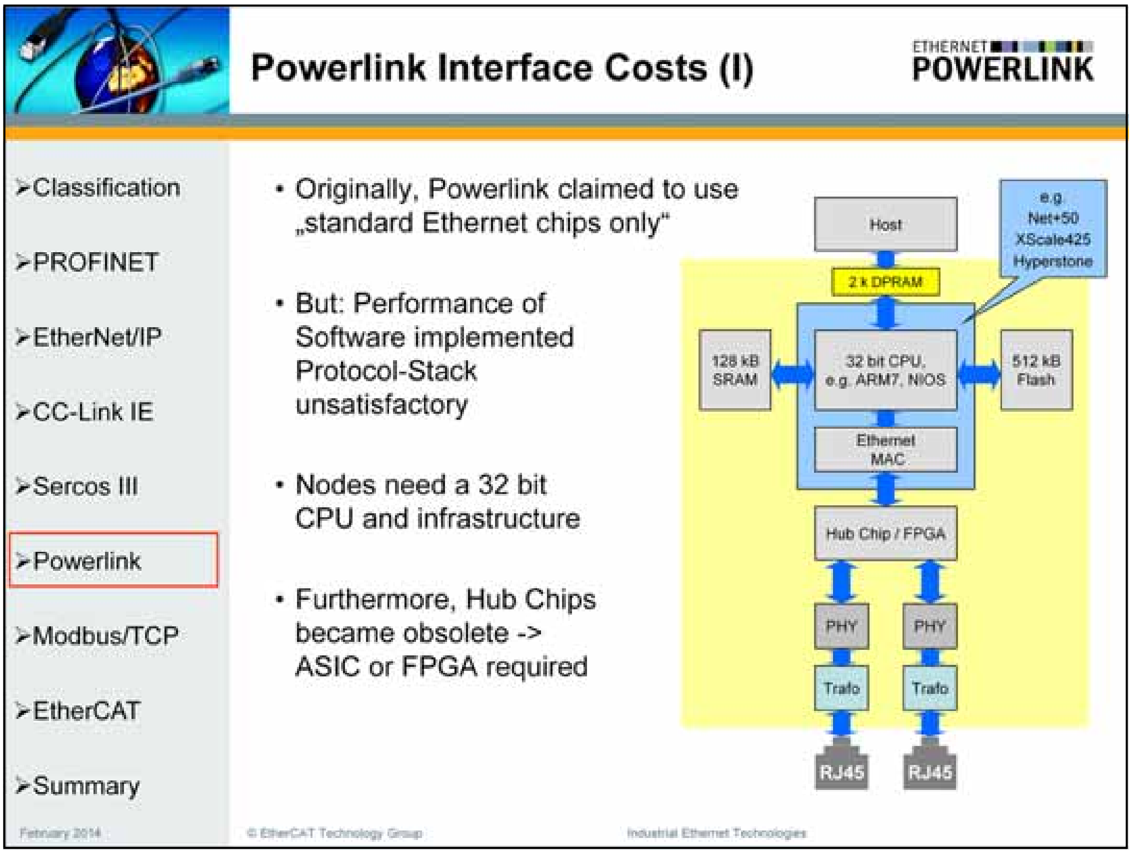
The Powerlink DS 301 V1.01 specification (which is the current one) does not contain any performance example any more.

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

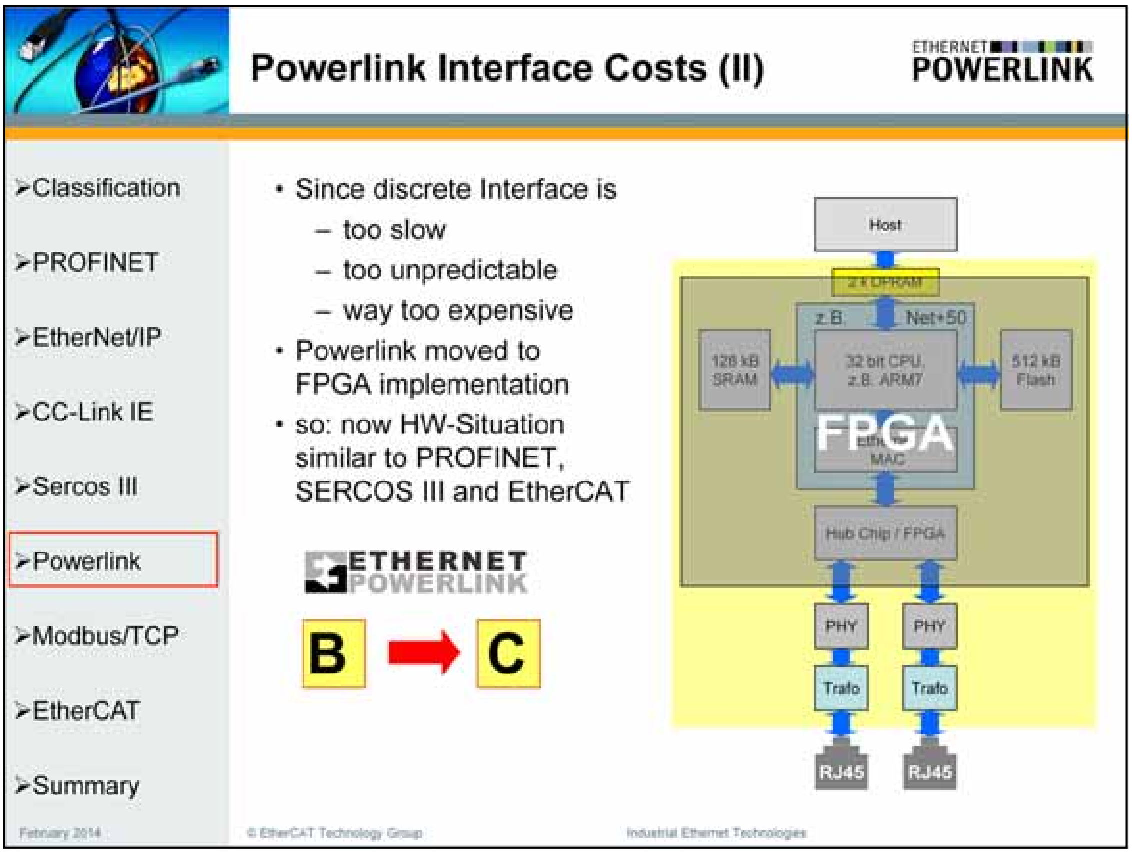


This performance example assumes a slave response time of 1µs (!) and a master response time of 1µs (!)

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 **149µs** (@50% bus load).



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.

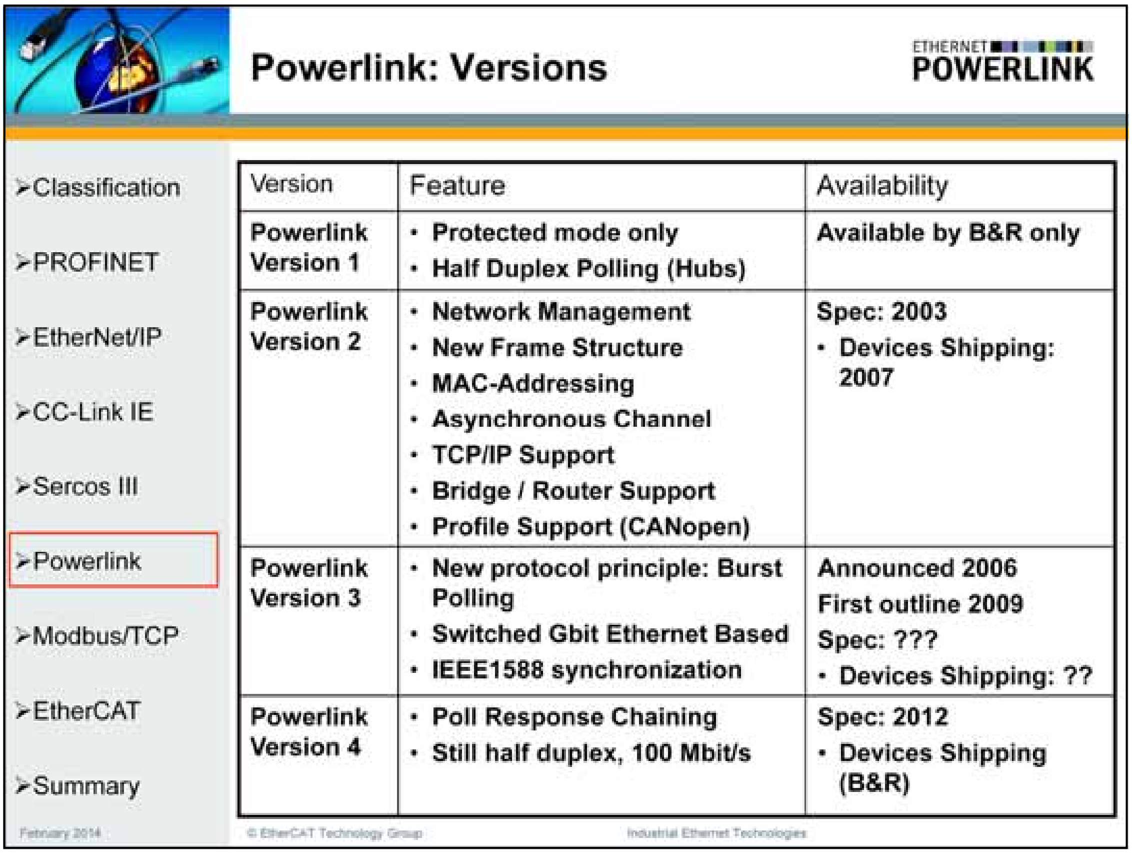


EPSG is now supporting different implementation possibilities – the most cost effective is the FPGA solution. It uses the same Altera FPGA that is used for EtherCAT as well, but requires additional 10ns 256k x 16 SRAM.

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



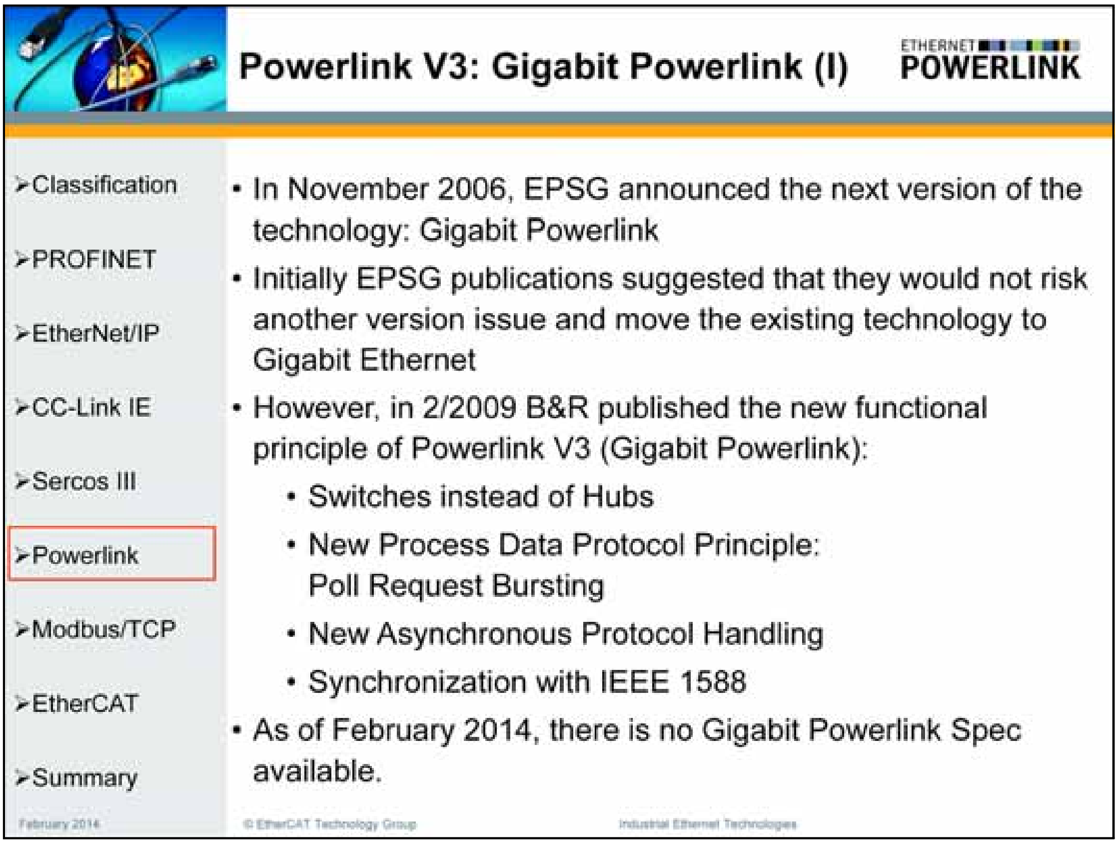
Version	Feature	Availability
Powerlink Version 1	• **Protected mode only** • **Half Duplex Polling (Hubs)**	**Available by B&R only**
Powerlink Version 2	• **Network Management** • **New Frame Structure** • **MAC-Addressing** • **Asynchronous Channel** • **TCP/IP Support** • **Bridge / Router Support** • **Profile Support (CANopen)**	**Spec: 2003** • **Devices Shipping: 2007**
Powerlink Version 3	• **New protocol principle: Burst Polling** • **Switched Gbit Ethernet Based** • **IEEE1588 synchronization**	**Announced 2006** **First outline 2009** **Spec: ???** • **Devices Shipping: ??**
Powerlink Version 4	• **Poll Response Chaining** • **Still half duplex, 100 Mbit/s**	**Spec: 2012** • **Devices Shipping (B&R)**

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.

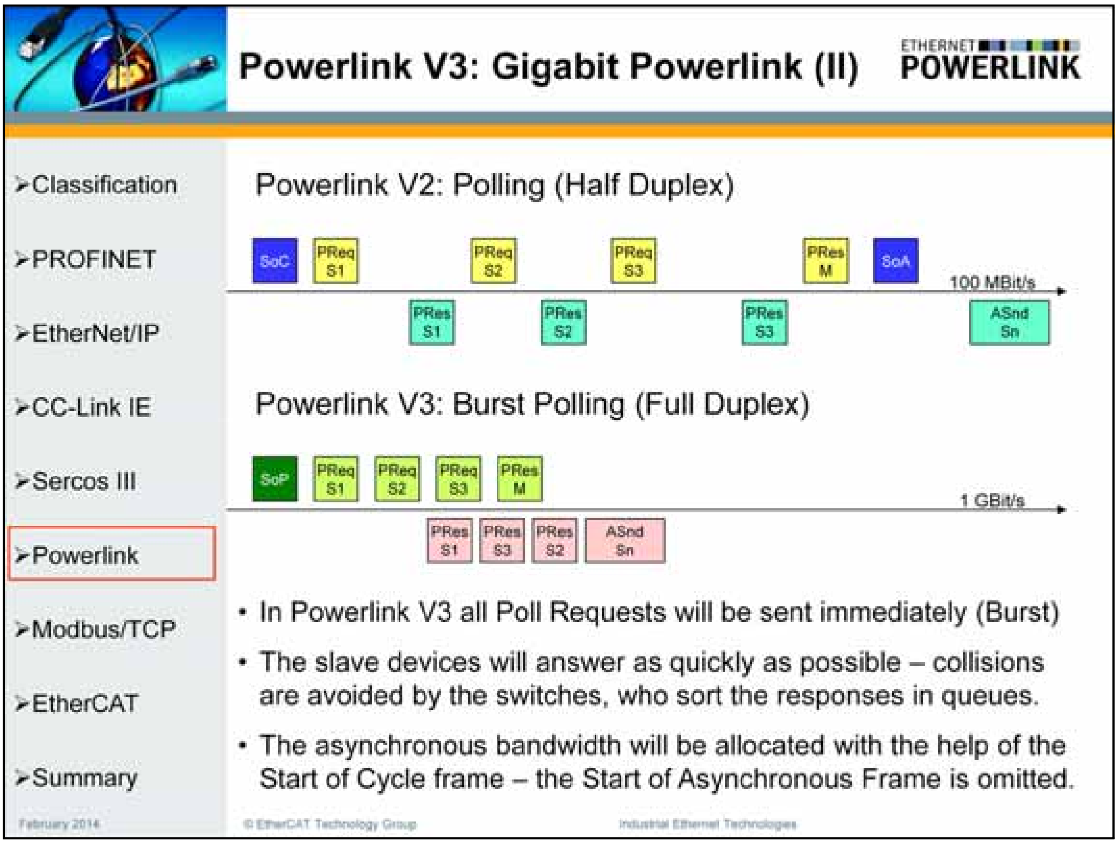


In November 2006, EPSG announced Gbit Powerlink as a simple hardware modification (Quote from Powerlink "Facts" 1/2007: "*POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer 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.

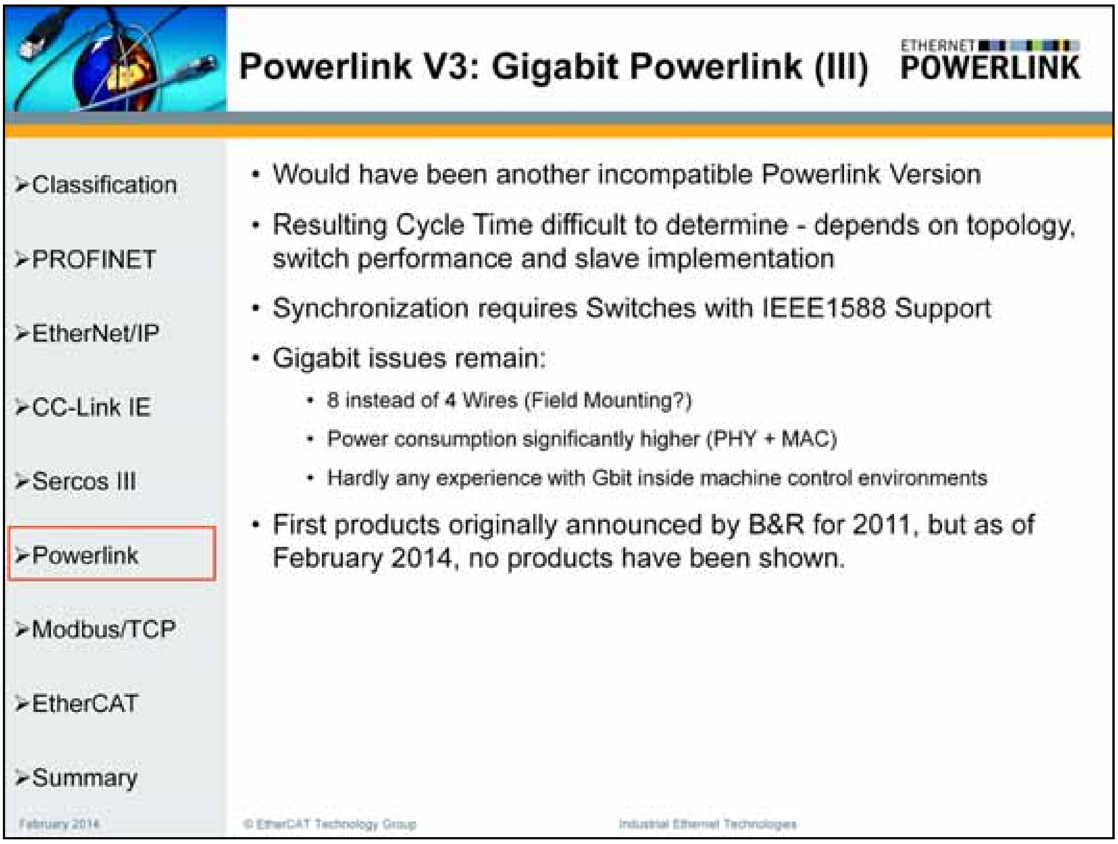
Hubs will be replaced by switches, and instead of individual polling a “burst polling” approach will be introduced.

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.

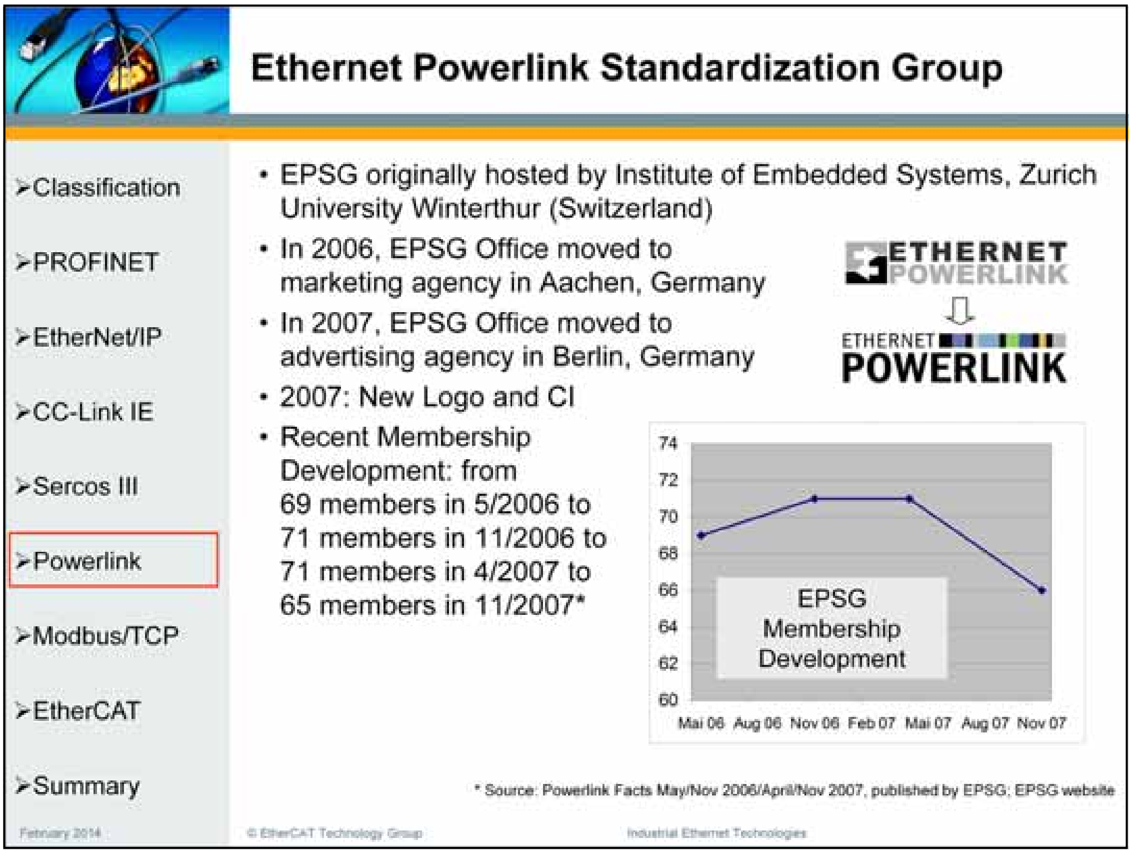
The shortest cycle time is either determined by the sum of frames sent by the master, or by the sum of frames sent by the slaves, or by response time and the overall propagation delay of the farthest slave device (including the switch delays). It is thus still difficult to predict and influenced by protocol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



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)



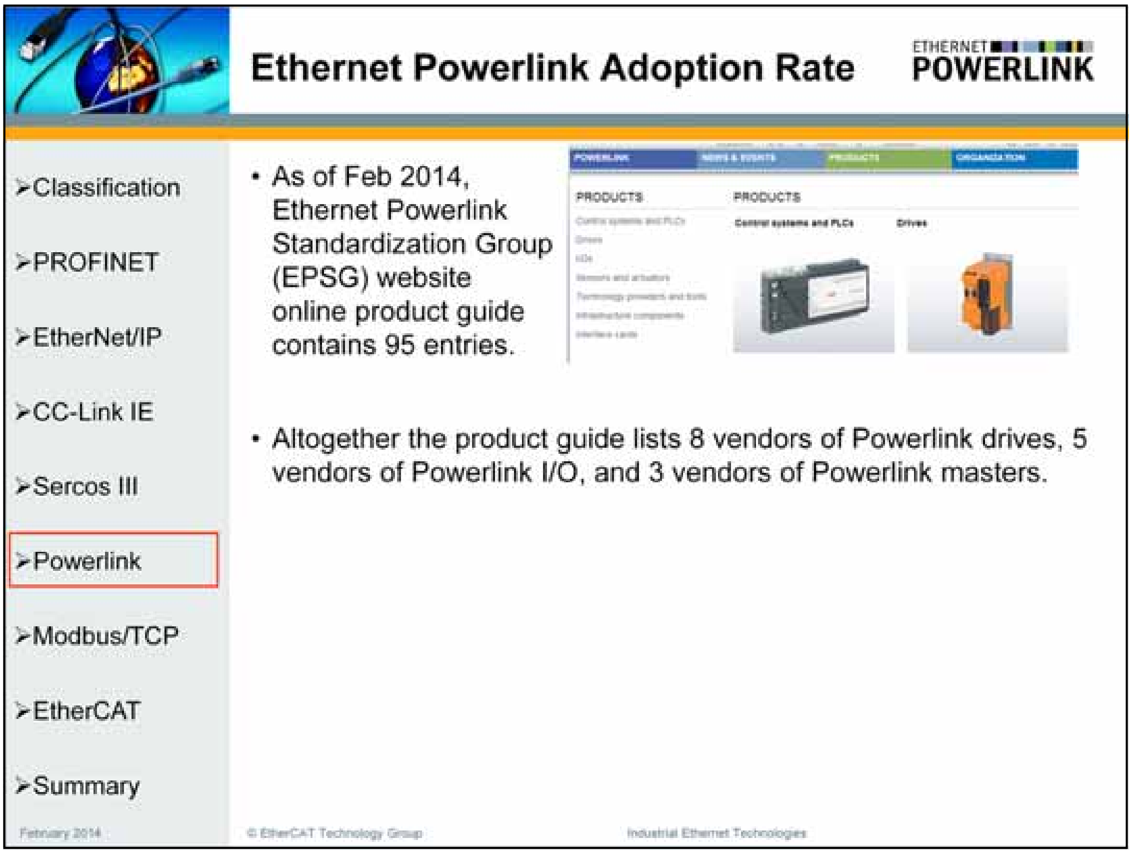
Ethernet Powerlink Standardization Group is managed and hosted by an advertising agency. Technical and implementation support is available by the advertising agency and by technology providers, who charge for these services.

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.

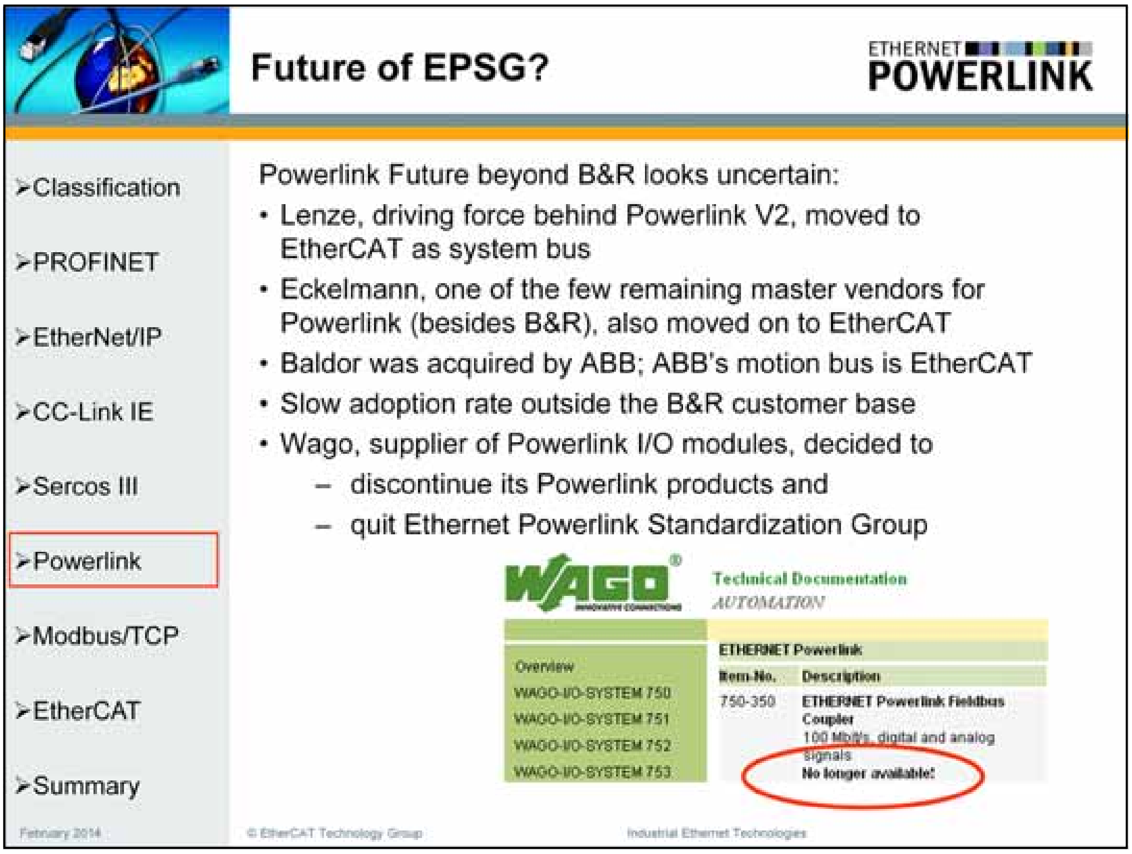


95 entries, out of which 32 are tools and services.

Third party (“non-B&R”) Powerlink products are typically complementary to the B&R products – so for B&Rs 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 ABBs 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.



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).

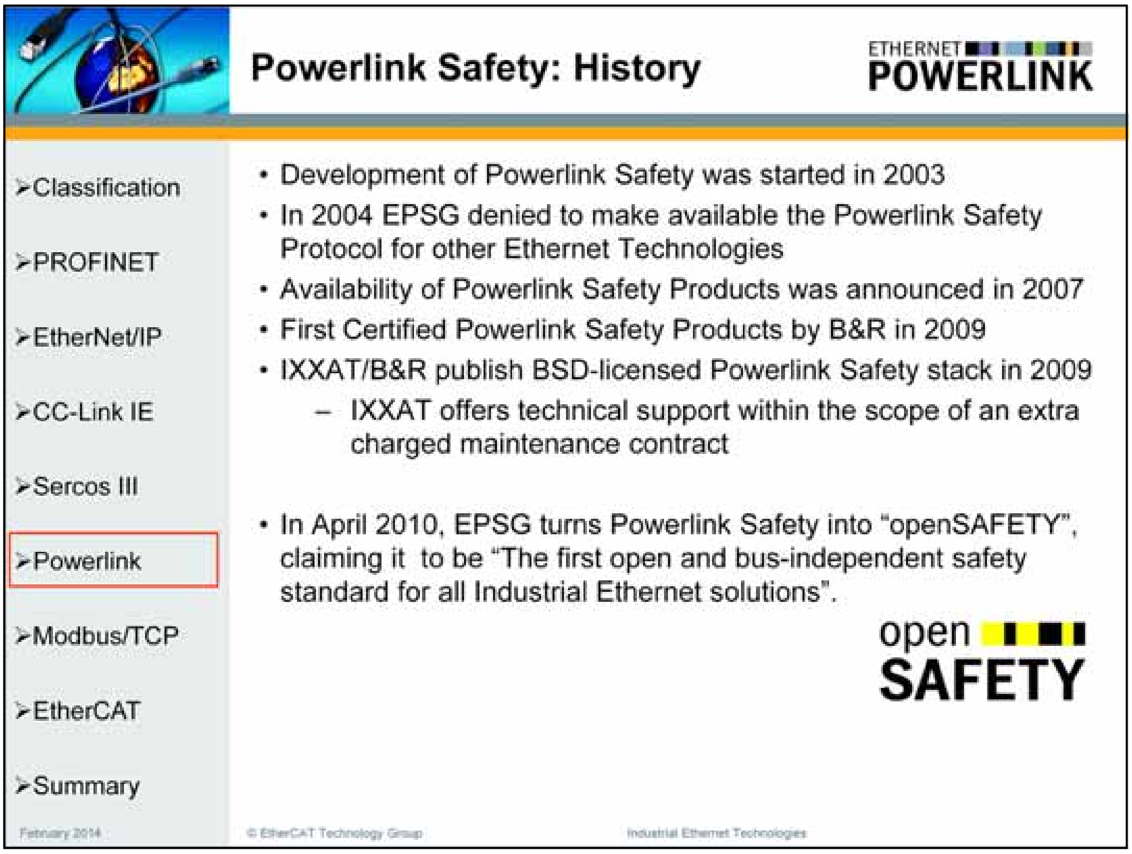
For many of the few new Powerlink Products introduced since 2007, B&R either implemented the Powerlink interface or paid for the implementation.

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

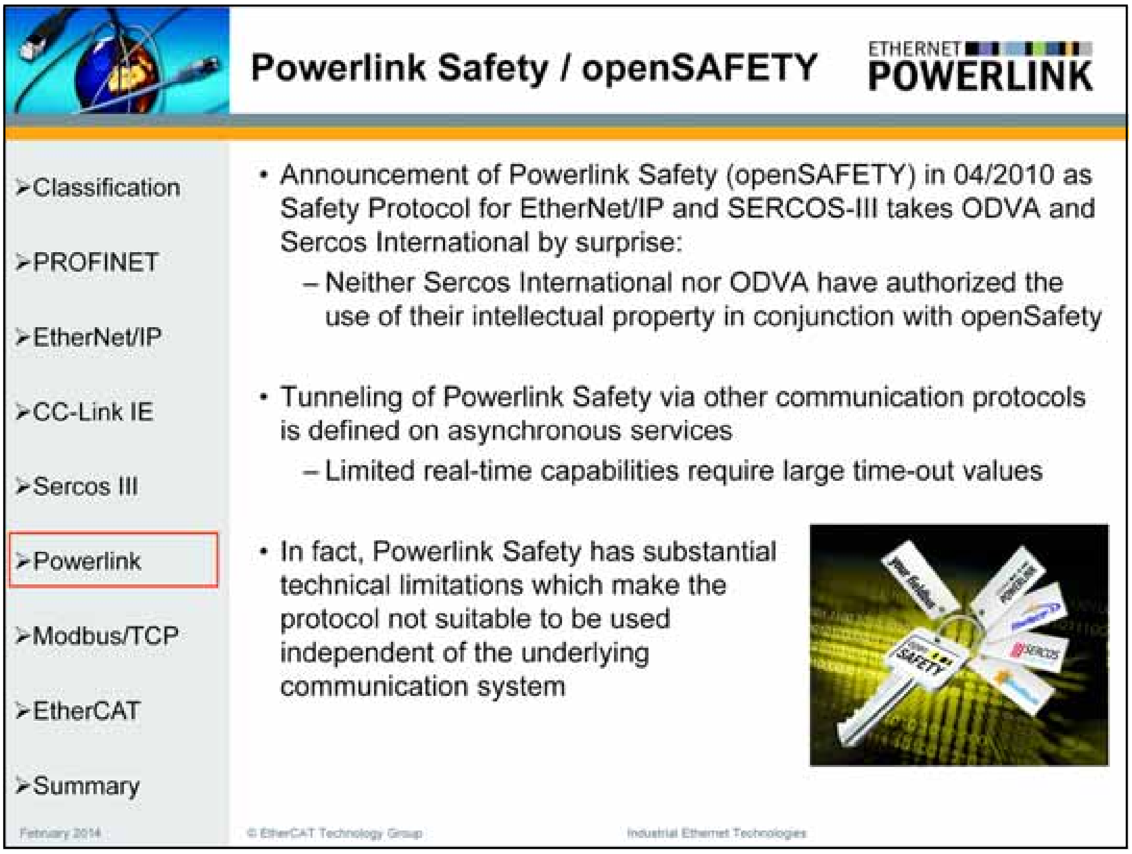
At SPS/IPC/Drives Show in November 2013, ABB/Baldors booth did not show any Powerlink products any more.

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



- 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



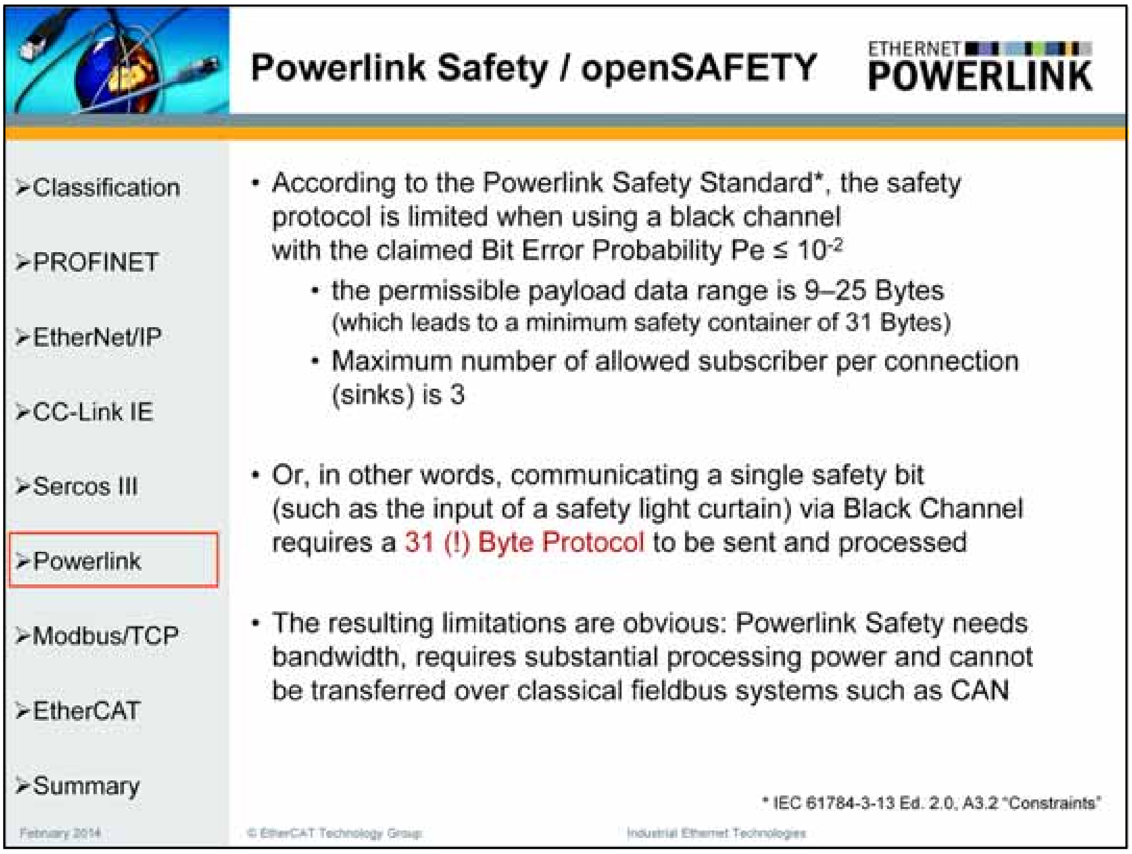
Statement# of Katherine Voss, Executive Director ODVA: *"ODVA and Sercos International are cooperating on the adaptation of CIP Safety to their respective industrial Ethernet networks, EtherNet/IP and Sercos III. At this time, ODVA does not have a similar cooperation arrangement with any other organization. … 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.

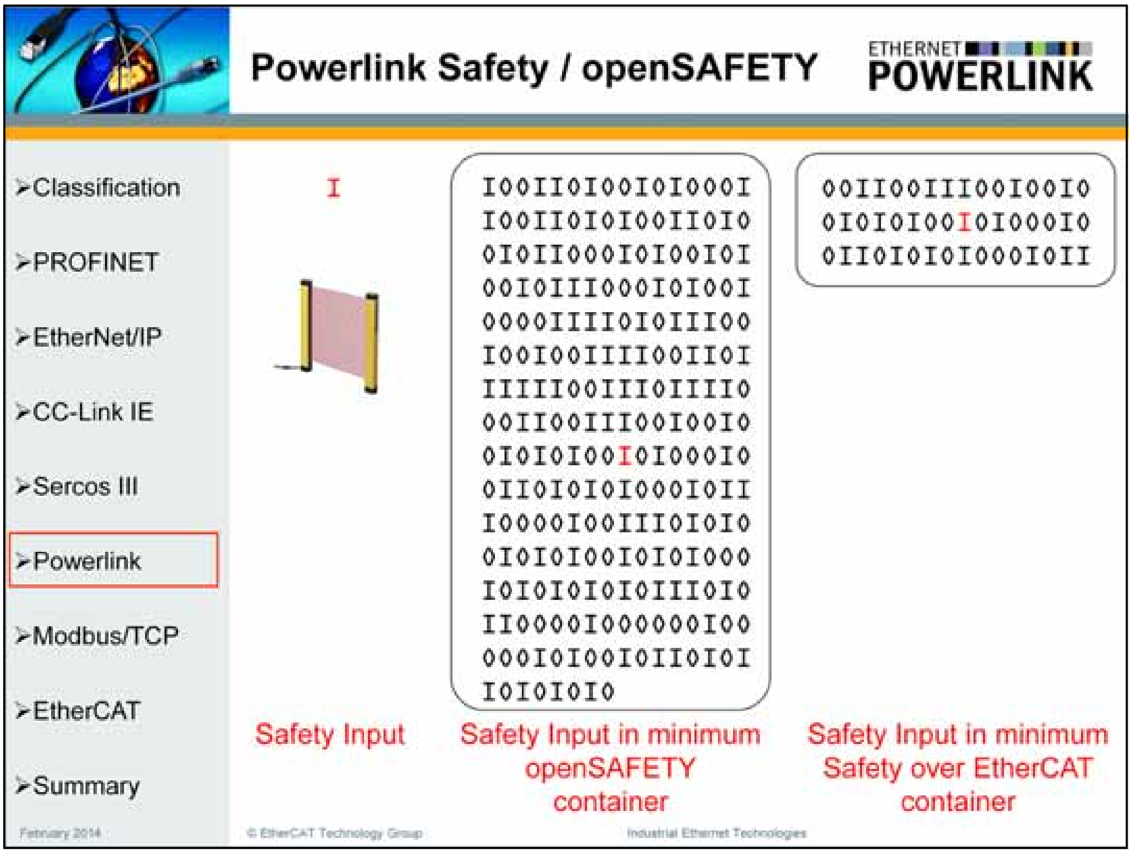
Statements quoted from: Industrial Ethernet Book Issue 58



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.

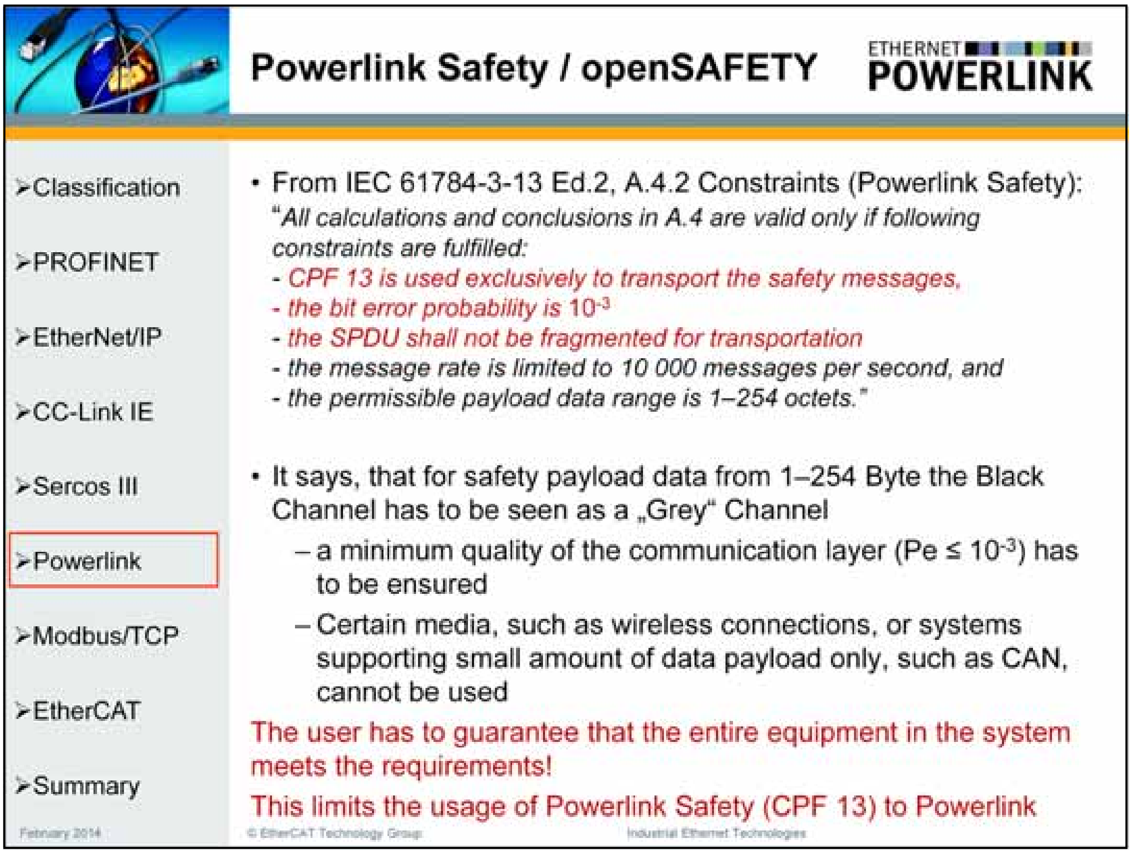
For comparison: the minimum safety container of Safety over EtherCAT (FSoE) is 6 bytes (for 1 Byte payload), thus FSoE is suitable e.g. for CAN as well.



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



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,…

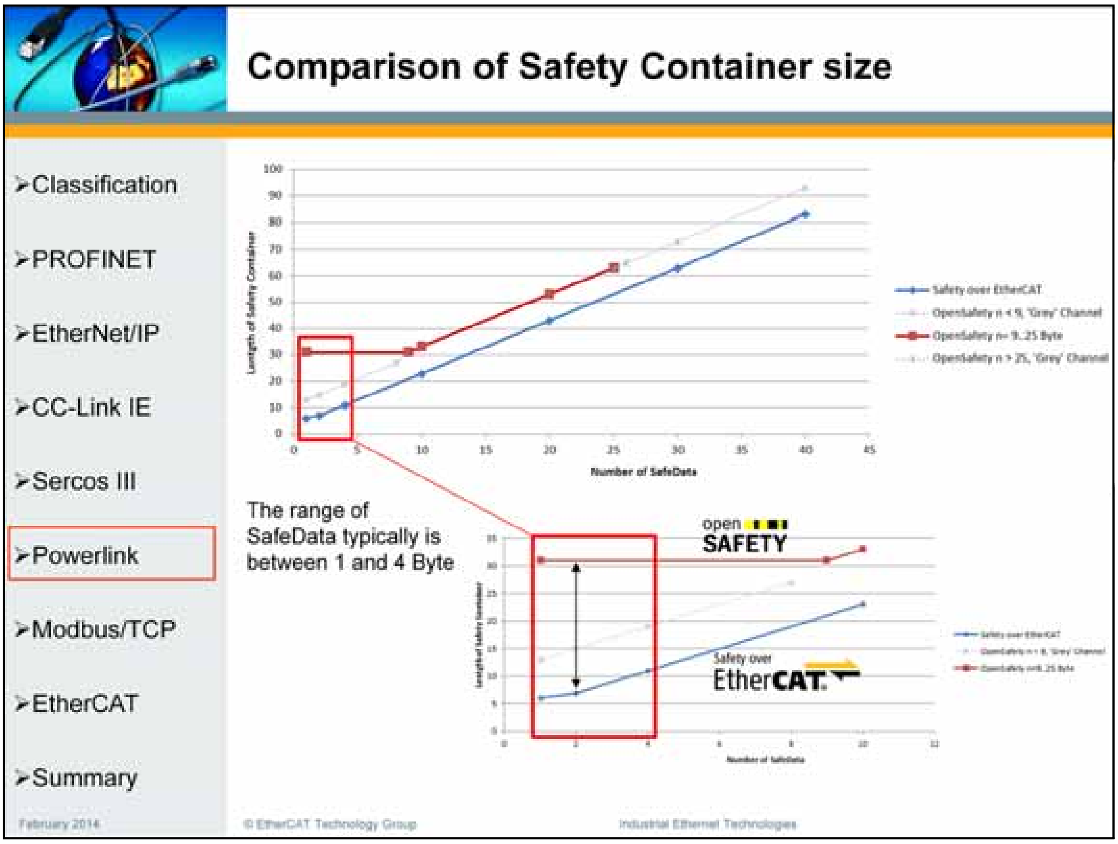
… but the Black channel may also consist of

- 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!

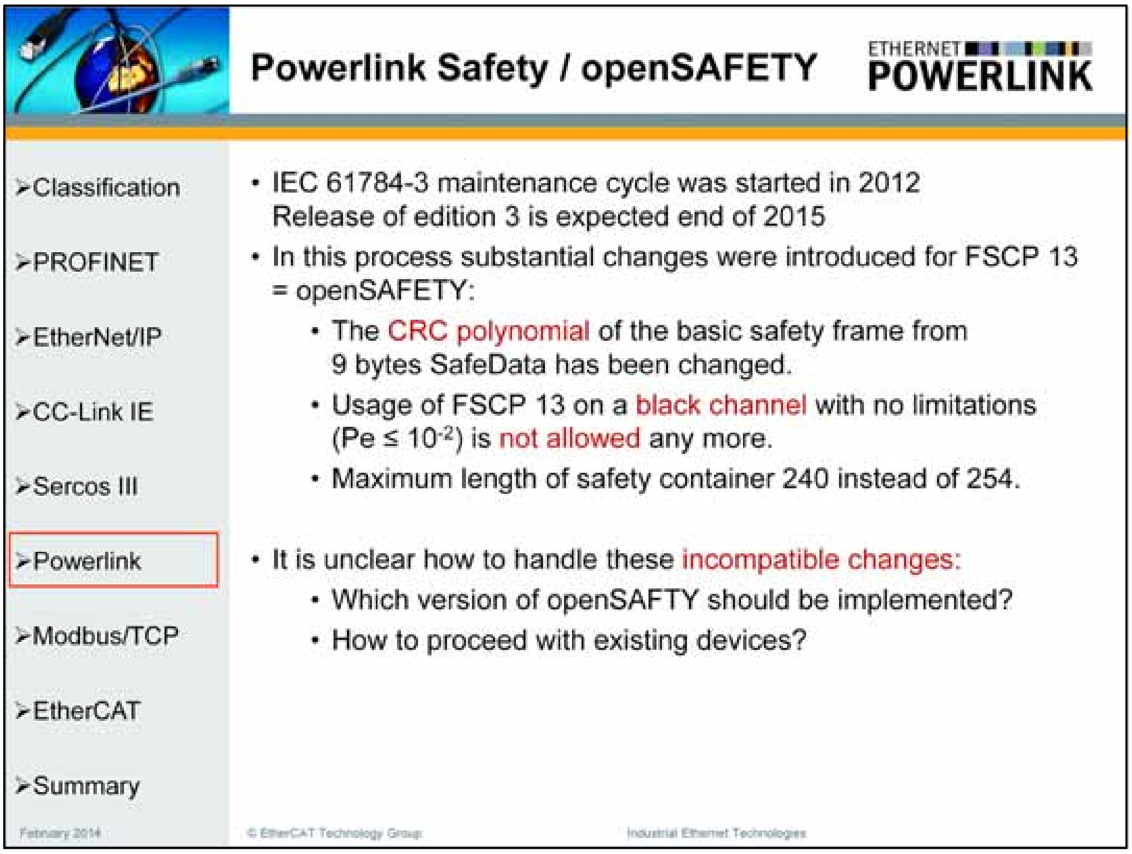
As of now we are not aware of any standard covering non-Powerlink based openSafety.



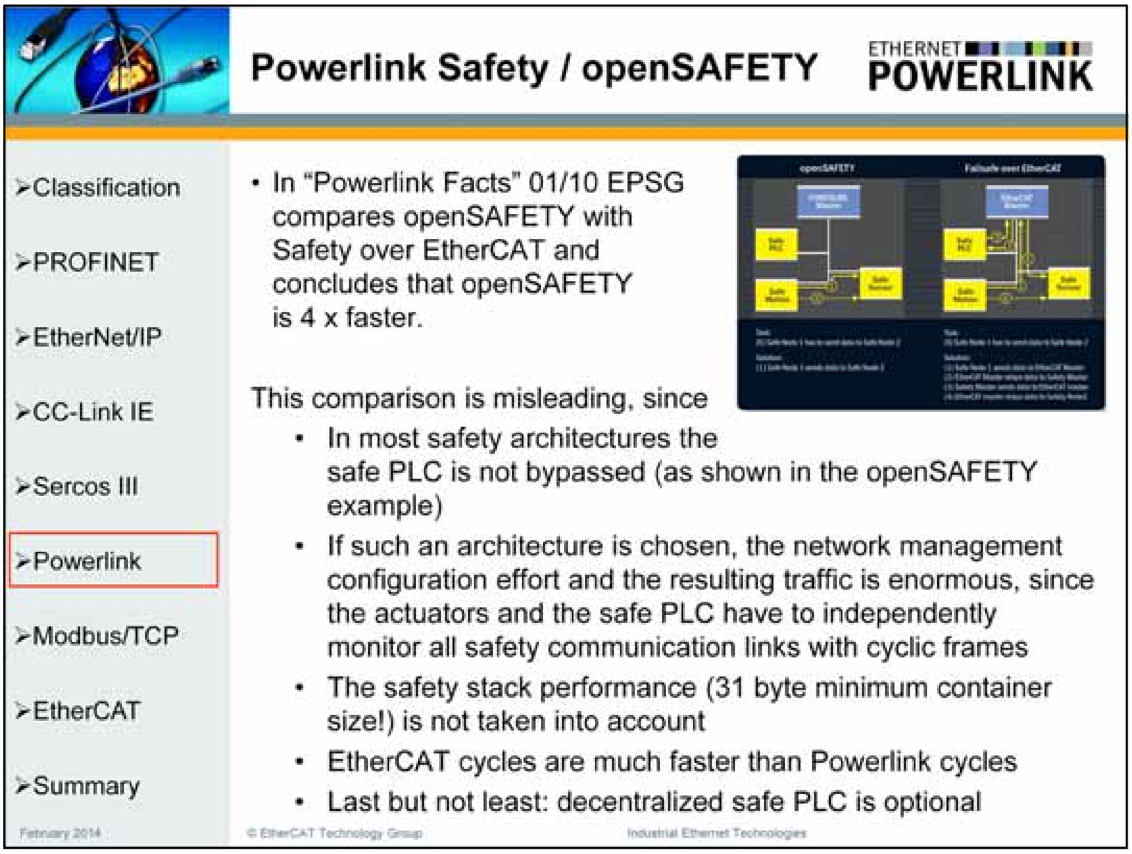
The typical number of safety payload data per connection is small, e.g. in the range of 1...4 Bytes.

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



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



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.

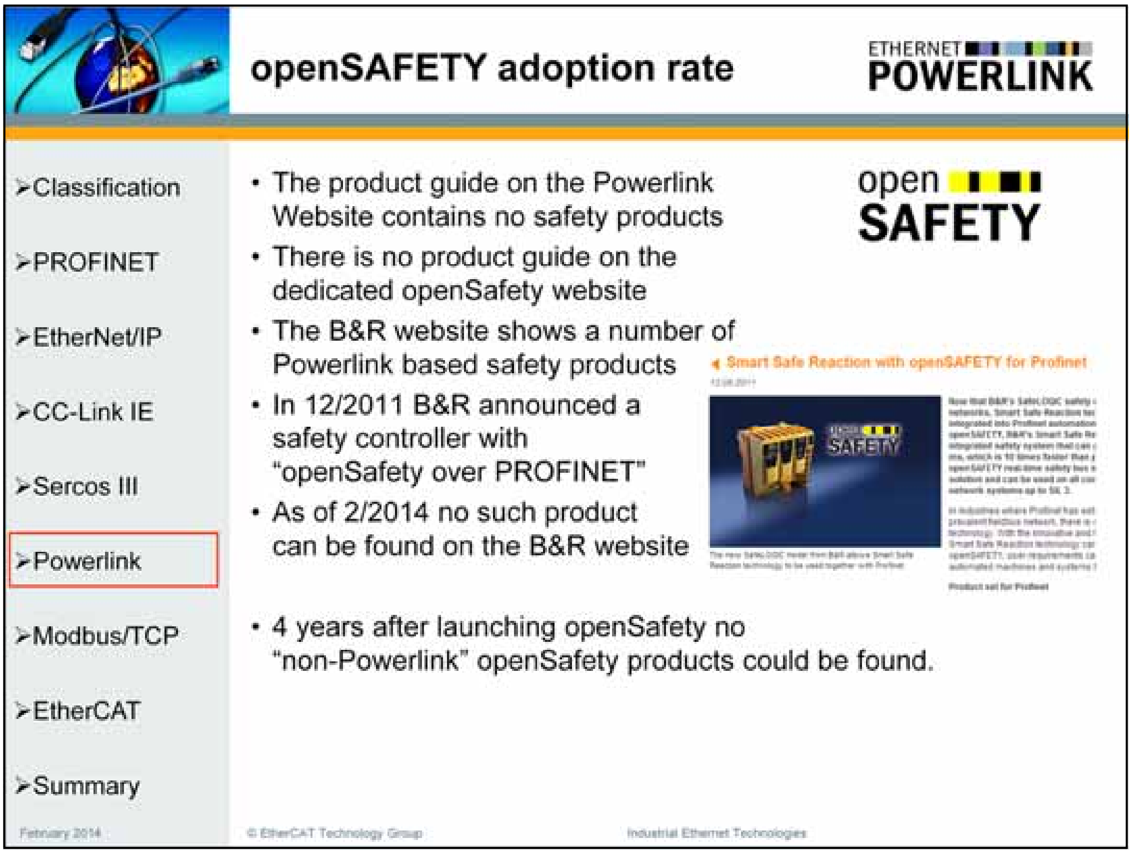
Example: 10 Emergency stop buttons acting on 10 drives

Powerlink Safety	10 * 10 = **100** communication relations
Safety over EtherCAT	10 + 10 = **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).

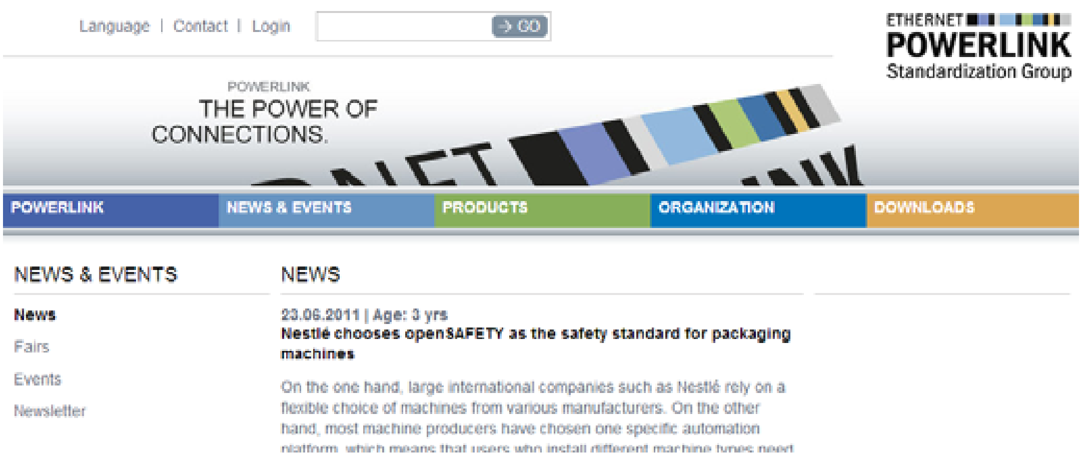
With Safety over EtherCAT a single connection per FSoE Slave device to the FSoE Master is sufficient. The logical combination of Safety Inputs is done in the FSoE Master device.

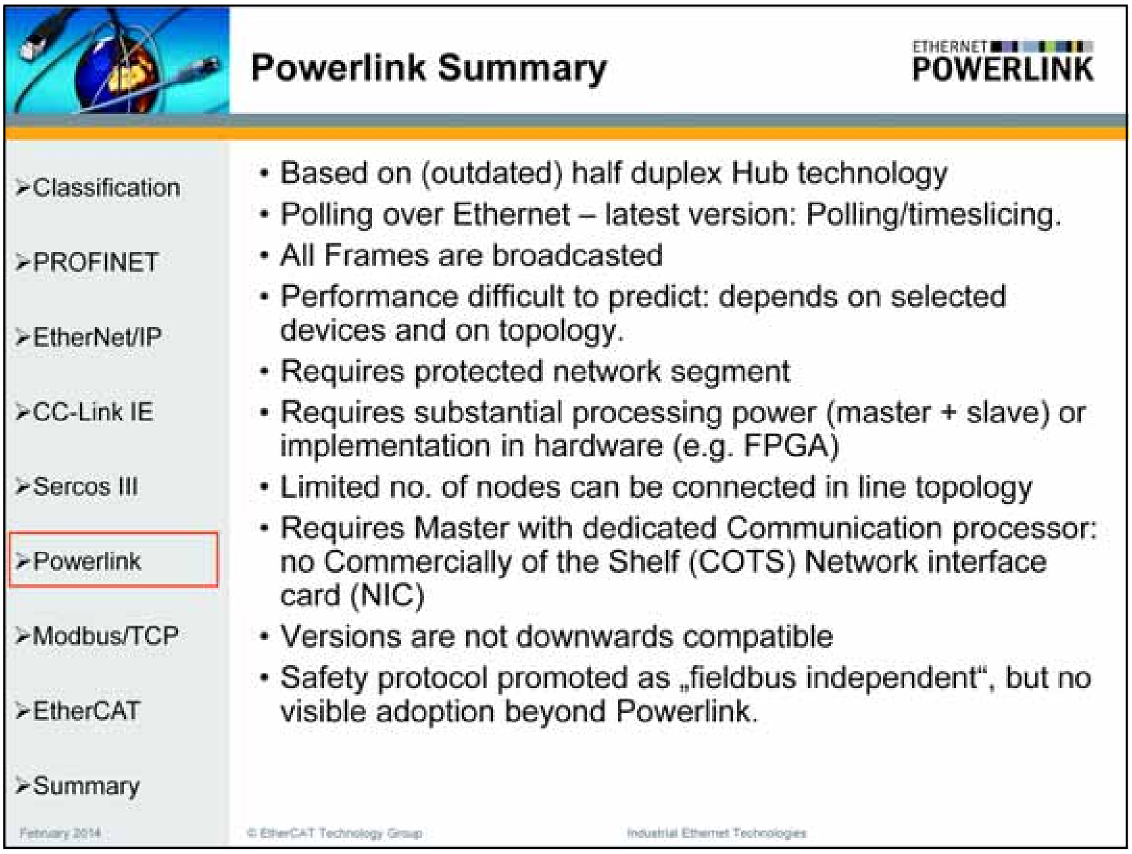


Safety rated products have to be certified by a "notified body" (such as e.g. TÜV). For the safety certificate not only the safety layer has to be tested, but also the (non-safe) communication protocol layer: the notified bodies request a conformance certificate for this layer as well.

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.





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:

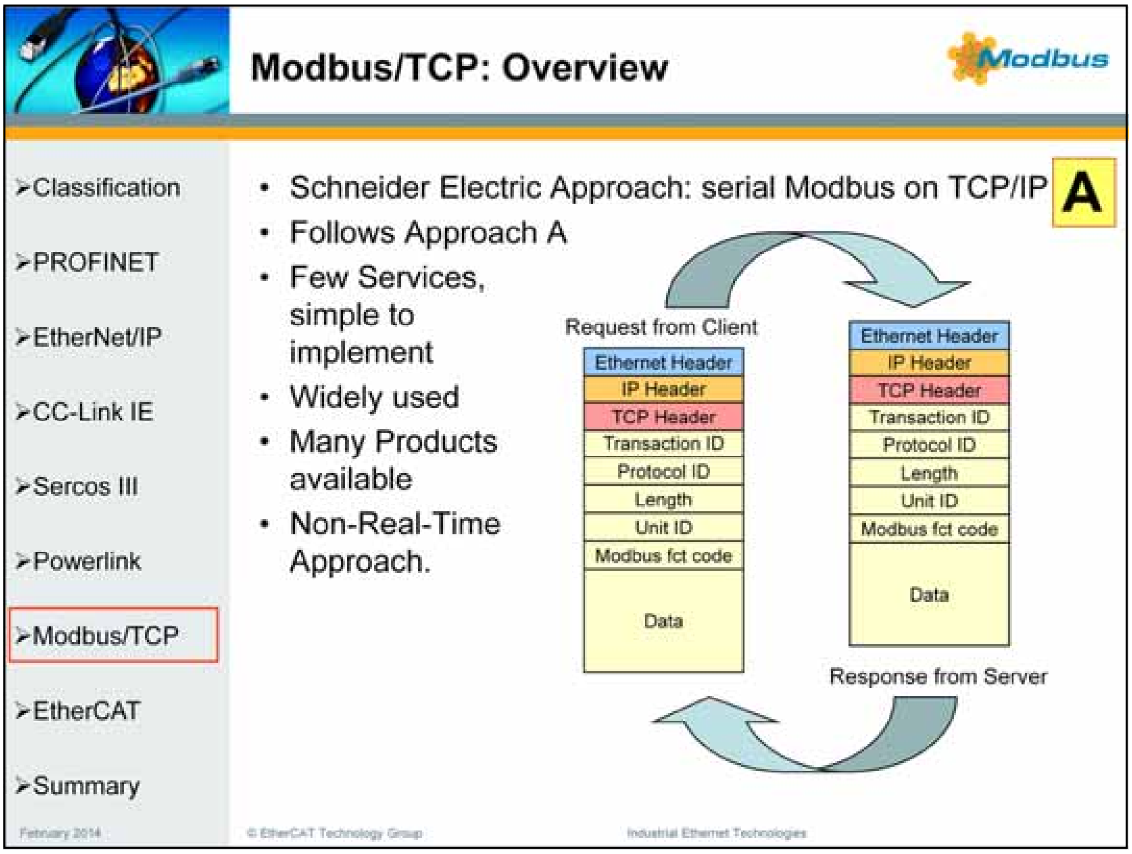
- if implemented with standard components: processor performance, software stack implementation quality, varying local CPU load due to application etc.

- 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.

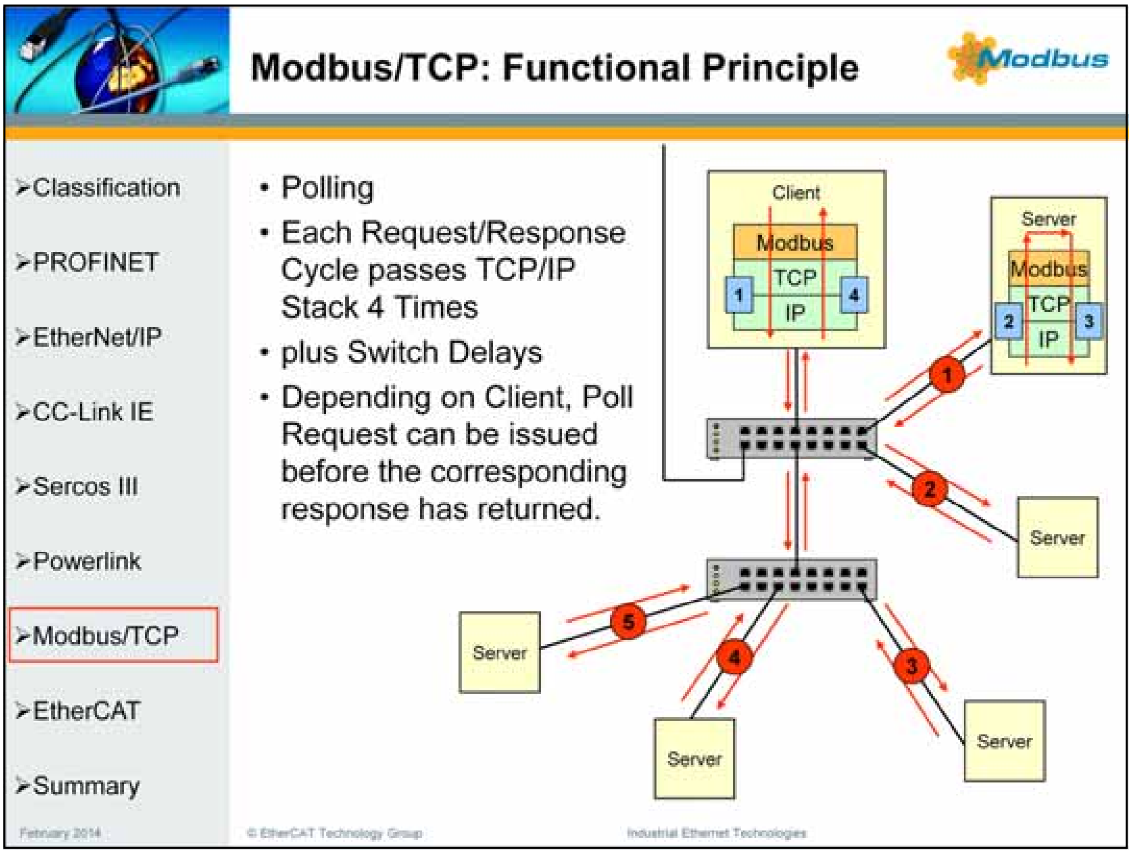
Performance limitations require complex bandwidth optimization in more demanding applications.



Modbus/TCP 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.



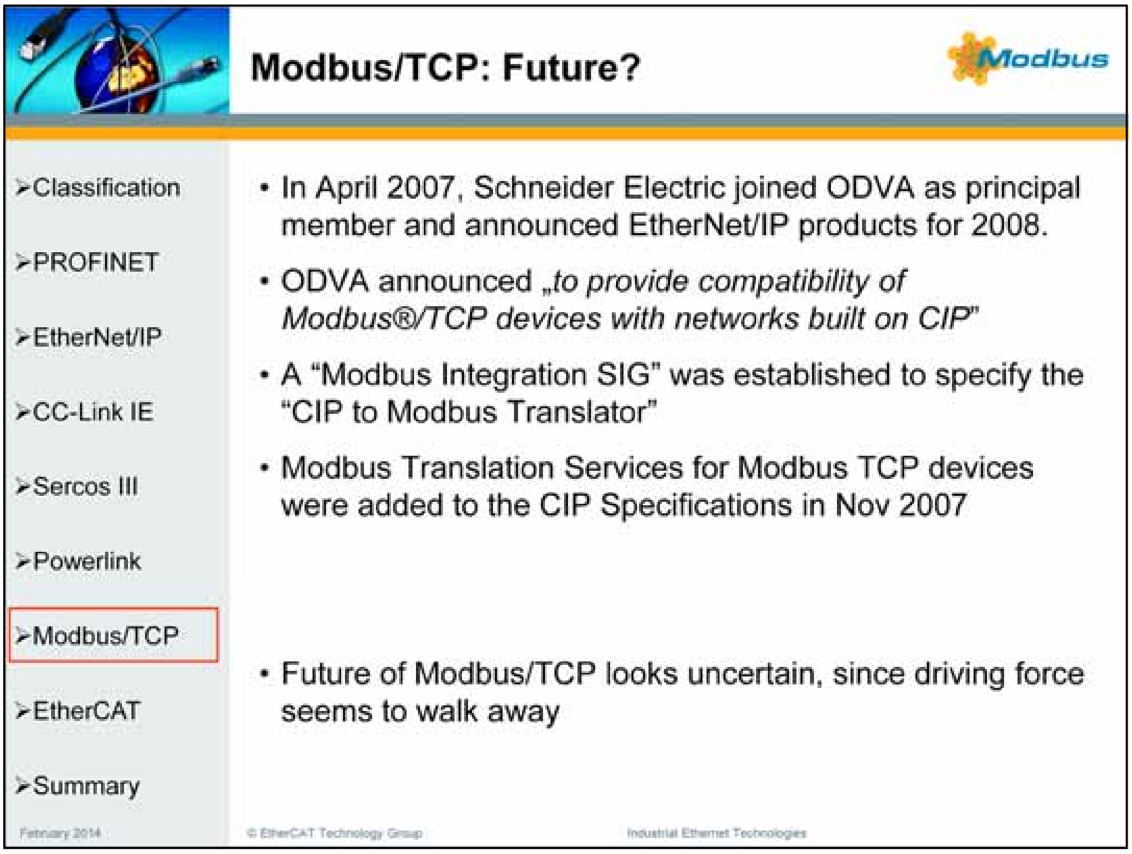
Modbus/TCP client/master implementations can either wait for each response to return before the next request is issued, or send several requests at once in order to allow for parallel processing in the server/slave devices. In the later case the overall performance is improved.

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 µC 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.



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

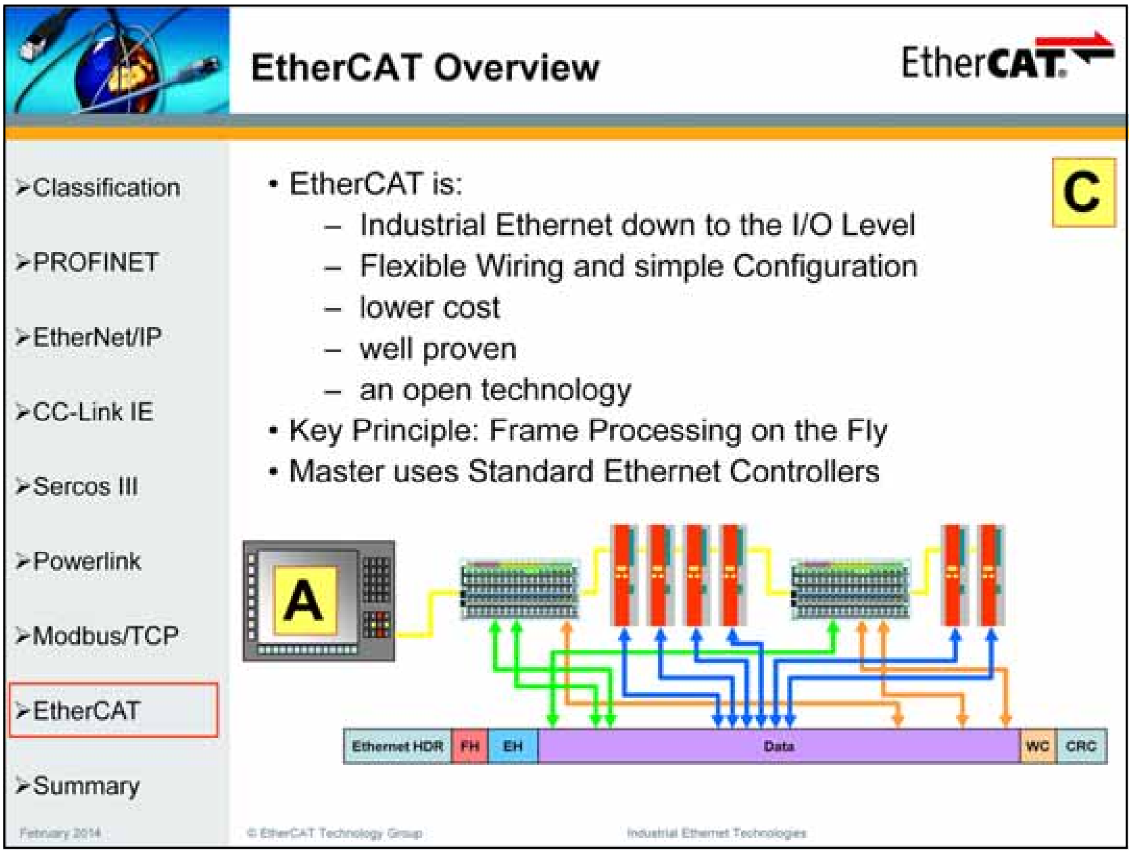
Details regarding the integration of Modbus TCP into CIP can be found here:

http://www.modbus.org/docs/CIP%20Modbus%20Integration%20Hanover%20Fair_0408.pdf

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.

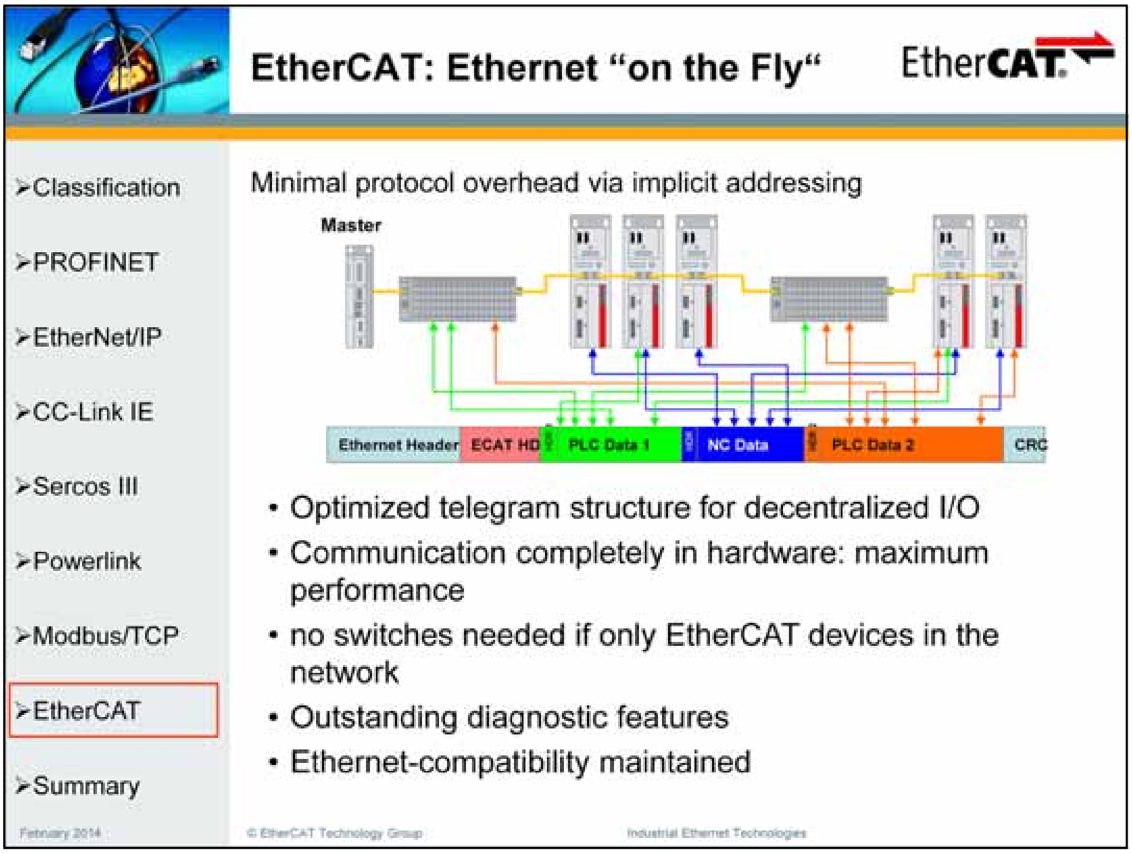
By the way: in 2009 the former "Modbus-IDA" organization (IDA meaning Interface for Distributed Automation) changed its name (and logo) to Modbus, and the web-address to www.modbus.org. www.modbus-ida.org was abandoned and is now used by a whirlpool company.



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 µController 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.



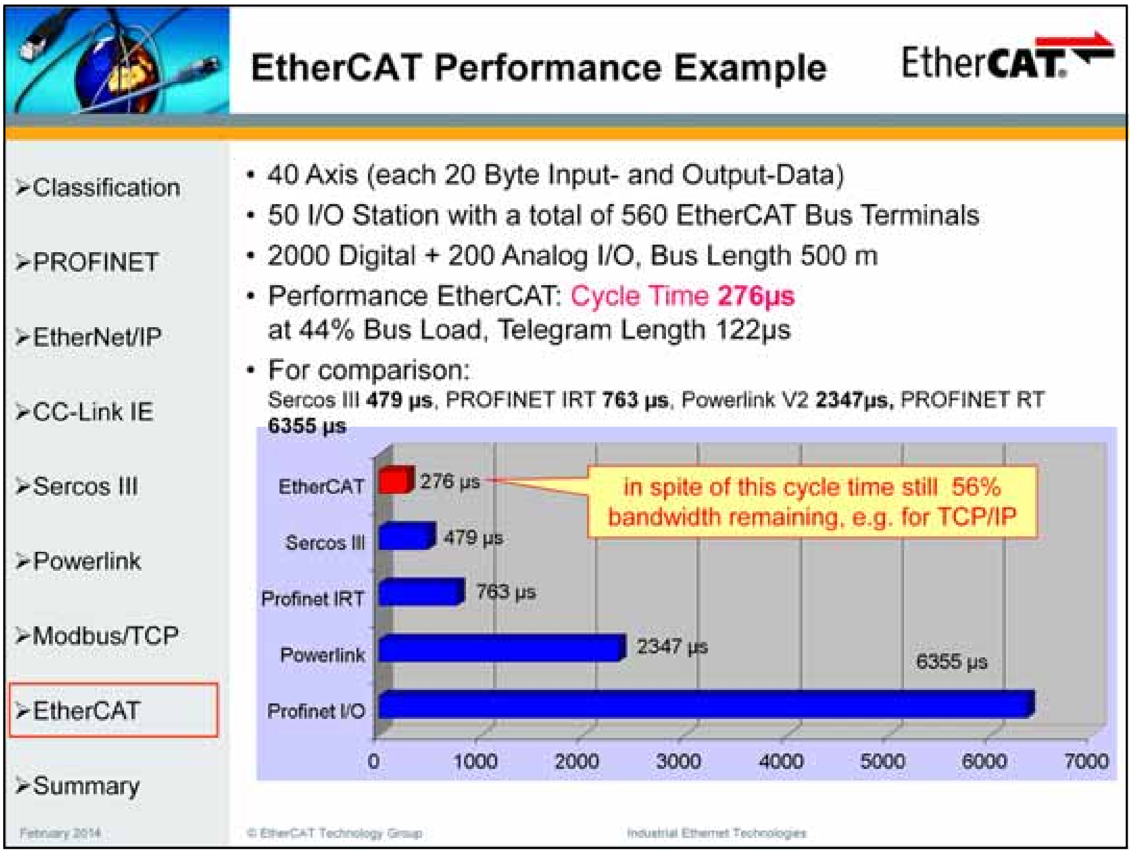
EtherCAT is very effective even with small amounts of data per slave device, since it is not necessary to send an individual Ethernet frame for each data unit.

Since process data communication is handled completely in hardware (EtherCAT Slave Controller), the network performance does not depend on the µC 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.

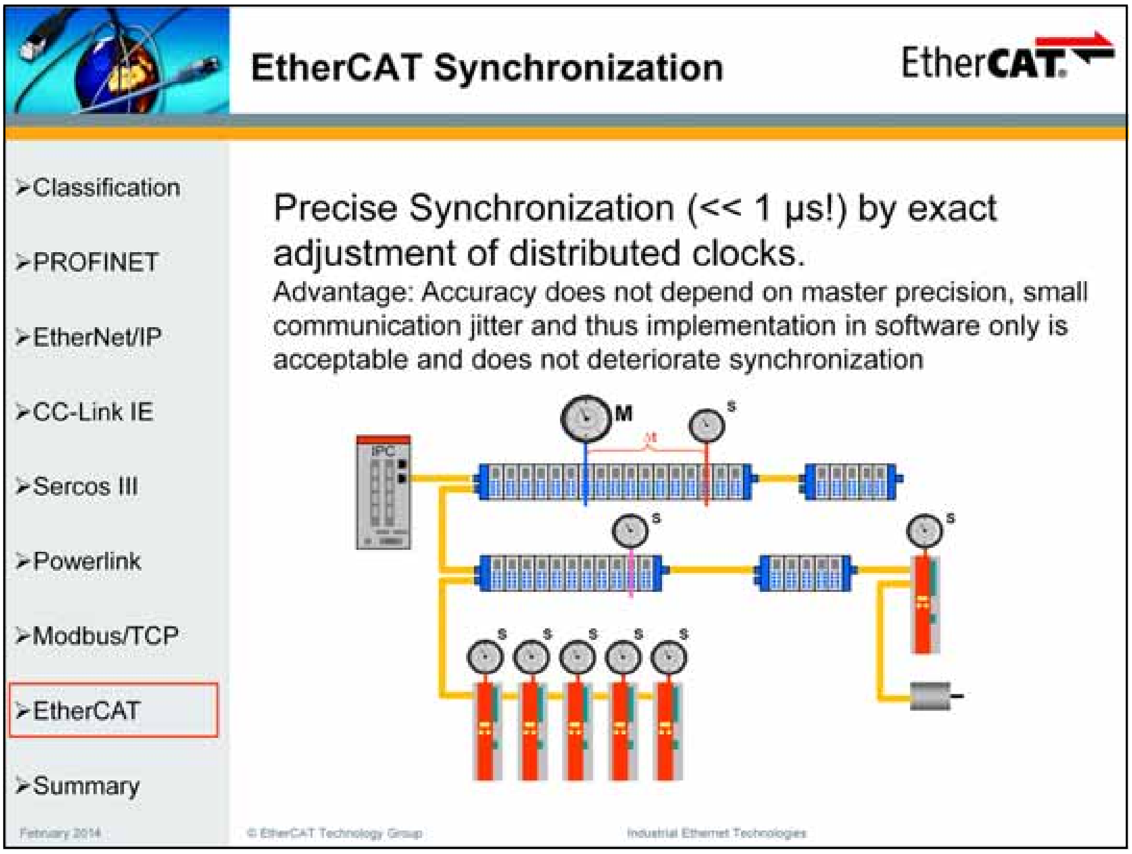


The cycle time figures of the competing technologies were determined as follows:

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).

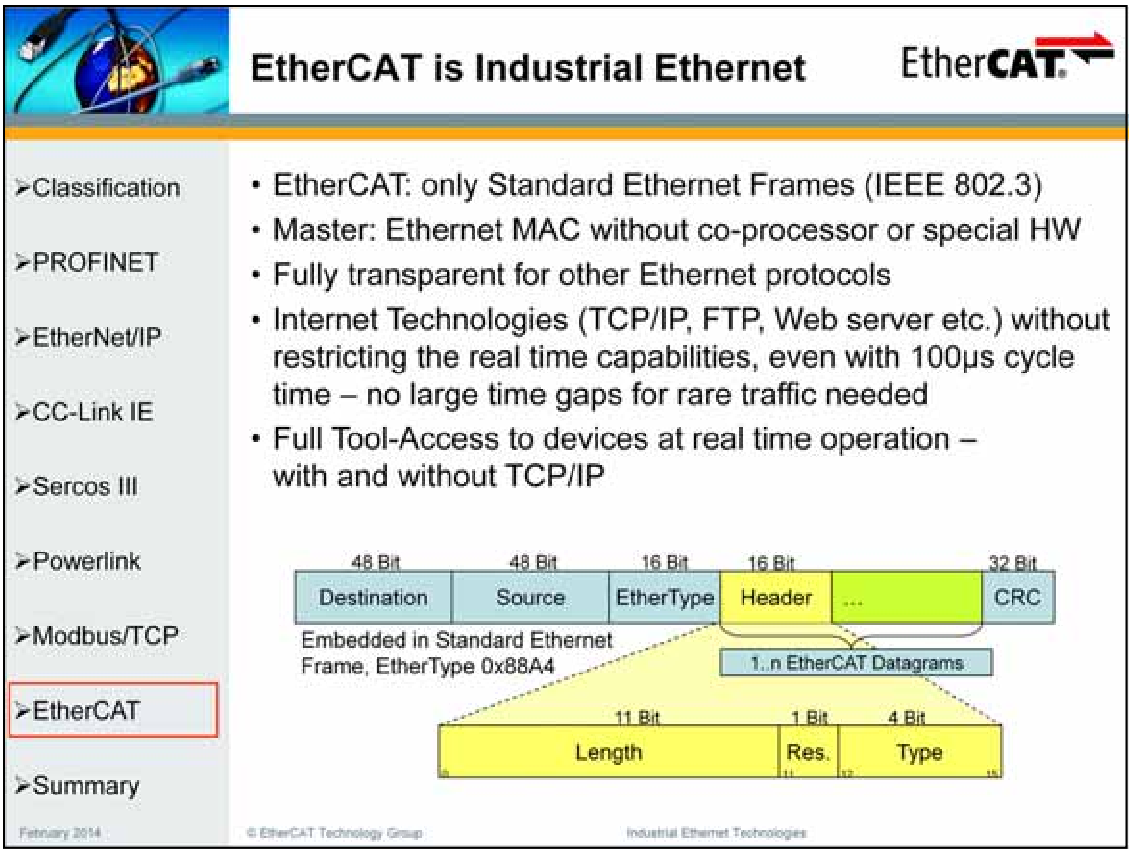
Powerlink: see Powerlink section of this presentation. With Powerlink at this cycle time there is no remaining bandwidth for asynchronous communication.

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).



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 ~20ns 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 << 1µs.



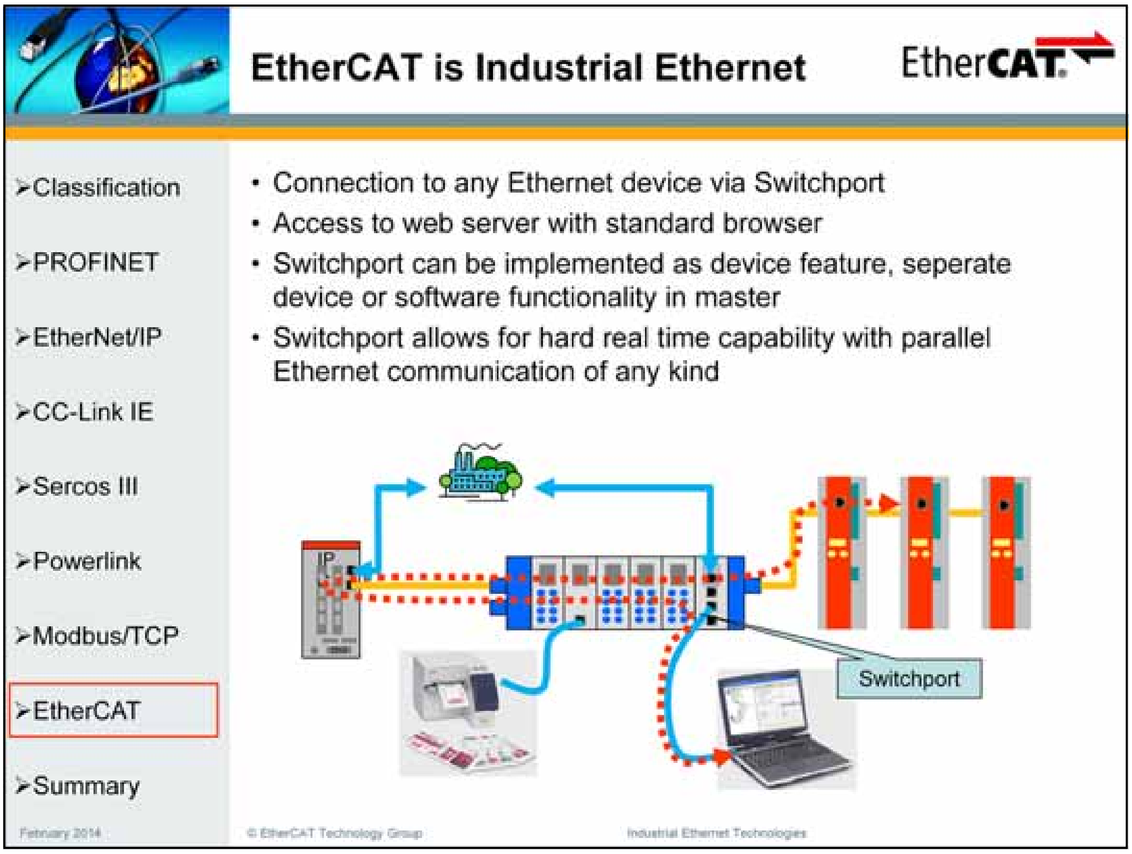
EtherCAT used only standard frames. Any other Ethernet Protocols are tunneled fully transparently – EtherCAT thus uses a method that is common with Ethernet itself and with many Internet technologies: every modem tunnels Ethernet frames as does WLAN, VPN uses this approach as well as TCP/IP itself.

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).

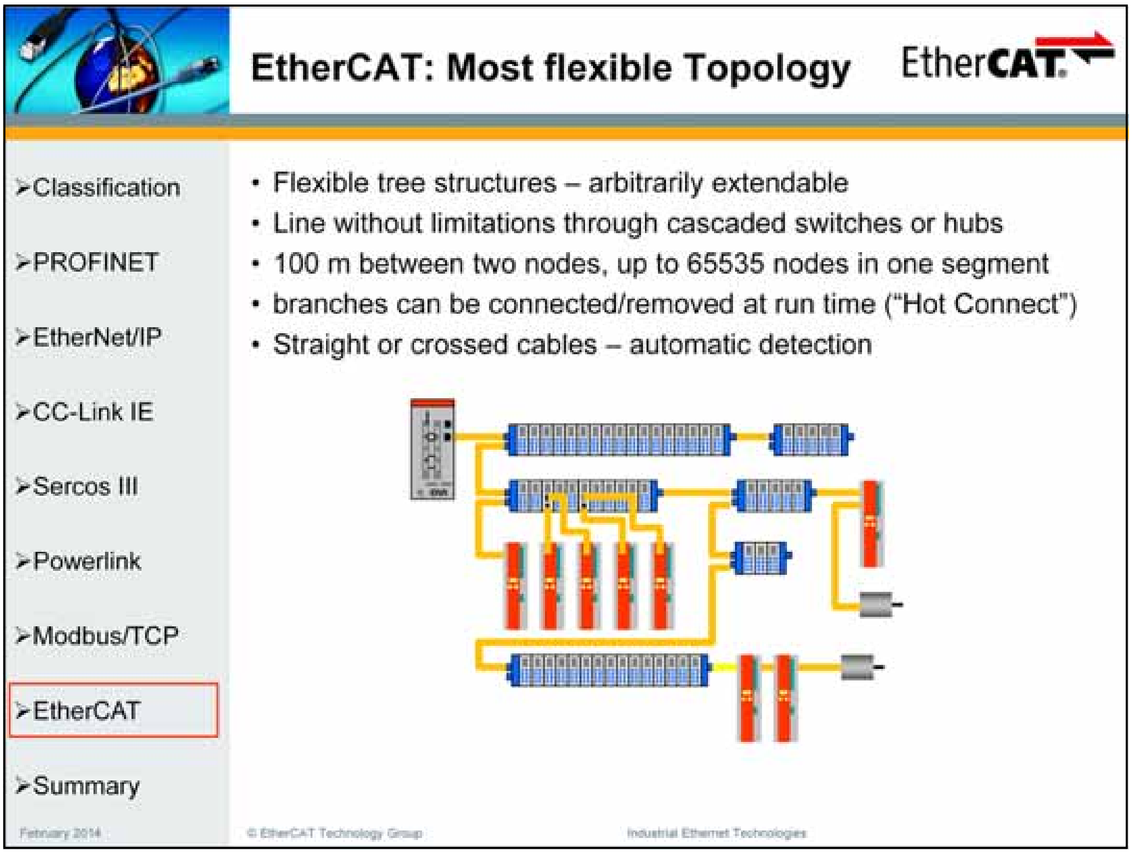
In addition, it is not necessary to keep a large gap in the data stream – like most other approaches have to.

The protocol used is named “Ethernet over EtherCAT”.

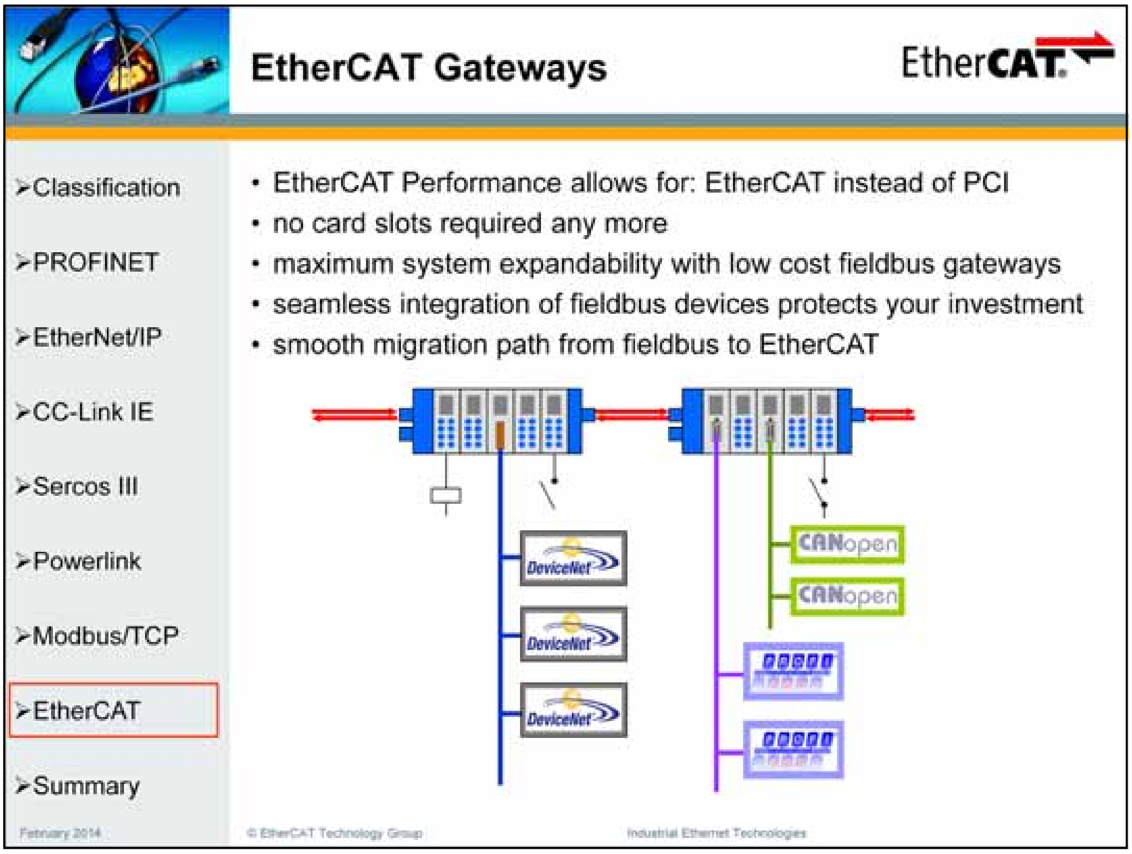
Many EtherCAT masters support tool access from outside: a tool can communicate via Ethernet e.g. by TCP/IP or UDP/IP with the master, who inserts this data into the EtherCAT communication in such a way, that a fully transparent access to EtherCAT devices is possible without restricting the real time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



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.

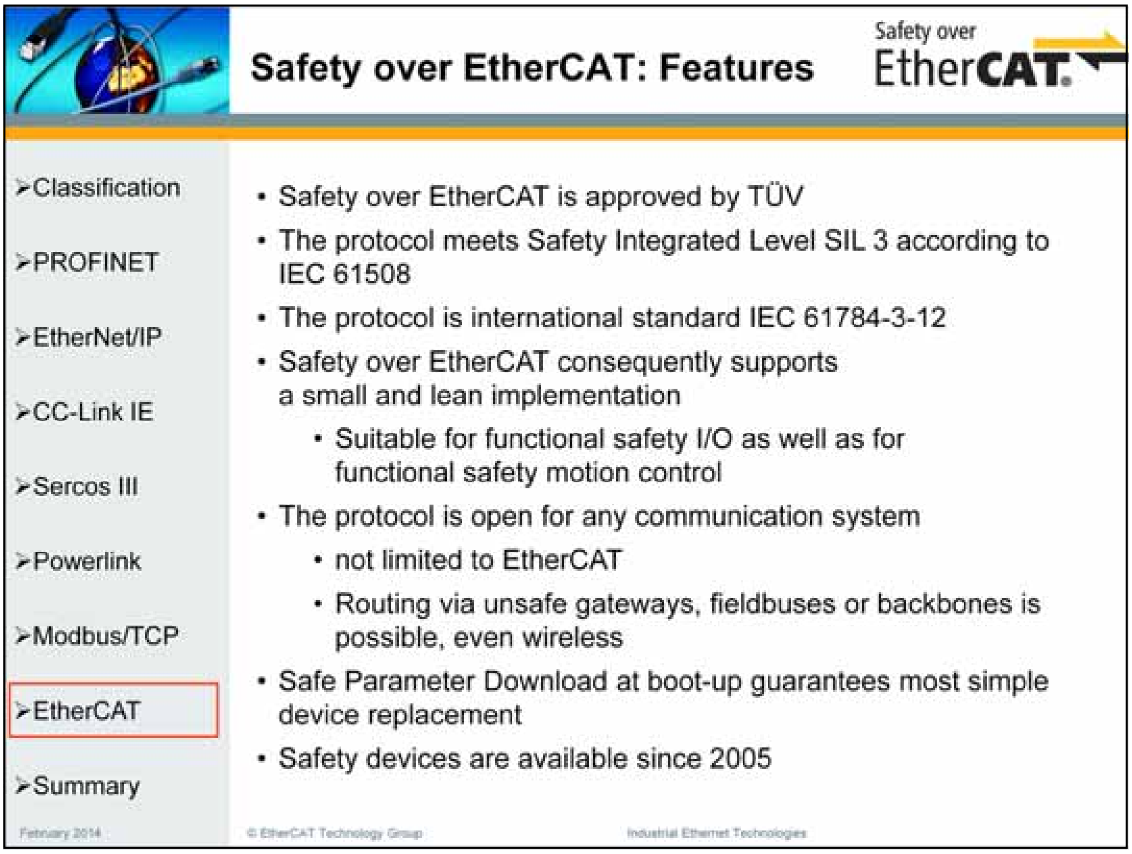


With EtherCAT almost any number of devices (up to 65535) can be wired in a line structure – there are no restrictions due to cascaded switches or hubs. Any number of drop lines or branches are possible, too, providing the most flexible topology.



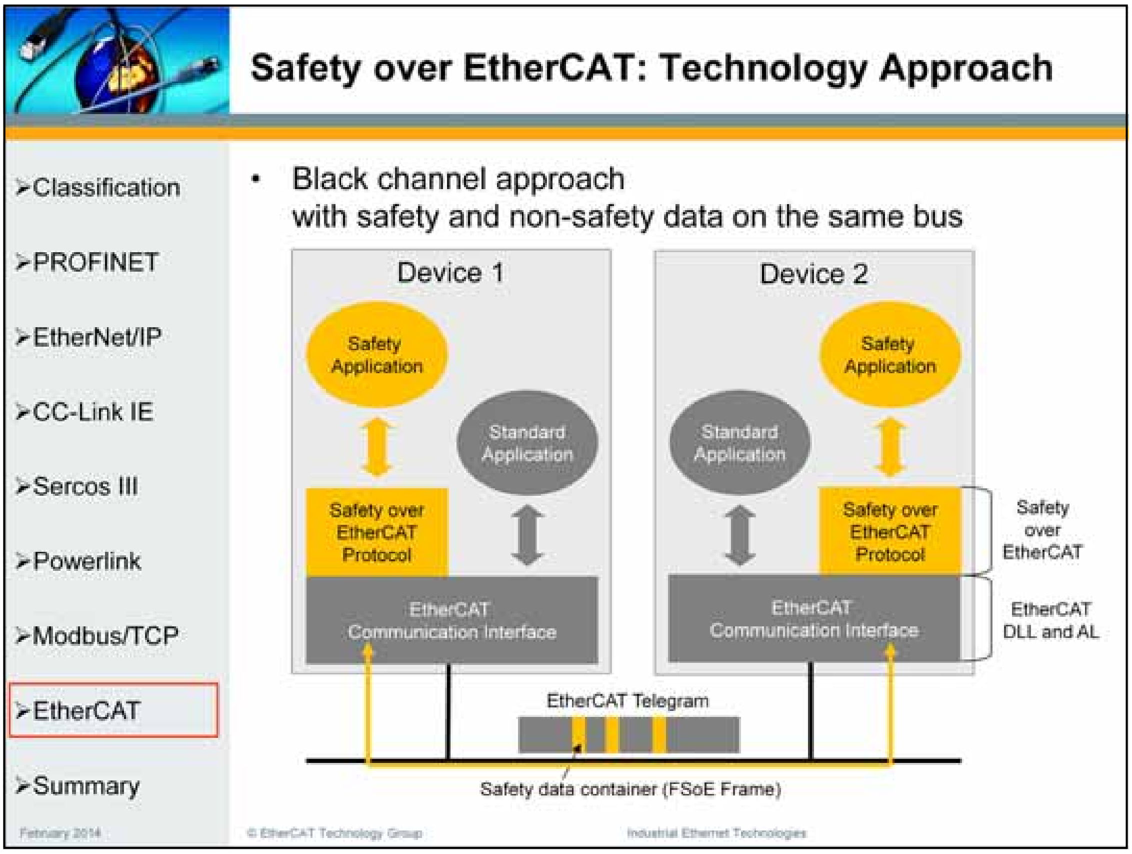
EtherCAT is so fast that it can replace the PCI bus (and thus the PCI slots) in almost all applications. Fieldbus master and slave card can be moved into the EtherCAT network. EtherCAT control computers can thus be very compact, without restricting the expandability.

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.

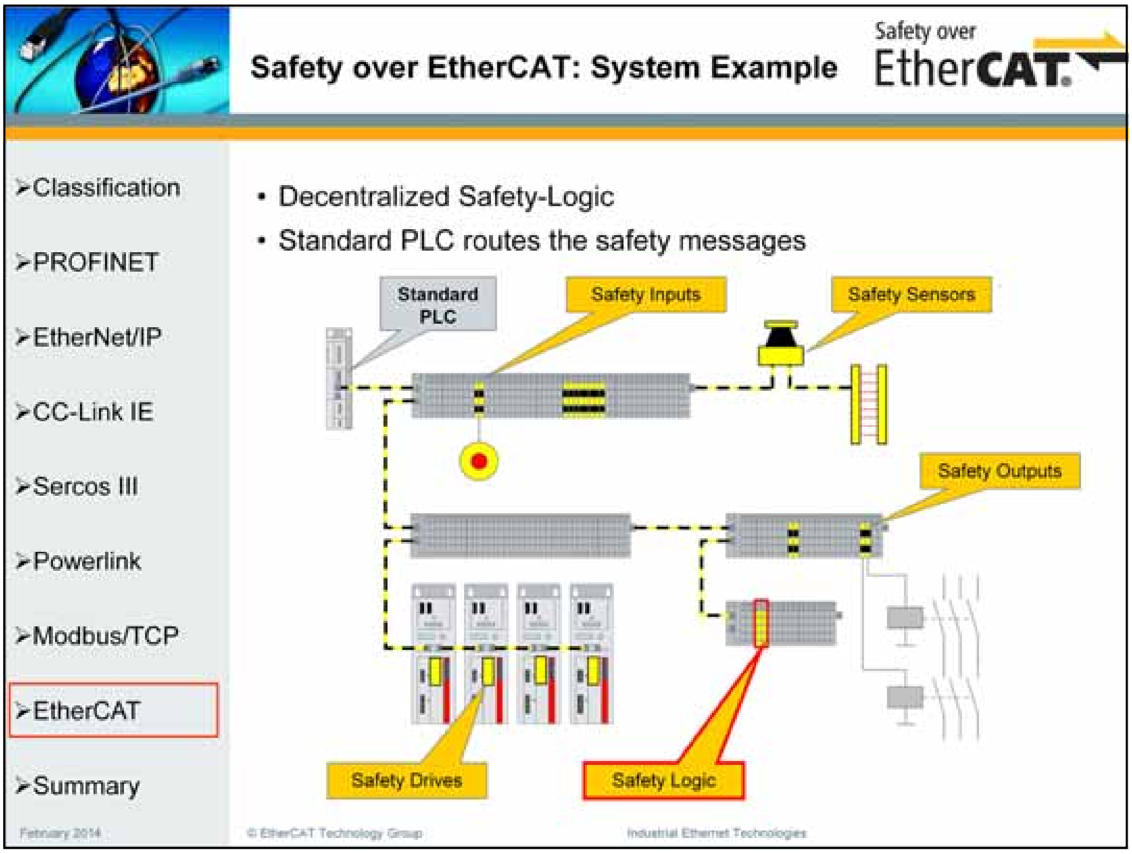


The open protocol Safety over EtherCAT (abbreviated with FSoE "FailSafe over EtherCAT") defines a safety related communication layer for EtherCAT. Safety over EtherCAT meets the requirements of IEC 61508 SIL 3 and enables the transfer of safe and standard information on the same communication system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

It 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.

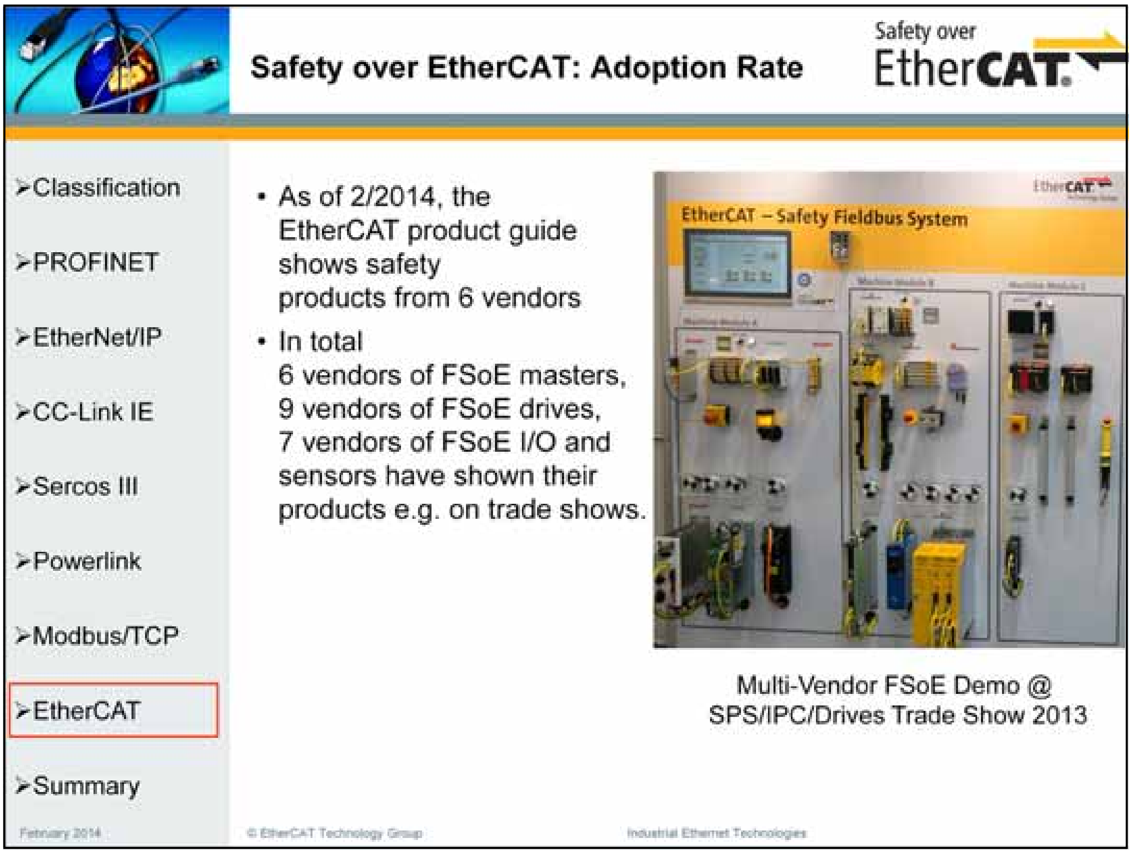


With Safety over EtherCAT the communication channel is really “black” (or irrelevant for the safety analysis), and not “grey”. Therefore e.g. no SIL monitor is required to check the current error rate on the network.



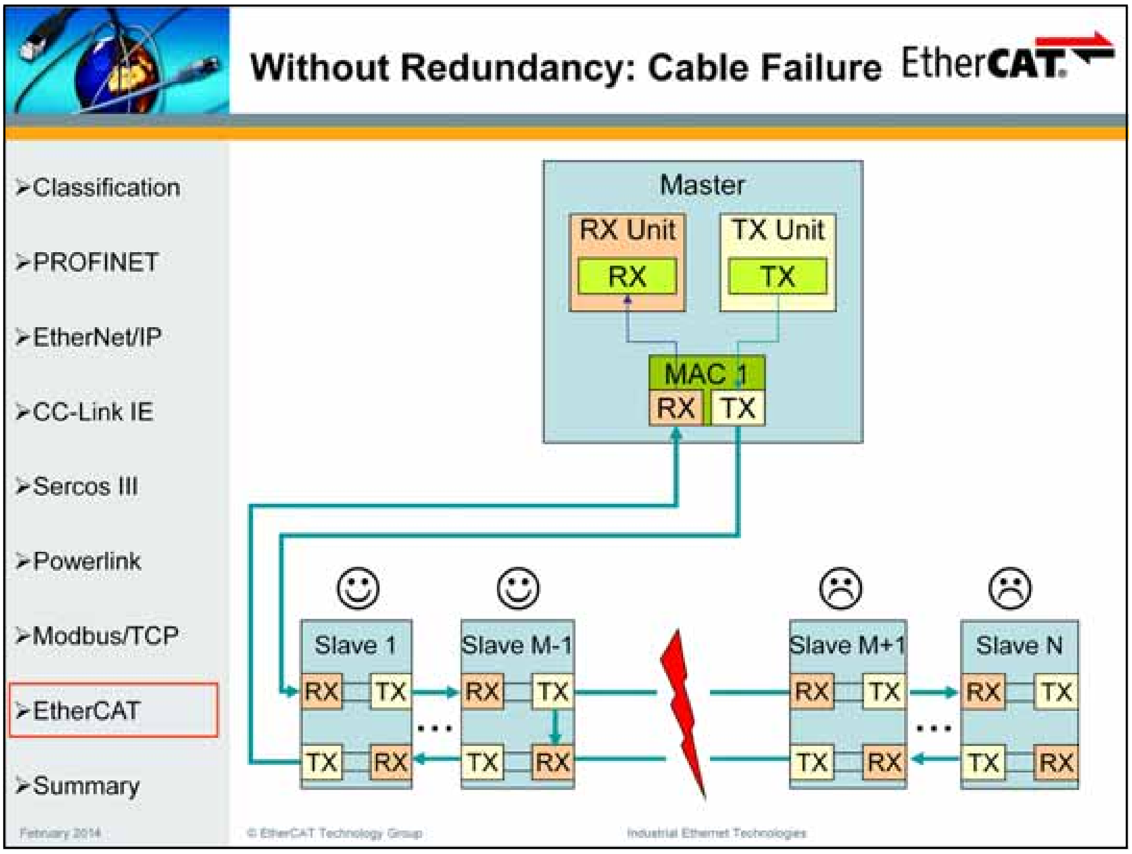
With Safety over EtherCAT a decentralized safety PLC ("Safety Logic") can be combined with a non-safe standard main controller. With this approach functional safety can be added to existing control systems without the need to replace the main controller with a functional safety PLC.

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

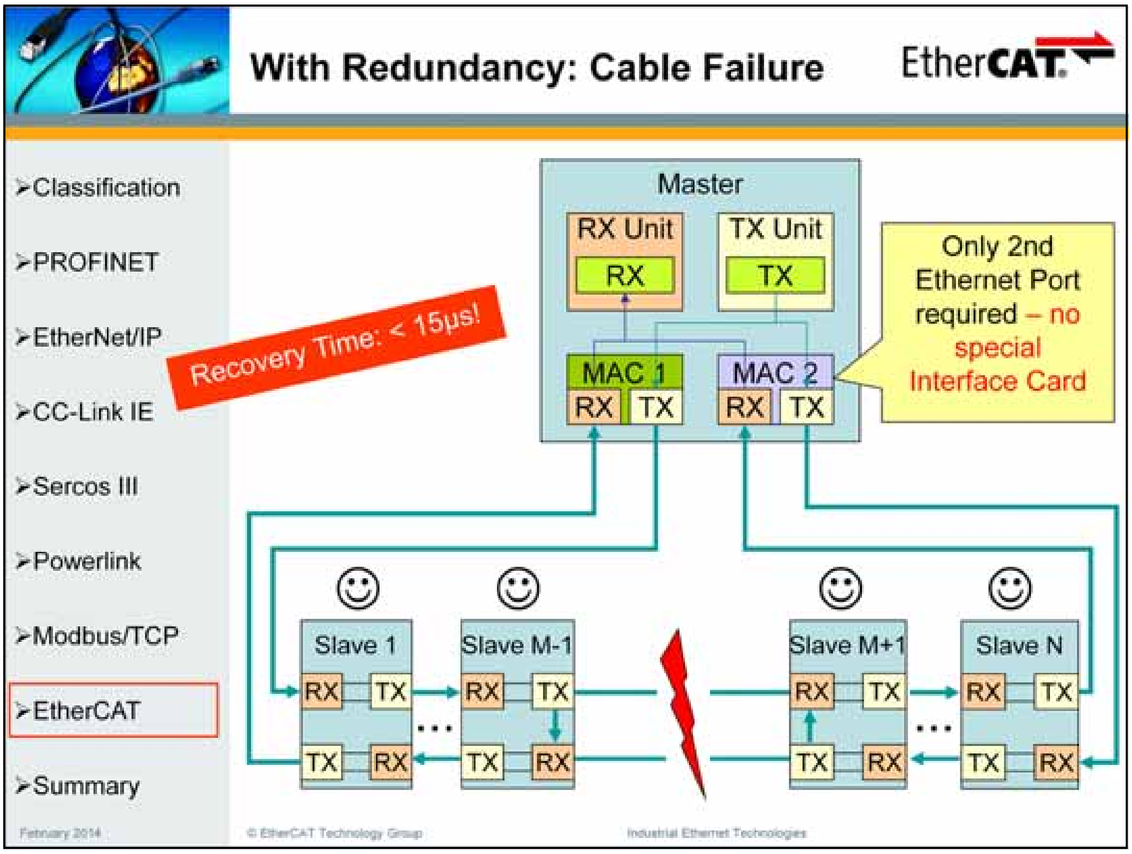


The FSoE license is provided free of charge.

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.

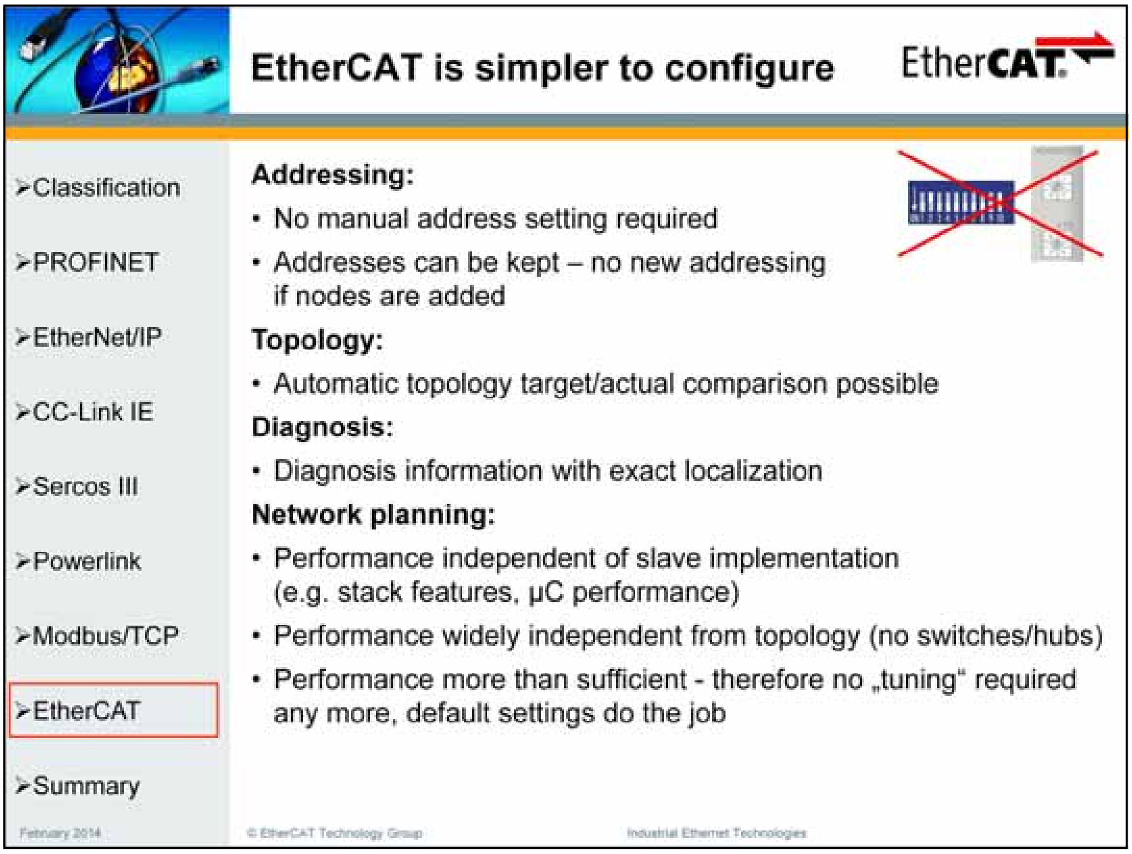


If the line is turned into a ring, there are two communication paths to each device: cable redundancy.

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 15µs. The initial switchover to the redundant line does not require any reconfiguration by the master.

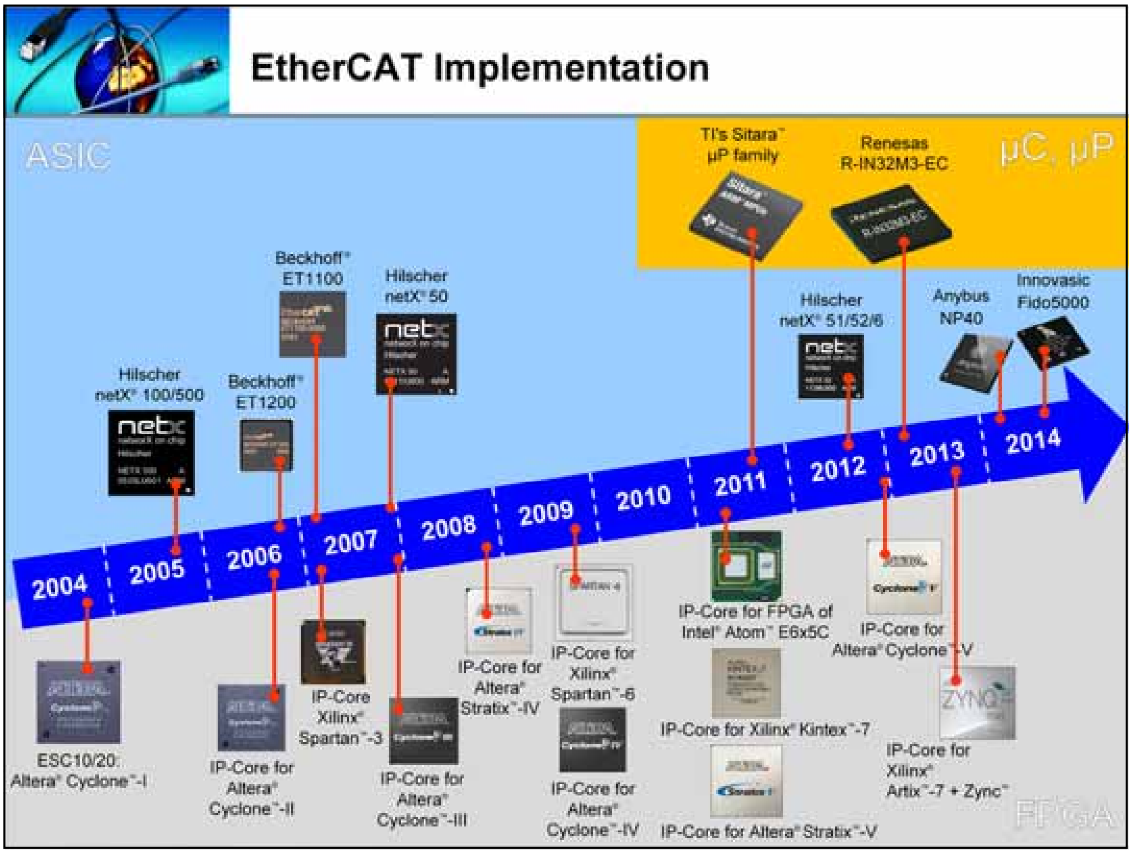
By using this feature it is feasible to exchange device exchange at run time (hot swap).



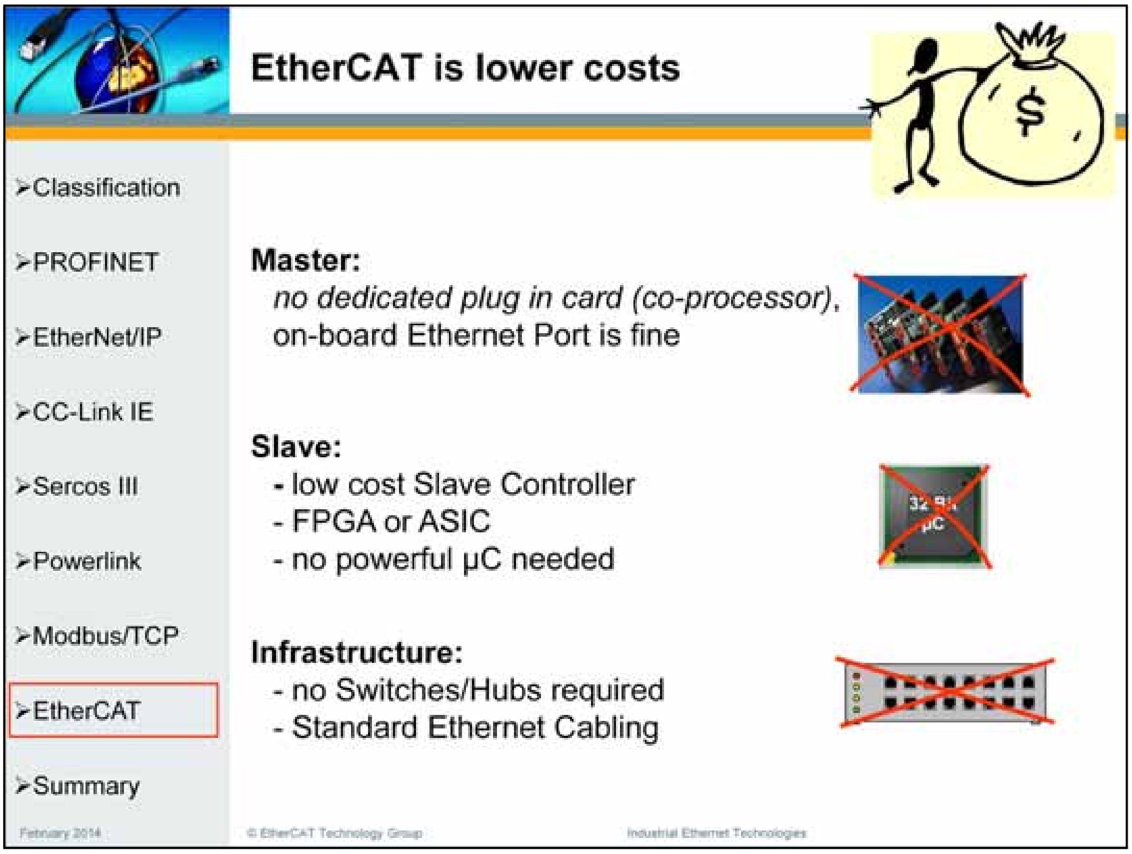
The configuration of an EtherCAT network is very simple.

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 µC 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).



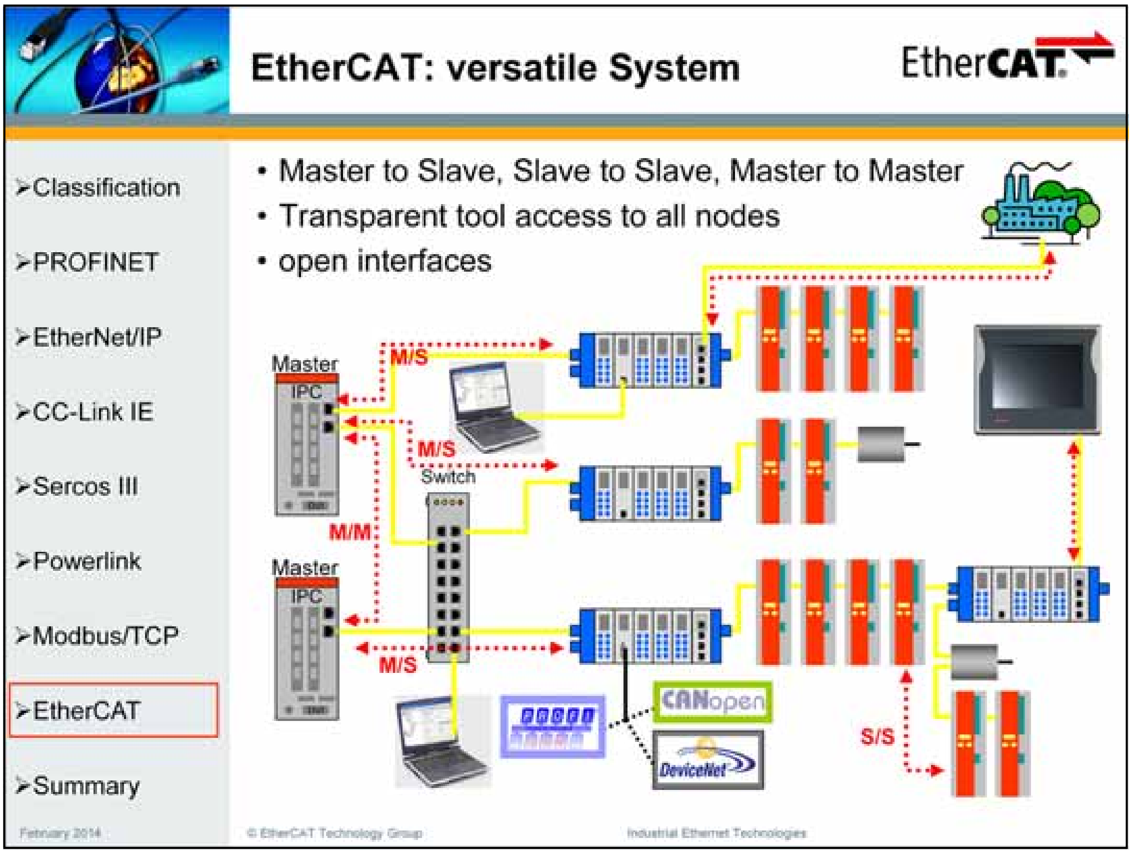
EtherCAT intends to even undercut the fieldbus cost levels – in spite of the much better performance and many additional features.

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.

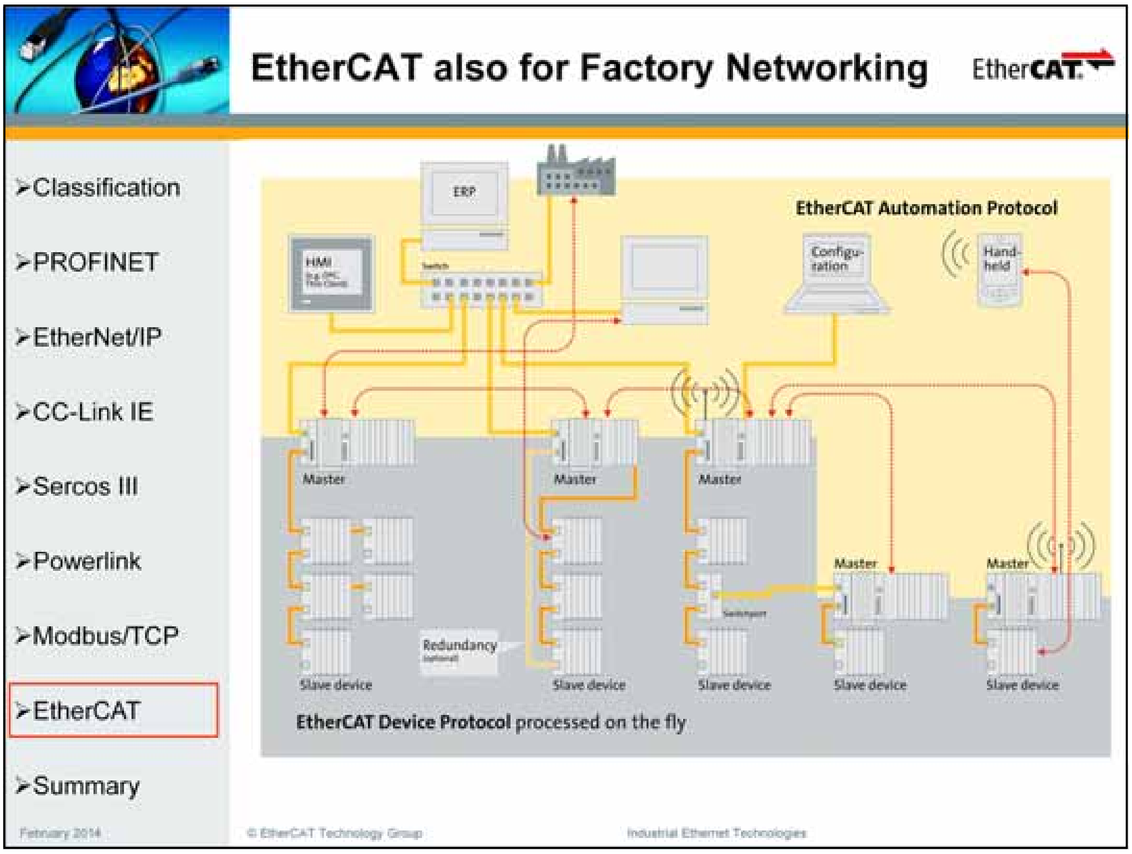


Besides the master/slave communication EtherCAT provides further possibilities: masters can communicate among each other as well as slave devices.

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 with accordingly. Wherever this is not possible, the second variant can be applied:

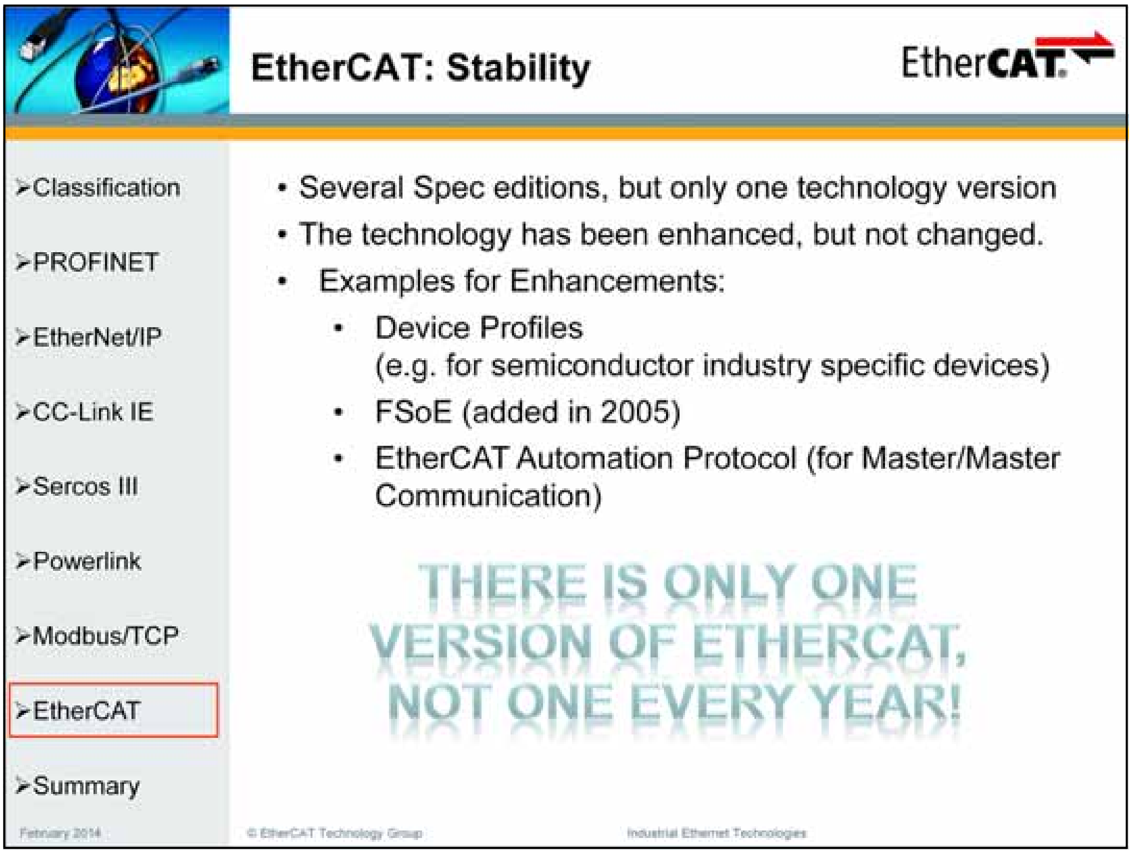
Topology independent two cycles are used for slave to slave communication. In most cases the corresponding delay time is not critical at all – in particular if one considers that EtherCAT is even at twice the cycle time still faster than any other solution….



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.

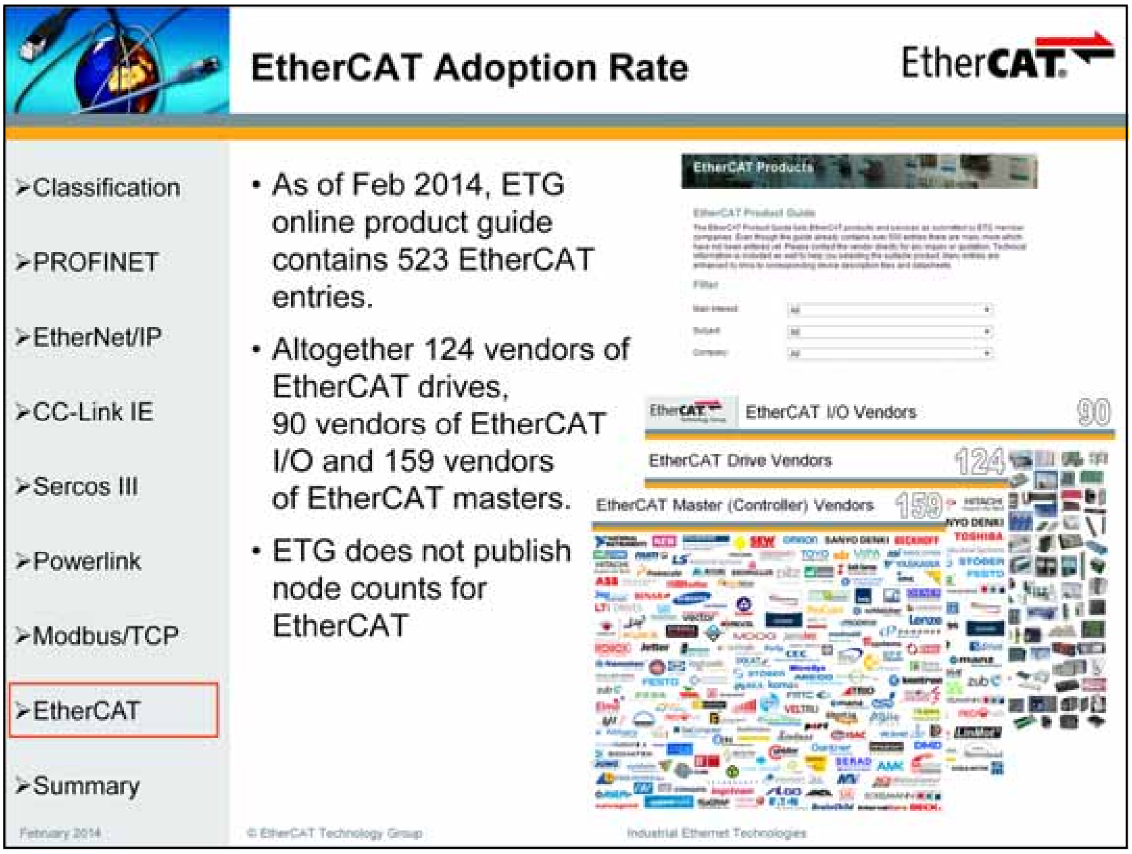
For the factory level, the base protocols for process data communication have been part of the EtherCAT specification from the very beginning. In 2009 ETG enhanced those with services for the parameter communication between control systems and for routing across system boundaries. Uniform diagnostic 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.



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.

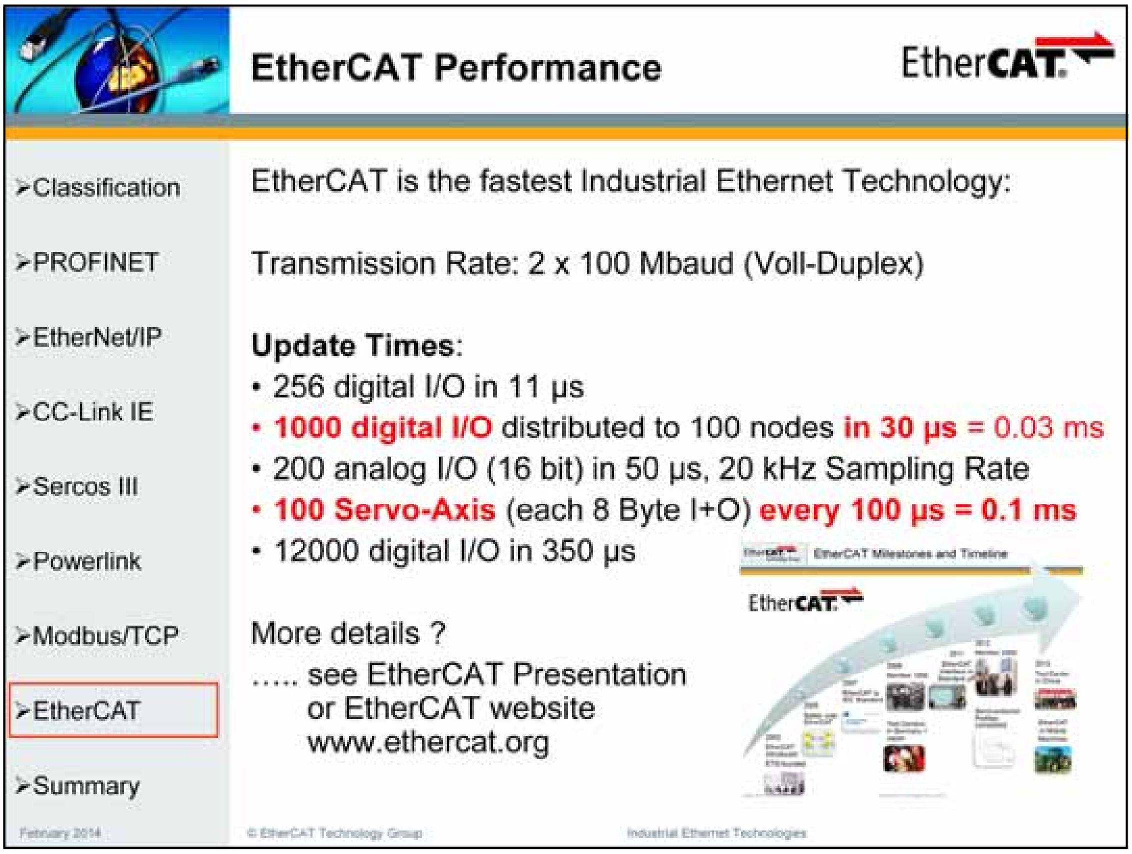


The adoption rate of EtherCAT is outstanding. In particular the adoption rate among master vendors underlines the wide spread support as well as the openness of the technology: it makes a difference if a vendor “just” support another fieldbus interface for his (slave) components such as drives or I/O, or if he adopts the fieldbus as own system bus and implements a master.

For two reasons ETG does not publish node counts:

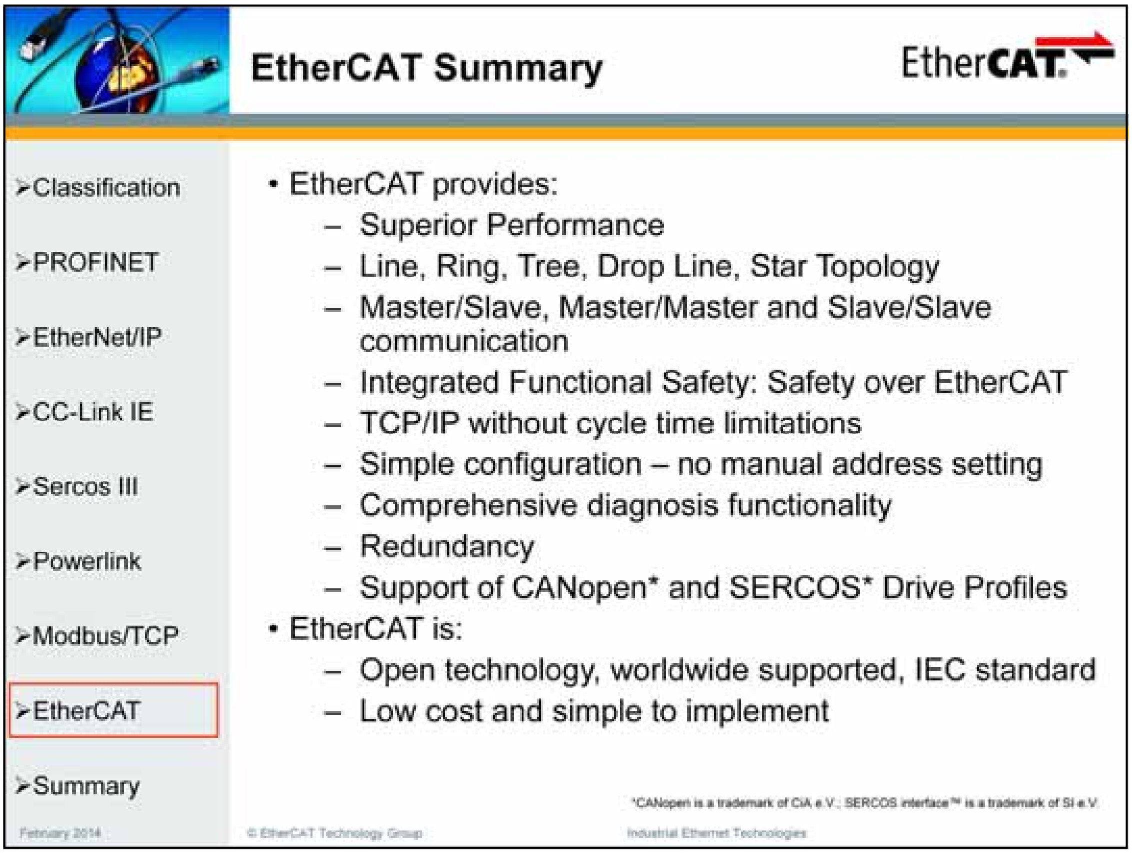
1. ETG does not know the numbers, since sales do not have to be reported and since the EtherCAT Slave Controller sales cannot be monitored do to the “buy-out” licensing of the IP Core.
2. It is obvious that the other organizations do not know their numbers either….

So ETG has to live with the fact that most market research organizations underestimate the EtherCAT market share.



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.

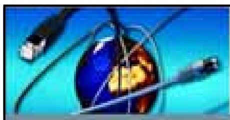


EtherCAT typically is chosen for one or more of these three reasons:

- superior performance
- flexible topology – even at large distances
- low costs

For more information regarding EtherCAT please go to

www.ethercat.org



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

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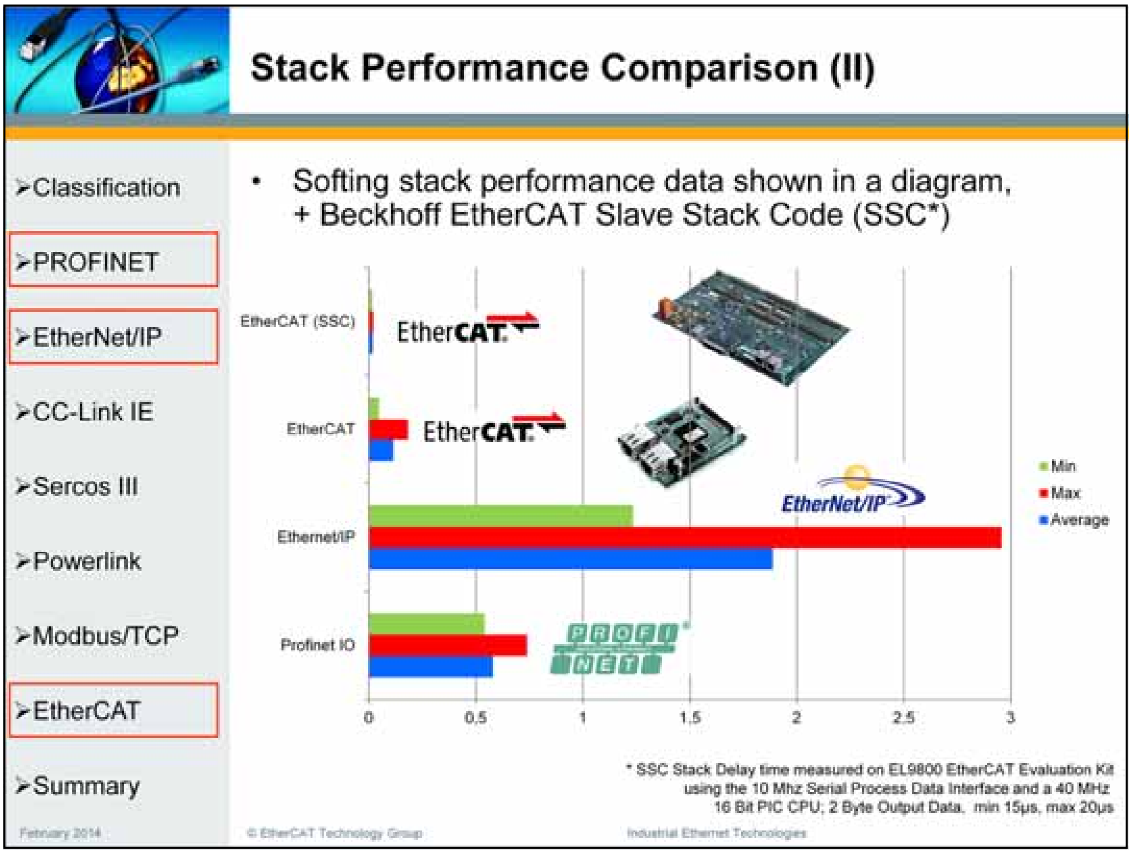
- Most performance comparisons only look at the network itself up to the slave controller chips, and neglect the stack performances.
- However, the stack performance is crucial when looking at the overall network system performance
- Softing is using the eCos RTOS on the Softcore CPU that runs the stacks
- 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

RTE Technology Comparison: Summary

Performance	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Cycle Time	--	--	-	o	+	o	+	++
Synchronicity	--	-- + (CIP sync)	--	- o (with special interface hw)	+	+	+	++
Throughput of IP Data	++	++	++	o (half duplex)	+	--	-	o

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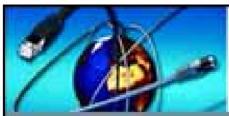
In principle, one should not compare technologies in such an overview table: since the ratings are based on figures, assumptions and assessments that cannot be given in full detail, one may come to a different conclusion. However, some like this and ask for these tables.

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).



RTE Technology Comparison: Summary

Topology + Wiring	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Topology Flexibility	--	-	-	+	+	-- (Control) + (Field)	-	++
Line Structure	--	-	-	O (10)	O (~25)	-- (Control) + (Field)	+ (511)	++ (65535)
COTS Infrastructure Components (Switch, Router, Connector etc.)	++	+	O	O (no Switch)	--	-- (Control) + (Field)	-	+

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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	-	✓	✓	✓	✓	✓	✓	✓

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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.

RTE Technology Comparison: Summary

Costs	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Node Interface Costs	o	o	o	o + (w. FPGA)	- ERTEC400 o ERTEC200	?	+ (w. FPGA)	++ + (w. FPGA)
Development Effort	++	-	--	o	--	?	+	+
Master Costs	+	+	+	-*	-*	-*	-*	++
Infrastructure Costs	- (Switch)	-- (Switch)	-- (Switch) o (Switch integrated)	o (Hubs integr.)	o (Switch integr.)	o (Switch integr.)	++ (no Switch)	++ (no Switch)

* Requires Special Master Card with Co-Processor

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Node Costs: Whilst Modbus/TCP – due to limited real time claims – can be implemented on 16bit µC, 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.

RTE Technology Comparison: Summary

Strategic Topics (I)	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Size of supporting organization	++	+*	+*	o	+*	+*	o	++
Worldwide User Group	++	++	++	o	++	+	+	++
Worldwide Vendor Group	++	+	+	-	--	--	--	++
Technology Stability	++	+	o	-	--	-	o	++

* Not all ODVA or PTO/PNO or CLPA members support Ethernet

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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?

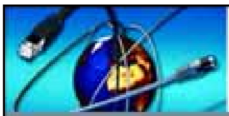
* since ETG membership is free of charge, membership figures should not be compared 1:1 with the other organizations.

** according to website www.sercos.de/www.sercos.com. + 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 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 as of Feb 2014



RTE Technology Comparison: Summary

Strategic Topics (II)	Modbus /TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	CC-Link IE	Sercos III	EtherCAT
Special Hardware used?	++	++ - (CIP Sync)	++	O (FPGA)	- (M+S)	- (M+S)	O (FPGA)	O (S)
Adoption Rate?	++	+ - (CIP Sync)	+	-	- (IRT) -- (IRT2.3)	--	O	++
International Standardization	+	+	+	+	+	(+)	+	+

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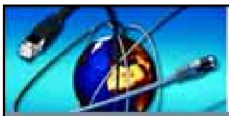
Special Hardware Used: Modbus/TCP, EtherNet/IP (not: CIPsync) + PROFINET RT can be implemented with standard hardware chips. For Powerlink, recommended implementation is with FPGA. PROFINET IRT, CC-Link require special chips in master and slave, Sercos-III need special chips (e.g. FPGA) in aster and 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