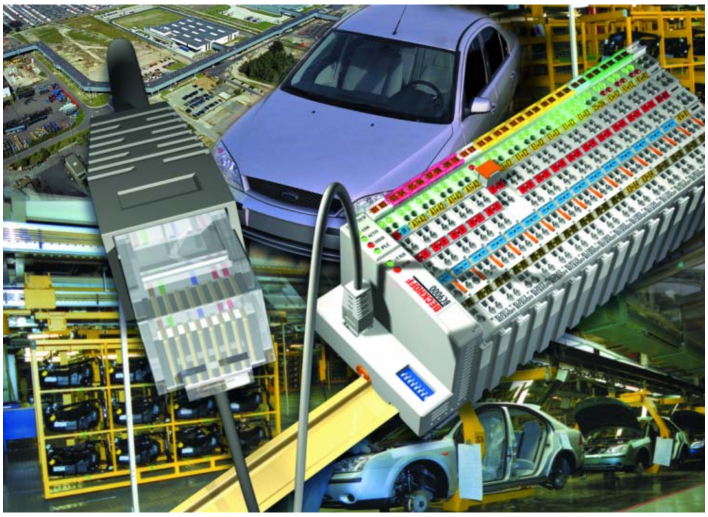
Industrial Ethernet Technologies: Overview

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary



 Industrial Ethernet Technologies

Editorial Preface:

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

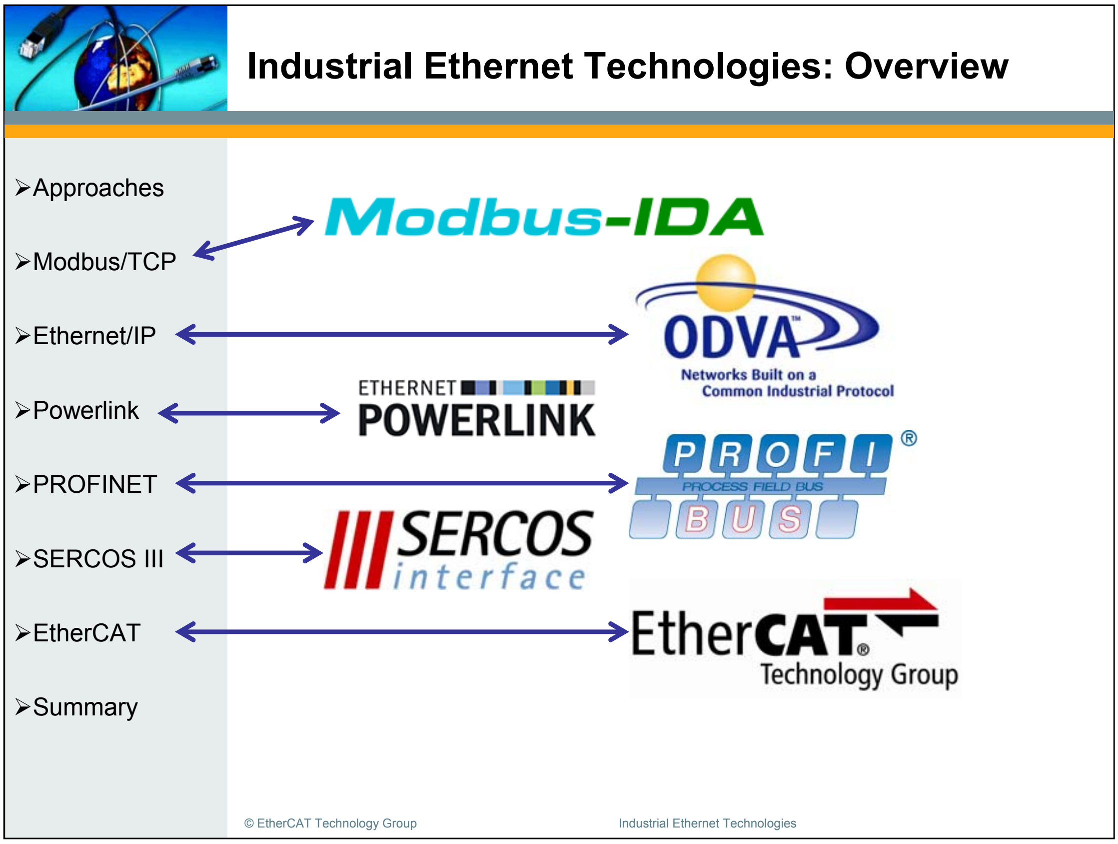
The content given represents my best knowledge of the systems introduced. Since the company I work for is member of all relevant fieldbus organizations and supports all important open fieldbus and Ethernet standards, you can assume a certain level of background information, too.

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

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

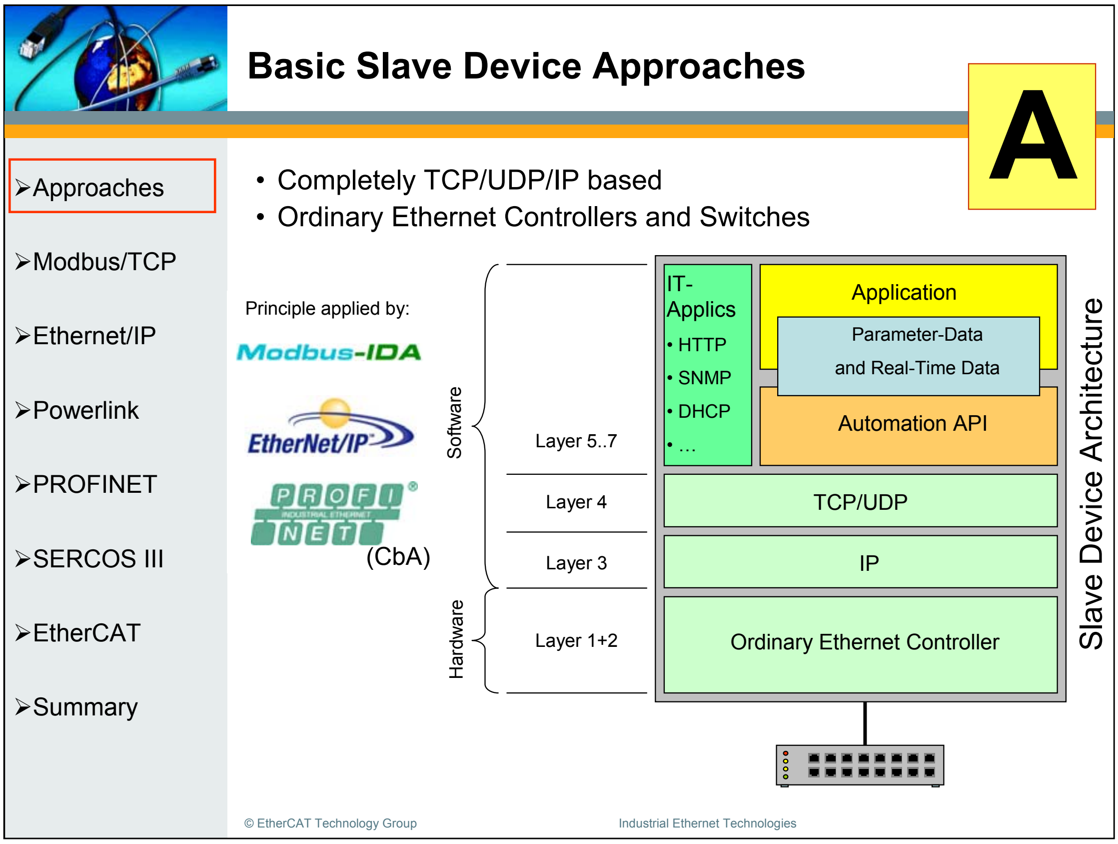
Nuremberg, January 2011

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.

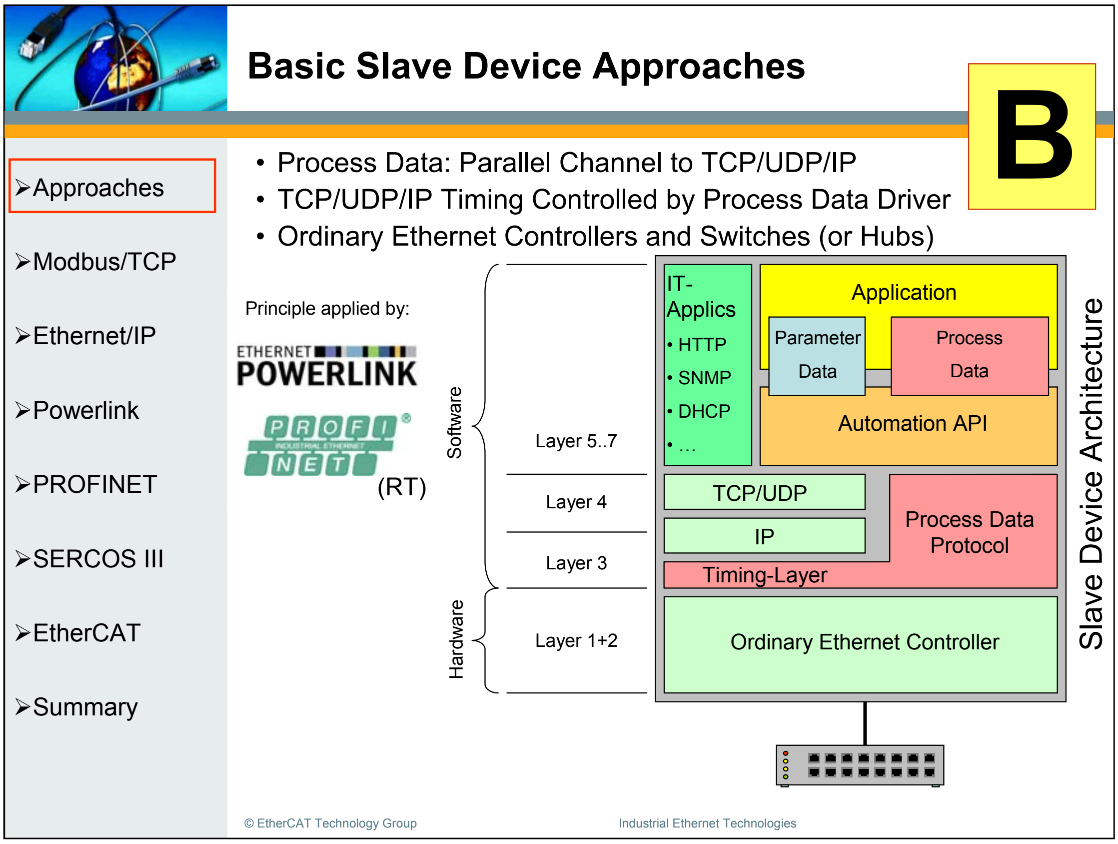
All technology names as well as the names of the organizations promoting and supporting those are trademarked. The trademarks are honored.



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.

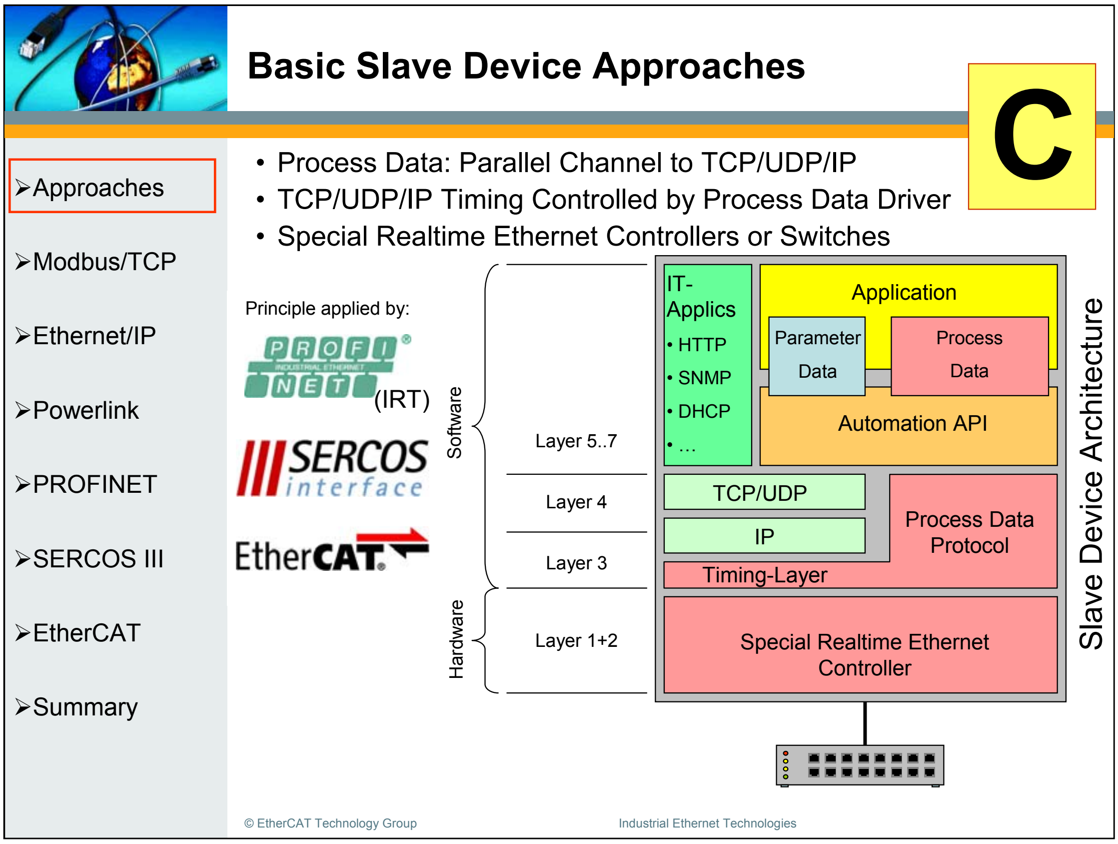
Class A approaches are also referred to as „best effort“ approaches. The real time performance is limited by unpredictable delays in infrastructure components like switches – no just due to other traffic on the network. The by far largest obstacle to better real time performance however is provided by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

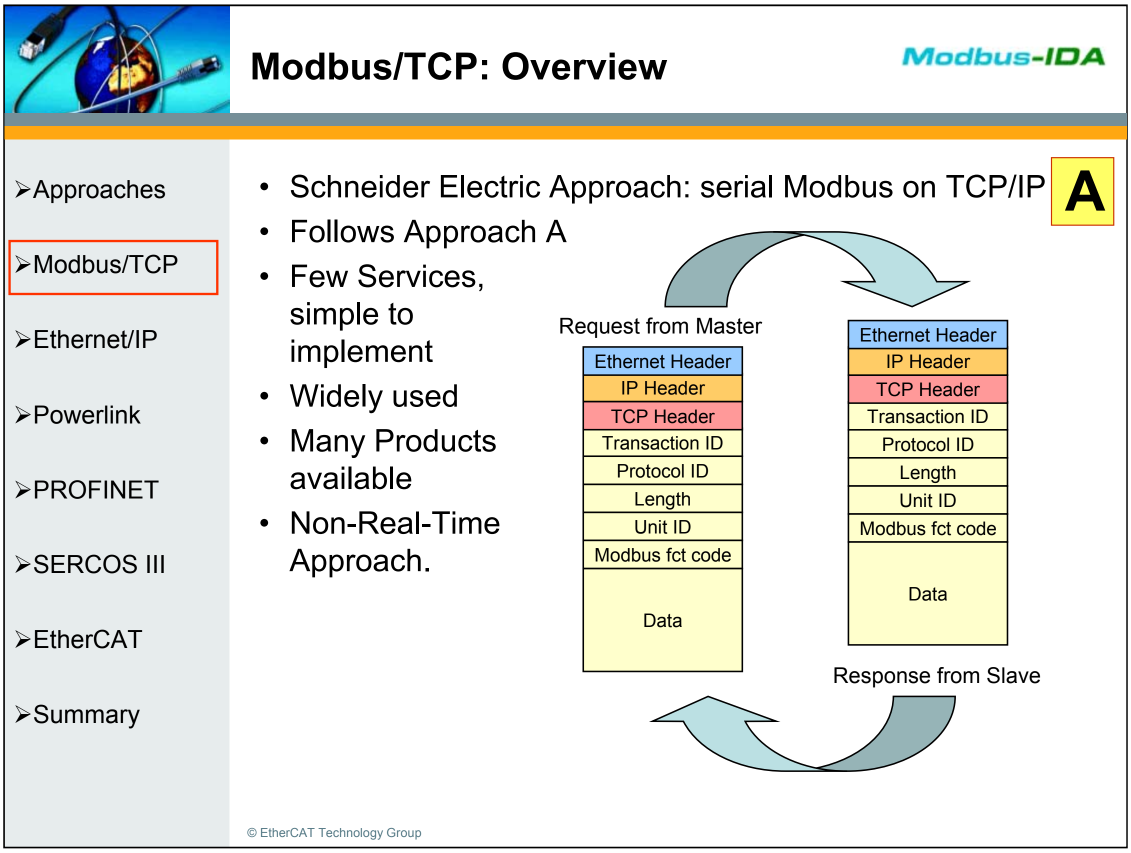
Of course this description is pretty generic – but more details are given in the technology specific sections.



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.

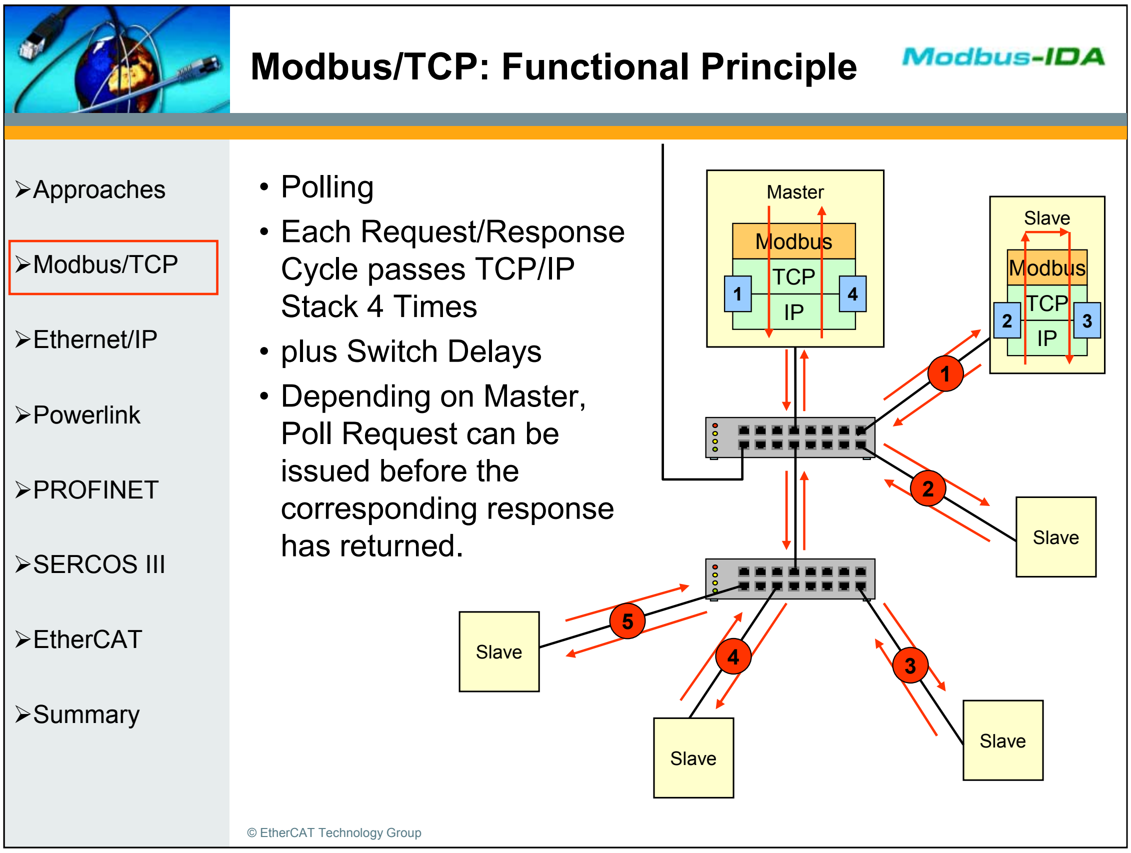
This does not exclude the use of TCP/IP and the Internet Technologies.



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 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 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 master and slave devices – which is difficult to assess.

If a master is implemented on a standard socket interface of a Windows OS, typical response times (per slave) 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 master with an RTOS and/or using a dedicated communication CPU and achieve better results.

A 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.

Modbus/TCP: Future?

Modbus-IDA

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

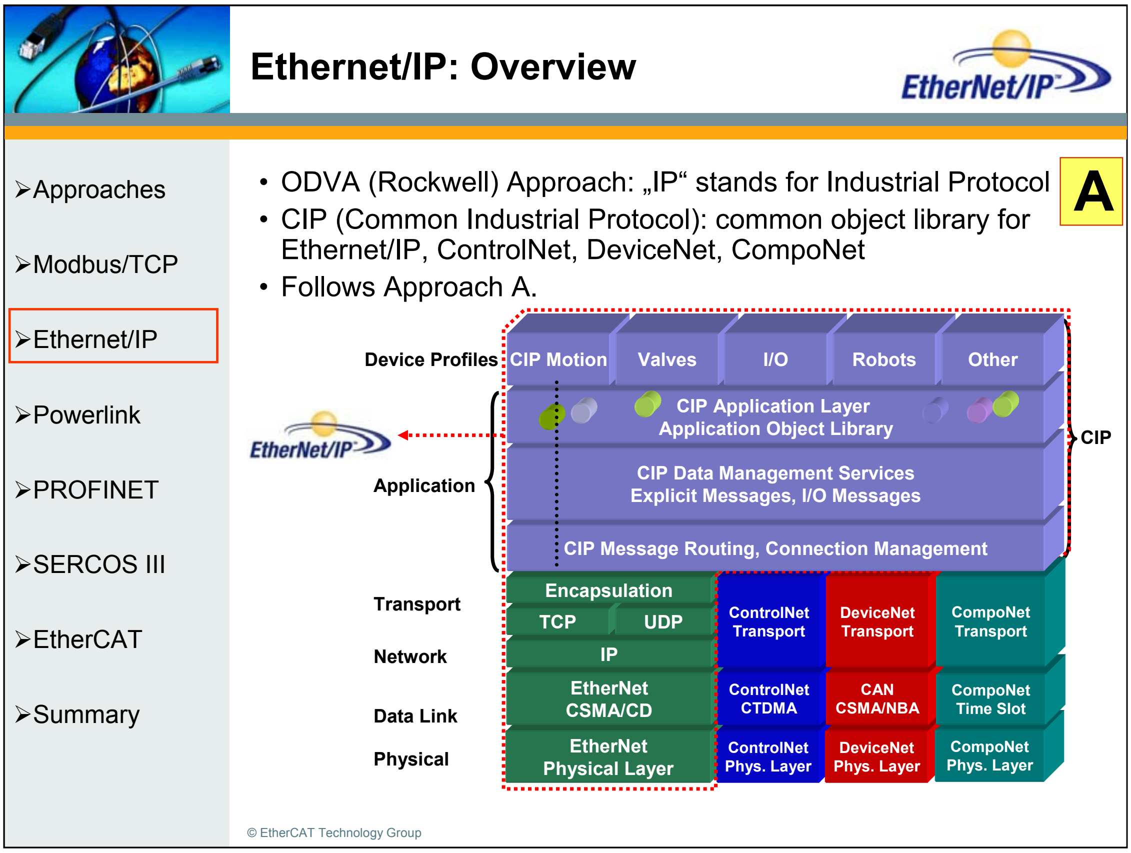
Modbus/TCP will certainly not vanish any time soon, but this move of Schneider indicates that there will not be enhancements or maintenance of the protocol.

The most recent technical document found on the Modbus website in Jan 2011 is the MODBUS MESSAGING ON TCP/IP IMPLEMENTATION GUIDE V1.0b from October 2006.

Schneider replaces 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



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.

Ethernet/IP Functional Principle

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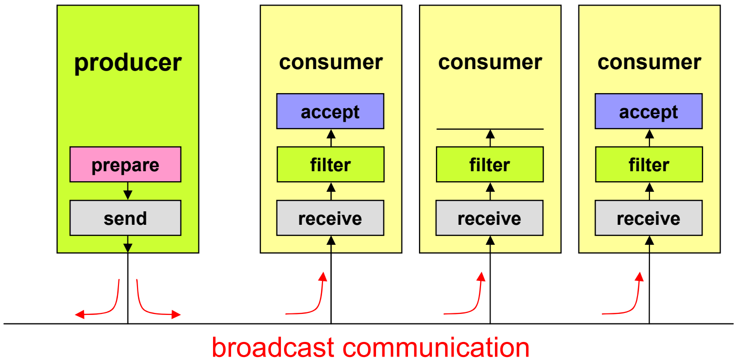
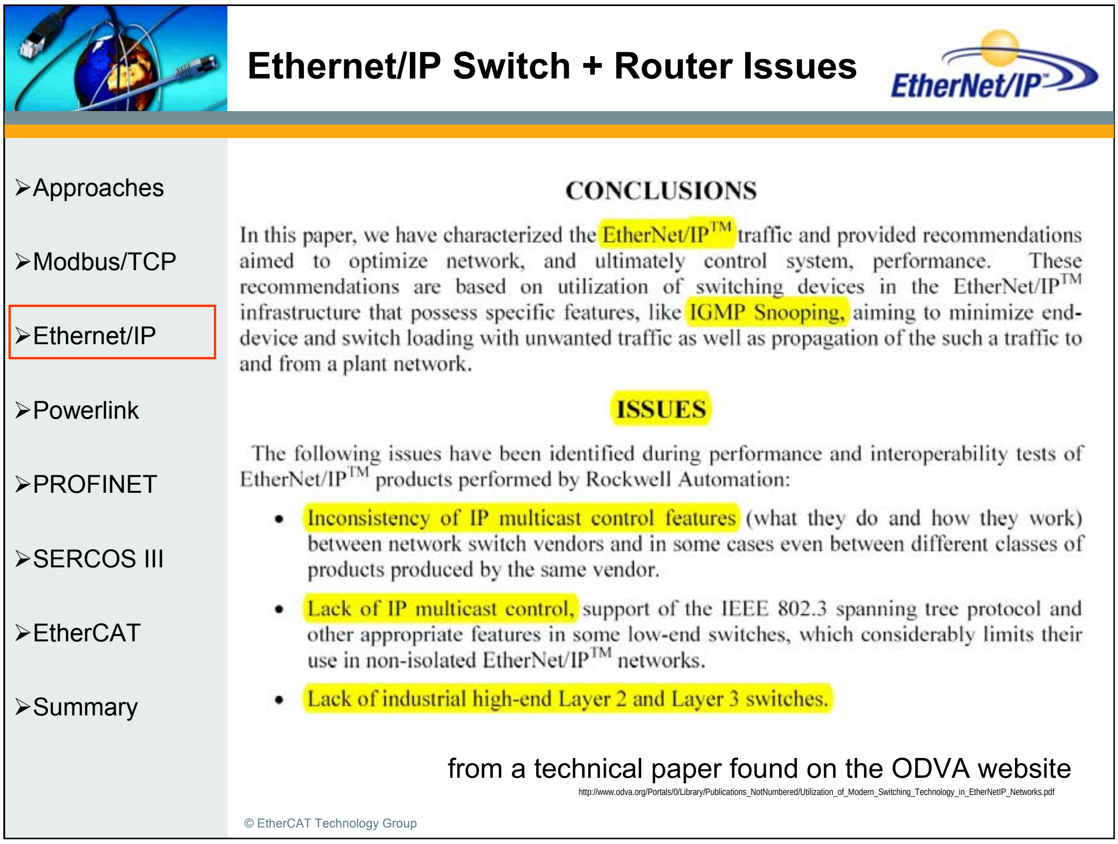
Consumer / Producer Model

- Advantage: very efficient for slave-to-slave Communication
- Disadvantage: requires Broadcast communication and thus filtering in each device



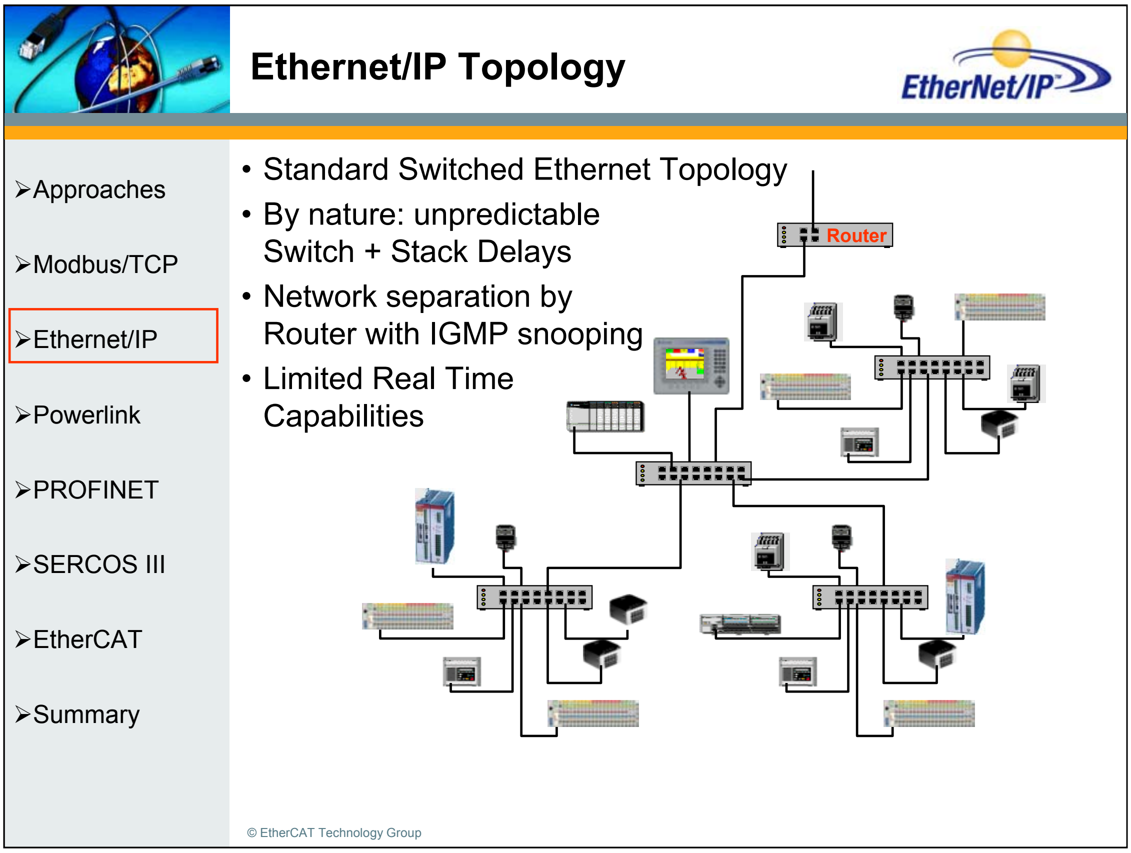
By applying broadcast or multicast communication, the switches cannot forward incoming frames to a single destination port only - so they act like (full-duplex) Hubs, but with larger delay.



This paper by Anatoly Moldovansky, a senior engineer from Rockwell Automation (and a nice guy!), 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.

Ethernet/IP Device Level Ring (DLR)

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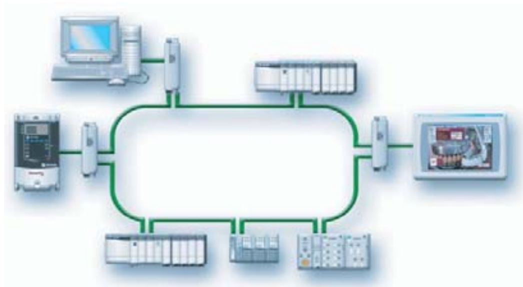
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



Picture: Rockwell Automation Press Release, Oct. 2009

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

Requires special nodes who support the DLR protocols

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

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

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

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

Ethernet/IP Performance

EtherNet/IP

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

min_RPI = (number of connections x 2) / (no. of frames/second)*

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

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

© EtherCAT Technology Group Industrial Ethernet Technologies

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

Most Rockwell Ethernet/IP devices support up to 64 TCP connections, the number of CIP connections differs from device to device (e.g. 1756-ENBT: 128 CIP connections, from which 32 can be end-node 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).

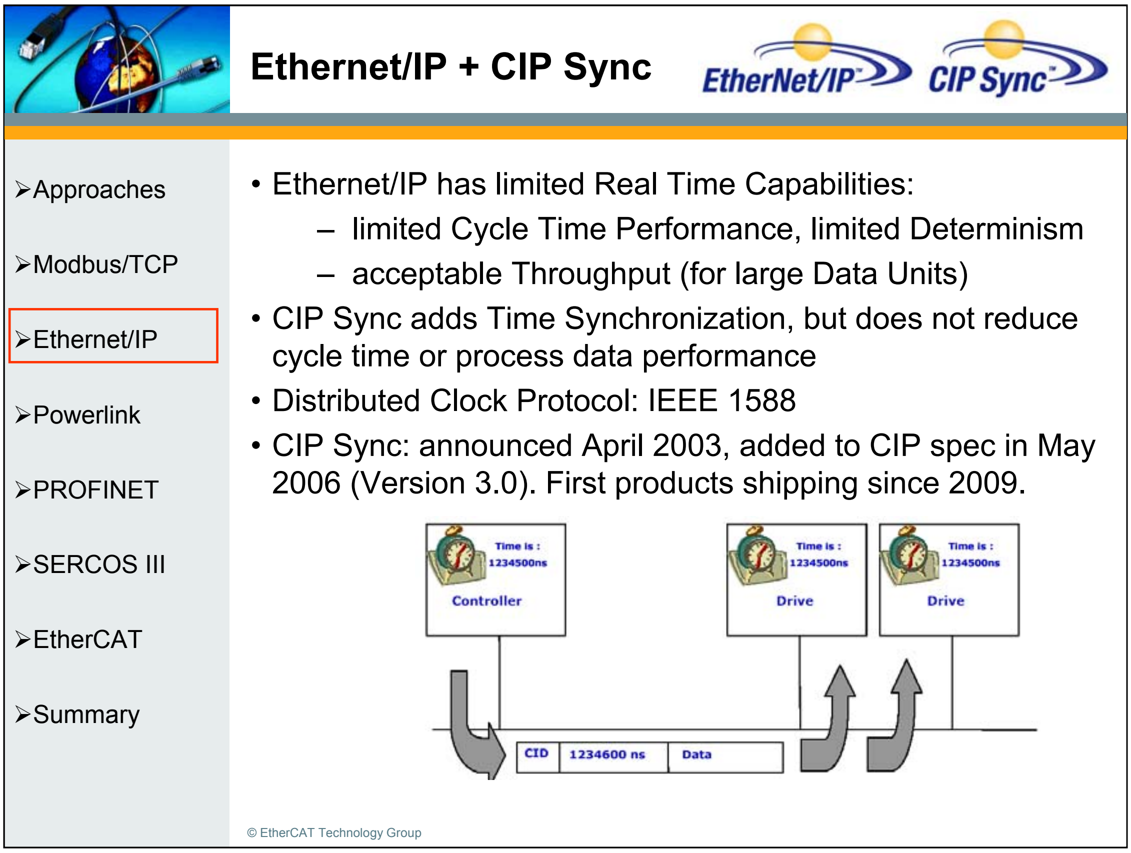
The Rockwell Automation (RA) publication „Ethernet/IP Performance“ (ENET-AP001D-EN-P, released October 2004, according to RA website still valid in Jan 2011) shows the complex process of how to predict the network performance. For an example system with just 5 I/O stations and two scanner cards in the host controller the maximum input delay was calculated with 32.5ms.

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 latest Rockwell Ethernet/IP scanner card generation supports up to 10.000 frames/second. 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 release notes (Publication 1756-RN591Q-EN-P - January 2008) of the Standard Contrologix Ethernet IP Bridge (1756-ENBT) 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.*



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.

What is IEEE 1588

CIP Sync

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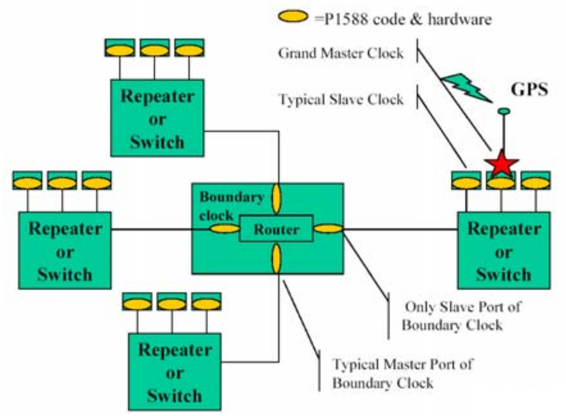
- A method for precision time synchronisation tailored to requirements of distributed measurement and control systems. Widely independent of transport protocol.
- 1588 on Ethernet: Version 1 (2002) based on UDP/IP, Version 2 (2008) also with direct Ethernet (Layer2) option



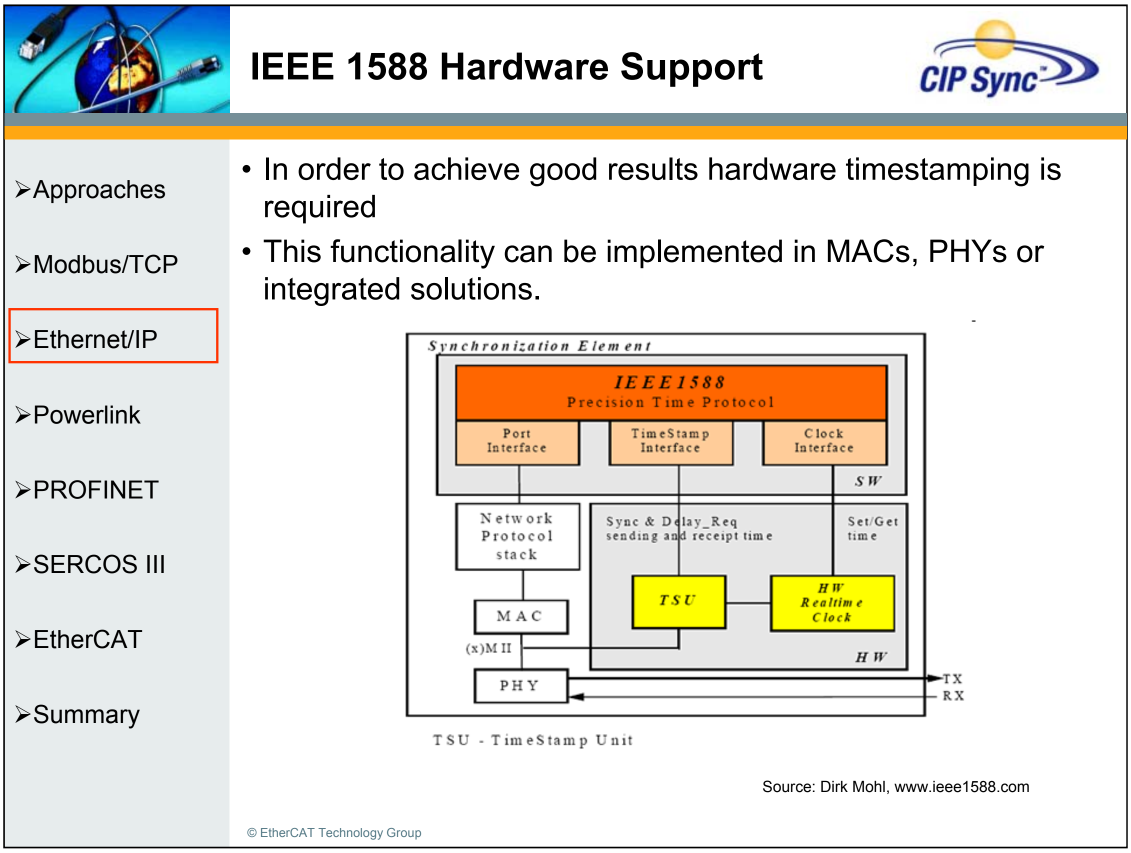
Source: introduction_to_1588.pdf by IEEE

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.

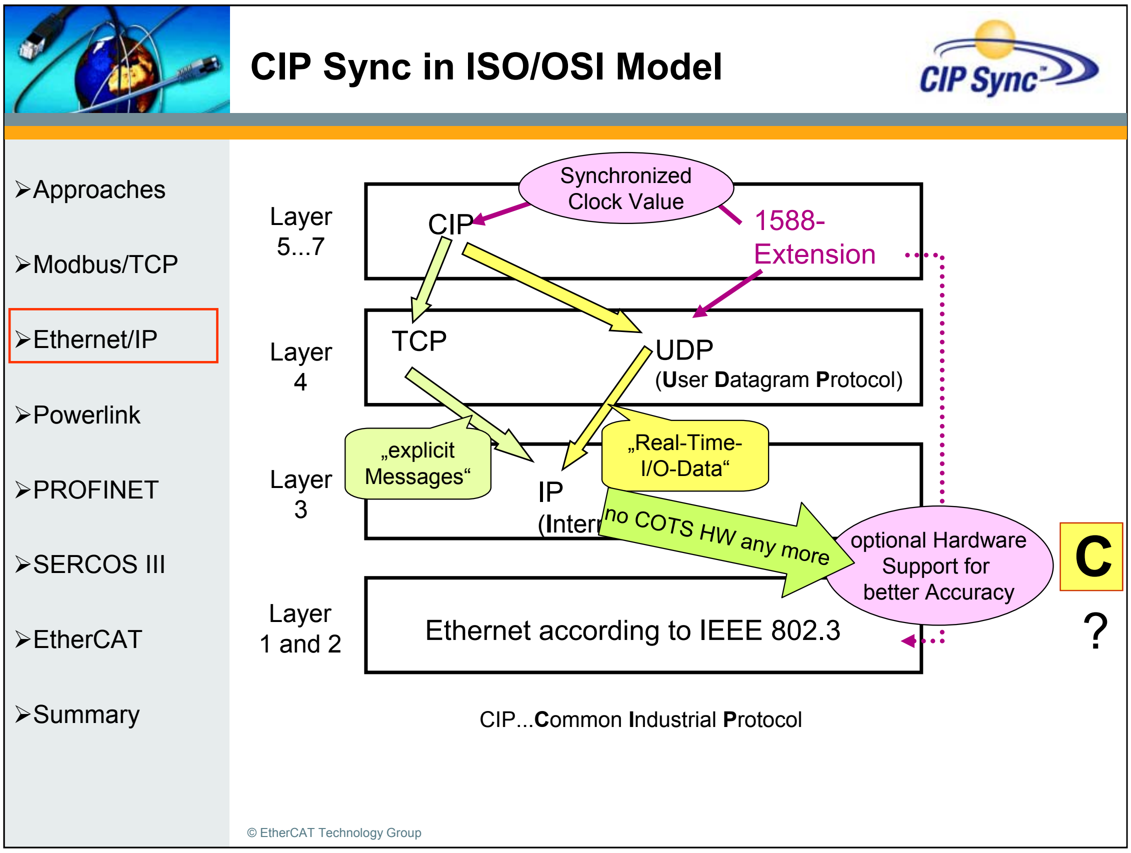
The first version of IEEE1588 was published in November 2002. Version 2 (IEEE 1588-2008) followed in March 2008 and added various features, including the layer 2 transport option (embedded in the Ethernet frame without UPD/IP) and the "transparent clock" approach which improves the accuracy for linear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

Ethernet/IP + CIP Sync

- ➢Approaches
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- ➢PROFINET
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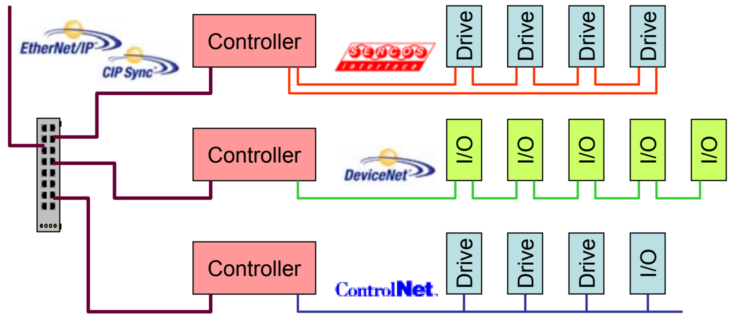
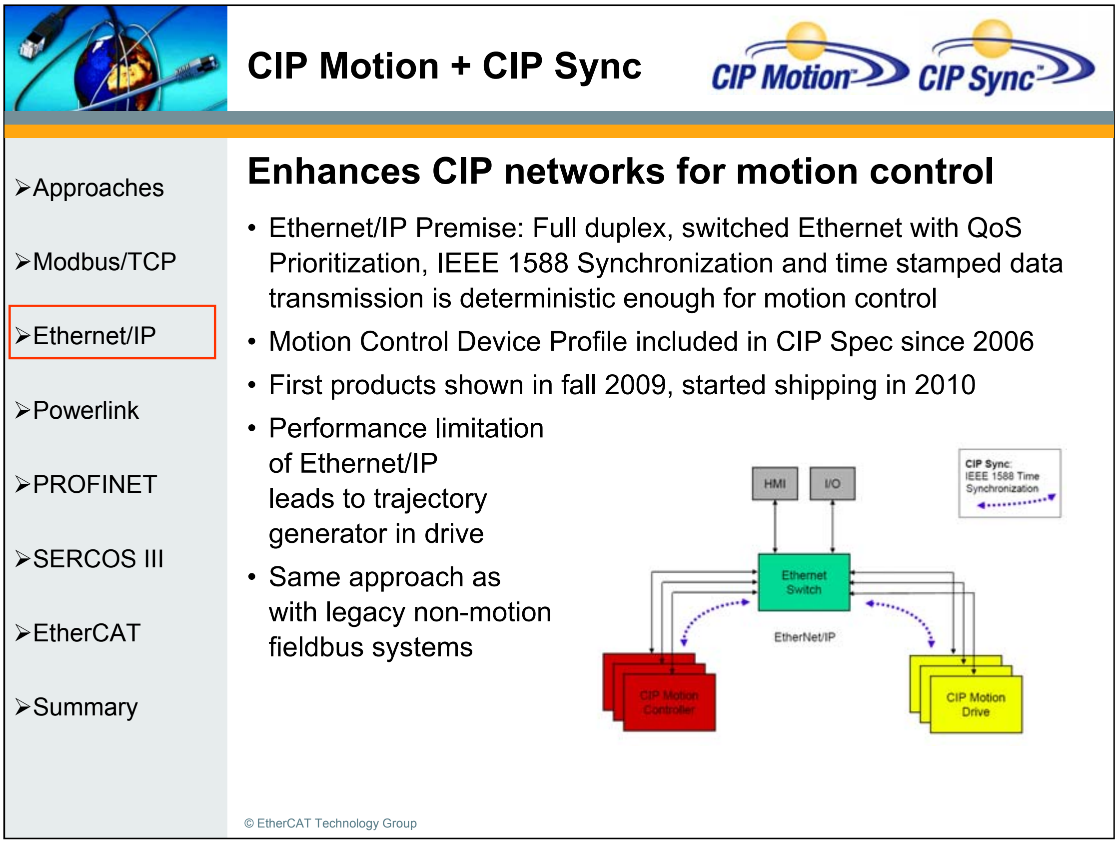
Best suited and typically used as Controller to Controller network

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



Example Ethernet/IP Network

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

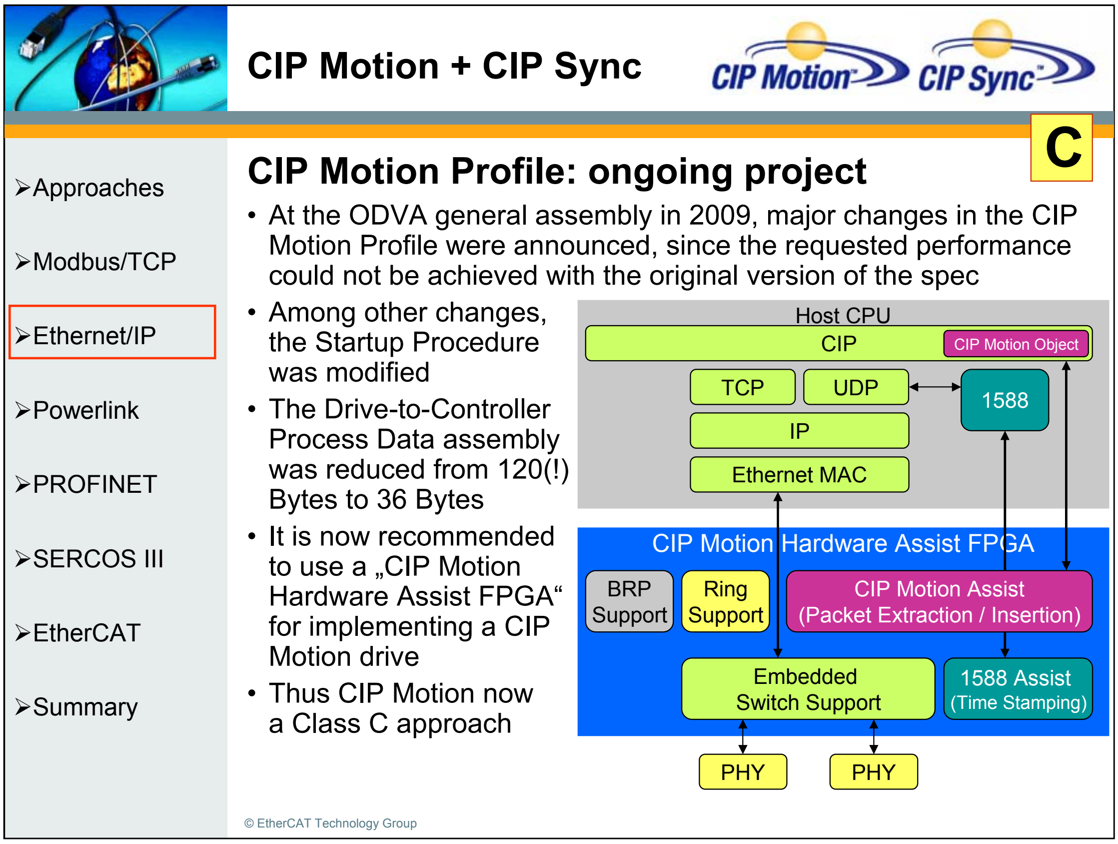
Timely Data Transfer: The goal is to use standard Mechanisms to ensure this:
- Full-Duplex 100-BaseT or 100BaseF “Fast” Ethernet.
- Ethernet switches to eliminate collisions.
- QoS frame prioritization to eliminate queuing delays

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.

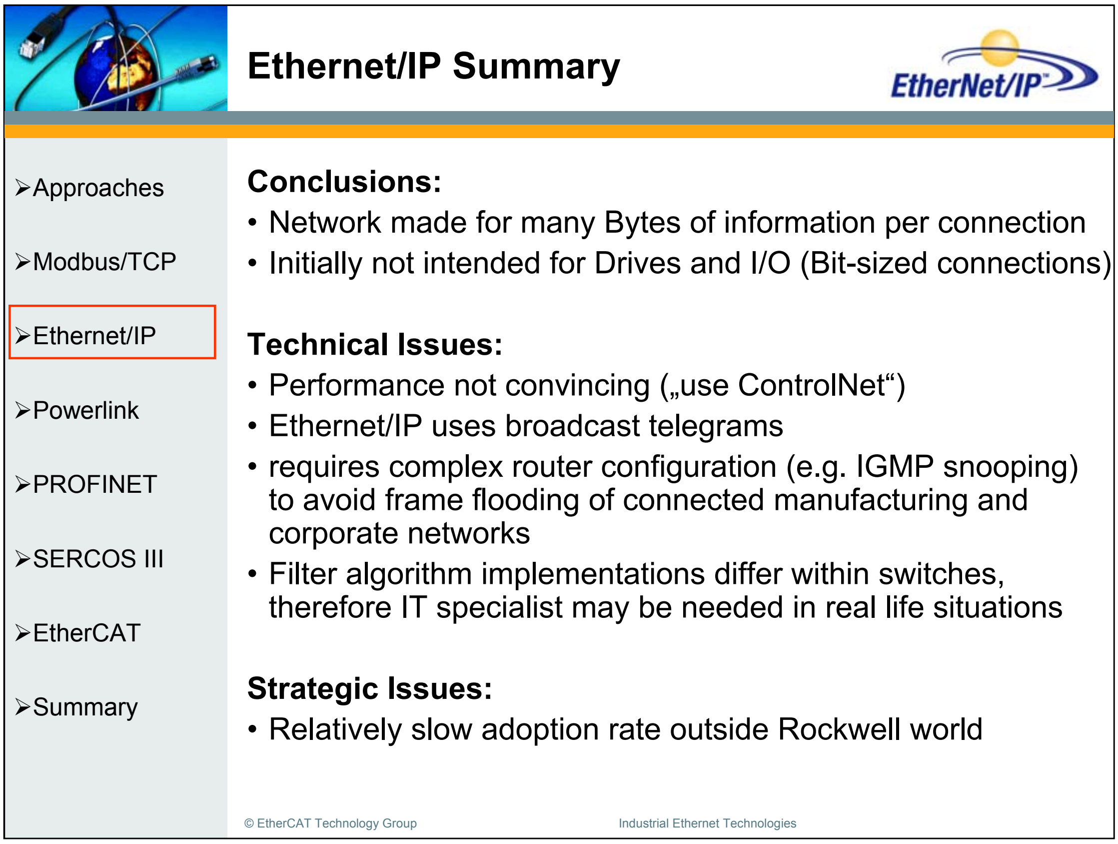
Introducing CIP Motion products implies that Rockwell – a Sercos vendor in the past – has turned down Sercos-III and tries to push an own motion bus approach.



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



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

Adoption rate: as of January 2011, more than 11 years after publication of the spec, the ODVA website listed 89 "non Rockwell"- product guide entries (130 altogether), out of which 27 are switches, cables and connectors.

For comparison: 6 years after publication of the spec, the EtherCAT (ETG) website lists 231 "non-Beckhoff" product guide entries (268 altogether, 14 switch, media converter, cable and connector entries).

Powerlink: Overview

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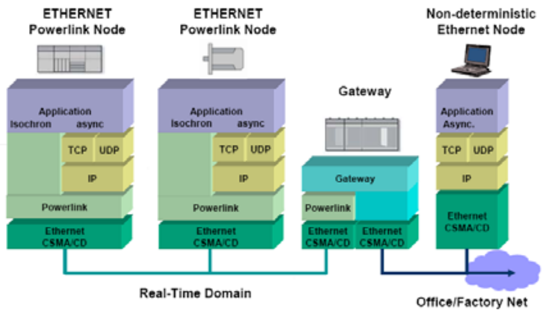
B

- Ethernet Approach originally introduced by B+R
- Medium Access Control by Polling (similar to Profibus)
- TCP/IP for Parameters, seperate Process Data Protocol
- uses Hubs
- active Master Plug-in-Card required, no Standard NICs
- soft realtime („open“) mode initially announced for 2005



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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 (according to Intel) of ~7,5µs. 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: Functional Principle

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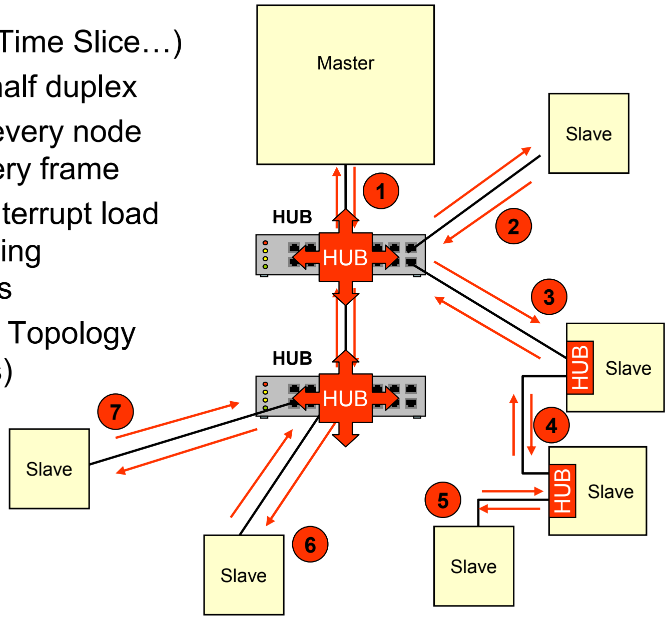
- Polling (Marketing: Time Slice…)
- Hubs only, half duplex
- Broadcast: every node receives every frame
- Thus high Interrupt load and processing requirements
- Limited Line Topology (Hub Delays)



 Industrial Ethernet Technologies

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

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

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

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

Powerlink Timing

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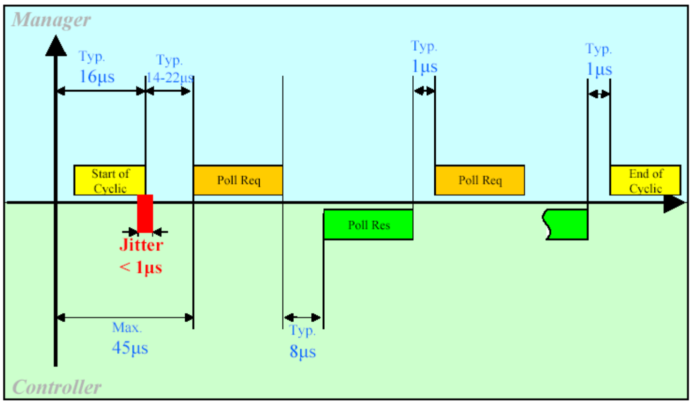
- Overall Network Performance depends on Slave Implementation:
- Fast response time requires powerful processors on the slave (controller) side – or implementation in Hardware (FPGA)
- A lot of „idle time" on the media



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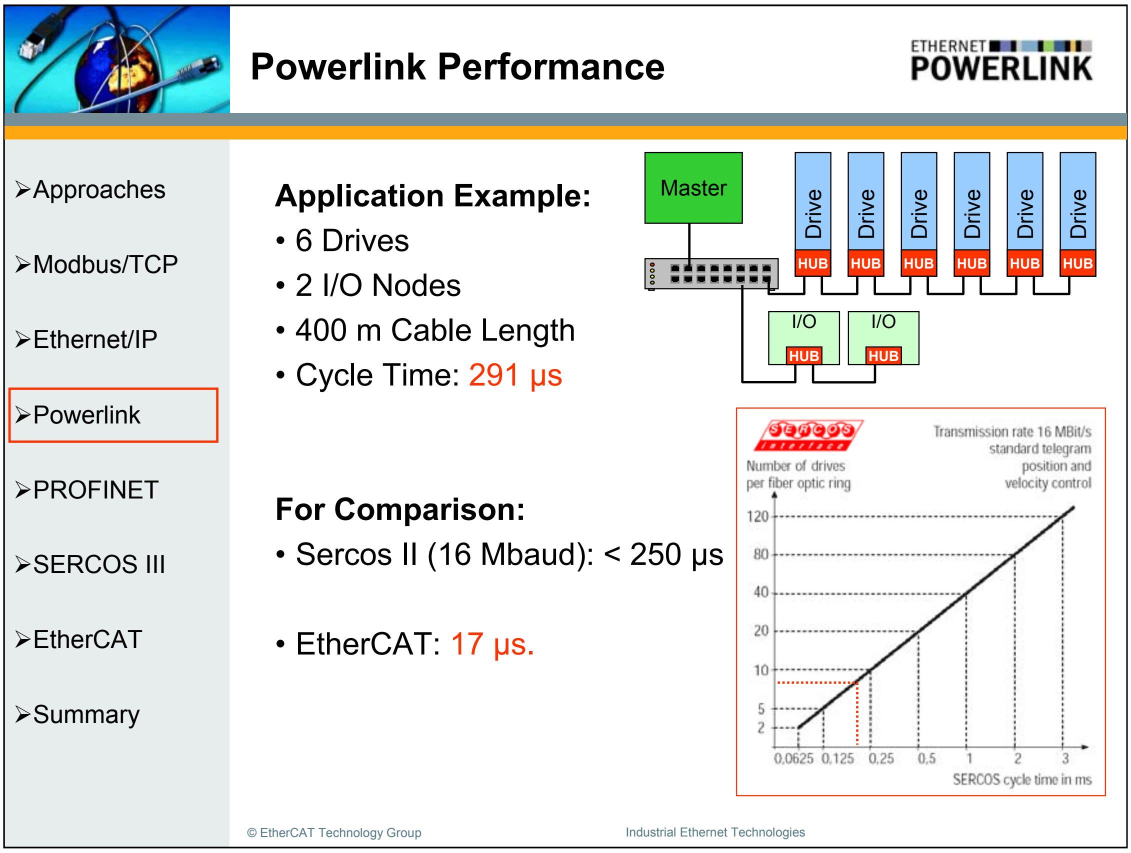
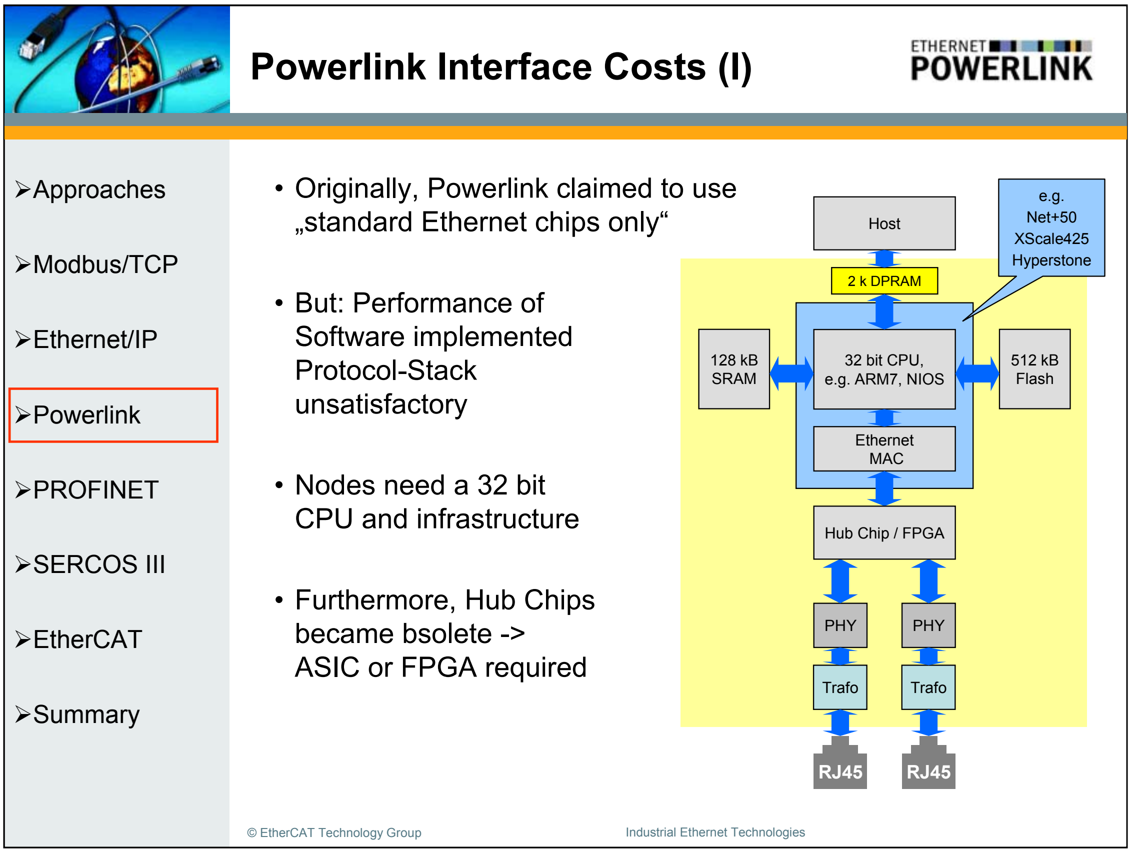
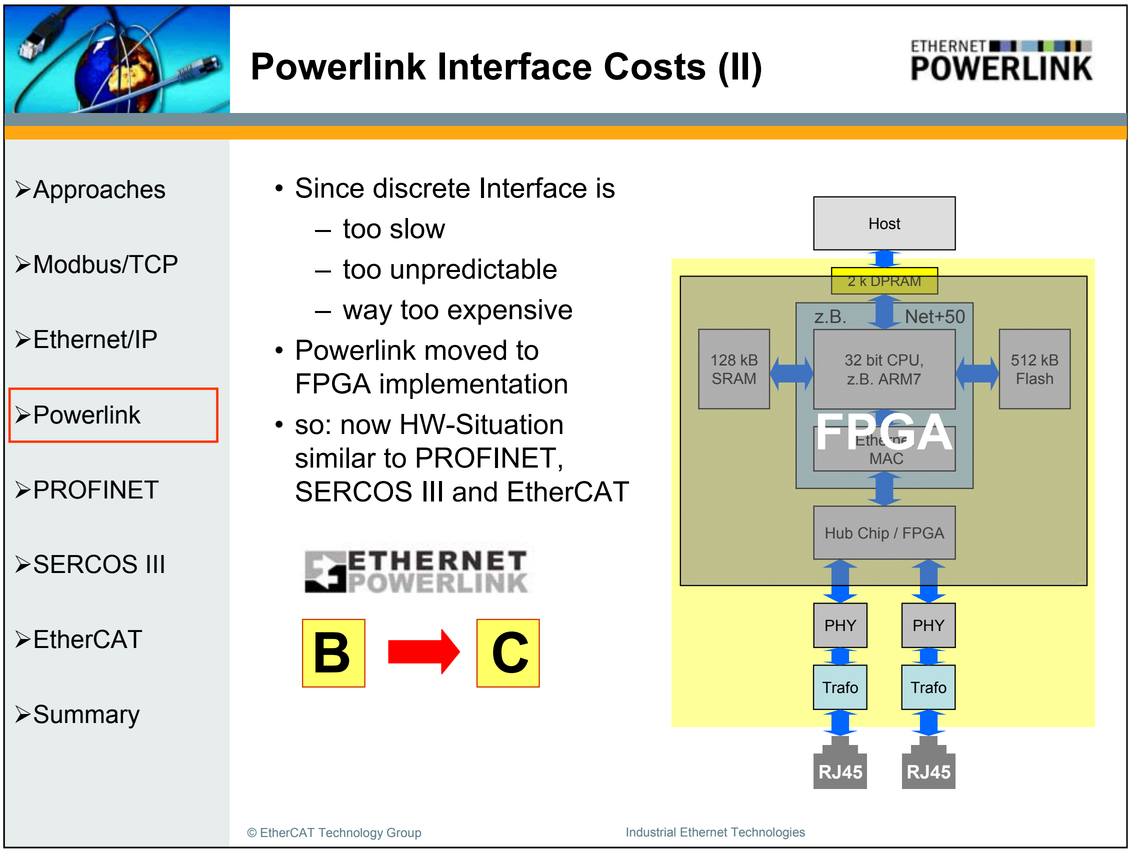
The diagram is misleading: A typical poll response (up to 46 Bytes of data) is 7µs and thus shorter than the typical response delay time of a slave device. Or, in other words, the idle time on the half duplex media is even longer than indicated.



The performance examples are taken from the Powerlink spec Version 2. There a Powerlink slave response time of 8µs and a master response time of 1(!) µs are assumed.



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 has announced 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

Powerlink: Versions

ETHERNET POWERLINK

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

Network 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 Ethernet Based** • **IEEE1588 synchronization**	**Spec: started in 2009** • **Devices Shipping: 2011?**

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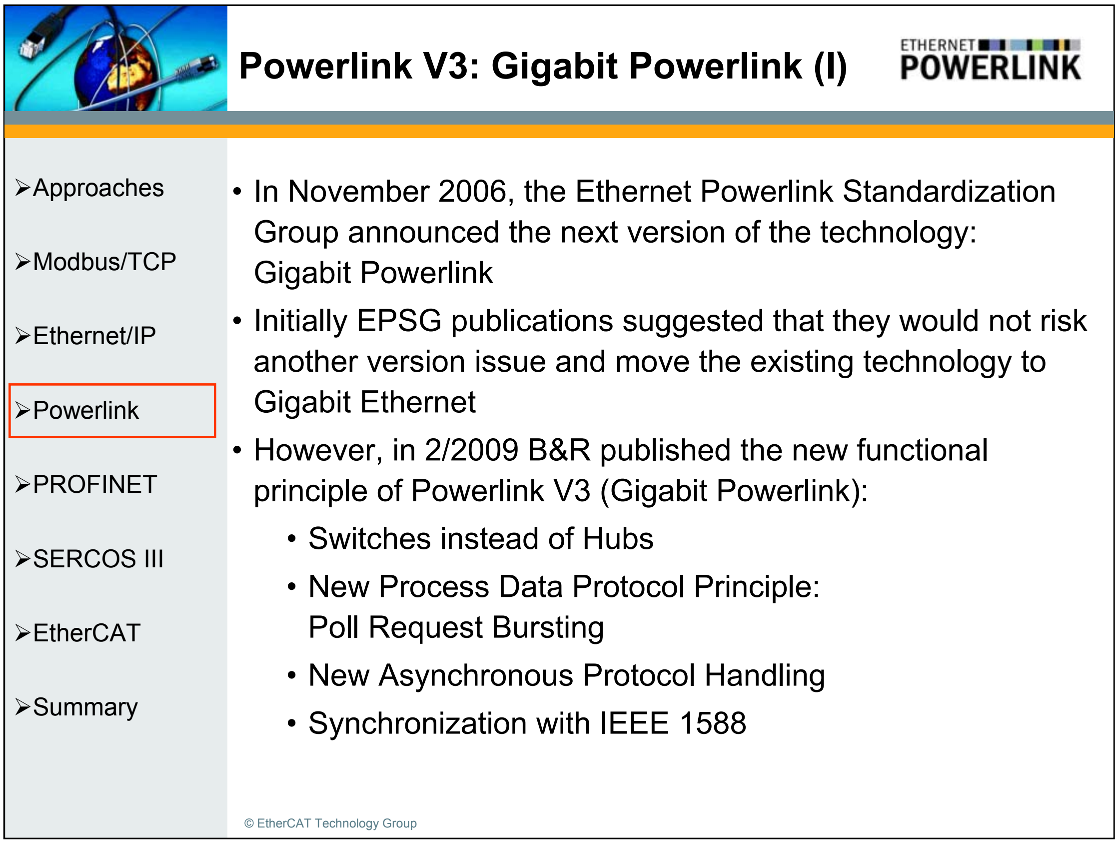
Powerlink Version 1 products are available from B&R only.

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 selected EtherCAT as system bus (Powerlink remains 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. As of Jan 2011, no Gigabit Powerlink specification has been published (neither within EPSG nor externally), but in 2009 there has been an article describing the functional principle (see next slides).

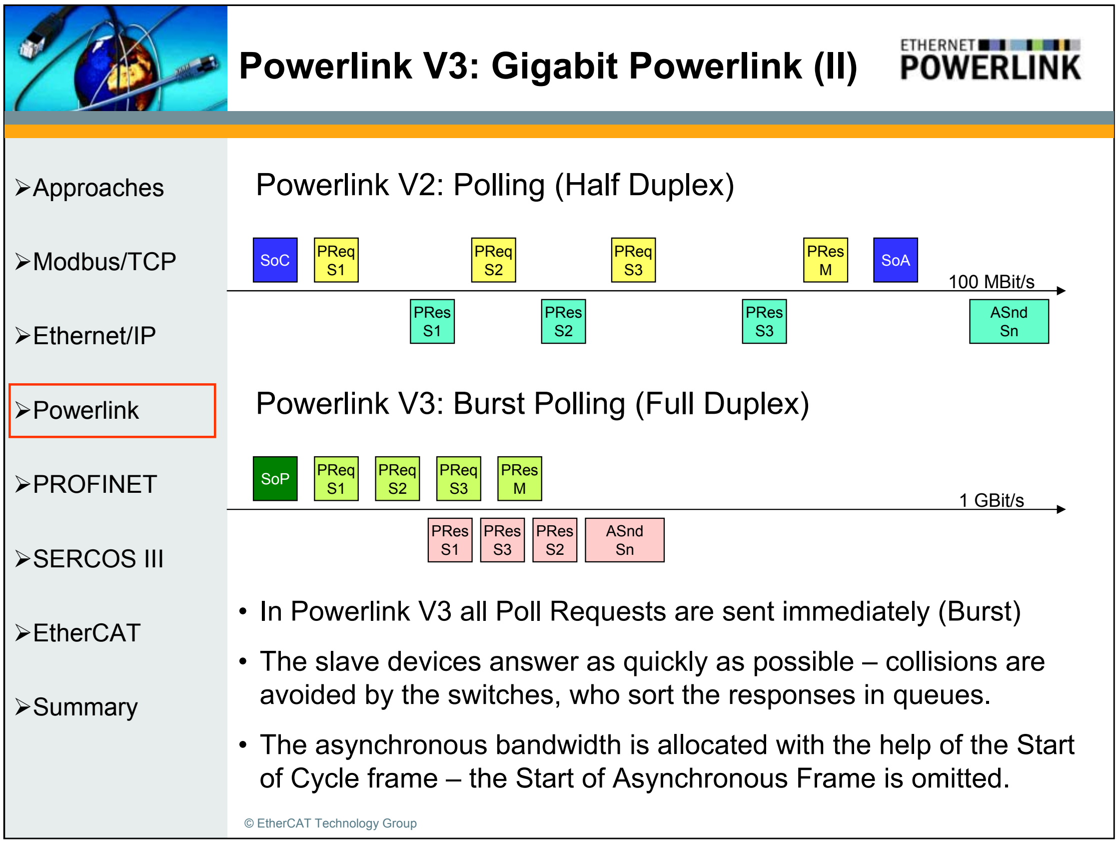


In November 2006, EPSG announced Gbit Powerlink as a simple hardware modification (Quote from Powerlink "Facts" 1/2007: "*POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer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

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

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

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



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

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

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

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

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

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

Powerlink V3: Gigabit Powerlink (III)

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Another incompatible Powerlink Version
- Resulting Cycle Time difficult to determine - depends on topology, switch performance and slave implementation
- Synchronization requires Switches with 1588 Support
- Gigabit issues remain:
  - 8 instead of 4 Wires (Field Mounting?)
  - Power consumption significantly higher (PHY + MAC)
  - Hardly any experience with Gbit inside machine control environments
- First products announced by B&R for 2011
- Functional Principle was introduced in 2001 by Beckhoff („RT-Ethernet" – a predecessor of EtherCAT)

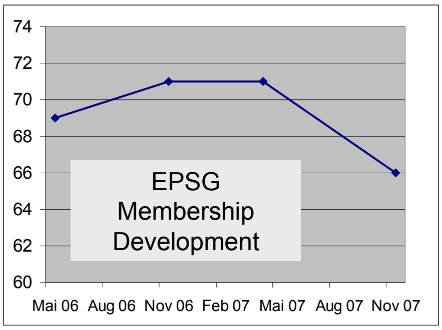
According to a B&R customer presentation (July 2008), the R&D phase for Powerlink V3 (Gigabit Powerlink) products is scheduled for 2009/2010, and first products are planned for 2011.

In Gigabit mode, MACs and PHYs consumer about 6 times as much power as in 100 Mbit mode – a challenge for small field devices.

Ethernet Powerlink Standardization Group

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



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

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, whilst ETG has adopted the philosophy that charging for access to a technology is not a sign of openness.

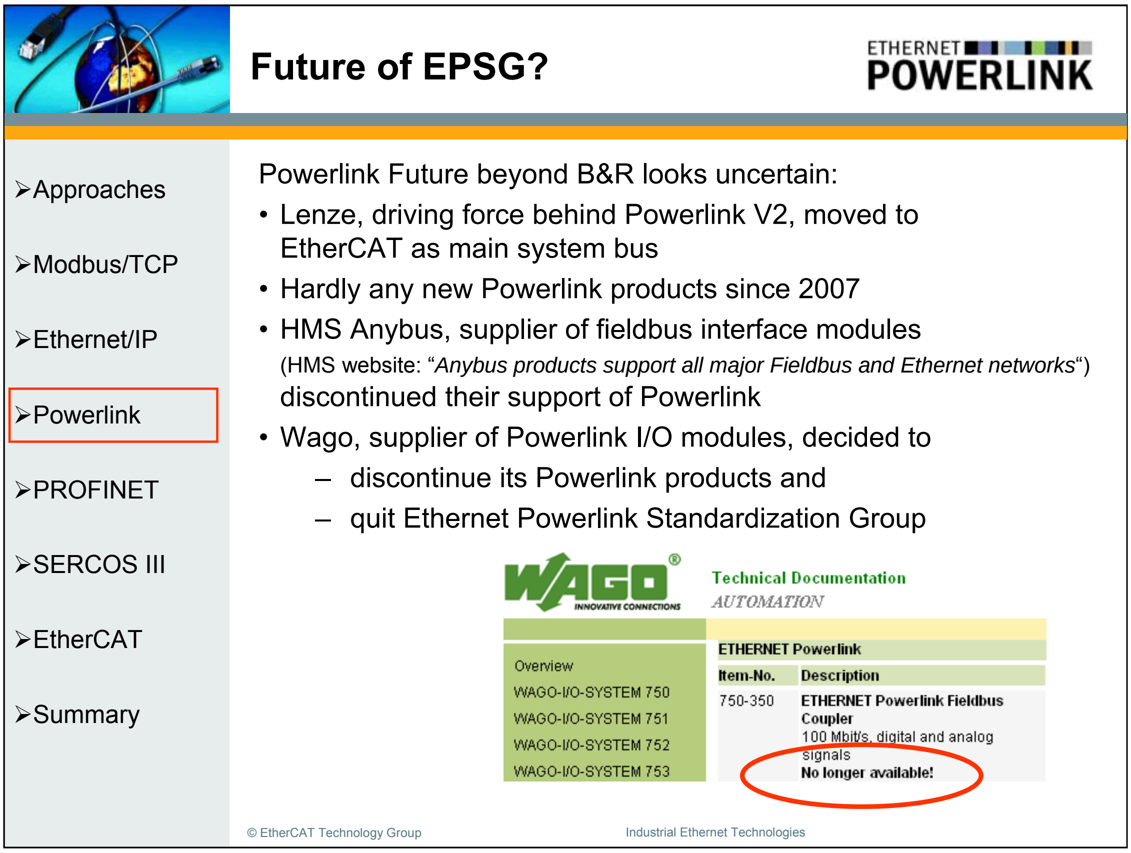
Therefore in small print: (Between 5/2006 and 11/2007, ETG grew from 315 to 634 members, exceeding 1500 members in Nov 2010).

The figures discussed above were taken from the EPSG publication “Powerlink Facts”, which 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.

According to EPSG website, one company (Yacoub Automation) joined EPSG in Nov 2007, another one (Kalycito) in April 2008, Yaskawa joined in July 2009 and Xilinx in Oct 2010. The website does not list those companies that have left EPSG since 2007, such as e.g. Wago.

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 01/2011, the website lists 144 “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.



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).

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

Powerlink Safety: History

ETHERNET POWERLINK

➢Approaches
➢Modbus/TCP
➢Ethernet/IP
➢Powerlink
➢PROFINET
➢SERCOS III
➢EtherCAT
➢Summary

- Development of Powerlink Safety was started in 2003
- In 2004 EPSG denied to make available the Powerlink Safety Protocol for other Ethernet Technologies
- Availability of Powerlink Safety Products was announced in 2007
- First Certified Powerlink Safety Products by B&R in 2009
- IXXAT/B&R publish BSD-licensed Powerlink Safety stack in 2009
  - As of 6/2010, documentation available in German, only
  - IXXAT offers technical support within the scope of an extra charged maintenance contract
- In April 2010, EPSG turns Powerlink Safety into “openSAFETY”, claiming it to be “The first open and bus-independent safety standard for all Industrial Ethernet solutions”.

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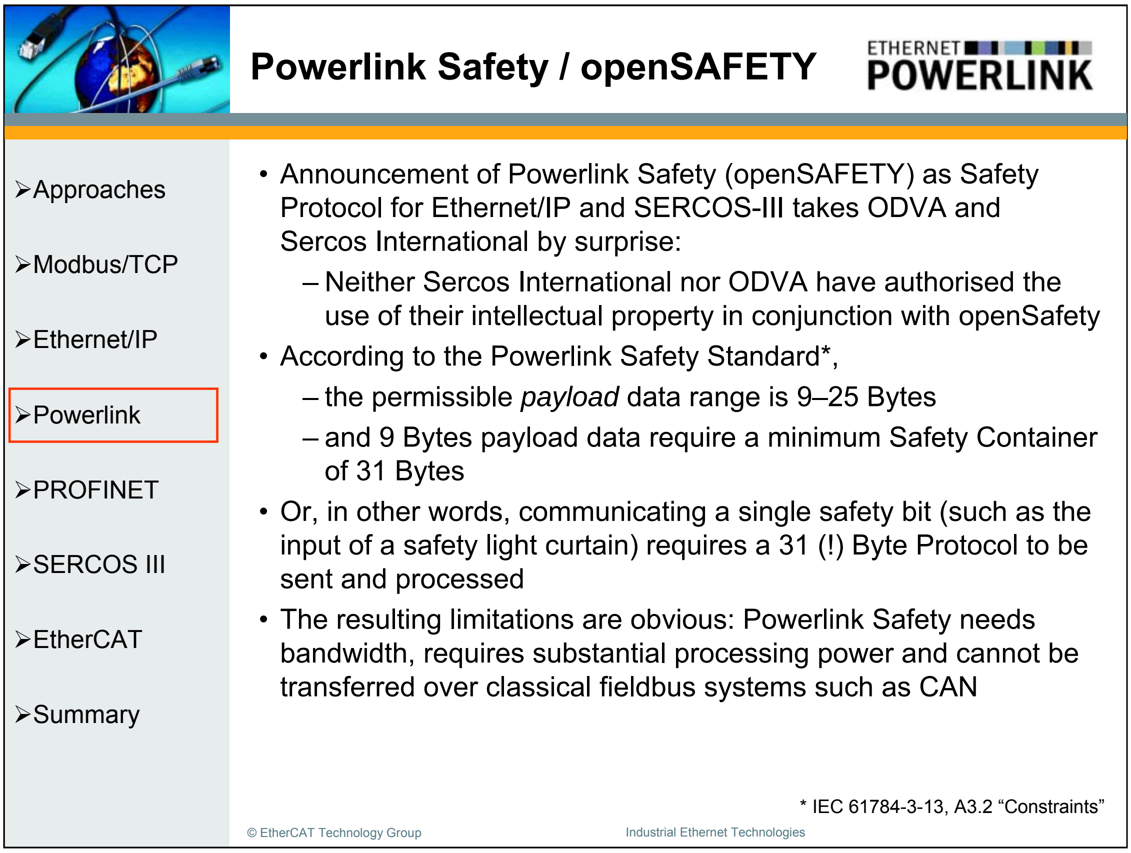
- In 2004 IAONA asked EPSG to make available Powerlink Safety for other Ethernet Technologies; this was turned down by EPSG.
- Also in 2004, innotec GmbH (a German Safety Consultancy company) filed several patents regarding Powerlink Safety / openSAFETY. These were granted in 2006.
- If the BSD-licensed safety stack is modified, the certification has to be started from scratch.



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. “*

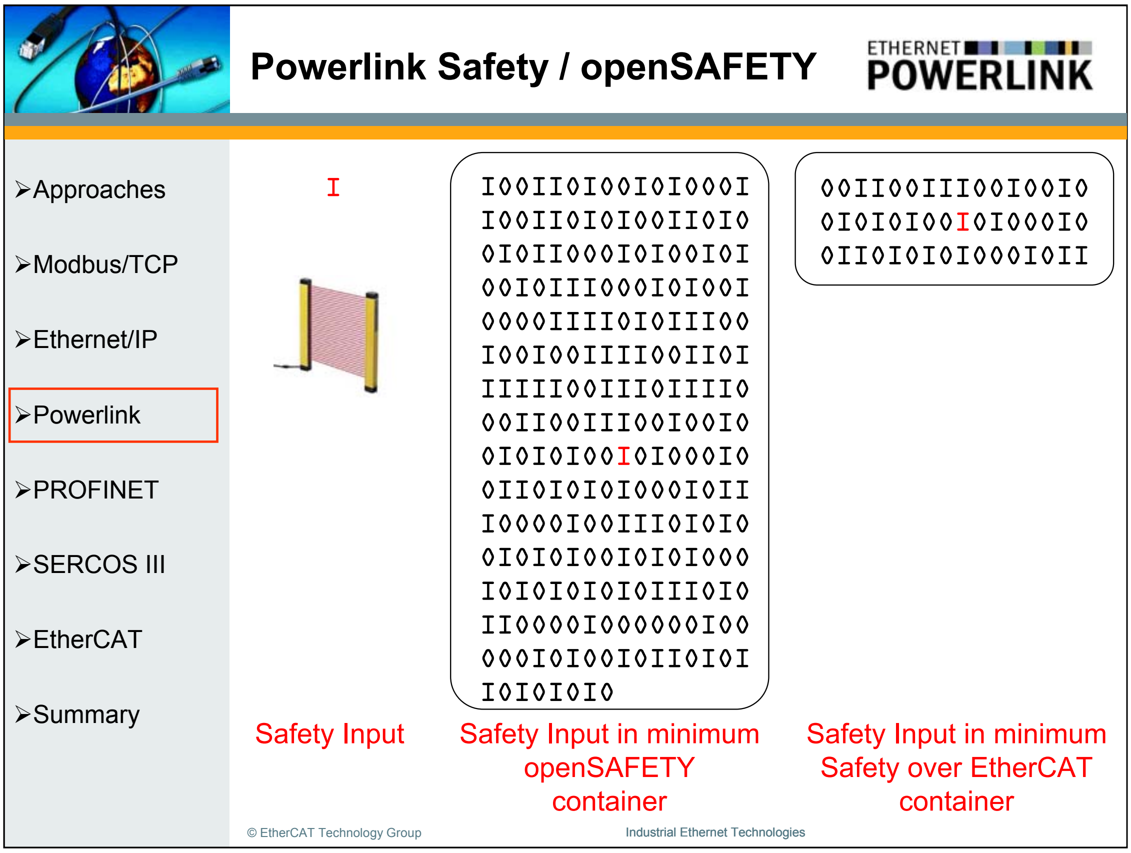
Statement# of Peter Lutz, Managing Director Sercos International: *“We were surprised by the unauthorized usage of our registered Sercos trademark in publications and displays on the Ethernet Powerlink Standardization Group (EPSG) booth at Hannover fair. This might imply that the announced concept and 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.

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.

Statements quoted from: Industrial Ethernet Book Issue 58



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

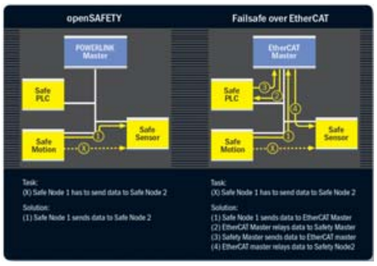
Powerlink Safety:	31 Bytes
Safety over EtherCAT:	6 Byte

Powerlink Safety / openSAFETY

ETHERNET POWERLINK

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



This comparison is misleading, since

- In most safety architectures the safe PLC is not bypassed (as shown in the openSAFETY example)
- If such an architecture is chosen, the network management configuration effort and the resulting traffic is enormous, since the actuators and the safe PLC have to independently monitor all safety communication links with cyclic frames
- The safety stack performance (30 byte minimum container size!) is not taken into account
- EtherCAT cycles are much faster than Powerlink cycles
- Last but not least: decentralized safe PLC is optional

 Industrial Ethernet Technologies

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.

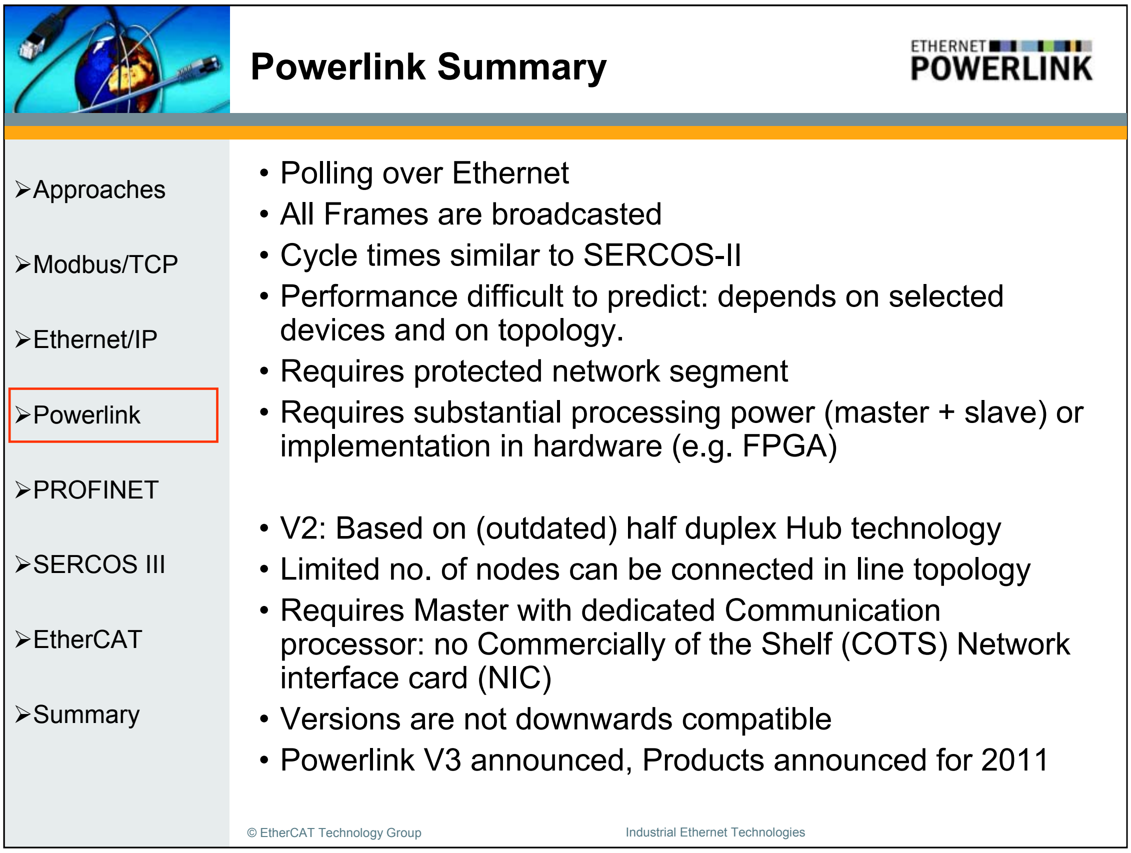
Example: 10 Emergency stop buttons acting on 10 drives

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.



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:

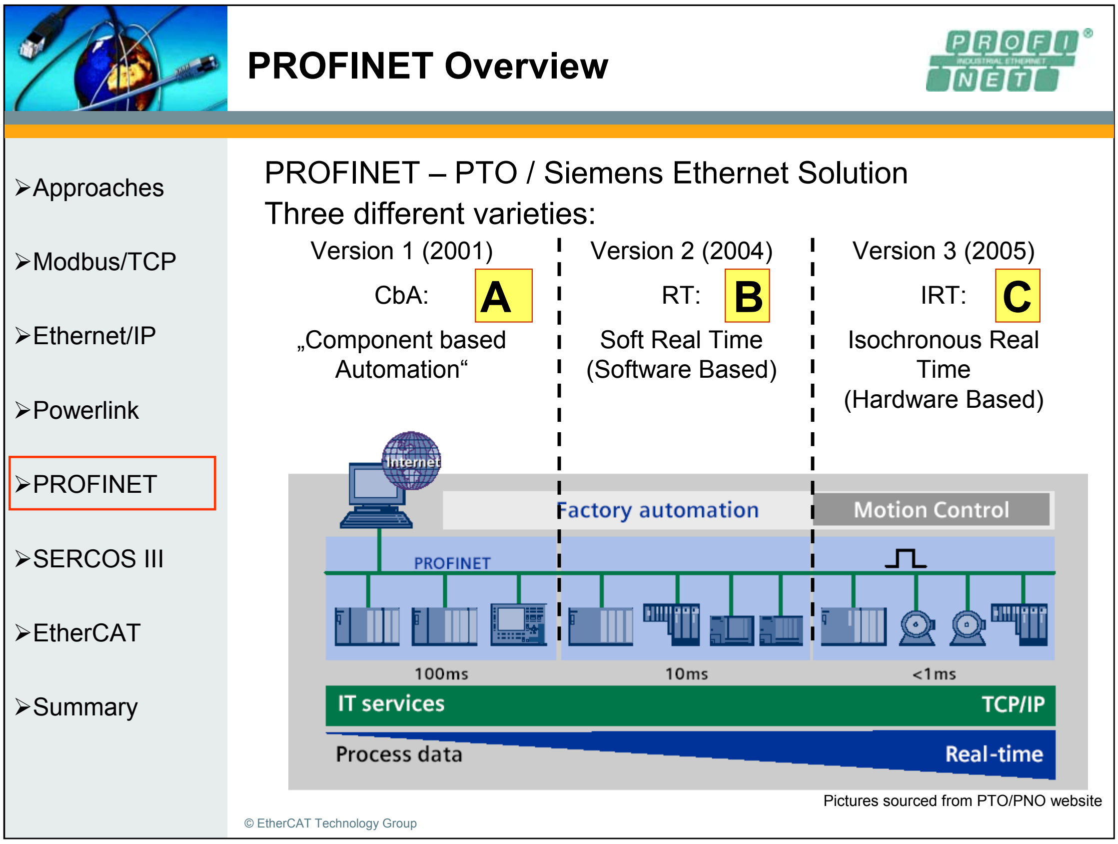
- if implemented with standard components: processor performance, software stack implementation quality, varying local CPU load due to application etc.

- 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.



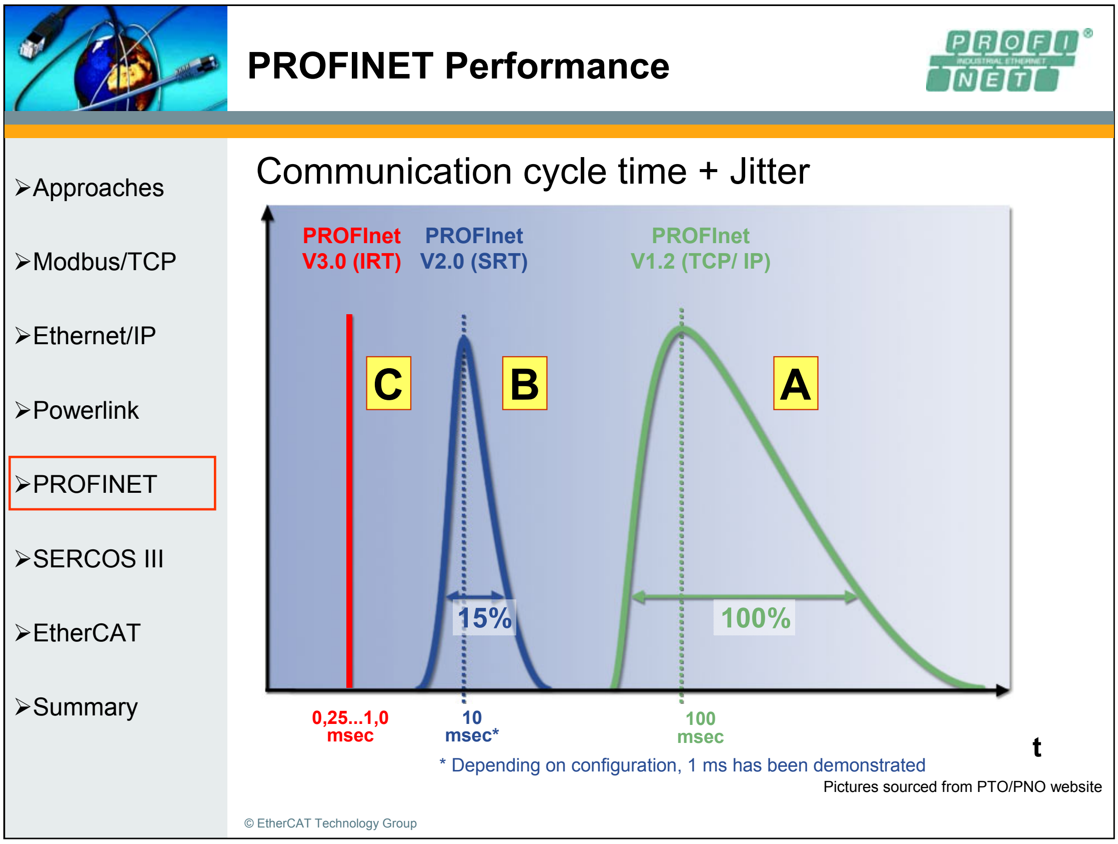
There are 3 PROFINET-Versions:

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

PNO tries to move away from the terms RT/IRT and introduced the term Profinet IO for both approaches…



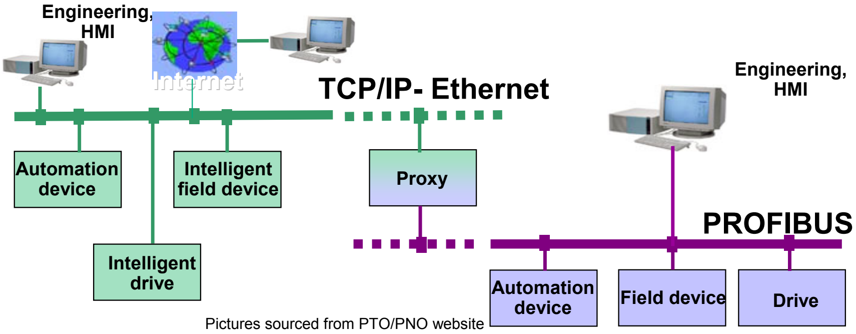
The cycle time range 0.25…1ms for IRT is misleading. Many IRT devices do not support cycle times < 1 ms.

PROFINET V1 (CbA)

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

A

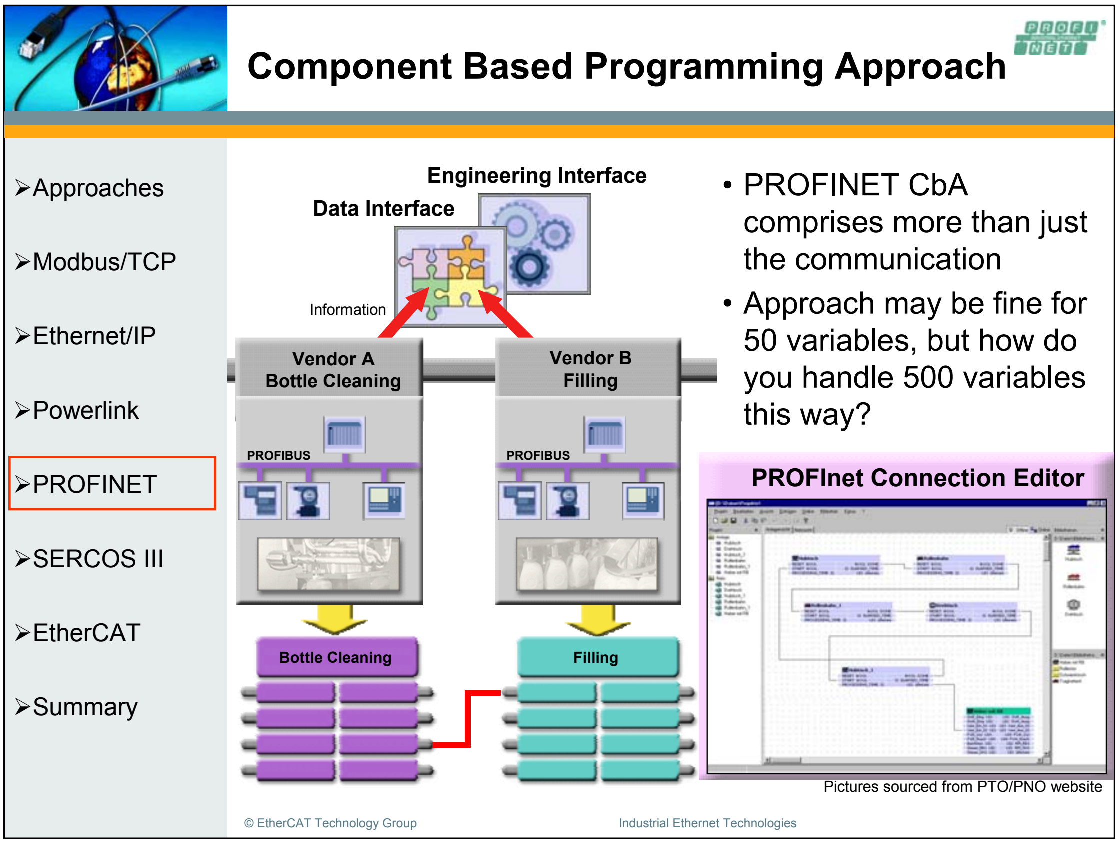
- Initial Profibus Answer to the Ethernet Hype: Profinet V1
- Remote Procedure Calls on TCP/IP originally using DCOM
- Access to Profibus Networks via Proxy Devices
- For Parameter Data only, not for Process Data
- since DCOM will not be advanced by Microsoft any more, Profinet CbA V2 has SRT Protocol Adaptation
- few known Products.



Pictures sourced from PTO/PNO website

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).



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 (RT)

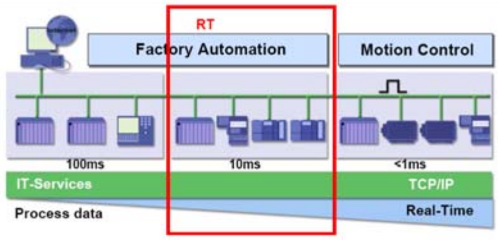
- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

B

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

Limitations:

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



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

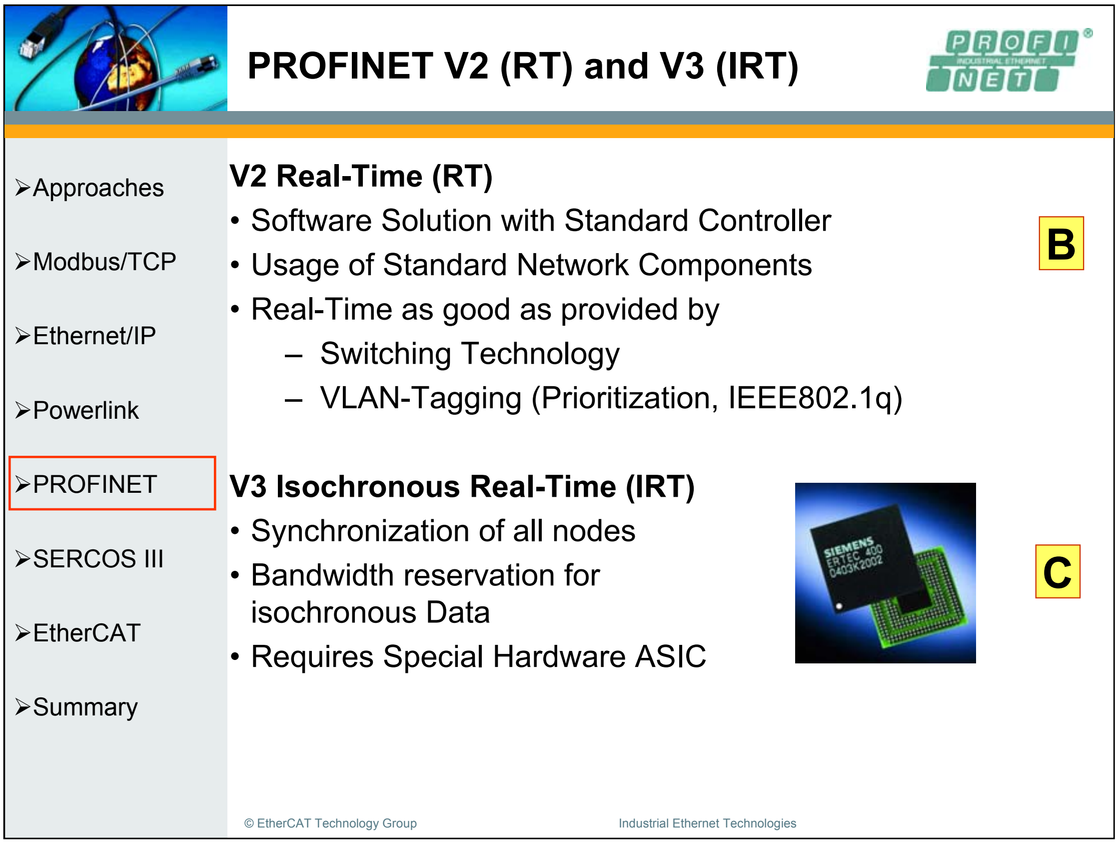
Pictures sourced from PTO/PNO website

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

Profinet RT is also addressed as Profinet I/O (together with IRT).

Siemens has started to communicate that Profinet RT will provide similar performance as 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 ;-)



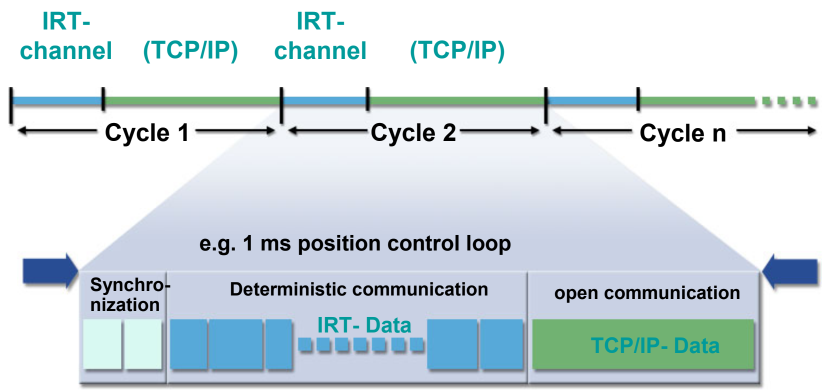
Profinet IRT is a class C approach which introduces special hardware in order to achieve sufficient performance and synchronicity for motion control applications.

PROFINET V3 (IRT) Features

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

C

- Timeslicing Approach by special Switch ASICs
- Switches can be integrated into devices
- Topologies: Line (up to 25 nodes), Branch, Tree supported
- Cycle Time 250 µs to 4 ms, 1 µs jitter



Pictures sourced from PTO/PNO website

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.

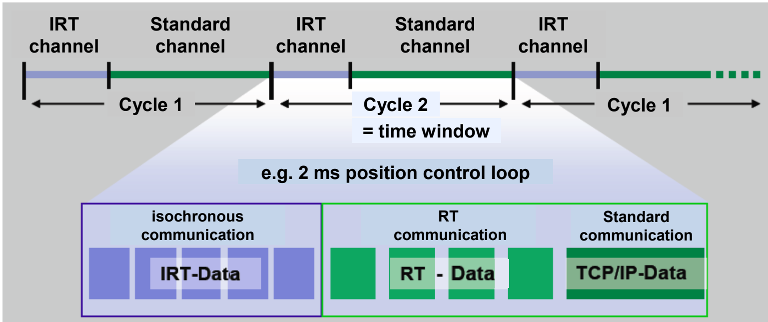
This approach leads to limited bandwidth utilization, since even though most applications only have sporadic TCP/IP communication, the bandwidth remains reserved for this kind of traffic.

Even though the specification allows for cycle times starting from 250µs, most Siemens IRT master devices only support cycle times starting from 500 µs.

PROFINET V2 (RT) and V3 (IRT)

➢Approaches
➢Modbus/TCP
➢Ethernet/IP
➢Powerlink
➢PROFINET
➢SERCOS III
➢EtherCAT
➢Summary

Both versions can be mixed, if
- supported by master
- only IRT switches are used
- enough bandwidth available



 Industrial Ethernet Technologies

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

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

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

* Source: Siemens Profinet System Description, page 153, "Setting up Profinet with IRT", 07/2010, A5E00298288-05

PROFINET IRT System Planning (I)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

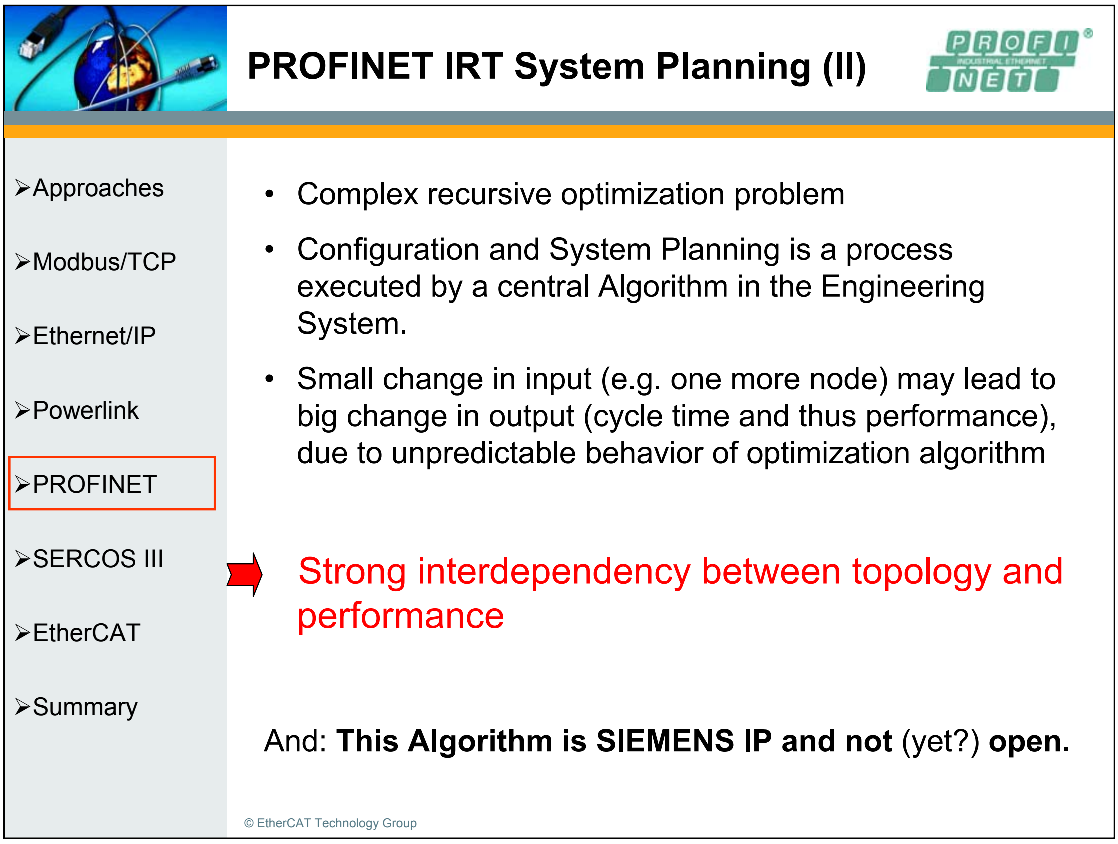
Input for planning/configuration of the network:

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

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

- Ports and exact transfer time timing for each frame

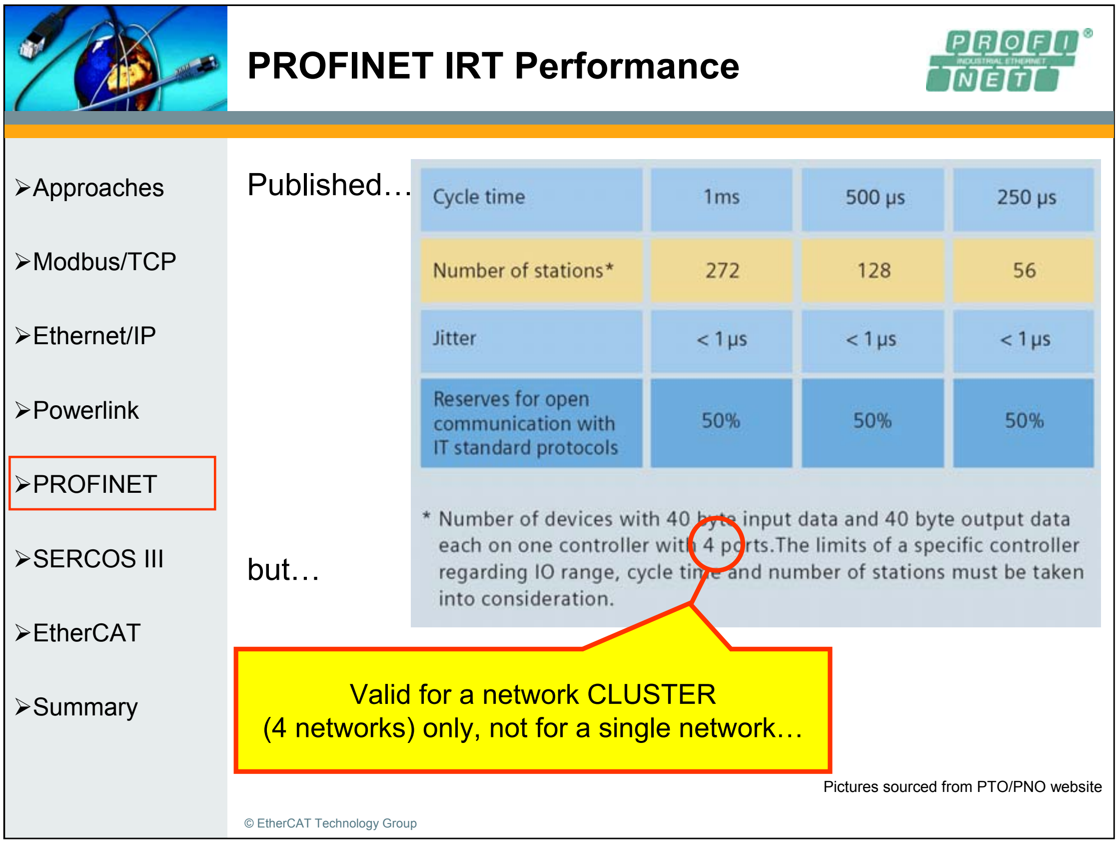
Besides hardware costs, the crucial issue of Profinet IRT is the complex system planning.



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.

To our best knowledge the planning algorithm itself is not open. However, Siemens apparently is prepared to make available parts of its configuration tool in dll format.

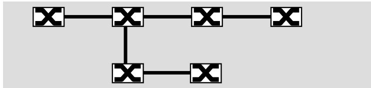


For several years, this was the performance data table published for Profinet IRT. Unfortunately, the table is valid only for a cluster of networks: 150 nodes sharing 50% bandwidth at 1ms cycle time means 500 µs / 150 = 3,33 µs per node. The shortest Ethernet frame takes 7µs to transmit.

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

IRT Topology – and some conclusions

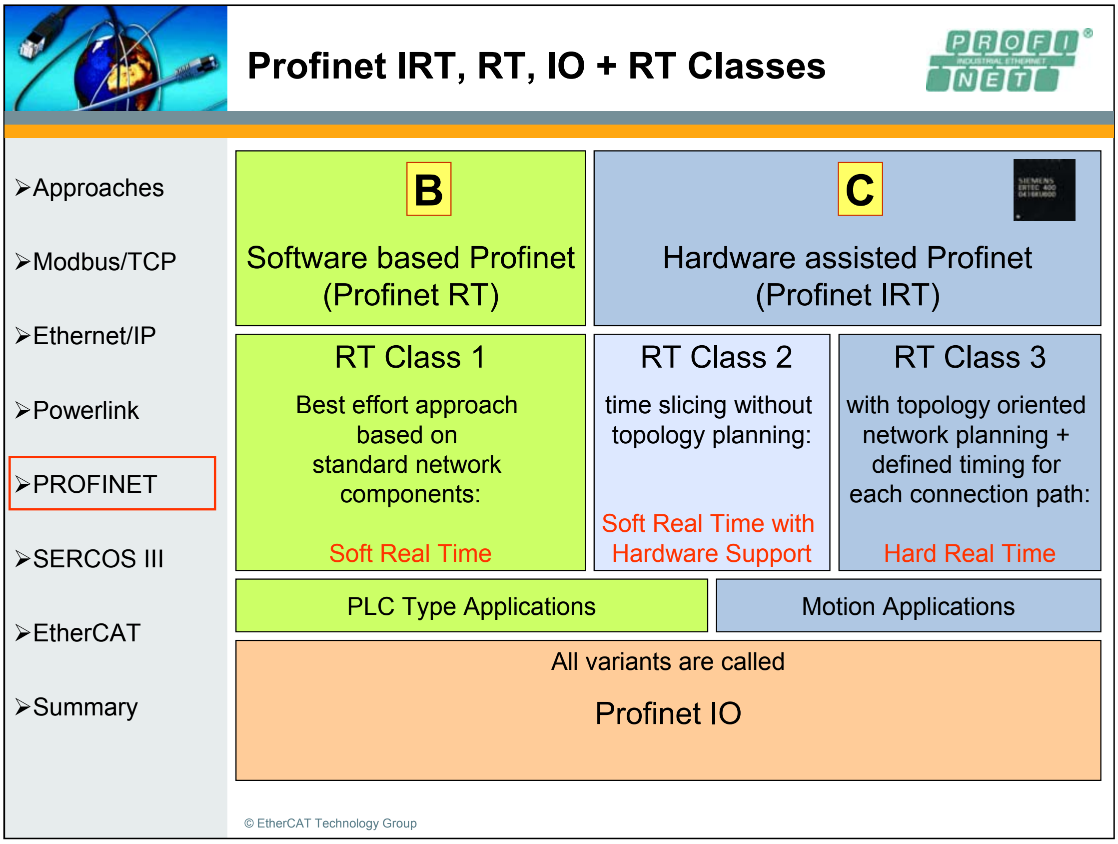
- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary



- Line, Branch, Tree Topology is supported
- Cascading of switches in a line has limit of 20 - 25 devices
- → this means: branch/star topology is the common design, whether desired or not
- For any installation with more than 20 - 25 devices, network branches are required
- The network topology layout requires a top-down approach
- The planning process will mandate the layout and wiring of a configuration
- performance data is true for a specific topology ONLY
- Topology restrictions apply when designing a network with a required performance

Pictures sourced from PTO/PNO website

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.

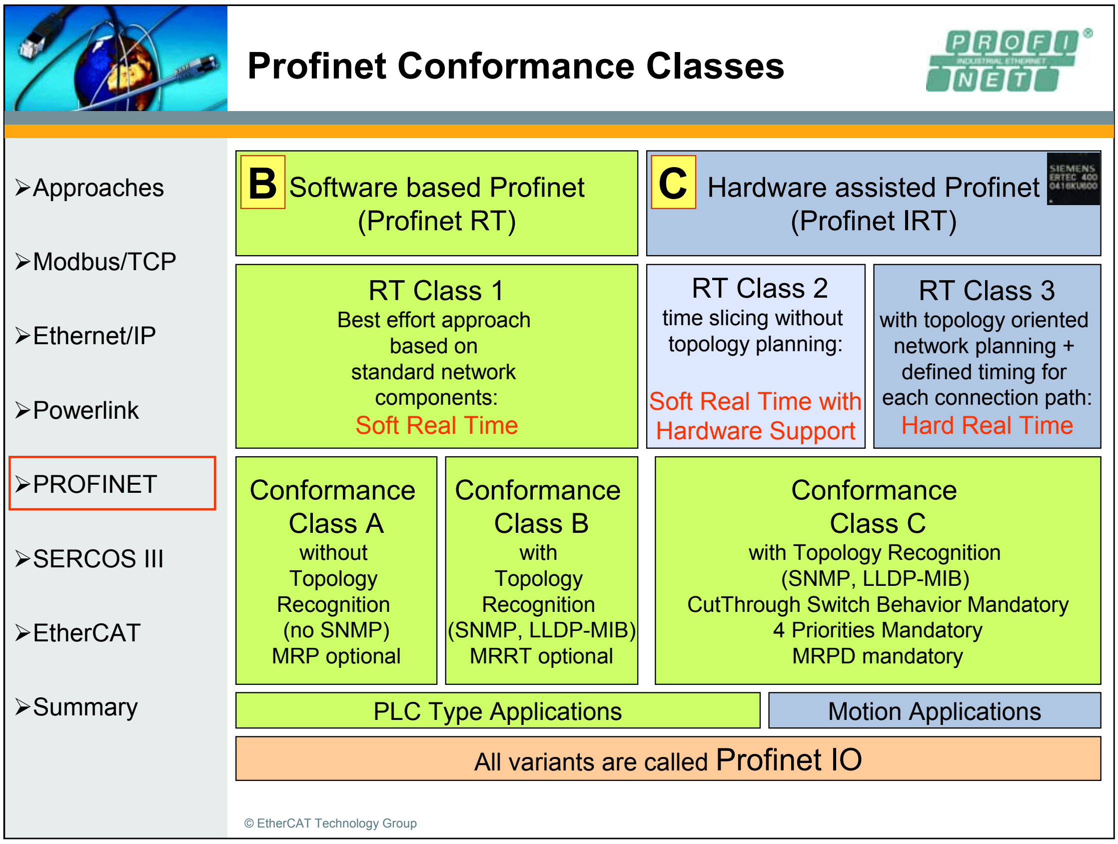


In order to avoid the complex topology network planning process, an intermediate approach had been introduced: RT Class 2 (within Siemens also called IRT “Flex” or “IRT with high flexibility”) using Profinet chips (e.g. ERTEC). High priority network traffic is sent in the IRT time slice, but without 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.

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; 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 is supported in Conformance Class B + C, only.

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 though in principle unmanaged switches can be used with Conformance Class A Profinet networks, they have to be selected very carefully (IT support required).**

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

Profinet Robustness (I)

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- Profinet can be vulnerable if certain non-Profinet network traffic occurs, such as high density of ARP requests
- This applies to RT as well as to IRT, since in IRT the NRT channel is used for supporting services, such as:
  - Synchronization (IEEE1588)
  - Discovery protocol (LLDP)
  - All acyclic services (which are used by some masters in a cyclic way).
- Therefore Profibus International is preparing a spec/guideline called „PROFINET IO Net load“

- Thus the Profinet user is now responsible to ensure that certain network load limits are not exceeded.

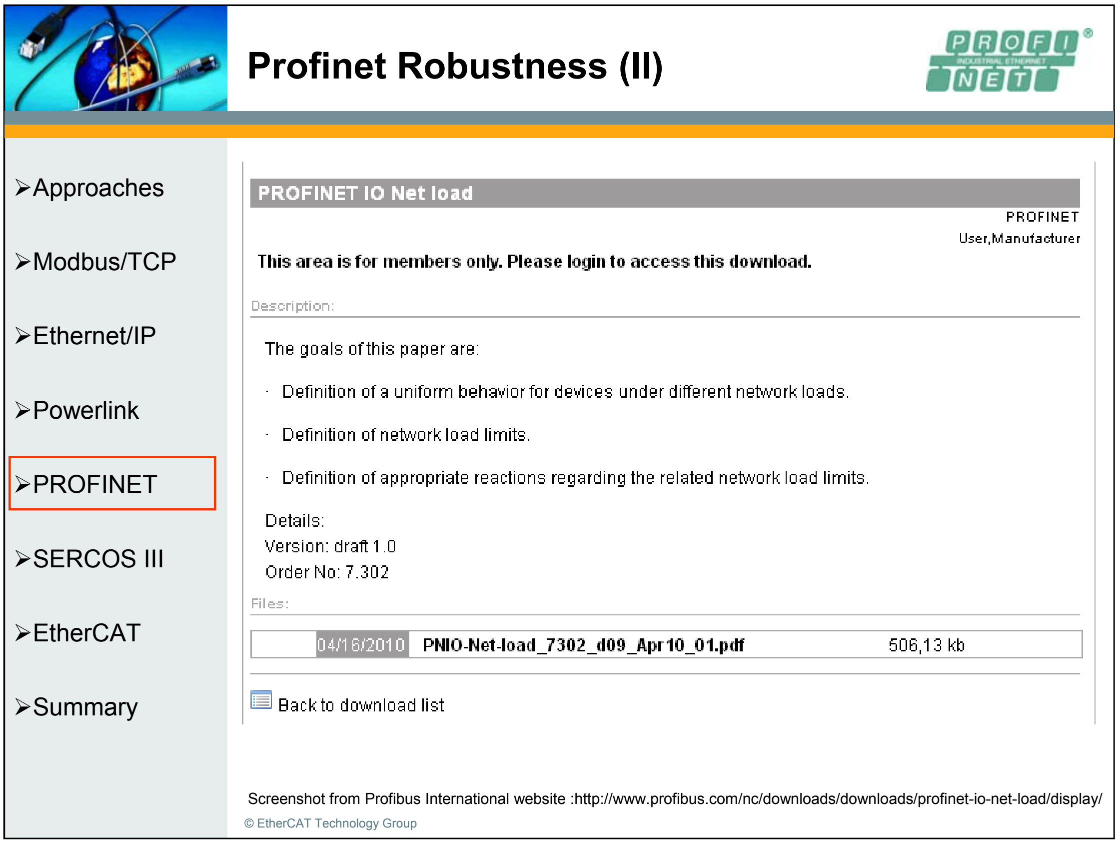
Profinet marketing has always claimed that Profinet provides (quote from PI “Profinet Benefits” presentation):

- “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 overload situations that cause the network to fail. If the communication processor of a drive is too busy to handle e.g. an occasional burst of broadcasted ARP frames and therefore cannot keep up with executing the IEEE1588 services, the synchronization fails (of this drive, and all nodes further downstream) and the master will consider these nodes to have an error – the system stops.

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.

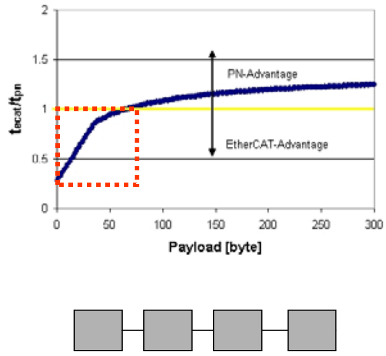


There are reports suggesting that exceeding 5% ARP load for 1 ms can already be an issue.

Profinet / EtherCAT Comparison by Profibus International (PI)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- On press conferences in Nov 2007, PNO/PI published performance comparsions with EtherCAT
- It was found that in typical application scenarios (line structure, 50 nodes, < 60Bytes cyclic data per node) EtherCAT is substantially faster than Profinet IRT
- According to the PNO, Profinet IRT is faster if the average payload per node exceeds 60 Bytes
- However, some features of EtherCAT (such as full-duplex frame usage and pipelining of frames) were not considered



Picture sourced from PNO press kit

Within the research project "ESANA", funded by the German Federal Ministry of Education and Research, Siemens, Phoenix Contact and some other parties were looking for performance enhancement possibilities for Profinet. This is remarkable, since it documents that in PNO/Siemens/Phoenix view the current Profinet IRT is not fast enough to succeed.

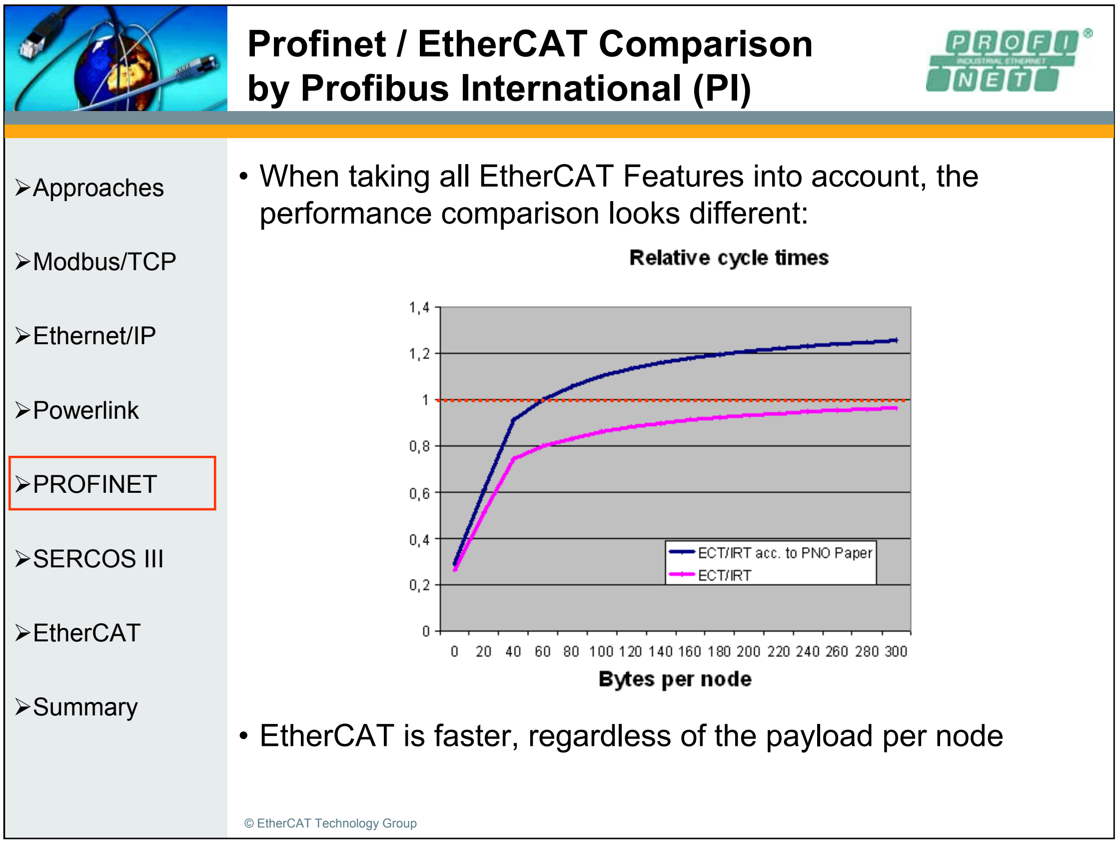
The performance comparison shown on this slide is at least questionable: even with very favorable assumptions for Profinet it was not possible to reproduce the results. EtherCAT is substantially faster than shown, since several EtherCAT features were not taken into account:
- EtherCAT can use the same bandwidth for input and output data (full-duplex usage of the frame).

- EtherCAT can send the next frame before the first one has returned (pipelining of frames).

One of the authors of the study has meanwhile admitted this shortfall.

So in fact EtherCAT is faster than Profinet IRT, regardless of the payload per node.

Furthermore, all the Profinet calculations do not include the local stack performance in the slave devices. Unlike with EtherCAT, in a Profinet IRT slave device a communication µC (ERTEC: ARM) is taking the data from the MAC interface and makes it available to the application. With EtherCAT, this is done on the fly in hardware, the data is made available in the DPRAM or Input/Output of the EtherCAT Slave Controller without further delay.



This slide shows the relative performance comparison if all the EtherCAT Features are taken into account (purple line). This calculation was confirmed by a conference paper of Dr. Gunnar Prytz, ABB Research Center, at ETFA 2008 („A performance analysis of EtherCAT and Profinet IRT“), which can be downloaded from the ETG website:

http://www.ethercat.org/pdf/english/ETFA_2008_EtherCAT_vs_PROFINET_IRT.pdf

The blue line shows the comparison according to the PNO paper.

ETG was asked to provide a statement regarding the PNO press conference. Here it is:

•*We are pleased that the PNO has chosen EtherCAT as performance benchmark and thank for the associated publicity.*

•*The PNO acknowledges our statement, that high-end performance with cycle times significantly below 1 ms is a relevant selection criteria for an Industrial Ethernet solution.*

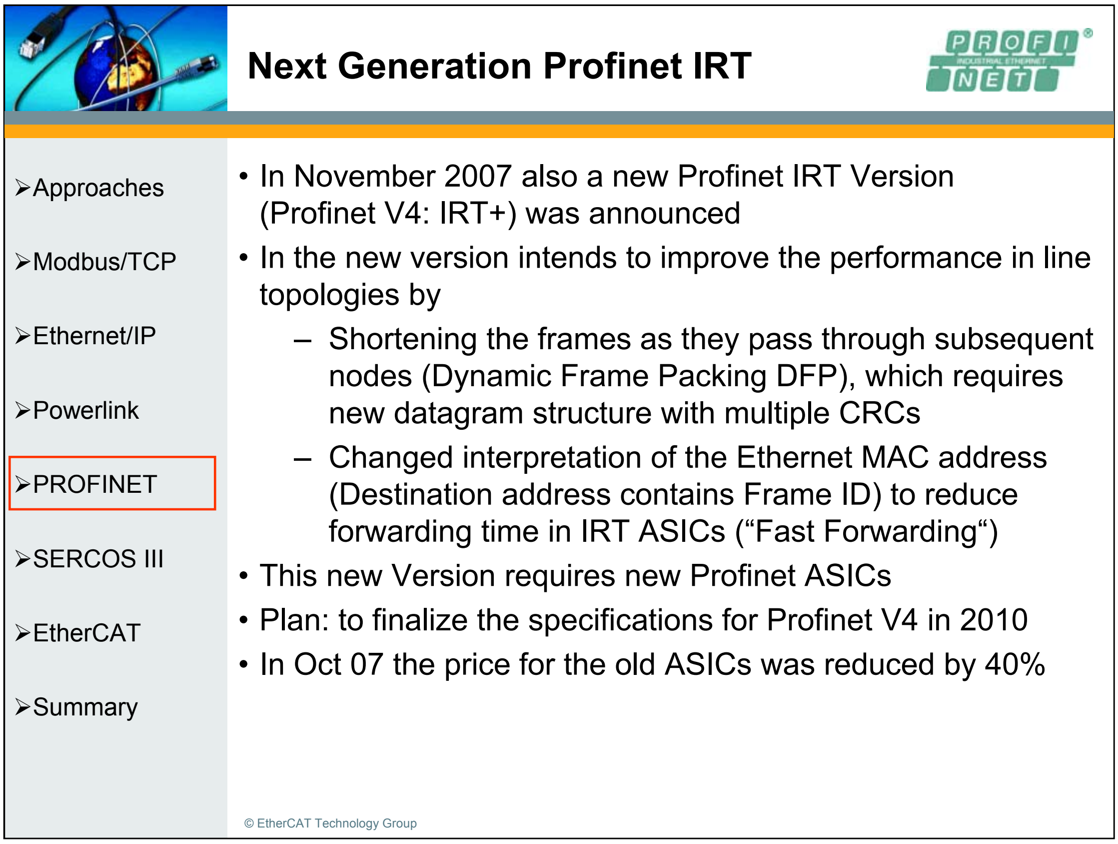
•*The PNO analysis shows clearly, that in typical application scenarios EtherCAT is much faster than the fastest Profinet variant IRT class 3.*

•*We congratulate the PNO on having found a special scenario (comb structure, in which the nodes in the branch lines are not updated in each cycle), in which a future version of Profinet IRT seemingly matches or exceeds EtherCATs performance.*

•*This comb structure was compared with an EtherCAT line structure – and not with an EtherCAT comb structure, in which the nodes in the branch lines can be updated in each cycle.*

•*EtherCAT is and remains the fastest Industrial Ethernet solution.*

•*EtherCAT does not need and will not need the complex network planing and optimization that current and future Profinet IRT variants require.*



Profibus organization PNO showed a Profinet V4 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+ (or Profinet V4) any more. The new version which requires new chips is contained in the Profinet specification V2.3, which was published in October 2010.

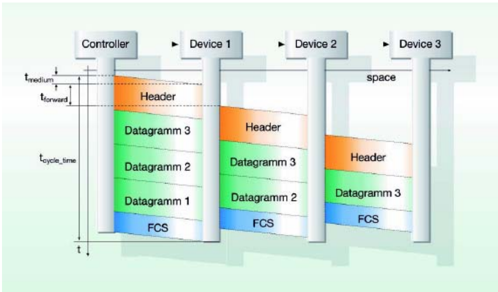
Since EtherCAT achieves a better bandwidth utilization (less overhead per node), it will remain the fastest Industrial Ethernet technology, even though there may be scenarios with just a few nodes where a carefully optimized network consisting of Profinet V4 nodes may match the performance of an EtherCAT with default settings.

DFP: Dynamic Frame Packing

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

DFP aims to enhances Profinet IRT Performance in Line Topologies

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



- In DFP-Lines, IP-Frames (other Ethernet Traffic) is fragmented and tunneled – just as with EtherCAT

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

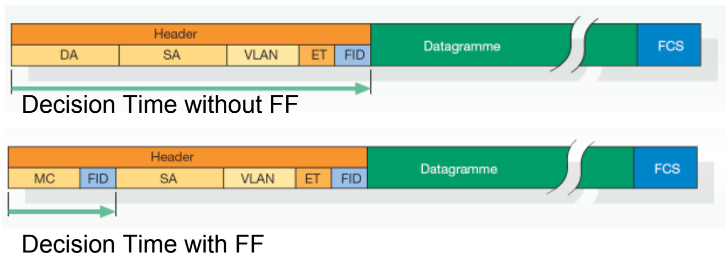
DFP will work in line topologies, only.

With DFP Profinet introduces the tunneling of IP-Frames – another feature that EtherCAT has introduced and which Profinet marketing used to condemn…

Fast Forwarding (FF)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Fast Forwarding (FF) reduces Cut-Through Forwarding Time by introducing Multicast MAC Adresses with integrated Profinet Address
  - Cut Through Switch can decide (forward to which port?) after reception of Profinet destination address (FID, frame ID)



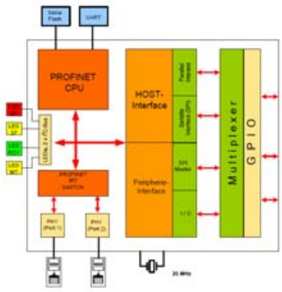
Picture: Phoenix Contact @ SPS/IPC/Drives Congress 2009

For introducing Fast Forwarding the address usage had to be modified. The goal is to reduce the „per-node-delay“ of Profinet.

New Profinet Chip TPS1 “Tiger”

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- Developed by Phoenix Contact, distributed by Renesas, marketed by KW Software
- Goal: Simpler to integrate than Siemens ERTEC200
- Initially intended to support Profinet V2.3 (“V4”, DFP - Dynamic Frame Packing, Fast Forwarding).
- PHYs integrated, but no µC
- Aimed at I/O and Drives
- Initially announced for 2009, now samples announced for Q2/2011, series production expected for Q1/2012
- Marketing: “Joint Development of Phoenix and Siemens” in order to stress compatibility with ERTEC



Picture sourced from KW Software Website

The TPS1 chip is a Phoenix Contact development – and Phoenix Contact (not Siemens) also was the driving force behind Profinet V4 (IRT+, now called Profinet V2.3). 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. Meanwhile Siemens seems to have recognized that this strategy backfires 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, apparently after the tape-out of the TPS1 chip – which means that at least the first version of the TPS1 chip will not fully support Profinet V2.3. Siemens itself is also working on a next generation Profinet chip, which is not expected before 2012 – and it seems that Phoenix had to accept that this chip will be the first one to support Profinet V2.3.

PROFINET ASIC Pricing

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Siemens/NEC	ERTEC 200	ERTEC 400
Functionality	**PROFInet RT + IRT** **IEEE 1588** **ARM 9 Processor** 2 Port Switch with PHY	**PROFInet RT + IRT** **IEEE 1588** **ARM 9 Processor** 4 Port Switch, no PHY PCI Interface RMII Interface (4port)
Application field	Single drives **Comparable field devices**	High-end Motion Controller **Network components**
ASIC Technology	**0.15 µm Technology** **304pin BGA 19 x 19 mm**	**0.15 µm Technology** **304pin BGA 19 x 19 mm**
Pricing (since Oct 2007)	12.57 € @ order size 350 units	30.00 € @ order size 350 units

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

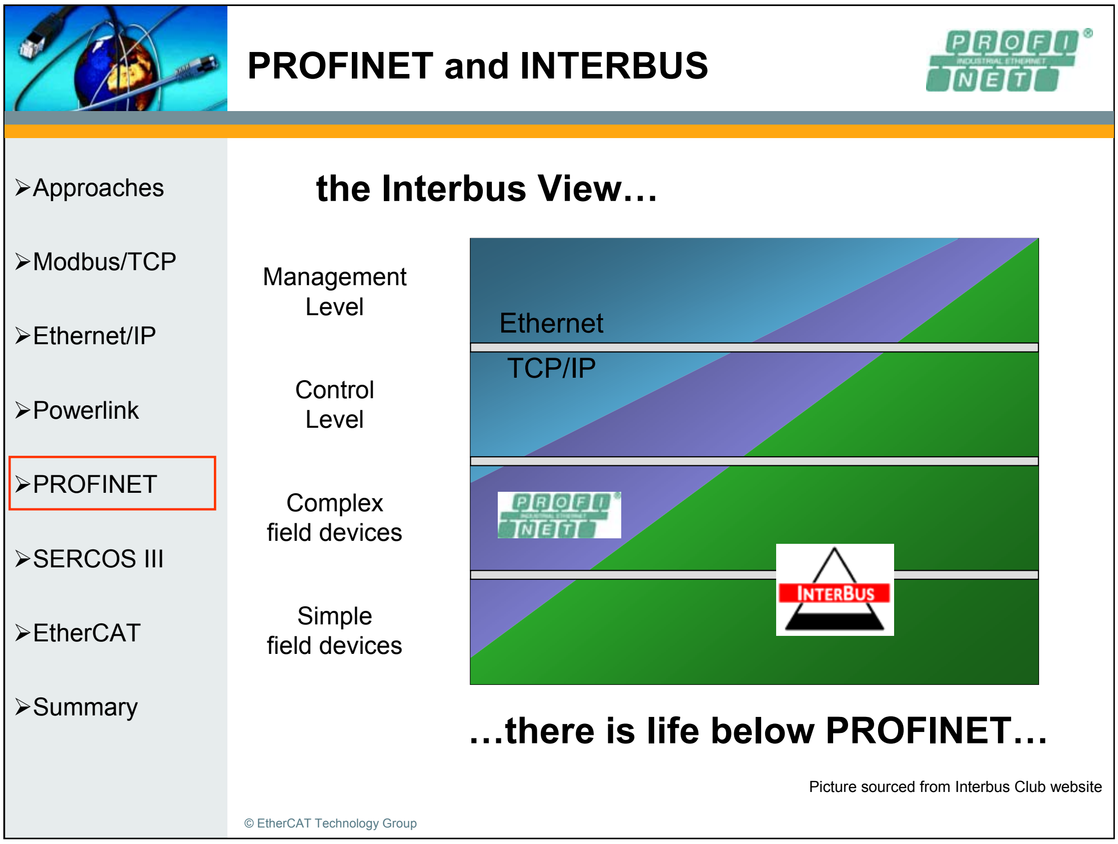
© EtherCAT Technology Group Industrial Ethernet Technologies

First samples of the ERTEC 400 were shipped in May 2005, first samples of the ERTEC 200 were shipped in May 2006.

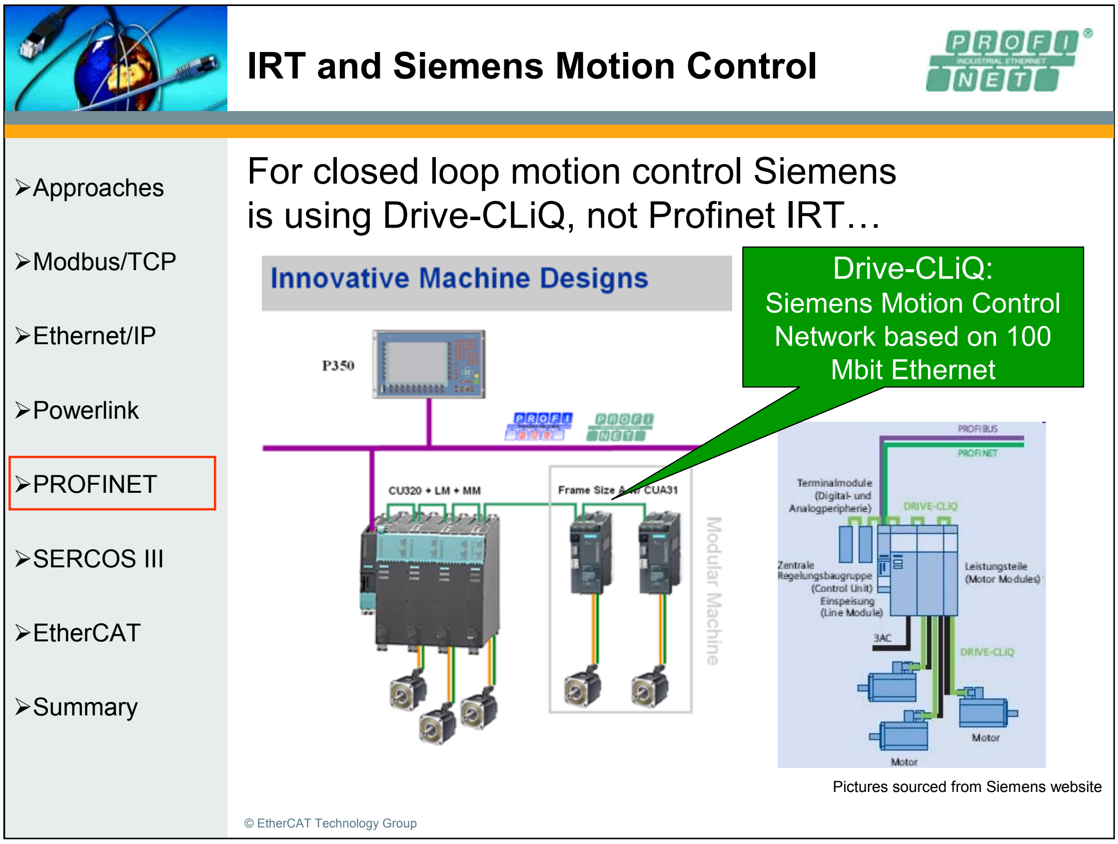
Initially, the ERTEC 400 was sold for 38€ and the ERTEC 200 for 19 € per chip (@ 10.000 units/year). As of Oct 1st, 2007, Siemens lowered the prices substantially, presumably since the next generation IRT which requires new ASICs is under development.

12.57€ 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 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.



Due to system complexity and costs Interbus as well as Profibus expect life below Profinet.



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

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

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

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

PROFINET Summary

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- 3 different Versions:
  Proxy Approach, Soft Real Time, Isochronous Real Time
- Proxy Approach: vaporware
- RT: rather complex Profibus replacement, but will have market share due to support by Siemens
- There will be underlying networks (for cost reasons)
- IRT for motion control: meets motion control requirements but very complex and expensive
- IRT expected to be predominantly Siemens only (like Profibus DPV2 for Motion Control)

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 RT 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. Furthermore, there will be underlying fieldbus systems in the car assembly line, too. But certainly the auto makers announcement gave Profinet RT a marketing push.

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.

SERCOS III Features

SERCOS interface

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

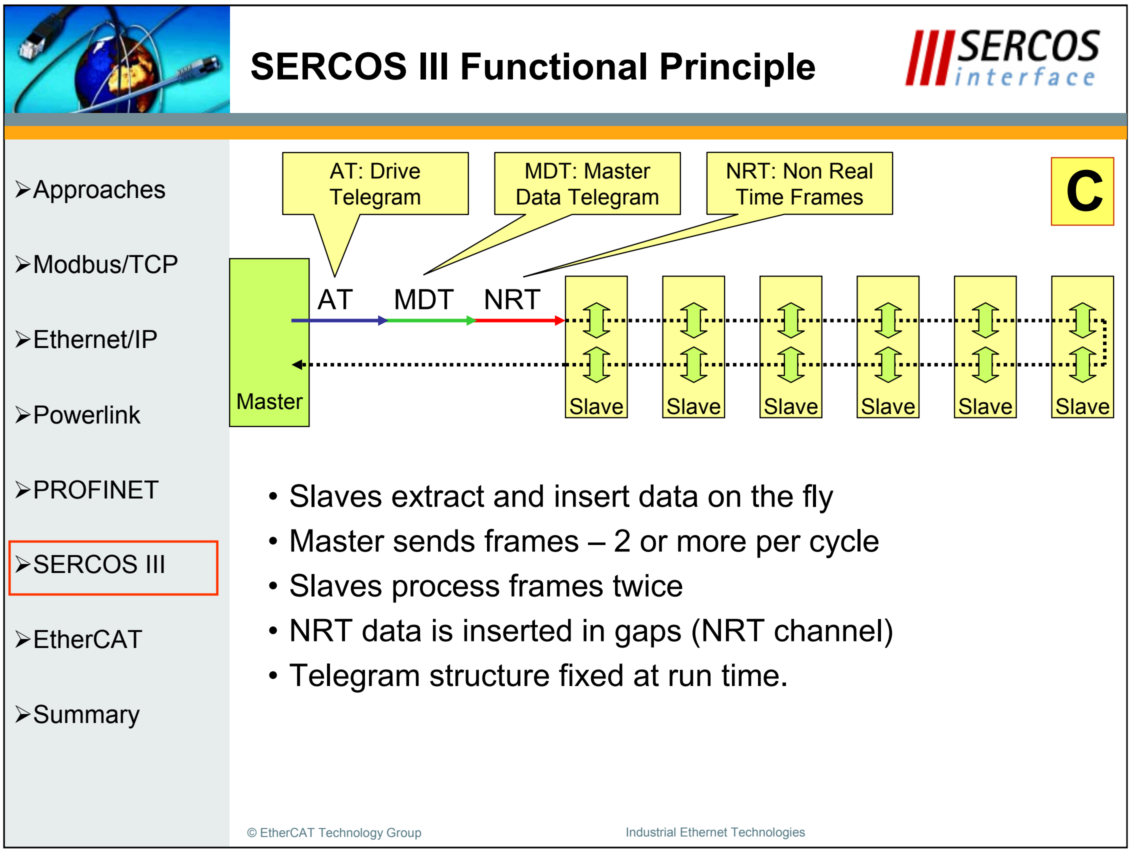
C

- Combining Sercos mechanism with EtherNet Physics
- 100 MBit network transmission rate
- Hardware based synchronization and ring topology
- Integration of NRT channel, e.g. for TCP/IP
- Cyclic and acyclic communication
- Cross-communication between slaves
- Media redundancy support
- Control recognizes the physical order of devices
- 100BASE-TX or Fibre Optics based physical layer

- Hard Real Time Requires Special Master Card
- maximum of 511 slave nodes per network (since V1.1)
- Line + Ring Topology, only.

© EtherCAT Technology Group Industrial Ethernet Technologies

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

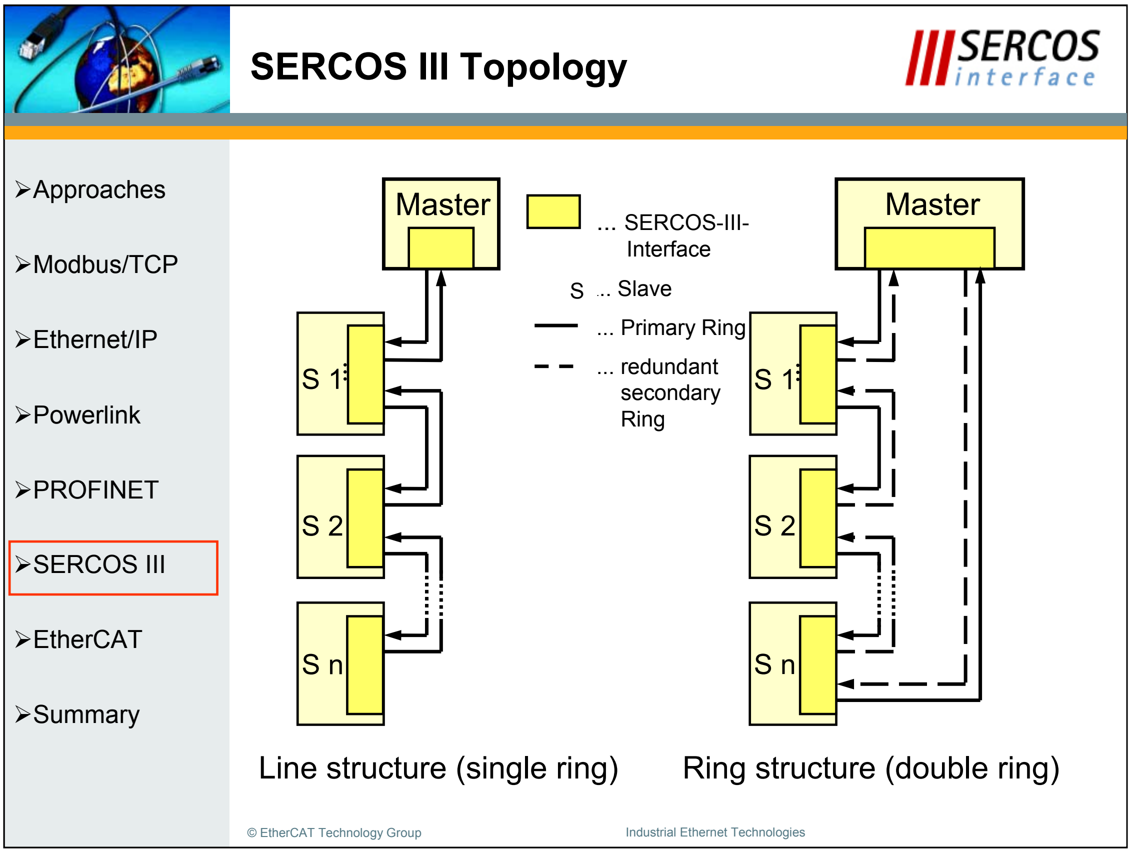


SERCOS-III has adopted the EtherCAT functional principle: processing Ethernet frames on the fly. There are some main differences, though:

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

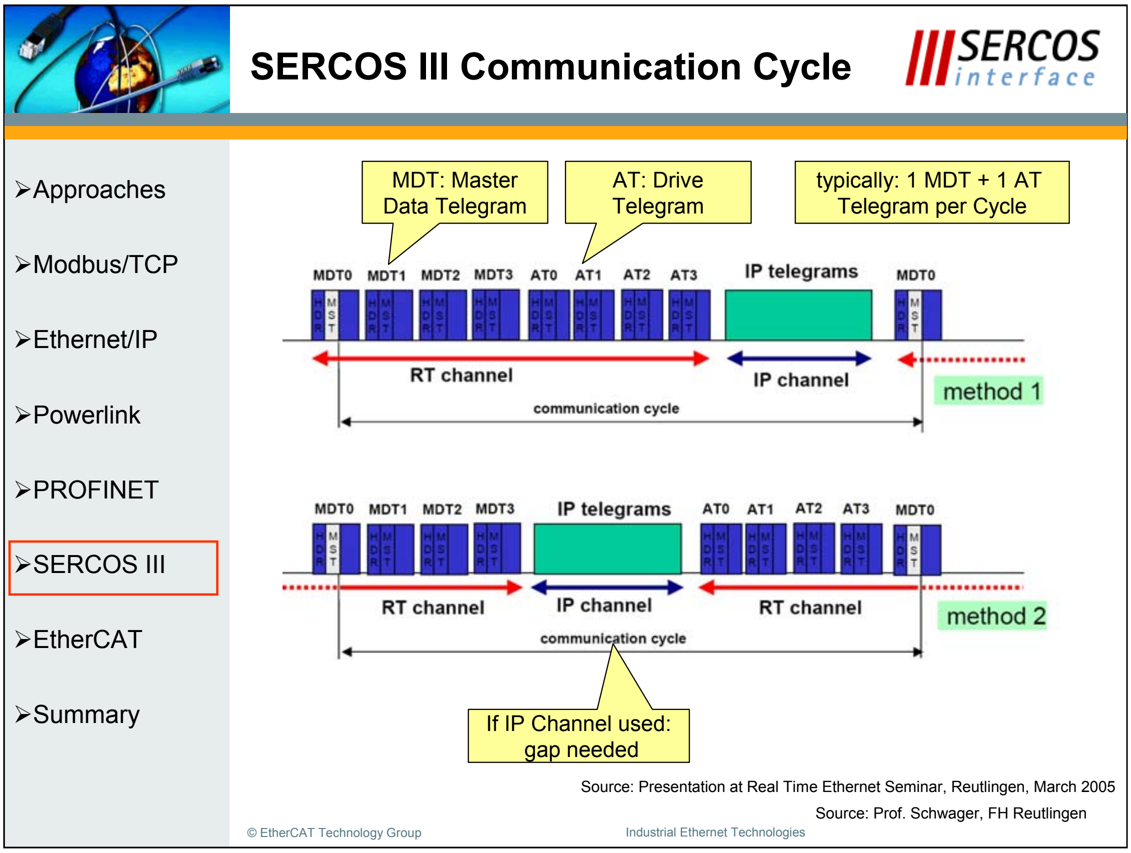
These differences have the following impact – compared with EtherCAT:

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

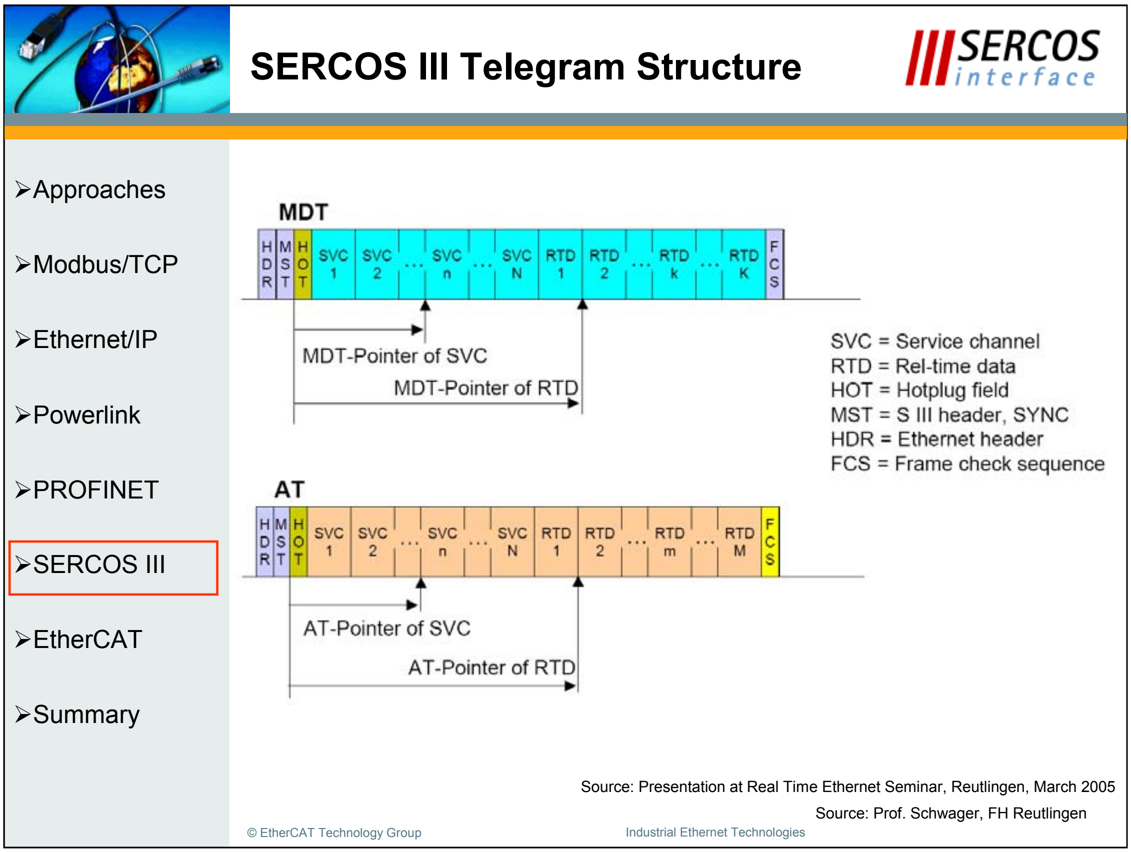


SERCOS-III supports line and ring topology, only.
Ring structure: Recovery time in case of cable failure < 25µs.

No star or tree topology, thus no hot-connect of branches.



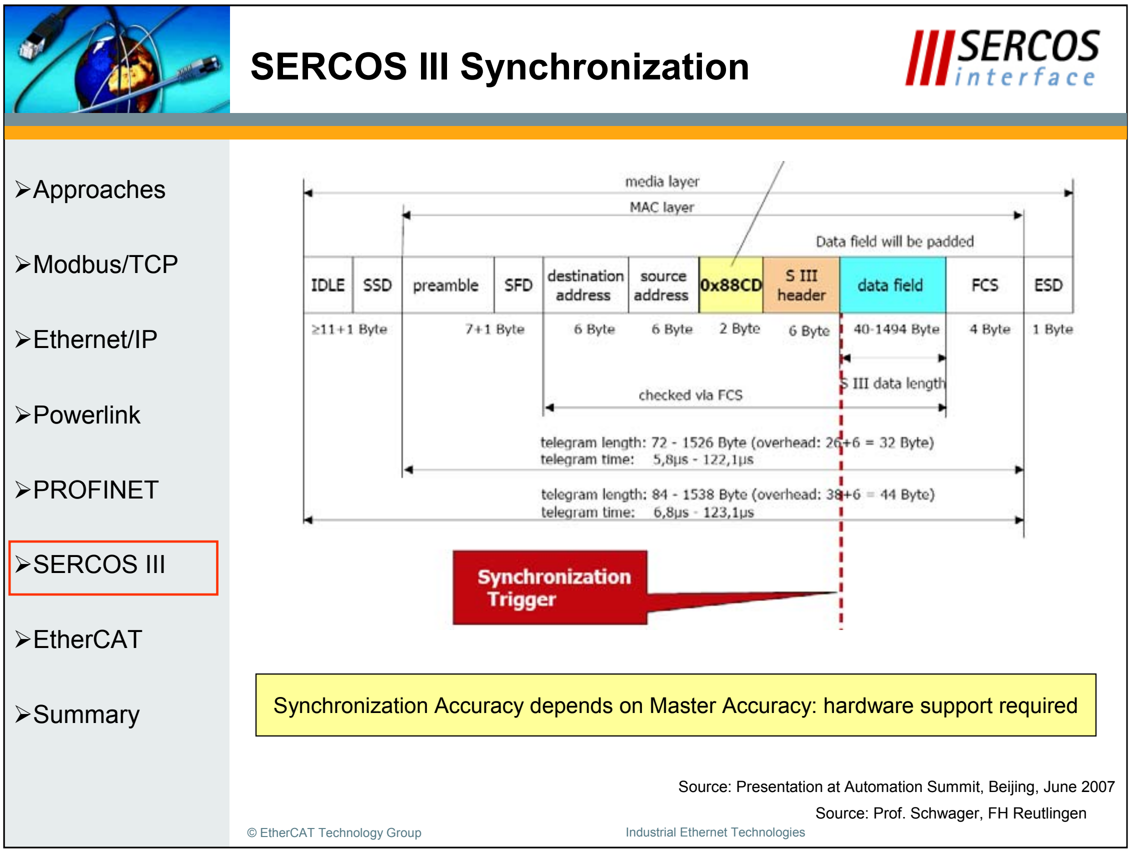
IP data is inserted in a gap („IP channel“).The gap can either be after the input and output frames (method 1) or in between (method 2).



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.

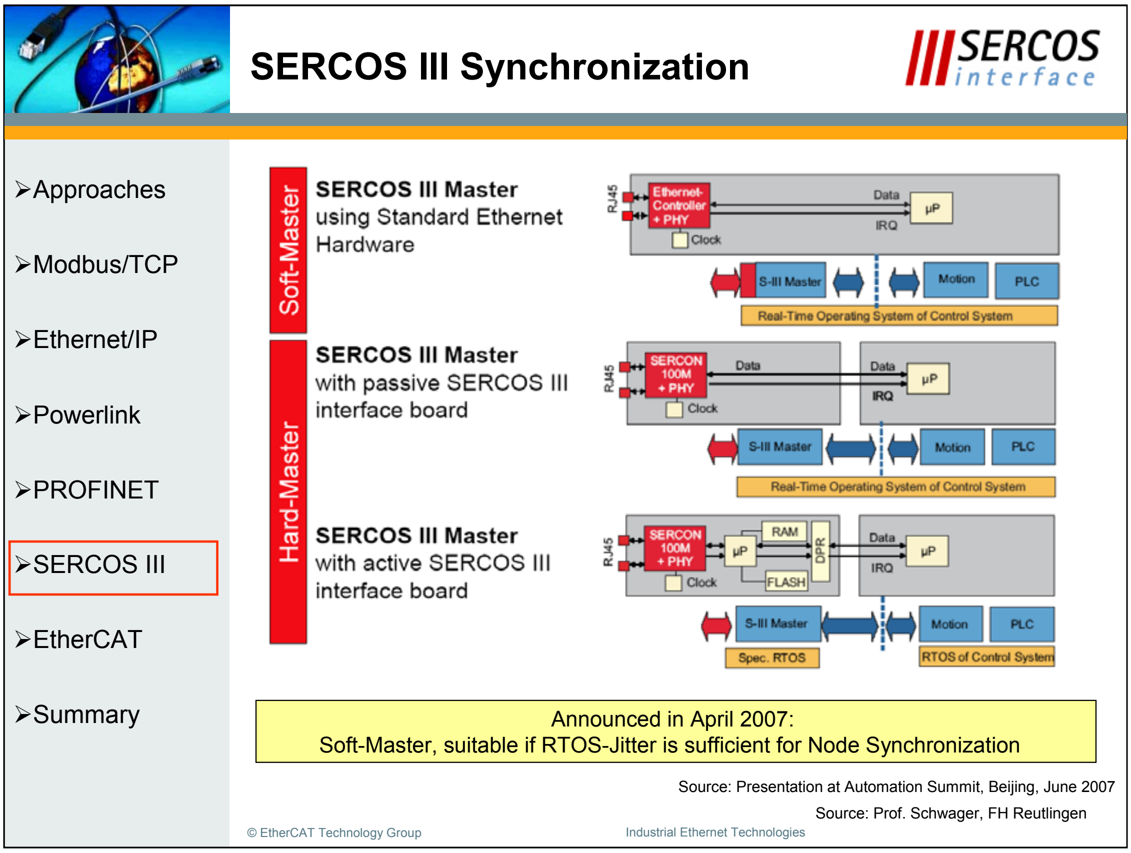
It is thus not possible to e.g. cyclically read a status bit of a device and request data only if this status bit indicates new data.

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.

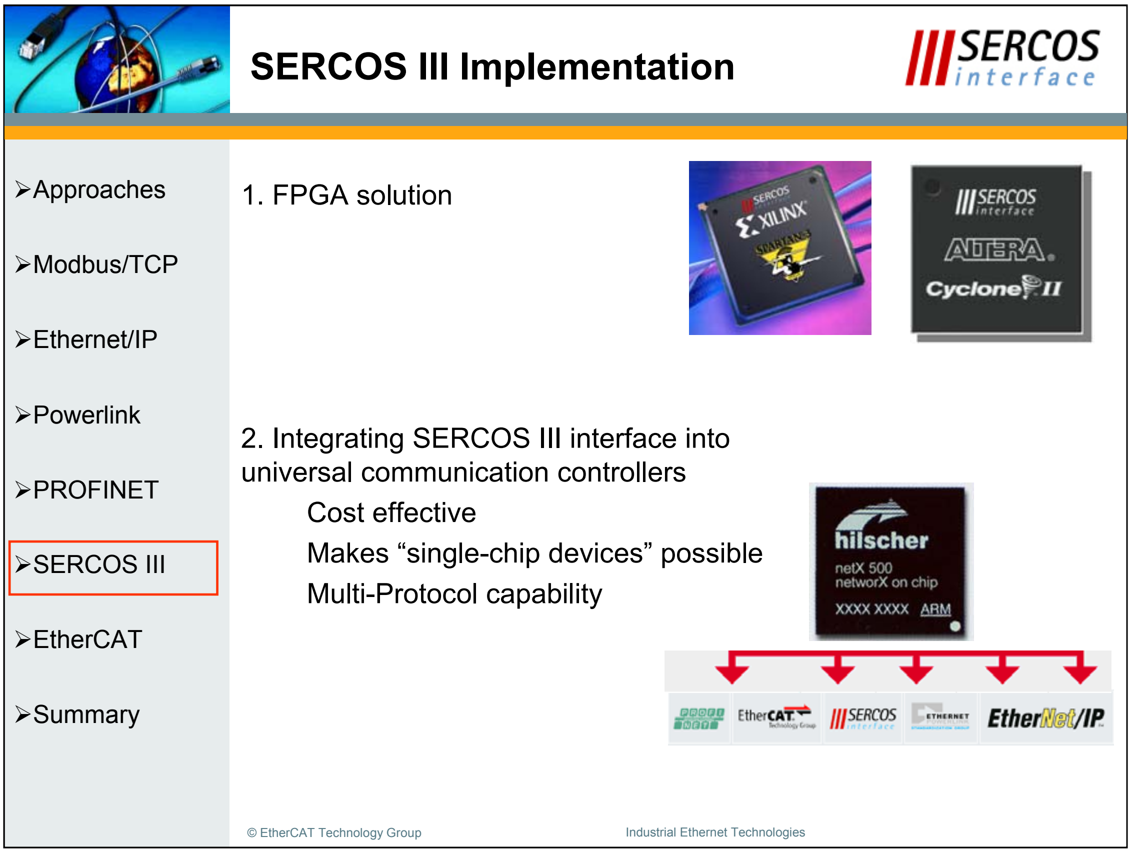


In April 2007, Sercos International announced the development of a Sercos-III “Soft-Master”, implementing the master functionality using software (+ a standard Ethernet Port). According to the press release (quote), ”The achievable synchronization accuracy of a SERCOS III real-time network using a soft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

Alternatively the Hilscher netX chip family can be used, which also supports EtherCAT + Profinet

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.

As of 1/2011, no product using this free IP-core is listed in the Sercos product guide.

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. As of Jan 2011, the API only supports the SERCON100M Master IP Core (no generic Ethernet MAC), documentation is in German language.

SERCOS III Performance Overview

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

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: Peter Lutz, Sercos International, 29.09.2008

This performance data was provided by Sercos International in September 2008. 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 all gateways – in fact, the only gateway listed in the Sercos product guide as of 4/2009 does not support this functionality.

SERCOS III Performance Comparison

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
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- EtherCAT
- Summary

No. of Nodes with given Cycle Time			SERCOS-III		EtherCAT	
Appli-cation 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.

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 4/2009, there is no gateway available supporting the shortened IP channel (which would lead to the values marked in green)

SERCOS III Performance Comparison

SERCOS interface

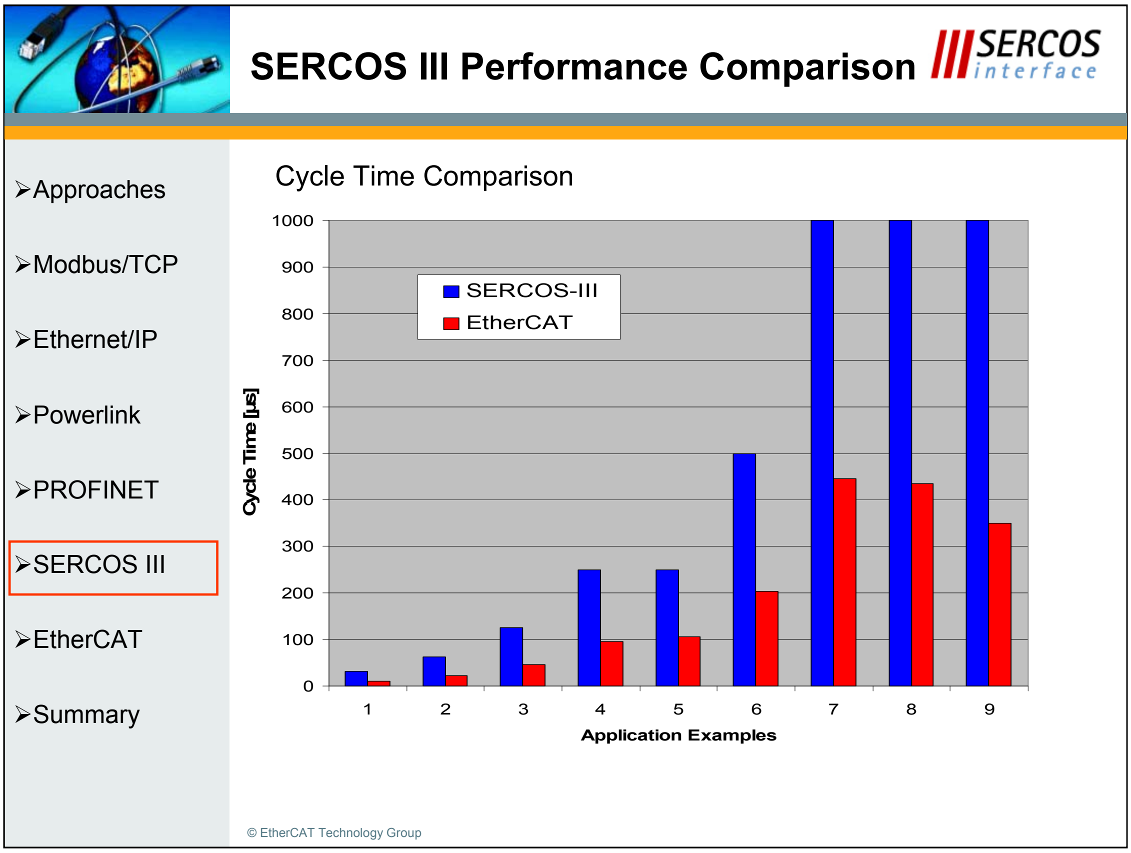
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

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**

 Industrial Ethernet Technologies

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



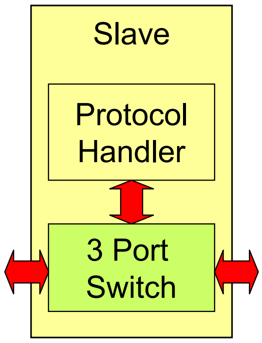
A graphical view for the previous table.

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

SERCOS III IP-Handling (I)

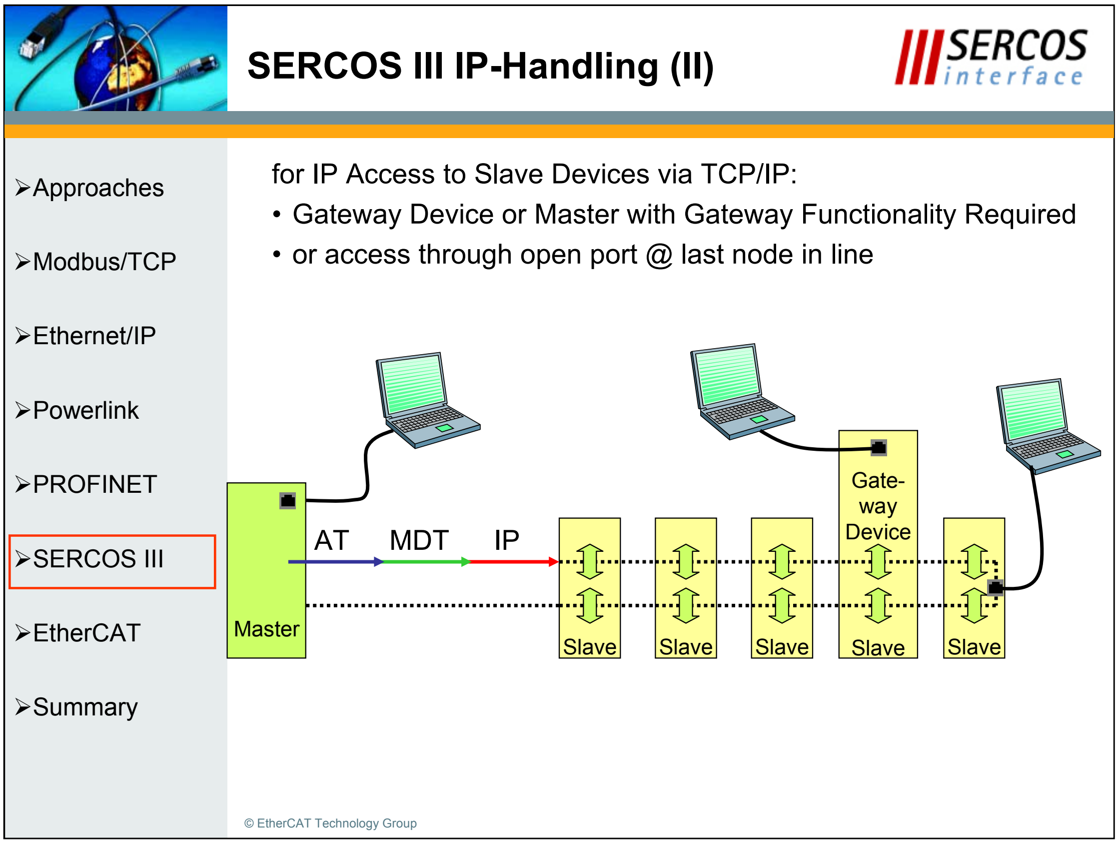
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

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



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.

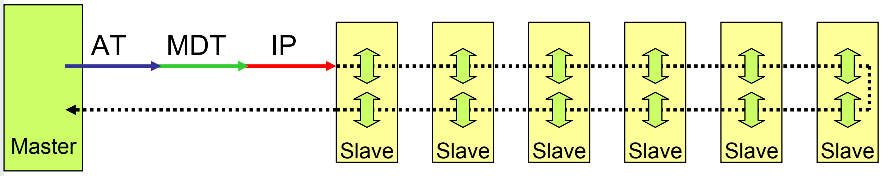
If an unused port is available, this can be used alternatively. Since Sercos-III Devices have two ports, in line topology there is one unused port at the last node in the line (no unused port in ring topology)

SERCOS III IP-Handling (III)

SERCOS interface

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- In RT Mode, IP Traffic is inserted in IP Channel
- During IP Channel, Slave is in Switch Mode



- If IP slot is short or slave controller chip works with store and forward methodology, forwarding of larger frames is delayed to the next cycle – in this case sending a frame e.g. to node 50 takes 50 cycles, response frame accordingly (TCP/IP handshake).
- IP channel performance strongly depends on No. of Nodes
- As of August 2010, Multi IP-Frame Operation not implemented: Within one cycle only one frame can be handled, regardless of IP-channel size

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

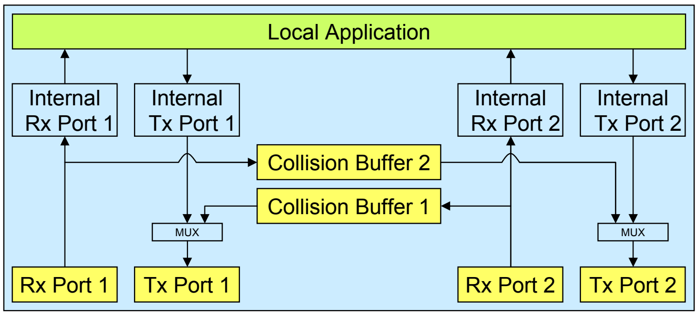
The forwarding behavior of IP frames in the IP slot depends on the slave device capabilities and on the network configuration

Sercos III IP-Channel, Store + Forward

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- In NRT Mode, incoming frames are buffered (Collision buffer)
- **Store + Forward**:

  Frame is buffered until next IP-Channel is active (next cycle)



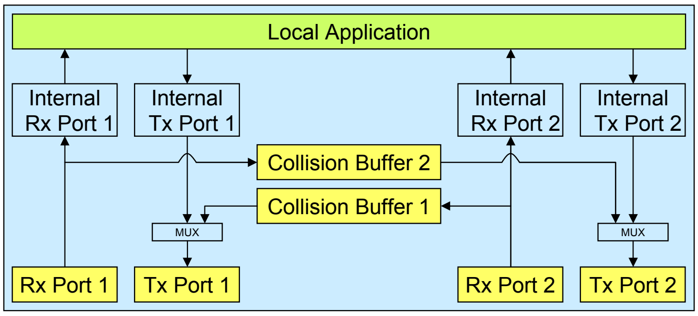
Example for Sercos-III Chip with Store + Forward Switch: Hilscher NETX Family

Current Sercos-III implementations support Store and Forward, which means that in NRT mode within one cycle an IP frame moves from node n to node n+1

Sercos III IP-Channel, Cut-Through

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- In NRT Mode, incoming frames are buffered (Collision buffer)
- **Cut Through**: Once destination address is received:
  - If Tx-Port is not allocated by internal Tx-Port and remaining IP-Slot is > 122µs (max. frame length), frame is forwarded
  - Otherwise: frame is buffered until next IP-Channel is active



- If IP slot is ≤125µs, Cut-through also forwards in next cycle, only
- Example for Sercos-III Chip with Cut-Through Switch: SERCON100 IP Core, for which, as of August 2010, the IP-Channel frame forwarding has not yet been tested.

Future Sercos-III implementations plan to support Cut-Through behavior in NRT mode, which means that an IP frame can move several nodes before it is stored for the next cycle. However, if the IP slot is shorter than 125µs, Cut-Through Sercos-III slave controllers will also have to behave like Store-and-Forward implementations and buffer the frame for the next cycle.

SERCOS III IP-Performance (I)

SERCOS interface

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

IP Channel Performance Considerations

Best Case Scenario:

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

Example:

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

* As of August 2010, Cut Through IP forwarding not yet implemented

If IP channel slot is long enough (>>125µs) and cut-through is supported, the performance of the IP communication may be sufficient. However, as of August 2010, according to information on the Sercos Website, the "Cut Through" Switch behavior is not yet implemented.

SERCOS III IP-Performance (II)

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

IP Channel Performance Considerations

Worst Case Scenario:

- All nodes support „Store and Forward“-Switch behavior
- IP channel slot is 125µs
- Large IP frames are forwarded in next cycle only

Example:

- Network with 220 Nodes, IP communication with last node (220)
- Cycle Time 1 ms, IP Slot **125µs**, 12 Bytes I/O data per device
- Propagation Delay Master → Node 220: **220** Cycles
- Response Time IP Communication (if TCP Connection already established): **440ms** + Stack delay
- If node implementation only supports forwarding in next cycle, then even *establishing* a TCP/IP connection takes >660ms (Three Way Handshake)

If IP channel slot is short IP communication performance may deteriorate substantially – especially in larger networks.

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

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

SERCOS III V1.1

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- In July 2007, SERCOS International released the 1.1 version of the SERCOS-III specification
- Main changes are:
  - Device addressing changed, now topology dependent
  - Parameter addressing changed from 16-bit IDN to 32-bit structured EIDN
  - status + control word format and content changed
  - Redundancy and hot-plug features introduced
  - Communication model changed from master/slave to connection oriented -
  - 511 instead of 254 slave devices supported
  - Mandatory IP channel introduced
  - Interrupt handling changed, now one Sync-IRQ
- The specification changes require hardware adaptations (Sercos controllers) and also major software changes.
- Version 1.0 and Version 1.1 devices are not interoperable
- First SERCOS-III V1.1 drives were shipped in Dec 2007.

This means that, as of beginning of 2008, Sercos-III field deployment and application experience started all over again.

On the other hand, since hardly any Sercos-III devices were shipped before 2008, this does not seem to be a major problem.

By introducing 32bit IDNs and thus enhancing the IDN address space, Sercos-III device profiling differs from the profiles used in Sercos-I and –II.

Current Sercos III version is V1.1.2, which introduced hotplug capabilities and the support of software implemented masters.

Version 1.3 is under development, and will introduce multiplexing of I/O data (underlying I/O cycles), and 3-buffer mechanisms for process data.

SERCOS III Summary

SERCOS interface

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- High Performance Industrial Ethernet Approach
- Focus on drives, so far very limited I/O, sensor, valve etc. support
- Topology: line and ring only, no branches, no drop lines, no hot connect of segments.
- Not more than 511 nodes per network, therefore modular I/O with bus couplers (and associated delays).
- Requires dedicated master-card for hard real time
- Soft-Master implementation for jitter up to 50µs
- Depending on configuration IP traffic can be slow

- Has been the approach that is the latest on the market
- Slow adoption rate (few Sercos I/II vendors move to Sercos III)
- EtherCAT supports the same device profile + application layer

 Industrial Ethernet Technologies

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

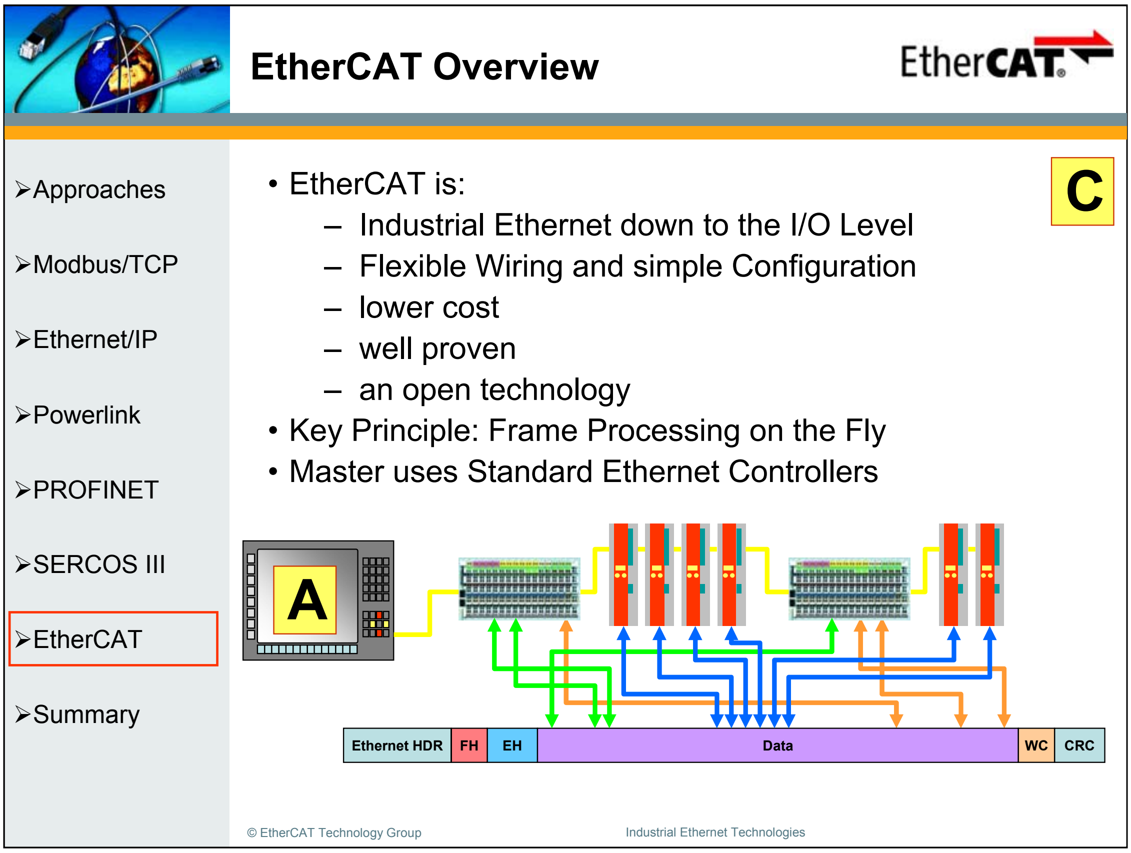
Whilst the SERCOS technology has a good reputation for servo drive control, support for I/O, sensors, or other devices is not yet established.

Slow adoption rate: So far few support Sercos-III in Servo Drives. And almost all these vendors have EtherCAT drives available.

In Nov. 2007, Elau announced support of Sercos-III as system bus. In Nov 2008, Keba did the same.

By the way: out of the 31 Sercos-I/II servo drive suppliers, 27 are ETG members. Out of the missing 4 vendors, two discontinued their Sercos business.

Out of the 27 ETG members also supporting Sercos I/II, 23 have already shown or announced EtherCAT drives (as of January 2011)



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

The slave controllers can be implemented as FPGA or ASIC – both solutions undercut the cost levels of the other technologies discussed in this presentation. It is not required to buy an ASIC, and there will be several sources both for FPGA and ASIC implementations.

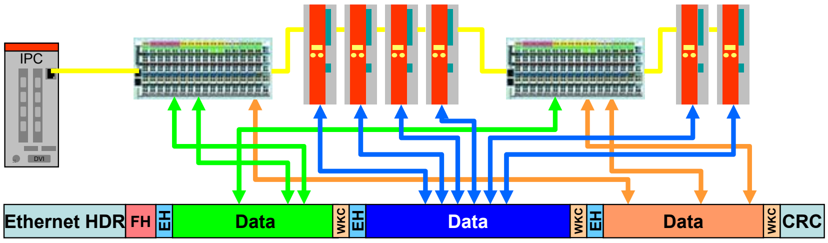
On the master side, EtherCAT does not require a dedicated master card: any standard Ethernet Controller is sufficient, the master functionality is implemented in software running on the host CPU that also runs the application program. It was found that the master code adds less load on the host CPU than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

EtherCAT: Ethernet “on the Fly“

EtherCAT

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

Minimal protocol overhead via implicit addressing



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

 Industrial Ethernet Technologies

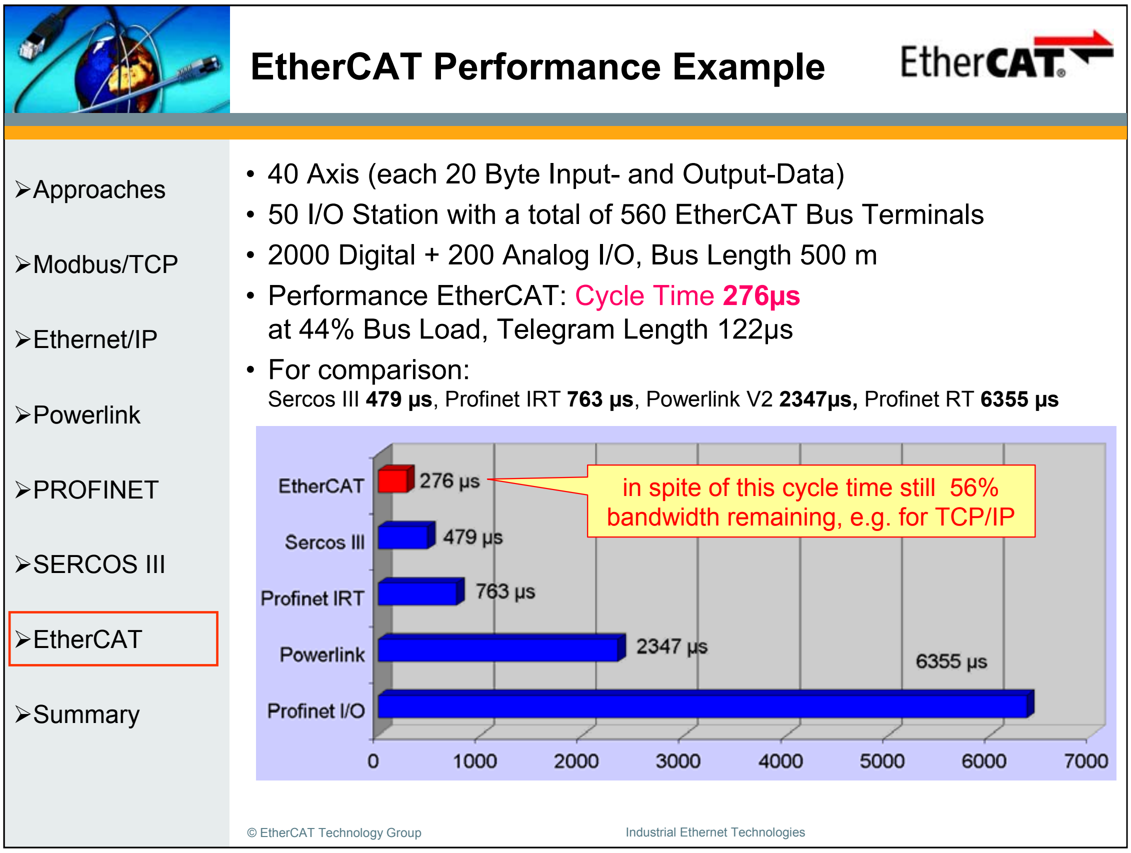
EtherCAT is very effective even with small amounts of data per slave device, since it is not necessary to send an individual Ethernet frame for each data unit.

Since process data communication is handled completely in hardware (EtherCAT Slave Controller), the network performance does not depend on the µC performance of the slave devices – and is thus predictable. This is not necessarily the case with Profinet, Ethernet/IP, Modbus/TCP and Powerlink.

Switches are optional. Thus 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 still 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: the network example used can be found in the annex of the Powerlink spec. 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 (new data every 122µs).

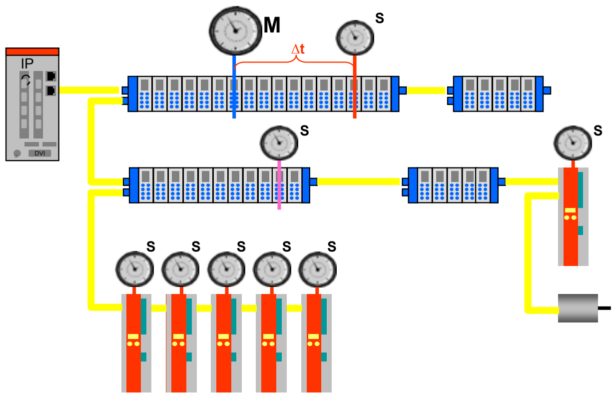
EtherCAT Synchronization

EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

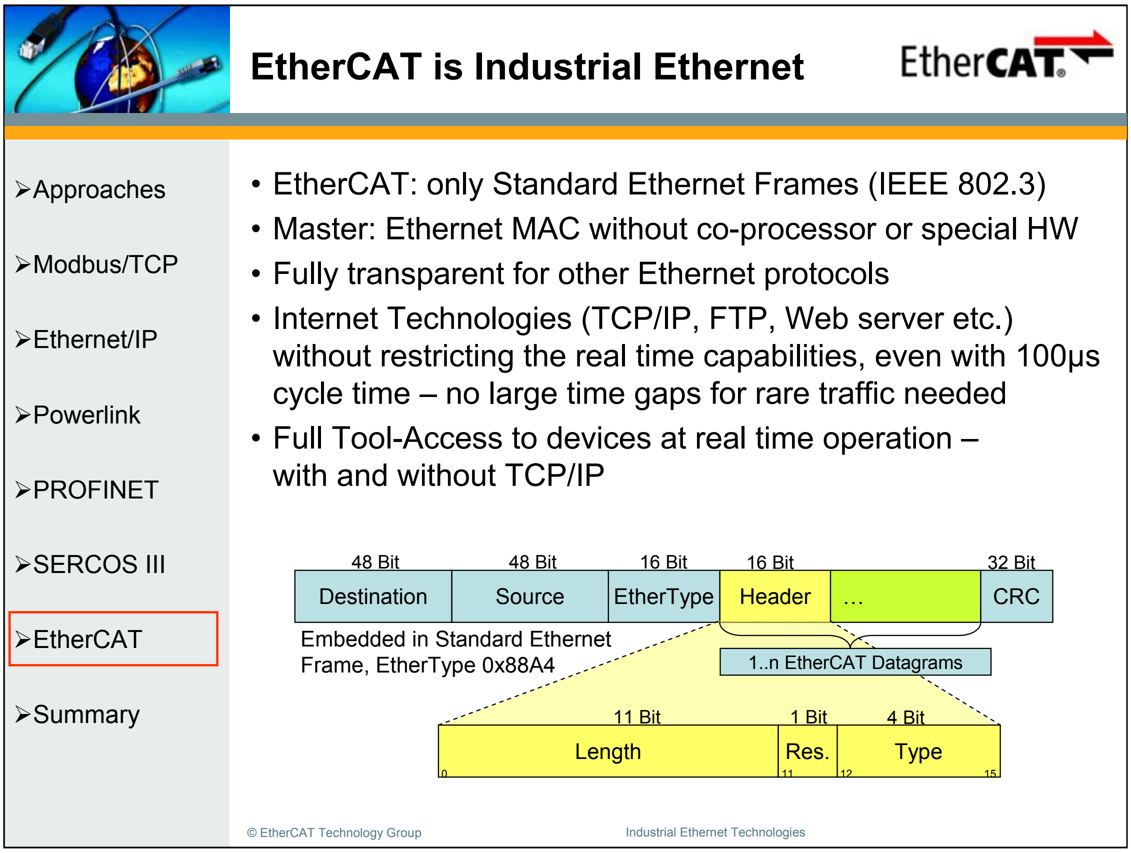
Precise Synchronization (<< 1 µs!) by exact adjustment of distributed clocks.

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



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 does TCP/IP itself.

By using this approach EtherCAT can transport any Ethernet protocol (not ony 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 other approaches have to.

The protocol used is named “Ethernet over EtherCAT”.

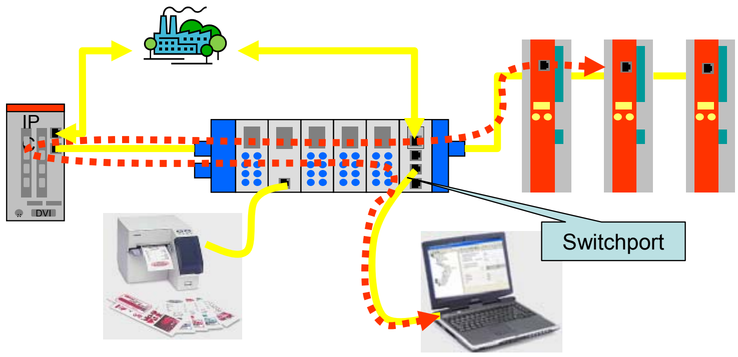
Many EtherCAT masters support tool access from outside: a tool can communicate via Ethernet e.g. by UDP/IP with the master, who inserts this data into the EtherCAT communication in such a way, that a fully transparent access to EtherCAT devices is possible without restricting the real time capabilities.

EtherCAT is Industrial Ethernet

EtherCAT

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



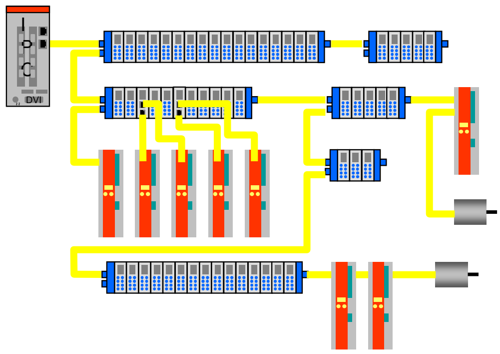
The “tunnel entrance” (Switchport) for any Ethernet protocol can be implemented in a variety of ways: as separate device, as feature of a slave device or as software feature of the EtherCAT master.

EtherCAT: Most flexible Topology

EtherCAT

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



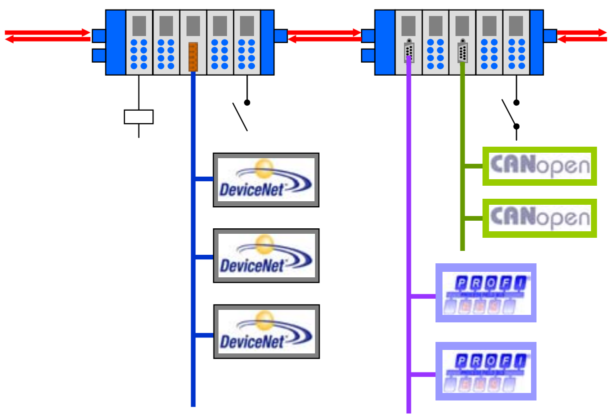
With EtherCAT almost any number of devices (up to 65535) can be wired in a line structure – there are no restrictions due to cascaded switches or hubs. Any number of drop lines or branches are possible, too, providing the most flexible topology.

EtherCAT Gateways

EtherCAT

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

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



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.

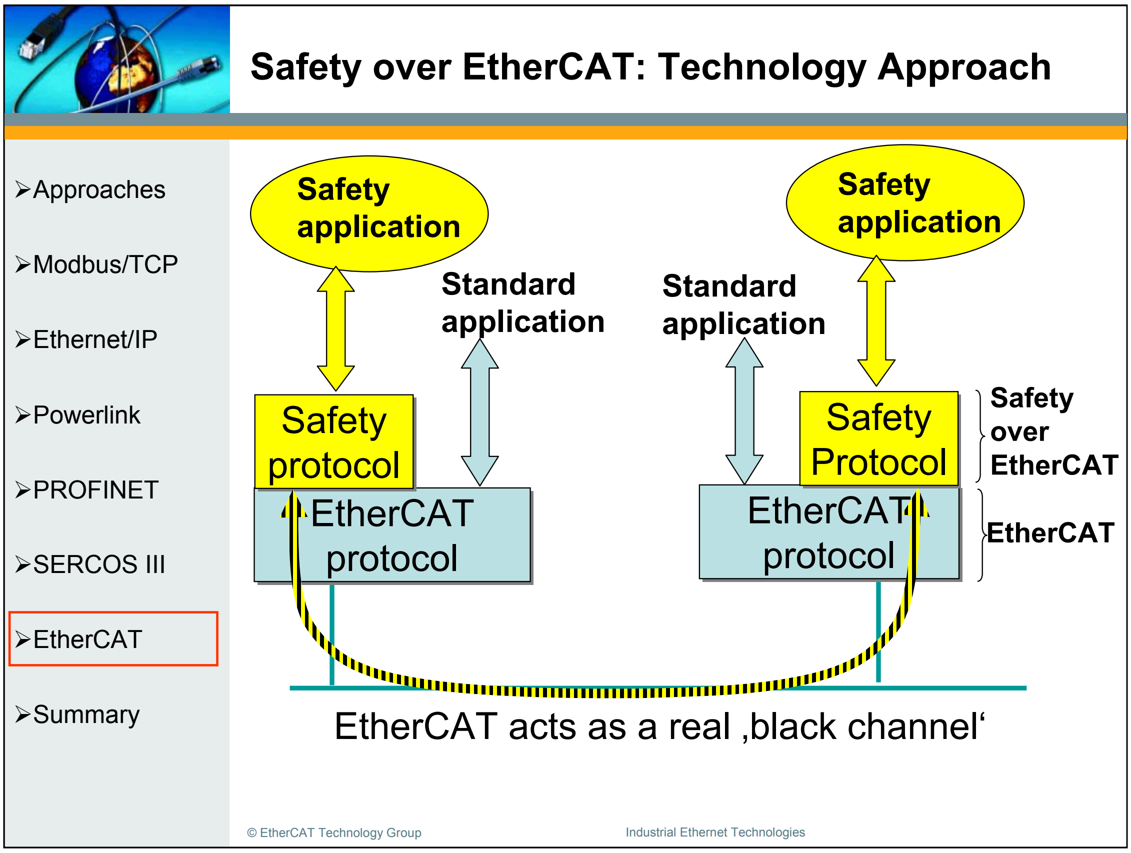
Safety over EtherCAT: Features

EtherCAT

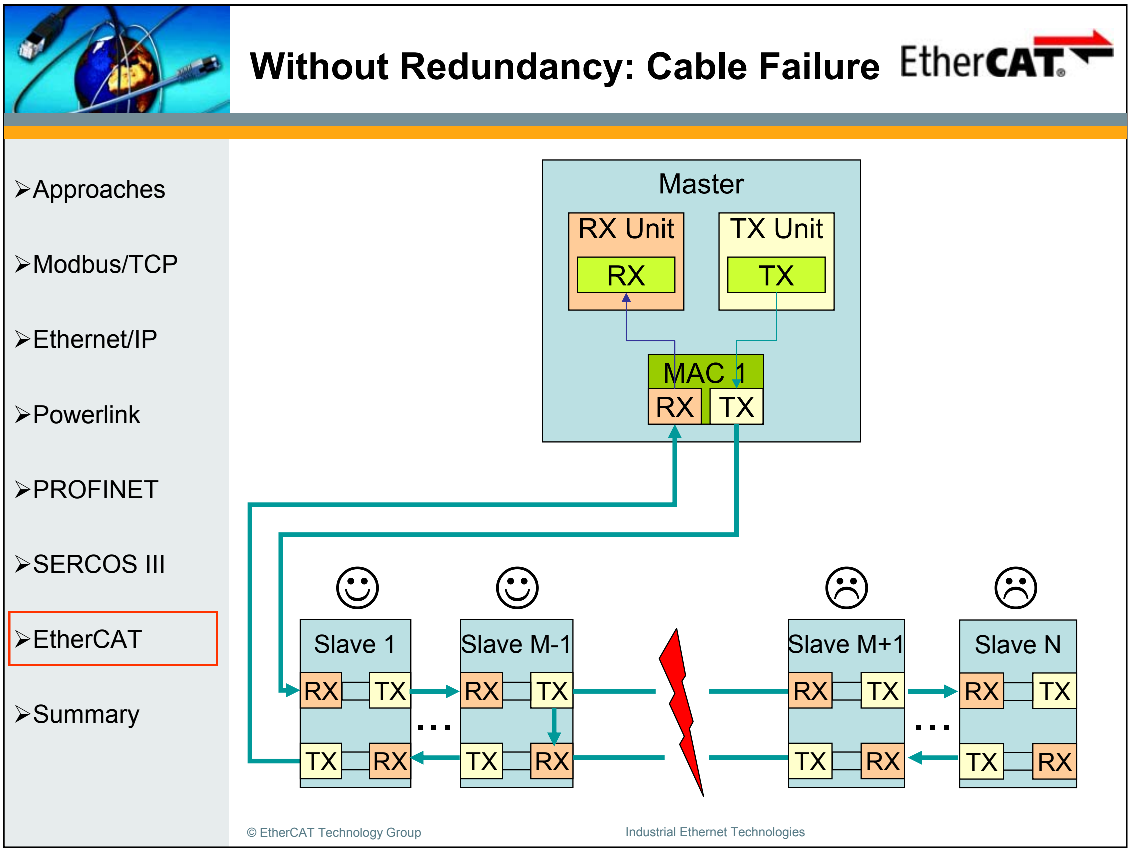
- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- TÜV certified technology
- Developed according to IEC 61508
- Protocol meets Safety Integrated Level (SIL) 4
- Device implementations typically SIL 3
- Suitable for functional safe I/O as well as for functional safe motion control
- Variable CRC size for minimal overhead
- Safe Parameter Download at boot-up: most simple device exchange possible
- Safety devices available since end of 2005

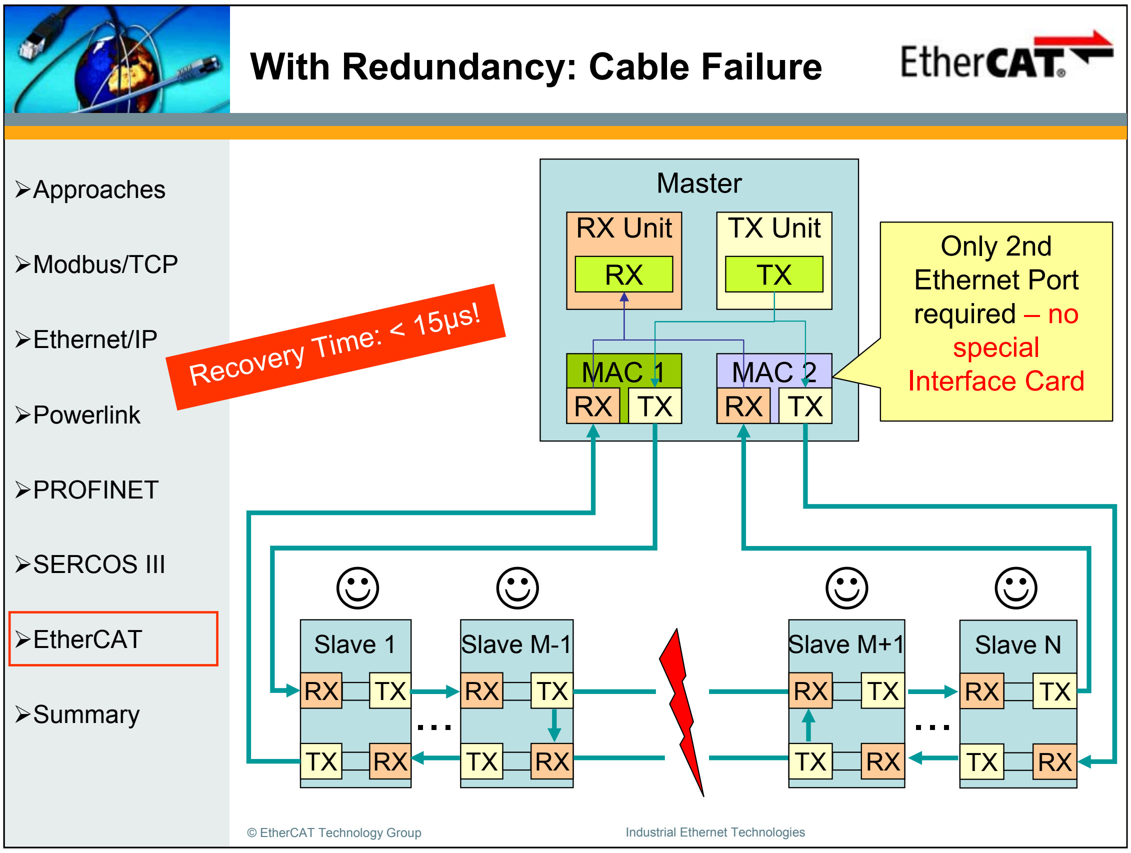
The error probability of the Safety over EtherCAT protocol is low enough, that the protocol itself meets SIL 4 requirements. However, devices implementing this protocol typically meet SIL 3 – and thus KAT 4 of EN 954-1.



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.



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: redundancy.

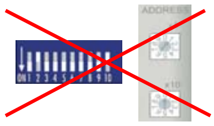
With EtherCAT even without special hardware in the master: a second Ethernet port is sufficient. All slave device with two (or more) EtherCAT ports support the cable redundancy feature anyhow.

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 device exchange at run time (hot swap) is feasible as well.

EtherCAT is simpler to configure

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary



Addressing:

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

Topology:

- Automatic topology target/actual comparison possible

Diagnosis:

- Diagnosis information with exact localization

Network planning:

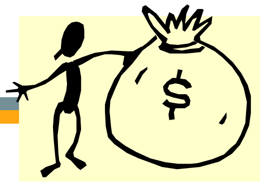
- Performance independent of slave implementation (e.g. stack features, µC performance)
- Performance widely independent from topology (no switches/hubs)
- Performance more than sufficient - therefore no „tuning" required any more, default settings do the job

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.

EtherCAT is lower costs



- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Master:

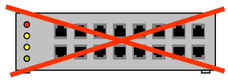
no dedicated plug in card (co-processor),
on-board Ethernet Port is fine

Slave:

- low cost Slave Controller
- FPGA or ASIC
- no powerful µC needed

Infrastructure:

- no Switches/Hubs required
- Standard Ethernet Cabling



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

EtherCAT: open technology

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Protocol is published completely:
- EtherCAT is IEC standard (IEC 61158, IEC 61784-2, IEC 61800-7, ISO standard (ISO 15745-4) and SEMI standard (E54.20)
- Slave Controllers from several suppliers
- Master Stacks from several suppliers (also open source)
- Supported by the EtherCAT Technology Group
- Foundation: November 2003
- Tasks: Support, Advancement and Promotion of EtherCAT
- Already more than1500* member companies from 52 countries in 6 Continents:
  - –Device Manufacturers
  - –End Users
  - –Technology-Provider
- ETG Offices in Germany, USA, China, Japan and Korea
- Membership is open to everybody

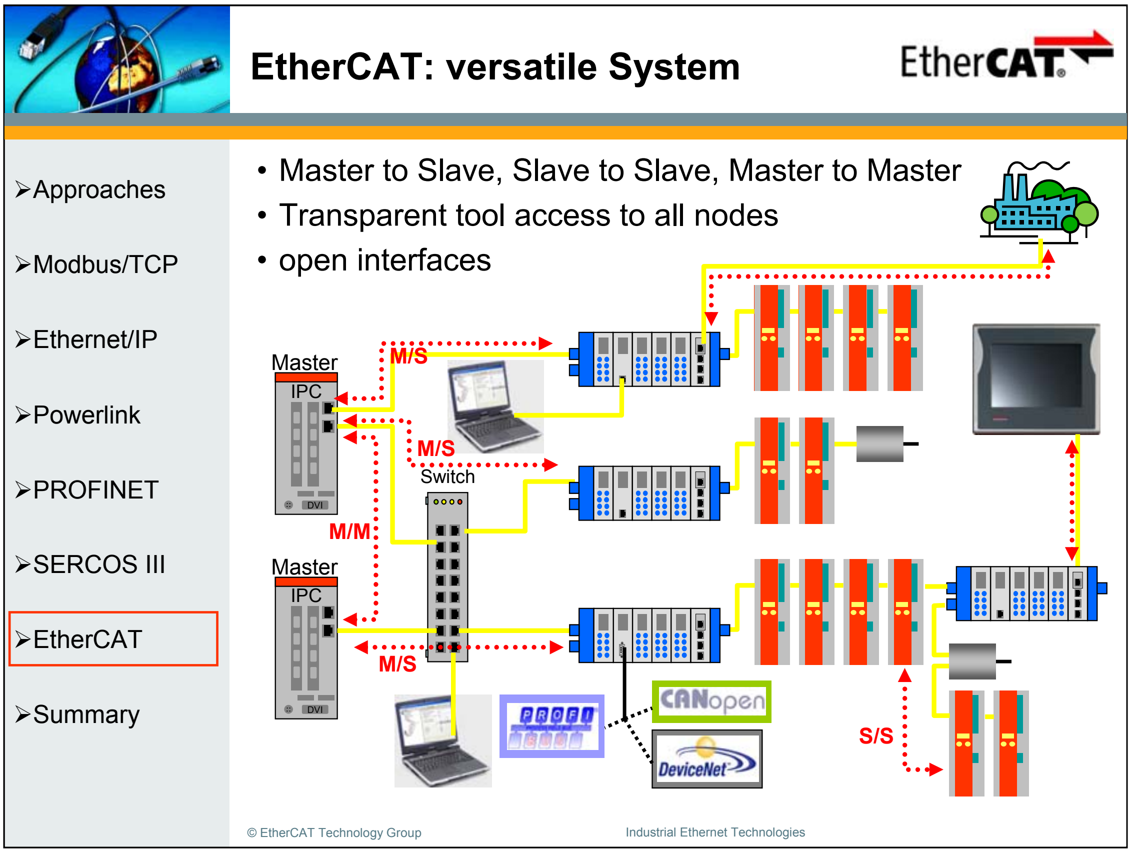
* as of Jan 2011

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.

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 1500 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.

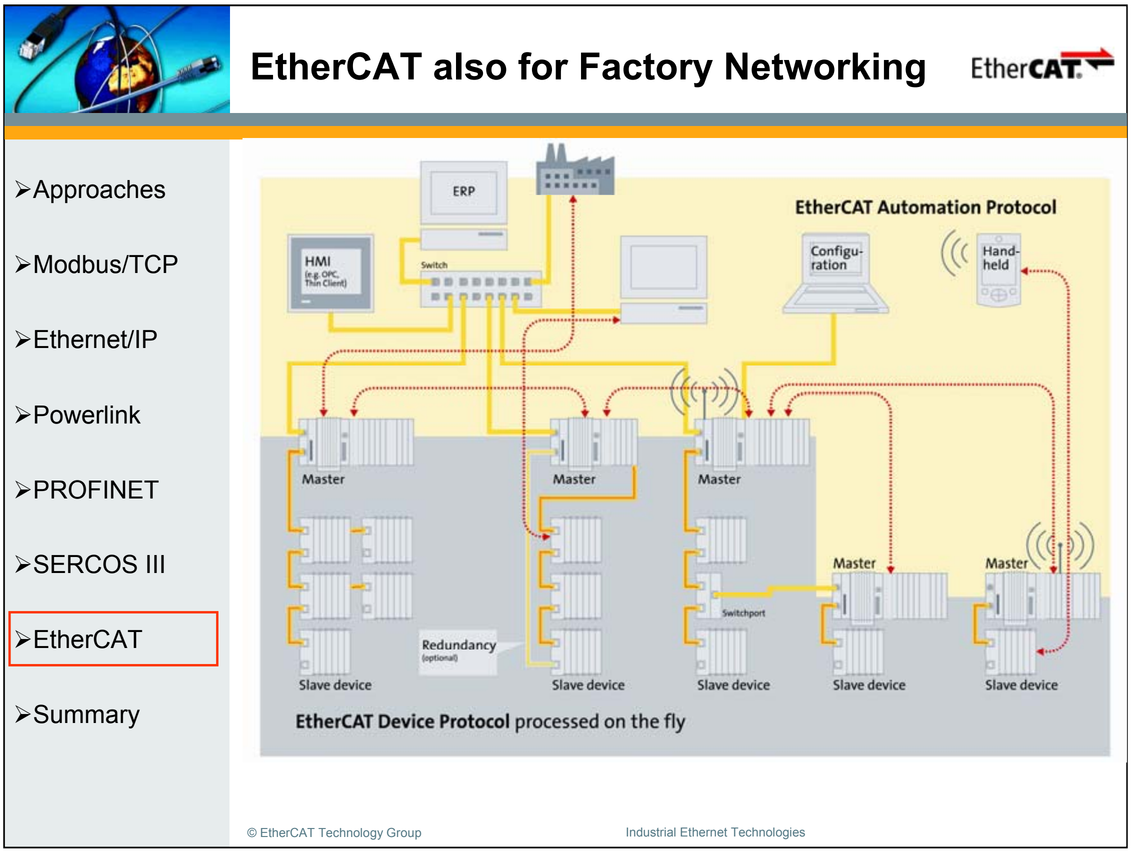


Besides the master/slave communication EtherCAT provides further possibilities: masters can communicate among each other as well as slave devices.

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:

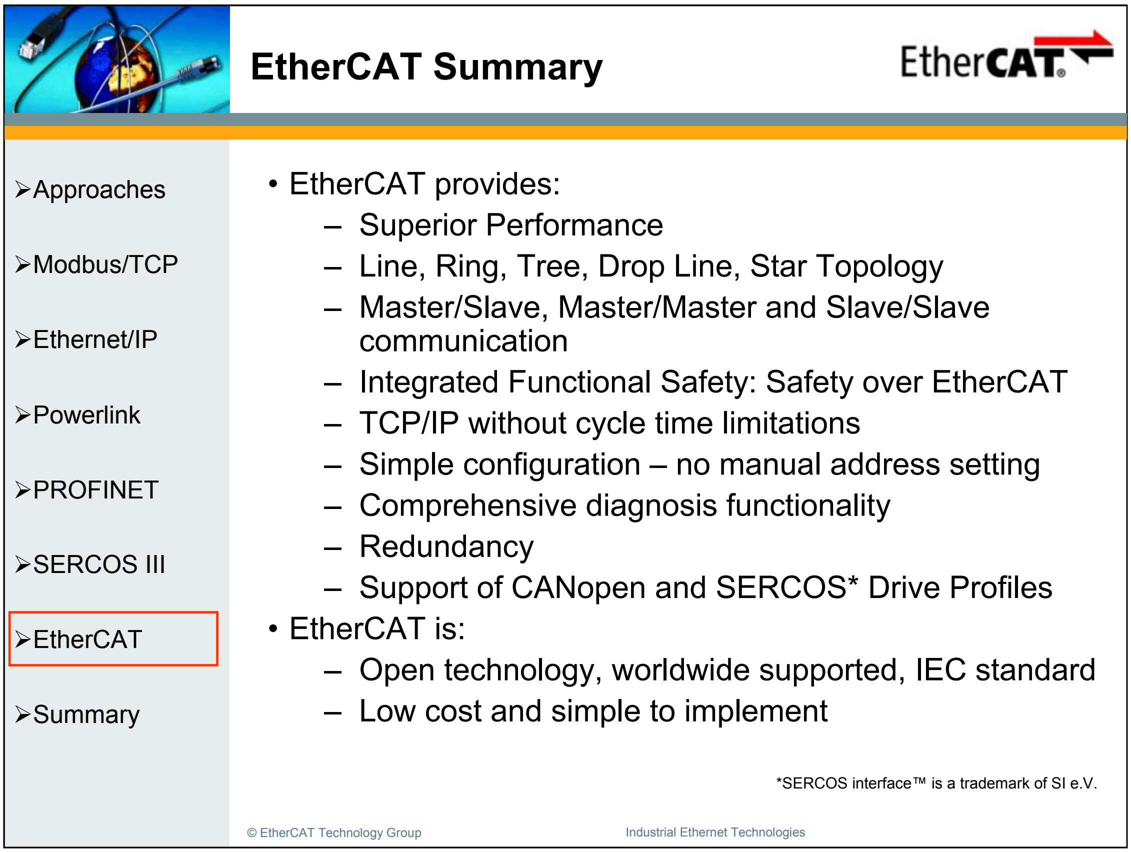
Topology independent two cycles are used for slave to slave communication. In most cases the corresponding delay time is not critical at all – in particular if one considers that EtherCAT is even at twice the cycle time still faster than any other solution….



End of 2009 the EtherCAT protocol portfolio was enhanced by the EtherCAT Automation Protocol (EAP). As a result, EtherCAT now 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. Now the ETG has 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.

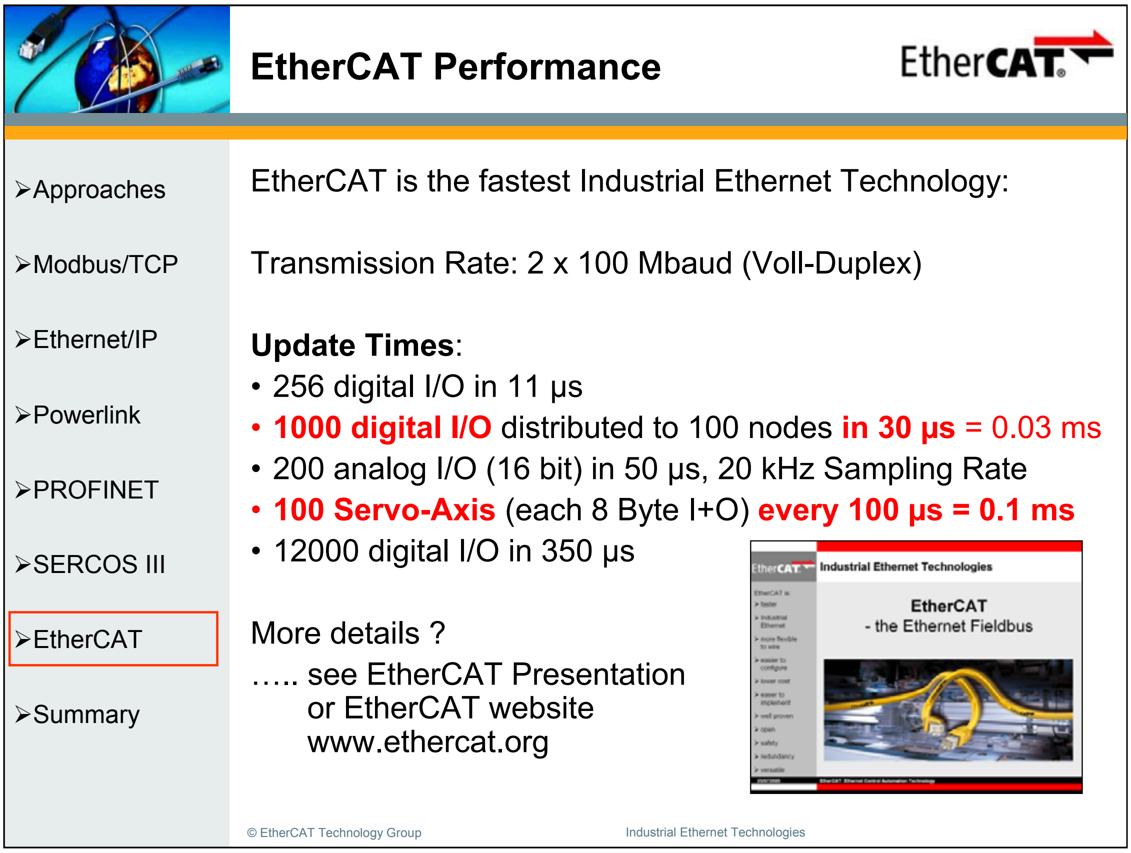


EtherCAT typically is chosen for one or more of these three reasons:

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

For more information regarding EtherCAT please go to

www.ethercat.org



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.

Stack Performance Comparison (I)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- 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

 Industrial Ethernet Technologies

- Most performance comparisons only look at the network itself up to the slave controller chips, and neglect the stack performances.
- However, the stack performance is crucial when looking at the overall network system performance
- Softing is using the eCos RTOS on the Softcore CPU that runs the stacks
- The stack times were measured from the interrupt that is generated at the reception of the Ethernet frame at the IP core until the data is made available to the application at the application interface (stack API).

Stack Performance Comparison (II)

➢Approaches

➢Modbus/TCP

➢Ethernet/IP

➢Powerlink

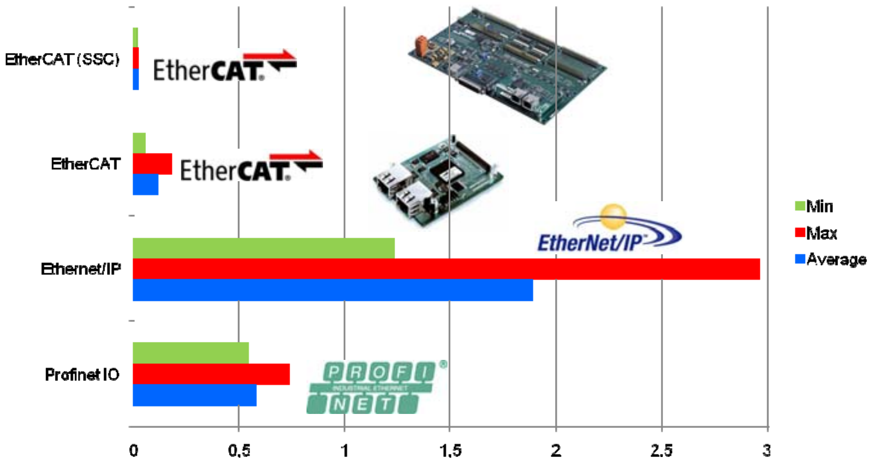
➢PROFINET

➢SERCOS III

➢EtherCAT

➢Summary

- Softing stack performance data shown in a diagram,
  + Beckhoff EtherCAT Slave Sample Code (SSC*)



* SSC Stack Delay time measured on EL9800 EtherCAT Evaluation Kit using the 10 Mhz Serial Process Data Interface and a 40 MHz 16 Bit PIC CPU; 2 Byte Output Data, min 15µs, max 20µs

- 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

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Performance	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power- link	ProfiNet IRT	Sercos III	Ether- CAT
Cycle Time	--	--	-	o	+	+	++
Synchronicity	--	-- + (CIP sync)	--	o	+	+	++
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 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. 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 and Powerlink the jitter depends on the communication jitter of the master, with Profinet-IRT it depends on the number of cascaded switches. All three technologies claim a jitter of <1µs – as does CIPsync.

Throughput if 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. Sercos-III suffers from the delay introduced by large no. of cascaded switches (in Realtime Mode).

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Wiring	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Topology Flexibility	--	--	--	+	+	-	++
Line Structure	--	--	--	o (10)	o (~25)	+ (511)	++ (65535)
COTS Infrastructure Components (Switch, Router, Connector etc.)	++	+	o	o (no Switch)	--	-	+

 Industrial Ethernet Technologies

Topology Flexibility: EtherCAT supports line, tree, star, ring, drop lines without practical limitations on number of nodes and hardly any influence on performance. Sercos-III: line and ring only. Profinet IRT: line, tree, star, drop lines, but limited no. of nodes and strong interdependency between topology and performance. Powerlink: line, tree, star, drop lines, but strong limitation due to hub delays.

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. 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.

RTE Technology Comparison

- Approaches
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Features	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Slave to Slave Communication	✓	✓	✓	✓	✓	✓	✓
TCP/IP & other Internet Technologies supported	✓	✓	✓	✓	✓	✓	✓
Cable Redundancy	(switches with spanning tree)	✓	✓	✓	o*	✓	✓
Safety	-	✓	✓	✓	✓	✓	✓

* planning algorithm extremely complex, no known implementation

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: 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.

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). Profinet IRT aims for redundancy (MRP is not suitable for IRT), but the planning algorithm for a redundant IRT topology is so complex that its implementation is questionable. 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 availability: Safety over EtherCAT products are shipping since end of 2005.

RTE Technology Comparison

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

Costs	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Node Interface Costs	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.)	++ (no Switch)	++ (no Switch)

* Requires Special Master Card with Co-Processor

 Industrial Ethernet Technologies

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.

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.

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, Powerlink, Profinet IRT 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) 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

- Approaches
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- EtherCAT
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Strategic Topics (I)	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power- link	ProfiNet IRT	Sercos III	Ether- CAT
Size of supporting organization	++	+*	+*	o	+*	o	++
Worldwide User Group?	++	++	++	o	++	+	++
Time to Market	++	++	++	o (V3/Gbit?)	o (new IRT Version in 2011)	o	++

* Not all ODVA or PTO/PNO 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 January 2011, the EtherCAT Technology Group has 1540 member companies (membership free of charge*), Sercos International has 51 member companies**. EPSG (Powerlink) has 66 member companies***. ODVA has 268 member companies****. Profibus International (PI) consists of 25 regional organizations with a total of over 1400 members (Siemens is 25 x member), but their membership is predominantly fieldbus (Profibus) related. ModbusTCP is so widely used that the Modbus IDA membership of 68 members***** only does not reflect its acceptance.

Worldwide User Group: ODVA and PI 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

Time to Market: Modbus/TCP is available since 1999. Ethernet/IP since 2001. Profinet RT has entered the market in 2005. Powerlink V3 is expected for 2011, Powerlink V2 is available since 2007, the B&R proprietary version 1 is shipping since end of 2002. The next generation Profinet IRT chips are expected for 2011, first Sercos-III V1.1 devices were shipped end of 2007. EtherCAT is used in series applications since end of 2003.

* 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 as of Jan 2011.

***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 Aug 2010

***** according to www.modbus-ida.org as of Jan 2011

RTE Technology Comparison

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Strategic Topics (II)	Modbus/ TCP	Ethernet /IP	ProfiNet RT	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Special Hardware used?	++	++ - (CIP Sync)	++	O (S: HUB FPGA)	- (M+S)	- (M+S)	O (S)
Adoption Rate?	++	+ - (CIP Sync)	+	O (2003-2006) - (since 2006)	O (IRT) -- (IRT+)	O	++
International Standardization	+	+	+	+	+	+	+

 Industrial Ethernet Technologies

Special Hardware Used: Modbus/TCP, Ethernet/IP (not: CIPsync) + Profinet RT can be implemented with standard hardware chips. For Powerlink, the integrated hub is implemented as FPGA, since 100MBit/s hub chips are obsolete. Profinet IRT and Sercos-III requires special chips in master 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 IRT+ (Profinet V4). Sercos-III 1.1 started shipping in December 2007. EtherCAT: large selection of master and slave devices from large variety of vendors (e.g. 58 different servo drive vendors, 38 I/O device vendors, over 70 master vendors); more than 900 implementation kits sold, many more devices expected soon.

International Standardization: As far as international standardization is concerned, all listed technologies can be considered to be even. Since Oct 2007, all are part of IEC 61158 and IEC 61784-2

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
Sercos-III: CPF 16, IEC 61158 Type 19
EtherCAT: CPF 12, IEC 61158 Type 12

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