industrial ethernet book
Enhancing Automation and Internet Connectivity

Industrial Ethernet Book Issue 29 / 31

Standards-based real time Ethernet now off-the-shelf

Almost every major user organisation is currently propagating its own Ethernet-based real-time method. This raises questions as to the differences in terms of modes of operation, architecture, performance capability and - ultimately - conformity to the Ethernet TCP/IP standard. We intend to show that Ethernet can deliver real-time performance and still conform fully to established TCP/IP Ethernet standards.

By Klaus Zwerina

The question of whether Ethernet will penetrate right down to the field level has become closely linked to the real-time issue. Real-time means that an event must occur within a defined maximum time span. Consequently, an automation system must exhibit a deterministic time response. This requirement initially appears to put a bar on the use of Ethernet, of which the collision response (CSMA/CD to IEEE 802.3) fundamentally leads to a nondeterministic behaviour. The last two to three years have thus seen various automation companies developing work-arounds to make Ethernet suitably deterministic.

Real-time requirements vary widely, and always depend on the application under analysis. We are going to take real-time processes at their most exacting level - namely those required for motion control applications. These demand response times between the controller and the drives of just a few milliseconds. We are going to investigate five different Ethernet-based real-time methods: Ethernet/IP, Ethernet-Powerlink (EPL), Profinet-IRT, Sercos-III and EtherCAT.

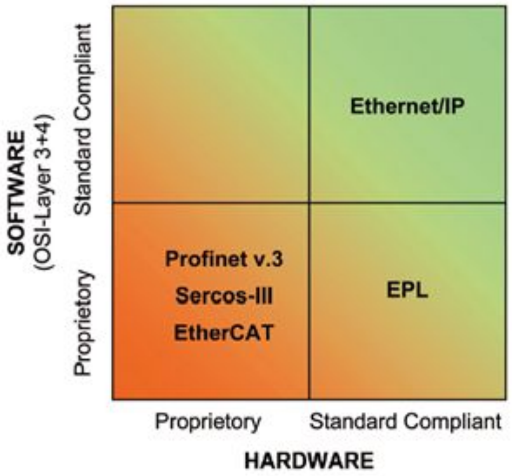
Hardware and software differences

The various real-time methods differ fundamentally in the extent to which they conform, or do not conform, to the Ethernet TCP/IP standard.

With regard to hardware, Profinet-IRT, Sercos-III and EtherCAT (in the slaves) use special hardware (asic or FPGA) not found on standard Ethernet controllers. This means these real-time methods depend for their operation on the manufacturers' custom silicon. Conversely, EPL and Ethernet/IP use standard Ethernet controllers as the hardware platform.

In terms of network software (OSI layers 3 and 4), Profinet-IRT, Sercos-III, EtherCAT and EPL use dedicated software stacks. Only Ethernet/IP is based entirely on Ethernet TCP/IP standards with conformance on both the hardware and the software side.

The real-time methods based on Ethernet standards have the advantage of profiting directly from advances made through Office Ethernet development. This was also one of the original reasons for rolling out Ethernet industrial applications in preference to the use of proprietary field buses. Today, for example, all five real-time methods are based on Fast Ethernet. Ethernet/IP and EPL are able to capitalise directly from the transition to Gigabit Ethernet and the associated leap in performance, because both methods run over standard Ethernet hardware.



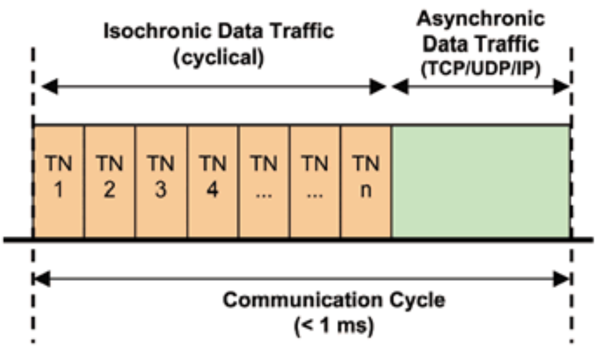
Classification of Ethernet real-time methods

Roads to determinism

In order to make Ethernet real-time capable, it must be taught to respond in a deterministic way. To this end, the various Ethernet-based real-time methods use different mechanisms.

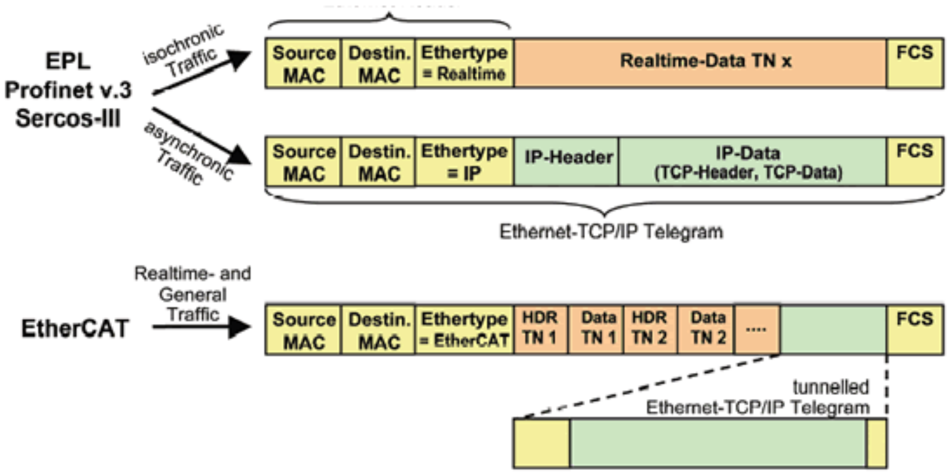
Ethernet-Powerlink (EPL) is a cycle-based real-time system. It superimposes a time slot mechanism over the CSMA/CD mechanism. The master (controller) successively polls the slaves (drives) within an allocated communication cycle period. The remaining cycle time is left over for asynchronous data traffic, such as for configuration of the devices. Data transport occurs via a standard Ethernet telegram, with the Ethertype set to 'Powerlink' for the real-time data and to 'IP' for the general data. All stations (master and slaves) within a real-time segment interconnect via a standard Ethernet hub.

A special gateway links the real-time segment to the standard Ethernet environment. The IEEE1588 time synchronisation method permits different real-time segments to be synchronised in a highly precise way, such as might be required for the control of multiple robots.



Time slot mechanism in EPL, Profinet-IRT and Sercos-III

Like EPL, Profinet-IRT for hard real-time also uses a time slot mechanism. Accordingly, a certain bandwidth is reserved for the real-time data traffic (IRT = Isochronous Real Time), and the remaining bandwidth is available for asynchronous communication. The stations are interfaced via special switches integrated into the field devices rather than by standard Ethernet switches. These special integrated switches comprise a special asic controlling two or four ports at a data rate of 100Mbps.



Simplified view of the structuring of various telegrams

Sercos-III uses the Ethernet physics (100Mbps) and the Ethernet telegram while retaining the existing Sercos mechanisms. Sercos-III is likewise based on a time slot mechanism in which bandwidth is reserved for the isochronous (real-time channel) and asynchronous (IP channel) data traffic. Sercos-III works without hubs or switches. Each station has a special integrated asic or FPGA with two communication ports, enabling it to be connected via line or ring topology. Eliminating the switches means shorter cycle times can be implemented, though at the cost of flexibility in the network topology. The synchronisation between different real-time segments, such as between two robot controllers, is hardware-based. Special gateways/PLCs separate a real-time segment from the standard Ethernet environment.

EtherCAT uses the telegram structure of Ethernet, but with an entirely different basic mode of operation. Within a communication cycle a telegram is not sent to each station separately, but rather a single Ethernet telegram runs trough all stations/slaves. The data area in the Ethernet telegram divides into sections for real-time and general data. In the real-time data area the headers and process data of all stations are defined in consecutive sub-telegrams, thereby increasing the user data rate in the protocol (in motion control applications the user data rate in the shortest Ethernet frame of 64 bytes is usually below 15%). The slaves feature special asics or FPGAs which convert the incoming Ethernet-framed data into an internal so-called E-bus. As the EtherCAT slaves are only able to interpret EtherCAT frames, general data is tunnelled in EtherCAT frames in order to guide it through slaves. If a general data packet is too large to be transferred in one cycle, it is distributed across multiple EtherCAT frames. Tunnelling and de-tunnelling takes place in the master (Virtual Ethernet Switch) or in slaves with gateway functionality. The entire protocol processing is hardware-based. The slaves do not treat incoming Ethernet telegrams in the normal fashion - interpreting the contents and then copying the process data for onwards transmission. Instead, the EtherCAT slaves read and write their process data from and to the predetermined location in the telegram while the telegram is passing through the slave. The EtherCAT mechanisms permit extremely short cycle times to be implemented.

Ethernet/IP is the only one of the real-time methods described to be based entirely on Ethernet standards. In contrast to the other protocols, Ethernet/IP is not cycle-based but time-based, meaning that it merely requires that control commands are received by the field stations in time. This means the performance of the overall system can be made independent of network performance. Real-time delivery is safeguarded by three mechanisms which are all standards-based: UDP, Quality of Service (prioritisation) and IEEE1588.

In the transport layer, the UDP protocol is used, because it is simpler and faster than TCP. The real-time data packets are assigned a higher priority than the general data packets. As a result, the real-time data is forwarded before the general data in the switch. The IEEE-1588 standard defines a method for high-precision synchronisation of real-time clocks in distributed systems. All actions in the devices are coordinated with the common system time. The master sends the control commands with a valid execution date to the slaves. The exact time of sending is not important, they merely need to be sent in good time.

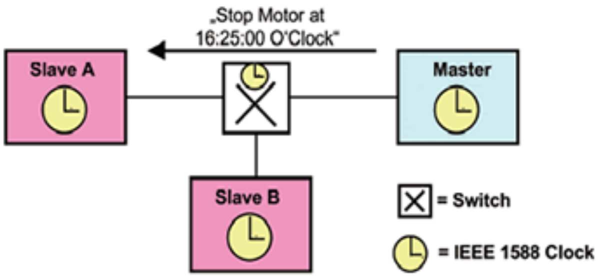
More proprietary=faster!

So how do the various real-time methods differ in their real-time behaviour? The fundamental point should be made that real-time behaviour is not an absolute, but always depends on the context. The table compares the real-time behaviour of an application in which 100 axles need to be controlled synchronously. The two criteria analysed in terms of performance measurement are the response time (cycle time) and the jitter (that is, the variation in response time).

Organization	**Response time** (for 100 axles)	**Jitter**	**Data rate**
Ethernet/IP CIPSync ODVA	1ms	<1ms	100Mbit/s
Ethernet Powerlink EPSG	<1ms	<1ms	100Mbit/s
Profinet-IRT PNO	<1ms	<1ms	100Mbit/s
Sercos-III IGS	<0.5ms	<0.1ms	100Mbit/s
EtherCAT ETG	0.1ms	<0.1ms	100Mbit/s

Real-time comparison of the various real-time methods

The first observation is that all five real-time methods are powerful in performance, with response times of less than or equal to one millisecond. Ethernet/IP, EPL and Profinet-IRT are similar in magnitude; Sercos-III and EtherCAT are faster and more precise than the other three real-time methods by an order of magnitude. The fundamental finding is that the more "proprietary" a real-time method is, the better will be its real-time behaviour. The selection criterion for the end-user is not, however, the maximum performance capability of a real-time method, but whether a specific real-time method meets the requirements of a specific application. In most application cases response times of a few milliseconds are adequate, enough for precise control of multi-axle drives for example. Even the specialist field buses for servo drives such as Sercos-II or Profibus DP do not necessarily perform better than the new Ethernet-based systems. The table below shows how many station pollings, measured in numbers of packets per millisecond, would be theoretically possible within a time unit (the actual throughput rate is lower because of processing and latency times).



Distributed IEEE 1588 clocks in Ethernet/IP

	Transfer rate	**Packet size** *with 8 bytes of user data*	**Theoretical packet throughput**
Profibus DP	12 Mbit/s	19 bytes	79 packets/ms
Sercos-II	16 Mbit/s	14 bytes	142 packets/ms
Ethernet	100 Mbit/s	72 bytes	174 packets/ms

Comparison of theoretical packet throughput: field buses vs. Ethernet

The theoretical packet throughput rate for Ethernet is about the same as for Sercos-II, and is around twice that of Profibus DP. (Because with Sercos-II a packet passes through all stations, its relative advantage increases the more stations that are connected).

Vertical IT integration

Ethernet/IP and Profinet are universal communication systems and their special add-ons - CIPsync and Profinet-IRT respectively - allow use for motion control applications. Systems based on EPL and Sercos-III are especially suited to multi-axle applications. EtherCAT provides an interesting route for very fast I/O delivery and operation. All the five Ethernet-based real-time methods have one decisive advantage over traditional motion control field buses: they support Internet technology and so allow vertical IT integration. Web technologies, in particular, are playing an increasingly important role in automation.

The deployment of Web Services down to field level is enabled by supporting (in some cases by way of an indirect route) the TCP/IP protocol stack on which HTTP is defined. In this way, for example, a controller with an embedded web server can use the HTTP protocol to send operator control and monitoring data in HTML code to a HMI terminal where the information can be displayed by a web client (browser). Freely available web browsers can thus make the use of special software superfluous.

These real-time methods also have Ethernet physics (OSI layer 1) in common. This means that all the methods can use standard Ethernet cables and connectors. The methods do, however, differ widely at OSI layer 2, the Data Link Layer. Here, EPL and Ethernet/IP offer the advantage of being able to use standard Ethernet controllers, whereas the other three methods rely on proprietary silicon. On the software side (OSI layers 3 and 4), only Ethernet/IP conforms to the Ethernet TCP/IP standard; the other four methods require special software stacks. Ethernet/IP has the advantage that it is entirely based on Ethernet standards, though it does require somewhat more care and attention in network planning than other real-time implementation methods.

Conclusion

In order to make Ethernet real-time capable, non-conformance to the Ethernet TCP/IP standard is not necessarily a consequence. The response time of an overall communication system typically depends less than 10% on the network; most of the system delay stems from the controller (the program cycle) and the delays of the S/As. The following Ethernet standard-conforming mechanisms enable real-time requirements for most applications - including for motion control - to be met today:

- Switched full-duplex Ethernet
- Fast Ethernet or Gigabit Ethernet
- Transport protocol UDP instead of TCP
- Quality of Service (data prioritisation)
- Network segmentation via VLAN
- Time synchronisation via IEEE1588

Our own company for instance offers industrial-graded switches meeting all these requirements. The appeal of open (as in standardconforming) methods is not only their independence from any single- manufacturer, but also that they enable end-users to profit directly from advances brought about by office automation in terms of performance and/or price. The use of Gigabit switches, for example, can increase network performance using the Ethernet/IP method by a factor of ten.

Dr. Klaus Zwerina, head of marketing, Hirschmann Automation & Control GmbH, Neckartenzlingen

---

Source: Industrial Ethernet Book Issue 29 / 31