Flexible network architectures, enabled by EtherCAT

Factory automation integrates systems from different disciplines for the purpose of controlling and managing production orders: production planning systems interact with recipe control at the plant management level, which in turn affects the machine and system control, ultimately resulting in control of the actual production process. This requires communication systems, which are suitable for the wide range of sensor/actuator communication requirements right up to production control level on the one hand, and on the other, can easily communicate with each other across the entire network. Beckhoff has a policy of using open technologies in its PC-based control systems, i.e. EtherCAT for the field and process control level and OPC UA for vertical integration. In other words, Beckhoff has already been meeting the requirements of integrated information exchange from the sensor to the management level and into the cloud for many years, as currently discussed in the working groups of the Industry 4.0 associations, for example.
Within machines and machine modules the focus is on the exchange of I/O data from sensors and actuators, including drives. The general requirements for a precise implementation of high-speed applications are proper real-time and synchronization capabilities as well as short cycle times. The horizontal communication between machines and production units is also subject to real-time requirements. The cycle times may be around 100 milliseconds or significantly less, if the communication is to be synchronized with the production processes. Vertical communication is used for integrating a production unit/line with a higher-level management system, e.g. for production control (ERP). In this case temporal requirements are much “softer”, in the seconds to milliseconds range. At this level, however, several other aspects are relevant, including: security, authentication, alarming, trending, historical data, service-based communication, etc.

Over the years, the OPC UA protocol as defined by the “vendor neutral” OPC Foundation has developed into a widely accepted communications solution for applications without demanding real-time requirements. In conjunction with existing advanced fieldbus systems, companies can therefore use the OPC UA protocol as a versatile link between the MES layer and the production level. Beckhoff recognized the relevance of OPC UA at an early stage. It demonstrated an OPC UA-based prototype control system at the first developer conference in 2006 and has been collecting experience in the field with this technology since 2008. Today, each Beckhoff controller can be equipped with OPC server or client functionality.

In cases where demanding real-time requirements must be satisfied, the open EtherCAT protocol, which was introduced by Beckhoff in 2003 and has been promoted to vendors from around the world by the EtherCAT Technology Group (ETG) since then, is particularly advantageous. Ten years later, the Beckhoff product portfolio includes more than 250 different devices with EtherCAT interfaces, not counting all the PC-based controllers with Ethernet ports, which can be used as an EtherCAT master when running TwinCAT automation software.

At the field level, the familiar EtherCAT device protocol – often (and also below) referred to simply as the EtherCAT protocol – is used for I/O communication within a machine or a machine component. Special features are, among others, highly accurate and deterministic performance with very low cycle times (down to <100 μs), precise synchronization for drive and measurement applications and low connection costs, facilitating use of the technology down to I/O level. The EtherCAT Automation Protocol (EAP) meets the requirements for protocols at the control and production control levels, thus strengthening the horizontal and vertical integration of EtherCAT into the overall system.

Wide range of EtherCAT topologies

With EtherCAT it is not the bus system that determines the network topology, but the system structure. No switches or hubs are required, which means there is no limit with regard to cascading. With EtherCAT there are virtually no restrictions in terms of the bus topology: line, tree, star and any combination thereof are possible, with almost any number of nodes.

For system wiring the combination of line and branches or stubs is particularly beneficial: the required branch ports are directly integrated into the Bus Couplers, e.g. EK1100. Cost-effective industrial Ethernet cables can be used for the 100BASE-TX mode with a length of up to 100 m between two
devices. For longer distances, fiber optic cables are used to establish EtherCAT connectivity. Modular machines or tool changers require an option to switch network segments or individual devices on or off during operation. The EtherCAT slave controllers already include the basic capabilities for this hot-connect functionality: if a partner station is removed, the respective port is closed automatically, so that the remaining network can continue to work undisturbed. Very short detection times (< 15 μs) ensure smooth switch-over. The Beckhoff EtherCAT master supports the hot-connect function for equipment groups or individual units. The user can choose this functionality through simple configuration.

For line redundancy the line is complemented to form a ring. On the TwinCAT master side all that is required (in addition to software activation) is a second Ethernet port. Slave devices already support this functionality in any case.

Naturally, EtherCAT also supports web communication technologies: the Ethernet over EtherCAT (EoE) protocol can be used for any Ethernet data traffic in the EtherCAT segment. Within the EtherCAT segment, standard Ethernet devices are connected via so-called switch-port terminals, e.g. the EL6614. The Ethernet frames are tunneled via EoE. The switch-port unit ensures correct “clocking” of TCP/IP fragments in the EtherCAT traffic, thus avoiding any negative impact on the real-time communication in the network.

TwinCAT, as an EtherCAT master, acts as a layer-2 switch, which forwards frames to the respective devices via EoE, based on the MAC address information. All web technologies can therefore also be used in the EtherCAT environment: integrated web server, e-mail, FTP transfer, etc.

**Integration of other bus systems**

EtherCAT also offers high flexibility in the network architecture down to the I/O level. Thanks to the available bandwidth it is possible to use conventional fieldbus connections as subordinate systems via EtherCAT gateways. This can be helpful for a migration from a conventional fieldbus towards EtherCAT, for example. It enables step-by-step conversion of a system to EtherCAT and integration of legacy devices or automation components that do not (yet) support an EtherCAT interface.

The compact Industrial PC and Embedded PC solutions from Beckhoff are based on this integration. Space for expansion cards is no longer required. In addition to local I/Os, axes and operating devices, complex systems such as fieldbus masters/slaves (gateways), fast serial interfaces and other communication interfaces can be addressed via a single Ethernet port in the PC. The data of the integrated fieldbus are directly available for the master in the process data image.

**System-wide communication with the EtherCAT Automation Protocol**

The EtherCAT Automation Protocol (EAP) defines interfaces and services for an equal exchange of information between controllers (master/master communication) or for interfacing with a central master computer.

The cyclic EAP communication can be handled directly in the user data of an Ethernet telegram, without the need for an additional transport or backup protocol. The EAP therefore enables very efficient data exchange without significant protocol overhead, with cycle times down to the milliseconds range. In cases where data routing within a distributed system is required, the EtherCAT frame can also be transmitted via UDP/IP. Furthermore, acyclic configuration data can
be transmitted via TCP/IP. The precise protocol type is specified in the header of the EtherCAT frame.

The EtherCAT Automation Protocol uses a conventional Ethernet infrastructure and can therefore be transferred via any Ethernet medium, including wireless communication.

The cyclic data exchange is based on the “pushed” or “polled” principle. In “pushed” mode, each communication device (publisher) sends its data cyclically or in a multiple of its own cycle. The receiver (subscriber) can be configured to specify which data should be received from which sender. As usual with EtherCAT, the sender and recipient data are configured via an object directory and process data mapping.

The EAP protocols were introduced in Beckhoff TwinCAT software as early as 2002 at the same time as the RT Ethernet control communication technology and have since been installed in thousands of systems. The open EAP specification is a compatible extension of this concept, which further simplifies system-wide configuration of machine-to-machine communication and enables the easy integration of devices from other manufacturers.

In the engineering environment of the TwinCAT system, the EtherCAT Automation Protocol is configured as an I/O device. A standard Ethernet port, which is interfaced with the real-time control system by the EAP kernel mode driver, is used as the hardware interface. Like for other I/O devices, the input and output variables can be linked in the System Manager, e.g. with a PLC control task or an NC, or directly with other I/O devices, such as a connected EtherCAT system.

To simplify matters further, in the future it will be possible to extend the device-specific configuration to a system-wide configuration with the aid of a central EAP configuration tool. The EAP configurator maps the communication dependencies of all controllers, enables their configuration and subsequently loads the EAP object directories of the individual devices. New communication dependencies, including their internal link with the control task, can be created dynamically.

Therefore, EtherCAT meets all requirements for present and future control concepts. In conjunction with support for vertical communication technologies such as OPC UA, EtherCAT today already offers the technological foundation to act as an enabling technology for the 4th industrial revolution, Industry 4.0.