Visitors to Hannover Messe 2018 had the chance to find out more about the new forms of real-time communication at a detailed demo presentation.

Cloud-based automation: Technology studies by Huawei and Beckhoff

Exploring new real-time communication technologies for industrial automation

Secure, standards-based data and information exchange – not just in and across devices, machines and services, but also within production lines and between manufacturing facilities – is a core challenge facing Industrie 4.0 and IoT initiatives today. PC-based control, with its open architecture, is an ideal fit when meeting this challenge. Beckhoff, as a technology-driven company, is constantly exploring new avenues with the potential to advance industrial automation – hence the company's current collaboration with telecom specialist Huawei on switching, routing and 5G mobile communication technology.

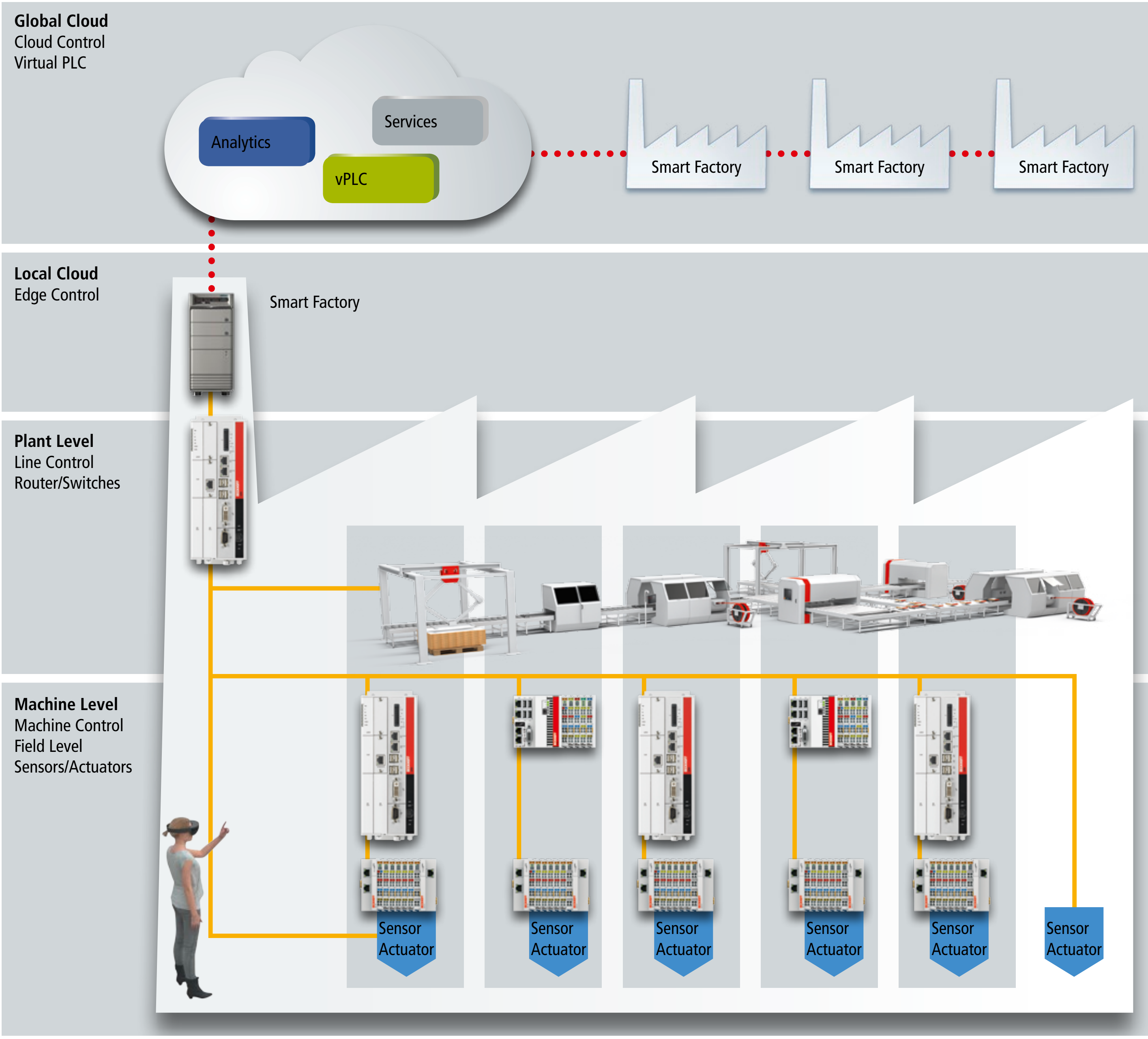

Figure 1: Communication requirements in cloud-based automation

Based on the pioneering role of Beckhoff in the implementation of open control technology, users benefit from the interoperability of the company's PC-based control systems with third-party systems. EtherCAT, a globally recognized communication standard, allows compatible devices from a range of vendors to integrate and interoperate at the field level. Interoperability is further supported by the OPC UA data exchange standard, which enables vendor and platform-independent communication in machine-to-machine interaction and in vertical business processes.

Industrial automation involves moving machine and production data from the I/O level to the cloud (see Figure 1). A unified, deterministic, low-latency communication system spanning these and intervening levels is essential in enabling advanced production control tasks, which is why Beckhoff is evaluating the capabilities of a range of next generation LAN, WAN and mobile communication technologies.

The collaboration with Huawei focuses on switching and routing methods and on 5G mobile communication technology. The goal is to reserve bandwidth by means of simple configuration to guarantee low latency and jitter. The technologies being explored serve purely to achieve real-time data routing capability on a heterogeneous network. The EtherCAT communication protocol itself remains intact, allowing seamless integration of existing EtherCAT segments as well as continued use of the huge variety of available EtherCAT devices.

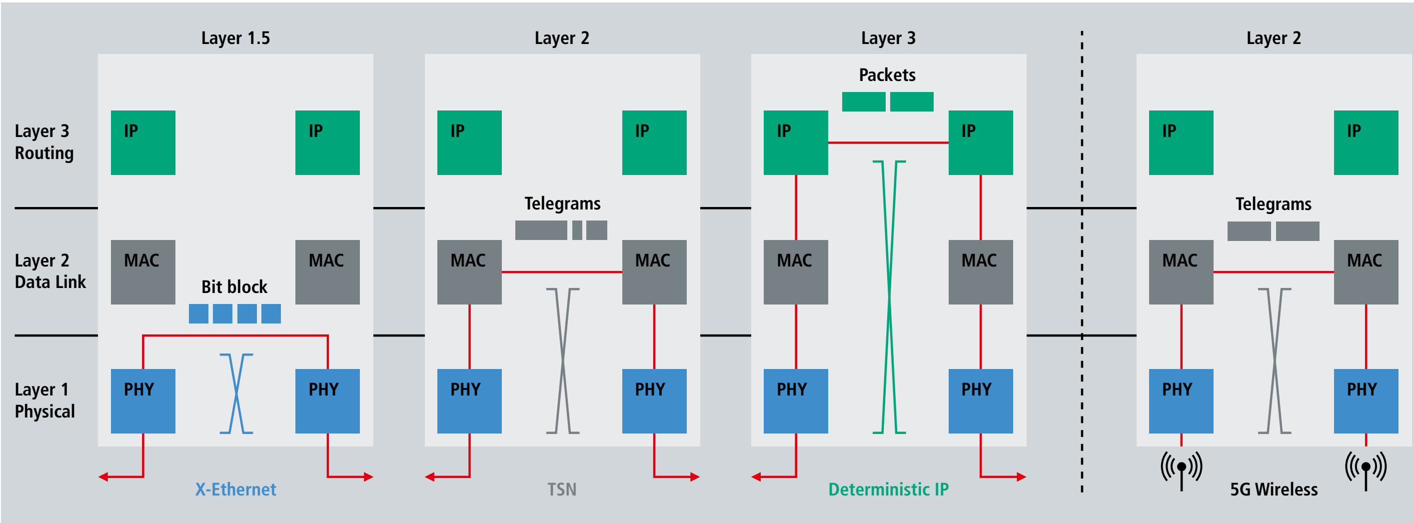

Figure 2: Switching and routing technologies

The way that EtherCAT works makes it particularly well-suited to integration in heterogeneous networks: Generally, all of the nodes on an EtherCAT segment can be reached with a single Ethernet frame. This one frame simply needs to be routed between a remote EtherCAT controller and the segment on which the EtherCAT devices are located, rather than sending a separate frame to each node on the segment in the way that other technologies require.

To date, three new communication technologies have been examined as part of the collaboration:

- X-Ethernet: The IEEE 802.3 Ethernet standard specifies how symbols are encoded between the physical layer and the MAC controller. It is at this encoding level that data streams are passed between X-Ethernet switches – at Layer "1.5" of the ISO/OSI model, so to speak.
- Deterministic IP: Deterministic latencies of less than 50 µs can be achieved by reserving bandwidth on IP-based networks (Layer 3).
- 5G wireless: 5G mobile technology promises not just higher data throughput but also lower latencies (in the region of 1 ms) and more reliable transmission. Routing is usually performed at the IP level, but approaches for routing between endpoints on Layer 2 exist as well.

Figure 2 shows the technologies as evaluated and how they map to the ISO/OSI model. Time-sensitive networking (TSN) technology fits in seamlessly here as well. The use of EtherCAT in a TSN network has been described in a white paper by the EtherCAT Technology Group (ETG), and the relevant specifications are set by the ETG as well.

Technology studies: Early identification and assessment of innovations' potential

- Technology evaluation: For Beckhoff, it is important to explore early on whether, and to what extent, innovations in the area of information and communication technology (ICT) offer potential that can deliver improvements throughout the communication chain, from the cloud to the I/O level, for the benefit of Beckhoff customers.
- Huawei invited Beckhoff to take part in the technology studies because they wanted to collaborate with a company that they regarded as a leader in automation.
- EtherCAT is an exceptionally powerful industrial Ethernet communication system that is ideally suited to pairing with heterogeneous network technologies such as Huawei's new X-Ethernet and Deterministic IP solutions, as well as TSN.
- X-Ethernet transmits fixed-length bit blocks instead of frames, which enables easier network configuration than with TSN.
- Compared to TSN, Deterministic IP offers the benefits of a real-time routed network, capable of supporting efficient communication between manufacturing halls, cells and subnets.
- The purpose of evaluating 5G wireless was, first, to help Huawei, an important global manufacturer of ICT chips and endpoint devices, understand the requirements involved in industrial-grade wireless communication and, second, to enable Beckhoff to gain valuable insights into the performance potential of tomorrow's 5G technology.

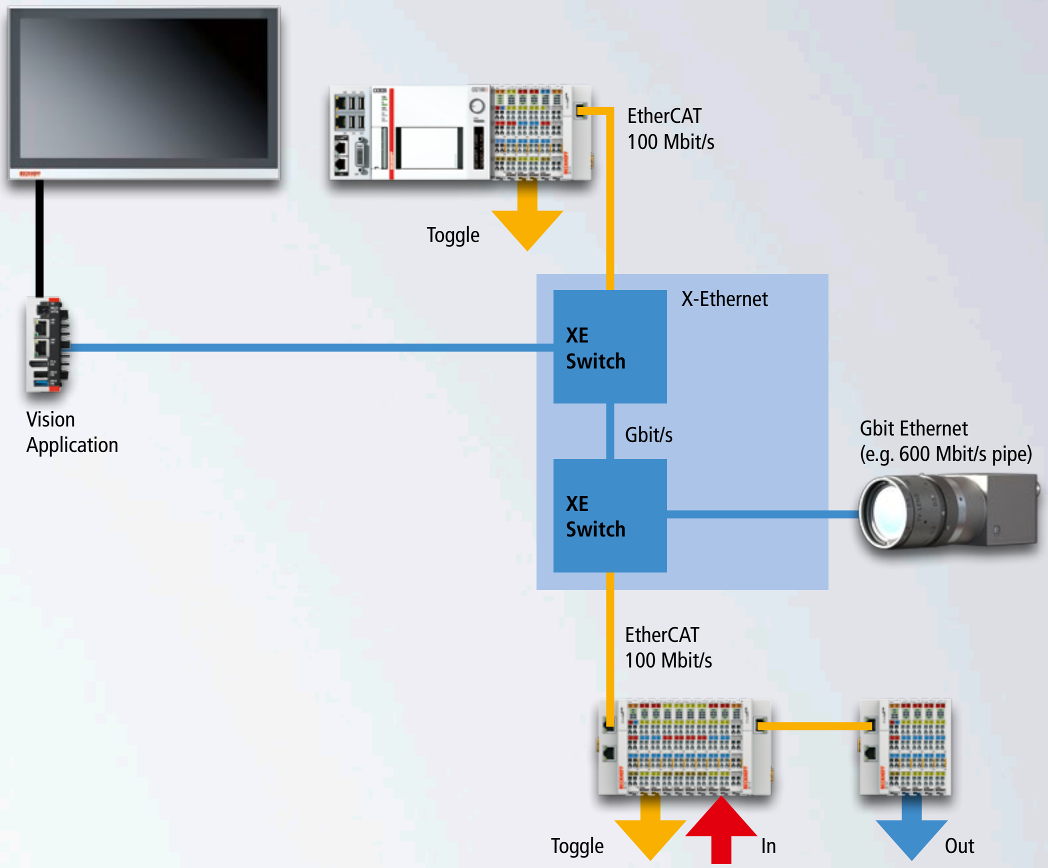

Figure 3: X-Ethernet demonstration setup

X-Ethernet: Layer 1,5 switching

X-Ethernet works with bit blocks of a fixed length that are transmitted from one port to another on the Physical Coding Sublayer (PCS). The blocks are PCS-encoded (e.g. 8B/10B or 64B/66B) as fragmentation blocks according to the IEEE 802.3 standard. Because the bit blocks have a fixed length, jitter is exceptionally low (< 100 ns). In addition, jitter is not affected by the variable frame length in the way it generally is in Layer 2 switching. In an X-Ethernet switch, so-called pipes are configured at the data rate required by the data stream. No store-and-forward switching or decision-making based on MAC/IP table lookup is necessary; no congestion will occur in output buffers.

This principle is best illustrated with an example: The setup in Figure 3 above shows a 100 Mbit/s pipe running from the EtherCAT master, over two X-Ethernet switches, to the EtherCAT segment. A 1 Gbit/s link is provided between the X-Ethernet switches. This allows a video stream pipe for image processing, for instance, to be set up through the switches, parallel to the EtherCAT data traffic. A residual bandwidth of 900 Mbit/s remains available – or perhaps just 600 Mbit/s, leaving 300 Mbit/s for other real-time or asynchronous, non-priority traffic. The non-reserved bandwidth of the 1 Gbit/s link is always available for asynchronous traffic; even long, asynchronous frames do not disrupt the real-time communication.

In the example, the X-Ethernet switches are configured to provide a virtual 100 Mbit/s EtherCAT pipe. With this simple setup, it was found that standard EtherCAT telegrams could be routed through the network without further modifications by the master, then processed on the standard EtherCAT segment. The PLC application cycle time reached 50 µs. With the X-Ethernet switches' exceptionally low jitter of less than 20 ns and latency of under 3 µs, time synchronization using distributed clocks on the EtherCAT segment worked without further modification: Jitter and simultaneity at the two toggle outputs before and after the X-Ethernet network were << 100 ns, with the X-Ethernet network behaving, in effect, like a long cable.

Currently being advanced and standardized by Huawei, X-Ethernet is a solid technology for use cases that involve running standard and multi-real-time communication in parallel across heterogeneous networks. Data streams (i.e. pipes) are easy to configure, and their real-time performance is excellent. A remote controller can exchange data with one or more EtherCAT segments (i.e. machine units) in real-time over the network. Closed control loops for highly dynamic drive applications are likewise possible.

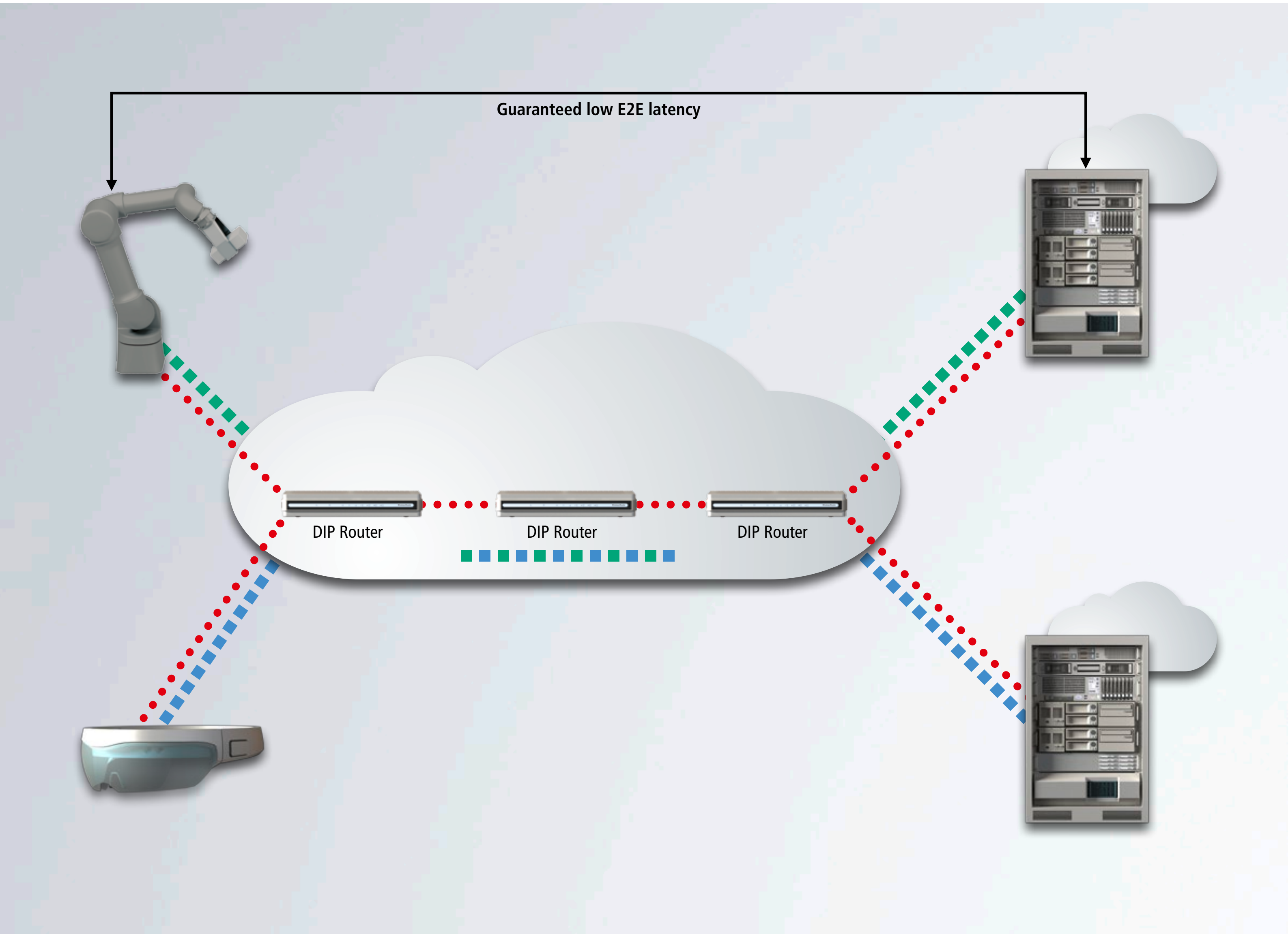

Figure 4: Deterministic IP with a guaranteed limit on end-to-end latency

Deterministic IP (DIP): Layer 3 routing

When machine modules or cells are interconnected over routers, switching at Layer 2 (or below) is no longer a sufficient means of logically separating traffic into subnets. Applications, however, depend on real-time performance to connect, for example, to an edge controller analyzing machine data online or to a machine controller in a server room, away from the machine it controls.

Computations carried out in an edge server to create a digital-twin machine model, for instance, rely on a deterministic response time to the actual process values acquired through machine monitoring: The actual values of the machine or system must be sent to the edge server at cycle speed and compared against the values expected in the machine model. The output vector must then be sent with low latency to the machine to fine-tune its settings.

Deterministic IP offers a solution. Already submitted to the European Telecommunications Standards Institute (ETSI) as a specification, DIP can deliver real-time services on Layer 3 in IP-based networks. In a defined IP options header, connected endpoints can ask DIP routers to reserve the bandwidth they need. In response, routers provide a guaranteed end-to-end bandwidth and latency. The routers are able to move the data with a guaranteed delay of less than 50 µs. Each router ensures that it prioritizes the traffic with the lowest time reserve.

Systems and devices can also be disconnected and reconnected as needed to enable flexibility in production. When they come back online, they can again request, and are provisioned with, the bandwidth they require.

The EtherCAT protocol is suitable for use at the IP level, too, because under the EtherCAT specification, each EtherCAT device can also process EtherCAT

Figure 5: The EK1000 Coupler from Beckhoff operates as an EtherCAT open mode coupler.

telegrams embedded in a UDP/IP datagram. This is referred to in the EtherCAT specification as Open Mode. Only the first device connected to a DIP router in an EtherCAT segment needs to be capable of evaluating the IP protocol.

The EK1000 EtherCAT TSN Coupler from Beckhoff, for instance, can be used for that purpose (see Figure 5). It supports both IP addressing and MAC addressing. The coupler has two Ethernet ports. One of these connects the coupler to the Ethernet network. The EK1000 passes frames from the Ethernet port to the EtherCAT port with a minimal delay. All other devices on the EtherCAT segment are standard EtherCAT devices.

In a test setup, a server PLC was connected with an EtherCAT segment over a DIP network via an EK1000 Coupler to run a motion application with a 2 ms cycle time and DC synchronization. EtherCAT telegrams embedded in a UDP/IP packet by the EtherCAT master were sent to the DIP network and received by the EK1000, which passed the telegrams straight to the EtherCAT segment. All that was required to accomplish this was an extension of the IP stack in the EK1000 and the EtherCAT master to implement the DIP options header. This made it possible to request the requisite bandwidth from the routers.

Flexible production operations that rely on frequent process reconfiguration need communication networks that are equally flexible to configure. With Deterministic IP, devices can be guaranteed the low latency and deterministic traffic flow that they require even on Layer 3. The same applies if routed subnets are needed – for example, due to IT requirements or the use of WAN links between cells or halls at a production facility.

5G wireless: Next-generation mobile communications

Fifth-generation (5G) wireless systems are often cited as a key technology for mobile communication in connection with Industrie 4.0 and the Internet of Things (IoT). In fact, 5G has compelling capabilities: Besides extremely high bandwidth, 5G is expected to achieve very short delays in messaging between stations and great reliability in data transmission – even with high user densities in small areas. These capabilities, taken for granted in today's wired networks, make this new wireless technology an interesting proposition for the automation industry.

A major difference between next-generation 5G mobile networks and current technologies is that 5G focuses heavily on machine-type communication and IoT. Its capabilities extend significantly beyond mobile broadband and ever-higher data rates. The International Telecommunication Union (ITU) is responsible for defining the performance targets for the next generation of mobile communications. The key functions summarized in Figure 6 include:

- Enhanced mobile broadband (eMBB)
  - Peak data rate: 20 Gbit/s (10 Gbit/s uplink)
  - Standard data rate: 100 Mbit/s (50 Mbit/s)
- Ultra-reliable, low-latency communication (URLLC):
  - Hop-to-hop latency of no more than 1 ms
  - Minimum reliability requirement 1×10^{-5}
- Massive machine-type communication (mMTC):
  - Minimum connection density of 1 million devices per square kilometer

All these capabilities are difficult to provide simultaneously because, from a technical standpoint, they can be mutually exclusive. For instance, a sensor used in condition monitoring will be designed to require as little power as possible to maximize battery life (mMTC), whereas the emphasis with a mobile robot will be on exchanging new actual and target values reliably with a controller in extremely rapid cycles (URLLC). However, 5G can combine these capabilities in parallel within a network due to a novel concept known as Network Slicing. This enables multiple logical or virtual networks to operate concurrently on a shared physical infrastructure in order to support different use cases.

It therefore appears that 5G technology could be suitable for deployment in a flexible production operation that combines transport vehicles, connected logistics and concurrent control of production lines.

At the 2018 Hannover Messe industrial trade show, Beckhoff and Huawei's X-Lab together exhibited a demonstrator that put 5G's capabilities to the test. Two controllers were connected via a 5G link. One of these was controlling a Beckhoff XTS (eXtended Transport System) acting as a passive drive system that users could manipulate manually; this was passing the actual positions of the XTS movers as a reference to the second controller. The second controller, working in synch with the first, replicated the manipulators' manual movements. The controllers' NC cycle time was 2 ms, and the latency between the 5G switches was 1.1 ms for 130 bytes of data (URLLC). The controllers were running the EtherCAT Automation Protocol (EAP) using raw Ethernet frames on Layer 2 (wireless switching). Parallel to the real-time traffic, the second controller streamed an IP video to the first to monitor the replicated movements (eMBB).

Working groups at 3GPP are currently setting the specifications for 5G. The capabilities are to be standardized in Release 16, due in late 2019, and can then be implemented by manufacturers in their chip and device interface designs.

To ensure that the telecommunications sector properly understands and addresses the specific needs and requirements of factory automation, and that vertical industries recognize and make use of 5G capabilities, all parties involved need to work together closely. To this end, organizations in the operation technology (OT) and information and communication technology (ICT) sectors recently formed the 5G Alliance for Connected Industries and Automation (5G-ACIA). Its goal is to promote greater mutual understanding and to assess relevant technical, regulatory and economic aspects surrounding 5G in the industrial sector. Beckhoff is a founding member of the alliance.

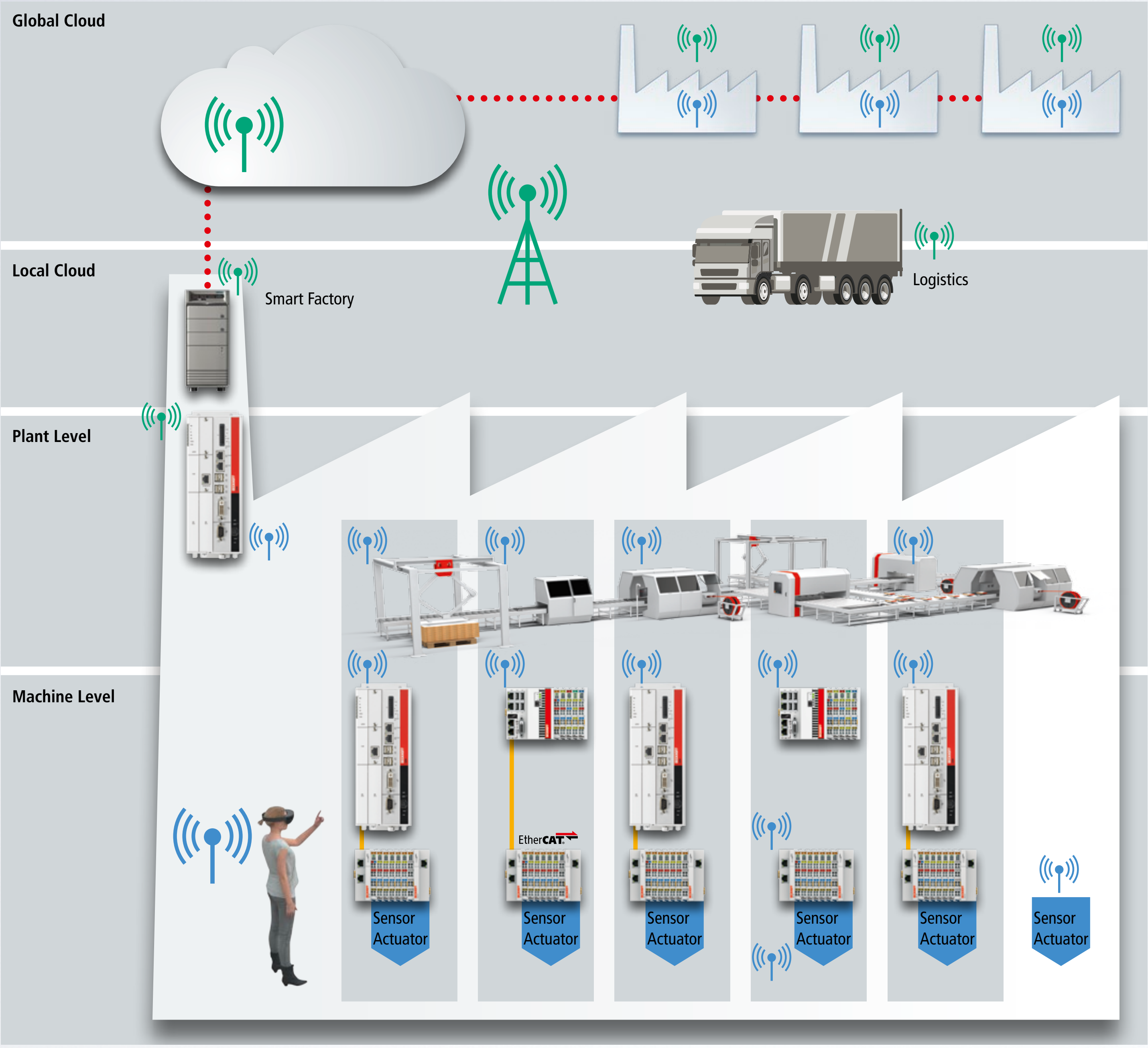

Figure 6: Communication requirements in and outside the smart factory

Successful collaboration

Beckhoff is constantly assessing the potential of emerging technologies that could cover the communication requirements in automation from the I/O level all the way up to cloud-based control. In the collaboration with Huawei, Beckhoff has explored how to incorporate the established EtherCAT technology into heterogeneous network structures – in an Ethernet subnet at the switch level, and between subnets at the routing level. Going forward, 5G may prove to be a viable wireless technology for edge control, for communication between machines and, possibly, for condition monitoring incorporated into machinery or other advanced applications. Huawei and Beckhoff both bring to the table vast expertise and experience in two largely complementary fields, creating synergies that can benefit both their respective market segments. In these collaborative initiatives, it is important to assess the specific benefits of IT-sector technology for industrial automation. Ultimately, time will tell which technologies are actually rolled out to customers.

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