Time-Sensitive Networking
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Time-sensitive networking (TSN) is poised to be one of the most important steps toward real-time monitoring and control of industrial machinery. Still in its developmental infancy, TSN has benefited from the ongoing testbed iterations that continue to add new capabilities to its evaluations. The brainchild of the Industrial Internet Consortium (IIC, www.iiconsortium.org), the testbed documents the value of TSN and provides feedback to standards organizations.

Supplier companies test implementations at testbed plugfests—face-to-face events where vendors test the interoperability of their products and technologies.

Manufacturers require coordination of sensing and actuation to perform closed-loop control. Often these systems use unconnected networks, which leave data siloed and difficult to access, creating a technical barrier to the Industrial Internet of Things (IIoT). Once IEEE updates its 802.1 and 802.3 standards, the technology will support real-time control and synchronization over Ethernet.

Time-sensitive networking will enable robot control, drive control and vision systems and will provide access to data in real time, allowing organizations to make better business decisions regarding equipment health and engineering capacity.

Because TSN is a deterministic enhancement to Ethernet, it is a foundational piece of the IIoT. The TSN testbed applies technology to various automation and control vendors’ devices to display and verify the capabilities, which include:
• time synchronization
• sending scheduled traffic flows
• central, automated system configuration.

This special report on time-sensitive networking is designed to explain:
• what TSN is
• how it came to be
• where it’s headed
• why it’s got the attention of the manufacturing community
• when you’ll be able to leverage its benefits
• who to turn to for additional information and help.

We hope you enjoy our wealth of articles tracking time-sensitive networking’s evolution into one of the critical advancements affecting factory monitoring and analytics.
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Earlier this year, the Industrial Internet Consortium (IIC), National Instruments, Bosch Rexroth, Cisco, Intel, Kuka, Schneider Electric and TTTech announced a collaboration to develop the world’s first time-sensitive networking (TSN) testbed to advance the network infrastructure that will support the future of the Industrial Internet of Things (IIoT) and Industry 4.0. Machine designers, builders and users need reliable and secure access to smart edge devices, and standard network technologies will evolve to meet the requirements of the next generation of industrial systems.

TSN is a set of IEEE 802 standards designed to enhance Ethernet networking to support latency-sensitive applications that require deterministic network performance.

The goal of the IIC testbed is to display the value of new Ethernet IEEE 802 standards, referred to as TSN, in an ecosystem of manufacturing applications (Figure 1). TSN powers a standard, open network infrastructure that supports multi-vendor interoperability and integration, as well as real-time control and synchronization between motion applications and robots, for example, over an Ethernet network. At the same time, TSN is designed to support traditional traffic found in manufacturing applications; this can’t be accomplished without the convergence of IT and operational technologies.
“This testbed seeks to discover and invent new products and services leveraging the Internet of Things in industrial systems,” says Dr. Richard Soley, executive director of the IIC. “The testbed developers realize that their markets will be disrupted by IoT and are developing this testbed to discover and invent that disruption. This testbed will prove the value and functionality of IEEE 802 time-sensitive networks in machine-control applications.”

Testbeds are a major focus and activity of the IIC and its members. “Our testbeds are where the innovation and opportunities of the industrial Internet—new technologies, new applications, new products, new services and new processes—can be initiated, thought through and rigorously tested to ascertain their usefulness and viability before coming to market,” explains Soley.

The testbed will combine different critical control traffic, such as OPC UA, and best-effort traffic flows on a single, resilient network based on IEEE 802.1 TSN standards. It will demonstrate TSN’s real-time capability and vendor interoperability using standard, converged Ethernet, and it will assess the security value of TSN and provide feedback.
on the ability to secure initial TSN functions. Equally important is the testbed’s attempt to show the IIoT’s ability to incorporate high-performance and latency-sensitive applications.

In the past, real-time control applications typically were deployed using nonstandard network infrastructure or unconnected networks that left the devices and data siloed and difficult to access. TSN’s value is in unlocking data in real time and fulfilling the IIoT promise of improved productivity from big data analytics and smarter systems.

IEEE 802.1 is the specification for switch operation. “One aspect we’re focusing on in this testbed is scheduling,” explains Todd Walter, chief marketing manager, National Instruments (NI, www.ni.com), and industrial segment chair, AVnu Alliance (www.avnu.org). “The profile of IEEE 1588 for precision time protocol (PTP) is to distribute time and synchronize all of the end nodes and all of the switches, so they all have common concepts of time, or synchronized time. Switches already have the ability to look at a packet and put it in different queues. TSN creates a reservation for a particular packet at a particular time. The bridge can identify the packet and gives it a fully scheduled pass through the network. For control applications, that’s ideal.”

The testbed is focused around smart manufacturing because TSN will have applicability across a lot of industries. IIC member companies bring their own devices to the testbed. “One application we’ll test will be machine-to-machine coordination between a robot and another machine,” explains Walter. “A robot has a controller, sensors, actuators, drives and motors. We’ll communicate through some standard interfaces and commands to coordinate the robot controller with another machine that has motion, sensor or vision integration; and we’ll be able to put those multiple...
controllers together with multiple systems being coordinated—for example, coordinating a Kuka robot with a Bosch Rexroth motion system. We’ve structured the testbed to be able to support many standard protocols.”

The testbed is physically hosted in Austin, Texas, at the National Instruments campus, where NI is handling the design. Cisco and TTTech are supplying the switching (Figure 2). The major components are scheduled to be integrated by the third quarter of 2016. “We plan to come out with feedback to the conformance bodies and then reference architectures and guidance by the fourth quarter,” explains Walter.

SECURITY AND SAFETY

For TSN, security has to be designed-in as a layered system, explains IIC’s Soley. “One cannot add security as a new feature later,” he warns. “Air-gapping, while the obvious approach to perimeter security, has major drawbacks—most obviously the loss of the air-gap, that is, the accidental or intentional connection of a supposedly air-gapped system to the Internet. But, more pervasively, air-gap security ignores the fact that the vast majority of security failures are perpetrated by insiders. Air-gap security, as a perimeter measure, cannot guard against insider threats. The developers for this IIC testbed are aware of the issues and developing their time-sensitive networks with security in depth designed-in.”

The security level needs to be pushed as far down as possible, adds NI’s Walter. “When there’s a network infrastructure that’s open, that creates a security hole,” he cautions. “If you can get access to that layer, you can get everywhere. We want to push security all the way into the end node. In addition to being able to adopt all of the IT best practices for security, we can add another layer of security because we have information about the data flows. We know the timing and the path, and that can be another powerful tool for the layers of security. In the testbed, we want to figure out what we can apply that’s already in use and what we also can add.”

Because TSN is standard Ethernet, control networks can take advantage of best practices for security that have been developed into Ethernet for decades, says Walter. “Additionally, TSN enables an additional layer of security to the data,” he explains. “The precise timing mechanism allows you to know exactly when the data was sent and when it is supposed to arrive, based on the packet information; therefore, you can see if someone else has accessed the network and intercepted or altered it. AVnu Alliance is evaluating additional security layers in TSN currently, as security is critical to these networks.”

Expectations would be that security for time-sensitive networking would use the same black-channel principles for the cur-
rent fieldbus solutions, notes Dr. Michael Hoffmeister, portfolio manager, software, at Festo (www.festo.com). “The strength of Ethernet-based protocols in general is the layered approach where each layer in a protocol stack adds a certain functionality to the entire communication channel,” he says. “The TSN layer adds the real-time capabilities to the communication channel while security is considered on higher protocol layers using, for example, the security mechanisms of OPC-UA.”

For cybersecurity, various aspects, including authentication, encryption and data security are being considered. “The point is to protect critical data and block unwanted data,” explains Sari Germanos, open automation business development manager, B&R Industrial Automation (www.br-automation.com).

Security in time-sensitive applications is sometimes circumvented by using physical security, such as completely isolated and dedicated networks, instead of electronically derived security, such as public key encryption of the data, explains Doug Taylor, principal engineer, Concept Systems (www.conceptsystemsinc.com), a system integrator in Albany, Oregon. “Latency-intolerant paradigms are usually local by nature, lending themselves to physical security,” he says.

One substandard for TSN is Time Based Ingress Policing (IEEE 802.1Qci). “This standard defines mechanism to count and filter frames, and it supports policing and service class selection,” explains Dipl. Ing. André Hennecke, researcher at DFKI (www.dfk.de), a research center in Kaiserslautern, Germany. “These mechanisms help against different network attack vectors like ‘man in the middle’ attacks, but also against faulty network components. Even when a flow gets hijacked, the flow still relies on the reserved stream and all frames outside the stream time window get dropped, which leads to a more secure network.”

TSN also will lead to a new challenge when it comes to security design. “To realize all functionalities of TSN successfully, a central network management component is needed,” advises Hennecke. “This management component helps in coordinating stream reservation or path control, compared with a classic hop-by-hop method, but leads also to higher security threat. The penetration of this management component can influence the whole network, depending on the functionality and implementation, which is still open.”

Protocols that reside on Ethernet and use the traditional TCP/IP protocol suite have security vulnerabilities, warns Sloan Zupan, senior product manager, Mitsubishi Electric Automation (us.mitsubishielectric.com/fa/en). “Customers should choose a deterministic network which has the benefits of traditional Ethernet networks but doesn’t
solely rely on the TCP/IP protocol suite,” he says. “Networks such as CC-Link IE provide protection against cybersecurity risks, which aren’t available from other Ethernet networks, and it is 100% deterministic.”

If your network knows when it’s supposed to be receiving information, it can more easily push away information when it’s not anticipated, says Steve Zuponcic, technology manager at Rockwell Automation (www.rockwellautomation.com). “It’s easier to filter out things that are not expected when they’re not expected,” he says.

However, in some ways, TSN doesn’t change the dynamics of security in a network, says Paul Brooks, business development manager at Rockwell Automation. “You’ve got management software and devices and switches,” he says. “Changes in the performance of those also changes the performance of the system. Those changes have to be secure. We would expect many of the same techniques to be used. The threat vectors are very similar.”

Deterministic Ethernet also can influence the way that safety systems are implemented, claims Markus Plankensteiner, vice president, sales industrial, North America, and global alliance manager, TTTech Computertechnik (www.tttech.com). “The fact that scheduled traffic flows can be isolated and not disturbed by other traffic on the network is very important,” he states. “By scheduling messages from safety applications, we can ensure high availability of safety systems even when converged with the wider network infrastructure.” Plankensteiner believes this will lead to a streamlining of safety systems and associated overheads without affecting the safe performance of the overall system.

“Safety always will take a path using older technology that has proven itself, rather than embrace newer technology, primarily because the decision makers in the safety field are risk-averse,” cautions Taylor. “Once the technology is commonplace and the failure modes are all well-known, then it will be considered for safety, regardless of the advantages it offers.”

The first phase of the TSN testbed, for instance, hasn’t factored in safety. “The most common way to do communications over any network infrastructure is black channel, where you build your safety structure, assuming the communications medium is not certified,” explains Walter. “It allows you to use off-the-shelf, but what is the latency through the network? You’re encapsulating in a safe domain, and then you decapsulate on the receiver and make sure it matches. That black-channel concept theoretically should apply very well to a TSN infrastructure. This is a long-term testbed so we could add it in the future. It’s just not part of this first phase.”
Brooks, however, thinks deterministic Ethernet will have no impact at all on system safety. “Safety protection systems are designed to move to a safe state in the event of any interference. TSN delivers some benefits. It’s easier to architect a system with no disturbances. The likelihood of a disturbance will be reduced. It also brings redundancy to the table. It’s a more reliable network, so the safety protection system will be less susceptible to trips or disturbances,” he notes.

“Safety is a vital part of our industry, and, as Ethernet becomes more and more prevalent, the two will have to cross paths at some time,” predicts Bill Dehner, technical marketer, AutomationDirect (www.automationdirect.com). “Safety is time-critical and as such will undoubtedly force Ethernet further into the deterministic realm. As seen with precision motion applications, protocols such as EtherCAT that use precision time protocol synchronization—IEEE 1588—are already being used to accommodate time-sensitive applications, and safety will further this effort.”

TO BE DETERMINED
Deterministic Ethernet is one of the foundational technologies for the industrial Ethernet, explains Paul Didier, solutions architect manager at Cisco (www.cisco.com). “We’ll be able to connect up a lot more devices and a lot more machines,” he says. “Because of that, it will enable this IIoT. Initially it will be preventive maintenance, then operational, then robot as a service and then car as a service. A lot needs to come into the IIoT, but none of it works if you can’t access the devices. You need that access to the devices and data and control loops. Fanuc is now becoming an engineering company providing a service, not just a robot company. I see this as being one of the big challenges for the IoT—getting these devices interconnected. I don’t want to say TSN is the key to these IoT models. Getting connectivity access is important because so many are still not connected. And all of the proprietary little schemes mean the data is really hard to get to.”

Deterministic Ethernet already exists, says Phil Marshall, CEO of Hilscher North America (www.hilscher.com). “Standard Ethernet chips provide a level of determinism that is quite good at many slower application requirements—for example, in the 10 ms response time offered by standard Modbus TCP,” he explains. “To provide determinism for high-speed applications, the Ethernet protocol standard organizations have used IEEE 1588. The industry issue is that the IEEE 1588 functions are not interoperable. Profinet, EtherNet/IP and other deterministic IEEE 1588-based Ethernet protocols are incompatible with each other. TSN may perhaps provide a common clock mechanism to create a universal protocol suitable for high-speed discrete parts manufacturing.”
Joey Stubbs, P.E., North American representative, EtherCAT Technology Group (www.ethercat.org), agrees. “Specifically, EtherCAT is a widely used Ethernet protocol for machine control using standard 100Base-TX Ethernet as the physical layer for high-speed, highly deterministic control of extremely complex and sophisticated machines and processes used across a wide range of industries and applications.”

Deterministic Ethernet will make it easier to consolidate multiple control systems onto a larger compute node, thereby reducing the complexity of hardware on manufacturing floors, predicts Mark Hermeling, director, product management, VxWorks, Wind River (www.windriver.com). “It will also facilitate connectivity between machines, providing the capability to do tighter integration of manufacturing lines,” he says.

It will lay the communications platform for Industrial IoT, says TTTech’s Plankensteiner. “The Industry 4.0 initiative has explicitly set out to use open standards for its reference architecture model,” he explains. “TSN now imbues IEEE Ethernet with the real-time features that were previously only available in proprietary protocols,” he says. “This means standard Ethernet being used all the way from the enterprise cloud down to the machine sensors for applications including low-latency motion, high-availability processes and safety control. If the goal of Industrial IoT can be somewhat bluntly condensed to ‘better use of machine data,’ then it is deterministic Ethernet that will enable the collection and use of this data in a standard, interoperable way.”

Deterministic Ethernet will have a tremendous impact on certain specialized users but will have a minimal impact on the general user, says Concept Systems’ Taylor. “Most people feel that their processes are time-critical, but they are thinking in human time and not computer time. In human time, 50 ms is the blink of an eye. To a computer, 50 ms is nearly an eternity,” he explains.

The impact of deterministic Ethernet on industrial communication is twofold, says Armin Pühringer, business development manager, Hilscher Gesellschaft für Systemautomation. “The real-time synchronous mechanisms are of interest, also for the existing real-time Ethernet standards which are used in industrial environments today,” he explains. “If and only if deterministic Ethernet will contribute to a simplification of industrial communication in the future, then there is potential to form a globally used technology base in industrial applications.”

Ultimately, what deterministic Ethernet enables is intelligent networked components’ ability to communicate with one another with dedicated time intervals and bandwidth, says Mitsubishi’s Zupan. “Machines have a wealth of information in them that can be used to improve operational...
efficiencies, but pulling this information from sensor devices and other automation components can burden the nondeterministic networks used in today’s automation networks,” he explains, adding that deterministic networks should handle cyclic and transient messages separately and with different priority.

A well-architected network is deterministic today, advises Rockwell’s Brooks. “TSN will provide engineers a tool to build that well-architected network,” he explains. “Bringing fast lanes to the network will make it easier to build.”

TSN is driving the whole concept of a system view of the network, explains Rockwell’s Zuponcic. “You lay things out more at a higher level, versus components, which allows you to design at a system level and make it easier to design those networks,” he says.

Much of the existing network infrastructure is not equipped to handle time-sensitive data such as critical control and fault detection data that must be processed, shared and acted upon immediately, regardless of other network traffic. “Many industrial systems and networks were designed according to the Purdue model for control hierarchy in which multiple, rigid bus layers are created and optimized to meet the requirements for specific tasks,” says NI’s Walter. “Each layer has varying levels of latency, bandwidth and quality of service, making interoperability challenging and flexibly changing data connections virtually impossible.” In addition, proprietary Ethernet derivatives have limited bandwidth and require modified hardware.

“The first meeting for the IEEE 802 standards was held in 1980,” says Walter. “It’s been continually added to. That’s definitely going to be true with the time-sensitive features. I fully expect these capabilities will be built on forever. One thing the Ethernet community has been extremely good about is ensuring the backward- and forward-compatibility. We can start building on this right away.”

Deterministic Ethernet allows machines to synchronize and interoperate in a standard way, especially when combined with an open architecture such as OPC UA, explains B&R’s Germanos.

Its use as a control network could replace other networks such as Profibus and DeviceNet, predicts Mike Justice, president, Grid Connect (www.gridconnect.com).

APPLICATIONS ACCEPTED

One example of an application that requires a deterministic network is a web printing press, offers Mitsubishi’s Zupan. “In this application, you have one or more controllers talking with upward of 100 axes of motion and hundreds of I/O points,”
he says. “The tension of the material and the torque to move the material through the press must quickly adjust as the roll of material is consumed. I/O control, motion commands and HMI updates, for example, all need to be in sync for the machine to run at an optimal level.”

Many examples of latency-sensitive applications already are kept separate from the wider infrastructure by gateways or proprietary solutions. “In a discrete automation plant with multiple robots working on production lines, TSN will enable far greater operational flexibility,” predicts TTTech’s Plankensteiner. “Today, these robots are controlled locally, with limited synchronization between them and bottlenecks for data access from beyond the factory floor. Where there is connectivity, it is either done over proprietary networks or via gateways. By removing local control functions or converging noncritical traffic in the same network, one could jeopardize the guarantees for communication of critical messages.”

By using a TSN connection between robots, the controls communication is guaranteed across the network, even when converged with noncritical traffic, and all robots are
synchronized to the same global time, explains Plankensteiner. “This means that controls networks can be integrated with data networks, and many control functions can be centralized away from the robot cell into a controls cloud where greater computing power can be utilized,” he says. Huge amounts of data from the robots then would be visible to higher-layer networks without the need for gateways, enabling machine-as-a-service (MaaS) type of business models, which simultaneously improves service and maintenance from machine builders and lowers capital expenditure for end users (Figure 3).

“Vision systems that use Gigabit-Ethernet (GigE) cameras often are completely isolated networks where the entire network consists of a network interface controller (NIC) card and a camera with no switches,” offers Concept Systems’ Taylor. “Using a time-sensitive network could lead to camera networks where multiple cameras live on a network in harmony, allowing multiple control systems to utilize their data in real time. In this paradigm, a smart device can morph from a basic source of information to a preparer of key information, thereby reducing the required bandwidth. A case in point would be a camera system that only reported the elements of the image that are changing between frames to the various smart concentrators that can provide real-time full-frame images to clients at the same speed as a dedicated camera-computer network with perhaps less latency than the dedicated full-frame network.”

Obviously, motion applications are latency-sensitive and would benefit from TSN, says Hilscher’s Pühringer, but, more than that, there might be a potential for sensor networks with an extremely high number of nodes.

“Our hope is that everything works better in a TSN environment, whether that’s voice communications, video surveillance or motion control,” says Rockwell’s Brooks. “There are potential benefits, for instance, a 10% increases in axes through a single link for motion control, most of which is delivered through preemption. The strategy is that everything works better with TSN.”

According to DFKI’s Hennecke, latency-sensitive applications that would benefit most from TSN include:

- safety-relevant communications, which are today mostly done by hardwired solutions—for example, safety-certified communication like safety-stop
- motion and robot controls: with a standard communication in these applications, accessing data gets a lot easier, which helps to improve techniques such as predictive maintenance and system optimization
- machine-to-machine communication, which needs low latency and a high synchronization
• high-level applications, which need a more deterministic communication to monitor and control machines in real time—for instance, condition monitoring or high-speed manufacturing execution systems.

“The number of applications that require minimum latency is in the thousands,” says IIC’s Soley. “Machine control systems are the obvious application and the target of the testbed. Systems for which control signals must be received in time, especially for safety and security reasons, require minimum latency. But there will be other, everyday applications of minimum-latency requirements in the Industrial Internet of Things.”

THE EDGE AND THE CLOUD
The rise in the number of intelligent devices has made it very clear that decentralized control is within reach. “They demonstrate how functions can be distributed over a network,” explains Festo’s Hoffmeister. “Edge computing will give a better-defined infrastructure to make use of these technologies. Maybe edge nodes can also serve for holding data and functions of passive devices, joining these data and functions with the ability of those intelligent devices. Additionally, they can serve for database and data-intelligence functions, allowing for closed loops in data analytics. In this sense, edge computing and its framework definitions can leverage the vision of autonomous, self-aware production systems.”

Edge computing has piqued the curiosity of many Mitsubishi customers. “We consider sequence CPUs, C-language controllers and IoT gateways to be examples of edge-computing devices that are commonly used by customers to aggregate data and convert it into useful information,” says Mitsubishi’s Zupan.

“It is the habit of every manufacturer to “gild the lily’ in order to drive sales,” warns Concept Systems’ Taylor. “Coupling this with the steady march of technology that is driven by consumer electronics leads us to products that are offered to us to solve problems we didn’t even know we had. This new technology and our lack of familiarization with the myriad offerings is fertile ground for innovators to connect the dots and come up with very desirable features in modern solutions. This edge-computing category is just one of the LEGO blocks that innovators are using, and most of the resistance to the innovations is being offered by experts within the industry, since the designs do not respect well-defined areas of responsibility.”

But edge computing is not new. The programmable automation controller (PAC) is the manifestation of edge computing, says Rockwell’s Brooks. “What the proliferation of intelligent devices is going to do is give companies the capability to build more into edge-computing devices and share more data with the cloud, more prognostic infor-
Cloud computing already is moving closer to the edge of the network in the form of fog computing, which is bringing greater intelligence and analytics to the machine world, says TTTech’s Plankensteiner. “Theoretically of course there is no reason why machine control can’t also be executed in this fog/cloud environment,” he explains. “In order to achieve this, there must be guarantees for both the latency and the jitter of communication between machines and the fog/cloud. Deterministic Ethernet in the form of TSN logically extends the cloud concept of virtualization into and through the network. This means that sensor data and actuator commands can be processed from the fog/cloud as multiple virtual machines, each with a dedicated logical communication channel, but over a single converged network. Machine control from the cloud is much closer than you might think.”

Before you can talk cloud, you’ve got to talk Layer 3 network and look at the work by the Internet Engineering Task Force (IETF) on deterministic networking (DetNet), explains Brooks. “For the cloud to happen, there has to be dramatic changes to the performance in wide area networks (WANs),” he says. “Never is a really, really big word, but, in the foreseeable future, it’s hard to imagine real-time control through the cloud. If we had infinite bandwidth in the Internet and infinite processing power in the cloud, we might have a different answer.”

Hilscher’s Marshall points out that HVAC from the cloud exists today, but he agrees high-speed motion control can’t be done yet. “If the motion control systems can be made more autonomous, you do have the ability to move the larger control system to the cloud,” he says.

Whether machine control from the cloud will become a reality depends on the type of machine and the type of cloud, says Wind River’s Hermeling. “There are many levels of “real-time-ness,” varying from minutes to control a device to microseconds or nanoseconds,” he explains. “Controlling your Nest thermostat from the cloud doesn’t have a tight real-time requirement, and that is already a reality. Controlling an industrial robot or manufacturing equipment that requires response times in the low microseconds requires a different architecture.” TSN with an on-premise cloud can reach these types of timeliness, but remote cloud control would be much more difficult.

“It’s foreseeable to provide new recipes from a cloud into a machine, but real-time machine control from the cloud may not be a practical application of the technology,” warns B&R’s Germanos.

First, you must differentiate the term
“cloud,” says DFKI’s Hennecke. “There are private, public and hybrid solutions,” he explains. “When it comes to private clouds, which means that the cloud functionalities are located in the private network, machine control from the cloud can become a reality in the near future. There are already solutions to map classic control components such as software functions and the virtualization of control components into cloud computing systems.”

Machines and stations are already executing a large number of different tasks: human-machine interface, recipe management, tracking and tracing, OEE measures, reporting, statistical process control (APC/SPC), machine control, help and assistance systems and further, Hoffmeister points out. “In this sense, the real-time-enabled machine control is only a fraction of all tasks a machine has to fulfill,” he says. “A cloud technology can address many of these topics in an efficient and user-friendly way. Therefore, ways should be identified how cloud technology can be implemented for many topics while linking and maintaining the real-time excellence of machine control.”

But nothing that’s technically feasible is also practical, warns Hennecke. “Controlling machines from the cloud can also lead to a few issues, especially when the network is faulty or not available,” he cautions. “Commissioning and troubleshooting will be more complicated, and, when the network is not available, the machine stops without the option of further or emergency operation. One concept to overcome these issues is the principle of apps in manufacturing. The idea behind this is to keep the basic operation functionalities in the local machine control and get more process-specific functionalities from the cloud, for example.” Beside these technical issues, data confidentiality, integrity and security become major issues when it comes to public clouds, preventing suitable solutions from emerging, says Hennecke.

Whether machine control from the cloud will ever become a reality depends on the understanding of what the cloud is, agrees Hilscher’s Pühringer. “Hilscher refers to cloud as a technology—as in using the cloud stack and technologies being developed for cloud applications—and not as topology, such as where cloud means connection to the Internet,” he explains.

It’s unlikely that clouds will be used to do machine control, says Zupan. “There are a couple of factors that need to be considered. The first and most important is human safety. Network communication is susceptible to interruptions and outages. If this were to happen in a machine, people can get hurt. Second is the designed purpose of the cloud environment. Cloud services are excellent resources for aggregating data from various sources and providing fast data analysis. But they don’t operate nearly
fast enough to handle machines with complex motion capabilities,” he says.

“Machine control, which is inherently time-sensitive—hard real time—is difficult to achieve with the most common networking technologies and thus with most of today’s cloud architectures,” says IIC’s Soley. “Local, private clouds, however, are already controlling machines.”

When a machine is working somewhere in the world, the control is going to have to stay close to that, assures Cisco’s Didier. “There are physics and economics and reliability that drives all of that,” he says. “A lot of data is going to come out. One of the cool concepts out there is that people will want to have a cyberphysical representation of the equipment in the cloud. That doesn’t mean the physical plant will be controlled in the cloud. Optimization and maintenance can be done in the cloud and will filter its way back to the machine. Most machines will have to have some close physical control because of physics, latency and economics. You’ll see highly distributed systems, but a lot of cloud data will be generated. I do think you’ll see cases for doing machine control, but these will be based on these cyberphysical concepts.”

EVERYTHING THAT RISES MUST CONVERGE

“The controls industry is conservative and will follow the IT market in a few years after security issues are well-addressed,” predicts Grid Connect’s Justice.

“Look at what the IIoT really means,” says NI’s Walter. “What is the value of a control system converged with standard IT? How do I take my control system and start to separate the functions? If I’m trying to close a loop at 100 KHz, it’s better to push that all the way to the edge. But for IoT, if I have information from a lot of control systems and edge devices, I can put that in an analytics package. Maybe it’s an on-site cloud, or fog. I can get very clean access to the data for on-site computing and have multiple layers of control running concurrently.”

Shop-floor control already executes a large number of tasks, many of which already demand a dependable connection into the office. “A greater convergence between shop floor and office floor will give the system architects a greater flexibility to decide where specific tasks or parts of tasks should be fulfilled,” suggests Festo’s Hoffmeister. “We’ll see a greater integration, fewer gateway solutions and more systems that will benefit from the data richness of shop-floor applications.”

The obvious advantages of a convergence between information technology (IT) and operational technology (OT) include access to cloud services, improved security and integration with ERP/MES. “It can also include the wider benefits that come from
the standardization of technology, such as a deeper engineering talent pool, increased resource sharing and faster innovation,” offers TTTech’s Plankensteiner.

“The convergence of operational systems with information systems can only be of tremendous value in all industries,” explains IIC’s Soley. “It’s amazing that the operational control systems—programmable logic controllers— in most factories have not been connected to the information systems of those factories, despite the need to track just-in-time delivery of factory-floor inputs and outputs.”

Mitsubishi Electric Automation has customers in virtually every industry who have integrated production machines with business systems to some degree, says Zupan. “It is used to keep the business system updated on the actual status of work in process, production asset health, inventory management and quality control,” he explains. “A business system can become much more intelligent when production information is provided to it on a regular basis. However, many of these benefits are better delivered by the edge-computing capabilities of the automated assets.” Data can be transformed into useful information and sent to a variety of business system consumers.

With automation and control, multiple networks are deployed, explains Rockwell’s Brooks. “If they’re wireless, having them in the same space makes them interfere with each other,” he says. “We allow cloud-centric applications, discrete devices and service-based delivery of analytics. You get the ability to start having other services that were never in place before. All of those promises are hard to deliver without a converged network architecture in place to support them.”

Connecting the controls network with the enterprise network also enables equipment health monitoring and maintenance. “The ability of connecting entire machines into the cloud allows for real-time data massaging and data analytics and improved overall factory performance, including capabilities such as predictive maintenance,” says B&R’s Germanos.

“Unifying the network communications at the control level with your IT gives you access from remote sites and gives you analytics,” explains Rockwell’s Zuponcic. “It’s required to enable the IIoT. You can’t accomplish it without it.”
Reports of my death have been greatly exaggerated

Ethernet networks are growing three times as fast, but fieldbus networks still account for more than half of industrial uses

By Mike Bacidore, editor in chief

Industrial Ethernet continues to grow, but don’t count out fieldbus networks just yet. The upgrade from 4-20 mA analog signals to fieldbus had a significant impact on industry, but Ethernet networks are positioned to support time-sensitive networking (TSN, http://www.controldesign.com/tsn).

Ethernet’s steady march over the decades has found its way into protocols such as Profinet, PowerLink, EtherCAT and EtherNet/IP. Still, it accounts for less than 40% of market share, according to 2016 research from HMS Industrial Networks (www.controldesign.com/industrialnetworks).

The fieldbus foothold remains strong at 58% of the market with an annual growth rate of 7%, thanks largely to Profibus’ dominance with 17% market share. Ethernet’s 20% annual growth, however, has continued its rapid expansion. But what are the major differences between Ethernet networks and fieldbus networks? Which protocols run where? And ultimately how do they affect the Industrial Internet of Things (IIoT) and TSN?

WHAT’S THE DIFFERENCE?

The major differentiation has focused on deterministic hard real-time performance for manufacturing and machine-building applications in discrete automation, explains Tom Burke, president of OPC Foundation (www.opcfoundation.org). “Safety and security have
been very important, and by definition the industrial fieldbus device networks have done a superior job building deterministic reliable real-time solutions,” he says. “The associations that represent the different fieldbus networks guarantee interoperability as their members who develop products for the respective technology certify their implementations of the standards and often use certified chipsets.”

The beauty of commercial off-the-shelf Ethernet allows any vendor to develop devices that can interact and communicate over the Ethernet, continues Burke. “The world is going to change with the deployment of TSN, given the focus on deterministic high-speed 50 GB real-time operation,” he says. “Clearly, you’re going to see all the fieldbus networks scrambling to address and support the TSN networks for their respective networking technology. I expect things like the safety protocol and reliability protocols of the respective organizations to be migrated to the TSN technology, so there still will be somewhat of a differentiation between the industrial networking alternatives and the commercial off-the-shelf TSN Ethernet solution.”

The majority of the industrial fieldbus networks claim connectivity of standard Ethernet devices on the network with the same deterministic operation, says Burke. “But the reality is the majority of the manufacturing operations always segregate the networks, having their standard Ethernet devices running on commercial off-the-shelf Ethernet and then having their fieldbus networking devices running on the fieldbus network, sometimes having a simple bridge or gateway between the two network connections,” he explains.

“One significant difference between fieldbus networks and Ethernet networks is speed, as in most cases Ethernet networks will be faster despite the additional overhead,” explains Ian Verhappen, senior project manager, automation, CIMA+ (www.cima.ca).

“Part of the reason for this is that fieldbus systems were designed for the typically noisy plant environment, and as a result speed needed to be slower and of course a suitable physical media found, especially for those protocols in which data and power are in the same single cable.”

Many end devices don’t support Ethernet, says Verhappen. “They don’t need the bandwidth and do need the ability to have power and signal in the same cable,” he explains. “I foresee a need for fieldbuses as a critical element of IIoT and beyond. Unfortunately, PoE doesn’t have the same voltage and power levels as field systems but certainly is useful to remotely power a switch or IP-based device such as a camera or a small controller on a process skid.”

Ethernet still has the distance challenge from the hub. “In many facilities, the pro-
cessing facilities are greater than this distance from even the distributed I/O or interface room,” says Verhappen. “This means having to build an infrastructure to within reasonable limits of the process, which isn’t difficult but is another step that fieldbus systems can avoid.” Both systems have the advantage for modular systems. “Each module can be fully tested independent of the full facility and then connected to the balance of plant by a single communication cable—Ethernet or fieldbus multiconductor—connection.”

**DESIGN AND USE DIFFERENCES**

The most obvious difference between fieldbus networks and Ethernet networks is the design intent, explains Talon Petty, marketing and business development manager, FieldComm Group ([www.fieldcommgroup.org](http://www.fieldcommgroup.org)). Most process applications don’t require high-speed communications. “Ethernet is a collision-based network, meaning it uses high speed to get data through in a timely manner,” he says. “If data-packet collisions occur, it just simply retries until it goes through. Because of the high bandwidth, collisions are typically not a concern for applications such as office Wi-Fi. In process, these collisions, depending on the severity, could have a major impact. The same is true with discrete systems such as assembly lines. These networks just need to repeat the same action over and over. In process, it is a constantly varying data network. Temperatures have to go up and down, and valves must fluctuate flow rates. It’s, by definition, a process. These processes also don’t require the high-speed capabilities of Ethernet. We’re bytes of data at a time, and we’re talking about processes that can have tolerances for updates in seconds and tens of seconds, even minutes for tank farms. Updates in the millisecond range are not necessary.”

Process skids are especially beneficial with Foundation Fieldbus (FF) because all the wiring and setup can be done at the factory and then the homerun wire simply landed when delivered on-site, says Petty. “It doesn’t get much simpler than that,” he notes. “GE currently does skid implementation on its gas and steam turbines. In fact, 61% of GE’s steam turbines use FF as the control bus, and 35% of gas turbines are delivered with FF. These numbers are 10 to 30 times more than Profibus and CANbus on those systems.”

In manufacturing, device or fieldbus networks such as DeviceNet have typically been applied in control systems at the production site, whether that is a factory floor or a process plant, explains Katherine Voss, president and executive director of ODVA ([www.odva.org](http://www.odva.org)). “Usually connected to a PLC or DCS, these systems have been islands of automation that typify what has been referenced in current literature as ‘Industry 3.0,’” she says. “Although EtherNet/IP has also been applied in islands of
automation, EtherNet/IP specifically differentiates itself from device or fieldbus networks because it can be and is used as a bridge to connect these islands. It is also used as a gateway to connect automation systems to supervisory systems, the enterprise and/or the cloud (Figure 1). The objects, services and profiles that can be supported in an EtherNet/IP network are significantly richer than traditional device or fieldbus networks because of the large data packets and architectural variants that are possible. An example of this is cybersecurity through which Ethernet can allow for more robust encryption methods than a network with a smaller data packet size such as DeviceNet.”

In manufacturing, assembly and conveyance systems, device or fieldbus networks can have advantages, particularly as it relates to ease of installation, system configuration and power on the network for use by devices, explains Voss.

Profinet network diagnostics leverage Ethernet protocols, such as HTTP, SNMP and LLDP, that are familiar to the IT staff, says Michael Bowne, executive director, Profinis & Profinet North America (PI NA, us.profinet.com). For hypertext transfer protocol (HTTP), “PLCs and other controllers often have a Web server built-in, so you can configure them and
access information,” says Bowne. “Simi-
larly, managed Ethernet switches, drives,
wireless access points and other devices
provide a Web interface, as well.”

Simple network management protocol
(SNMP) provides information about Ether-
net networks by accessing data in Ethernet
switches—stand-alone switches or those
built into Profinet devices. “Is this port
sending and receiving data?” asks Bowne.
“Are there lots of retries on that port?
SNMP can tell you, so you can act before
production is impacted or quickly recover if
the line does go down.”

Link layer discovery protocol (LLDP) checks
on network neighbors, explains Bowne. “It
exchanges messages with the device on the
other end of the wire and stores that data.
That data can be accessed using standard
IT tools and special-purpose industrial tools
to determine the network topology. It also
can alarm if a link goes down. LLDP is re-
quired in Profinet devices,” says Bowne.

“Industrial Ethernet networks like Profinet
are faster with larger address spaces and
greater bandwidth than serial fieldbuses,”
explains Bowne. “Profinet particularly adds
network diagnostic capability from the IT
world to the already-comprehensive de-
vice diagnostics of Profibus. Profinet, like
Profibus before it, provides diagnostic data
if a device fails, a module in a device fails
or a channel on a module is broken. For
example, a channel failure could be ‘broken
wire’ for a digital output.”

Industrial Ethernet as a fieldbus provides
many advantages from a commercial
and technological perspective, says Joey
Stubbs, P.E., North American representa-
tive, EtherCAT Technology Group (www.
ethercat.org). “Because the innovation,
available products and high performance
of Ethernet, unlike legacy fieldbuses,
is driven by the much larger consumer
electronics and IT markets, this keeps the
price of Ethernet-based devices low, while
the interoperability and performance
remain high,” he explains. “This is key for
keeping protocols open and hardware
 interoperable, not to mention lowering the
price of PC-based controllers and inter-
face devices.”

FRESH INVESTMENT
From a user-centric perspective, the pool
of talent available that knows Ethernet is
far larger than the pool of talent that under-
stands fieldbus, says Paul Brooks, business
development manager at Rockwell Automa-
tion (www.rockwellautomation.com). “The
tools available make EtherNet/IP far easier
to deploy and use than fieldbus technolo-
gies,” he explains. “The ability to standard-
ize on a single technology has a significant
reduction in total cost of ownership (TCO).
There are many operational reasons that
the TCO of an Ethernet infrastructure low-
ers the cost over fieldbus.”
From a vendor perspective, the amount of investment that goes into developing Ethernet and IP-centric technologies is massive compared to what’s available in the fieldbus technologies, continues Brooks. “Inherently, Ethernet and fieldbus have many security challenges in common,” he admits. “We’re able to talk about a whole suite of tools developed for Ethernet that will never be in place with fieldbus. Being a global ubiquitous technology, we’re able to focus on the things no one else is doing.”

Cost difference between Ethernet and fieldbus is a major factor to be considered, says Sloan Zupan, senior product manager, Mitsubishi Electric Automation (us.mitsubishielectric.com/fa/en). “Fieldbus networks typically require an additional network interface card whereas Ethernet is typically built into the CPU itself, so no additional hardware is required,” he explains. “With that being said, there are many more field devices already in the market that support fieldbus networks. These devices typically connect to a block, which provides support for Ethernet connectivity. Once on Ethernet, customers enjoy using standard Cat. 5E cable with Ethernet RJ45 connectors. The speed of Ethernet provides value over fieldbus networks. However, fieldbus networks are often considered to be more reliable than nondeterministic Ethernet solutions.”

The primary differentiators between device/fieldbus networks and Ethernet networks are speed and stable and common physical layer, explains John Wozniak, P.E., automation networking specialist, CC-Link Partner Association (CLPA, www.cclinkamerica.org). “Device/fieldbus networks have multiple physical layers, between RS-485, CAN and RS-232, for example,” he says. “All Ethernet networks, on the other hand, rely only on the same Ethernet physical layer, all based on the IEEE standard 802.3. Even though some are older and slower 802.3c—10 Mbps—or newer and faster 802.3ab—1 Gbit/s—they all have the capability to operate with the same Cat. 5e cable, making it easier for end users to implement Ethernet.”

From a user-centric perspective, the pool of talent available that knows Ethernet is far larger than the pool of talent that understands fieldbus.
With the upcoming Industry 4.0/IIoT and the increasing demand for more and more information, the use of device/fieldbus networks is becoming the bottleneck for today’s automation applications, says Wozniak. “With speeds topping off at 10-12 Mbps, some of today’s most popular device/fieldbus networks just are not able to handle the flood of information desired by end users,” he explains. “Even some of today’s Ethernet networks at speeds of 100 Mbps are having difficulty keeping up with today’s tsunami of information. One of the downsides of Industrial Ethernet is the lack of intrinsic deterministic behavioral control with a majority of the Ethernet implementations. Most of the Industrial Ethernet implementations rely on TCP/IP, UDP/IP, for media access. While this collision-based approach is all well and good for general office and home use, it was not really designed for use in an industrial environment, which requires deterministic control.”

Dipl. Ing. André Hennecke, researcher at DFKI (www.dfki.de), a research center in Kaiserslautern, Germany, provides a list of Ethernet’s advantages over fieldbus. They include:

- supporting the vertical integration (interoperable on all levels and to the IT networks)
• future safety and protection of investment (until now, real-time fieldbus solutions are bought by changes on Layer 2, which leads to incompatible communication; also new Ethernet evolutions, such as 400 Gb/s, which are mainly driven by IT, can also be used)
• reducing costs (specialized network components are more cost-intensive than standard IT components)
• access to higher bandwidth—1,000 Mbs/s up to 10 Gb/s, instead of 100 Mbs—together with full duplex communication.

“Ethernet permits multiple protocols to run over the same network,” says Bill Dehner, technical marketer, AutomationDirect (www.automationdirect.com). Setting up an Ethernet network is typically less expensive and easier to configure than with fieldbus protocols, he says (Figure 2).

UBIQUITOUS ETHERNET

“Ethernet technology has proven incredibly successful and is a near ubiquitous method of communication in the IT world,” says Markus Plankensteiner, vice president, sales industrial, North America, and global alliance manager, TTTech Computertechnik (www.tttech.com). “It’s a very well standardized and open technology that is easily accessible to everyone, provides a wide range of bandwidth and physical layer options and has significant support in a diverse range of application areas. Up until now, there has been no real-time support in IEEE standardized Ethernet, leading to a number of proprietary modifications of Ethernet being used in industrial and transportation systems where real-time communication is a critical requirement. These solutions have typically been developed for specific tasks or domains. Profinet, EtherCAT and Ethernet/IP compete for recognition in industrial automation. While these protocols perform their specialized tasks capably, they have limits, when it comes to combining with standard Ethernet networks and devices. Deterministic Ethernet, with its real-time functionality, is able to fulfill these specialized requirements while also offering all of the advantages of being an open IEEE standard.”

Ethernet really is ubiquitous, which has created undeniable momentum. “With this level of inertia, we can be completely confident that there will be Ethernet in our near and even distant future,” says Doug Taylor, principal engineer, Concept Systems (www.conceptsheetsystemsinc.com), a system integrator in Albany, Oregon. “Furthermore, the available knowledge base on Ethernet is galactic. If there are 10 networks being installed in industry, I would wager that nine or more of them are Ethernet, so it pays to be on the bandwagon, even if a fieldbus offers significant specific advantages. Selecting a fieldbus that is not based upon Ethernet puts the designer in the unenviable position of having to defend the choice to
management, especially if there are downtime events being blamed on it. With Ethernet’s current bandwidth, liberal constraints and industry acceptance, it presents a near fait accompli to designers as the medium of choice for their networks.”

WHERE DOES THIS BUS GO?

“While both Profibus and Profinet are highly deterministic networks, Profinet comes with all of the extras associated with being Industrial Ethernet,” says PI NA’s Bowne. “Profinet provides deterministic cycle times for all speed requirements using two techniques: real-time (RT) and isochronous real-time (IRT). RT can provide update times down to 250 microseconds; IRT can provide update times down to 31.25 microseconds while synchronizing all devices on its network.”

When time-sensitive networking is available, Profinet will take advantage of it, says Bowne. “TSN is after all an update to standard Ethernet that Profinet uses for RT communications,” he says. “TSN impacts layers 1 and 2 of the ISO/OSI reference model for networks. Layer 7, the application layer, is unaffected. Web browsing, email and Profinet are all Layer 7 applications.”

Profibus and Profinet International (PI) currently has working groups investigating how best to rely on TSN and other Ethernet evolutions, such as Gigabit and IPv6. “Profinet has the advantage that high-speed and determinism are already available and have been for a long time,” says Bowne. “Profinet is an ideal fit in Industry 4.0 and Industrial Internet of Things infrastructures. It provides the data needed for collection and then analysis. After that analysis, Profinet provides the data path back to the system in order to improve processes. It gives the ability to organize that data into application profiles, or objects, for specific types of devices and applications, simplifying configuration, programming and transparency.”

Profinet diagnostics help manufacturers to avoid downtime, says Bowne. “It’s all based on open standards, even down to the means of integrating serial fieldbuses like Profibus and DeviceNet into Profinet,” he explains.

DeviceNet, like EtherNet/IP, utilizes a producer-consumer approach to network communication, explains ODVA’s Voss. “This approach improves network efficiency, and thus performance, by helping to optimize the amount of message traffic on the network,” she says. “DeviceNet has a flexible approach to network architecture unencumbered by the typical constraints in scheduled networks, which are typically associated with deterministic message delivery. DeviceNet is however extensively used for real-time control where update rates, and jitter with respect to message delivery times, measured in milliseconds are adequate.”

Today’s Ethernet solutions are point-to-point communications, explains Holger
Zeltwanger, managing director of CAN in Automation (CiA, www.can-cia.org). “CAN is a real bus topology,” he says. “In Ethernet, you have single point of failures—switches. In CAN networks, you can easily add nodes without disturbing the communication of the others, not considering timing requirements. CAN provides a lower bandwidth than Ethernet; however, if you just want to transmit a single bit, it could be that CAN is faster from end to end. The robustness and reliability of CAN is unique, if you implement the physical layer appropriately. CAN is also available for low-power applications, such as battery-powered systems. And it’s available for very reasonable prices and doesn’t require huge resources in the host controller. The footprint of CAN interfaces is much smaller compared with Ethernet. The automotive industry goes the direction of CAN FD, the next-generation CAN technology. Bit rates are increased to 5 Mbit/s, and the payload is enlarged to 64 bytes. Other CAN-using industries will follow this improvement.”

While discrete applications aren’t impossible with Foundation Fieldbus (FF) or HART, both are process-oriented technologies, and they have a bigger impact in the process space, says FieldComm Group’s Petty. “Foundation Fieldbus, in particular, absolutely supports deterministic control, and that is in fact one of its strongest features,” he says. “For this reason, the role is strong and will continue to be strong. Determinism is important in traceability in the process industries, and it also allows closed-loop feedback.”

Foundation Fieldbus’ role already is well-established in deterministic control, says Petty. “Determinism has been an integral part of FF since its birth,” he explains. “With HART, it’s slightly different. The control portion is actually done over 4-20 mA, so determinism isn’t inherent or measurable. In a HART system, if you have a valve and want to move it to the closed position and you want to know when it reaches the closed position, you need an additional set of wires run to the valve that feed to a closed sensor, if you will. The sensor’s job is basically just to report when closed has been reached. Think of it like a light switch. A valve begins closing, and, once closed, it hits a contact point, which then sends a signal back down the wire to indicate it is closed. The same would be true for full open. So closed-loop control is possible in that way, but it requires some additional effort and engineering.”

Because FF is all digital, the information is all internal in the device, explains Petty. “It knows when it’s fully open or fully closed, so it simply just reports confirmation that the device has reached its requested state and in the requested time,” he says. “This is an example only to illustrate how determinism is important. Without determinism, an operator would have no way of know-
ing when that valve would actually close. It may close in 100 milliseconds, or it may close in 3 seconds.”

CC-Link Industrial Ethernet (IE) is poised to handle the requirements and demands of the next step in automation, says CLPA’s Wozniak. “With the fastest available Industrial Ethernet speed at 1 Gbps, CC-Link IE is able to handle even the most information-rich IIoT application,” he states. “Add in the token-based media access, and you have a complete Industrial Ethernet network that’s able to handle vast amounts of data while still maintaining complete deterministic manufacturing control. With an integrated-safety communication function, the ability to handle motion control and the ability to provide energy management functionality, CC-Link IE is a complete Industrial Internet of Things/Industry 4.0/Smart Factory automation network.”

CC-Link IE is already somewhat a time-sensitive network since the network is token-based and therefore completely deterministic, explains Wozniak. “With the token architecture, each individual device maintains communication control of the network for a specific time period,” he says. “The actual TSN movement, the latest in a series of potential enhancements to Ethernet to provide greater manufacturing deterministic control on top of the collision-based TCP/IP architecture, is a fascinating new feature for a collision-based Ethernet network to potentially provide the ability for a TCP/IP network to be more deterministic, a feature already completely provided by CC-Link IE.”

OPC UA is deliberately working with all of the fieldbus organizations, says OPC Foundation’s Burke. “It has become the solution of choice, allowing the respective fieldbus network devices to be able to interact with higher-level tier systems, as well as the cloud,” he explains. “For example, at Hanover this year Microsoft announced and demonstrated the connectivity of OPC UA embedded devices using the OPC unified architecture and connecting directly to the Microsoft Azure cloud. Similarly, SAP did a demonstration showing OPC UA embedded devices directly plugging into the SAP architecture and having the ability to push data into Hana.”

**IIoT**

“OPC UA is actively working at supporting time-sensitive networking as part of the publish/subscribe architecture that we are developing to address seamless interoperability between disparate devices in the IoT environment, as well as having a streamlined performance alternative for information integration and connectivity to cloud-based solutions,” says OPC Foundation’s Burke. “I’m careful not to say, ‘real-time.’ But the expectation is, with the high-speed performance that TSN will give us, there will be significant opportunities for embedded OPC UA devices to talk to other OPC
UA embedded devices, giving the ability for devices that currently exist on one particular industrial fieldbus to be able to seamlessly interoperate and share information with other devices on a different industrial fieldbus network.”

In the short term, Burke expects vendors on the same industrial Ethernet fieldbus network to use that respective industrial Ethernet fieldbus to have their devices communicate. “But, with the power of the OPC unified architecture and the information model that will probably change over time, you will see more and more OPC UA enabled devices providing information exchange between different types of devices on the same fieldbus network,” he says. The real use case will be the ability to connect devices on different fieldbus networks, to do it deterministically and to achieve a significant increase in communication bandwidth over TSN.

“One of the very few Industrial Ethernet implementations that was designed for the industrial environment with inherent deterministic behavioral control is CC-Link IE, with a token-based media access for complete deterministic behavior, says CLPA’s Wozniak. “Industrial Internet of Things, Industry 4.0, Smart Factory or whatever term the industry is using today is the next step in automation, with networks collecting all sorts of information related to the manufacturing process, including diagnostics, sensor data and parts traceability,” he explains. “Now, add in the requirement that a network combine everything into one network, including deterministic manufacturing I/O control, energy management, safety communications, motion control and the ability to provide your plant-management information system with constant complete manufacturing updates. You really do have one smart integrated factory.”

THE ONCE AND FUTURE NETWORK
The role of FieldComm Group’s technologies, regarding the IIoT is as enablers, says FieldComm Group’s Petty. “If you think about it, these existing fieldbus networks
have been an ‘Internet of Things’ before the term even existed,” he explains. “We’ve basically been creating the network of things for more than 20 years. People just need to recognize and connect to it to use the data. Pull that data into their management tools and data analytics tools to make better business decisions.”

Though Ethernet is technically not deterministic, with switched networks supporting quality of service (QoS) it is real time enough—at least six times faster than the process—for the majority of applications and certainly fast enough for communications between local controllers or I/O gateways, in the vein of the ExxonMobil concept, which could be PoE-powered, explains CIMA+’s Verhappen. “There are some manufacturers that supply IS PoE if required,” he notes. “The almost 30 fieldbus standards in the IEC 61158 documents will continue to serve the niche for which they were designed and developed because those unique needs, driven by the application and the process, still exist and will continue to do so.”

Unlike EtherNet/IP, DeviceNet is based on the standard for the controller area network or CAN. As such, TSN, which is part of IEEE 802.1 standards, is not generally considered to be applicable to CAN and therefore DeviceNet, explains ODVA’s Voss. However, DeviceNet is directly applicable to the Industrial Internet of Things. “Because it is based on CAN—a low-cost network widely used in automotive control modules—DeviceNet offers a cost-effective way to connect devices currently not connected to the Industrial Internet,” says Voss. “Recognizing this potential, ODVA has established a technical working group, known in ODVA as a special interest group or SIG, called the SIG for the DeviceNet of things, which is aimed at the application of DeviceNet to previously unconnected devices through simplified connection and configuration schemes. Industry 4.0 is a German initiative aimed at leveraging technology trends, such as the Industrial Internet of Things, in order to make German manufacturing more competitive. To the extent that many of the ideas and principles of Industry 4.0 are applicable to industry in general and that industrial networks are key enabling technologies for the realization of Industry 4.0, DeviceNet is one of the potential enabling technologies for Industry 4.0.”

CAN is and will be the dominating network in automotive in-vehicle networks, says CiA’s Zeltwanger. “The number of CAN FD nodes will further increase,” he predicts. “In 2017, we expect about 1.5 billion new CAN nodes to be installed. The same is true in many other industries. CAN is the dominating embedded and deeply embedded network in real-time control systems. CAN is used to bring the sensor and actuator information to the Ethernet-based IT infrastructure by means of standardized CAN-
to-Ethernet gateways.” For more than 10 years, CiA has provided the 309 series of interface specifications, which standardize the communication between CANopen and ModbusTCP, generic Ethernet, Profinet IO and HTTP, making any CANopen device a “thing” in the Internet.

CiA is anticipating migration from Classical CAN to CAN FD by industries that haven’t already begun to make the change. Although 80% of CAN nodes are installed in automobiles, CiA expects to reach 2 billion nodes by 2020, which means 400 million nodes in industrial applications such as machine control. “CANopen is the CAN-based higher-layer protocol used mainly in what I like to call, ‘embedded machine control,’” says Zeltwanger. “DeviceNet, another CAN-based higher-layer protocol is mainly used in factory automation. In my experience, the overlap of embedded machine control and factory automation is not that huge.”

CiA also is working on the standardization of logical addresses for CANopen, explains Zeltwanger. “This means, the user will no longer address parameters by means of network-ID, node-ID, and local address for parameters—16-bit index and 8-bit sub-index—but by logical names such as ‘speed demand value of the second motor driving the saw,’” he says.
I know you are not a networking expert, but I am. I found it difficult to read your cover article for the November 2016 edition. Let me explain.

Ethernet is a communications technology widely used to solve problems in industrial Fieldbus communications. Let me illustrate—EtherNet/IP, Profinet, PowerLink, EtherCAT, Sercos III, Foundation Fieldbus HSE and CC-Link IE are all fieldbuses and use Ethernet technology at layers 1 and 2 (physical and data link layer). Why do I say they are fieldbuses? They are all in the International Electrotechnical Committee (IEC) Standard 61158 that defines industrial fieldbuses. Each has different ways to use Ethernet, but none of them tolerate any collisions because it is collisions that caused old-fashioned coaxial cable Ethernet to be nondeterministic. Therefore all of these forms of Ethernet are fieldbuses and are deterministic. Twenty years ago, offices and industry stopped using 10Base-2 coaxial-cable-based Ethernet because it just didn’t work well in the office and not at all in the factory. Since then, all Ethernet networks have used full duplex switches to buffer all messages and prevent collisions. While many industrial networks have used ruggedized Ethernet switches, several very high-speed machine control fieldbuses such as EtherCAT, PowerLink and Sercos III use Ethernet switch chips at each node and have the capability to form lightning-fast deterministic networks based on unmodified Ethernet protocol, and they call themselves fieldbuses.
All of the Ethernet-based fieldbuses avoid the use of transmission control protocol (TCP) because it is nondeterministic.

By the way, anyone who refers to full duplex switched Ethernet in any form as nondeterministic is just behind times. We are so far advanced from those days, but there are some who are stuck in the old folklore that they cannot accept modern technical facts.

All of the Ethernet-based fieldbuses avoid the use of transmission control protocol (TCP) because it is nondeterministic. Instead, for real-time communications they use different applications of user datagram protocol (UDP) with Internet-protocol (IP) addressing. Some, such as Foundation Fieldbus HSE, do not allow any TCP-encoded messages, while others allocate fixed time slots for such TCP messages. This is only one type of time-sensitive networking (TSN) mentioned but not defined in your article.

So, it is not Ethernet vs. fieldbus. The question is: Will old non-IP fieldbus protocols go away? That would mean implementing IP at the edge device itself. This has already begun in both factory automation and process control, but there are many millions, or perhaps billions, of existing not-very-smart devices in the field that are not going away overnight.

Dick Caro, CEO, CMC Associates (www.cmc.us), Arlington, Massachusetts; ISA life fellow; and author of “Automation Network Selection” and “Wireless Networks for Industrial Automation.”
First, let me address the major differentiators between device/fieldbus networks and Ethernet networks. So far, we can distinguish two generations of fieldbus networks. The fieldbuses of Generation 1 were based on different physical and data link layers (not Ethernet) and designed for dedicated purposes, such as drive communication (Sercos), I/O communication (Profibus, Interbus, DeviceNet) or safety communication (for example, Safetybus-p). This led to the situation that within a manufacturing unit, or between manufacturing units, different buses were required to meet the application requirements, such as a combination of Sercos + Profibus, or Sercos + DeviceNet. Ethernet was not used at all at the field level, but only when connecting machines via the machine controls to the superior IT systems (MES/ERP/SCADA). The disadvantages were not only the large number of heterogeneous and incompatible interfaces, but also the high total cost of ownership—different tools for engineering, monitoring and diagnosis, high overall complexity.

The fieldbuses of Generation 2, developed in the early 2000s, were based on Ethernet and could be used, because of the high bandwidth of > 100 Mbit/s, for universal purposes (motion + safety + I/O over one bus). Ethernet-based networks were supporting higher speeds,
but due to the non-determinism of Ethernet, different variants of real-time Ethernet were created as successor technologies of fieldbus technologies of Generation1 (Sercos III for Sercos I/II; Profinet for Profibus; Ethernet/IP for DeviceNet). Also, new protocols were created by automation companies. For example, B&R created PowerLink, and Beckhoff created EtherCAT. To reach a high performance—short run times, short cycle times, high protocol efficiency, sub-microsecond synchronicity—special hardware is needed for Profinet IRT, Sercos III and EtherCAT. The disadvantages of Generation 2 fieldbuses are that these RTE technologies are not interoperable, and most RTE do not even support multiple protocols to co-exist in one network infrastructure. Because of this, the networks for IT and automation are still separate and many RTE technologies need the network exclusively for real-time traffic—no protocol coexistence.

Ethernet TSN now will be the basis for the next-generation fieldbuses—Generation 3. This is an exciting milestone because for the first time, after 43 years, Ethernet by itself becomes deterministic. As no modified hardware is required to achieve network determinism, TSN will support and enable
the convergence of IT and OT networks. Because TSN allows different Ethernet protocols to co-exist and share the network infrastructure—no gateways, only switches are needed. Thus, a consistent and transparent access from sensor to cloud and vice versa becomes possible. TSN not only will support real-time communication but also higher-speeds and lower costs because of the cross-industry support of the TSN technology from automotive, multimedia, automation.

Sercos has been using time-triggered and time-slot-based communication since the introduction of the Sercos technology in the late 1990s in order to meet the requirements for high-speed real-time communication for all kinds of production machines and demanding automation applications. Sercos I/II was mainly used for drive communication. Ethernet-based Sercos III became a universal automation bus supporting motion, safety, I/O, vision, TCP/IP and other Ethernet protocols over one single network. In the future, Sercos will rely on deterministic Ethernet (Ethernet TSN), which will lead to significant advantages, including standardized hardware, lower cost, higher speeds and IT connectivity, for the users of the technology.

At the same time, Sercos supports the requirements of Industry 4.0/IoT, regarding semantic interoperability. For this, a standardized OPC UA Sercos information model was defined that brings together the well-defined device profiles of Sercos (semantic for drives, I/Os, encoders, energy) with the information model and data exchange standard of OPC UA. With this approach, the functions and data of Sercos devices are made available and accessible via OPC UA.

Use cases cover a broad range from device parameterization and network configuration up to energy management and preventive maintenance. The mapping rules specified by Sercos can be used for different implementation approaches. On the one hand, the OPC UA server functionality can be implemented in a Sercos master device—for example, CNC or PLC. On the other hand, it is possible to implement this functionality in a Sercos slave device. In the latter case, the OPC UA accesses are executed in parallel to the Sercos real-time communication or even without any Sercos real-time communication.

Dipl.-Ing. Peter Lutz, managing director, Sercos International (www.sercos.org), Suessen, Germany
What is time-sensitive networking?

TSN is purported to be the next step toward realizing an Industrial Internet of Things, but let’s define it and understand what it is

By Mike Bacidore, editor in chief

Time-sensitive networking (TSN) is the most recent leg of the journey that will make critical data available where and, most importantly, when it’s needed. The automotive industry’s use of audio video bridging has evolved into time-sensitive networking for in-vehicle and out-of-vehicle communications.

BUT WHAT EXACTLY IS TSN, AND WHY DOES IT MATTER?

“On the one hand, time-sensitive networking denotes a set of IEEE 802 standards, which extends the functionality of Ethernet networks to support a deterministic and high-availability communication on Layer 2,” explains Dipl. Ing. André Hennecke, researcher at DFKI (www.dfki.de), a research center in Kaiserslautern, Germany. “In particular, this includes an improved timing synchronization and a real-time scheduling method, enhancements of the stream reservation protocol, explicit path control and network policing procedures.”

On the other hand, the term “time-sensitive network” is also used to designate a series of acts from different organizations to enable a deterministic communication via Ethernet, not only with a focus on Layer 2, but also with a view on Layer 3 (DetNet), applications and certification processes, such as those from AVnu Alliance, says Hennecke.

“It’s possible to have a network that offers no value to a customer, even though it conveys 100% of the requested information, simply because of the transmission latency it introduc-
es,” warns Doug Taylor, principal engineer, Concept Systems (www.conceptsyste- sinsc.com), a system integrator in Albany, Oregon. The aim of TSN is to eliminate that latency for critical data by reserving a traffic lane for those packets.

At one level, time sensitive networking it is a set of IEEE 802.1 and 802.3 standards, explains Paul Didier, solutions architect manager at Cisco (www.cisco.com). “The objective is to enhance Ethernet and core standard networking to better support time-sensitive applications, such as industrial automation control,” he says. “We’re trying to match up standard networking with a lot of the requirements coming out of industrial automation and control. The concept of these control transactions or messages is a little challenging. Control engineers think they’ve got a controller or motor, and there’s a wire between the two of them. Technically, they understand that moving to standard networks and being able to do things in those models makes things a lot easier. Queuing the stuff up is counterintuitive. They’re looking for deterministic network performance characteristics around latency, jitter and reliability that are easy to implement and use. It gives them an open and interconnected network that allows much more freely flowing information from those devices and to enhance and add to those devices over time, which drives the overall story of the IoT, where you can do off-line or close-to-the-machine.

You need access to the data without having to drop extra lines in. It’s about convergence. There’s all of this IIoT, and it’s all about these things using the Internet. Aren’t there different requirements? Isn’t there a reason they haven’t used the Internet? Should we make some modifications?”

At the heart of TSN are mechanisms that provide time synchronization for networked devices and scheduled forwarding of defined traffic flows through the network, explains Markus Plankensteiner, vice president, sales industrial, North America, and global alliance manager, TTTech Computertechnik (www.tttech.com). “Through time synchronization and scheduling, TSN delivers deterministic communication over standard Ethernet, thereby enabling the convergence of critical control traffic with data traffic over one infrastructure without the need for gateways or proprietary solutions,” he says.

“The TSN standards define mechanisms for the time-sensitive transmission of data over Ethernet networks; these in particular address the transmission of data at very low latency and high availability, allowing for time-determination communication and synchronization,” says Sari Germanos, open automation business development manager, B&R Industrial Automation (www.br-auto- mation.com).

Time-sensitive networking is a collection of
projects aimed at improving Ethernet, and specifically Internet technologies for time synchronization, explains Joey Stubbs, P.E., North American representative, EtherCAT Technology Group (www.ethercat.org). “These projects are intended to improve routing, pre-emption, time synchronization, security and throughput of Ethernet traffic for A/V streaming and bridging,” he says. The IEEE 802.1 standard encompasses the work of the TSN Task Group, which used to be called the AVB Task Group for audio video bridging.

Fieldbuses are proprietary, well-designed for the applications they support, but getting data out of them is a bear, says Didier. “We can support that much better than the much-less-deterministic methods that we currently have,” he explains. “They have control problems they’re trying to solve. We’ve got an ecosystem we’re trying to build this into. This isn’t going to be a separate network configuration. It’s simply incorporated in the standard tools that you use. The idea is those programs understand the control loops and what information needs to come in and leave. The network will say it can handle it, sometimes with modifications, and push it out into the network. That’s the architecture we’re putting together on top of the IEEE standards.”

Time sensitive networking, as a concept, is analogous to real-time networking, where real time is the amount of time that network data is accurate and consistent enough for the control system to make reliable decisions, explains Phil Marshall, CEO of Hilscher North America (www.hilscher.com). “In some applications, this requirement is measured in milliseconds, in others, in microseconds,” he says.

The standardization of time-sensitive features within IEEE 802.1/802.3 to be rolled out in a large number of consumer and industrial chipsets will mean that many more people will be able to gain access into the development of industrial applications, explains Dr. Michael Hoffmeister, portfolio manager, software, at Festo (www.festo.com). “This is expected to stimulate a diversity of new use cases, applications and software tools and will therefore trigger also new impulses on the shop-floor level,” he predicts. “Moreover, TSN allows for real-time communication in parallel to standard Ethernet-based office communication over the same network infrastructure, which increases flexibility in the network architecture.”

Time sensitive networking is the capability to do true real-time traffic with known worst-case end-to-end transmission times, says Mark Hermeling, director, product management, VxWorks, Wind River (www.windriver.com). “Ethernet as we know it today is best effort, at best,” he cautions. “There is no way to calculate the time it will take for a packet to go from A to B. There is...
a lot of variability in the transmission times that can be caused at multiple levels in the OSI model.”

There are fieldbus protocols, such as EtherCAT and Profinet, that have sprung up over the years to remedy this, continues Hermeling. “Many networks have one connection for real-time traffic to real-time devices and one connection for general-purpose traffic such as connecting to IT networks,” he explains. “Time-sensitive networking promises to provide known transmission times for real-time packets, while allowing general-purpose traffic to be intermixed on the same connection.”

Time-sensitive networks have very little latency, explains Sloan Zupan, senior product manager, Mitsubishi Electric Automation (us.mitsubishielectric.com/fa/en). “In machine control, it’s critical that automation components communicate with one another using a deterministic network,” he says. “Protocols that use standard TCP/IP Ethernet introduce latency because it is a non-deterministic protocol.”

In the generic sense, TSN is a set of capabilities being added to standard Ethernet to support applications that need deterministic characteristics for data transfer, explains Todd Walter, chief marketing manager, National Instruments (www.ni.com) and industrial segment chair of AVnu Alliance (www.avnu.org). “If you want to do a control loop, that is very difficult today,” he says. “You can engineer and constrain what traffic goes on the network. The level of performance isn’t as high as you could get. Time sensitive-networking actually will schedule a class of traffic through the network. An analogy is, if you have an express lane on a highway, cars in that lane can get higher priority. If you still have a bunch of cars at the same time, you can still have congestion. You can control and time when cars go in and when the lights change, so you can get deterministic transfer. That’s what’s being added.”
For once, the industry has a term that means exactly what it sounds like, says Dr. Richard Soley, executive director of the Industrial Internet Consortium (IIC, www.iiconsortium.org). “It’s connecting devices for which the connectivity is time-sensitive—that is, communications must be received with minimum latency and/or maximum throughput,” he explains. “The common technical term is hard real-time, meaning that there is an absolute deadline, after which the system fails—the worst-case execution time can be characterized precisely; or there’s soft real-time, meaning the system may fail gracefully after the deadline.”

Rockwell Automation (www.rockwellautomation.com) follows the IEEE definition of time sensitive networking. “It’s a bundle of extensions primarily to the 802.1 spec, with some also impacting 802.3 capabilities such as scheduling,” says Paul Brooks, business development manager. “We very much see it as being a bundle of separate things.”
Ethernet has taken over industrial automation communications in many areas, but its lack of determinism has limited use in many real-time control applications. Suppliers are addressing this issue by modifying Ethernet to add determinism, and a new Ethernet time-sensitive networking (TSN) standard is also being developed to deal with this problem.

One application using a variant of Ethernet to provide determinism is the deployment of automated guided vehicles (AGVs) by Fori Automation (Figure 1). In one deployment, their AGVs move at speeds up to 2 ft/s across the floor of an aerospace manufacturer’s cavernous production facility. One AGV carries a 30-ton, 60-ft-long wing frame for a commercial jet aircraft to its assembly point. With the payload worth several million dollars, the AGV must be controlled precisely to within 5 mm. And with workers walking all around, it must operate safely.

AGV movements are monitored and controlled by a wireless Profinet network, using a modified version of Ethernet to add the required determinism and real-time control. Profinet uses Ethernet’s TCP/IP standards for non-time-critical communications such as diagnostics, but adds deterministic channels to achieve real-time communications in as little as 31.25 microseconds. This is critical to the application requirement, which specifies wireless communications, among up to 50 AGVs in any given deployment, be uninterruptible.
AGV safety and control devices communicate via Profinet to a managed switch connected to a wireless client onboard each AGV. This onboard client then communicates over the 5 GHz spectrum to fixed-mounted access points, which are IP65-rated for use in industrial environments. These access points are located in regular intervals throughout the plant, usually in a plant’s rafters or ceilings, for maximum range with overlapping radio signaling to prevent any coverage gaps.

Historically, AGVs were guided in a fixed circle by a large induction loop, making it difficult to change or add new routes. Lacking real-time communication, functionality and flexibility were limited. With Profinet, continuous communication between the AGV and the plant’s master PLC is possible every step of the way, providing much greater flexibility of movement and positioning of travel circuits within a plant.

Many control system engineers aren’t nec-
nessarily networking experts, but this wasn’t a problem for Greg Stegner, the controls project leader at Fori Automation (www.foriauto.com). “You open a browser and follow a series of wizards that walk you through the process,” he says. “It gives you all your wireless and security settings. I was able to get the wireless Profinet network up and running in a couple hours on my own.”

With the Profinet-based wireless solution, Stegner says Fori Automation can now deploy as many as 50 AGVs across a single customer plant, almost three times as many as previously, providing customers with much greater flexibility. “Typically, in-plant conveyance systems are straight-line designs, but now our AGVs can move in all directions and around corners, so plant operators can make much more efficient and flexible use of their real estate,” explains Stegner.

An important corollary benefit of this flexibility is enabling industrial and plant engineers to think differently about plant-floor layouts. “If they have no constraints on how they develop floor plans due to AGV movement restrictions, then they can optimize layouts for maximum output,” says Stegner. “They can also modify floor plans much more quickly and easily to accommodate new production requirements.” Eliminating tethered HMI controls makes operating the AGVs much easier because plant personnel no longer have to worry about cables breaking or becoming tripping hazards.

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The AGV example demonstrates determinism using wireless Ethernet, and this application shows how wired Ethernet can provide determinism.

Deterministic Ethernet communications in this application and many others are provided with EtherCAT, a modified version of Ethernet. “EtherCAT permits communication to as many as 256 digital I/Os in 12 µs, and up to 100 servo axes every 100 µs,” claims Matt Prellwitz, the drive technology application specialist at Beckhoff Automation (www.beckhoffautomation.com). And for applications requiring real-time control and power over Ethernet, Beckhoff recently introduced EtherCAT P, a solution combining industrial Ethernet communication and
a 24 Vdc power supply in a single, standard four-wire Ethernet cable.

A Beckhoff customer implements robotic work cells positioned along a conveyor system in a large manufacturing facility, and it uses EtherCAT to provide the required high-speed communications. “In this application, EtherCAT delivered a wide range of benefits, including increased speed of data transmission and pulse rates,” says Prellwitz.

By leveraging real-time EtherCAT in assembly cells, communication speeds increased exponentially. The real-time production data from the robotic systems is fed directly into the enterprise systems, thereby enabling closer integration into the production process with a higher-quality end-product as a result. Weld patterns are also tracked in real-time, providing a means of ensuring high product quality and repeatability of processes.

Processing on the fly is one of the biggest enablers of the real-time performance of EtherCAT. Prellwitz says the general operating principle for Ethernet frames in EtherCAT, along with mapping through a fieldbus memory management unit (FMMU), distinguishes it from other industrial Ethernet protocols.

One EtherCAT frame holds data for many network devices. The frame is not received and interpreted with the process data copied at each individual device. Instead, each EtherCAT slave device reads the data specifically addressed to it from the frame and inserts data into the frame while that frame passes through the node at full speed. Also, the frame’s cyclic redundancy check (CRC) is updated to reflect the new contents of the frame.

“That’s just the technical description of how EtherCAT works,” explains Prellwitz. “Customers who have heavily implemented this technology focus more on the many benefits and tangible results of real-time functionality in industrial Ethernet systems.”

Profinet and EtherCAT work well in these applications to add determinism to Ethernet, but the networks aren’t compatible with each other, nor with any of the many other variants of Ethernet designed to provide determinism. This creates a problem as too many Ethernet “standards” can result in no standard at all.
No one is driving time sensitive network (TSN) standards. Literally. Deterministic Ethernet could make automobile electronic systems more adaptable to the requirements for advanced driver assistance systems, priming vehicles for the age of driverless vehicles and connected cars. See? No one driving?

Anyway, that pioneering work from the automotive industry has changed the idea of what’s possible for deterministic control in manufacturing. Actually, we’re almost beyond considering what’s possible. We’re at the testing stage.

National Instruments (NI, www.ni.com) and other members of the Industrial Internet Consortium (IIC, www.iiconsortium.org) have announced a collaborative effort on the first TSN testbed for manufacturing.

“The goal of this testbed is to display the value of new Ethernet IEEE 802 standards, referred to as TSN, in an ecosystem of manufacturing applications,” explains Todd Walter, chief marketing manager at NI. “IEEE 802.1 will support all of the bandwidth standards. In industrial, it’ll largely be 100 MB and some 1 GB, plus 2.5 GB and 10 GB. There’s even work going on for a 400 GB bandwidth. Because it’s Ethernet, it can keep scaling with the Ethernet standard.”
TSN powers a standard, open network infrastructure supporting multi-vendor interoperability and integration with new guaranteed performance and delivery, says Walter. “The technology can support real-time control and synchronization, for example between motion applications and robots, over a single Ethernet network,” he says. “TSN can at the same time support other common traffic found in manufacturing applications, driving convergence between IT and operational technologies.”

Standardized and open communication is a key feature in drive and control automation solutions at Bosch Rexroth (www.boschrexroth.com), one of the testbed collaborators. “The IIC TSN testbed is a very important contribution for further improvement of vendor interoperability and of exchanging data in an IIoT infrastructure,” says Ralf Koepppe, vice president of engineering and manufacturing electric drives and controls. “The new IIC TSN testbed is an opportunity to work with other industry leaders to prove standard technology for distributed real-time control systems as needed for edge cloud computing also known as fog computing,” says Christian Schloegel, chief technology officer at KUKA (www.kuka-robotics.com), another testbed participant. “We view TSN, combined with OPC UA publish/subscribe, as a core element to implement Industry 4.0 standards.”

Yet another collaborator, TTTech (www.tttech.com) has 20 years of experience in time-scheduled networks and critical real-time controls. “We look forward to collaborating with the other testbed members to build an open, standard platform for the IIoT,” says Georg Kopetz, TTTech cofounder and executive board member.

Other testbed collaborators include Cisco, Intel and Schneider Electric.

Learn more about the testbed at www.iiconsortium.org/time-sensitive-networks.htm.

Pioneering work from the automotive industry has changed the idea of what’s possible.
Time-sensitive networking (TSN) has its own gravitational pull, said Steve Zuponcic, technology manager at Rockwell Automation (www.rockwellautomation.com). “We think we’re in charge of our own destiny, but TSN started as an audio-video bridging outside of our industry,” he explained. “IEEE is starting to make changes to standard Ethernet, and some forces are starting to pull. We have to start paying attention and responding to that. We need to be aware and take appropriate actions.”

Zuponcic’s warning was one of many discussions regarding TSN, including enhancements to IEEE 802.1 and the Internet Engineering Task Force (IETF) DetNet for wide-area deterministic networks, at the 2017 ODVA Industry Conference in Palm Harbor, Florida. “IEEE is driving at Layer 2, and IETF is driving at Layer 3,” explained Zuponcic. “IEEE 802.1 is a lot of standards—some published, some in final ballot, some in progress and some under consideration. It’s safe to say that among the different technologies and standards, a significant amount of work is being done with scheduled Ethernet, including new prioritization and tight predictable control of multiple traffic streams.”

Scheduled traffic is given the highest priority above all else. Today’s implementation of CIP traffic would fall into a rate-constrained or best-effort category. On a lightly loaded system, rate-constrained traffic can coexist. When you look at a frame of time and the duty cycle becomes large enough, the CIP traffic, the rate-constrained traffic, has less and less. And,
if planned data streams can’t be accommodated, the network can be modified by adding topology paths, increasing speed or altering requested packet intervals (RPIs). “A core precept of the TSN value proposition is that all network communications are managed so that there is a guarantee for performance and for data delivery,” explained Zuponcic. “If all streams are defined, payloads are known and maximum data delivery latencies are provided, system network calculations can determine if successful operation of the network is achievable. All devices need to participate in traffic planning by publishing to or notifying a centralized network configuration (CNC) engine of their traffic requirements for the connections involved.”

The CNC function has the role of configuring the infrastructure, explained Zuponcic. “It communicates with the centralized user configuration (CUC) tools to receive stream information,” he said. “In an industrial system, the CUC is most likely part of the PLC programming software for off-line configuration or part of the PLC during runtime. When we configure a PLC, we set up the RPIs. The payloads are already given; that information is already there.”

How do we get things to coexist? “System-level configuration allows for control of both the network and the application,” explained Zuponcic. “The CNC must solve and configure for successful operation of the application given all existing constraints. Policy-based prioritization is counterbalance against data delivery mechanisms. The CNC policy engine configures the network based on policies, as well as capabilities and constraints of the infrastructure and the devices it’s configuring.”

The CNC is responsible for blending scheduled traffic and rate-constrained traffic or both to provide proper management of the system.

“A logical place to put the CNC is in the PLC,” offered Rudy Klecka, technical lead at Cisco (www.cisco.com). “It’s just a piece of software. We could run it in an appliance. We could put it in a switch. But, most likely, it will be put into a PLC. Define the inputs and the outputs of the CNC, and then let the market figure out the best algorithms. The CNC knows the topology.”

Modern industrial networks combine the disciplines of both information technology (IT) and operations technology (OT) to meet the requirements of industrial applications. “The industrial control networking legacy is long established,” Zuponcic reminded. “We haven’t been motivated toward convergence historically. It demands an holistic approach and a system view as we go toward TSN. Lack of participation results in lack of service. Your traffic will get run over.”
The time-sensitive networking (TSN) testbed is overseen by the Industrial Internet Consortium (IIC, www.iiconsortium.org), and its goal is to bring together technologies from various companies and demonstrate Ethernet (IEEE 802) standards in a manufacturing ecosystem.

At the 2017 ODVA Industry Conference in Palm Harbor, Florida, Paul Didier, Internet of Things solution architect at Cisco (www.cisco.com), shared a comprehensive update on the testbed and related plugfests. Four ODVA (www.odva.org) members—Cisco, Bosch Rexroth, Schneider Electric and Innovasic, which was acquired by Analog Devices—are participating in the testbed.

The testbed will combine different traffic flows on a single network based on IEEE 802.1, will demonstrate the real-time capability and interoperability using standard, converged Ethernet, will evaluate security value of TSN, will show the ability to incorporate high-performance and latency-sensitive applications and will provide integration points for smart edge-cloud control systems.

“We’d like to see applications use a single open-architecture infrastructure,” explained Didier. TSN is an Ethernet enhancement. Without it, suppliers must use specialized non-IEEE conformant network technology in their products, restricting their participation in IoT de-
developments. “We’ve already had four plug-
fests,” said Didier.

“On June 20-23, we conducted the first TSN plugfest with the testbed at National Instruments headquarters in Austin, Texas,” said Didier. “The testbed was officially open and available. Participants included National Instruments, Cisco, TTTech, GE, Schneider Electric, Kuka, Intel, Analog Devices and Ixia.” The objectives were to establish end-device synchronization via 802.1AS networking-based time services; to define TSN flows in central network controller and distribute schedule to network infrastructure; to communicate I/O traffic via TSN flows; and to measure and verify TSN performance with Ixia testing tools. “All participants with end devices achieved synchronization,” said Didier.

On Oct. 3-5, the second TSN plugfest was conducted in Austin. The objectives were similar, but in a demonstrable testbed. “Time synchronization, traffic scheduling and system configuration were tested,” explained Didier. “These were the key goals of the plugfest. First, we wanted to validate that they have the time synchronization working.”

Traffic scheduling entailed proving deterministic qualities.

“For system configuration, right now we’ve got one domain,” explained Didier. “What we want is the users’ tools telling the network-configuration tool, ‘This is what I need,’ and then taking the requirements and figuring a solution and distributing a schedule.” In the near future, centralized configuration of the time-sensitive features will be achieved, making it possible to coordinate motion control, I/O, controller-to-controller and machine-to-machine communications, seamlessly across the same network backbone, explained Didier. “Further data from any or all of these applications can be made seamlessly available to the user via the network or through the cloud,” he said.

“We’re building another testbed at Bosch Rexroth in Germany and will be having a plugfest there in March,” said Didier. “We are going to try to get a linear-motion application working in Germany. Our objective is to have a line-motion application running over TSN.”
Carmakers embraced deterministic control for in-vehicle and out-of-vehicle systems years ago. This is largely what has driven the transformation of audio video bridging into time sensitive networking.

Automobiles have different latency-sensitive applications than manufacturing does, but the two are learning from one another in their respective pursuits of TSN via deterministic Ethernet.

“The automotive industry can be a strong partner to get to a global and unified standard for a deterministic communication,” advises Dipl. Ing. André Hennecke, researcher at DFKI (www.dfki.de), a research center in Kaiserslautern, Germany. “This can be used not only in the automotive or manufacturing, but also in all IoT sectors. Stream reservation and real-time scheduling methods have long played an important role in industrial Ethernet solutions such as Profinet. TSN is more adapted from manufacturing than the other way around. Until now, the manufacturing industry couldn’t reach an agreement for a uniform and interoperable communication.” With the automotive industry as a pioneer in using TSN, manufacturing will also move in this direction, Hennecke predicts.

“TSN is another step in the journey,” says Paul Brooks, business development manager at Rockwell Automation (www.rockwellautomation.com). “All of the previous steps allowed
companies to solve applications with Ethernet. TSN will allow more applications. The industrial companies have been some of the earliest companies to engage in the move from what was previously AV bridging to TSN as a more industry-independent name.”

Networking technologies often migrate from one sector to another, as complimentary solutions and benefits for alternative applications become apparent. “This has been demonstrated in the case of the CANbus protocol, which after being developed initially for in-vehicle communication was widely adopted for use as a fieldbus in industrial automation,” says Markus Plankensteiner, vice president, sales industrial, North America, and global alliance manager, TTTech Computertechnik (www.tttech.com). “The transition was helped by commercial factors, such as the enviable efficiencies of scale found in the automotive industry, which led to the availability of low-cost CAN controllers and processors for industrial customers. This process can be seen again today with deterministic Ethernet technology, and it’s clear that the best result for all involved would be a TSN standard that straddles both automotive and industrial applications.”

The industrial sector requires TSN to provide for aspects, such as scaling systems to larger subnets and adding devices, that aren’t fully represented by what’s already been done in the automotive industry, says Steve Zuponcic, technology manager at Rockwell Automation. “The idea of TSN is being able to provide more solutions, but the industrial sector will expand its capabilities,” he predicts.

The development of TSN started with calls for interest (CFIs) in 2012, when several companies from the automotive, manufacturing and semiconductor domain asked the IEEE for a joint development of an enhancement of Ethernet toward real-time communication, explains Dr. Michael Hoffmeister, portfolio manager, software, at Festo.
“Although the way of implementing TSN in a vehicle or a machine might be different, both industry domains benefit from each other in terms of higher volume for Ethernet devices and a higher maturity for the technology itself,” he says.

The needs of automation and the needs of in-car entertainment and vision systems are somewhat related, sharing only the need to transmit and receive information in a timely manner, explains Joey Stubbs, P.E., North American representative, EtherCAT Technology Group (www.ethercat.org). “However, automation requirements are typically stricter,” he notes. “For example, industrial or surgical robotics or complex process controls of pharmaceuticals have much different needs than driverless vehicles or AV systems. That being said, there will undoubtedly be innovations introduced in the subgroups of TSN that will be of interest to manufacturing. However, manufacturing has an 11-plus-year headstart using industrial Ethernet as a fieldbus for automation devices and systems. In reality, the use of industrial Ethernet is most likely driving the interest of the automotive industry, not the other way around.”