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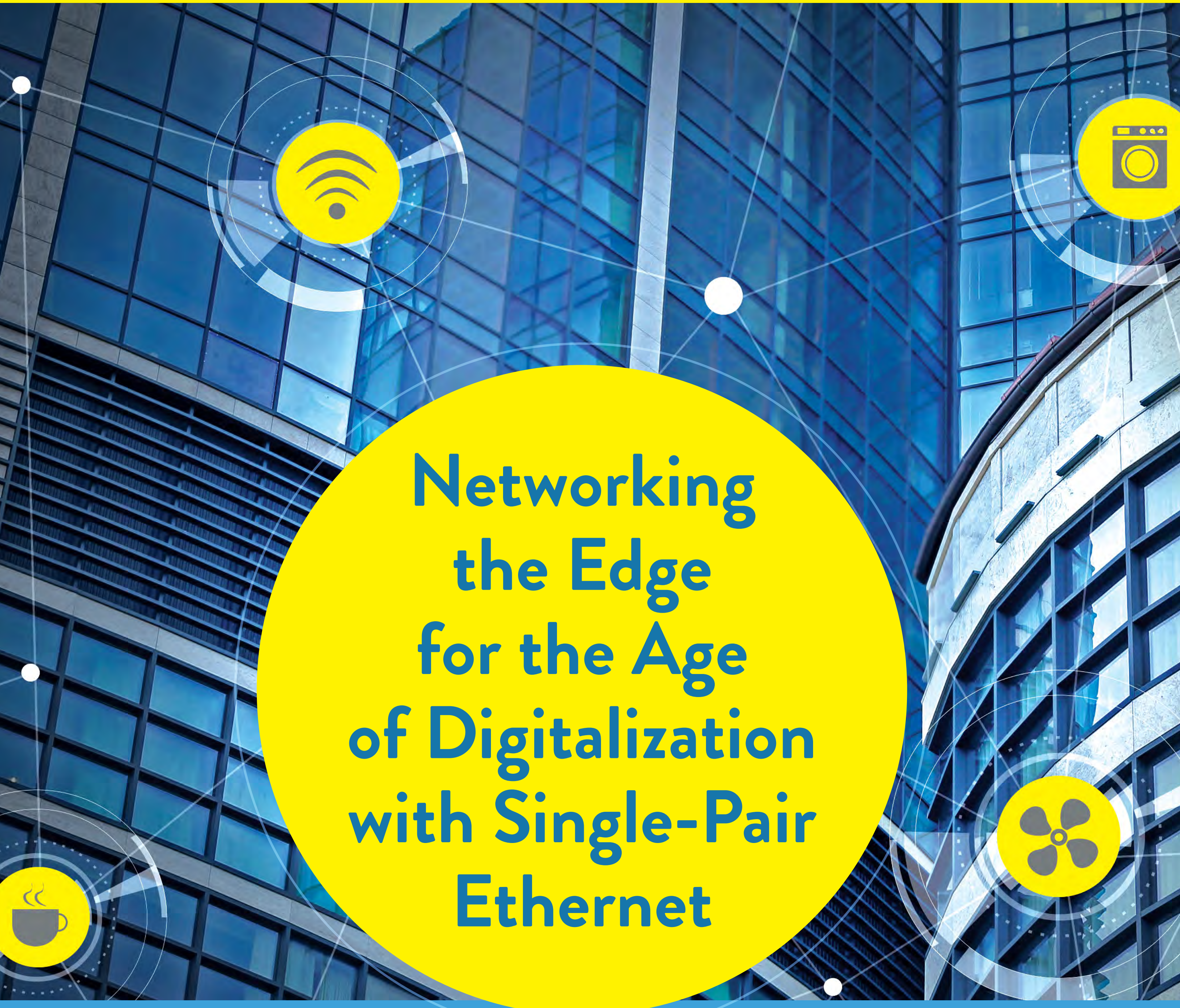

Networking the Edge for the Age of Digitalization with Single-Pair Ethernet

The information age is over. This era began in the 1980s with the advent of computing and internet networking that has led to a boom in computers, data centers, smartphones, and the communications backbone that connects them. It has opened a world of information accessibility and communication that has created entire new industries and upset those not ready for the change. The information age was about information accessibility, global communications, and connecting people with ideas and information so that better decisions could be made. This age has been replaced by the age of digitalization.

COVER ARTICLE By Mike Vermeer

Delivering Data in the Age of Digitalization

Businesses run on data. This data can take the form of sales leads that come from business development, marketing, and sales, which turn into pipeline data to provide visibility to future bookings and profitability. In the information age, this data primarily came from human inputs. More and more, this data is being automated through inputs created at the source, whether those inputs are from order entry systems on order bookings or from operations teams that identify when an order has shipped and is ready for billing. In the digitalization age, business-critical data will be collected automatically and flow seamlessly to wherever it is needed (e.g., enterprise resource planning [ERP] systems, manufacturing execution systems [MES], logistics systems). A new physical layer technology, called single-pair Ethernet (SPE), is now standardized through IEEE, IEC, and TIA to form a foundation for this next stage of digitalization.

The way data is captured today often requires engineering intervention and human inputs. A task that is conceptually as simple as capturing a new piece of data from a system can be quite complex. In some cases, the data is already available and merely requires an engineer to reprogram a gateway to move the data (e.g., from the MES system to the ERP system). Often, the data requires some level of reprogramming and validation of an existing operation.

Engineering teams faced with this task begin by defining what is needed from the customer. This task is especially important because of the skilled personnel needed to capture the data; they need to get it right the first time. Next, they need to wait for a system shutdown window or shut down the operation so they can access the system. Once they can shut down the system, they can access the programmable logic controller (PLC) and reprogram it to capture the required data. Sometimes, this also requires updating input/output (IO) or implementing new sensor inputs so that new data can be captured. These updates must be thoroughly tested and validated to ensure that the changes to the system have not created ill effects to the original operation.

In some markets, such as pharmaceutical operations, the onerous validation requirements make it very difficult to justify any such updates. Finally, the data becomes available. It can be programmed into the system where the customer needs it (e.g., ERP system, machine learning algorithms, dashboards, reports). The nature of the process is that the amount of work may take one to two days but getting the right information and collaboration between parts of the organization can extend the timeline by a week or more.

Single-pair Ethernet is not merely a new connection technology, it is also a technology that enables digitalization and the accessibility of critical data at the decision point. Ethernet is the communication backbone of the cloud, enterprise networks, and even plant and building operations. Devices in intelligent buildings and many sensors in factory automation, however, create and communicate data over analog signals or various fieldbus protocols. In these systems, there are usually barriers between different systems in the form of PLCs or gateways that interpret the data and execute commands at the edge. Building and industrial control systems have evolved so that data is created in one manner (e.g., fieldbus) that requires special conversion to be consumed in another (e.g., Ethernet) which creates inefficiency of data flow.

Entering the age of digitalization, much of the data that is being automatically connected cannot be used straightaway.

How Data Comes from Edge Devices

Visualize the data translation between two different protocols by looking at how this translation occurs in the context of the 7-layer open systems interconnection (OSI) model, which describes the communication function from the bits that travel on the physical layer to how the data is interpreted at the application layer (Figure 1). At first glance, analog sensors appear to be a very simple system. The sensor delivers an electrical signal that is calibrated to correspond to a certain parameter, such as temperature, humidity, pressure, flow rate, or another environmental characteristic. Read the electrical signal and perform minimal conversion, if any, and the data is ready to use. When looking at this from the context of the OSI model, however, it becomes clear that the analog sensor and its data transmission is only part of the story. For the sensor data to be a usable part of a system, it must be connected to an IO card that can read the data on set intervals, perform any conversions required, and transmit the data to whatever systems require the data—and do so in the correct application layer protocol. So, while the sensor itself is simple, complexity remains on a separate device, whether that be an IO card, wireless gateway, or small form factor computer (e.g., Raspberry pi, ASUS Tinker Board S, Onion Omega2+).

OSI Layers		Purpose
7	Application	Data format and translation
6	Presentation	
5	Session	Managing routing and connections between devices
4	Transport	
3	Network	
2	Data link	Transmission of raw bits and frames
1	Physical	

FIGURE 1: The OSI model for standardizing communication functions.

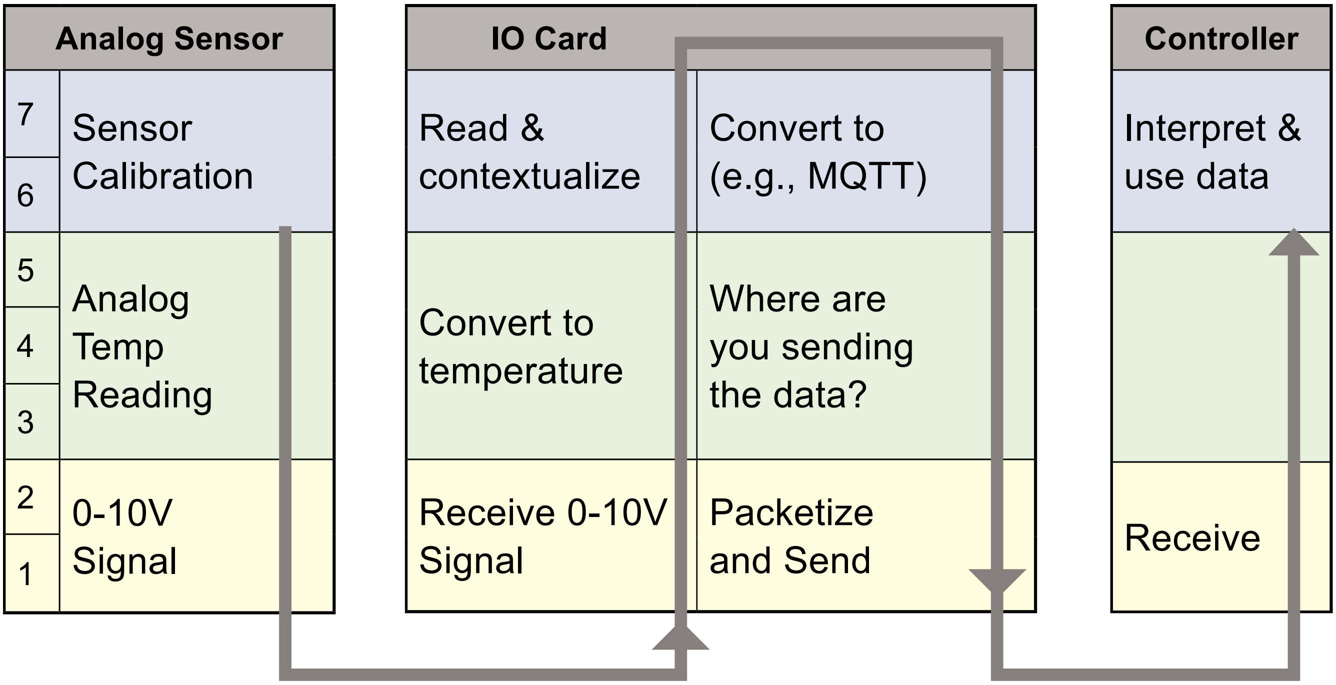

FIGURE 2: How analog and fieldbus sensors send data in context of the OSI model.

Consider what this looks like for reading analog data through an IO card and sending it over an Ethernet link to another device (Figure 2). The analog sensor constantly provides a signal that reflects its current condition, such as temperature. On a set interval, the IO card reads the signal and converts it to usable units. Once this is done, it must decide on the application layer framework in which to deliver the data and its context. There are many options. It could use an internet of things (IoT) protocol such as MQTT (originally an acronym for MQ telemetry transport) or another open ISO standard protocol supported by existing industrial vendors. From there, the IO card decides where the data needs to be sent, puts the data into a packet, and delivers it over the transportation layer. Much of the above process must be programmed into the IO card either from the factory or by engineers at system commissioning. The process is repeated at each interval of device reading.

While this architecture is described for analog sensors, much the same can be said of other systems that use legacy serial protocols, as well as emerging wireless IoT sensor systems that are sold as kits. In the case of wireless IoT, the kitting approach is required for sensors to communicate their data to servers. A gateway is required to interpret the data communicated over a wireless protocol and to forward as a TCP/IP packet through the traditional network. These gateways are typically custom designed to work with proprietary wireless communications or to reach the objective of reducing engineering implementation effort as much as possible. Entering the age of digitalization, much of the data that is being automatically connected cannot be used straightaway. Currently, there is a lot of effort to take the data gathered at edge devices all over the world and convert them for use.

It stands to reason that efficiency can be gained if data is created and communicated from the source in the same form in which it will be consumed at the ERP, MES, or other servers. Consider the above scenario but now with a smart architecture in place that communicates by Ethernet all the way down to the edge temperature sensor or actuator. In the prior example, the data was collected by an analog sensor but was never made accessible outside of the cell. In this current example, the sensor is on an IP network and can be accessed through its IP address rather than requiring data accessibility that requires the PLC to provide a tag. The sensor can publish the data to any location where it is needed through

MQTT, OPC-UA, or another IoT protocol. When the data is needed elsewhere, the new system can merely subscribe to this data so it can access it as well. No reprogramming of the PLC is required. The sensor itself can be accessed, and settings can be updated since it can communicate not only the data it is collecting, but also the current state and configuration information of the sensor (Figure 3).

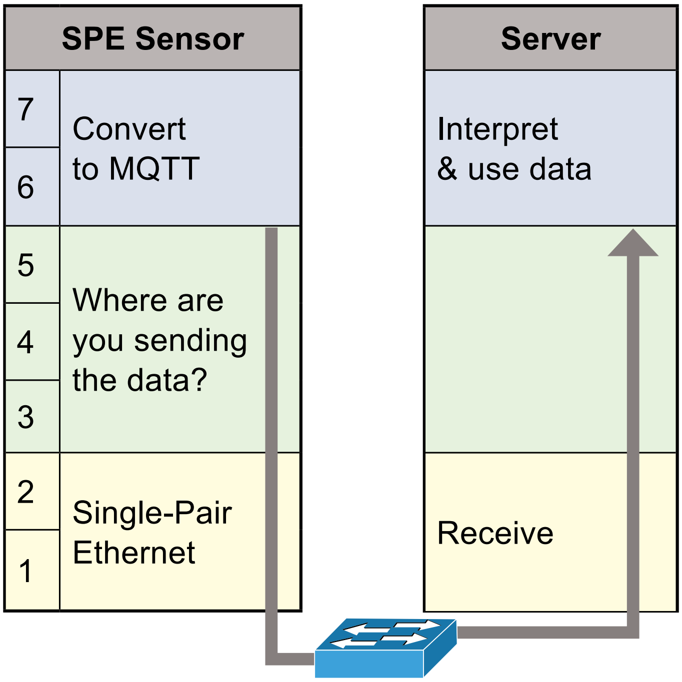

FIGURE 3: How Ethernet sensors send their data in context of the OSI model.

Single-Pair Ethernet: Ethernet to the Edge

There are millions of building and industrial automation devices sold every year that do not communicate their information over Ethernet TCP/IP. Rather, they use a different communication stack. This is understandable, since devices at the edge do not require more bandwidth than Ethernet is able to deliver over 2 or 4 twisted-pairs of cable. Indeed, it can be surprising that so many companies that sell devices which do not need nearly 100 Mb/s or greater transmission bandwidth are still standardizing on 2-pair and 4-pair Ethernet communications. This is happening at an accelerating pace, according to an HMS report. "In industrial markets, the use of Ethernet as a fieldbus has grown to 64% in 2019, edging out serial field-bus protocols to niche status."[1] While larger bandwidth may not be required, a common net-work and addressable devices are becoming more valuable and a demanded part of customer specifications.

Single-pair Ethernet supports 10 Mb/s of band-width to the edge device over its one kilometer reach. When this bandwidth is compared to current Ethernet technology that surpasses Gigabit speeds, this capability seems hopelessly low. However, when compared against the data that is actually being communicated by devices in the field, such as sensors, variable frequency drives, and cameras, this communication rate is sufficient and much higher than bandwidth of serial commu-nication systems often used. Single-pair Ethernet is right sized to bring Ethernet to the edge (Figure 4).

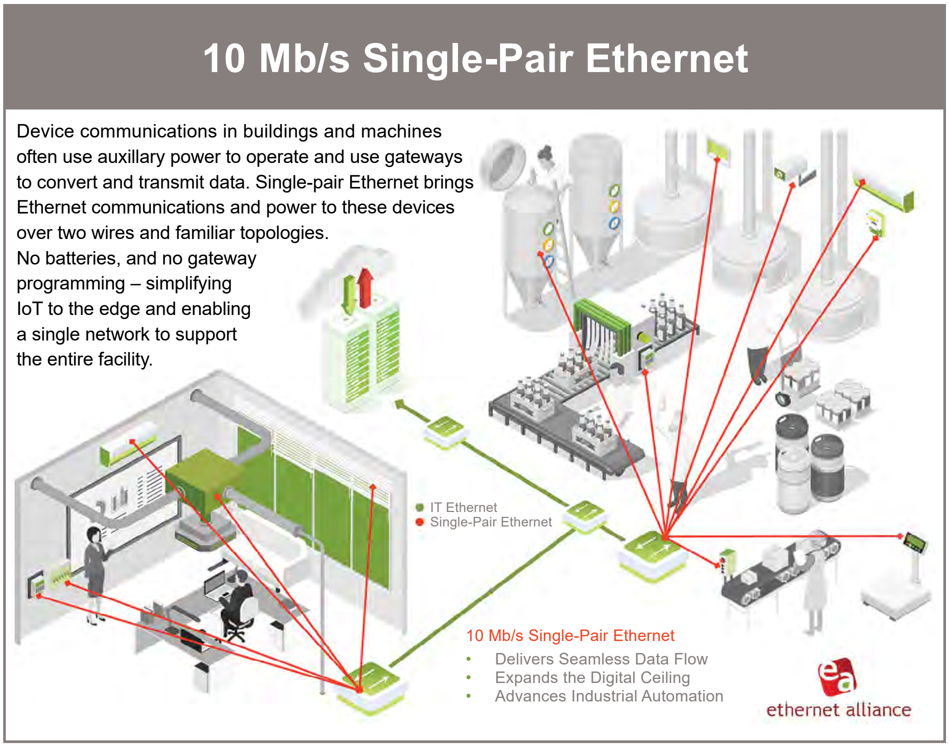

FIGURE 4: Single-pair Ethernet technology enables operational network technology found in building and industrial automation to become part of a seamless, Ethernet-based network.

Single-pair Ethernet supercharges the customer-driven expansion of Ethernet adoption by significantly reducing the size and cost of applying Ethernet to edge devices. While larger gauge cables are required to bring SPE to its full one kilometer reach, the more typical 23 AWG twisted-pair cabling is expected to be standardized to provide 400 meter reach, sufficient for many applications.

Reducing pairs reduces copper usage and will have a significant impact on cost. Reducing pairs on the system also substantially reduces the complexity of the electronics required to connect the medium dependent interface (MDI) safely and reliably to the physical layer interface (PHY), thereby reducing the complexity of the power over data line (PoDL) variant of PoE. This provides better options for miniaturization and cost reduction of edge devices, while still using Ethernet TCP/IP to communicate.

Accessing a fieldbus system for the first time can be intimidating. There is a transition that is required over the next 20 years between the current and future generations of workers that build and support automated systems. Therefore, a lot of learning needs to happen, ranging from protocol translation to how to make sure polarity is not switched for the fieldbus on the screw terminals. With SPE, installation can be simplified as well as moves, adds, and changes (MACs) to the system with simple connectivity instead of screw terminals or cage clamps. Simply strip the outer jacket, position into the connector, and snap close. This creates a reliable and repeatable termination reminiscent of terminating an Ethernet jack, yet it is far easier and faster because of connecting only a single pair.

Single-pair Ethernet supports 10 Mb/s of bandwidth to the edge device over its one kilometer reach.

Connectivity for SPE provides several possible options, and industry standardization efforts continue to make progress. For IP20 applications, IEC and TIA have standardized on the IEC 63171-1 interface, which uses the proven small size form factor LC optical fiber connector that includes two copper pins. This connector is very robust and has been tested to perform in high electromagnetic interference (EMI) environments that are common to industrial control panels, as well as some building automation applications (Figure 5).

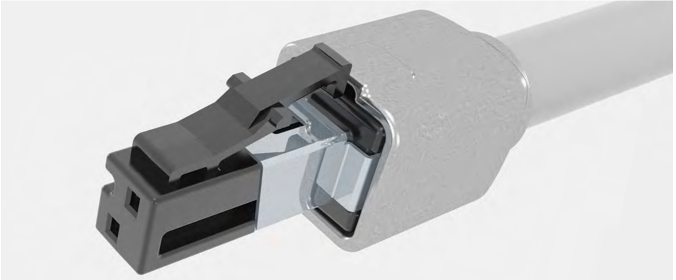

FIGURE 5: Representative IP20 connector for SPE.

Most IP67 applications are more difficult since there are a breadth of applications and needs for sensors and other devices. The process industry, which is the first mover on 10 Mb/s over SPE, has adopted the A-Code M8 connector that allows IP65 or better sealing and a standardized 4-pin interface (Figure 6). There are several other options in the industry being considered using new connector designs; standardization through four key industrial fieldbus vendor organizations should settle what the preferred interface will be.

FIGURE 6: Representative IP67 connector for SPE.

When past upgrades were made from fieldbus to 4-pair Ethernet, there was no question that new cabling infrastructure would be required. This is not a foregone conclusion today with SPE. While the cabling infrastructure for SPE is newly standardized by TIA and IEC, there is the possibility that existing infrastructure could meet the requirements of SPE for the application being considered. Project teams should take into careful consideration the gauge, condition, and balance of the legacy wires, along with the topology used for the legacy system. Testing systems are already available to help evaluate the performance of the cabling infrastructure and understand whether cable reuse will be an option for the client.

As with 4-pair Ethernet, the most common topology will be a star topology where devices have a point-to-point connection to the switch with structured links between them, depending on the distance and system requirements. Single-pair Ethernet delivers point-to-point connectivity across one kilometer and up to 10 structured links between the switch and the edge device. However, a second topology is standardized that provides a true multi-drop topology that allows one SPE switch port to connect up to 8 devices across a 25 meter trunk. In this topology, each device "taps" into the trunk cable. This does not require dual ports on the device as is common with traditional Ethernet ring and bus architectures.

There may be lingering questions about the security of connecting more edge devices onto an IP network:

- In the case that that every individual device is IP addressable, will the network be at greater risk? This is a good question and should be investigated in its specific application for any architecture that is deployed. One way to begin answering this question is by comparing the systems that this will be replacing.
- Did the existing systems connect to the network in any way (e.g., through gateway systems)?
- How accessible were these systems?
- What network security architecture was in place over the existing systems?
- What exceptions were built into the network security to allow legacy systems to function?

A second topology is standardized that provides a true multi-drop topology that allows one SPE switch port to connect up to 8 devices across a 25 meter trunk.

Typically, a network infrastructure with a higher amount of complexity and more legacy technologies will be more difficult to secure and will have increased security risk. Adding more IP devices in the right way, while making the TCP/IP network larger, can serve to simplify the network. As a result of simplifying the network, a simpler and more robust security architecture can be maintained.

Applications for Single-Pair Ethernet

Single-pair Ethernet does not belong to a single industry. It was standardized by IEEE 802.3, which is the same working group of the IEEE that has defined and standardized wired Ethernet for LAN technology. Subsequently, SPE has been incorporated into standards by the IEC, TIA, BICSI, automotive, industrial, and process standards organizations. As a physical layer technology that enables the expansion of Ethernet, there are several use cases and applications for SPE that can be anticipated.

One of the first applications for SPE will be for the process industry. Single-pair Ethernet will apply to both hazardous environments represented by oil, gas, and chemical plants, as well as non-hazardous process environments represented by the food industry. The major challenge faced by the process industry has been the effort required to design a communication system that can safely operate in a hazardous environment, requiring intrinsically safe circuits which are incapable of producing a spark. Traditional Ethernet systems have been unable to meet these stringent requirements. As a result, Ethernet has not made progress to the edge of process automation. This is changing with the implementation of SPE and the Ethernet-APL organization, which has formalized the use of SPE with modifications to allow its use in these environments.

Another application ripe for SPE is building automation. Intelligent buildings struggle to make progress against the multiple legacy silos that exist for various building systems. These systems include HVAC, access control, security, lighting, and other various subsystems. These systems use separate software systems and support various organizations and policies. Even the very infrastructure used to communicate to individual devices on these networks are incompatible, such as DALI for lighting, BACnet for HVAC, and RS-485 for fire alarms.

The vast installed base of BACnet MS/TP for HVAC, for example, is ripe for an upgrade to TCP/IP; the upgrade is beginning to gain traction. Single-pair Ethernet provides a physical layer technology that can provide much needed cost and complexity reduction from device to installation, while still providing massive bandwidth upgrade and security improvement from traditional MS/TP networks. Even better, the 2-wire MS/TP protocol has potential to allow for an upgrade to SPE, depending on the future-proof status of the original system.

Logistics automation, with its long conveyors and increasingly large warehouses, also will benefit from SPE. Condition monitoring sensors throughout a warehouse can be connected without worry about distance limitation, and switches can be more centralized as a result. Drives and IO placed on conveying lines can also be connected without requiring extra switch cabinets because the distance requires optical fiber connectivity or extra repeaters.

Finally, SPE will be coming to the analog sensor. This may take longer than other applications to miniaturize and adapt the technology for the wide variety of very small sensors. However, the benefits of SPE with other emerging technologies, such as time sensitive networking (TSN), will drive the advantage of the converged Ethernet machine. This converged Ethernet machine will more intuitively share its data across the machine control system, enabling owners to leverage machine learning and artificial intelligence to drive further advances to their operation.

Conclusion

Ethernet has long been the standard for the computers that operate building and industrial automation systems. Over decades of development, many unique communication protocols have become entrenched for specific applications. The data produced in these systems must be converted to Ethernet in order to be usable by plant operation systems. However, this conversion comes at an expense of engineering effort as well as reduced two-way communication to the device supplying the information.

Single-pair Ethernet is a technology that moves the industry forward by providing international standardization of the physical layer onto Ethernet. It enables application and network layers, as well as network security architectures, to be brought even deeper to the edge of the network. Device vendors in intelligent building and industrial automation have an opportunity to take advantage of this technology and simplify their clients' networks by delivering seamless SPE integration into the automation system of the future.

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