Ethernet-APL for Evolving Field Devices and the Future of Industrial Ethernet

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Communication technologies used in process automation (PA) plants must satisfy several requirements such as long-distance communication and stable operation in hazardous areas. Although 4–20 mA devices and fieldbus devices satisfy these requirements and thus have been used for many years, general-purpose Ethernet technology in PA plants is expected to achieve DX and IT/OT convergence at the field device level.

From the viewpoint of standardization, this paper explains how Ethernet Advanced Physical Layer (Ethernet-APL) can meet the requirements of PA plants, shows what benefits Ethernet-APL will bring to PA plants and what challenges are expected to emerge, and describes the prospects and expectations of Yokogawa's contribution to this field.

INTRODUCTION

Digital Transformation (DX) is accelerating in the manufacturing industry, and the same trend is seen in the operational technology (OT) domain, including the process industries. In plants, large amounts of OT data are available from field devices, while Yokogawa has accumulated various solutions and know-how. By combining these, DX in plants could be accelerated[(1)]. One solution is to introduce industrial Ethernet to the field network, as it has sufficient bandwidth to cope with the combination of IT and OT, or "IT/OT convergence."

However, to deploy industrial Ethernet across a process automation (PA) plant, especially for the field network, the following issues must be solved: (1) how to deploy it in hazardous areas where there is a risk of explosion, and (2) how to arrange cables over long distances to cover a vast plant including outdoor areas.

Intrinsic safety is a key requirement for field devices to be installed in the harshest hazardous areas (Zone 0). The Ethernet-Advanced Physical Layer (APL) is being developed as the physical layer that enables Ethernet devices to be deployed in such areas[(2)].

Yokogawa has been participating in the development of Ethernet-APL. This paper describes its technical requirements and the trend of industrial Ethernet in the PA domain, and explains the prospects from the viewpoint of standardization.

TECHNOLOGIES IMPLEMENTED IN ETHERNET-APL

Background of the APL Project

Ethernet-APL is a physical layer of the OSI reference model, which is needed for intrinsically safe field devices that can be installed in Zone 0. Its development started in 2011. In 2018, the APL project was started, in which 12

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major suppliers in the PA domain and four major standard developing organizations (SDO) for the industrial network are working together to develop IEEE and IEC standards and conformance test specifications. The SDOs are FieldComm Group, PROFIBUS and PROFINET International (PI), Open DeviceNet Vendor Association (ODVA), and Open Platform Communications (OPC) Foundation.

Basic Concept of Ethernet-APL

For PA applications, Ethernet-APL has the following requirements, which are different from conventional Ethernet:
(1) Transmits frames and power over a 2-wire cable
(2) Provides intrinsically safe parameters dedicated for APL
(3) Transmits over a long distance (Trunk: 1000 m, Spur: 200 m)
(4) Reuses existing fieldbus cables

The following sections discuss the standards, rules, and their operation to meet these requirements.

Standards for Ethernet-APL

Table 1 shows the standards that constitute Ethernet-APL. They are classified into specifications for Ethernet-APL and those for certifying Ethernet-APL devices. The functions and features of Ethernet-APL are standardized in the IEEE 802.3cg-2019 and Port Profile Specification. Additional specifications are described in IEC TS 60079-47 to ensure that an Ethernet-APL device complies with 2-Wire Intrinsically Safe Ethernet (2-WISE), an intrinsically safe standard dedicated for Ethernet-APL. The Port Profile Specification and EMC Test Specification are scheduled to be internationally standardized by PIEC.

Table 1 Standards for Ethernet-APL

Standard	Description
IEEE 802.3cg-2019	Specifications of 10BASE-T1L physical layer
IEC TS 60079-47	2-wire Intrinsically Safe Ethernet (2-WISE)
Port Profile Specification	Power unit specifications, topology, rules, etc.
Power Port Profile Test Specification	Specifications for certifying APL devices: for the power unit
PMA, PCS and ANEG (Data) Test Specification	Specifications for certifying APL devices: for communication
EMC Test Specification	EMC test conditions for APL devices and criteria

System Configuration of Ethernet-APL

Trunk and Spur

In addition to the power provision specifications, the Port Profile Specification standardizes how to use 10BASE-T1L in Ethernet-APL-compliant devices and systems. Among them, APL Trunk and APL Spur ("Trunk" and "Spur") are the basic concepts for configuring an Ethernet-APL system. Figure 1 shows a typical configuration of an Ethernet-APL system.

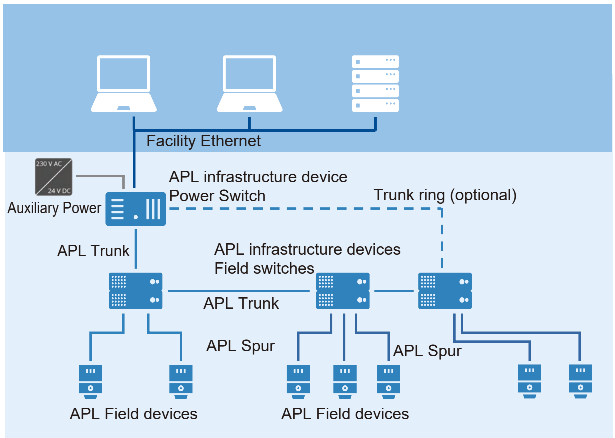

Figure 1 Typical configuration of an Ethernet-APL system

The Ethernet-APL system is based on the point-to-point connection. Trunk serves as a backbone line to connect APL Infrastructure devices ("Infrastructure device"). Trunk can communicate over distances of up to 1000 meters in 2.4 Vp-p mode of 10BASE-T1L. It also supplies power from a Power Switch (a kind of Infrastructure device) to Infrastructure devices at the distal end. Infrastructure devices are equipped with Trunk Port for connecting Trunk, but APL Field devices cannot be equipped (note that the APL Field device ("Field device") is different from general field devices).

Spur connects Infrastructure devices and Field devices. It can communicate over distances of up to 200 m in 1.0 Vp-p mode of 10BASE-T1L. Just like Trunk, power is supplied from a Field Switch (a kind of Infrastructure device), but it is limited to satisfy intrinsic safety.

Types of Infrastructure device and resulting system configurations

The Ethernet-APL system consists of three types of devices (Table 2).

Table 2 Devices comprising Ethernet-APL

Device	Feature
Infrastructure device	Switches, media converters, etc. Configures the Trunk network and connects Field devices to the network via Spur.
Field device	Can be connected only to Spur.
Auxiliary device	A device that does not have a communication function. Serves as a surge protector. Two devices can be connected to a single cable.

Among them, Infrastructure devices are further subdivided into three types, increasing the diversity of configuration of Ethernet-APL systems. Table 3 shows their types and characteristics.

Table 3 Types of infrastructure devices

Type	Feature
Power Switch	Converts signals from the upper-level general-purpose Ethernet to APL and transmits signals and power to the lower-level Field Switch via Powered Trunk.
Media Converter	Converts signals from the upper-level general-purpose Ethernet to APL and transmits signals to the lower-level Field Switch via Unpowered Trunk.
Field Switch	Supplies signals and power to Field devices connected to Spur via Trunk from Power Switch or Media Converter. Connects to another Field Switch via Trunk. A Field Switch that converts the signal from the general-purpose Ethernet directly to Spur is under development.

Figure 2 shows another configuration of the Ethernet-APL system, which is achieved by the difference in types of Infrastructure devices. The major difference between Figures 1 and 2 is the number of Field devices that can be connected to a single Ethernet-APL segment.

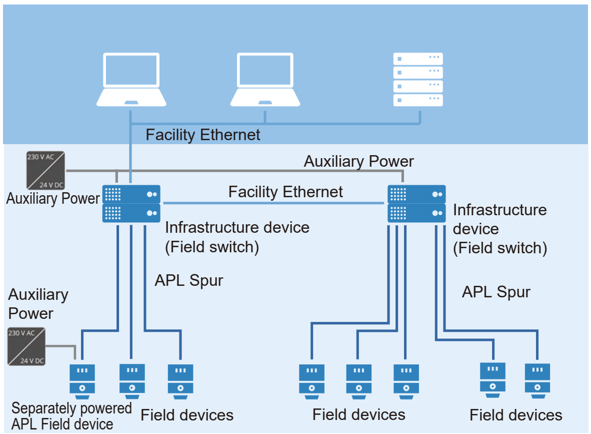

Figure 2 Another configuration of the Ethernet-APL system

In Figure 1, Field Switch is connected to Power Switch via Powered Trunk. Therefore, the number of Field devices to be connected is subject to the same two constraints as in conventional fieldbus devices: power and communication volume. Meanwhile, Field Switch in Figure 2 directly converts signals from general-purpose Ethernet to Spur and superimposes power from an auxiliary power source to APL. In this case, the number of Field devices is not limited by power, and the restriction on the communication volume is not so tight because general-purpose Ethernet (100 Mbps or 1 Gbps) is faster than Trunk (10 Mbps). Therefore, more Field devices can be connected than in the case of Figure 1.

However, the system configuration in Figure 2 has some disadvantages. Since conventional Ethernet is used, the length of lines is limited to only 100 m, in contrast to up to 1000 m when Field Switches are connected via APL. Fiber-optic cables are too expensive to compensate for this shortcoming. Another disadvantage is that it is necessary to arrange power supplies for Field Switches.

Power Classes for Ethernet-APL and Intrinsic Safety

Table 4 summarizes the power classes that have been standardized for each Trunk and Spur in Ethernet-APL. The classes of non-intrinsically safe Spur and Unpowered Trunk and other power classes are planned to be specified. They will be added in response to requests from vendors who develop devices.

Table 4 Power classes of Ethernet-APL

Class	Power	Voltage	Intrinsic safety
Trunk	57.5 W	50 V	–
Spur	0.54 W	15 V	Ex ia
Spur	1.1 W	15 V	Ex ic

When the power transmitted over Trunk is 57.5 W, Field Switch probably consumes a little more than half of the power. Even so, power can be fed to about 50 Field devices, each of which consumes 0.5 W. This number exceeds the maximum number of devices that can be connected in ordinary fieldbus systems (theoretically 32 devices, but practically about 16 devices when the power provision is taken into account).

Next, we discuss the relationship between the 2-WISE intrinsic safety and the maximum usable power. 2-WISE is a simple method for determining convertibility without the need to carefully examine intrinsic safety parameters such as voltage, current, and power (this examination is usually performed when installing intrinsic safety devices). This concept is similar to the Fieldbus Intrinsic Safety Concept (FISCO). However, the power class values for intrinsic safety in Table 4 are not the 2-WISE parameters. Based on the evaluation method for intrinsic safety required for Ex ia (can be installed in Zone 0 locations) and Ex ic (can be installed in Zone 2 locations) and the 2-WISE parameters, an Ex-certification body confirmed that the equipment will not ignite with these values.

When installing an Ethernet-APL device in hazardous areas, users only need to confirm its 2-WISE marking and the power class; complex calculations are not required. In addition, users do not need to consider the intrinsic safety restrictions when estimating the number of devices to be connected.

Difference between Ethernet-APL and Single Pair Ethernet (SPE)

For 2-wire Ethernet, Single Pair Ethernets (SPE) have been standardized by IEEE 802.3 (Table 5). These SPEs satisfy the requirements of various domains such as automobiles and building automation. Among them, 10BASE-

T1L is used for PA and all other industrial automation applications.

Table 5 Various SPE standards

Name in IEEE802.3	Communication speed
100BASE-T1	100 Mbps
1000BASE-T1	1 Gbps
10BASE-T1S	10 Mbps (for automotive applications)
10BASE-T1L	10 Mbps (for industrial applications)

Although Ethernet-APL also uses 10BASE-T1L, it can provide devices to perform PA-dedicated applications that 10BASE-T1L-compliant SPE devices cannot do. This is because Ethernet-APL configures an original system by combining the way to use the amplitude mode defined in 10BASE-T1L, the dedicated power provisions dealing with intrinsic safety parameters that are required for PA, and other 10BASE-T1L elements.

Meanwhile, several industrial organizations, mainly in the connector industry, have been established to promote SPE for factory automation (FA) and are promoting their own SPE-specific connector standards. Since Ethernet-APL uses existing fieldbus cables, it does not allow the use of these SPE connectors but uses conventional terminal blocks and M8 and M12 connectors commonly used in Europe and the US.

For Ethernet-APL, four SDOs responsible for industrial Ethernet certify hardware including connectors, which guarantees a minimum level of interoperability. This certification is another major difference between Ethernet-APL and SPE devices.

VALUE ADDED BY ETHERNET-APL TO PLANTS

Communication Speed

The 10 Mbps communication speed of Ethernet-APL will bring various advantages to PA plants in contrast to 31.25 kbps of fieldbus and other conventional digital networks. One example is faster configuration, commissioning, and firmware updates. A 300-fold increase in communication speed enables a five-minute task per unit to be completed in one second.

In addition, since the amount of data required for control does not increase significantly in Ethernet, more time is available for communication during operation, making it possible to send diagnostic data and pre-scaling raw data simultaneously with control data. As a result, not only the final output signals from field devices but also intermediate signals that were previously used only within devices can be used for more accurate predictive maintenance. The ample bandwidth allows sound and image data to be transmitted together.

Power for Field Devices

Even in the smallest power class, 2-wire Ethernet-APL devices can use the power of 0.5 W. This value is about 15 times higher than that for conventional 4-20 mA 2-wire devices and about three times higher than that for 2-wire fieldbus devices. Although not all this 0.5 W can be used because of limitations on the power supply unit and power needed for communication, more power than before can be used depending on the circuit design.

As more Ethernet-APL devices are released, some will differentiate themselves by allocating the increased power to enhance the functionality. For example, conventional electromagnetic flowmeters and Coriolis flowmeters are 4-wire systems because it is difficult to achieve 2-wire transmission due to magnetic excitation and drive units. Ethernet-APL will be able to convert them into the 2-wire system. In addition, Ethernet-APL will be able to turn 2-wire transmitters into a multi-sensor system, in which multiple sensors are driven by a single instrument and data are transmitted over a single Ethernet-APL cable. It is also possible to make a 2-wire transmitter smart by allocating the extra power to increase the calculation speed and memory capacity.

Although these examples have been achieved by the conventional fieldbus technology, they are a minority in the market because their functionality is not satisfactory due to power limitations. Ethernet-APL is expected to turn these products into the mainstream in the market.

Generality of Ethernet

Ethernet-APL is an Ethernet physical layer that operates according to its own rules while satisfying the requirements of PA. Since its higher layers are the same as those of general-purpose Ethernet, Ethernet-APL can use proven Ethernet-based technologies. For example, Wireshark (a popular network protocol analyzer) can be used to monitor the communication on Ethernet-APL.

A single device can use multiple protocols even simultaneously, for example, one for control and another for leveraging data.

TRENDS IN INDUSTRIAL ETHERNET

Requirements for Using Industrial Ethernet in the Field and their Solutions

Ethernet-APL enables Ethernet-related communication technologies to be deployed to the field level. In this case, however, it is difficult to meet the technical requirements of the OT systems with general communication technologies for IT systems.

Industrial Ethernet satisfies OT requirements and is widely used at the control level, mainly in the FA industry. Typical industrial Ethernet protocols are PROFINET developed by PI, EtherNet/IP developed by ODVA, OPC UA developed by OPC Foundation, and HART-IP developed by FieldComm Group. These protocols account for about 60% market share of industrial Ethernet products(3). Research and development to apply them to the field level is actively under way.

Table 6 shows the technical requirements for applying industrial Ethernet to the field level and the solutions to them.

Table 6 Requirements for applying industrial Ethernet to the field level and their solutions

Requirement	Solution
Explosion-protected long-distance transmission	Ethernet-APL
Real-time communication	IEEE-standard TSN*
High availability	IEC-standard communication redundancy
Safety	IEC-standard functional safety communication
Security	Authentication and encryption at the protocol level
Use of installed base, migration	Gateway to existing fieldbus

*TSN: Time-sensitive networking

By Ethernet-APL, deployment in hazardous areas and long-distance communication can be achieved.

Real-time communication in PA plants has been achieved by each industrial Ethernet. However, the IEEE-standard Time-Sensitive Networking enables deterministic and reliable communications in an environment where not only multiple industrial Ethernet communications but also IT communications exist at the same time.

To deliver the improvement in availability, IEC-standard communication redundancy protocols such as Media Redundancy Protocol and Parallel Redundancy Protocol have been used with PROFINET and EtherNet/IP. These communication redundancy protocols can also be used with OPC UA and HART-IP.

When Ethernet communication with improved reliability and availability is used throughout a PA plant, communication related to safety (functional safety) and other communication can be logically separated even while physically coexisting on the same Ethernet. The "black channel" approach for functional safety communication, standardized as IEC 61784-3, enables this kind of usage. In this approach, the safety communication layer comes with a function to detect any communication errors, and as long as safety applications communicate through this layer, no functional safety assessment is required for the layers below the safety communication layer. PROFIsafe, which can be used with PROFINET, and CIP Safety, which can be used with EtherNet/IP, have been standardized based on IEC 61784-3 by the IEC and are already widely used. Similar safety specifications are being developed for OPC UA in collaboration with PI, which has experience in PROFIsafe.

Security is one of the requirements that were not present in the conventional field level. Remote monitoring of PA plant networks and optimization of operations by connecting to cloud-based applications are already in widespread use. When Ethernet-APL enables the use of Ethernet in the field, security threats and cyberattacks are likely to reach field devices. As a conventional security measure for plant networks, the defense-in-depth approach has been adopted, in which firewalls and intrusion detection systems are installed between plant cells/areas for multiple protection. In addition, industrial Ethernet protocols for field devices must have security measures. OPC UA, EtherNet/IP, and HART-IP have already specified security functions such as authentication between peers and encryption of communication contents. PROFINET is also in the process of developing the specifications of similar functions.

PA plants have fieldbus assets such as 4-20 mA HART and FOUNDATION Fieldbus (FF) that have been installed in large numbers and operated for several decades. Accordingly, it is necessary to consider their continuous use and a smooth migration to industrial Ethernet. For example, PROFINET specifies proxy/gateway functions (mapping and protocol conversion) with various fieldbus protocols such as HART, FF, and PROFIBUS-DP/PA. This feature allows existing fieldbus devices to be handled in a PROFINET network and facilitates a gradual migration to PROFINET. HART-IP is useful for migration because it uses the HART application layer as it is and can use existing HART devices without mapping.

The Role of OPC UA as the Information Exchange Standard and the Standardization of Next-generation PA Field Devices

Various industrial Ethernet protocols are widely used at the control level, and SDOs are developing and standardizing technology that combines these existing protocols with Ethernet-APL to apply them to the field level. Figure 3 shows an overview of this trend: the expansion of industrial Ethernet in the automation pyramid derived from ANSI/ISA 95.

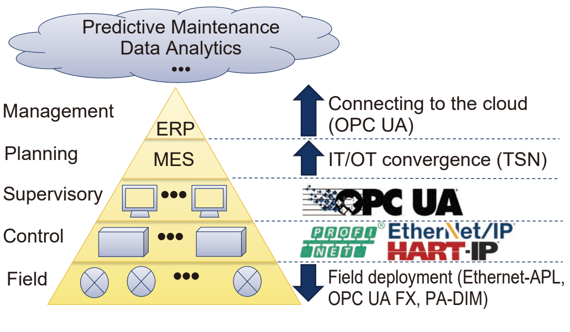

Figure 3 Expansion of industrial Ethernet to the field

The major trend in standardization activities is that SDOs no longer aim to develop similar but non-interoperable technologies; instead, they are working together to use existing superior technologies and avoid duplicate development.

In line with this trend, the role of OPC UA as an information exchange standard is becoming important in DX and IT/OT convergence. OPC UA has a high affinity with IT because it adopts an advanced architecture, featuring an extensible information model, platform independence, scalability, multiple transport/encodings, and support for machine-to-machine communication. In addition, companion specifications are being actively developed in collaboration with other SDOs. For example, the FieldComm Group and the OPC Foundation jointly developed the process automation device information model (PA-DIM) as the OPC UA information model for PA field devices. When the OPC UA server and the PA-DIM are implemented in devices at the control level (controllers and gateways), the data and information of each industrial Ethernet field device can be mapped to the PA-DIM. This allows field devices to exchange information with devices at higher levels than the control level (currently, this is difficult to achieve because industrial Ethernet protocols have little affinity with IT). When the OPC UA server and the PA-DIM are implemented in field devices, information can be directly exchanged with the field level.

The PA-DIM is based on NAMUR Open Architecture[4], which is a concept for achieving DX without affecting the existing control operation of a PA plant. Currently, the PA-DIM is applicable to monitoring and optimization applications. For control applications, it is necessary to add specifications such as the state transition between controllers and field devices in the control loop (this has been achieved with FF). The FieldComm Group is studying the next-generation technology based on OPC UA and the PA-DIM for PA field devices[5]. The OPC Foundation is also developing OPC UA FX (Field eXchange) as the technology and specifications to apply OPC UA to the field level of FA and PA.

To increase the value of customers' business, Yokogawa will continue to work with SDOs to maintain interoperability through these activities.

CONCLUSION

The introduction of Ethernet is needed to achieve data-driven operations in PA plants and its enabling technology is Ethernet-APL. This paper explained Ethernet-APL and discussed the trend of industrial Ethernet protocols that are used with Ethernet-APL. The APL project aims to standardize Ethernet-APL, and since it was founded, Yokogawa has been involved as a key member in the development of Port Profile, explosion-protected standards, EMC, and other standards. The field level is the last mile in customers' plants. Yokogawa will apply the knowledge gained through these standardization activities to this level and continue to provide products and solutions that contribute to the promotion of DX across a PA plant.

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