# IEEE 802.3cg (10SPE) – 10 Mb/s Single Pair Ethernet meeting Industrial Automation objectives

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**Abstract**

Since the turn of the century, Industrial Automation has seen an ever increasing adoption of Ethernet-based networking and the associated IP stack. One vision is that of a single network paradigm from the Cloud to the field devices – yielding many lifecycle benefits. Industrial Ethernet can bridge IT and OT, being appropriate for MES, most controllers and user interfaces, and many field applications. However, a number of practical concerns limit the utilization of Ethernet at the field edge. In particular, the 100 m distance limitation and the high implementation cost relative to the smallest components have held back complete Ethernet adoption. In addition, special environment requirements such as intrinsic safety have held back some markets, in particular Process Automation. Currently, a variety of non-Ethernet solutions, typically buses or point to point links, augment Ethernet for a complete solution. Issues with such a mixed system include the additional complexity of application gateways and proxies, obtaining specialized skill in many networking technologies, and the lack of IP-related protocol convergence for IIoT and related usage. Demand and feasibility are shown for long distance by Process Automation industry fair demonstrations, and for low cost by continued Automotive push for innovative cost reduction techniques beyond the established single pair architecture. In July 2016, the IEEE 802.3 authorized the “10 Mb/s Single Twisted Pair Ethernet Study Group” (informally known as “10SPE”), kicking off the development of a set of Ethernet enhancements aimed at closing these gaps. This paper discusses this IEEE activity and the potential benefits to the Industrial Automation markets.

**Keywords**

Ethernet, IEEE 802.3, IEEE 802.3cg, 10SPE, Single-pair, Industrial Automation, Process Automation, In-cabinet, Fieldbus, IEC 60079, Intrinsic Safety, NAMUR, ODVA, EtherNet/IP

 

**Definition of terms**

| | | |
|---|---|---|
| Industrial Automation | - | Discrete, Process, and Hybrid (Batch) Automation |
| NAMUR | - | Process Automation user group, Germany |
| IEEE 802.3 | - | Ethernet standard, including MAC and PHY definitions |
| PHY | - | PHYsical layer connecting a link layer to a physical medium |
| MAC | - | Medium Access Control layer (IEEE) |
| IP | - | Internet Protocol |
| CFI | - | IEEE 802.3 Call For Interest |
| SG | - | IEEE 802.3 Study Group |
| TF | - | IEEE 802.3 Task Force |
| PAR | - | Project Authorization Request |
| CSD | - | Criteria for Standards Development |
| Fieldbus | - | Industrial network protocol for real-time control |
| Industrial Ethernet | - | Fieldbus protocol operable over Ethernet |
| Edge | - | Leaf nodes attached to a network core, i.e., sensor and actuators |
| Gateway | - | Network protocol converter spanning ISO model layers |
| Switch | - | IEEE 802.3 bridge, forwarding based on MAC addresses |
| IT | - | Information Technology |
| OT | - | Operational Technology |
| MES | - | Manufacturing Execution Systems |
| Purdue Model | - | Layered functional automation model |
| IIoT | - | Industrial Internet of Things |
| IEC 60079 | - | Explosive atmosphere standards, including intrinsic safety |
| Intrinsic safety | - | Method to allow safe equipment operation in explosive environments |
| Zone | - | Explosive environment classification, commonly EU |
| Division | - | Explosive environment classification, US |
| FISCO | - | Fieldbus Intrinsic Safety COncept |
| Point-to-point | - | Communication link with a single device at each end |
| Multi-drop | - | Communication link with multiple devices sharing the same link |
| Full-duplex | - | Simultaneous communication in both direction on a link |
| Half-duplex | - | Communication in a single direction at a time on a link |
| CAN | - | Communication protocol, Controller Area Network |
| HART | - | Communication protocol, Highway Addressable Remote Transducer |
| MCU | - | Micro Controller Unit |
| ASIC | - | Application-Specific Integrated Circuit |

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**Single network (Ethernet) vision**

A common industrial automation vision is that of a single network paradigm from the Cloud to the field devices. Industrial Ethernet with IP protocol can bridge IT and OT, being appropriate for MES, most controllers and user interfaces, and many field applications.

Figure 1 illustrates one single network vision for Process Automation, as an example described in a prior ODVA conference. Factory Automation, Automotive, and other industries share the same vision. For Industrial Automation including Process Automation and Factory Automation, Ethernet solutions have been adopted and mostly satisfy the upper levels of the Purdue Model.

The question posed is whether Ethernet can ever be used for all of the process instruments at the edge in Process Automation and whether Ethernet can ever be used for all of discrete sensors and actuators at the edge in Factory Automation? Currently, there remains a gap. Ethernet lacks specialized capability that is necessary to replace the fieldbuses for a large number of devices at the edge.

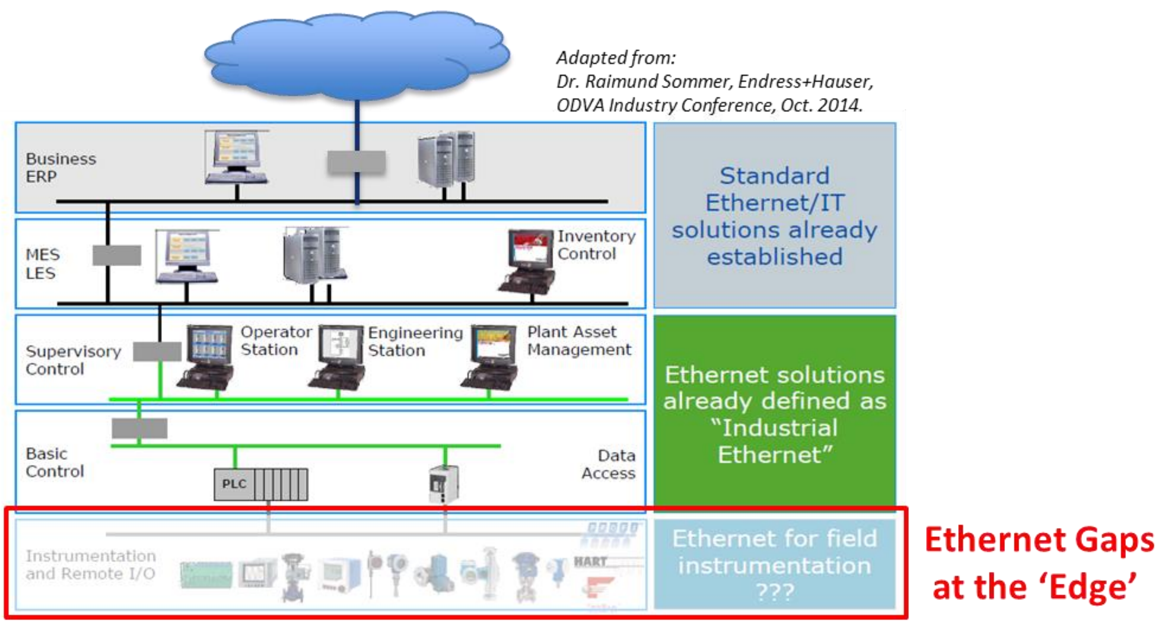


*Figure 1: Gap in a single network vision*

**Added lifecycle cost of a fragmented network**

A variety of non-Ethernet solutions (typically fieldbuses or point-to-point links) augment Industrial Ethernet for a complete solution. As shown in Figure 2, Gateways are placed at the boundary. Conversions are made at each network layer from the physical layer up to the application layer.

Numerous additional lifecycle costs are associated with systems that utilize gateways.

There are more network standards to manage, and some are obscure. One cost is associated with sourcing appropriately qualified labor. Most secondary education provides some familiarity with Ethernet and most utilize some Ethernet within their personal life. Fieldbus knowledge is less common, and based in geography and popularity.

 

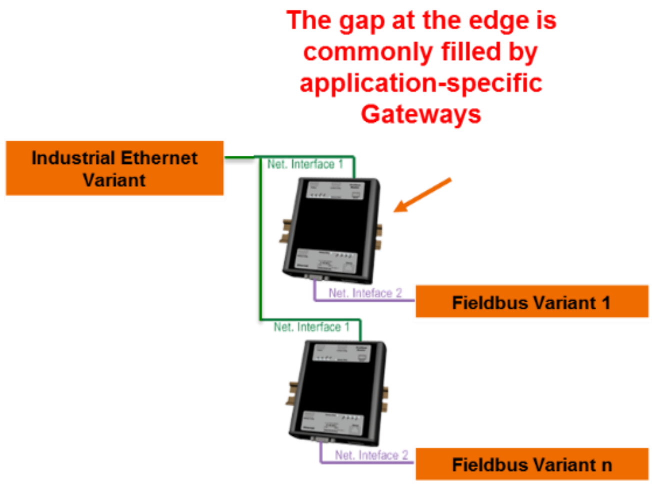


*Figure 2: Gateways interconnecting Industrial Ethernet and fieldbuses*

Design complexity is increased. Separate application programming is generally required. Separate tags may be scanned between the networks and timing issues can result in interoperability issues. Client/server protocols are often hard to pass between the networks and can result in feature loss.

Installation complexity is increased. Multiple differing cables, connectors, terminator rules, and tooling exist.

Maintenance complexity is increased, especially if a single person does not possess intimate knowledge of both networks. Separate programs in the gateway and controller can result in consistency problems.

Certification complexity is increased.

The fieldbuses and point-to-point typically lack IP-convergence, complicating usage for modern trends in IIoT and converged enterprise.

**Partial migration to Industrial Ethernet**

Until the late 1990s, industrial automation relied exclusively on non-Ethernet *fieldbuses* for deterministic communication between controllers and I/O. The emergence of economical Ethernet switching enabled adequate determinism for *Industrial Ethernet* to emerge. Since then, there has been an escalating adoption of Ethernet-based networking and usage of the associated IP stack.

In 2016, HMS Industrial Networks, Inc. reports that the entire Industrial Communication market is still growing. The Fieldbus share is 58%, with 7% growth. The Ethernet share has reached 38%, with 20% growth.

Over time, the number of fieldbus variants has grown quite large. Figure 3 shows a partial list. The fieldbuses included entire network stacks with little overlap. Industrial Ethernet allowed the migration of many of the application layers – enabling an increase in common hardware and configuration concepts for the end user.

An additional driver toward Industrial Ethernet has been the nearly complete replacement for information purposes, including configuration and monitoring via PCs and Application Servers.

In spite of the attractiveness of Industrial Ethernet, there has only been a partial migration.

 

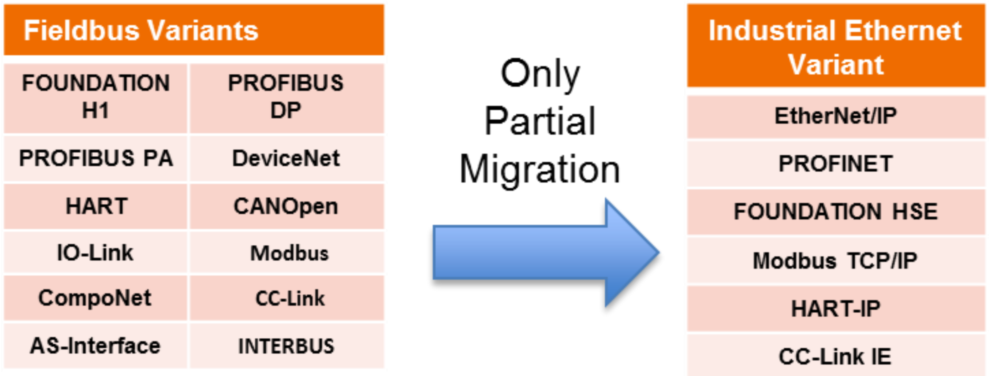


*Figure 3: Migration from Fieldbus to Industrial Ethernet*

**Existing Ethernet gaps at the edge**

There are a variety of practical concerns that limit the utilization of Ethernet at the field edge, especially for instruments in Process Automation and in-cabinet components in Factory Automation.

One concern is the distance limit of 100 m for wired Ethernet. Process Automation commonly requires 1000 m or more. Glass fiber can increase the distance, but only with increased installation and interface complexity. Plastic Optical Fiber (POF) distance is similar to wired Ethernet. In either case, fiber does not carry power directly.

Special environments exist at the edge and bring requirements. One example is the explosive environment, driving a preference for intrinsically safe device and system solutions in Process Automation.

Power distribution brings further concerns. Cable and connector size can be an issue for small components. Single pair power and communication solutions are a benefit. Intrinsically safe power is another specialized need.

It can also be advantageous to allow operation over legacy cables (shielded twisted pair) and connectors, especially in Process Automation. One reason is to allow the economical substitution of fieldbus or point-to-point end nodes with Ethernet nodes. Another is to maintain current simple screw terminal installation practice. Furthermore, some plants are in service for long periods (30 years or more) and pulling one cable may compromise others. Finally, explosive environment common practice (FISCO) leads to ease of design and certification for specific cables (IEC 61158-2).

In-cabinet components and other constrained devices in industrial have difficulty tolerating a high implementation cost in comparison to the existing fieldbus or point-to-point solutions (often called sensor networks). Requirements for switches or linear topologies may economically exclude the smallest components from Ethernet.

These Ethernet deficiencies are currently addressed within the fieldbus and point-to-point solutions. Unless Ethernet addresses these deficiencies, the single network vision for Industrial Ethernet will never be complete. Ethernet is a “family” of solutions that can be extended within IEEE 802.3 to overcome these gaps.

 

**Process Automation demand**

An example Process Automation plant is shown in Figure 4.

The network installation is characterized by a high number of field devices (sensors and actuators) that are widely separated (>1000 m) from the control room and often in explosive environments. There is widespread usage of legacy 4-20 mA analog signals for control with the addition of HART (1200 baud digital communication modulated on the 4-20 mA signal) for configuration and asset management purposes. More modern Fieldbus solutions (PROFIBUS PA and FOUNDATION Fieldbus) provide 31.25 kb/s digital methods for both purposes.

A large amount of legacy cable is in place. The most common is single pair with power. Since plant life often exceeds 30 years, cable materials may be fragile. Pulling new cables is therefore a risk. The preferred cables are designed to ease certification for intrinsic safety. One reason for HART success is that it preserved the installed cable base.

Based on explosive environment hazards, a plant is divided into different areas; called Zones or Divisions depending on the local regulatory authority. The Zone (0, 1, or 2) defines the probability of hazardous material being present in an ignitable concentration in the surrounding atmosphere. The explosive characteristics of the air mixtures of gases, vapors, or dusts vary with the specific material involved. Limitations must be placed on the equipment to stay below ignition temperatures and explosion pressures.

- Zone 0: Area in which an explosive gas-air mixture is continuously present or present for long periods.
- Zone 1: Combustible or conductive dusts are present. Area in which an explosive gas-air mixture is likely to occur for short periods in normal operation.
- Zone 2: Area in which an explosive gas-air mixture is not likely to occur, and if it occurs it will only exist for a very short time due to an abnormal condition.

Different protection methods are applied in the zones. The intrinsic safety method (Ex i) strictly limits energy by appropriate protective circuit design in order to avoid any explosion in case of faults. Ex i is the preferred method in Zone 0. The increased safety method (Ex e) is less restrictive for powering devices and appropriate for Zone 1.

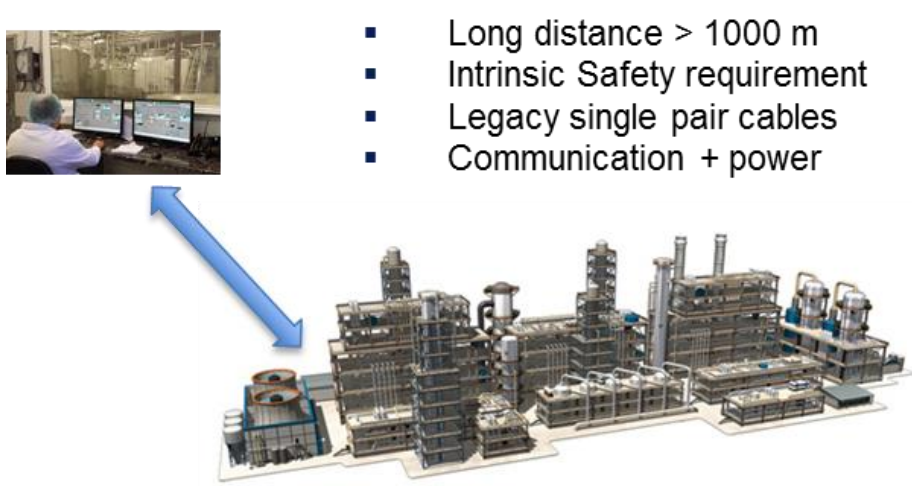


*Figure 4: Example Process Automation plant*

 

Process Automation has already adopted Ethernet for part of the applications.

One advantage of usage Ethernet-based solution down to the field is to provide a homogeneous network that requires less engineering effort for the customer. Since Information Technology (IT) is converging into Operational Technology (OT), it becomes easier to monitor events, processes and devices and make adjustments in enterprise and industrial operations.

Long plant life brings a push to upgrade rather than replace existing plants – a long term trend. In order to further improve the existing processes and to decrease downtime, information from the process and the device (diagnostic data) are necessary. A homogeneous network based on Ethernet technology brings increased rates and better connectivity optimize the plant and extend its life, leveraging techniques from Industrial Internet of Things, Big Data, Cloud, and Analytics.

Users have recently put forth the vision of standardizing on Ethernet for all of the plant.

NAMUR (Normenarbeitsgemeinschaft für Meß und Regelungstechnik in der chemischen Industrie) is an international user association of automation technology in the process industries. Although founded in Germany and initially focused on the chemical industry, their scope and influence has broadened. They count 151 member companies and >2000 experts.

In 2016, NAMUR released: "Position paper An Ethernet communication system for the process industry", stating the single network vision of Ethernet. It is required that Ethernet meet the generic legacy requirements of a fieldbus (NAMUR NE 74) – along with new Ethernet-specific requirements.

Protocol requirements (partial):

- Minimum application protocol requirement of IEC 61784-2 CPF2/2 (EtherNet/IP) and CPF3/5 (PROFINET IO Class B)
- Safety, time synchronization, optional redundancy, security, IPv6…
- Simple device integration and exchange

Ethernet PHY-related requirements:

- Two-wire cable carrying communication and field device power
- Suitable for both explosive and non-explosive environments (intrinsic safety)
    - Allows FISCO or a similar (simple) certification methodology
- NE 21 EMC compatibility
- NE 74 connectors and installation
- Comparable cost to 4-20mA HART

With a migration to Ethernet, a switched architecture (Figure 5) will be adopted. This is a transition from the homerun wiring of 4-20mA and from the multi-drop topology of the fieldbuses. Upgrades in the marshalling cabinets (Zone 2, near the control room), the field junction boxes (Zone 1), and the field devices (Zone 0) give access to cable ends for a simplified transition.

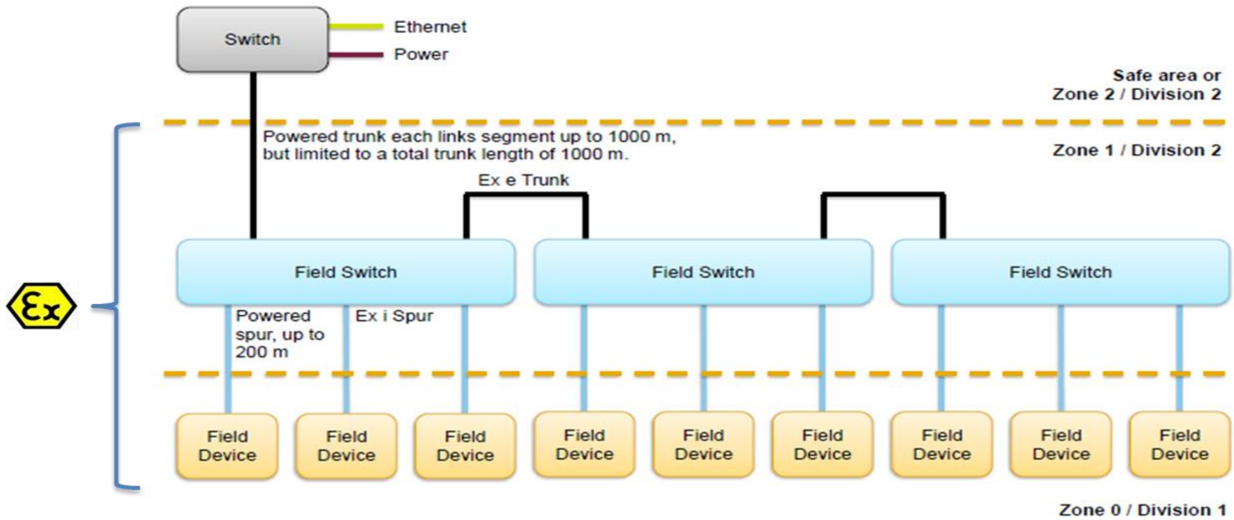


*Figure 5: Ethernet-based switched system architecture*

In order to reduce installation costs and cabling effort, the connection to the field is realized by a *Trunk* and *Spurs* as depicted in both Figure 5 and Figure 6. The Trunk and Spur provide sufficient bandwidth for the communication into the field and provide the field devices with power. Ideally, the Trunk and Spur utilize single twisted pair shielded cable as described by IEC 61158-2 type A cable.

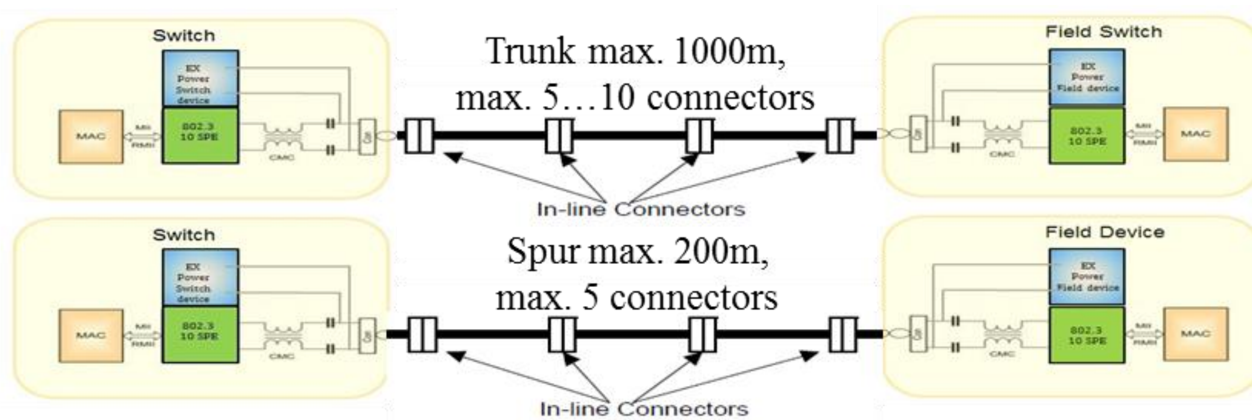


*Figure 6: Trunk and Spur*

 

The following Trunk and Spur requirements have broad consensus in the industry.

Trunk requirements:

- Data exchange follows the standard Ethernet 802.3 specifications
- Reach of 1000 m from a Switch located in a safe area (Zone 2) to a Field Switch that is located in a hazardous area (Zone 1)
- Maximum 10 inline connectors are required for this long distance. Heavy cable may be laid in sections and joined
- Since the Trunk goes into the Zone 1 hazardous areas, the Trunk ports of the Switch and the Field Switch, and the cable must fulfill appropriate Ex e protection requirements.
- The Switch must provide Trunk power for the underlying Field Switches and Field Devices. Economics and application requirements dictate support of 50 field devices from one Switch, where each field device requires less than 500 mW of power.

Spur requirements:

- Data exchange should be based on the IEEE 802.3 specification
- Reach of 200 m from the Field Switch to the Field Device
- Maximum 5 inline connectors are considered to reach this distance
- Since the Spur goes into the Zone 0 hazardous areas, the Spur ports of the Field Switch and the Field Device, and the cable must fulfill appropriate Ex i protection requirements.
- Each port of the Field Switch must provide 500 mW for a Field Device

Bringing Ethernet to all the devices, and meeting the end user vision at the edge as described by NAMUR means filling Ethernet gaps:

- Spanning the long distances between the control room and the field devices -> more than 1000 m and hundreds of devices
- Economical cabling and power delivery to the field -> power and communication over legacy single pair cabling
- Operation in explosive atmosphere –> intrinsic safety

The IEEE 802.3 – 10SPE project objective cover the exact requirements for Process Automation.

**Automotive demand**

Beginning in 2011, Automotive began a long transition to Ethernet within vehicles. The OPEN Alliance SIG (One-Pair Ether-Net) began the standardization of single pair Ethernet at 100 Mb/s. The OPEN specification was brought into the IEEE to become 100BASE-T1. A second complementary IEEE single pair Ethernet standard is now also available (1000BASE-T1).

An early driver of Automotive Ethernet is the "Infotainment" application. This drives relatively high rates, but is not a part of the critical vehicle control. Open connectivity benefits are gained from Ethernet.

Part of the justification for single pair is that the wiring harness has become one of the heaviest individual components in a car. Further wiring reduction will be possible by the compatible IEEE 802.3bu 1-Pair Power over Data Lines – combining communication and device power.

The various Ethernet enhancements are part of a larger vision. Current architectures deploy multiple specialized and incompatible networks (analogous to the fieldbus situation) across the entire vehicle. Figure 7 depicts an Automotive architecture based on Ethernet. There is core and an edge with routing and computational resources between. Dramatic benefit is seen in consolidation to a single network (Ethernet). Applications that span the vehicle can then utilize virtual networks – saving cost, reducing wiring, and adding expansion flexibility.

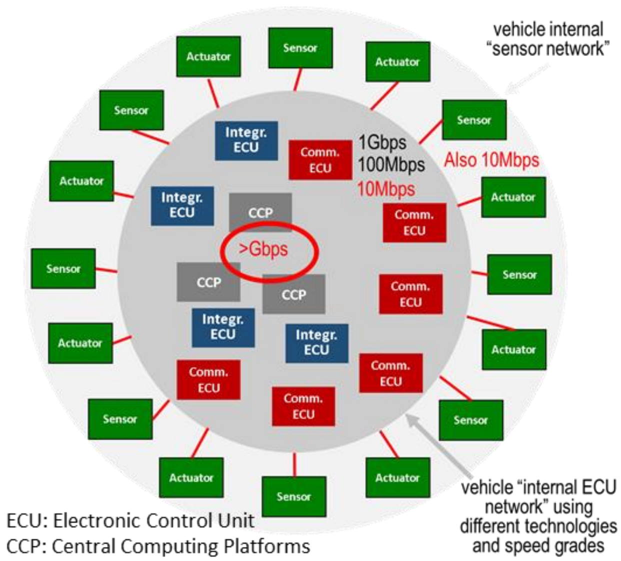


*Figure 7: Automotive Ethernet architecture concept*

Further Ethernet options are required to allow the full migration. At the high end, an IEEE group was recently formed to study "Multi-Gig" Ethernet to address the high rates required by devices such as radar and vision sensors required for autonomous operation and related applications.

At the edge, there are also a very large number of simple sensor and actuator devices. Many of these are server by networks such as CAN that can meet tight cost constraints. There is a demand within Automotive to utilize Ethernet here as well, but the Ethernet system cost must be reduced significantly.

Within Industrial Automation, in-cabinet and similar cost-constrained applications stand to benefit from an economical Ethernet solution. Past leverage of CAN from Automotive brought supplier and part choice and economic benefit.

 

**10SPE emerges to fill Ethernet edge gaps**

In July 2016, the IEEE 802.3 authorized the “10 Mb/s Single Twisted Pair Ethernet Study Group” (informally known as “10SPE”), kicking off the development of a set of Ethernet enhancements aimed at closing the gaps for Ethernet edge devices.

Participating industries included: Industrial Automation, Automotive, Building Automation and Lighting.

**Abbreviated IEEE process and 10SPE status**

A simplified IEEE process is shown in Figure 8.

A potential new standard activity begins with the Call For Interest (CFI). Interested parties collaborate on a presentation describing the market need and basic requirements to satisfy the need.

If there is enough interest and agreement on the value of the activity, a Study Group (SG) is formed. The purpose of the SG is to complete 3 deliverables. The first is a Project Authorization Request (PAR) – requesting the formation of a project and describing the purpose. The second deliverable is the Criteria for Standard Development (CSD) - answers a set of questions (i.e., whether the project is unique, whether there is broad market potential, whether it is feasible, etc.). The third deliverable is a set of Objectives (high level requirements) that set important success criteria and bound the solution.

If the SG deliverable are completed and accepted by the SG and a set of supervising bodies, a Task Force (TF) is formed. The purpose of the TF is to draft amendments to the base IEEE 802.3 standard.


*Figure 8: Abbreviated IEEE process and 10SPE status*

Figure 8 shows the 10SPE status. The CFI completed in July 2016. The 10SPE SG completed in November 2016. The first face-to-face meeting of the TF (IEEE P802.3cg) was scheduled for January 2017. It is currently estimated that the standard will be completed during 2019.

 

**Simplified 10SPE Objectives**

A simplified set of the 10SPE SG Objectives is shown:

- Up to 2 PHYs
  - One optimized for up to at least 1 km reach
    - Point-to-point
  - One optimized for up to at least 15 m reach
    - Expectation is a reduced system cost
    - Optional multi-drop was not excluded
- Operation in automotive and industrial environments (EMC, temperature)
- Existing MAC interface
- 10 Mb/s
- Optional Auto-Negotiation
- Single balanced twisted pair
- Optional power distribution over pair
- Fast startup (100 ms)
- Does not preclude intrinsic safety

The Objectives were driven primarily by Industrial and Automotive concerns. Building Automation and Lighting expect the objectives to be adequate for their needs to be satisfied.

A primary driver for Industrial is to achieve an extended reach (*reach* is the IEEE term for distance). For Industrial, the reach is at least up to 1000 m. For Automotive, the reach is at least up to 15 m.

A primary Automotive driver is achieving a reduced system cost. This has potential applicability for in-cabinet and other cost constrained application in Industrial.

It was recognized that the communication channels and environments were different and optimizations for distance and cost would yield 2 different PHYs.

Since many of the objectives are common, it is still hoped to achieve overlap and reuse.

Both expect to utilize existing MAC interfaces, providing standard interface to existing MCUs, switch ASICs, and IP cores. An optional simple serial interface is not excluded for a low cost edge devices in Automotive.

Both are satisfied by a 10 Mb/s rate. The target application are not currently very demanding. Process Automation migrates from 31.25 kb/s. Future upgrade of rate is anticipated by the optional Auto-Negotiation objective.

Both have the objective to operate over a single balanced twisted pair. This facilitates the reuse of some important legacy Industrial cables. It also has the potential to reduce implementation cost and cable harness weight for Automotive. Optional power distribution over the single pair can have similar benefits.

Automotive has the larger need for fast startup of 100 ms. Industrial has some similar fast start requirements for robot end effector tooling (500 ms).

A special need of Industrial (and in particular Process Automation) is for intrinsic safety. While the IEEE cannot standardize an intrinsically safe PHY (only a device and system are certified), measures can be taken to assure it is possible to design an intrinsically safe device and system.

Both Industrial and Automotive will support point-to-point and full-duplex. It is however possible that a case will be made in Automotive for a multi-drop option. Reduction of the average number of interfaces per device could be important in adequately reducing system cost.

### Implications and suggestions for ODVA

Since IEEE 802.3 – 10SPE is progressing rapidly, it is appropriate to consider related ODVA technical activities.

The IEEE PHY standard will set a foundation, but does not describe complete solutions. Completing the solution requires:

- Front-end circuitry, interfacing from the PHY chip to the wire, including intrinsic safety
- Power on the communication channel, including intrinsic safety
- Connector specification
- Cable specification
- Management objects
- Potential multi-drop protocol enhancement
- Conformance testing for multiple purposes

Complementary solutions are anticipated to emerge from industrial consortia and via related international standards. These may be adopted to accelerate the process. Figure 9 illustrates the combination of the IEEE standard (blue) and complementary solutions (green) accelerating ODVA activities (yellow).

ODVA has already started to broaden EtherNet/IP solutions for the Process Automation market. The joint collaboration between ODVA and NAMUR on the Optimization of Industrial Ethernet for the Process Industry will only accelerate this progress. The Process Optimization SIG currently deals with HART integration into the EtherNet/IP system and defining Diagnostic handling for process automation devices. Now, the IEEE 802.3 - 10SPE activities broaden the possibilities to direct integration of process automation devices into EtherNet/IP. This has implications for multiple SIGs within ODVA.

ODVA might also consider expanding EtherNet/IP to small industrial components and other constrained devices at the edge of industrial automation system, to achieve a single EtherNet/IP network solution.

ODVA vendors are encouraged to start their research or development activities on the above areas for a complete solution and are also encouraged to participate the IEEE PHY standard development by providing requirement inputs and even technical proposals to the link segment definition, PHY design, and noise model etc.

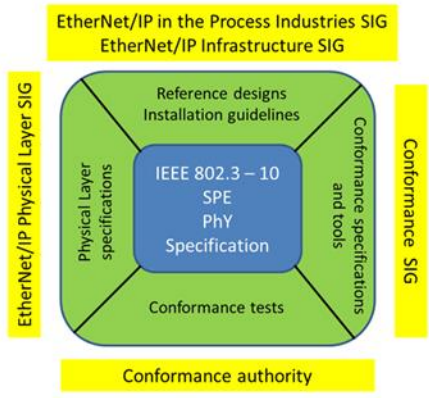


*Figure 9: Potential implications for ODVA*

 

**Summary**

Despite ongoing Ethernet migration across automation domains, the single network vision is thwarted by existing Ethernet limitations. The IEEE 802.3 – 10SPE project - recently established – has released the objectives to specify and standardize a new Physical Layer to close the Ethernet gaps at the edge. A paradigm change is likely, almost certainly in Process Automation and possibly for in-cabinet and other constrained components. ODVA is encouraged to enhance their specifications based on the results in order to deliver on the single network vision and expand into the resulting new markets. ODVA vendors are encouraged to participate in IEEE standard and ODVA specification development to realize the single network vision.

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