Single Pair Ethernet (SPE)

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1. Introduction

With the advancements made with regards to the Industry 4.0 (i4.0) movement, new technologies have emerged in order to meet needs that have been created – whether such needs are new and/or involve adaptation of legacy systems. One of the key aspects of the concept of i4.0 involves the capacity to connect systems, devices, and people. For these purposes, several different pieces of IoT (*Internet of Things*) and IIoT (*Industrial Internet of Things*) equipment have broken new ground and drawn attention from individuals/companies concerned with the exchange of data and information between two points.

In terms of connectivity, there are several means through which two points are able to communicate with one another, with the main differences related to use of wired/wireless solutions and communication protocols. With regards to communication protocols, there is currently a global trend towards the use of Ethernet solutions, given their reliability, interoperability and ease in the manipulation of data. However, despite being a widely disseminated technology, it is important to note that, in some cases, organizations will opt for the use other forms of communication in certain systems for several reasons, including: distance between communication points, network junctions, low bandwidth consumption, etc.

Therefore, the scientific and professional community has been studying means of resolving these limitations, including **Single Pair Ethernet (SPE)**. In short, as its name suggests, SPE solutions aim to transmit Ethernet data using a single pair. However, development of this technology presents many other advantages, some of which are described in this document.

2. Single Pair Ethernet – A Disruptive Technology?

The convergence between IT/AT (IT - Information Technology / AT - Automation Technology) is becoming increasingly widespread in companies not only in terms of integration between teams, but particularly in relation to the communication technology used in connectivity systems. As a result, exponential growth has been seen in equipment based on IP (*Internet Protocol*) communication in the areas of both IT and AT.

A fact that corroborates this data is the annual report released by HMS Networks (an independent organization) that monitors the installation of new nodes (*i.e.*, IP addresses) in the area of automation in plants across a range of sectors. In Figure 1, it can be observed that the protocols based on Industrial Ethernet have already significantly exceeded the number of new nodes based on *fieldbuses* protocols, that is, serial solutions (also known as legacy systems).

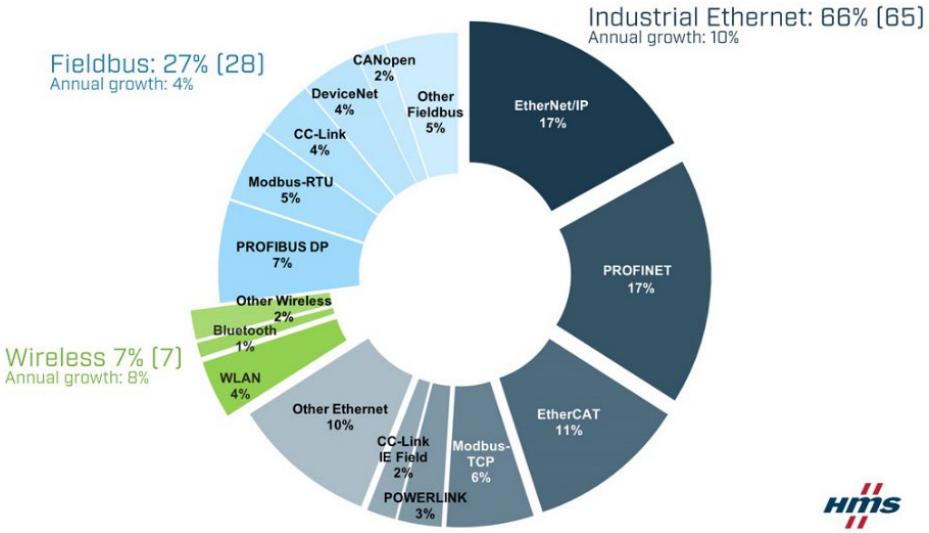

Figure 1 – Development of industrial protocols *vs.* fieldbuses *vs.* wireless protocols (2022).
Source: HMS Networks < link >.

When analyzing this year-on-year survey (see Figure 2), it is possible to verify that industrial solutions based on Ethernet grew at an average rate of approximately 10.83%p.a. (~4.1pp/year). In contrast, *fieldbus* solutions declined at an approximate average rate of 11.38%p.a.(~4.9pp/year).

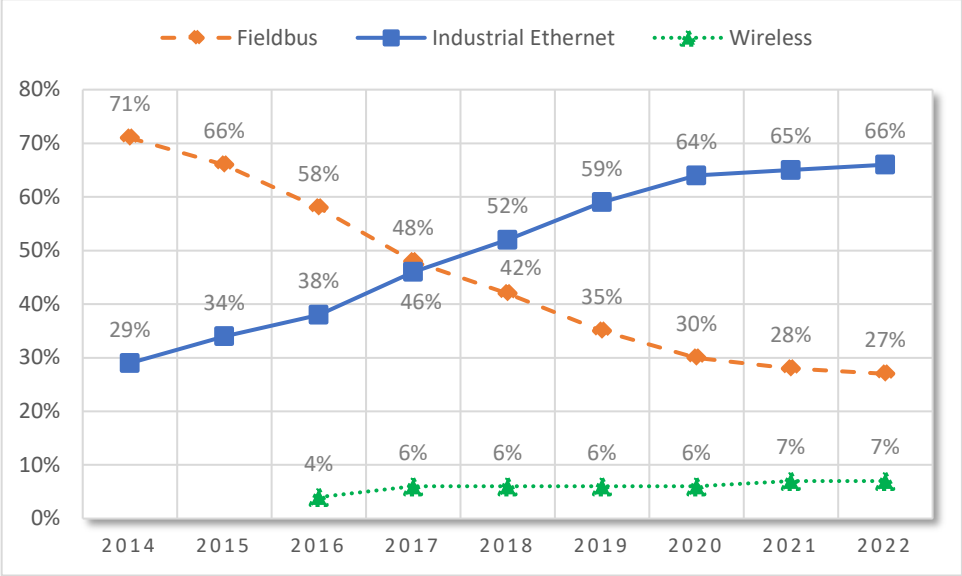

Figure 2 – Development of industrial protocols: new nodes.
Source: Adapted from HMS Networks; data from 2014-2022 annual reports.

Despite being enticing data in terms of the acceptability of Ethernet solutions on the factory floor, it is relevant that this number is not even higher because many of the legacy systems use traditional serial protocols due to the fact that they require low bandwidth capacity and/or they are able to cover large distances – sometimes nearly 1000m. However, as is commonly know, Ethernet protocols provided in 2 or 4 metal pairs are currently limited, in normative terms, to 100m, which is a much shorter distance than that usually found in legacy solutions. Additionally, the most basic version of traditional Ethernet, can upload up to 100Mbps (Fast Ethernet). However, in these systems, it is common that an amount of data close to a few kbps be consumed.

With this in mind, IEEE (*Institute of Electrical and Electronics Engineers*) study groups have chosen to develop a metal cabling solution that:

- Meets requirements in terms of bandwidth;

- Meets network requirements in terms of distances between devices;
- Integrates point-to-point Ethernet communication into a single architecture (see Figure 3).

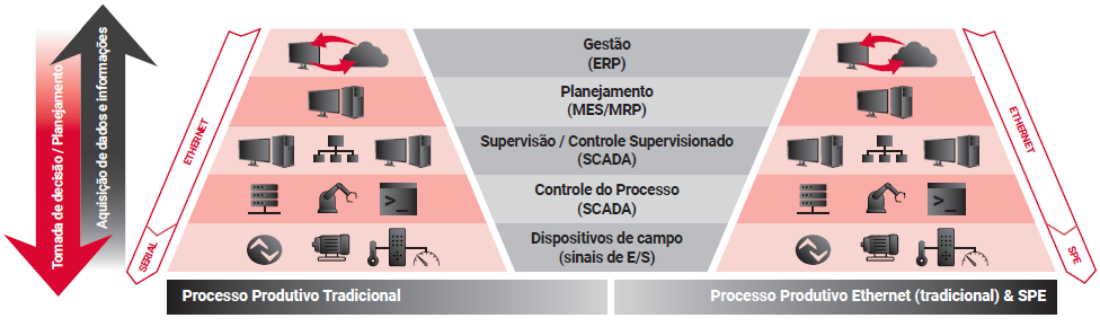

Figure 3 – Automation Pyramid: Point-to-point Ethernet.

Therefore, one of the main objectives of creating and standardizing Single Pair Ethernet is precisely to provide greater and improved integration between systems – whether industrial and/or corporate.

Although, SPE initially emerged to meet demands for internal networks in motor vehicles and passenger entertainment, the disruption of technology and market acceptability stems from the intent to implemented widespread use of these technologies in order to meet demands for other challenges encountered, as well as solve problems of which companies are aware up to the present date.

2.1. Standards – IEEE, ANSI/TIA and ISO/IEC

In terms of development, SPE can be considered a technology that is still under construction, given that certain regulations are in the process of being finalized. However, it is clear that the technology itself is not a recent development, since there are relevant regulations from 2015. This suggests that a process of adapting/extending SPE to the intended applications is currently underway. As shown in Table 1, there are three normative institutions working in parallel in developing and defining the scope of use of SPE, particularly: IEEE, ANSI/TIA and ISO/IEC.

As previously mentioned, Single Pair Ethernet technology was initially focused on automotive applications (IEEE 802.3bw, 2015), but has since evolved and is no longer limited to this market. With the development of the standard IEEE 802.3ch (2020), applications of the technology has been expanded to solutions such as: replacement of legacy protocols, industrial automation, building automation, access control, HVAC control (heating, ventilation and air conditioning), among others.

Institution	Normative Ref.	Year	Description
IEEE	802.3bw	2015	*100BASE-T1 – 100 Mbit/s Ethernet over a single twisted pair for automotive applications*
	802.3bp	2016	*1000BASE-T1 – Gigabit Ethernet over a single twisted pair, automotive & industrial environments*
	802.3bu	2016	*Power over Data Lines (PoDL) for single twisted pair Ethernet (100BASE-T1)*
	802.3cg	2019	*10BASE-T1L and 10BASE-T1S – 10 Mbit/s Single twisted pair Ethernet*
	802.3ch	2020	*MultiGigBASE-T1 Automotive Ethernet (2.5, 5, 10 Gbit/s) over 15 m with optional PoDL*
	802.3da	–	*10BASE-T1S 10 Mb/s Operation over Single Balanced Pair Multidrop Segments, extended length up to 50 m*
	802.3dd	–	*Power over Data Lines of Single Pair Ethernet Maintenance*
	802.3de	–	*Time Synchronization for Point-to-Point Single Pair Ethernet*
ANSI/TIA	568.5	2020	*Single Pair Cabling & Components*
	568.6	2020	*Single-Pair Multidrop (SMPD) Cabling & Components*

	568.7	2020	*Single-Pair Cabling & Components for Industrial*
	5071	–	*Single-Pair Cabling Field Testing*
	TSB xxxx	–	*Power Delivery over Single-Pair Cables*
	862-B	–	*Structured Cabling Infrastructure Standard for Intelligent Building Systems*
ISO/IEC	TR 11801-9906	2020	*Balanced 1-pair cabling channels up to 600 MHz for single pair Ethernet (SPE)*
	61156	2021	*Symmetrical single pair cables with transmission characteristics up to 600MHz*
	63171	2021	*Shielded or unshielded free and fixed connectors for balanced single-pair data transmission with current-carrying capacity - General requirements and tests*

Table 1 – Regulations pertaining to Single Pair Ethernet in March/22 (standards that are complete or in the process of being finalized).

It is important to note, therefore, that SPE technology is no longer restricted to automotive networks and/or replacement of legacy protocols, but is now mainly aimed at expanding the concept of Ethernet to various applications and market verticals.

2.2. Associations (Consortia)

In order to maximize the development of this new concept, several consortia have emerged with the objective of collecting *insights*, assisting in the development and dissemination of concepts and new technological applications. In short, these consortia are series of companies that came together to identify market needs and introduce solutions created with a focus on SPE, not only with regards to cabling solutions, but also the equipment required in use of technology.

The main consortia that are actively contributing to the development of the Single Pair Ethernet are listed below. These consortia define themselves in the following manner:

- **Ethernet Alliance: "**a global, non-profit industrial consortium of member organizations dedicated to the continued success and advancement of Ethernet technologies, bridging the gap between standards and end users, working to promote, adopt and provided for the use Ethernet technologies across all markets.
- **SPE Industrial Partner Network:** "an equalitarian association of companies promoting Single Pair Ethernet technology as the basis for the rapid and successful expansion of IIoT (*Industrial Internet of Things*)";
- **Single Pair Ethernet System Alliance (SPESA):** "consortia formed to take advantage of the enormous potential of this new technology in terms of the future, with all members sharing the common goal of promoting the use of Single Pair Ethernet technology for *Industrial IoT* (IIoT) and all other relevant applications";
- **TIA Single Pair Ethernet Consortium (TIA spec):** "represents leaders in the area of technology in order to accelerate the adoption of the next generation of operational technology (OT) and *Internet of Things* (IoT) connectivity through the use of SPE technologies."

Such consortia have put their efforts into contributing to the development of SPE regulations (in terms of cable and connector specifications) as well as in the widespread dissemination of this technology on the marketplace.

3. General Characteristics, Benefits, Challenges and Applications of SPE

3.1. Characteristics and Main Advantages

The main characteristics of Single Pair Ethernet technology have already been described throughout this document. However, in order to summarize these points, the following topics are presented below:

- Ethernet communication with the use of a single (one) balanced pair;

- Initially emerged to meet demands for low bandwidth (<10Mbps). However, today it is already possible to transmit speeds of 1Gbps using an SPE cable (these solutions are still being studied, but are referred to as "*MultiGiga*");
- Undergoing a process of standardization in order to meet demands for industrial and building automation;
- Provides for the transmission of power in powering remote equipment (known as "*Power over Data Line*" (PoDL));
- The main focus is on the dissemination of standards: 10BASE-T1L (point-to-point communication of up to 1000m with up to 10 connections along the channel) and 10BASE-T1S (point-to-multipoint communication of up to 25m with up to 8 junctions/nodes and, with variation still underway, for a length of up to 50m with up to 16 nodes);
- Compacting of the cabled solution, i.e. reduction in terms of space (density) and weight;
- Cross-sectional variation across different applications, with options ranging between 26AWG and 18AWG.

3.2. Connectors

Given that Single Pair Ethernet technology makes use of a single pair (*i.e.*, only 2 copper-insulated conductors), it was necessary to consider the development of a connector that fulfills the need for metallic contacts. Several options were therefore created and made available on the market in order to collect *feedback* regarding their use and applications. As can be observed in Table 2, the standard IEC 63171 was used as a reference, however, with some variations (1 ... 7), each presenting a physical format, application and ingress protection rating that differed from one another.

Standard	**IEC 63171-1**	**IEC 63171-2**	**IEC 63171-3**	**IEC 63171-4**	**IEC 63171-5**	**IEC 63171-6**	**IEC 63171-7**
Known as	LC-style	Rectangle	Rectangle-shaped	Square-shaped	M8 / M12	Rectangle / M8 / Push pull	Hybrid M12
Number of pairs	1	1	1 or 4	1	1 or 4	1	1
Ingress protection rating (IP)	IP20	IP20	IP20	IP20	IP67	IP20 / IP67	IP67

Table 2 – Connector formats developed to meet demands from SPE.

For example, the connector format referred to in IEC 63171-1 is generally used in building automation, while IEC 63171-2 and -5 formats tend to be applied in industrial automation. These last two models In particular are identical to one another, varying only in the enclosure used. As a result, there is a difference in terms of the connectors' ingress protection rating, which is, IP20 and IP67, respectively.

3.3. Main Advantages

There are a diverse range of benefits associated with the use of Single Pair Ethernet technologies, including:

- SPEs will not replace traditional Ethernet solutions with 2 or 4 twisted pairs, and will only be used to complement relevant applications, mainly those involving *edge communication*;
- SPE will enable point-to-point Ethernet communication (from ERP/MES systems to field devices, which are known as I/Os). This represents a certain convergence between the areas of IT and AT;
- Potential to replace legacy protocols (*fieldbus* solutions) for equipment based on Ethernet protocols that make use of IP addressing;

- Given that this solution is based on Ethernet, it would not be necessary to make use of gateways for the purpose of converting protocols (e.g.: Serial Ethernet, and vice versa). As a result, users will be provided with a lower level of latency and increased reliability;
- Distribution of power and data across a single pair via PoDL (*Power over Data Line*);
- Service involving several different topologies, whether point-to-point (up to 1000m) or multi-point (up to 16 connections along a distance of 50m);
- Meeting demands for new applications based on IoT and IIoT solutions, as well as new environments;
- Focus on sustainability, since less PVC material (used in covers/insulation) and copper (used in conductors) will be used.

3.4. Main Challenges

As a new solution for connectivity, there are currently several uncertainties that remain with regards to the use of SPE. From among these challenges, the following can be highlighted:

- Defining of the type of interface to be used in terms of connector format;
- Development of new tools for field connectorization;
- Defining or reduction of variations in cabling, since cable may vary between 26 and 18AWG, with/without shielding, etc.;
- Development of new forms of testing, since certain parameters evaluated in traditional metallic Ethernet cabling do not apply to Single Pair Ethernet;
- Development of active components, including switches, remote modules and other devices;
- Acceptability of the concept, particularly on the part of the manufacturers that provide industrial automation solutions, as well as teams working in these areas.

3.5. Applications

Applications that may benefit from SPE solutions include:

- **Industrial automation:** control of edge devices such as IOs modules, valves, actuators, drivers, control panels, etc.;
- **Building automation:** control of access, monitoring/sensor environments, powering remote devices with a low level of consumption, etc.;
- **Embedded systems:** entertainment during travel, control and reading of sensors, etc.

4. Conclusion

Given the brief explanation and conceptualization of the Single Pair Ethernet technology provided above, it can be concluded that:

- This is an important stage in the ongoing convergence of IT/AT within the industry and IoT/IIoT systems;
- SPE will not replace the traditional Ethernet standard consisting of 2 or 4 twisted pairs ;
- SPE is able to coexist with other technologies;
- SPE seeks to meet demands with regards to edge computing equipment;
- SPE is an alternative in replacing legacy protocols;
- SPE allows for the development of new applications and connectivity solutions;
- SPE is particularly adherent to the concept of Industry 4.0.

In summary, SPE technology is a means of further disseminating Ethernet solutions for applications for which demand is currently met through the use of legacy protocols that can be expanded to new network demands arising from the development and integration of IoT and IIoT devices in our daily lives, thereby allowing for true convergence between IT and AT solutions.