The Emerging Role of Single-Pair Cabling in Enterprise Networks

Did you know that it's possible to support up to 1000 Mb/s Ethernet transmission rates over a 1-pair copper cable? While initially developed to support automotive applications, it is now recognized that single-pair or "BASE-T1" Ethernet could fill the gap to support industrial (e.g., RS-432 and RS-485), automation, and other low-speed connections with non-proprietary cabling, while also providing a path for them to merge with Internet of Things (IoT) devices in the enterprise space. BASE-T1 Ethernet offers many advantages, including reduced cost, operation over distances greater than 100 meters (m), delivery of dc power, and potential compatibility with traditional 4-pair cables and connectivity, making it an attractive alternative to traditional fieldbus communication protocols. This article summarizes IEEE 802.3's BASE-T1 single-pair Ethernet standardization efforts and investigates the activities currently underway by the TIA TR-42 Telecommunications Cabling Systems Engineering Committee to develop performance requirements for single-pair cabling in commercial, intelligent building, and industrial spaces.

The Machines Can Talk

M2M, or machine-to-machine, communication typically occurs between low-complexity components, such as commonly found in control and other automation systems. Fieldbus devices in control systems include sensors that can detect light, heat, motion, moisture, pressure, or any other one of several environmental phenomena and respond with information or an instruction. They also include actuators that can move or control a mechanism such as a valve, light, or an electrically-controlled switch used for opening or closing a power circuit (e.g., a disconnect, relay, or contactor). The M2M data generated is often associated with low transmission speeds (i.e., 10 Mb/s) and, historically, these systems have been considered part of a building's mechanical/industrial network. However, as the cost to produce these small devices decreases and their presence in the enterprise space increases, the benefits of integrating these components with intelligent automation systems already operating over the traditional IT local area network becomes clear.

In July of 2016, a successful IEEE 802.3 Ethernet Working Group call-for-interest (CFI) led to the formation of a Task Force charted with developing an amendment describing 10 Mb/s Ethernet operation over a single balanced twisted-pair to support M2M communication.

"SP2 is expected to be the media of choice for generic support of single-pair Ethernet in enterprise (i.e., non-industrial) environments."

The objective of single-pair Ethernet is to provide a path for a wide range of legacy fieldbus communication protocols, including not only BACnet (RS-232), Modbus (RS-232 and RS-485), and LONWORKS®, but also lesser known protocols such as HART modem (4–20 mA analog instrumentation signaling), to operate over one standardized media and communication protocol. In addition, single-pair Ethernet potentially offers compatibility with newer protocols, such as Modbus over IP that already operate over familiar 4-pair cabling.

While in theory, low-speed fieldbus device connections could be supported by 4-pair cabling, the objectives of minimizing cost, keeping the physical size of the cables and connectors as small as possible by eliminating unused pairs, and delivering 10 Mb/s bandwidth are optimally achieved with single-pair cabling. The business opportunity is huge; according to the CFI, a mid-range estimate, excluding projected growth, for 10 Mb/s single-pair Ethernet in industrial and building automation applications (automotive applications excluded) is in the range of 65 million new ports per year.

A Growing Need for Single-Pair 10 Mb/s Ethernet

Fieldbus communication is typically low data rate (i.e., ≤ 10 Mb/s) and can be found operating today over a wide range of media from 1-pair and 2-pair shielded and unshielded cables with conductor sizes varying from 16 to 24 AWG, RG-6 coaxial cable, instrumentation cable, and even category 5 cable. When 2-pairs are present, the second pair typically provides 15V DC, 100mW power delivery. Supported lengths can vary from 100m to 1,400m depending upon the media and application. Example legacy connector interfaces include terminal block connections, LONWORKS FTT termination modules, and the RJ45 interface, with terminal block connections being most prevalent and found on both controllers and devices such as sensors and actuators. The wide range of media choices makes fieldbus device communication a highly challenging landscape. Fortunately, adoption of single-pair Ethernet will ensure interoperability between diverse systems and system vendors, eliminate proprietary interfaces and cables (i.e., fragmentation at the edge), facilitate deployment of generic cabling for future applications, and support plug and play device connections.

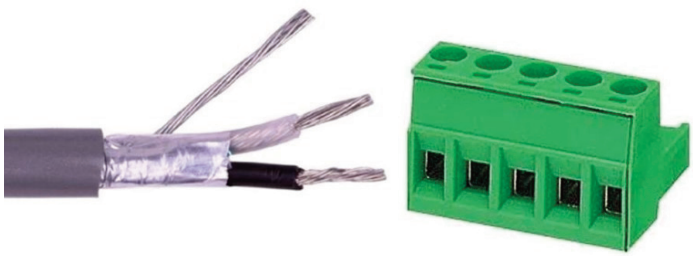

Figure 1: Example shielded single-pair cable and terminal block connector traditionally used to support fieldbus communication

The single-pair Ethernet amendment under development by the IEEE P802.3cg 10 Mb/s Single Pair Ethernet Task Force is titled, "Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors" and publication approval is tentatively projected for September of 2019. While previous single-pair Ethernet standards support operation over 15m (100BASE T1 and 1000BASE-T1) or 40m (1000BASE-T1) maximum cabling lengths, the developing P802.3cg amendment includes an implementation with reach extending out to 1000m. As a result, this is the first single-pair Ethernet solution that can potentially integrate with traditional 4-pair structured cabling network architectures that support lengths up to 100m. The two 10 Mb/s physical layer (PHY) technologies under development by the P802.3cg Task Force are:

10BASE-T1S: 10 Mb/s Ethernet over short reach single balanced twisted-pair cabling up to at least 15m
10BASE-T1L: 10 Mb/s Ethernet over long reach single balanced twisted-pair cabling up to at least 1000m

Short reach 10BASE-T1S will be optimized for support of automotive and other transportation applications, as well as in-cabinet industrial automation, machine, appliance, and other applications, that operate over engineered wiring solutions such as harnesses and PCB connections. 10BASE-T1S is not an application that is targeted for operation over structured cabling and is unlikely to integrate with traditional LAN networks.

On the other hand, key opportunities for 10BASE-T1L include a wide range of industrial automation (both process and factory automation) and building automation applications, which include HVAC, security/access, and lighting control that do cross over into the enterprise building space. Here, there are countless opportunities to support sensors, actuators, relays, contactors, and other low-speed devices with single-pair Ethernet and ultimately network them with IoT devices supported by traditional LAN cabling.

Link Segments and Mixing Segments

All IEEE 802.3 single-pair Ethernet standards operate over a cabling channel, which is referred to as a link segment. The 10BASE-T1S link segment supports the connection of equipment to a device with an allowance of up to four in-line connectors and up to at least 15m of single-pair cable. The 10BASE-T1L link segment supports the connection of equipment to a device with an allowance of up to ten in-line connectors and up to 1000m of single-pair cable. The P802.3cg link segment specifications will be supported by cabling standards that are currently under development by the TIA TR-42 Telecommunications Cabling Systems Committee and the ISO/IEC JTC1 SC25/WG3 Customer Premise Cabling Working Group.

"Emerging single-pair cabling standards will provide a solid roadmap describing the infrastructure needed to truly converge IoT devices and technology operating over 4-pair and single-pair cabling networks."

Unlike previous generation single-pair Ethernet applications, 10BASE-T1S and 10BASE-T1L will additionally accommodate operation over a new type of cabling configuration called a mixing segment. The main difference between a mixing segment and a link segment is that a mixing segment can support more than two devices (or nodes) in a channel. The mixing segment, sometimes referred to as multidrop, will be specified by P802.3cg to support at least eight nodes within 25m of cabling.

Mixing segment implementations are expected to be supported by 10BASE-T1S in automotive and non enterprise applications. A non-automotive application example is the support of future smart (i.e., networkable) Ethernet devices in an in-cabinet industrial automation control application. In this scenario, 10BASE-T1S Ethernet devices, which are responsible for a variety of actions such as circuit protection, motor control, and operator interface (e.g., selector controls, push buttons, and signal indication), are snapped into place in rows on DIN rails inside a control panel. The nodes may be interconnected with very short length single-pair cables or via a single-pair trunk and drop scheme - there is no structured cabling. It is anticipated that other applications, such as elevator control or ultra-low voltage lighting in building automation systems (e.g.., DALI™) will take advantage of single-pair Ethernet operation over a mixing segment in the future. However, these systems are not expected to utilize structured cabling, but rather be engineered systems more akin to machine or appliance wiring.

Optional Power

10BASE-T1L will support optional remote power provisioning with four classes of Type E power sourcing equipment (PSE) expected to be specified to deliver up to a minimum of 13.6W over 1000m of single-pair cabling. The actual maximum power available to the device will be dependent upon the single-pair channel resistance. The technology to provide power over a single balanced twisted-pair is described in the IEEE Std 802.3bu™ amendment and referred to as Power over Data Lines or PoDL (pronounced "poodle"). Note that PoDL is a 1-pair remote power delivery technology and is not inherently compatible with 2-pair Type 1 and 2 and 4-pair Type 3 and 4 Power over Ethernet (PoE) technology.

TIA is Developing Single Balanced Twisted-Pair Cabling Specifications

While a direct point-to-point connection is a valid IEEE 802.3 link segment configuration, there are many advantages to deploying at least two connectors in a channel configuration. As shown in Figure 2, three familiar basic channel configurations applicable to single balanced twisted-pair cabling include:

1. A patch panel in the mechanical or telecommunications room and a service outlet (SO) at the device,
2. A patch panel in the mechanical or telecommunications room and a zone enclosure housing service concentration point (SCP) outlets serving multiple devices, and
3. A patch panel in the mechanical or telecommunications room, a zone enclosure housing SCP outlets serving multiple devices and an SO at the device.

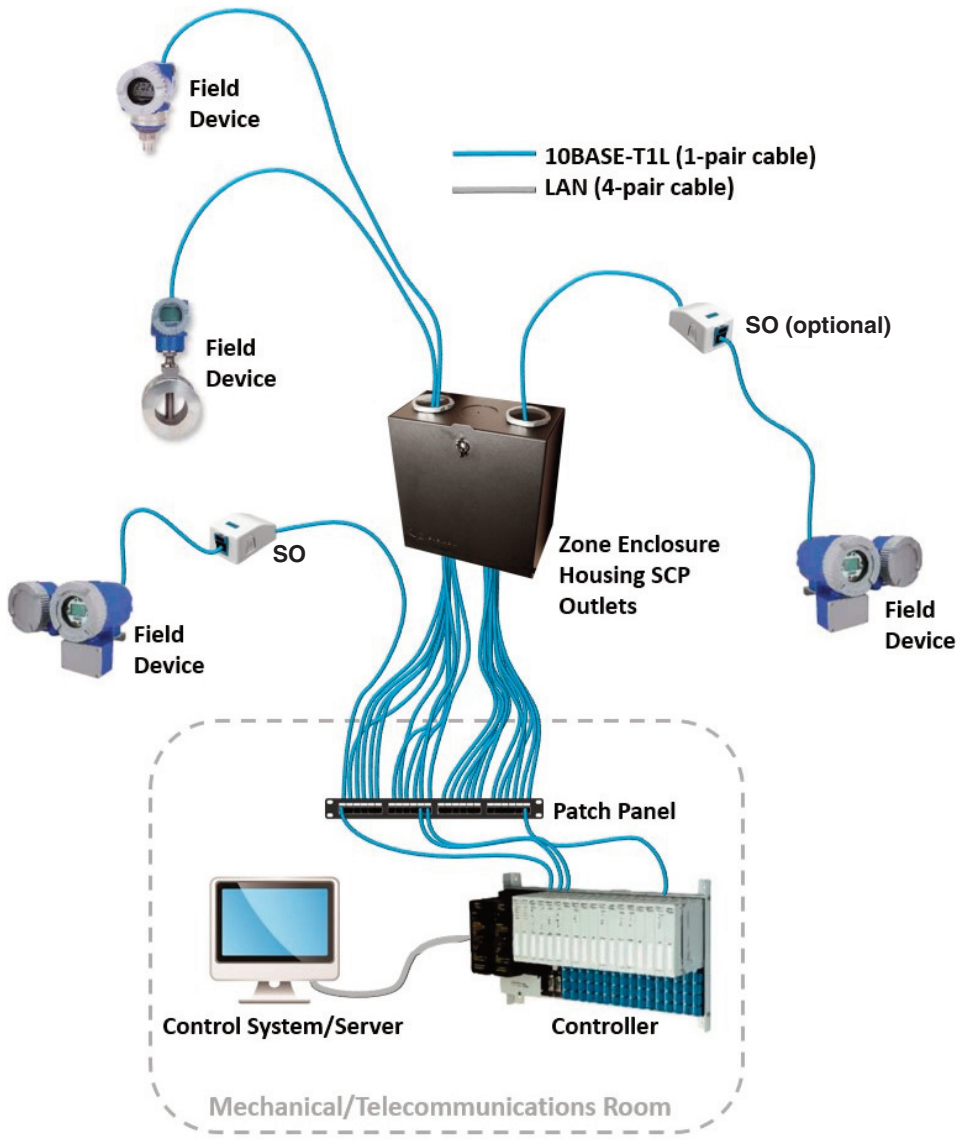

Figure 2: Example Single-Pair Cabling Channel Configurations

The benefits of a structured single-pair cabling architecture include:

- Device interoperability and elimination of proprietary cables and interfaces
- Ability to pre-cable for future applications
- Generic support of a wide range of applications
- Simplified labeling and administration
- Accessibility for testing
- Ability to provide data and power over the same conductors
- Rapid deployment with plug and play connections One network infrastructure has the potential to become a common platform for cabling of data and BAS connections optimizing management and control

TIA TR-42 is currently developing cabling standards for enterprise, light industrial, and heavy industrial environments that will simplify the design and deployment of single balanced twisted-pair systems. The main differentiator between cabling specifications in 10BASE-T1L enterprise and industrial deployments is that industrial implementations will require ruggedized media and components, such as those having improved oil, UV, temperature, and chemical resistance, as well as possibly more stringent immunity/emissions requirements. It will be necessary to know the target installation environment to identify the correct TIA single-pair cabling standard.

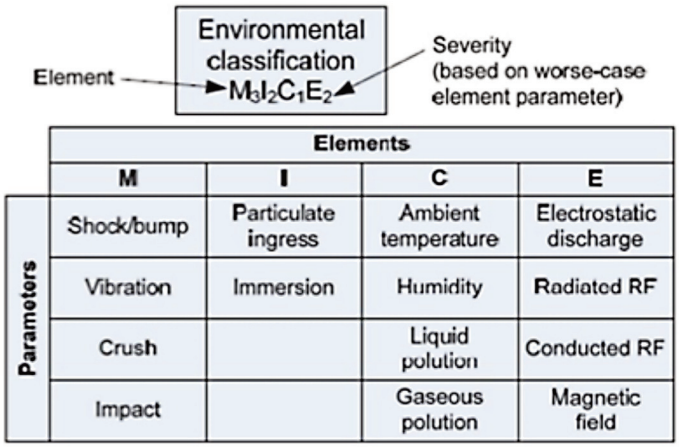

Figure 3: Sample TIA TSB-185 MICE Operating Environment Classification

Both TIA and ISO/IEC classify various operating environments by their Mechanical, Ingress, Climatic/Chemical, and Electromechanical or MICE characteristics. Figure 3 shows an excerpt from TIA TSB-185, "Environmental Classification (MICE) Tutorial" showing a sample $M_3I_2C_1E_2$ environmental classification. $M_1I_1C_1E_1$ is the only classification for the enterprise LAN environment - all other MICE classifications are considered light or heavy industrial. The four TIA single balanced twisted-pair cabling standards that are under development are shown in Table 1. ANSI/TIA-568.0-D-2 and ANSI/TIA-568.5 are in the earliest development stages. Currently, drafts do not yet exist for ANSI/TIA-862-B-2 or ANSI/TIA-1005-A-4.

Table 1: Developing TIA Single Balanced Twisted-Pair Cabling Standards

Number	Title	Environment
ANSI/TIA-568.0-D-2	Single Balanced Twisted-Pair Use Cases and Topology	Enterprise Customer Premises ($M_1I_1C_1E_1$)
ANSI/TIA-568.5	Single Balanced Twisted-Pair Cabling and Components Standard	Enterprise ($M_1I_1C_1E_1$)
ANSI/TIA-862-B-2	Single Balanced Twisted-Pair Use Cases and Topology	Intelligent Building Systems ($M_1I_1C_1E_1$)
ANSI/TIA-1005-A-4	Single Balanced Twisted-Pair Use Cases and Topology for Industrial Premises	Light/Heavy Industrial

Owners of customer premises looking to deploy single balanced twisted-pair cabling will want to follow the development of ANSI/TIA-568.0-D-2 closely. This standard will describe use cases, topology, and architecture related to single-pair cabling. It is expected to define terminology for related terms such Internet of Things, machine to machine, and single-pair conversion point (i.e., point of transition from other media to single-pair cabling). Placeholders currently exist for specification of pull tension, bend radius, cable termination, cords and jumpers, bonding, separation from power, and electrostatic discharge. Most importantly, this standard is expected to specify installation requirements and additional guidelines, including sheath sharing, for transitioning from 4-pair to 1-pair cabling. This final aspect is critical to the integration of low-speed automation and fieldbus applications into the LAN IT network, which will ultimately enable these devices to join the Internet of Things.

Single-pair cabling and component specifications form the core content of ANSI/TIA-568.5. This standard, under development by the TIA TR-42.7 Copper Cabling Systems Subcommittee, will accommodate a wide range of single-pair cable conductor diameters – from 26 AWG to 18 AWG – to support up to 1000m in length. The standard will permit the use of cables with smaller conductor gage size for shorter reach architectures. Single-pair horizontal cables may have solid or stranded conductors, and while a shielded construction is likely, it is not required. Copper clad aluminum conductors will not be permitted.

Four possible single-pair cabling channel configurations are specified in ANSI/TIA-568.5 as shown in Table 2. These channels are characterized over bandwidths of either 100 kHz or 1 MHz up to either 20 MHz or 600 MHz as needed to accommodate all single-pair Ethernet applications from 10BASE-T1L to 1000BASE-T1. Possible names, which are still subject to change, for the four channel configurations are SP1, SP2, SP3, and SP4 where SP signifies single-pair and the number that follows represents a specific channel configuration. Note that SP2, SP3 and SP4 are characterized to a higher bandwidth than specified for category 6A, which is specified to 500 MHz. At this time, a category name has not been established for single-pair cabling, although 600-1P is being used as a placeholder.

Table 2: TIA-568.5 Single Balanced Twisted-Pair Cabling Channel Configurations

Reach	Topology	Possible Name	Bandwidth
1000m	1000m 18AWG solid or stranded cable plus up to 10 connectors	SP1	.1 - 20 MHz
100m	90m 23AWG solid cable, 10m 24AWG or 8m 26AWG cords, plus up to 4 connectors	SP2	.1 - 600 MHz
40m	30m 22AWG cable, 10m 22AWG cord plus up to 4 connectors	SP3	.1 - 600 MHz
15m	11m 26AWG cable, 4m 26AWG cord, plus up to 4 connectors	SP4	.1 - 600 MHz

The transmission parameters specified for the four ANSI/TIA-568.5 channels include: return loss, insertion loss, TCL, ELTCL, coupling attenuation for screened/shielded pairs, propagation delay, PSANEXT loss, PSAFEXT loss, and PSAACRF. Some familiar parameters, such as pair-to-pair NEXT loss and pair-to-pair ACRF are not specified because of the single pair construction. Measurement procedures will also be described for all transmission parameters.

The four grades of single-pair cabling will be characterized to align with the performance needs of the single-pair 15m 100BASE-T1 (IEEE Std 802.3bw™), 15m and 40m 1000BASE-T1 (IEEE Std 802.3bp™), and 1000m 10BASE-T1L (draft IEEE P802.3cg) applications as shown in Table 3. The key takeaway is that the specifications under development for SP2 are expressly intended to accommodate the needs of all single-pair applications up to the specified operating distance or a maximum length of 100m. SP2 is optimized to provide generic support of single-pair Ethernet in the same space as traditional 4-pair LAN and intelligent building cabling, and is expected to be the media of choice for generic support of single-pair Ethernet in enterprise (i.e., non-industrial) environments.

Table 3: Single-Pair Applications Support Matrix

	SP1	SP2	SP3	SP4
10BASE-T1L	√	√	√[3]	√[2]
100BASE-T1	X	√[2]	√[2]	√
1000BASE-T1	X	√[3]	√	√

[1] Upper bandwidth of 600 MHz required

[2] Up to 15m

[3] Up to 40m

Content is also under development for inclusion in ANSI/TIA-568.5 that is anticipated to address recommendations for adaptation of 1-pair cabling to 4-pair cabling. While multiple single-pair Ethernet connections can be supported within a multi-pair or 4-pair cable (i.e., a shared sheath application), 2- and 4-pair BASE-T Ethernet chipsets are inherently incompatible with BASE-T1 type chipsets. Therefore, it is anticipated that some type of media conversion device will be a necessary component for the adaptation at the Ethernet level.

The most significant cabling-related milestone reached in the development of the ANSI/TIA-568.5 specification was the identification of a single-pair connector form factor in October 2018. The TIA TR-42.7 Subcommittee evaluated designs against an established matrix of required and recommended features. Examples of the required features included:

1. Appropriately sized to fit into bulkhead, equipment, and outlet mounting openings,
2. Low manufacturing complexity and ease of use,
3. Suitability for use at equipment connections (e.g. at the equipment medium dependent interface or MDI),
4. Robust and consistent performance electrical and mechanical performance, and
5. Reliability under remote powering load conditions, which includes the ability to carry 1.36 A per conductor and withstand un-mating under load without contact performance degradation.

Examples of recommended features included quick and easy plug, jack, and adapter (if applicable) factory and field termination, support of both screened and unshielded cabling, an anti-snag design, and the ability to provide tactile feedback (e.g., make a “click” sound) upon connection.

It is worth noting that concurrent to this activity, the TIA TR-42.9 Industrial Telecommunications Infrastructure Subcommittee also evaluated a panel of ruggedized connecting hardware for inclusion in their developing ANSI/TIA 1005-A-4 standard. TIA-TR-42.7 selected the form factor specified in IEC 63171-1 based on the LC optical fiber form factor for use in enterprise and intelligent building ($M_1I_1C_1E_1$) environments and TIA TR-42.9 selected the ruggedized form factor specified in IEC 60176-3-125 for use in light and heavy industrial environments.

ISO/IEC Activity

Not surprisingly, ISO/IEC is working on a corollary document to ANSI/TIA 568.5. ISO/IEC TR 11801 9906 will define the performance of application specific single-pair channels and amendments to the ISO/IEC 11801-X series will describe cable, component, and cabling requirements in both generic and premise specific environments such as industrial and distributed building services. While the ISO/IEC Working Group completed their connector evaluations a month before the TIA TR-42 Subcommittee did, they also selected the IEC 63171-1 form factor (see Figure 4) for use in enterprise and intelligent building ($M_1I_1C_1E_1$) environments and the ruggedized IEC 60176-3-125 form factor (see Figure 5) for use in light and heavy industrial environments.

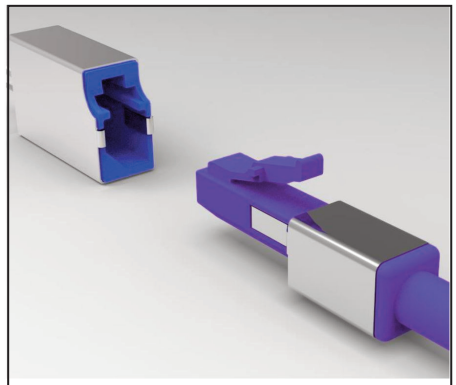

Figure 4: LC-Based Single-Pair Connector Variant Selected by ISO/IEC for Enterprise and Intelligent Building Spaces

Figure 5: Ruggedized Single-Pair Connector Variant Selected by ISO/IEC for Light and Heavy Industrial Spaces

Closing Thoughts

While the power and data needs of M2M and automation communication devices have historically been well-served by a version of twisted-pair cabling, the landscape has been difficult to navigate with the myriad choices related to cable type, pair count, and interface connection style. 10BASE-T1L Ethernet, with reach up to 100m and beyond, and structured SP2 cabling offers a much-needed opportunity to eliminate these proprietary interfaces and protocols, as well as facilitate networking a wide range of building and automation devices. In addition, PoDL remote power delivery can uniquely maximize efficiency and reduce waste by consolidating power and data onto one balanced pair.

With the preponderance of connected low-speed devices entering the building automation space, designers of integrated and intelligent building systems would be remiss not to anticipate the networking needs of devices that have historically been under the purview of the maintenance, electrical, and facilities groups. Fortunately, emerging single-pair cabling standards will provide a solid roadmap describing the generic infrastructure needed to truly converge IoT devices and technology operating over both 4-pair and single-pair cabling networks.

Biography

Valerie Maguire, BSEE holds the position of Global Sales Engineer at Siemon. Her expertise is focused on balanced twisted-pair and optical fiber telecommunications cabling and transmission theory. She is the TIA TR-42 appointed liaison to IEEE 802.3, Treasurer of the IEEE 802.3 Ethernet Working Group, Chief Editor of the P802.3cg Single-Pair Ethernet project, and has held leadership positions in the TIA TR-42 Telecommunications Cabling Systems Engineering Committee and TIA TR-42.7 Copper Cabling Subcommittee for eight two-year terms. In addition, Valerie has authored over 50 technical articles and engineering papers, holds one U.S. Patent, received the 2008 Harry J. Pfister Award for Excellence in Telecommunications, and was named one of CI&M's Top 20 Positive Contributors to the Cabling and Networking Industry.

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