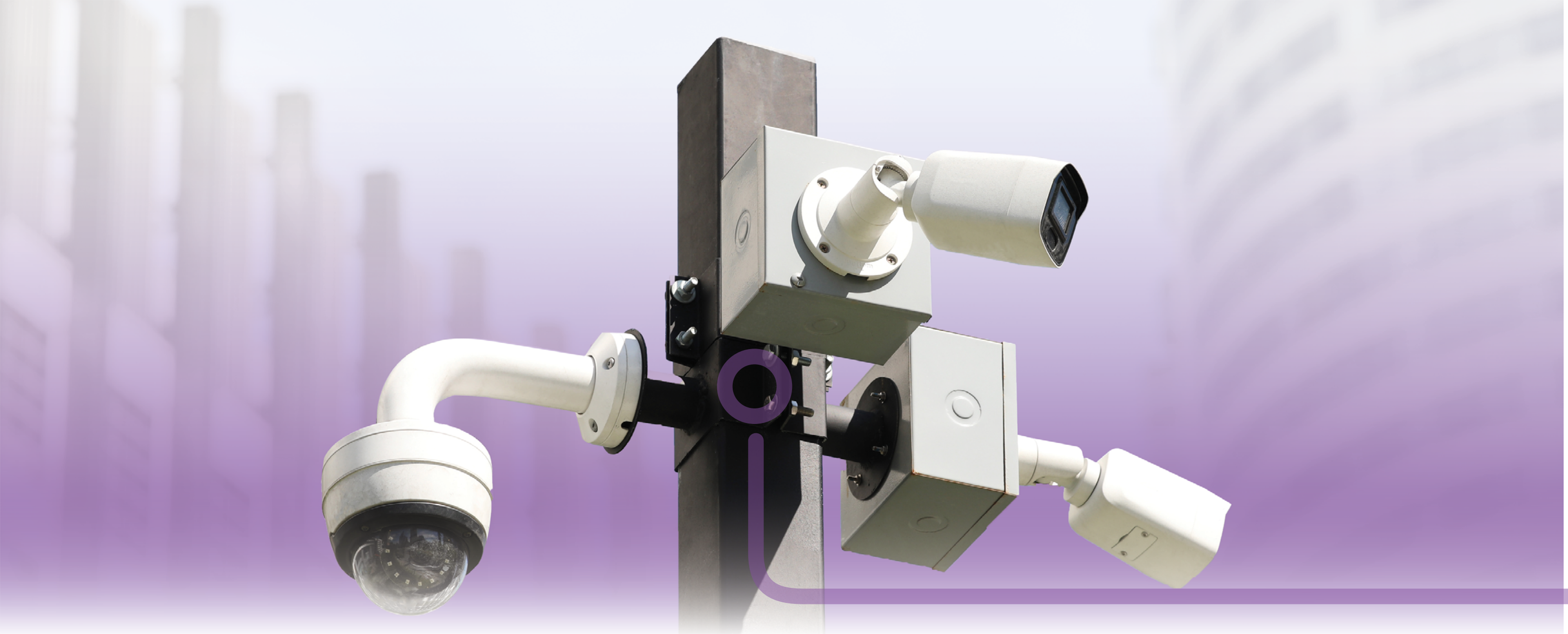

Exploring Solutions that Support Extended Distances

By Todd Harpel

IOT EXPANSION NECESSITATES EXTENDED DISTANCE SUPPORT

Educational institutions, healthcare organizations, and enterprise-level businesses face an increasingly common conundrum. More network-connected devices are in locations that may be hard to reach or are outside the footprint of the building and beyond the traditional capabilities of standards-based copper cabling. The benchmark for performance and interoperability remains at ~100 m (328 ft); however, many organizations often need to extend their connectivity beyond this standard distance.

IoT-connected systems like occupancy sensors, smart thermostats, and air quality monitoring devices are being implemented throughout an organization's facilities, and occasionally, these devices are located more than 100 m from the building's telecommunications room (TR). More commonly, IP security cameras and Wi-Fi access points are placed on the exterior of facilities or in outdoor areas like athletic fields and parking lots where no remote enclosures exist and AC power is inaccessible. Attempts to connect these devices within a typical structured cabling framework are limited in success, as the overextension results in high error rates, poor performance, and frequent interruptions.

Installing some devices more than 100 m from a TR is sometimes unavoidable and, the time, effort, and capital required to build another TR functionally eliminates that option. Leaders want to know: is there a way to extend the distance of their structured cabling systems beyond the 100 m standard without sacrificing performance and quality?

It is possible to do so, though not without careful consideration of transmission performance and the potential impacts of engineered solutions. This article will explore the situations in which it is possible to achieve extended distances with copper cable-based structured cabling, as well as the limitations of those channels over time. It will also examine a future-proofed approach to extended distances, pivoting away from short-term fixes into long-term, sustainable solutions.

UNPACKING THE 100 M STANDARD

The ANSI/TIA cabling standards were created to support IEEE BASE-T network transmission requirements, and predominantly Ethernet network requirements. Established from the earliest days of cabling standards, the 100m channel limit has remained a foundational principle for modern structured cabling. This distance allowed the cabling industry to create predictable worst-case transmission performance, while also meeting the requirements of the IEEE standards for each successive generation of Ethernet. This allowed network designers to create cost-effective networks and for BASE-T Ethernet to dominate the LAN market.

Going beyond 100 m, then, can be a risky proposition, as most networking equipment is not designed to support greater distances. While certain grades of copper cabling are crafted to support quality performance beyond the TIA transmission performance standards, most cabling infrastructure is created to operate optimally within the 100 meter standard. It may be possible to extend a twisted-pair channel further than 100 meters, but the system may not support the same level of performance.

Altering the construction of a typical structured cabling solution to extend beyond the standards-defined distances often results in unintended consequences for transmission quality. As the channel length increases, these effects become more pronounced:

- **Insertion Loss**
  Highly length-dependent, insertion loss is defined as the portion of a signal that does not reach the end of the channel when compared to the signal sent from the transmitter. The longer the channel, the more the signal will degrade due to insertion loss.

- **Propagation Delay**
  Delay skew is the time difference of signals arriving on different pairs. Data packets are split up between the pairs in the cable for 1000 Mbps and faster speeds, so the timing of signal delivery on each pair becomes crucial to successfully transmitting data.

- **Power Over Ethernet (POE) Loss**
  100 m is also the supported distance between power sourcing equipment (PSE) and a powered device (PD). Going beyond that limit can significantly increase power losses, resulting in insufficient power levels, interruptions, and outages.

Not all IEEE-compliant Ethernet devices have the same level of tolerance for cabling channels exceeding standards-compliant lengths. Even if a specific combination of devices is able to establish a connection over a 170 m (558 ft) channel, if just one of those devices were replaced, there is a chance the new combination would not be able to function over that same 170 m channel. Another concern is equipment aging. While it may work now, as the equipment ages, that tolerance for going beyond the standard distance may shrink. The same equipment may not work as expected four years from now, for example, depending on the components used.

However, a lack of standardized support for extended distance channels has not precluded many organizations from deploying them. Cable manufacturers have offered products that exceed the TIA and ISO standards minimum requirements since the inception of structured cabling standards. In some cases, manufacturers even offered performance guarantees for channels of lengths up to 116 m (380 ft). Extensive research has been conducted over the years on this subject, testing risk factors to uncover the causes of transmission degradation and understand how to secure reliable connectivity beyond 100 m.

FACTORS THAT IMPACT TRANSMISSION QUALITY

Transmission Speed

In a study conducted by Leviton and presented at the International Wire and Cable Symposium (IWCS) titled "Quality of Twisted Pair Ethernet Applications at Lengths Greater Than 100 Meters," the transmission quality was tested for 11 different channels longer than 100 m consisting of cables with various gauge sizes and using different combinations of network switches. A total of 396 port combinations were set up for one hour each, while measuring the channel's frame error rate (FER) to determine the quality of each channel's transmission performance at different speeds and lengths beyond 100m.

Three different transmission speeds were used: 10BASE-T, 100BASE-TX, and 1000BASE-T. Of the three, 10BASE-T transmission was the most reliable, as each channel supported error-free transmission for one hour at lengths up to 210 m (689 ft). 100BASE-TX also consistently performed well, with all channels supporting relatively error-free transmission at distances up to 180 m (590 ft); a shorter range than 10BASE-T, but given the increase in speed, still generally positive results. At lengths beyond 180 m, including 210 m, channels with both 22 AWG and 23 AWG conductors exhibited a significant number of dropped frames (errors) during the test.

1000BASE-T transmission exhibited very different performance as the quality of the transmission was

Length	Cable Type	Channels	Switch Combination		
			A	B	C
210 meters	22 AWG Cat 5e	1	x	x	x
		2	x	x	x
	22 AWG Cat 6/6A	3	x	x	x
		4	x	x	x
	23 AWG Cat 6	5	x	x	x
		6	x	x	x
	23 AWG Cat 6A	7	x	x	x
		8	x	x	x
		9	x	x	x
		10	x	x	x
		11	x	x	x
180 meters	22 AWG Cat 5e	1	✓	x	x
		2	x	x	x
	22 AWG Cat 6/6A	3	x	x	x
		4	x	x	x
	23 AWG Cat 6	5	x	x	x
		6	x	x	x
	23 AWG Cat 6A	7	x	x	x
		8	x	x	x
		9	x	x	x
		10	x	x	x
		11	x	x	x
150 meters	22 AWG Cat 5e	1	✓	✓	x
		2	✓	x	x
	22 AWG Cat 6/6A	3	✓	x	x
		4	✓	x	x
	23 AWG Cat 6	5	✓	✓	x
		6	✓	x	x
	23 AWG Cat 6A	7	✓	✓	x
		8	✓	✓	x
		9	✓	x	x
		10	✓	x	x
		11	✓	x	x
120 meters	22 AWG Cat 5e	1	✓	✓	✓
		2	✓	x	x
	22 AWG Cat 6/6A	3	✓	x	x
		4	✓	✓	✓
	23 AWG Cat 6	5	✓	✓	✓
		6	✓	✓	✓
	23 AWG Cat 6A	7	✓	✓	x
		8	✓	✓	✓
		9	✓	x	x
		10	✓	x	x
		11	✓	✓	x

✓	Acceptable FER
x	Unacceptable FER

FIGURE 1: 1000BASE-T Link Quality Test Results. Source: Leviton

significantly compromised at channel lengths longer than 150 m (492 ft), regardless of the cable's conductor size (Figure 1). The study showed that most 1000BASE-T applications past 150 m can suffer significant frame errors, and the error rate can be significantly detrimental to the proper operation of the connected devices. At 210 m, all links tested dropped so many frames that the connected device would be non-functional.

Length

With copper cabling, insertion loss is heavily dependent on the length of the channel. The longer the channel, the more signal strength is lost before it reaches its intended destination, the greater the signal delay, and the more the original signal is degraded. Additional losses, like return loss reflections from connectorization can compound this effect, weakening the signal even further.

It is possible to mitigate the effects of additional length, but it is not currently possible to eliminate it as a factor entirely. In another study, several thousand unique device connections were made using five different cables, all from different manufacturers, with different constructions, performance ratings, and conductor gauges, using three different network speeds. Figure 2 from the study, titled "Twisted Pair Ethernet Applications at Lengths Greater than 100 m," shows that the greater the cable length, the higher the insertion loss, and the lower the probability a link could be established.

Active Equipment

Active equipment also plays a significant role in successfully transmitting error-free 1000BASE-T data at extended distances.

The study, "Quality of Twisted Pair Ethernet Applications at Lengths Greater Than 100 Meters", showed that different switch port combinations produced significantly different results at lengths over 100 m. Switch combination A (Figure 3), previously found to be the most capable combination to establish a link at extended distances, exhibited error-free transmission at 150 m for one hour using different cables with different conductor gauges. Switch combinations B and C, previously shown to be

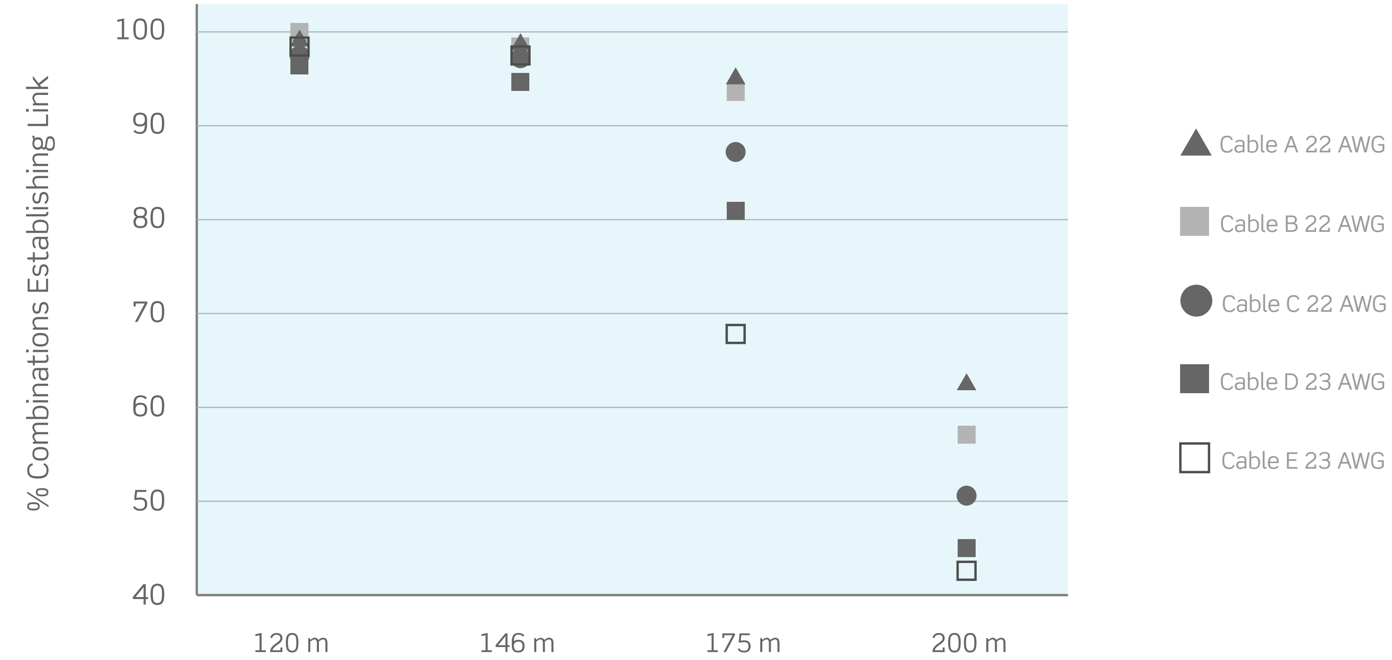

FIGURE 2: Percentage of equipment that established link for the cable samples, 1000BASE-T. Source: Leviton

progressively less tolerant of extended distance connections, had much more variable results at this 150 m length. These switches recorded an unpredictable number of dropped frames for all channel types, regardless of their conductor size. Finally, channel lengths that exceeded the 150 m length with all three switch combinations exhibited a significant number of dropped frames and errors for 1 Gbps Ethernet, regardless of the cable's conductor size.

Through testing thousands of different device combinations, this study demonstrated that different pieces of network equipment exhibited different abilities to support extended distance connections, even with the same cable. In other words, there is variability in capability and performance between identical device types of different age, manufacturer, and quality, with trends showing certain devices had a higher probability of failure at longer lengths than others. Essentially, this means a switch to a device

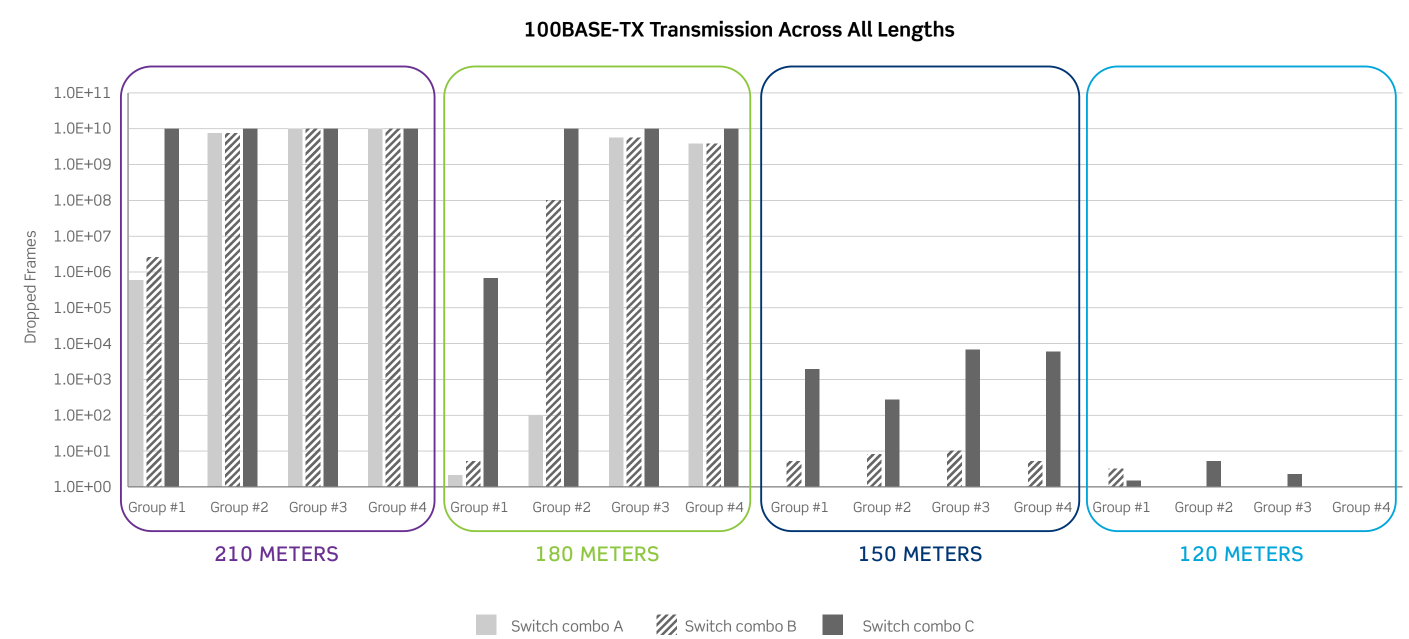

FIGURE 3: 1000BASE-T results. Source: Leviton

combination that is functional at 175 m (574 ft) may become unreliable if the remote device is swapped out for another from a different manufacturer or a different model from the same manufacturer.

Channel Components

Finally, there are elements of a cable's construction that can passively enhance signal propagation and boost the network's performance over extended distances. It is possible to purposely design cables and channels that will support extended distances by modifying the cable conductor size, pair twist rates, and dielectric materials. However, these channels may not support all levels of PoE and Ethernet speeds up to 1000 Mbps with minimally compliant network equipment.

The maximum supported distance of any cable will vary depending on the Ethernet speed (as explored previously) and the PoE level (15 W, 30 W, 60 W, and 100 W) to be carried. This was demonstrated in the two tests using five different cables from five different manufacturers and two different conductor gauges. Deliberately constructing a cable to support an extended distance may offer stable support at lower Ethernet speeds and PoE levels; however, if the design worsens the noise mitigation while improving its signal strength, it may do more harm than good.

Additionally, several of the extended distance claims in the industry today are for plug-to-plug connections that cannot be considered structured cabling, and with their supporting verification testing conducted at ~20 °C (68 °F) only. As temperatures rise, cable attenuation and resistance will increase, and the maximum distance supported by any copper cable will decrease. For installations with pathways outside of a temperature-controlled environment, a change in temperature could make the difference between a functional IP camera and an inoperative one.

Installation Environment

Quite often, extended distance channels are routed in a pathway that is not temperature controlled or outside the footprint of a building. In a study titled "Environmental Resilience of Twisted Pair Ethernet Applications at Lengths Greater than 100 Meters," a set of channels consisting of cables with conductor gauges ranging from 21 AWG to 23 AWG were connected to a number of switch ports from various manufacturers. A section of the cables was routed through an environmental chamber that allowed the temperature to be raised and lowered. The frame error rate (FER) of each channel was observed at various Ethernet speeds, channel lengths, and temperatures (Figure 4).

The results of this study, seen in Figure 4, showed that 1 Gbps Ethernet transmission exhibited a significant number of dropped frames when cable temperatures were raised above ~30 °C (86 °F) and channel lengths were longer than 150 m, regardless of the cable's conductor gauge. At distances below 150 m, these channels were capable of supporting an acceptable FER for 1 Gbps Ethernet even at temperatures as high as ~60 °C (140 °F).

REWRITING THE NARRATIVE AROUND EXTENDED DISTANCES

Much of the narrative on extended distances seems to be centered around shooting for the stars, based solely on how far it is possible to push DC power. Many manufacturers fail to account for data transmission performance and how that can negatively impact their customers' network performance and business objectives. Extensive tests have demonstrated that copper cable-based channels are capable of successfully transmitting Ethernet signals and PoE beyond 100 m. However, there is clear evidence that different Ethernet transmission equipment has different tolerances for supporting extended distance channels.

Additionally, some claims guarantee channel lengths at more than double the TIA 100 m specification but do not take into account this equipment variability, nor do they account for the fact that cable temperature can also have a significant impact on transmissions at these lengths. This is especially true as transmission speeds increase to 1 Gbps. The studies have shown that regardless of conductor gauge, channels of 150 m or less have the greatest probability of supporting Ethernet speeds up to 1 Gbps at an acceptable FER with the greatest variety of active equipment, with cable temperatures ranging from ~20 °C (68 °F)

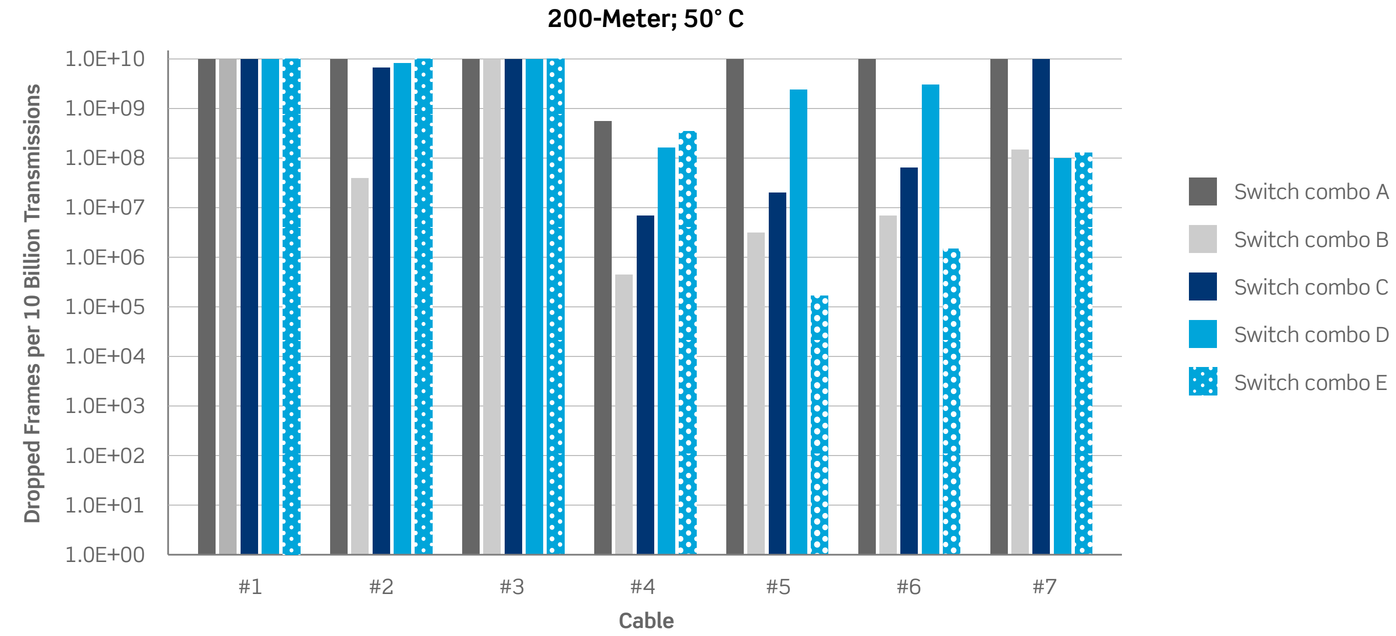

FIGURE 1: 1000BASE-T Link Quality Test Results. Source: Leviton

to ~60 °C (140 °F) while still supporting up to 90 W PoE transmission.

LOOKING AHEAD: STANDARDLIZING EXTENDED DISTANCE SOLUTIONS

While the challenges of extending copper cabling beyond 100 m are well-documented, the industry is not standing still. Organizations worldwide continue to face the reality that IoT expansion, security requirements, and facility layouts often demand ubiquitous connectivity solutions that stretch beyond traditional boundaries. Recognizing this growing need, the information and communications (ICT) industry is actively working to provide clearer guidance and standardized approaches to extended distance applications.

The TIA TR-42.7 Extended Distance Task Group has been developing comprehensive guidelines that will help network designers, installers, and facility managers make better informed decisions about extended distance implementations. This important work promises to bridge the gap between theoretical possibilities and practical, reliable solutions that organizations can deploy with confidence.

Network professionals should watch for the upcoming Technical Service Bulletin (TSB) from the TIA TR-42.7 Extended Distance Task Group. This publication will offer practical guidance and technical detail around evaluating, designing, and implementing copper cabling systems beyond the traditional 100 m limit while maintaining acceptable performance and reliability.

Until this TSB is published, organizations considering extended distance implementations should proceed with careful attention to the factors outlined in this article, ensuring thorough testing and validation of their specific equipment combinations and environmental conditions. The future of extended distance cabling looks promising, with technical guidance on the horizon that will make these applications more predictable and reliable for years to come.

AUTHOR BIOGRAPHY: Todd Harpel has more than 30 years of experience in communications infrastructure design and specification. He holds an M.S. in telecommunications from the University of Colorado, and has designed and implemented communications infrastructure for a variety of clients nationwide. During his career he has managed marketing, product management, technical support, and training staffs for several structured cabling industry manufacturers. Todd is the current chairman for the CCCA Communications Committee.