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Stretch More Out of Your Data Centre's Multimode Cabling System

1. Introduction:

Multimode fibre remains the preferred economic cabling media in the data centre due to its advantage of utilizing relatively inexpensive transceivers over short (<20m) or long (>120m) links in the data centre. While multimode fibre is economically preferred, it may be considered to have limitations for very long links (>300m) and for channels requiring several connections (increased insertion loss). In this paper, we will explore the possibility of pushing beyond the standard limits for channel length and loss.

An Analogy Demonstrating the Interdependence of Attenuation and Bandwidth

Before the words in this article can be interpreted by the brain, the black-curved and straight-lined shapes (letters) must be recognizable. In order for that to happen, there are two fundamental requirements: the letters must be illuminated enough so that they reach the sensors in the eye, and the image must be focused so that the brain can recognize the shape. Consider this three-part analogy: 1) think of the letters as analogous to light pulses in a fibre (information), 2) the eye's dependency on light intensity, like the receiver's sensitivity and the influences of signal attenuation (signal strength) and 3) the focus or blurred image of the letter like the resultant signal at the receiver with distortions related to bandwidth limitations (signal purity).

Descriptive Context	Fibre Optic Receiver World	Analogous Equivalent in the Eye's World
Original Information Element	Light pulse 	Letter e
Influence of Signal Strength (Attenuation)	Attenuated pulse 	Dim/faint letter
Influence of Signal Purity (Focus/Bandwidth)	Pulse shape, distorted by fibre system bandwidth limitation 	Blurry letter, distorted by focus limitation of eye 

After having excellent eyesight for most of my life, at the age of 45, I now suffer from far vision (can't focus on things that are too near; i.e., I need reading glasses). I first noticed this when trying to determine the recording date of an album/song by reading the copyright dates on CDs. I needed to move the CD away from my normal reading distance before the text was in focus. More recently related to my work, I suffer from "can't get the fibre in the hole" syndrome, when working with various fibre connector or tubing products. Some of the focus problems can be compensated with a brighter light source (headlamp). However, there is a limit to what an increase in light can do to compensate for the focus problem. Alternatively to increasing light, I may need to move the object in order to move it to the proper focal point (as I did with the CD case). As any of you with farsightedness know, the solution to being able to see is one of the following:

1) Adjust the light level and distance between your eyes and the object until you find your ideal operating point and can see clearly.
2) Buy glasses!

Just as there is a relationship between the light intensity and focal distance of your eyes, there is also a relationship between the decreased signal strength (mostly due to insertion loss of connectors and fibre) and distance limitation (mostly due to bandwidth) of a fibre, especially at increasing transmission speeds. And few solutions:

1) Increase the strength of the light pulse and/or decrease the distance between the source and receiver until you find the ideal operating point.
2) Upgrade your system!

The relationship between light and focus when reading is not linear. There is a point where the light level is so low that even if the text is within my "window of focus," I cannot see the shapes. Equally, if the lighting is ideal, but the text is not in my "window of focus," I will not be able to read the printed text.

In order for an optical receiver to interpret light pulses in a 10G optical link, we must ensure that the light intensity and "focus" relationship remains in the ideal operating point. As with the aging eye, the aging transceiver also succumbs to poorer performance over time, which is more significantly influenced by bandwidth and loss than in its early years.

The IEEE model simulates several parameters and the subsequent ability of a receiver to interpret the light pulses passing through a fibre. Corning has run the same model with improved parameters and Corning passive components in the system, which allows one to have confidence for designs which go beyond the conservative IEEE model parameters and allows for extended reach (longer links) or higher channel loss (more connections) solutions.

This article provides an in-depth look at the model and the Corning De-Rating Tables' output so that system designers can find the ideal operating points and real limits for their networks.

2. Background/Motivation:

We see a step-change increase in the transmission speeds of LAN and SAN protocols about every five to seven years, as seen in Table 1. But system designers are typically forced to reduce channel length and channel loss for the benefit of the increased speed. The standards employing multimode fibres, such as Ethernet [3] and Fibre Channel [5] usually define a maximum channel loss for a maximum length. These standards do not provide options for channels of higher loss or longer distances other than those stated for a given multimode fibre type. Table 2 summarizes the maximum length and channel loss limits for several of the commonly used protocols running on multimode fibre in the data centre. **If armed with the proper design tools and high-performance cabling components, one can exceed link length or channel loss limits and still achieve full transmission speeds.**

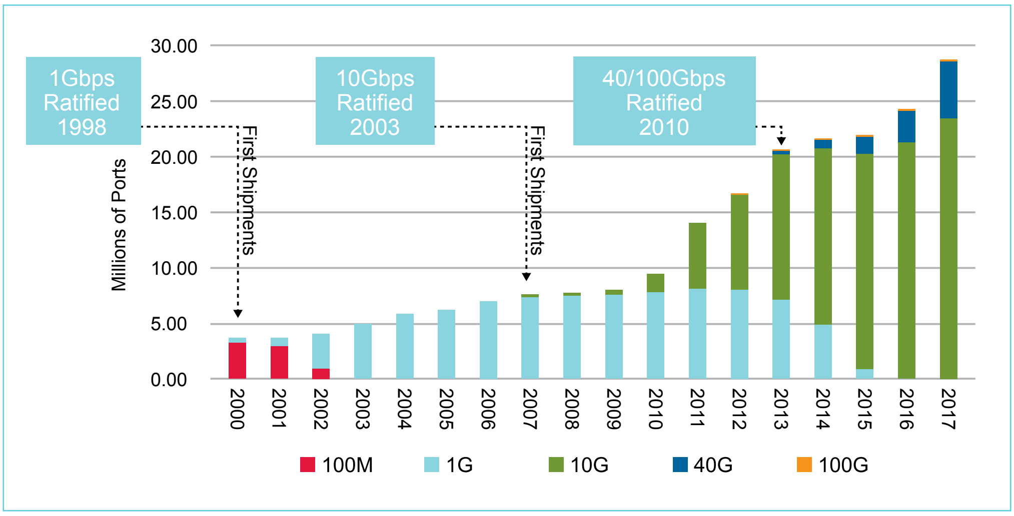

Table 1: Number of Servers Supporting Ethernet Speeds and Ratification Date Compared to Presence in Market

Application (with 850nm VCSEL)	OM3 Max length [m]/ Attenuation [dB]	OM4 Max length [m]/ Attenuation [dB]
1GbE	1100* / 4.1	1100* / 4.5
10GbE	300 / 2.6	400 / 2.71
40/100GbE	100 / 1.9	150 / 1.5
4GB Fibre Channel	380 / 2.88	400 / 2.95
8GB Fibre Channel	150 / 2.04	190 / 2.19
16GB Fibre Channel	100 / 1.86	125 / 1.95

Table 2: Maximum Channel Length/Insertion Loss for Common Protocols
* OM3/4 not defined for 1G in IEEE

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3. Model:
This discussion focuses on the IEEE (Institute of Electrical and Electronic Engineers) requirements for 10Gbps Ethernet transmission, defined in 10GBase-SR [3] (10Gbps over multimode fibre using 850nm VCSEL). Although focusing on the 10G standard, the logic of the discussion also applies to the 40G and 100G Ethernet and the Fibre Channel standard limits.

The single operating point defined in the 10G standard for OM3 fibre (300m/2.6dB) is derived from the 10G Base-SR (10G Ethernet) physical media transmission model from IEEE[2]. This model is based on multiple parameters including but not limited to fibre loss, connector insertion loss, fibre bandwidth, dispersion, source spectral width, source centre wavelength, modal noise penalties and receiver sensitivity. The IEEE model used to simulate Ethernet operation and the Fibre Channel Physical Interfaces [5] (FC-PI-5) endorsed model for 8GFC and 16GFC Fibre Channel analyse a myriad of parameters (some listed above) and predict several output parameters and the resulting eye diagram of such a system. Basically, the models confirm that the received signal for each protocol is of adequate quality, given the transmitted signal conditions and the worst-case distortions that may occur before it arrives at the receiver. There is a trade-off between channel length and loss. If we reduce our system length, we can gain back some margin (in dB) in the form of more connections and still receive a good signal. The question is: what is the relationship of channel loss to channel length? Unfortunately, it is not linear. Therefore, we need the model as an aid to confirm that relationship. A screenshot of the modeling tool for IEEE 10GBase-SR is shown in Figure 1.

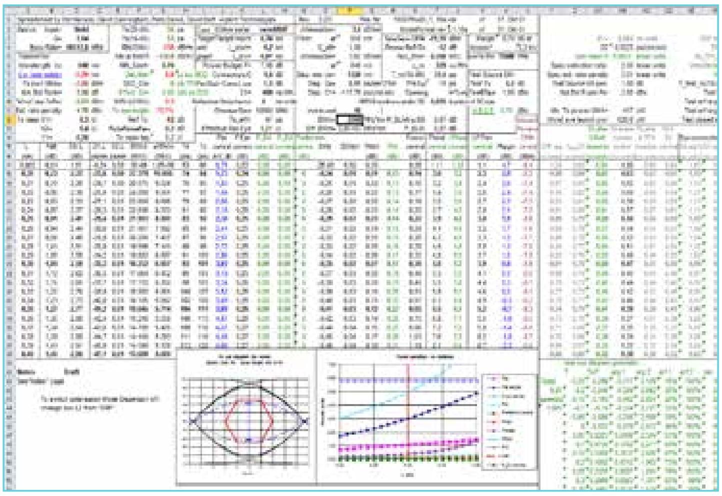

Figure 1: Modeling Tool Used for IEEE 802.3ae, 10GBase-SR

4. Concept of the Corning De-Rating Tables:

The values used in the IEEE 10G-Base-SR model assume worst-case parameters for the performance of the components in the link, including transmitters, physical media cabling and the receiver. Typically, the published standard considers conservative values for these parameters and only provides one operating point of distance and insertion loss, which is a snapshot, as shown in Table 2.

Corning Cable Systems offers passive products with higher performance parameters than those assumed in the standard model. Corning De-Rating tables provide a matrix of operating distances and channel losses like those shown in Table 2. Consider that Corning products provide consistently better performance (specifically fibre loss, fibre bandwidth, connector insertion loss) than those used in the standard model. Additionally, instead of listing the single, snapshot view provided in the standard, the Corning De-Rating Tables give the designer a complete set of detailed images relating the distance and insertion loss trade-off, while ensuring a quality signal arrives at the receiver, as verified by the IEEE model.

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There is a nonlinear relationship at play with the trade-off between channel loss and channel length. The values in Corning De-Rating Tables are derived using the same IEEE model as the standards' derived values. This model considers the non-linear relationships among all of the parameters of the system. Additionally, the Corning De-Rating Tables provide a series of "ideal operating points" for links of a specific fibre type. This is helpful for system planners who have links that do not fall within the IEEE default maximum length/maximum loss limit, like 2.6dB/300m for 10GbE running on OM3 fibre. A planner wants the confidence that the link will work over a variety of channel conditions, and the Corning De-Rating Tables provide that assurance.

5. Supporting methodologies using this concept:

While some readers may have questions when first learning about de-rating tables, this concept is not unique to Corning; the de-rating table form has been embraced by the standards bodies. In CENELEC's *Information technology - Generic cabling systems. Part 5: Data centres* (EN50173-5) [4] and Fibre Channel's Physical Interfaces [5] (FC-PI-5), we no longer find the single data point of length and channel loss, which provides inflexible design guidance for passive cabling, as shown in Table 2. Instead, we find the de-rating tables have been adopted, based on the influence of additional connector loss on the channel length. The result is a matrix within the standards, which offers a range of length/channel loss combinations. With these length/loss combinations, a data centre designer can more freely and confidently design a network without feeling "locked in" to the perceived limits of the standards.

6. How to use the Corning De-Rating Tables:

A **Ethernet**	**Ethernet Distance Capability and Channel Insertion Loss 12-fiber MTP® Connectivity**					
Corning Cable Systems	Number of MTP Connections					
B LANscape® Solutions Cabled Fibre Category - Core/Cladding Dimensions in µm	Data Rate [Gb/s]	Distance [m]/Channel Loss [dB]				
	C	**2**	**3**	**4**	**5**	**6** D
Ultra-Bend 7.5 OM3 (50/125)	1	1100 / 4.14	1000 / 4.68	1000 / 4.68	1000 / 4.68	950 / 4.89
	10	320 / 3.45	320 / 3.45	320 / 3.01	320 / 3.01	320 / 3.01 E
	40 / 100	150 / 1.18	140 / 1.44	120 / 1.65	105 / 1.88	90 / 2.09

Table 3: Corning De-Rating Table for Ethernet and Corning OM3 Fibre

Let's get familiar with to the table's main areas:

A: The header of the table indicates the protocol for this table. The protocol options are Ethernet or Fibre Channel.

B: The first column indicates the fibre category for which the values in the table apply. Currently, the fibre category options are OM3 and OM4, based on Corning's standard Ultra-Bend multimode fibres.

C: The second column indicates data rate. The data rates available are related to those currently defined by the respective protocols indicated in A.

D: This row indicates the number of MTP® connections in the channel. Figure 3 provides examples of an MTP connection. The connection may be an MTP to MTP connection or an MTP to MTP module (cassette) connection. Both MTP connections are considered equivalent in the context of the Corning De-Rating Tables and the associated loss. We do not assume a worst-case MTP Connector loss but instead a connector loss based on statistical distributions of Corning product.

E: The two values within the cells indicate the maximum channel length in meters and the allowable loss of the link in decibels. This is *not* the traditionally calculated link-loss budget using worst-case values for fibre and connectors.

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In the example highlighted above, we want to confirm the channel limits for an Ethernet 10Gbps channel using Corning OM3 fibre, with Corning's Pretium EDGE® products in a link, which has four MTP connections. The table indicates that we can successfully operate 10G-Base SR link up to 320m with a maximum allowable loss of 3.01dB. Note that 3.01dB is the maximum *allowable* channel loss and not the *budgeted* link loss, which is normally calculated using worst-case values for connector loss and fibre loss. The Corning De-Rating Table maximum allowable loss includes unallocated margin, which is not associated with any passive component or power penalty.

The length for 10GbE data in Table 3 remains constant for all combinations of two to six MTP connections. This seems illogical as one expects an increase in the channel loss with the increase in number of connections, which should consequently impact (decrease) the channel length. However, when using Corning product with higher bandwidth and lower connector loss, the IEEE model indicates the allowable channel length limit remains constant. Remember, the Corning De-Rating Table indicates the maximum *allowable* distance-loss relationship; for this distance (320m), there is limited PENALTY caused by the relatively low incremental insertion loss associated with adding up to six connections. The limitation in this case is driven mainly by the power penalties associated with the inter-symbol interference, which is a function of bandwidth. The limitation at 1G and 40/100G is driven by both insertion loss and bandwidth, as we see a decrease in length as the connectors (and associated channel loss) increase.

When I was young, I could read small text close or at a far distance in dim or bright lighting. My ability to interpret the words on the page was constant across a large range of distances and light levels. There was effectively no penalty for changing the location of the text. Conversely, as I've aged and my eye sensitivity has deteriorated, I have a restricted range of vision, which is significantly affected by small changes in distance or light. Similarly, a restricted system with poor bandwidth and channel loss will experience significant changes when the length is varied. A system composed of higher-performance passive components will be less susceptible to the limitations caused by the active devices.

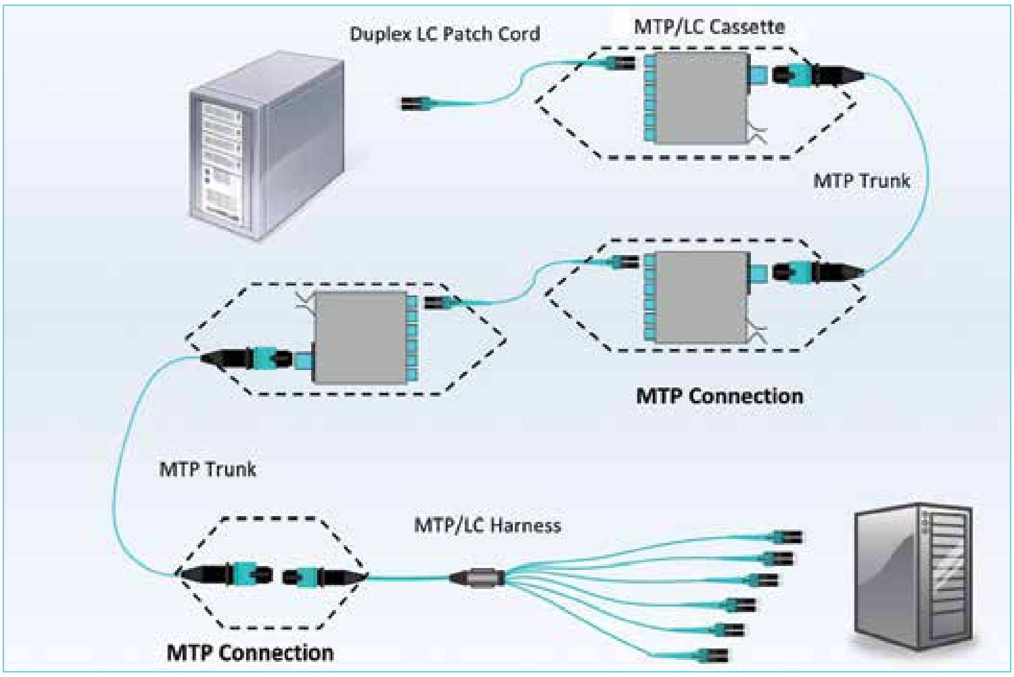

Figure 2: MTP® Connection in Modular Plug & Play™ System

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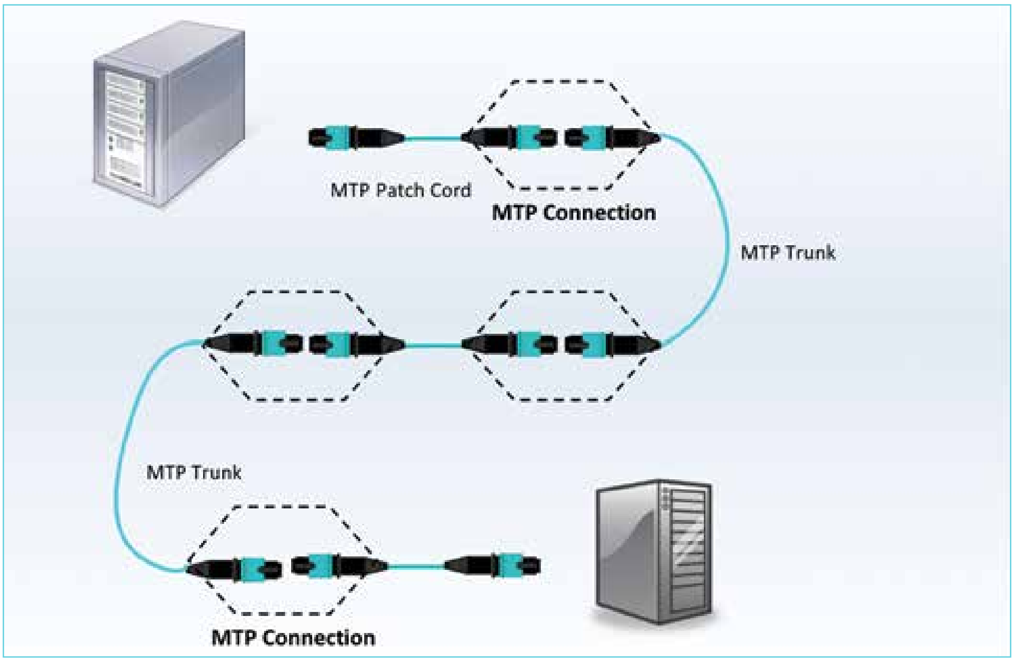

Figure 3: MTP Connection in Parallel Optics System

Regardless of the system, the MTP connection is considered equivalent when using the Corning De-Rating Tables. For both systems above, there are four MTP connections.

7. Conclusions

The Corning De-Rating Tables offer planners an alternative to the fixed maximum operating points found in the IEEE and Fibre Channel standards (Table 2). The tables provide a set of operating points for the channel (length/loss) in which a system can operate based on fibre type, data rate and number of connections.

While the Corning De-Rating Tables provide insight into what can be attained with a system, the maximum lengths defined in the standards and those guaranteed by the active component manufacturers typically correspond to the limits shown in Table 2. However, with unexpected challenges, planners must consider channels that exceed the limits defined in the standards. The Corning De-Rating Tables allow a planner to confirm that a multimode cabling design may be stretched beyond the defined standard limits.

The values in the Corning De-Rating Tables are derived using the IEEE model, which considers the relationship among all the relevant parameters of the system but with parameters based on *typical* values found in Corning's products (dispersion, bandwidth, insertion loss, etc.). In evaluating the inter-dependencies of these many parameters, the Corning De-Rating Tables have been developed to provide a series of operating points for channels of a specific fibre type utilising Corning product. This is helpful for system planners who have links that do not fall within the IEEE single-reference point (maximum length/maximum loss). A planner wants the confidence that a link will work if operating "outside" this single-value limit provided by the standard. Other applications of the Corning De-Rating Tables include system design with optical splitters, which introduce significant loss, possibly exceeding the limit defined by IEEE. Although the discussion and examples presented are focused on 10G Ethernet, the concepts apply to Fibre Channel and the transmission speeds listed in the table, including parallel optics.

If you have any further questions, please contact a Corning Cable Systems Representative or send email requests to EMEA.AE@corning.com.

Fibre Channel	**Fibre Channel Distance Capability and Channel Insertion Loss 12-fiber MTP® Connectivity**					
Corning Cable Systems	Number of MTP Connections					
LANscape® Solutions Cabled Fibre Category - Core/Cladding Dimensions in µm	Data Rate [Gb/s]	Distance [m]/Channel Loss [dB]				
		2	**3**	**4**	**5**	**6**
Ultra-Bend 7.5 OM3 (50/125)	4	500 / 2.27	480 / 2.43	440 / 2.62	420 / 2.78	380 / 3.04
	8	215 / 1.40	205 / 1.62	190 / 1.91	180 / 2.08	165 / 2.32
	10	320 / 3.45	320 / 3.45	320 / 3.01	320 / 3.01	320 / 3.01
	16	140 / 1.17	130 / 1.45	115 / 1.65	100 / 1.95	90 / 2.11
		2	**3**	**4**	**5**	**6**
Ultra-Bend 7.5 OM4 (50/125)	4	600 / 2.64	580 / 2.78	540 / 2.86	500 / 3.08	480 / 3.18
	8	270 / 1.59	260 / 1.77	235 / 2.00	220 / 2.20	205 / 2.38
	10	485 / 2.45	485 / 2.45	470 / 2.89	470 / 2.89	465 / 3.25
	16	185 / 1.38	175 / 1.59	155 / 1.78	140 / 2.00	125 / 2.18

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Ethernet	Ethernet Distance Capability and Channel Insertion Loss 12-fiber MTP® Connectivity					
Corning Cable Systems	Number of MTP Connections					
LANscape® Solutions Cabled Fibre Category - Core/Cladding Dimensions in µm	Data Rate [Gb/s]	Distance [m]/Channel Loss [dB]				
		2	**3**	**4**	**5**	**6**
Ultra-Bend 7.5 OM3 (50/125)	1 10 40 / 100	1100 / 4.14 320 / 3.45 150 / 1.18	1000 / 4.68 320 / 3.45 140 / 1.44	1000 / 4.68 320 / 3.01 120 / 1.65	1000 / 4.68 320 / 3.01 105 / 1.88	950 / 4.89 320 / 3.01 90 / 2.09
		2	**3**	**4**	**5**	**6**
Ultra-Bend 7.5 OM4 (50/125)	1 10 40 / 100	1100 / 4.51 485 / 2.45 185 / 1.25	1100 / 4.51 485 / 2.45 170 / 1.50	1050 / 4.76 470 / 2.89 135 / 1.71	1050 / 4.76 470 / 2.89 125 / 2.10	1000 / 4.97 460 / 3.25 115 / 2.18

Table 4: Complete Corning De-Rating Tables for Fibre Channel and Ethernet Operating with Corning Cable Systems Ultra-Bend OM3 and OM4 Fibres and Low-Loss MTPs

* Maximum allowable channel loss

References

1. Doug Coleman, Corning Cable Systems, representative to Fibre Channel Industry Association

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3. Part 3: Carrier Sense and Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Amendment: Media Access Control (MAC) Parameters, Physical Layers, and Management Parameters for 10Gb/s Operation, IEEE Standard 802.3ae, IEEE Computer Society, August 30, 2002.

4. EN50173, Chapter 5: Information technology - Generic cabling systems Part 5: Data centres, CENELEC, 2002

5. Fibre Channel Industry Association

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