WHITE PAPER

TWISTED-PAIR ETHERNET: COPPER CABLING FOR HIGH-PERFORMANCE NETWORKING

CONTENTS

INTRODUCTION

Escalating Internet data traffic has stimulated an unprecedented transformation in the telecommunication infrastructure. As a result, network designers are struggling with critical path design choices to address a fundamental reengineering of the telecommunication infrastructure. With multiple media and technologies to choose from, the network upgrade paths for the managers of enterprise networks and data centers are many and varied. Ethernet over twisted-pair copper continues as the preferred protocol and media for in-building horizontal network cabling applications operating at distances less than 100 meters (328 ft.). It provides the advantages of plug-and-play simplicity and cost-performance benefits over alternative networks and media types.

There are strong reasons for the broad acceptance and rapid growth of twisted pair as the horizontal media of choice: low initial cost, the ability to deliver higher data rate LAN services and the flexibility to use one medium for all services. As speeds increase, copper-based LANs will require more complex and expensive electronics. It is important to note, however, that fiber has a significant bandwidth distance advantage over twisted-pair in centralized architectures as well as between buildings and in the backbone.

Ethernet has become the default network communications protocol and has evolved from first generation 10 megabits per second (Mbps) speeds that were predominant in the early 1990s to the 100 gigabits per second (100 Gbps) of today's networks.

TWISTED-PAIR ETHERNET: COPPER CABLING

This white paper will discuss twisted-pair copper cabling performance specifications as related to signal transmission aspects with special emphasis on twisted-pair Ethernet applications. It will also discuss some installation and environmental considerations that affect the performance of cabling. Additionally, the paper will illustrate the performance differences when running several applications over different twisted performance levels of twisted-pair copper cabling. End-users should carefully consider the available cabling technology options so they can select a cabling system that will meet both their current and future application requirements.

THE NEED FOR SPEED

In today's modern enterprise, organizations have shifted away from the centralized mainframe computing environments of the early 1990s to more distributed client-server architectures. Servers, now clustered in data centers, require both resilient and high-speed network connectivity. Vertical markets, especially the financial industry, have seen tremendous growth in network traffic over the last decade. As an example, the New York Stock Exchange processes roughly $700 million in transactions per day.[1]

The Internet continues to evolve. With the advent of more video content providers and video hosting websites such as YouTube, the expectations of consumers are also changing. Consumers will no longer tolerate slow server response, slow download speeds or low-resolution video. A series of performance tests conducted by the Anixter Infrastructure Solutions Lab demonstrates the download speed and response time of a Category 5e and Category 6 cabling system when sending a 450 MB file between two workstations.

Cabling System	Average Throughput*	Response Time
Category 6	86.83 Mbps	41.46 seconds
Category 5e	0.454 Mbps	2.20 hours

Table 1: 450 MB TCP Windows File Send (Short Connections)

* These frame error rates represent the file transfer of data packets over a 100BASE-T Link using a marginal Ethernet adapter and switch port.

Additionally, the enterprise network has started to expand into the area of the physical building infrastructure controls. More of these controls are becoming IP enabled and added to the network; a universal concept for a single building cabling approach will be required. This IP Connected Enterprise℠ will need a robust, utility-grade cabling plant to be able to act as a single transport for both IP and analog signaling at the device level. As Web-enabled gateways become more pervasive, from the integration of building automation systems (BAS) and physical security solutions such as video surveillance and access control to the now ubiquitous corporate network, a single cabling plant of four-pair copper and fiber optic design will interface directly to these BAS devices. The transition to running analog signals on twisted-pair is a tried and true conversion, and it works smoothly when the cabling has superior copper conductors. As most BAS signals are serial in nature, the strength lost is proportional to the length of the copper cabling.

CABLING STANDARDS

End-users use the ANSI/TIA-568 and ISO/IEC 11801 series of standards that define Category 5e, Category 6 and Category 6A performance levels to establish the minimum transmission medium requirements necessary to support a wide array of data, voice and video communications systems within their enterprise. The cabling system that meets the performance and test parameters within these standards demonstrates sufficient "headroom" or margin to operate the communications equipment.

Ethernet Port Type	Existing Cabling	New Installations
10BASE-T	Category 3	Category 5e
100BASE-TX	Category 5 with TSB-95 field testing	Category 5e
1000BASE-T	Category 5e	Category 6
10GBASE-T	Category 5e/Category 6 with TSB-155 field testing	Category 6A

Table 2: Twisted-Pair Ethernet and TIA Cabling Performance Specifications

There is also an "TIA/EIA-854 Full Duplex Ethernet Specification for 1000 Mbps (1000BASE-TX) Operating over Category 6 Balanced Twisted-Pair Cabling" standard. The main difference is that it requires Category 6 cabling instead of Category 5e cabling. Because of the improved performance of Category 6 cabling, the TIA/EIA-854 standard does not implement NEXT cancellation or echo cancellation.

INSTALLATION ISSUES

Installation and environmental issues can also affect the cabling that supports Ethernet networks. Just as a new car's value drops the moment it is driven out of a showroom, so does the signal to noise ratio of a cabling system as soon as you install it. The following issues can affect the performance of a cabling system:

- Excessive untwisting to terminate
- High-temperature environments such as plenum ceilings
- Excessive bending
- Pulling tension

When you have a cabling system that just barely meets the required standards for your applications, poor installation practices can put it below the necessary performance requirements and cause problems on your network.

ENVIRONMENTAL ISSUES

With any standard, there is the assumption that total interoperability and all possible environmental and installation issues are included. To some degree, this is true; nevertheless, in the real world, there are always installation, environmental and hardware issues that are present, which could never be demonstrated in the developmental process. Take the environment for an example. In both the TIA and ISO performance rating classifications, attached to the requirement is a statement for insertion loss (attenuation of signal strength through the copper conductor) related to the testing being performed at 20° C; however, the cabling is allowed to be installed into an environment of up to 60° C.[1] This reflects an actual loss of signal strength in a Category 5e cable of 16 percent. This means that at 60° C, the actual loss would increase by 16 percent. Instead of expecting a 21 dB loss in the link test, you would get 24.4 dB loss, which is like adding another 53 feet of cable to the link, which would reduce the delivered power by almost 50 percent. It cannot be expected that all cabling will be installed in a 20° C environment from end to end, and this is just one of many factors that can affect the actual performance of cabling (another being transmitters and receivers that are less than perfect).

In just that single parameter of insertion loss for Category cables, it can be seen how dramatically the building automation system performance can be degraded by temperature variations and installed cable lengths. From the accompanying performance chart **(Table 3)**, it is apparent that as cable design changes according to bandwidth requirements, it also requires copper connectors with larger diameters. The minimum cabling system for use in any enterprise should be Category 6, with the potential for Gigabit Ethernet speeds and the possible inclusion of integration into building automation systems.

Performance Comparisons (dB at 100 MHz)
Twisted-Pair Category Cables
Permanent Links (100 meters plus [3] connections)

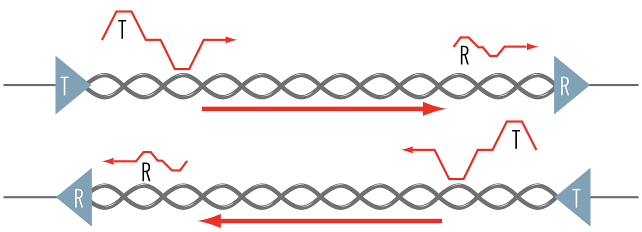
Parameter	Cat 5e	Cat 6	Cat 6A
Max Operating Frequency (MHz)	100	250	500
Insertion Loss	21.0	18.6	17.9
Near-End Crosstalk	32.3	41.8	41.8
Powersum Near-End	29.3	39.3	39.3
Return Loss	12.0	14.0	14.0
Powersum Alien Near-End Crosstalk	Not Tested	62.0	60.0
Approximate AWG American Wire Gauge)	24	23	22
Typical Copper Diameter (inches)	0.0204	0.0226	0.0248

Table 3: Electrical Properties Source: ANSI/TIA-568-C.2 Standard

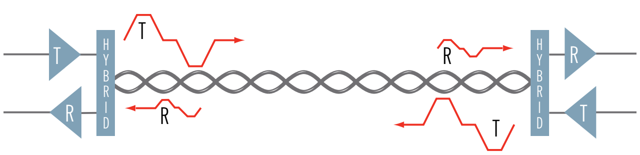
TWISTED-PAIR ETHERNET

The 10BASE-T and 100BASE-TX signaling transmission characteristics are classified as unidirectional; the signals are transmitted in one direction on a single wire pair. In contrast, 1000BASE-T and 10GBASE-T signaling transmission characteristics are bidirectional; the signals are transmitted simultaneously in both directions on the same wire pair (i.e., the transmit and receive pair occupy the same wire pair). **(See Figure 1 and Table 4.)**

For 10BASE-T and 100BASE-TX unidirectional signaling, the far-end crosstalk is coupled into a transmitter and not into a receiver at the far-end and therefore does not impact the receiver performance. 1000BASE-T and 10GBASE-T use bidirectional signaling on each of the four pairs to support full duplex operation **(Figure 2)**. Due to the higher degree of complexity of the bidirectional signaling techniques associated with 1000BASE-T and 10GBASE-T transmission versus those associated with 10BASE-T and 100BASE-T transmission, the selection of the correct cabling media type becomes more critical.



Unidirectional – Transmit and receive on different wire pairs (10BASE-T and 100BASE-T)



Bidirectional – Transmit and receive on the same wire pair (1000BASE-T and 10GBASE-T)

Figure 1: Twisted-Pair Ethernet Signal Transmission

The 1000BASE-T and 10GBASE-T bidirectional signal transmission on a single pair is enabled by a device called a hybrid. The hybrid stops the local transmitted signals from being mixed with the local received signals. Bidirectional transmission on the same wire can result in echo. Echo is the combined effect of the cabling return loss and the hybrid function appearing as noise at the receiver. Return loss (RL) is a measurement of the reflected energy caused by impedance mismatches in the cabling system. In a balanced twisted-pair cabling system, the impedance should normally be 100 ohms. Far-end crosstalk (FEXT) is another noise source, which is induced by a transmitter at the near-end into a far-end receiver due to unwanted signal coupling **(Figure 3)**. FEXT needs to be considered in multipair, bidirectional signaling such as 1000BASE-T and 10GBASE-T. Pair-to-pair equal level far-end crosstalk (ELFEXT), also known as attenuation crosstalk ratio far-end (ACRF), is expressed in decibels as the difference between the measured FEXT loss and the insertion loss of the disturbed pair. In addition, because the signal transmission is on all four pairs, powersum crosstalk loss needs to be considered. The powersum crosstalk specifications take into account the combined crosstalk on a receive pair from all near-end and far-end sources.

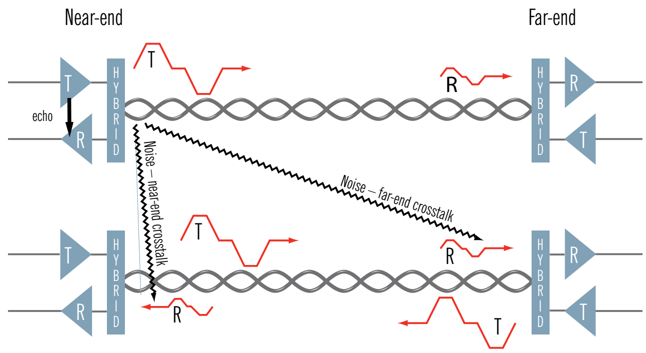


Figure 2: 1000BASE-T and 10GBASE-T – Bidirectional Transmission

Ethernet Port Type	Data Rate	Signal Transmission
10BASE-T	10 Mbps	Unidirectional 2 pairs
100BASE-TX	100 Mbps	Unidirectional 2 pairs
1000BASE-T	1,000 Mbps or 1 Gbps	Bidirectional 4 pairs
10GBASE-T	10,000 Mbps or 10 Gbps	Bidirectional 4 pairs

Table 4: Signal Transmission Over Twisted-Pair Cabling

The additional cabling performance parameters of return loss and ELFEXT and the need to specify a powersum for the crosstalk disturbers for 1000BASE-T and 10GBASE-T, which were not specified for 10BASE-T and 100BASE-TX, are related to the differences in the signal transmission implementations.

Figure 3 illustrates the bidirectional signal transmission on one of the four wire pairs used for 1000BASE-T and 10GBASE-T. The transmitted signal is impaired by the cable insertion loss. The FEXT and NEXT from the other three pairs and the echo combine with the received signal. The ratio of the impaired signal to the noise (e.g., FEXT, NEXT and echo/return loss) is the signal-to-noise ratio (SNR). The SNR at the receiver is the most important figure of merit for a communication channel.

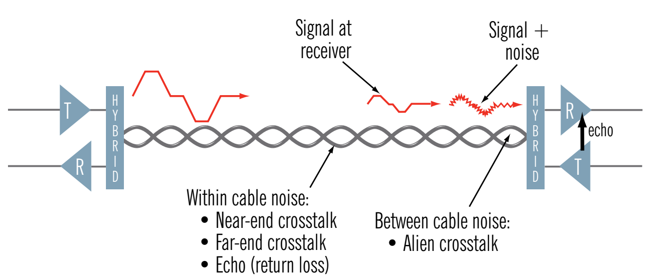


Figure 3: Signal Impairments at the Receiver

MHZ VS. MBPS

Insertion loss and near-end crosstalk loss for cabling are derived from swept frequency measurements. Specifications range from 0.1 MHz to 500 MHz. The insertion loss and near-end crosstalk loss specification values represent the loss of a sinusoidal voltage at the specified frequency and should not be confused with bandwidth limitations, bit rate or baud (e.g., 622 Mbps does not necessarily require cabling specified to 622 MHz). Modulation, the additional variations of amplitude, frequency or phase, and signal conditioning are used to transform the desired bit rate into an acceptable signaling rate (baud) based on the design objectives.

Figure 4 illustrates the signal reference for bit rate and baud. Bit is an abbreviation for binary digit. Bit rate is the number of bits transferred per unit of time expressed in bits per second or in millions of bits per second (Mbps). Baud is the unit of signaling speed on the physical media, equal to the number of discrete conditions or signal events per second.

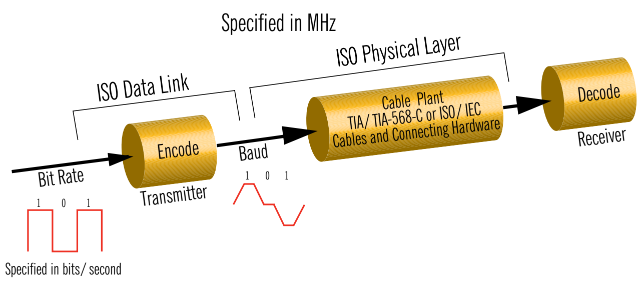


Figure 4: Signaling Reference

SIGNAL TO NOISE (SNR) AND LINE CODING

The bit error ratio (BER), the ratio of the number of bits incorrectly received to the total number of bits received, is mathematically related to the SNR and the line code utilized. Line coding is the process of converting the discrete bits into signals suitable for transmission over the communication channel. The conversion of bits into codes (encoding) and the transformation of the encoded data into symbols increases the bandwidth efficiency of the data transmission.

The symbols are representations of the encoded bits as voltages on the pairs. For binary transmission, where two symbols are used (e.g., 1 and 0), the number of symbols per second (the signaling rate in baud) is equivalent to the data rate in bits per second. For multilevel signaling, the relationship between the signaling rate in baud and the data rate is dependent on the number of voltage levels of the symbols. As an example, if four voltage levels are used as symbols, each voltage level can represent two binary digits (bits of data); therefore, the data rate in bits per second is twice the signaling rate in baud (two bits of data for every baud). In this example, the signaling rate in baud is one-half of the data rate resulting in a reduction in the signal bandwidth.

SNR FOR 10GBASE-T

10GBASE-T will incorporate advanced digital signal processing (DSP) techniques to perform crosstalk cancellation between the pairs in the cable as well as echo cancellation on each pair. The noise coupled between cables referred to as alien crosstalk is not easily canceled. **(See Figure 5.)** For 10GBASE-T, alien crosstalk is the dominant noise source and, therefore, the SNR at the receiver is the ratio of the signal (insertion loss) to alien crosstalk noise appearing at the receiver.

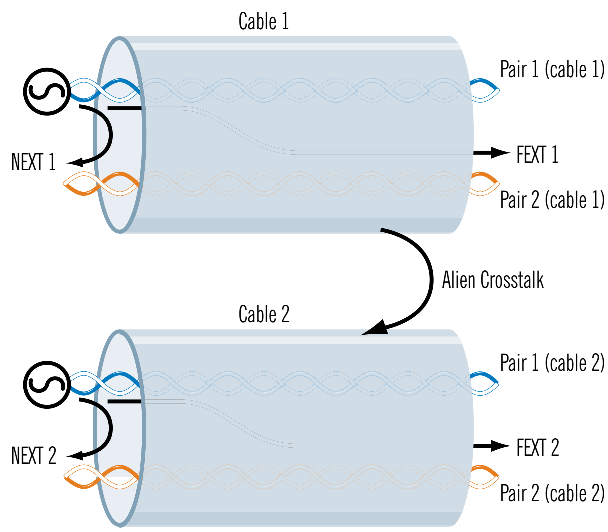


Figure 5: Alien Crosstalk

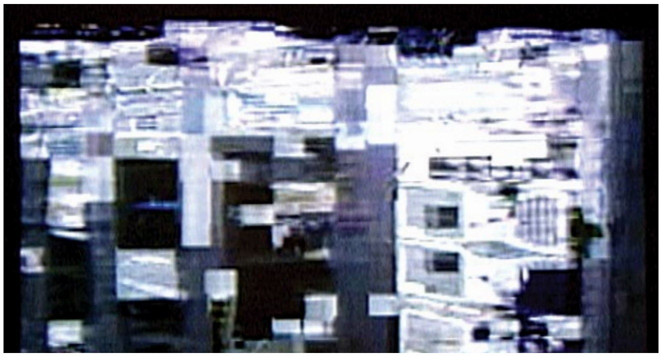
REAL-TIME APPLICATIONS

Today, many of our applications are time sensitive. Voice over IP and Video over IP require that the data packets be sent across an IP network at a particular time and in a particular order. Unlike normal data transfers (e.g., file transfers), if a packet cannot be decoded, these applications cannot ask the transmitter to resend the missing data. Refer to **Table 5** for the recommended network design criteria for real-time applications.

	Data File Transfer	Data Interactive Application	Real-Time Voice	Real-Time Video
Response Time	Reasonable	Within a second	100 ms of delay with low jitter	Minimum delay and jitter
Throughput/ Packet Loss	High/ Medium	Low/Low	Low/Low	High/ Minimum
Reliability (Downtime)	Reasonable	Low	Low	Minimum

Table 5: Transfer Rates

If the problem is bad enough, it can completely interrupt the communications. Therefore, it is recommended to build margin into the network by using minimum Category 6 rated cabling for real-time applications. **Figure 6** demonstrates a comparison of streaming video running over a minimally compliant Category 5e cabling versus Category 6 cabling. These streaming video tests were conducted on a lab 100BASE-T link using a marginal Ethernet adapter and switch port.



Category 5e

Category 6

Figure 6: Streaming Video Running Over Category 5e vs. Category 6 Cables

CONCLUSION

While it is technically correct that Gigabit Ethernet can run over a Category 5e cable from a standards perspective, the results will not always be positive in real-world scenarios. The bottom line: starting with the best cabling system creates an infrastructure that allows all needed applications to run productively in tomorrow's IP Connected Enterprise℠ environment, even as that technically driven environment continuously evolves. Today, the recommended cabling system for high-speed Ethernet systems would be a minimum of a Category 6, while the minimum for 10GBASE-T would be Category 6A.

REFERENCES

[1] NYSE Composite Index CNN Money – money.cnn.com/data/markets/nyse/7january2014

Anixter Inc. World Headquarters
2301 Patriot Boulevard
Glenview, Illinois 60026
224.521.8000