Discussion Paper

Category 6 vs Category 5e Cabling Systems

and

Implications for Voice over IP Networks

By

Galen Udell

Belden CDT Networking

2006

Category 6 vs Category 5e Cabling Systems and Implications for Voice over IP Networks

Over the last 10 years we have seen some tremendous improvement in the transmission performance for both cables and connecting hardware from the early days of Category 5. With the publication of the Category 6 standard by TIA, we see at least double the bandwidth (usable frequency range) compared with Category 5/5e cabling. In addition to baseline Category 6 products, there are some cabling systems on the market today that go well beyond Category 6 standard. Systems, such as the Belden IBDN System 4800LX, provide even more impressive performance and available bandwidth. If Gigabit Ethernet runs on Category 5e, then why does the end user need the extra performance? The answer lies in convergence. There are several benefits for a converged network through improved cabling performance.

Cabling Performance

We can understand cabling performance by looking at "channel". The channel consists of all the components that comprise a cabling system including cables, cords and connectors. A channel is also called a "link segment" by IEEE and represents the physical link between the local and the remote equipment. The performance of the channel is determined from a series of measurements based on inputs to and outputs from the channel. The majority of the parameters specified within the Category 6 standard can be classified as either a measure of "Signal" level or "Noise" level. The most important parameter is Attenuation. Attenuation, also referred to as Insertion Loss (IL) is the measure of the output Signal level compared to the input Signal level. Two other important parameters are Near End Crosstalk (NEXT) and Far End Crosstalk (FEXT). They are the measure of internal noise that is generated between pairs within the same cable or within a connector. Another parameter of note is Return Loss. This is the measure of "self generated" noise on a given pair due to component impedance mismatches or due to impedance variations along the cable. In addition to these parameters, the channel is also subjected to external noise that can come from many sources including RFI, EMI, or alien crosstalk between adjacent cables. Because the overall performance of your network is determined by comparing the Signal level and the total Noise level from all noise sources at the Receiver (Signal-to-Noise Ratio expressed in dB), the doubling of the bandwidth through the use of Category 6 cabling, helps to mitigate potential noise problems and increase signal strength.

According to Paul Kish, Director of Networking Systems at Belden CDT, "There is a direct relationship between the Signal-to-Noise Ratio (SNR) and the Bit Error Rate (BER) performance of digital networks. The higher the Signal-to-Noise Ratio over the available bandwidth, the fewer bit errors are generated and the higher the data throughput. For Ethernet systems, information is transmitted in frames (a sequence of bits with an address header) using TCP/IP protocol. It has been shown that a 1 % frame error rate can slow down the performance of your network from 100% to 20%, which is quite dramatic. In order to meet satisfactory network performance, IEEE specifies a bit error rate objective of less than 1 error in 10 billion (10^{10}) bits of information transmitted. The biggest advantage of Category 6 cabling compared with Category 5/5e is that it provides about 10 dB (or ten times) higher Signal-to-Noise Ratio over the bandwidth utilized by existing Ethernet networks. This means that Category 6 systems are less susceptible to transceiver impairments and other environmental effects such as temperature that can slow down your network."[i]

While it is true that the Standards for both Category 5e and Category 6 components have been developed around a nominal Impedance of 100 Ohms, the Category 6 components must meet tighter tolerances on Impedance variations (Return Loss). A higher value of Return Loss (in dB) means better Impedance matching between components and lower signal reflections and re-reflections. The improved Return Loss on Category 6 vs Category 5e provides better Bit Error Rate (BER) performance for Fast Ethernet (100BASE-TX) and Gigabit Ethernet (1000BASE-T) networks. More frequently occurring bit errors means that your expensive networking devices are caught in unproductive cycles of error detection and re-transmission. Fewer bit errors means that your network is accurately and rapidly transferring the information that drives your business and improves productivity.

Bandwidth

When determining the speed of the channel, two elements are evaluated: frequency range and usable bandwidth. Bandwidth is defined as the frequency range where the Power Sum Attenuation-to-Crosstalk Ratio (PSACR) is positive. Category 6 yields a Bandwidth of 200 MHz at 20 °C (utilizing a 4 connector topology) for a 100 meter channel configurations compared to a bandwidth of 100 MHz for Category 5e. If we consider bandwidth to be the 'speedometer' for cabling systems, then a Category 6 channel effectively doubles the 'top speed' of earlier standards.

From a cost/benefit perspective the doubling of system performance for Category 6 vs Category 5e can be achieved for approximately 20% pricing premium. When you also take into consideration the ability to deploy greater levels of technology and increase the operational life span of the network Category 6 systems will far out reach Category 5e systems.

As a further study on increased bandwidth, the following chart reflects the bandwidth comparisons of the various Belden IBDN Systems vs the TIA Standards. The Belden IBDN performance guarantees make an even greater case for the cost/benefit of moving from Category 5e to Category 6.

PSACR The difference between the insertion loss (attenuation) of the signal and the power sum crosstalk measured in dB at a specified frequency, higher values are better.	Frequency (MHz)	Standard (dB)	IBDN 1200 (dB)	Measurement
	100	3.1	10.4	400% better than standard
	160	N/A	0.3	60% more bandwidth guaranteed
	Frequency (MHz)	Standard (dB)	IBDN 2400 (dB)	Measurement
	100	15.8	20.9	200% better than standard and 1000% better than IBDN 1200
	200	0.4	6.3	250% better than standard
	250	-5.7	0.1	250% better than standard and 25% more bandwidth guaranteed
	Frequency (MHz)	Standard (dB)	IBDN 4800LX (dB)	Measurement
	100	15.8	26.2	900% better than standard, 1500% better than IBDN 1200 and 400% better than IBDN 2400
	200	0.4	11.8	1200% better than standard and 300% better than IBDN 2400
	250	-5.7	5.6	1200% better than standard and 300% better than IBDN 2400
	300	N/A	0.1	50% more bandwidth guaranteed

Bandwidth precedes data rates just as highways come before traffic. Doubling the bandwidth is like adding twice the number of lanes on a highway. The trends of the past and the predictions for the future indicate that data rates have been doubling every 18 months. Current applications running at 1 Gb/s are really pushing the limits of Category 5e cabling. As streaming media applications such as video and multi-media become commonplace, the demands for faster data rates will increase and spawn new applications that will benefit from the higher bandwidth offered by Category 6. This is exactly what happened in the early ’90s when the higher bandwidth of Category 5 cabling compared to Category 3 caused most local area network (LAN) applications to choose the better media to allow simpler, cost effective, higher speed LAN applications, such as 100BASE-TX. It is also important to note that cabling infrastructure is generally considered a 10 year investment as opposed to two or three years for electronics.

For today’s applications, there has been some work done by others that indicates Category 6 provides higher Data Throughput (fewer bit errors) than Category 5e for 100BASE-TX and 1000BASE-T applications.

To demonstrate that Category 6 cabling solutions provide measurably better throughput performance than solutions compliant with the Category 5e standards, Bell Laboratories conducted experiments utilizing three high speed, bandwidth intensive applications. The applications chosen were 270 Mbps Serial Digital Video, 100BASE-TX streaming video, and 100BASE-TX data file transfer. Sheath sharing was incorporated into the experiments to simulate worst-case NEXT noise conditions.

The results of these experiments indicate that overall throughput can be significantly improved by using a cabling system with performance margin over the standards defined requirements. It additionally shows that there are existing applications in the market today that can take advantage of the performance offered by Category 6 cabling systems.[ii]

This work, and the work of others, shows that some network switch ports are at the limits of the IEEE 802.3ab standard (i.e. marginally compliant) and are more susceptible to cabling installation and temperature variations. According to Paul Kish, "From a performance perspective, Category 6 cabling provides twice the Bandwidth (200 MHz) and 16 times (12 dB) better than Signal-to-Noise margins compared with Category 5e cabling. These additional performance margins compensate for deficiencies in the equipment and external noise and temperature variations in the environment."[iii]

Implications for VoIP

To successfully implement IP telephony requires a network with a high Quality of Service (QoS). How does cabling affect the QoS? Isn't Category 5e good enough for Fast Ethernet (100BASE-T)? Feedback from most communications consultants experienced with IP telephony installations indicate that additional headroom beyond Category 5e is required to assure satisfactory QoS. Although IP telephony doesn't need a huge amount of bandwidth, it is sensitive to errors on the network. These errors have much more effect on a voice signal than on a data signal, since voice is real time, and a lost frame is quite apparent in the quality of speech. In the case of data transmission, bit errors can result in retransmissions and some additional delay, which is not that apparent for most applications.

"Developed in the 1960s, TCP/IP is a suite of protocols supported by practically every networked device in the world. It enables communications between those devices across local and wide area networks. It can be used in enterprise network, and is obviously one of the enabling technologies of the Internet.

IP would seem the logical choice for the inclusion of voice. Nevertheless, IP is a connectionless protocol which delivers information on a best efforts basis. The protocol was not developed with real time information such as voice or video in mind."[iv]

Any Voice over IP transmission must use IP (by definition). The basic protocol is completely unsuited to voice transmission: its delay characteristics cannot be easily predicted and no guarantees are made by the protocol that its data will be delivered in the correct order, or that it will be delivered at all. Real time applications such as voice and video require guaranteed connection with consistent delay characteristics.

In order to offset this unpredictability, a number of encoding schemes are used, such as IP, UDP and RTP headers. The IP, UDP and RTP headers are then followed by the data payload of the RTP header. This comprises digitized samples of voice and video. The length of these samples can vary, but for voice, samples representing 20ms are considered the maximum duration for the payload.[v]

According to Cisco, the sum of all bandwidth allocation for voice and data flows on the network cannot exceed 75 percent of the total available bandwidth. Bandwidth allocation for voice packets takes into account the payload plus the IP, RTP, and UDP headers, but not the Layer 2 header. Allowing 25 percent bandwidth for other overhead is conservative and safe.

From the user's perspective, the functionality of the network is even more important. The most important barrier for VoIP to overcome is latency. A two-way phone conversation is quite sensitive to latency, Most callers notice round-trip delays when they exceed 250mSec, so a typical one-way latency budget would be set at 150 mSec in order to achieve high-quality voice calls. Beyond that round-trip latency, callers start feeling uneasy holding a two-way conversation and usually end up talking over each other. At 500 mSec round-trip delays and beyond, phone calls are impractical. By comparison, data networks were not affected by delay. An additional delay of 200 mSec on an e-mail or web page goes mostly unnoticed. Yet when sharing the same network, voice callers will notice this delay.[vi]

One of the main causes of latency is packet loss. Packet loss is a normal phenomenon on packet networks. Loss can be caused by many different reasons: overloaded links, excessive collisions on a LAN, physical media errors and others. Packet loss starts to be a real problem when the percentage of the lost packets exceeds a certain threshold (roughly 5% of the packets), or when packet losses are grouped together in large packet bursts. The results of these packet losses will be degraded voice quality.[vii]

Other important barriers are the functionality of the of the voice network, compared with a traditional PBX. Two key measurements of network performance are:
Call setup time - the time required from the initial dialing of digits, to establishing a voice connection. Users accustomed to fast call setup times in the traditional PBX world and expect to get similar performance on the VoIP network.
Call success ratio - the ratio of successful connects to dial attempts.

The total network load is a very important factor affecting latency, voice quality and functionality of the voice network. When the Ethernet network load is high, or near its bandwidth capacity, jitter and frame loss typically increase. For example, when using Ethernet, higher loads lead to more collisions. Even if the collided frames are eventually sent over the network, they are not sent when intended to, resulting in excess jitter. Beyond a certain level of collisions, significant frame loss occurs. This would mean that a physical network high bandwidth capability would provide a more stable and therefore reliable voice and data network.

Conclusions

While there are a number of impairments that can affect throughput performance of high-speed, bandwidth intensive applications when transmitted over a structured cabling channel, much of the impact can be mitigated through the deployment of Category 6 vs Category 5e channels. Many tests have been run by various manufacturers that clearly show that currently available Category 5e applications, such as file transfer, LAN video streaming and RF Video over UTP, run markedly better over the Category 6 systems, even under extreme noise conditions. Whether using Category 6, or Category 5e cabling, the network performance effectively boils down to Signal-to-Noise Ratio at the Receiver. All the different noise sources need to be taken into account, including NEXT, FEXT, Signal reflections, Alien Crosstalk and Impulse noise. The biggest benefit of Category 6 cabling is the much-improved Signal-to-Noise Ratio (SNR) using the Bandwidth employed by today’s applications and also for future applications. The main result is that Category 6 provides about 12 dB (or 16 times) better Signal-to-Noise Ratio compared to Category 5e over a wide frequency range.

References

[i] Kish, Paul (2002) ‘Broadband Video over Twisted Pair Cabling’, White Paper
[ii] Bell Laboratories (2003), ‘The Effect of Channel Margin on Throughput Performance For Structured Cabling Systems’, White Paper
[iii] Kish, Paul (2002) ‘Category 6 Cabling Questions and Answers’, White Paper
[iv] VoIP Calculator (2005) ‘The Drivers for Voice over IP’, Technical forum supported by Cisco, IBM, AT&T, Microsoft and Intel, www.voip-calculator.com
[v] VoIP Calculator (2005) ‘Voice over IP Protocols for Voice Transmission’, Technical forum supported by Cisco, IBM, AT&T, Microsoft and Intel, www.voip-calculator.com
[vi] Cisco Systems (2005) ‘IP RTP Priority’, White Paper
[vii] Cisco Systems (2003) ‘Echo Analysis for Voice over IP’, White Paper