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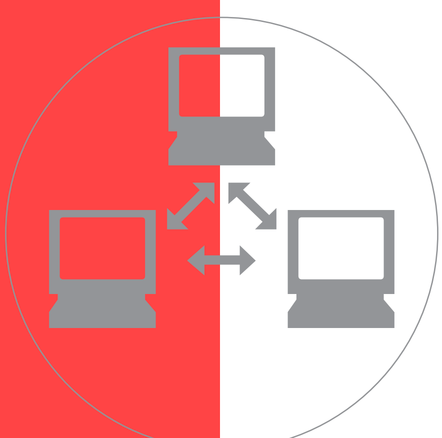
Gigabit 1000BASE-T & 1000BASE-X:

Media Options for Gigabit Networks



Gigabit 1000BASE-T & 1000BASE-X
Media Options for Gigabit Networks

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Once thought to be improbable, if not impossible, Gigabit speeds are now a reality over twisted pair copper cabling. Many of the large network hardware manufactures have been quick to adopt this new technology, and most are now offering products with Gigabit UTP interfaces. Gigabit speeds have been available over fiber optic media for several years, while Gigabit over copper media is a relatively new phenomenon. With the thirst for network bandwidth increasing exponentially, moving to Gigabit in network backbone connections is not as much a choice, as it is an eventuality. Although the need for greater bandwidth is becoming less of a question, the type of interface you choose (copper vs. fiber) is.

Background

In the Fall of 2000, the IEEE 802.3ab task force began working on a scheme which, by design, would allow data to be delivered at Gigabit speeds over much of the existing installed based of Category 5 UTP cabling. This group proposed using an 8B/10B (8 bit user data converted to 10 bit symbols) encoding/decoding scheme which would serve to push the center frequency transmission below the 100MHz threshold required for category 5 copper cables. The 802.3ab task force had the foresight to base Gigabit on existing proven specifications, like FibreChannel (ANSI X3T11), as well as published Ethernet standards (IEEE 802.3). This ensured that the standard could be developed quickly and that it would provide for compatibility with existing Ethernet and Fast Ethernet devices. The IEEE, under 802.3ab, approved the standard for Gigabit transmission over UTP in the Fall of 2000; now known as "1000BASE-T."

Gigabit over fiber optic media borrowed heavily from the existing FibreChannel standards. Again, the IEEE developed this standard via a task force which published its work in 1998 under IEEE 802.3z (1000BASE-X). Approved and proven, the standard for Gigabit over fiber describes high-speed transmission of data over SX (850nm short wavelength fiber), LX (1310nm long wavelength fiber), as well as CX (Gigabit over twinaxial copper cabling). Fiber optic media, because of its inherently high bandwidth carrying capability, seemed to be the most logical choice for transmitting higher speed protocols. However, the higher cost of fiber optic interfaces (vs. copper interfaces) and the large number of networks with installed Category 5 cabling made development of a copper solution for Gigabit necessary.

Using copper or fiber interfaces on your network hardware is a choice that requires some thought based on your unique requirements. Copper interfaces allow you to add Gigabit to your network at a lower cost than fiber, and theoretically, allow you to deploy it over your existing Category 5 cabling plant. However, there are technical issues with Gigabit transmission over UTP that you should understand before you decide which media type you will use in your Gigabit network connection.

With increasing numbers of users demanding more frequent access to storage devices and servers, requirements for higher speed connections have become a necessity.

Applications for Gigabit
Gigabit speed has become necessary in network backbones as a result of ever-increasing thirst for bandwidth. Applications for Gigabit include:

- Aggregation of bandwidth; such as backbone connections for Fast Ethernet switches
- High-speed data transfers between clients and server farms
- Accommodating very high bandwidth users in CAD and image editing applications

Currently, the most common application for Gigabit is aggregation of bandwidth for backbone connections between Fast Ethernet devices (most often switches). This Gigabit connection is often accomplished by using a modular device that can be installed in switches, which is available from all of the major switch manufacturers, known as a Gbic. Gbics are relatively inexpensive and can facilitate most Gigabit backbone connections of this type; provided they do not exceed the maximum distance allowed by the media and fiber optic transceiver used.

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The increasing complexity of graphics used in engineering CAD software as well as software used by graphic artists, will require that these "power users" have access to a bigger and faster pipe.

Issues in Half-Duplex Networks
Gigabit achieves 1Mbps throughput by effectively transmitting 250 Mbps of data over each of four wire pairs simultaneously in both directions; where the cumulative result is a 1 Gbps duplex connection. The Gigabit 1000BASE-T standard was written to accommodate both full-duplex and half-duplex operation (Shared Ethernet regulated under CSMA/CD rules). Full-duplex is clearly the preferred architecture, as there are some inherent problems with running Gigabit in a shared architecture over copper, in terms of distance and throughput.

In shared Ethernet, an increase in speed typically equates to a decrease in distance, because of the method in which Ethernet deals with collisions. Ethernet devices "listen" for an opportunity to transmit on a shared wire pair. If a device detects that no other devices are transmitting, it deems it safe to send its data. Collisions occur if two devices on the same network attempt to transmit at the same time. These collisions, if not too frequent, are perfectly normal and easily dealt with by the protocol (under the provision of CSMA/CD - Carrier Sense Multiple Access/Collision Detection - part of the IEEE 802.3 standard).

In Ethernet, the smallest packet size allowed is 64 bytes (8 bits per byte = 512 bits). The purpose of establishing a minimum packet size was to ensure that a station could detect collisions at the furthest point of the network, allowing the CSMS/CD portion of the protocol to deal with it appropriately (referred to as the 512 bit-time rule). As speed increases by factors of 10 (10 Mbps to 100 Mbps to 1 Gbps), the distance that you can transmit and still properly detect collisions is decreased by a factor of 10. Consequently, at Gigabit speeds in a shared Ethernet environment, you are limited to about 20 meters over UTP.

The Gigabit standard addresses this distance limitation issue by a method known as "carrier extension." Carrier extension effectively increases the packet size to 512 bytes (4096 bits), by adding "extension symbols" to increase the size of the packet to a size that can be detected by all devices on a Gigabit link up to 100 meters away. The end device then strips this additional data or "extension symbols" off when it is received. The problem is that increasing the packet size (adding 448 bytes of extension symbols) means that you have actually decreased the throughput to about 100 Mbps Fast Ethernet speed. (Sending larger amounts of data down a larger pipe nets you no significant gain.)

To deal with this reduction in throughput, a method known as "packet bursting" is used in conjunction with carrier extension. Packet bursting improves the efficiency of carrier extension by decreasing the inter-packet gap when multiple packets are transmitted. (Reducing the amount of data you send down a larger pipe nets you a nominal gain.) However, even when both methods are used, throughput in half-duplex Gigabit remains hindered and never achieves full 1 Gbps speed. The bottom line is that half-duplex is possible but not recommended in Gigabit environments.

Carrier detection and packet bursting are not required in a full-duplex Gigabit environment.

Cabling Considerations

Theoretically, IEEE 802.3ab intended to make use of much of the existing Category 5 cabling by enabling 1000BASE-T to operate at the 100 MHz rating of CAT 5 UTP. The cabling system used to support 1000BASE-T requires four pairs of Category 5 balanced cabling with nominal impedance of 100 ohms as required in the TIA/EIA 568-A standard. The demands placed on a Category 5 cabling plant to support Gigabit speed may surpass the ability of much of the installed base of Category 5 cable to support it reliably. To make certain that a given Category 5 cabling plant is able to support 1000BASE-T, IEEE developed additional requirements.

In addition to the requirements stated in EIA/TIA 568A for Category 5 cabling, additional requirements were added (Annex 40A) with further requirements for the 1000BASE-T installations. The transmission parameters in Annex 40A call out additional requirements for insertion loss, delay, characteristic impedance, return loss, and most importantly, NEXT/ELFEXT (Near-end cross talk/equal level far-end cross talk). Cross-talk is simply electrical interference to each of the individual transmitters caused by noise from the other three transmitters on a segment (NEXT) or interference to each receiver caused by the three adjacent transmitters (ELFEXT). Effectively, much of the installed Category 5 UTP, because it was installed prior to the publication of Annex 40A, and therefore, not tested to meet its requirements, may not support 1000BASE-T. To provide a safety margin, some network hardware manufacturers recommend that Category 5e cabling be used in 1000BASE-T installations. Category 5e installation requirements include testing parameters for return loss, NEXT, ELFEXT, etc., with a built in margin for error sufficient to support 1000BASE-T (designed with 1000BASE-T in mind).

The cost benefit of being able to deploy Gigabit over the existing Category 5 cabling plant is enticing, but can be somewhat diminished, since it is believed that many existing Category 5 cabling plants will not support 1000BASE-T. Additionally, the cost of installing, testing, and certifying Category 5E or Category 6 cabling (including cables, cords & connectors) exceeds that of Category 5 UTP. However, the lower cost of 1000BASE-T (copper) devices, when compared to 1000BASE-X (fiber) devices, tends to offset this to some degree. You are also limited to 100 meters with UTP in 1000BASE-T, whereas you can transmit up to 550 meters across multimode fiber (see Table 1) with additional headroom for more bandwidth in the future.

Table 1

	Ethernet 10BASE-T/ FL	**Fast Ethernet** 100BASE-TX/FX	**Gigabit Ethernet** 1000BASE xx
Data Rate	10 Mbps	100 Mbps	1 Gbps
Category 5 (UTP)	100 m	100 m	100 m
STP/Coax	500 m	100 m	25 m
Multimode Fiber 62.5 micron	2 km	412 m half-duplex 2 km full-duplex	220 m**
Multimode Fiber 50 micron	2 km	412 m half-duplex 2 km full-duplex	550 m**
Single Mode Fiber	20 km long haul: 80 km	20 km long haul: 80 km	5 km long haul: 65 km
Repeats per Segment	3	2	1

**Dependent on Modal Bandwidth of the fiber and wavelength of the optics used.

Auto-Negotiation

With the advent of Fast Ethernet (100 Mbps), a means of establishing backwards compatibility with existing Ethernet (10 Mbps) devices had to be established. The IEEE, when they released the 802.3u standard several years ago, addressed this with a method known as "auto-negotiation". Auto-negotiation in Fast Ethernet can be viewed as a language that 10/100 (referred to sometimes as N-way or dual-speed) devices speak to establish at what speed and in what mode the link should operate. Fast Ethernet auto-negotiation "advertises" its capabilities to the device it is connected to in terms of speed (10 or 100 Mbps), and mode (full or half-duplex) of operation. Based on the capabilities of the device it is communicating with, it will establish the most appropriate link.

In 1000BASE-T, auto-negotiation has four elements, rather than two, as in Fast Ethernet. Because it has to be backwards compatible with other Ethernet devices, it too must be able to establish speed (10, 100 or 1000 Mbps) and mode of operation (full-or half-duplex). Additionally, 1000BASE-T requires that auto-negotiation establish a Master-Slave relationship between the two devices, as well as establish if both devices are "pause" enabled. Typically, a multi-port device (switch) will assume the role of Master and single-port devices (servers, end stations, etc.) will be the slave unit. The 1000BASE-T protocol has a means of arbitrating which device will assume a given role (master/slave). The purpose of this Master/Slave relationship is to determine which device will provide the clock for the link. Additionally, because of the high transmission speed of Gigabit, there is the possibility that the device being transmitted to may be overwhelmed with data. Pause is a means by which the device receiving the data can signal to the transmitting device to stop transmitting momentarily so that it can "catch up."

Auto-negotiation does not currently exist for Gigabit devices with fiber interfaces due to differences in transmission wavelengths (850nm vs. 1300nm) between Ethernet, Fast Ethernet and Gigabit.

A Word About Fiber

If you are going to incorporate Gigabit Ethernet into your network there is a strong possibility that you will need to implement some of your Gigabit connections over fiber optic media. You will most likely be doing this because of the distance limitations of 100 meters over copper media (UTP). But what distances can you achieve using fiber optic cabling? The answer to that question is: it depends.

With the increase of transmission speed to 1 Gbps, the bandwidth carrying capacity of the fiber optic media you are using will come into question. The "Modal Bandwidth" is a measure of the information carrying capacity of the given medium and is expressed in MHz per kilometer. In optical fiber, bits of data are represented by pulses of light. Each pulse of light will disperse, or spread, over time and distance as it travels through the fiber optic cable. As these bits of data disburse, they eventually begin to overlap with each other and distort the data that is being transmitted. A multimode fiber optic cable's data carrying capacity is ultimately determined by its "dispersion characteristics."

There are two types of dispersion: intermodal dispersion and chromatic dispersion. Intermodal dispersion occurs because, in multimode fiber, light can travel in multiple modes or paths, which can ultimately arrive at different times at the receive end of the fiber. Chromatic dispersion is caused by the slight variations in wavelengths of light that are transmitted over the fiber. Different wavelengths of light travel at different speeds, and over a given distance will eventually begin to overlap. Intermodal dispersion is not a factor in single mode fiber. Chromatic dispersion affects all fiber but it affects single mode fiber to a lesser degree.

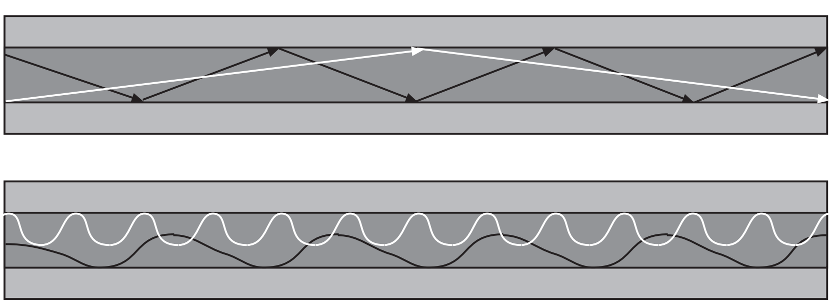


Figure 1: Intermodal & Chromatic Dispersion

To truly understand the distance that you can transmit data at Gigabit speeds over multimode fiber you must take into account the modal bandwidth of the fiber. Typically, modal bandwidth specifications are provided by the fiber manufacturer. Table 2 offers some general guidelines for determining approximate distances that can be achieved over a Gigabit fiber link.

Table 2:
Typical Modal Bandwidth and Corresponding Distances for Gigabit Transmission Over Fiber Optic Media

100BASE-SX	Fiber Type	Modal Bandwidth at 850nm	Range
	62.5 µm	160 MHz / km	220 m
	62.5 µm	200 MHz / km	275 m
	50 µm	400 MHz / km	500 m
	50 µm	500 MHz / km	550 m
100BASE-LX	**Fiber Type**	**Modal Bandwidth at 1300nm**	**Range**
	62.5 µm	500 MHz / km	550 m
	50 µm	400 MHz / km	550 m
	50 µm	500 MHz / km	550 m
	10 µm single mode	N/A	5,000 m

Mixed Gigabit Copper and Fiber Environments

As mentioned earlier, there is a strong possibility that many people implementing Gigabit in their networks will be transmitting over both copper and fiber optic media. The lower cost potential of UTP copper interfaces will compel people to deploy 1000BASE-T in some applications, while the requirement to extend distances beyond the 100 meter limitation of copper will require that they deploy 1000BASE-SX/LX in other applications. There are several options available for those who face this mixed-medium challenge. Options include:

- Purchasing separate network devices; some with copper, some with fiber interfaces
- Purchasing a network device that has a slide-in-module option that offers a choice of copper or fiber (Gbic) interfaces
- Using an external device such as a media converter

In case you haven't looked recently, Gigabit Ethernet devices are not among the least expensive pieces of network hardware available. Although they may be worth their weight in gold when network bandwidth reaches critical mass, the cost can be imposing. Being a relatively new technology, the configuration options for Gigabit devices may be difficult to match to your specific needs. Effectively, you may end up purchasing more Gigabit ports than you require for your application, and at a time when the cost of the technology is at a premium. (As the technology matures, prices will eventually decrease.)

There is always the option of purchasing a Gigabit device that offers a slide-in-module option for adding either copper or fiber modules. These devices typically offer a single port for an uplink module that can be populated with a fiber Gbic or copper UTP card. The intent is, most often, to use this as a backbone connection, and is most commonly populated with a fiber Gbic slide-in-card. This is a good choice if all you require is a single Gigabit backbone connection. However, there are two issues that may require additional consideration. Although you have the flexibility of "modularity" with the slide-in-card, the remaining ports will likely be of a "fixed" configuration. Should you need to change the type of media on any of these fixed ports you, will need to employ an external device, such as a media converter, or purchase a new network device altogether. You need to also consider that not all Gigabit network devices offer a modular uplink port, and if they do, it is usually at a premium.

There is yet another option that offers the flexibility of being able to add any port configuration (copper or fiber) you require where and when you need it. This device can allow you to take advantage of the lower cost of purchasing a switch with copper Gigabit interfaces and add Gigabit fiber links only where you need them. The device is known as a "Media Converter," and can be used to change one media type (copper or fiber) to another media type (copper or fiber) to facilitate the transition between two disparate media types. There are media converters that will allow you to convert 1000BASE-T to 1000BASE-SX/LX or to convert 1000BASE-SX multimode to 1000BASE-LX single mode port-by-port as the need arises. Converters can be added to a Gigabit link without disturbing the communication over other links on the device. Media converters are also relatively inexpensive and can be managed via an SNMP GUI interface.

Long Haul Options - Extending the Reach of your LAN

An option that is currently unique to media converters is the concept of "Long Haul" for extending fiber connections up to 65 kilometers away. Longer distances can be achieved across a Gigabit fiber link by increasing the launch power and receive sensitivity of the fiber optic transceivers used. These long haul options are currently not available from major switch manufacturers. There are several applications for "Long Haul" Gigabit devices.

• MANs - Metropolitan Area Networks

• Large Campus LANs

There is a growing popularity of MANs (metropolitan area networks) which allow native LAN protocols to be transmitted between remote facilities over leased or privately owned single mode fiber. Entities that have remote facilities can effectively make a LAN backbone connection between buildings that are as far as 65 kilometers away from each other. In recent years, companies such as telcos, public utilities, etc., have been installing vast amounts of single mode fiber optic cable in their right-of-ways. Much of this fiber (as much as 90%) is currently "dark" (not currently being used). Companies with excess fiber are, in many cases, offering access to their fiber through a lease arrangement.

There are significant benefits to making a native Gigabit backbone connection between facilities compared to other options. Connecting LANs together using more conventional methods, such as T1 or leased lines, are expensive and require additional active hardware (routers, etc.) to facilitate the translation of transmission protocols. Also, most commonly used WAN protocols cannot transmit at speeds anywhere near Gigabit (i.e. T1 transmits at only 1.544 Mbps). Lastly, a leased or private fiber connection offers you security (you are the only one who has access to the fiber), and the ability to manage the connection remotely via your existing SNMP management software (converters as well as Gigabit switches are capable of management via SNMP). Transmitting native Gigabit is more efficient, easier to maintain, and less expensive than other options.

There may also be applications for long haul Gigabit devices in larger campus environments where single mode connections must be made over distances greater than 5 kilometers (theoretical maximum distance for Gigabit over standard single mode connection). There may also be instances in campus environments where there is excess attenuation resulting from loss at multiple connection points (i.e. patch panels). A larger number of termination points may be used in campuses as the single mode fiber moves from building to building. To overcome attenuation that falls outside the norm, a high powered single mode device can be employed.

Media Converters offer the option of long haul connections over single mode fiber that range from 5 kilometers (standard) to 15 kilometers (long haul) all the way up to 65 kilometers (long wavelength 1550nm long haul). Whether you need distance extension on an existing multimode fiber or 1000BASE-T Gigabit link, media converters can meet most requirements efficiently and economically.

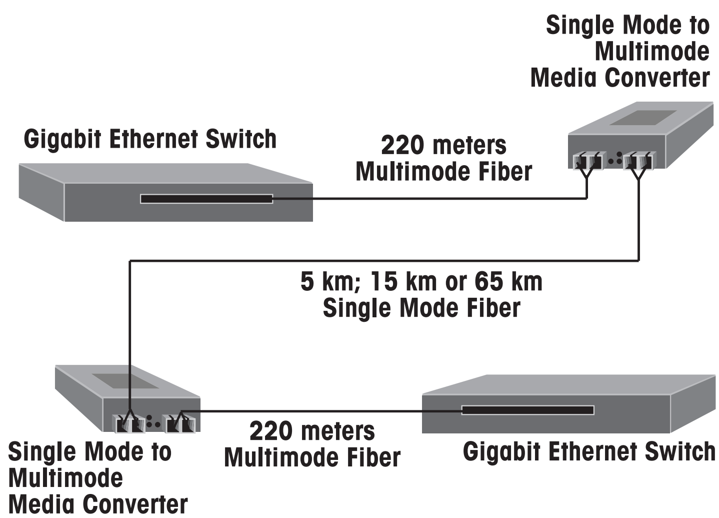
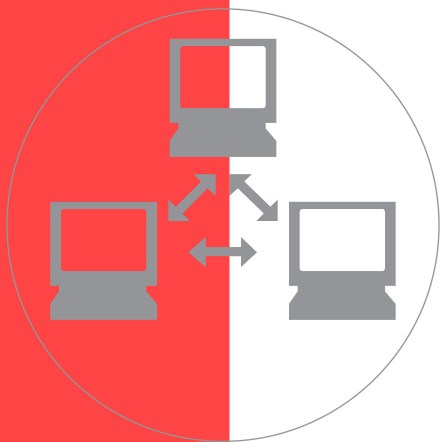


Figure 2: Media Converter Application

Note: Keep in mind that distances are estimates based on industry averages for attenuation. To calculate the actual distance you can transmit across a given fiber link you should always properly calculate the link budget.

Summary

The IEEE 802.3z and 802.3ab task forces have developed standards that have enabled network hardware manufacturers to produce products with transmission speeds of 1 Gigabit per second. Most recently, they have developed standards that allow Gigabit speed over UTP copper cabling. Although some issues do exist with regard to cost (cabling infrastructure) and throughput (half-duplex), 1000BASE-T is well on its way to becoming a viable standard. Fiber-based solutions for Gigabit, although relatively expensive, offer network managers the additional reach to connect virtually any two network devices together. In most cases, a need will exist for both the cost benefit of copper and the distance benefit of fiber in a Gigabit-enabled network. Various options exist to facilitate the co-existance of copper and fiber in a Gigabit network. Conversion technology offers an easy to implement, low-cost option for connecting disparate interfaces with long haul options not available from major switch manufacturers.



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