

FTTH Design with the Future in Mind

Get ready for 10 Gbps and beyond; all it takes is the right fiber

By John George ■ *OFS*

Football season is finally here. It has been a long wait since January, and this past season was loaded with awesome highlights. I for one would love to have seen highlights for my favorite player – instantly, in high definition, at any time during the long football drought.

Or how about that 2000 Nokia Sugar Bowl, when we were all dazzled by a quarterback now called the most exciting player in the NFL? I want to see it now, and in Super High Definition. I want to download the whole game in 2 minutes and fast forward at will. And I am willing to pay a few bucks for this, if it's instant and easy.

And while I am downloading this scratch to my football itch, my wife decides to download and watch her sister's vacation video on the upstairs Super HD monitor. Our daughter talks to her best friends by 3D-video conference. Each of our two sons watches a streaming educational video in super 3D. Sound like science fiction? Not for Fiber to the Home.

We are entering the era of custom, personalized video. Anytime, anywhere, instantly, and in high definition – just like we were promised during the Internet boom. But it never because there was no time to develop it, commercialize it, build the access pipes to connect us. FTTH networks can supply enough bandwidth to make the promise a reality – if we deploy FTTH designed with the future in mind.



The Need for Gigabit Speeds is Inevitable

Today a fast DSL or cable modem connection provides 4 Mbps downstream to the home and less than 1 Mbps upstream. Today's typical FTTH systems are capable of providing a worst case rate of about 20 Mbps downstream and 5 Mbps upstream. But will this be enough for applications on the horizon?

Fully digital networks, instant video on demand, HDTV, and streaming Internet video will eventually more than consume the bandwidth provided not only by DSL or cable, but even today's FTTH systems. Instant and personalized video streams are enabled by IP video technology. Improved video for-

mats now being developed, such as Ultra HDTV, high definition video telephony, and 3D "telepresence" will require hundreds or even thousands of megabits per second.

Optical fiber has the theoretical capacity to support these demands, but how can today's FTTH systems and architectures evolve to meet this challenge? Optical cabling systems should last at least 25 years and it is desirable to avoid replacing or upgrading this outside plant, due to high labor costs and environmental disruption.

Before investing in any new access infrastructure, it makes sense to understand bandwidth requirements over the coming decades, to maximize the

value of our new optical assets. We are charging toward 1 Gbps access speeds by 2020, to millions of homes in the US. While this seems unbelievable, current trends and application demands clearly show where we're headed. Figure 1 shows the current and projected trend in bandwidth growth.

\$16 billion in annual revenues generated by video store rentals and video sales according to the Video Software Dealers Association's 2005 annual report.

- **Video Gaming** – Two and three-dimensional remote video games that will create a Star Trek "Holodeck"-like experience. Why would customers spend 1

opportunity for the FTTH service provider.

- **Telemedicine** – High definition video and imaging from the individual to the physician can be a cost effective aid in medical diagnosis, monitoring, and treatment. The aging of the population and immense pressures to reduce health care costs may drive massive adoption of telemedicine. If only 3 percent of the \$1.5 trillion in US healthcare revenues is converted to telemedicine, an opportunity of \$45 billion awaits.

- **Virtual Meetings** – This will enable a larger percentage of workers to telecommute. With higher definition, the effectiveness of in-person meetings will be possible.

- **Video Phone** – Video communications will finally become dominant.

- **Video Mail** – Video mail clips of a child's birthday, a product presentation, detailed damage assessment for an insurance company, advertising, and so forth.

- **Video Security** – Monitoring the home and yard by video from the office.

- **Video Learning** – Two-way interactive video links between instructors and students with high definition to create an "in person" experience.

All of these applications look promising. But will bandwidth be available to support these services as they rapidly evolve, enabling increased revenues?

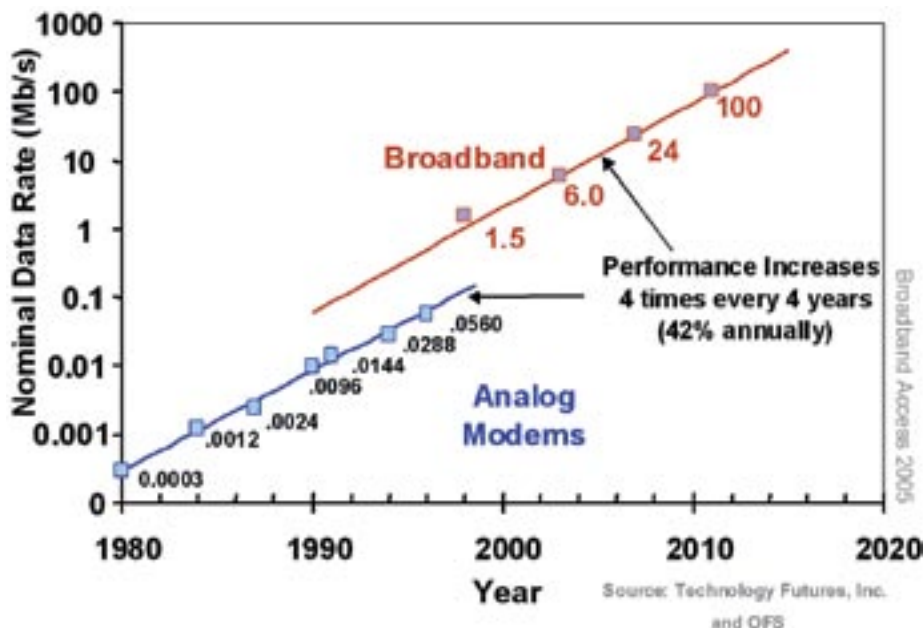


Figure 1 – Projected bandwidth demand per subscriber for home internet services.

While ever-increasing bandwidth is great, it requires investment. What applications will provide the return to justify this investment in high bandwidth infrastructure?

Just one Word: Video

Video is the foundation of several killer applications that will drive increasing bandwidth demand for many decades. Customers have demonstrated they will pay for video services already, but much of this potential gold mine is untapped. Video is quickly expanding into other uses, while increasing definition is driving greater bandwidth requirements. Video will immerse our daily lives in the coming years in many different ways.

- **Instant Video on Demand (IVOD)** – The entire contents of a video store, 10,000 or more titles, available at any time for instant viewing or download. This will eventually replace the current

hour buying this software at the store, when it could be downloaded in 1 minute with an optical broadband connection? That's another \$8 billion annual

Video Type	Format	Frames Per Second	Resolution (Mega Pixels)	Mb/s per Stream (unless noted)	
				MPEG-2	MPEG-4
Analog	NTSC	30	0.2	6MHz	6MHz
Standard Definition (SDTV)	480i	30	0.5	7	2
High Definition (HDTV)	1080i or 720p	30	2	20	8
Super HD (SHDTV)	2160i	30	8	60	32
Ultra HD (UHDTV)	4320i	60	32	480	256

Table 1 – Bandwidth required for current and future video formats (estimated).



Figure 2 – Volumetric display available today. Source: LightSpace Technologies.

HDTV is not the end game for video. Increasingly higher definition versions are planned as shown in Table 1.

Ultra High Definition Television (UHDTV) was demonstrated by NHK in Japan last year. The resolution of UHDTV is 16 times that of HDTV, and the frame rate is doubled to 60 per second.

In addition, 24 channels of audio were included. The resulting “sensory immersion” approaches “being there” according to witnesses of the demonstration. The bandwidth required was 24 Gbps uncompressed. With compression at MPEG-4 ratios, 256 Mbps might transport UHDTV, requiring 1 Gbps to

support 4 channels for a home subscriber by 2020.

From 2020 and beyond, three dimensional “volumetric” displays could become common for home and business communications. For example, one company offers such a product today, shown in Figure 2, a 3D LCD-based display that is approximately 16” x 12” x 4” deep, with 50” sizes possible according to an April 2005 IEEE Spectrum article. While scientific, engineering, and medical applications will be the first to adopt 3D technology, it will surely be applied to business and home applications. As we see in Table 2, 3D video versions of volumetric displays could push bandwidth requirements per home to gigabits or even tens of gigabits per second.

Video and especially personalized video will require bandwidths dwarfing what access connections provide today. It is estimated that by 2010 one will require a continuous 100 Mbps connection to download or e-mail a 120-minute HDTV video in 10 minutes. By 2020, an Ultra HD version of the same video would require 1 Gbps for a 30-minute transfer. For potential 3D video applications in 2030, a 10 Gbps connection would require 30 minutes to transfer a 120-minute video. Even in the case of a 5-minute birthday video, the 32 minutes

required to e-mail a Super 3D version at 100 Mbps is excessive, while a 10 Gbps connection would reduce the time to about 20 seconds.

The total household bandwidth requirements should drive network design and planning to maximize return on investment. It’s obvious from Table 3 below that 1 Gbps and even 10 Gbps to the home will likely be needed within the lifetime of an FTTH cabling system. This seems at first glance to be ridiculous. But only 10 years ago 10 percent of households had a connection speed of only 52 kilobits per second (0.052 Mbps) that was considered “fast” and in the decade since we have over 30 percent of U.S. households with roughly 1 Mbps connection speeds, an increase of 2000 percent. Given the adoption of personalized video with ever increasing definition and 3D, data rate requirements will continue grow at 1000 to 2000 percent per decade.

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3D Video Type	3D resolution (L x W x Depth)			Frames per sec	Resolution (Mega Voxels)	Mb/s at MPEG-4 compression
Std Definition	1024	768	20	60	16	63
High Definition 3D	2160	1080	20	60	47	187
Super Definition 3D	3720	2160	20	60	161	643
Ultra Definition 3D	7440	4320	20	60	643	2,571

Table 2 –Data rate required for current (standard definition) and projected future 3D video formats (estimated, assuming volumetric display).

2010 - Access Speed Req'd				2020 - Access Speed Req'd				2030 - Access Speed Req'd					
High Definition	Qty	Mb/s	Total Mb/s	Ultra HD 2D	Qty	Mb/s	Total Mb/s	Ultra HD 3D	Qty	Mb/s	Total Mb/s		
Video Streams	3	8	24	Video Streams	3	256	768	Video Streams	3	2,571	7,714		
Internet/E-mail	1	50	50	Internet/E-mail	1	1,562	1,562	Internet/E-mail	1	15,942	15,942		
Gaming	1	16	16	Gaming	1	512	512	Gaming	1	5,143	5,143		
Voice	3	0.3	1	Voice	3	0.3	1	Voice	3	0.3	1		
			91				2,843				28,799		
Std. Definition				Std 3D				Super 3D					
Video Streams	3	2	6	Video Streams	3	63	189	Video Streams	3	643	1,928		
Internet/E-mail	1	12	12	Internet/E-mail	1	390	390	Internet/E-mail	1	3,985	3,985		
Gaming	1	4	4	Gaming	1	126	126	Gaming	1	1,286	1,286		
Voice	3	0.3	1	Voice	3	0.3	1	Voice	3	0.3	1		
			23				706				7,200		
				Super HD 2D				HD 3D					
				Video Streams	3	32	96	Video Streams	3	187	560		
				Internet/E-mail	1	198	198	Internet/E-mail	1	1,157	1,157		
				Gaming	1	64	64	Gaming	1	373	373		
				Voice	3	0.3	1	Voice	3	0.3	1		
							359				2,091		
Assumptions				Assumptions				Assumptions					
Data Rate		Std	HD	Data Rate		Super	Std 3D	Ultra	Data Rate		High 3D	Super 3D	Ultra 3D
(Mb/s w/MPEG-4)		2	8	(Mb/s w/MPEG-4)		32	63	256	(Mb/s w/MPEG-4)		187	643	2,571
File transfer time (sec)		60		File transfer (sec)		60			File transfer (sec)		60		

Table 3 – Access speed per household (projected).

Designing FTTH For Future Needs

We can transition FTTH from megabits to gigabits per home, but first we must understand how today's FTTH networks are configured. The two common types of FTTH networks being built today are the Passive Optical Network (PON) and the Switched Ethernet Network (SEN) shown in Figure 3. Both typically use a small number of feeder fibers from Central Office (CO) that serve a larger number of homes, so each feeder fiber is shared among multiple homes.

The PON has a passive optical splitter between the feeder fiber and subscriber, and the SEN has an active Ethernet Switch that directs

data between relatively few feeder links and many subscribers. As an option for PONs, video as used in cable TV networks can be broadcast to all users at 1550 nm. The Optical Line Terminal (OLT) can send and receive IP video, data, and voice to and from the homes. The Optical Network Terminal (ONT) at each home can send and receive the same services to the OLT. The OLT is connected to the global Internet, voice, and video network.

If we design an FTTH network with the future in mind, we can assure that bandwidth upgrades won't require digging up streets and flower beds to replace cables for many decades. We will

now look at FTTH upgrade options and how far each of them can take us into the future.

CWDM PONs for the Next Level

Conventional PONs use just two wavelengths of light – 1490 nm to transmit downstream to homes, and 1310 nm from the homes to the CO. Full Spectrum Coarse Wavelength Division Multiplexing (CWDM) can increase the data rate to homes by 8 to 32 times with no changes to the optical cabling. It uses up to 18 wavelengths, or colors of light, that can each carry up to 10 Gbps on a single fiber at the same time, for a total capacity of up to 180 Gbps. While dense WDM (DWDM) could produce

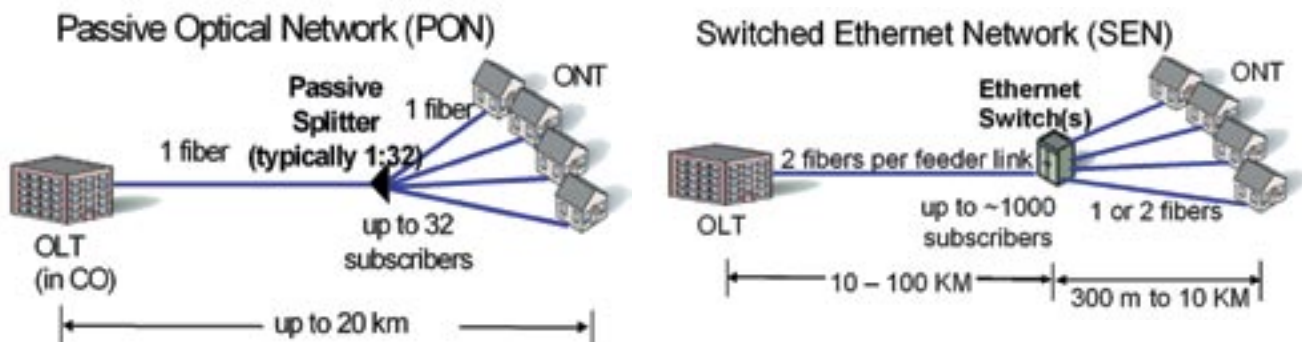


Figure 3 – PON and SEN, per feeder link

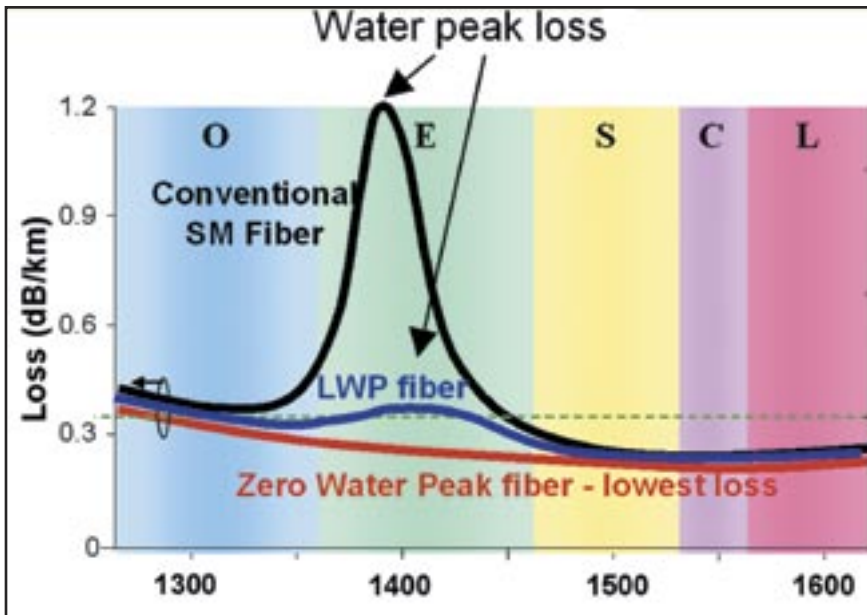


Figure 4 – Signal loss vs. wavelength (nm) of full spectrum ZWP fiber vs. alternatives.

the same data rate multiplying effect, DWDM costs 50 percent more than CWDM because of the precise optics required.

Employing Full Spectrum CWDM in FTTH networks requires the use of a Full Spectrum single mode fiber in the optical cabling system. Full Spectrum Zero Water Peak (ZWP) fiber, shown in Figure 4, enables the use of 18

CWDM wavelengths, versus only 12 for conventional single mode fiber (CSMF). The practical number of wavelengths in CWDM PON applications is 16 for ZWP fiber, double the 8 possible for CSMF. Thus ZWP fibers are best suited for both current and future PON applications.

Full Spectrum cabling systems installed for today’s PONs can support the

10 Gbps per subscriber rates that may be required over the 25-year life of the cabling system. This ultimate optical broadband can be accomplished with no changes in the optical cabling, if 1 feeder fiber is initially installed for every 8 subscribers, which in the case of the typical 1:32 split ratio PON would require 4 fibers for every 32 homes passed. Upgrade options for PONs are shown in Table 4, and the Full Spectrum CWDM PON in Figure 5.

Switched Ethernet Network Upgrades

Switched Ethernet Networks (SENs), like PONs, also have an upgrade path to 10 Gbps per subscriber with no cabling system changes if Full Spectrum ZWP fiber is used for the initial cabling system. Such fibers can support up to 180 Gbps per pair in the feeder using Full Spectrum CWDM, 50 percent more than conventional fibers. Most current SENs enable tens of Mbps per home worst case. By coincidence, as in the PON, a ratio of 1 feeder fiber per 8 homes passed enables the upgrade to 10 Gbps per home using Full spectrum CWDM, as shown in Table 5.

Video Trends and Considerations

Broadcast analog Video on PONs is still being deployed but is expected to be replaced by digital video over time. Multiple Service Operators (MSOs) that provide analog video using Hybrid Fiber/Coax (HFC) networks are rapidly transitioning from analog to digital video in order to increase HFC network bandwidth.

Driven by bandwidth demands and HDTV, all of the major MSOs are transitioning to full digital video distribution and analog video will soon be obsolete. The IP video planned by SBC, Verizon, and BellSouth is fully digital. Digital video is the only kind possible over SENs. For legacy analog video on PONs, modern RF transmitters and improved RF receivers have made stimulated Brillouin scattering (SBS) power limits irrelevant for the most cost effective architectures.

	Full Spectrum CWDM							
	Conventional PON		Conventional PON with Lower split ratio		Full Spectrum CWDM/PON Hybrid		Full Spectrum CWDM PON	
Bandwidth Split ratio	32		8		4		1	
Homes passed per feeder fiber	32		8		32		8	
Mb/s per Home	Down	Up	Down	Up	Down	Up	Down	Up
BPON	17	4	70	17	140	35	622	155
EPON	28	28	112	112	224	224	1,000	1,000
GPON (Emerging)	70	35	280	140	560	280	2,422	1,244
10G PON (future?)	281	281	1,125	1,125	2,250	2,250	10,000	10,000

Mbps per home is worst case. 90% throughput efficiency assumed.

Table 4 – PON data rates per home (Mbps).

Mixing Water and Glass

Since Corning invented optical fiber 35 years ago, fiber vendors have battled light scattering and absorption in the fiber itself, to cut signal attenuation and thus to improve bandwidth. Designers try to minimize bending radius as well for the same reason.

The relationship between bandwidth, scattering, and absorption is not immediately obvious to those outside the technical end of the industry. Think of it this way: If some of the light pulse signal is delayed, or scattering lengthens the path the light pulses must follow, each pulse is essentially broadened. Thus, fewer pulses can flow through the fiber in a given time, cutting the bandwidth. Light is scattered and slowed by impurities in the glass fiber core and cladding. Unwanted water ions cause a particularly annoying signal loss around 1383 nm. So low-water fiber has become the norm, and the definition of “low” has been dropping toward zero.

All physical systems of any useful size have a region of optimal operation, and fiber is no exception. The wavelength at which dispersion is closest to zero is called the zero-dispersion wavelength. This is the wavelength at which fiber has its maximum information-carrying capacity. For standard fibers ZDW for glass is usually around 1310 nm, and for silica-based glasses, around 1500 nm. Water is not an issue in that wavelength range; silica-based fiber products are used for longer distance cable runs.

– Steven S. Ross

Full Spectrum CWDM PON

- up to 10 Gb/s up/down dedicated to each subscriber
- Feeder Cable needs at least 1 fiber per 8 homes passed

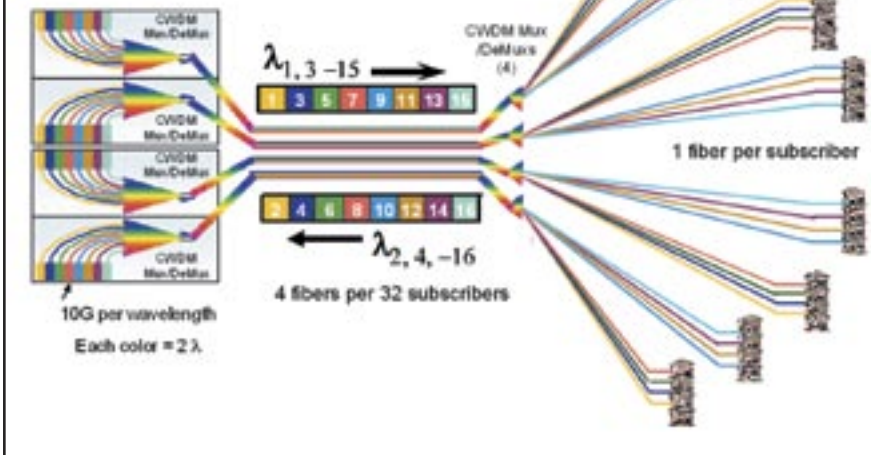


Figure 5. Full Spectrum CWDM passive optical network.

Full Spectrum CWDM

Rate per Feeder fiber pair	1G	10G	40G (16 x 2.5G FS - CWDM)	160G (16 x 10 G FS - CWDM)
Homes passed per Feeder Fiber	64	32	16	8
Mb/s per Home	8	156	1,250	10,000

Table 5 – SEN data rates per home (Mb/s) for various configurations.

Lowering Loss Increases the Bottom Line

Optical loss is the enemy of FTTH cabling systems. Using lower loss connectors, splices, splitters, and optical cable can reduce loss by 50 percent, and double the reach of an FTTH network. Doubling the reach can increase the area served by 4 times, and reduce costs by reducing the number of COs required to support customers. In addition, analog video over PONs requires expensive high power amplifiers, though the power and cost can be reduced by using a low loss cabling system.

In Conclusion

The bandwidth load on access networks continues to grow at 1,000 percent to 2,000 percent per decade driven by both competition and applications.

Video applications with increasing definition, 3D, and customized content will provide the ROI justifying super high data rates per home.

To keep pace, FTTH networks designed with the future in mind can evolve over the 25 to 40 year life of the optical cabling system. These simple optical cabling system design rules for FTTH networks installed today can enable cost effective migration to higher data rates for both Passive Optical Networks and Switched Ethernet Networks. **BBP**

About the Author

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