WHITE PAPER

Drivers for Deep Fiber Access Solutions

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A deep fiber access solution is the best way to deploy the triple play of video, data and voice.

Abstract

This paper outlines the various drivers and factors behind the push for higher bandwidth access and offers general guidance in choosing the right FTTx solution. End-user demand for higher bandwidth services, an easing regulatory environment and increased competition are driving traditional telephone companies to deploy deep fiber access solutions. Delivery of services like High Definition Television (HDTV), Video on Demand (VoD) and Internet Protocol Television (IPTV) are crucial to optimizing revenue and also drive the specific access network implementation. These services can require 50 Mb/s and greater bandwidth to each home. This necessitates an access solution that pushes fiber deep into the network to within 500 feet via a Fiber to the Curb (FTTC) implementation or a solution that brings fiber all the way to the home with a Fiber to the Premises (FTTP) solution.

Section 1: Introduction

Many wireline telecom service providers are evaluating solutions for higher bandwidth service delivery to homes and small businesses. This white paper focuses on fiber-based — Fiber to the Node (FTTN), Fiber to the Curb (FTTC) and Fiber to the Premise (FTTP) solutions for service providers. Which fiber solution is the right one depends on many factors including service requirements, technological capabilities, regulatory requirements, existing installed infrastructure, capital and operational costs and return on investment goals.

Section 2

Market and Service Drivers for Deep Fiber Access Solutions

The "last-mile" has long been the final challenge for end-user broadband services, both for business enterprises and consumers. In recent years, network service providers have moved aggressively toward breaking this bottleneck through increased deep-fiber access penetration coupled with more efficient bandwidth usage. As is often the case with such a strong industry shift, the drivers for change are a combination of shifting demographics, technology innovation, cost improvements and new business models. Such is the case with fiber-based broadband services.

2.1 End-User Service Demands and Other Economic Forces

Last-mile fiber deployments are now beginning in earnest because of two factors: end-user services that push the limits of copper twisted pair and the macroeconomic forces relating to such things as economies of scale, technology standardization and competition. From a services standpoint, demographic shifts shape today's residential broadband needs. The rise of the "echo boomers," the children of the baby boomers, signals the emergence of a large pool of tech-savvy consumers with an ever-increasing appetite for online entertainment, communication, e-commerce and telecommuting. This rise not only leads to demand for new services, but to services such as Voice over Internet Protocol (VoIP) and video distribution that are increasingly bandwidth-hungry and are intolerant of network congestion issues. The total economic value of consumer

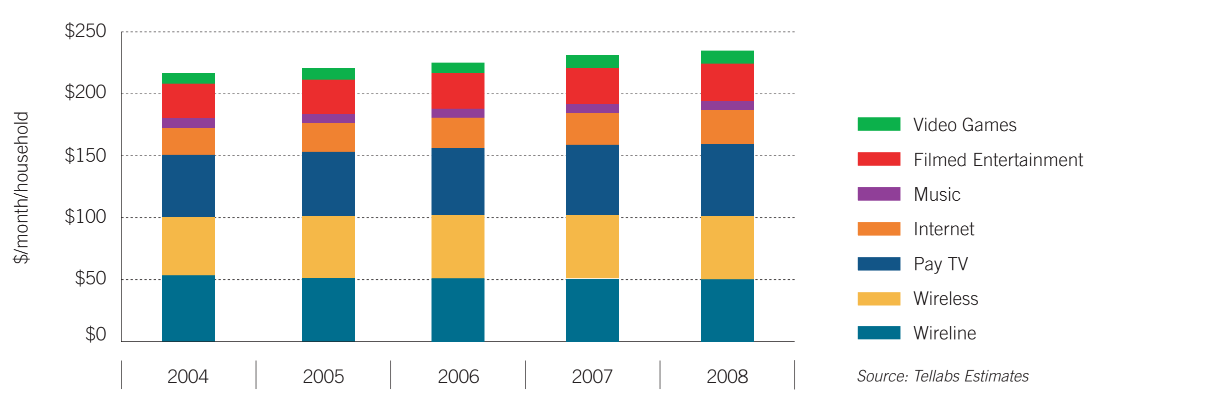

Figure 1. Consumer Entertainment Spending Per Household

spending in communications is estimated to reach $230 per household per month by 2008, as illustrated in Figure 1. This spending includes products like compact disc music, movie attendance and video games. These products may not have been traditionally thought of as addressable from a wireline service provider perspective. However, it now is possible with improvements in technology and the development of new business models to potentially deliver these as services over a broadband access network directly to the echo-boomer consumer.

2.2 Service Provider Competition is Driving Video and Services Bundling

Historically, there has been a stratification of the service providers targeting specific services; primarily the cable company (Multiple Service Operator) deploying video services and the wireline (telephone or Telco) company deploying voice services. With today's broader service demands, relaxed regulatory requirements and increasingly difficult profitability environment, this separation has collapsed and real competition for the complete services set has shifted into high gear. Both the cable companies and the wireline service providers are focused on increasing their Average Revenue Per User (ARPU) and reducing churn by offering a more complete service bundle of video, voice and high-speed data services. Bundling is both a defensive and offensive strategy to maintain existing customers and add new revenue.

Video services are a key to increasing ARPU. Whether broadcast video, Standard Definition Television (SDTV), High Definition Television (HDTV), Video on Demand (VoD) or Internet Protocol Television (IPTV), video services have become the battle ground for the traditional wireline service provider to compete for additional revenue. Echo boomers may also lead the transition to the downloading of "video" content that could ultimately replace the traditional packaged DVD or VHS media. Building on the transition that started with the addition of data services to their existing voice service offering, wireline service providers are upgrading their networks to provide the deep fiber last-mile access infrastructures that are required to support the high-bandwidth requirements of video services today and tomorrow. When considering solutions for the last-mile delivery of video services, the first step is to understand the bandwidth requirements.

2.3 Technology Considerations in Video Bandwidth Delivery

To determine the bandwidth requirements for video deployment, a few key service parameters must be selected. The first is whether the service provider will choose a video broadcast service model, a Video on Demand (VoD) model or a combination. With traditional broadcast video, all available channels are transmitted to each user at once, with the end user selecting the specific channel(s) that he/she wants to watch. This requires very high bandwidth and has been traditionally implemented in terrestrial/satellite broadcast or Hybrid Fiber Coax (HFC) networks by broadcast and cable television service providers. There are two methods that can be used by wireline service providers to deliver the equivalent broadcast video service over wired or fiber last-mile delivery systems: Radio Frequency (RF) video overlay broadcast and switched video carried in-band as an IP-over- Ethernet data stream or streams, also called IPTV.

2.3.1 RF Overlay Broadcast Video

The RF video overlay solution is considered only applicable in an FTTC or FTTP deployment. In both cases, the broadcast video is carried as a separate wavelength outside the normal downstream data path. This separation enables the complete group of broadcast video channels to be encoded as a high bandwidth 500 MHz or higher composite RF signal. The signal consists of hundreds of frequency division multiplexed video channels from 50 MHz to 500 MHz or higher that are transmitted over this separate wavelength to each user. With FTTC, the RF wavelength is sent over fiber to the optical network unit at the curb, and then via coax to the home. In FTTP implementations, the RF overlay wavelength stays as an optical wavelength all the way to the home and then is converted to coax. In both cases, the end user receives all of the channels. This is basically equivalent to the method that MSOs have traditionally used to deliver broadcast cable TV and offers the fastest time to market, and the least risk path for wireline service providers to offer video services.

2.3.2 IPTV Broadcast Video

An in-band IPTV service-delivery model transmits only the specific channels that are required at any one time, resulting in tremendous bandwidth savings over sending the complete set of channels at once. In this switched digital video model, when an end user switches channels, the change is made upstream in the network versus at the home endpoint. While only sending the required channels, fully implemented, IPTV can simulate the equivalent broadcast TV service. The number of channels that are required to be transmitted to the end user at once is typically from four to eight channels. This model is based on two to four television set-top boxes (and televisions) with the ability to watch one channel while recording another channel or watching multiple channels in a picture-in-picture application. In-band IPTV, television encoded in IP and transported over Ethernet, is the method used to deliver each video stream to the set-top boxes. While this method does save access bandwidth over a traditional broadcast video deployment model, the user experience relative to operations such as channel changes must be equivalent from a look and feel perspective. This can be problematic and is a challenge for IPTV implementations that over time will be overcome. All FTTx delivery solutions ultimately will deploy some form of IPTV service for video delivery.

2.3.3 Video on Demand

Video on Demand (VoD) enables the end user to pick what he or she want to watch when they want to watch it. Contrast this with a broadcast television service where the end user can only watch the programs that are broadcast at the times of broadcast. VoD uses content servers and IPTV streams to transport the video to the end user. The number of simultaneous VoD streams per house is usually modeled to be between two and four. If broadcast television is implemented via IPTV, the total number of IPTV streams for both broadcast and VoD service should still fall between four to eight simultaneous streams. With the RF video overlay broadcast implementation, two to four IPTV streams will be required to support VoD. To determine the actual bandwidth required in the last-mile for delivery of broadcast television and VoD, we first have to discuss standard-definition video vs. high-definition video and alternative compression technologies.

2.3.4 Standard Definition Television, High Definition Television and Video Compression Alternatives

A key factor in determining the required video bandwidth to each home is based on whether SDTV or HDTV is required. In the United States, the future of television is initially digital and, ultimately, high definition. The FCC has a current target date of December 31, 2006, for the completion of the transition to digital television and the return of the current terrestrial analog broadcast spectrum. This date is based on the condition that 85% of the market served has the ability to receive digital television transmission. While this deadline has continued to move out in time, it will eventually be met, driven by the Federal Communications Commission (FCC) and the economic value of the analog television spectrum. Anticipating the final changeover to all digital television broadcast, television manufacturers have been changing their product portfolios. Today, a majority of new televisions are digital and a growing proportion of these digital TVs are high-definition capable. Figure 2 illustrates the strong forecasted growth rate of HDTV sales in the United States. Over time, HDTV will become the norm and a key part of the service bundle. Today, service providers need to plan on offering HDTV VoD services as they choose their FTTx deployment model.

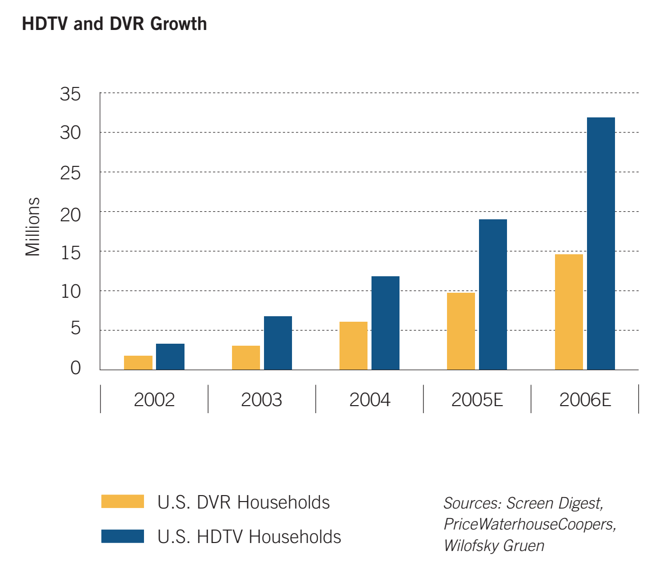

Figure 2. HDTV and DVR Growth

Improved picture quality is one of the key drivers for the adoption of HDTV. In the United States, SDTV resolution is 480 active lines by 704 pixels per line. These lines are actually displayed in two fields per video frame, with the first 240-line field displayed first and the second 240-line field interlaced with the first field to form the whole picture frame. While the frame resolution is theoretically 480 vertical lines, if the content changes too rapidly between the scanning of the fields, the actual resolution could be as low as half of that, or 240 lines. With HDTV, higher resolution picture options, including 720p (progressive) active lines by 1,280 pixels, 1,080i (interlaced) x 1,920 pixels, and 1,080p x 1,920 pixels are added, dramatically improving picture quality. In addition, progressive scan options that display all lines progressively in the frame, all in one field, are supported to eliminate the artifacts introduced when interlacing two separate line fields to form one video frame in SDTV. This option enhances video content that is rapidly changing across the whole video frame — like sporting events. Both the higher resolution and progressive scan options increase the raw bandwidth required for each HDTV data stream versus a lower resolution SDTV data stream; HDTV raw data rates can range over 500 Mb/s for each stream before compression.

Compression technology determines the actual bandwidth required to transmit an individual television channel. Even though compression reduces the overall amount of bandwidth required per channel, HDTV still requires on the order of five times the bandwidth of SDTV. The main compression algorithm used for video is based on a standard from the Moving Picture Experts Group (MPEG), an ISO/IEC working group established in 1988 to develop digital video and audio standards. MPEG compression uses a discrete cosine transform function that discards frequency components that are perceived not to affect picture quality. MPEG-2 is the current compression standard on which SDTV, set-top boxes and Digital Video Discs (DVD) are based. MPEG-2 will also scale to support HDTV resolution and bit rates. MPEG-4 was developed as a standard for multimedia and Web compression and performs object-based compression on individual objects in an image, resulting in an efficient and scalable compression algorithm. Given its greater compression capabilities and HDTV's larger bandwidth requirements, MPEG-4 is gaining momentum and eventually will replace MPEG-2. A recent enhancement to MPEG-4 is the adoption of the H.264 codec into the MPEG-4 standard (MPEG-4 AVC) to yield even better picture quality while significantly lowering the bandwidth required. Windows Media 9 (WM9) is an additional proprietary compression algorithm developed by Microsoft Corporation. It also can deliver compression capabilities similar to MPEG-4. While there is debate over whether MPEG-4 or WM9 is the better algorithm, they are both generally considered to have the same quality results given a particular bandwidth setting. In the future, there will continue to be refinements to compression algorithms and additional new standards efforts such as MPEG-7 and MPEG-21.

The table, in Figure 3, lists the bandwidth required to carry a single SDTV or HDTV data stream or channel for the various compression algorithms. The total bandwidth required after compression is shown as a range to indicate that the actual bandwidth can differ based on the variation of user settable parameters within the compression algorithm. These parameters can be set to achieve a certain perceived quality level and can vary based on the type of content. Sporting events usually cannot be compressed to the same extent as more static video content. To carry one HDTV channel using MPEG-2 requires 15 Mb/s and somewhere between 7.5 Mb/s and 13 Mb/s for MPEG-4 and WM9 compression algorithms. Generally, we can assume that 10 Mb/s is required to transport a single MPEG-4/WM9 HDTV stream.

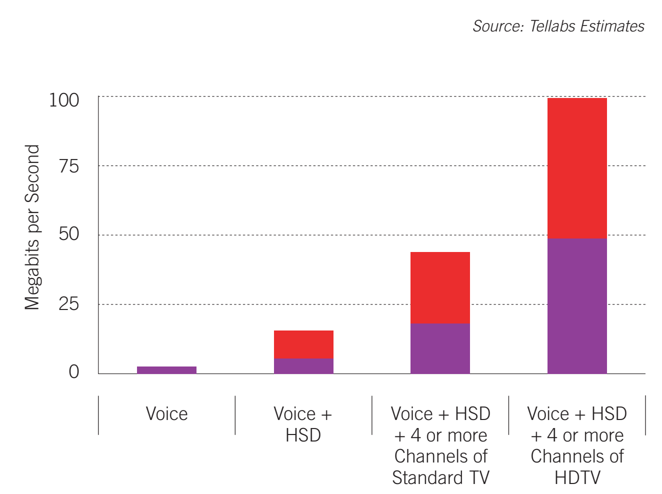

Figure 4. Bandwidth Access Needs

2.4 Bandwidth Requirements Summary

The overall bandwidth requirement for multiple HDTV VoD streams ranges from 40 Mb/s for support of four HDTV channels to 80 Mb/s for support of up to eight HDTV channels. If an additional 20 Mb/s for data and VoIP is allocated, then the total bandwidth required for triple-play services is between 60 Mb/s and 100 Mb/s. Figure 4 illustrates the additional bandwidth required when adding video services. Now that the target service bandwidth is understood, we can examine the technology to deliver it — DSL and Passive Optical Networking (PON) technology.

Section 3

Wireline Service Provider Bandwidth Delivery Technology

This section will review the current capabilities of Digital Subscriber Loop (DSL), fiber in the loop and PON technologies for delivering high-bandwidth services. While there are other technologies available, these three are the ones most likely to be deployed by wireline service providers for residential broadband access.

	Broadcast	MPEG-2	MPEG-4/H.264	WM9
Standard Definition Television Stream	6 Mb/s	3.5 Mb/s	2–3.2 Mb/s	2–3.2 Mb/s
High Definition Television Stream	19.2 Mb/s	15 Mb/s	7.5–13 Mb/s	7.5–13 Mb/s

Figure 3. Bandwidth after Compression Notes: WM9 is a Microsoft standard. H.267 is a joint MPEG / ITU standard. *Source: Tellabs Estimates*

3.1 Bandwidth Delivery — DSL Technology

Asymmetrical Digital Subscriber Loop (ADSL) technology has been deployed for years to support the delivery of high-bandwidth data, with rates approaching 8 Mb/s over standard twisted pair copper phone lines. In July 2002, the ITU released the G.992.3 standard for full-rate ADSL2 and the G.992.4 standard, also known as G.lite.bis or G.lite, to further increase the bandwidth and lengthen the usable loop length. In 2003, the ITU released G.992.5 or ADSL2+, which doubles the bandwidth used for down-stream transmission, equating to rates of up to 20 Mb/s on phone lines as long as 5,000 ft. This technology, based on Discrete Multi-Tone (DMT) encoding and Asynchronous Transfer Mode (ATM) technology, continues to evolve to support even greater data rates over longer distances. Both ends of the copper connection, including the one in the home, require a DSL modem that supports the equivalent DSL technology. More recently, ITU-T G.933, known as Very High-Bit-Rate Digital Subscriber Line 2 (VDSL2), increases data rates ranging from 50 Mb/s to 100 Mb/s and is optimized for shorter copper loop lengths (< 2000 feet).

DSL has been deployed for service delivery in three primary architectures. In the first, "home-run," a DSL Access Multiplexer (DSLAM) is placed in a service provider local office and directly drives the copper loop all the way to the DSL modem in the home. The next architecture is FTTN, also known as remote DSLAM. In this case fiber is deployed to a remote node that is 4,000 to 5,000 feet from the home. The signal is then transported via DSL over copper to a DSL modem in the home. The final DSL-based deployment architecture is FTTC, where fiber is deployed to a remote node that is within 500 feet of the home. DSL is used for transport over the last short copper loop length into the home.

Figure 5 illustrates the various DSL bandwidth capacities over various copper loop lengths. When considering today's higher bandwidth requirements of 60 Mb/s to 100 Mb/s for triple-play services deployment, only a short distance VDSL2 line has the necessary capacity. This is the primary reason why deep fiber access solutions that push fiber to within 500 feet or less of the home are recommended. They maintain the shortest possible copper loop distance and, thereby, maximize DSL bandwidth delivery capacity. An additional DSL technology option is to "bond" two DSL lines together to meet the higher end of the range of bandwidth requirements.

When reviewing the number of high bandwidth addressable shorter copper loop lengths at the major North American wireline service providers as illustrated in Figure 6, only about one quarter are capable of supporting the very high DSL bandwidth capacities required for triple-play services. These shorter copper loop lengths are supported by fiber-fed remote terminals in DLC applications or deep fiber fed optical network units (ONUs) within 500 feet of the home in FTTC deployments. In addition to the length of the copper cable, the condition of the copper plant is very important. Older copper cable or poor-quality copper deployments may not support high-bandwidth DSL and may require replacement. If copper has to be replaced, it is more cost effective to lay fiber, given the longer life span of fiber, and the corresponding lower ongoing maintenance costs.

3.2 Bandwidth Delivery — Optical Standards

In addition to DSL, standardization is playing its part in last-mile fiber deployment. Standards such as Fiber in the Loop (FITL) and PON are now mature enough for large service providers to have confidence in continued interoperability and scale. This paper will not address additional optical

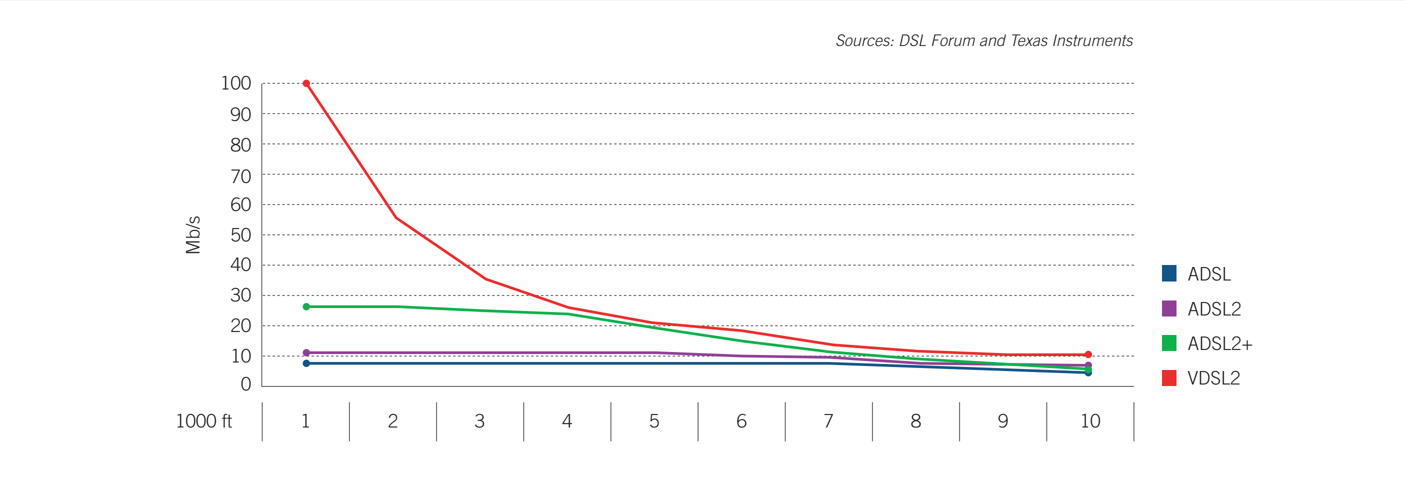

Figure 5. Bandwidth versus Distance

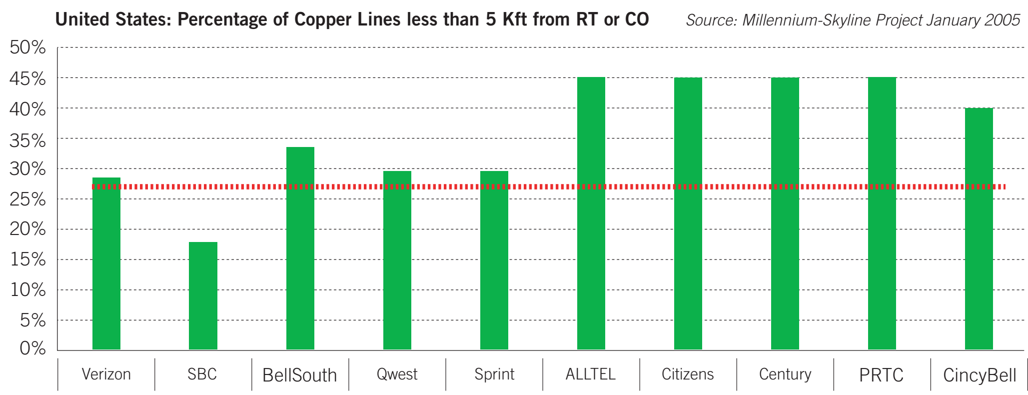

Figure 6. Copper Loop Lines Less Than Five Thousand Feet from an RT or CO

standards such as HFC or active optical Ethernet, but will focus on the standards that are likely to be deployed by wireline service providers for residential access.

Telcordia GR-909-CORE is the standard FITL access system to support the delivery of video, voice and data. This standard utilizes a combination of fiber and DSL to deliver triple-play services. With this deep-fiber architecture, an optical signal is sent from a Host Digital Terminal (HDT) to an active remote Optical Network Unit (ONU) that is about 500 feet from the home. DSL delivers services from the ONU to the home. As discussed earlier, FTTC can also support RF overlay broadcast video delivery over a separate wavelength for video. Based on this standard, millions of lines of FTTC have been deployed in the United States. Most of these systems deploy voice and data today, but can be upgraded to support video services by increasing the capacity of the active optical link between the HDT and ONU, and upgrading the DSL technology that drives the last 500 feet of copper to the home. With VDSL2, 50 Mb/s bandwidth rates and above can be achieved with this very short copper loop length.

The other key area of last-mile optical standardization is PON technology. The three key PON standards are Broadband PON (BPON), Gigabit PON (GPON) and Ethernet PON (EPON). In all three solutions, a single optical signal is split and fanned out to multiple endpoints or homes. This type of deep fiber access solution is an example of the FTTH or FTTP architecture since the fiber terminates at the home. The key attribute of PON solutions is that once the signal leaves the Optical Line Terminal (OLT), no active electronics are required until the termination of the optical signal on the ONT at the home. Other common attributes of the various PON alternatives are that they all broadcast downstream from the OLT to the home and use some form of Time Division Multiple Access (TDMA) for upstream or transmission from the home to the OLT. In the United States, an industry consortium of service providers, the Full Service Access Network (FSAN) Group makes technical access network recommendations with the goal of multivendor PON equipment interoperability.

Table 7, on page seven, summarizes the specific differences between the three primary PON standards. Some key differences include:

- BPON (ITU-T G.983) uses an ATM media access control (MAC) protocol for data transmission and currently supports a maximum downstream bandwidth of 1.2 Gbps.
- GPON (ITU-T G.984) includes both an ATM MAC and adds the GPON Encapsulation Method (GEM), which is a variable-length ATM-like protocol that has the additional flexibility to transport multiple protocols including native Ethernet and MPLS. GPON increases upstream and downstream bandwidth options and improves bandwidth efficiency with implementation of the GEM MAC.
- EPON (IEEE 802.3ah) is based on the Ethernet protocol.

PON technology is utilized in FTTP and FTTH architectures to deliver video, voice and data services to the home. Both FTTH PON-based solutions and FTTN or FTTC fiber- and DSL-based architectures can deliver in-band IPTV video streams (or channels), but PON-based FTTH solutions (along with active FTTC) have the additional advantage of support for RF video overlay. As discussed earlier, RF video overlay uses an additional wavelength to carry a very wide bandwidth

	BPON	GPON	EPON
Downstream Bandwidth	622 Mbps / 1.2 Gbps	2.4 Gbps*	1.2 Gbps
Upstream Bandwidth	155 Mbps / 622 Mbps	1.2 Gbps*	1.2 Gbps
Max. ONTs	32	128	256
MAC Layer Protocol Flexibility	ATM Only	Flexible GPON Encapsulation Method (GEM) & ATM	802.3 Ethernet Only
Protocol Efficiency	Medium	High (GEM)	Low
Native TDM Support	Yes	Yes	No
Multicast Support	Added in May 2005 FSAN Amendment	Native Support	Native Support
Standards Control	FSAN / Operators (ITU-T G.983)	FSAN / Operators (ITU-T G.984)	IEEE

Figure 7. PON Technology Comparison

* FSAN mandated support; additional bandwidth options are also available.

video signal. Figure 8 illustrates a FTTH PON deployment with an OLT in the serving office and an ONT at the home. Two separate downstream wavelengths are used — 1,490 nm for data and voice and 1,550 nm for video overlay services.

In the downstream wavelength, the bandwidth available for video, data and voice services can range from 30 Mb/s to over 100 Mb/s depending on the specific PON downstream rate and split ratios. Note that it also is possible to use both the overlay video wavelength and the downstream data wavelength for video services. Some service providers plan to use the overlay wavelength for traditional "broadcast" like video services and the in-band data wavelength for premium VoD IPTV services. Figure 9 illustrates more specifics on the use of the three wavelengths in a PON-based FTTH solution.

In the United States, BPON has been the initial FTTP deployment choice with a transition to GPON expected to occur over the long term. Internationally, EPON has been deployed, but GPON continues to gain momentum due to its higher bandwidth support, greater efficiency and protocol support flexibility.

Beyond optical standardization and technical maturity, regulatory policy is an additional major factor in broadband access and video services deployment. The next section provides an overview of FTTx unbundling rules and an overview of the current video franchise agreement debate in the United States.

Section 4

FTTx and Broadband Public Policy

The FCC is trying to build a positive business environment for broadband services. It has recognized that service providers are less likely to invest in broadband infrastructure when they are forced to share that investment with competitors and when there is regulatory uncertainty. The FCC is removing this uncertainty by making rulings that will move the telecom industry to a place where the rules of competition are clear and understood by all. The FCC is also attempting to level the playing field for broadband services provided by telecom service providers and MSOs.

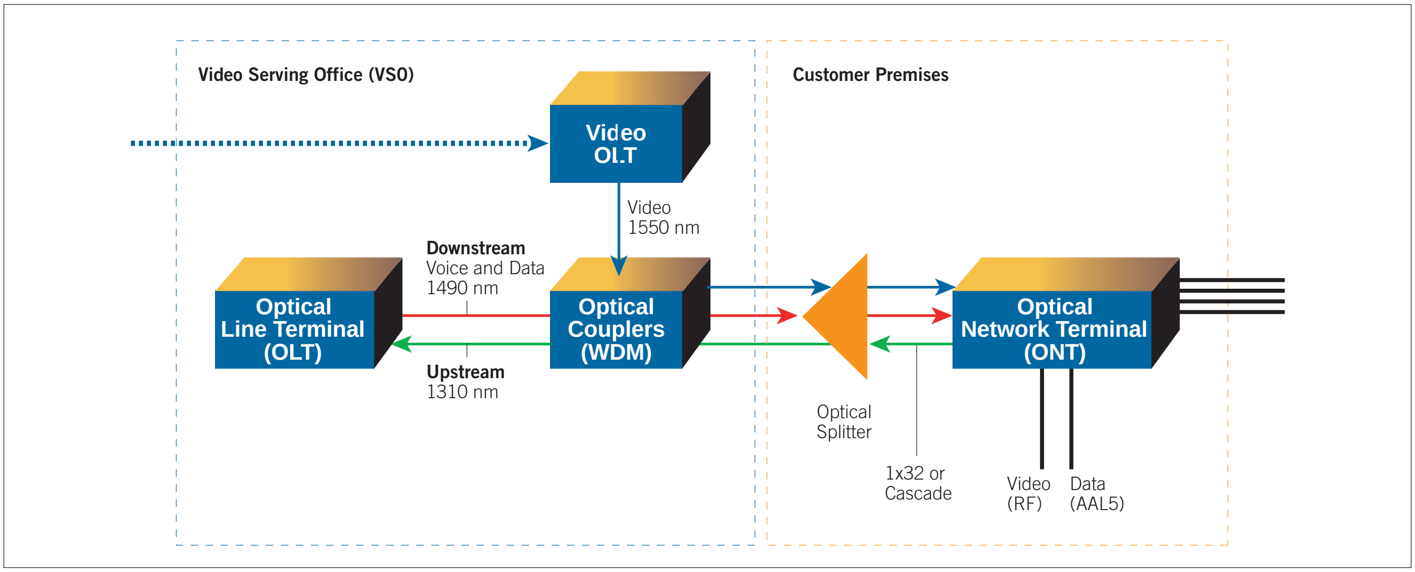

Figure 8. FTTH PON Wavelength Deployment

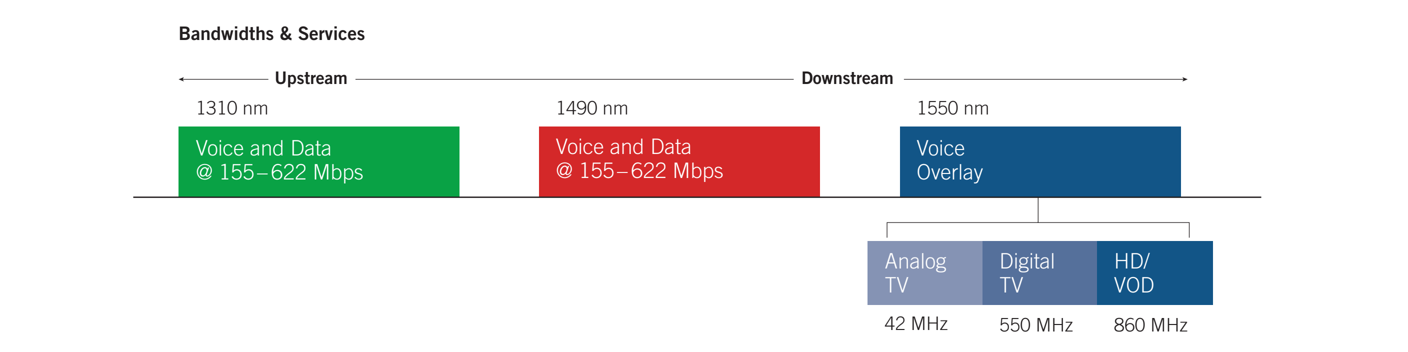

Figure 9. FTTH BPON Bandwidth with RF Overlay

4.1 FTTH & Unbundling: New Investment ... New Rules

4.1.1 TRO Unbundling Ruling

In 2003, the FCC issued the Triennial Review Order (TRO), in which the FCC shielded incumbent LEC (ILEC) Fiber to the Home (FTTH/FTTP) deployments from unbundling obligations that have arisen from section 251(c)(3) of the Telecommunications Act of 1996. The rules differ slightly based on whether it is a new build ("greenfield"), overbuild ("brownfield") or hybrid fiber/copper deployment.

- **Greenfield Deployments:** ILECs are not required to lease to their competitors portions of their FTTH network at regulated rates for "greenfield" deployments.
- **Brownfield Deployments:** In overbuild or "brownfield" scenarios, ILECs must either provide unbundled access to a 64 kbps transmission path over the fiber loop or unbundled access to a spare copper loop.
- **Hybrid Loops:** For hybrid copper/fiber loops, ILECs need not unbundle the packet-switched capabilities of those loops, but must provide unbundled access to any TDM features, functions and capabilities for requesting carriers seeking to provide broadband services. When a requesting carrier seeks access to a hybrid loop to provide narrowband service, the ILEC may provide either unbundled access to an entire hybrid loop capable of voice-grade service via TDM technology or provide unbundled access to a spare copper loop.

4.1.2 Residential Multi-Dwelling Units (MDUs) Ruling

In August 2004, the FCC ruled that predominately residential MDU locations also are shielded from unbundling obligations. General examples of MDUs include apartment buildings, condominium buildings, cooperatives or planned unit developments. The general use of these locations must be mostly residential. For example, a multi-level apartment building that houses retail stores such as a drycleaner and/or a mini-mart on the ground floor is predominantly residential, while an office building that contains a floor of residential suites is not.

4.1.3 FTTC Ruling

In October 2004, the FCC included some FTTC architectures in the domain of being shielded from unbundling obligations. These architectures are shielded provided that fiber is extended within 500 feet of the customer's premises. These new rules free companies to choose between FTTH/FTTP or FTTC networks based on marketplace characteristics, rather than regulatory differences.

The FCC also clarified that ILECs are not obligated to build Time Division Multiplexing (TDM) capability into new packet-based networks or into existing packet-based networks that never had TDM capability.

4.2 Franchise Agreements: Video Hurdles

Video entertainment services are one of the drivers for the deployment of FTTx networks. ILECs intend to deploy these services to compete with MSO cable services. One of the hurdles facing ILECs in entering the video delivery market is the franchise agreement. MSOs are required to have a franchise agreement in place with the local community to offer video services to the citizens of that community. MSOs argue that ILECs also should be required to establish similar agreements with these communities. The ILECs would like to expedite the process of offering these new video services by being relieved of the franchise agreement obligations. The ILECs are working at both the state and federal levels to get this relief:

- **Federal:** ILECs have argued at the FCC that IPTV services are not Cable services and thus do not require franchise agreements. ILECs have also lobbied Congress to pass legislation that will speed up the process of securing these franchise agreements. On June 29, 2005, this lobbying resulted in the introduction of the Video Service Act to both houses of Congress. This act would allow ILECs to pay the same franchise fees as cable operators when offering video services, while eliminating the time required to obtain franchise agreements. The downside for the ILECs is that they would inherit obligations such as:
  – must-carry rules for local TV stations
  – provide public-access and public TV channels

- State: Recently, the Texas House and Senate passed a bill that will allow for a statewide franchise agreement for new entrants in the entertainment video services market. This bill will likely be signed by the Texas governor. Similar measures are in the works in California and New Jersey.

In the meantime, ILECs are working diligently to establish franchise agreements in target markets. For example, in its May 17, 2005, announcement of the deployment of FTTP to communities in Bergen County New Jersey, Verizon indicated that it will seek a franchise agreement before offering cable TV service in a selected community.

Section 5

FTTx Deployment Models

5.1 Current Architecture Realities

While we have introduced various deployment architectures utilizing DSL and PON technologies, we will review these architectures and discuss today's current architecture realities. Most service providers have large embedded networks that impact their access bandwidth decision when considering upgrade options for video service support. Figure 10 outlines the various access bandwidth delivery alternatives. Currently, most wireline (Telco) service providers have deployed DSLAM, Remote DSLAM or DSL-enabled DLC systems to deliver data services. In addition, there is a large installed base of FTTC in the United States. Moving forward, service providers will deploy a combination of FTTN and deep fiber access solutions such as FTTC and FTTP for delivering video, voice and data services.

Many service providers will leverage their existing networks when choosing an upgrade path to add the necessary bandwidth required for video services. In cases where remote terminals already exist, the cabinet, fiber connection and availability of power enable deployment of upgraded FTTN capabilities. Specifically, an upgrade to ADSL2+ and/or VDSL2 enables an increase to the supported bandwidth within limitations governed by the distance between the remote terminal cabinet and the home. Upgrades to existing FTTC deployments are particularly well-suited to handle video services given their short distance to the home, enabling bandwidth capabilities in excess of 50 Mb/s with an upgrade to ADSL2+ and ultimately VDSL2. Some existing DLC deployments also have the capability to be upgraded to FTTH deployments with the addition of PON modules at the local serving office. This requires that fiber be installed and an optical network terminal be placed at each home that requires service.

In greenfield situations or in cases where the copper plant has to be upgraded, the cost to deploy fiber is on par with that of copper. When longer term lower operational costs are considered, deploying fiber has a reduced total cost of ownership than installing copper. FTTP and FTTC are good deployment alternatives for new greenfield installations that will enable high-bandwidth video services, with their support of both IPTV and RF video overlay capabilities.

A service provider will choose a solution that optimally leverages its installed network while also best enabling its video, voice and data service requirements now and in the future.

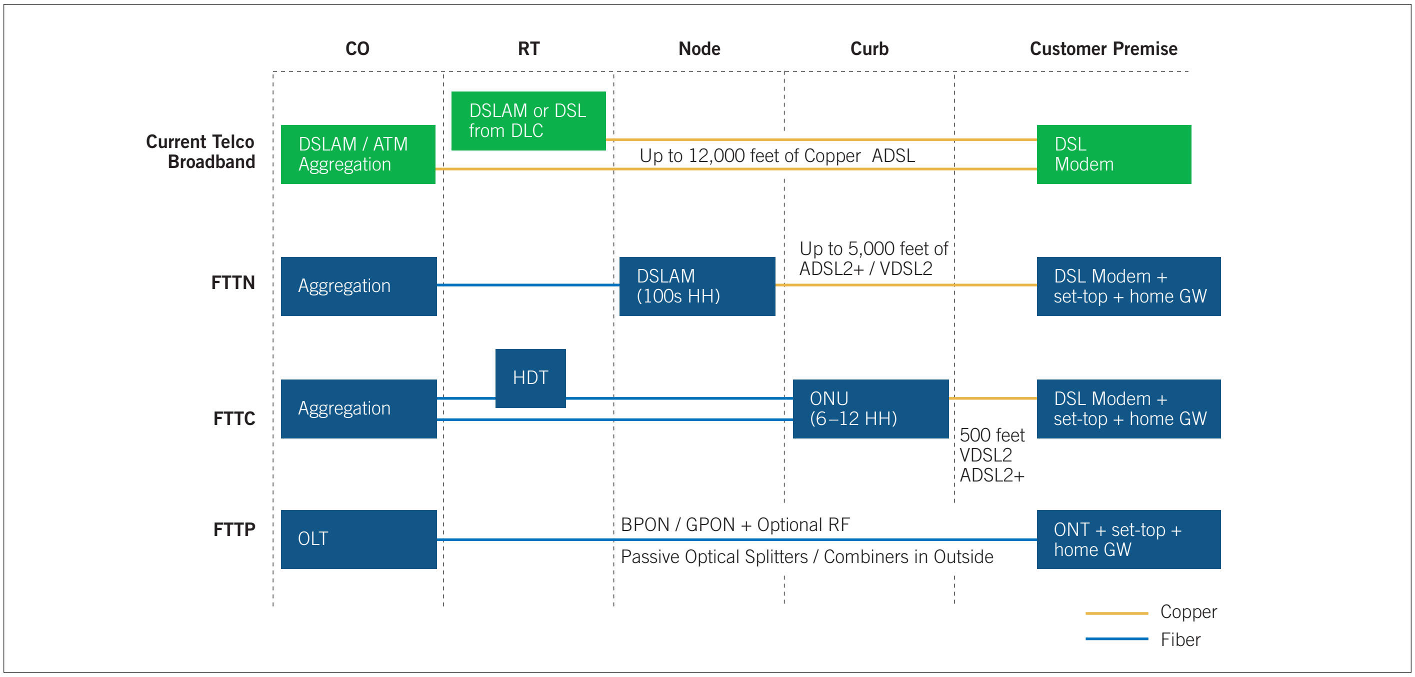

Figure 10. Current Broadband and FTTx Architectures

5.2 Choosing the Right FTTx Alternative

Each FTTx deployment alternative has strengths and limitations. Ultimately, a deep fiber access solution, or fiber to within 500 feet or all the way to the home, offers the best opportunity to support full video capabilities today, while offering the best investment protection for the future.

5.2.1 Fiber to the Node (FTTN)

Fiber is deployed to an active node that is within 4,000 to 5,000 feet of the home, and then copper drops are deployed between the node and each home.

- **Opportunity:**
  - In low-density applications, FTTN can enable incremental ARPU while limiting capital expenses.
  - Enables delivery of higher bandwidth Internet data services.
  - Supports one HDTV or up to four SDTV VoD channels.
- **Considerations:**
  - Cost is dependent on leveraging existing infrastructure.
    - Leverages existing copper binder groups and distribution pairs into the home.
    - At a minimum, existing DLC deployments may be leveraged for a physical location to place, power and connect the remote node, or potentially, as an actual upgrade to the existing DLC remote terminal.
  - Actual bandwidth throughput is dependent on the quality of the copper distribution plant and potential interference effects. Older copper deployments may need to be upgraded. One type of interference that FTTN deployments are susceptible to is binder group interference. This interference results from the multiple pairs (25 or 32) in binder groups interfering with each other when transporting high-speed DSL signals. (Binder group interference is not an issue with FTTC deployments since the loop length is so short that individual distribution pairs are used versus the larger binder group cable.)
  - Longer copper-loop lengths limit the ultimate bandwidth capacity into the home and, therefore, the ultimate ARPU.
    - Inability to offer broadcast video as an RF video overlay.
    - Limited to no more than two HDTV channels.
  - Operational cost of maintaining active remote node electronics including power and battery backup systems.
  - Bandwidth upgrades require upgrades at both the node and the home and may also require upgrades at the serving office.
  - FTTN deployments are currently subject to regulatory unbundling requirements because they are greater than 500 feet from the home.
  - 27% of residential access lines are within 5,000 feet of existing node locations.

5.2.2 Fiber to the Curb (FTTC)

A deep fiber access solution where fiber is deployed to an active ONU placed at the curb within 500 feet of the home and then copper drops are deployed between the curb and each individual home.

- **Opportunity:**
  - Maximum addressable ARPU opportunity with support of video, voice and data services.
  - FTTC deployment enables service providers to increase ARPU by leveraging copper assets in the last 500 feet to offer the full suite of triple-play services.
  - Large bandwidth support also enables in-band IPTV video support.
    - Supports more than four HDTV (using VDSL2) VoD and many SDTV VoD channels.
  - Enables delivery of higher bandwidth Internet data services.
  - Capable of supporting RF video overlay or in-band IPTV broadcast video.
  - No regulatory requirement to share facilities.
  - Offers efficient amortization of electronics cost across multiple customers.
- **Considerations:**
  - Video service deployment is required to maximize ARPU. There are various time-to-market factors that could delay mass video deployment, including:
    - The support of RF overlay video from the curb-node to the home requires that an additional HFC cable be installed between the optical network unit at the curb and the home.
    - RF video overlay deployment may require obtaining local TV franchise rights from each local governmental body.
    - Maturity of in-band IPTV and DSL technology. VDSL2 (or ADSL2+ bonding) is required to over the highest bandwidth video services.
  - Actual bandwidth throughput is dependent on the quality of the copper distribution cable, though normally this should not pose a problem with newer copper deployments.

- – Copper interference effects are minimized since the loop length is less than 500 feet.
- – Older copper deployments may have to be upgraded.

– There is an ongoing operational cost for maintaining the active curb node electronics including power and battery backup systems.

– Bandwidth upgrades require upgrades at both the curb optical network unit and at the home and may also require upgrades at the serving office.

5.2.3 Fiber to the Premise (FTTP)

FTTP is a deep-fiber solution based on PON technology where a fiber "feeder" is deployed to a PON splitter and then individual fibers are deployed to each home.

- **Opportunity:**
  - Maximum addressable ARPU opportunity with support of video, voice and data services.
  - Time-to-market advantage for video services deployment with out-of-the-gate support of broadcast RF video.
  - Large bandwidth support also enables in-band IPTV video support.
    - Supports more than four HDTV VoD and many SDTV VoD channels.
  - Has the potential to support the greatest upstream bandwidth of all of the FTTx architectures.
  - Enables delivery of higher bandwidth Internet data services.
  - Offers the most future-proof investment protection for delivery of today's and tomorrow's high-bandwidth services.
    - Fiber has the highest theoretical bandwidth delivery capability.
    - Fiber distribution plant has a longer life-span than copper.
    - Bandwidth per subscriber flexibility.
  - No regulatory requirement to share facilities.
  - Lower operational cost since the passive optical splitter does not require power and the homeowner pays for powering the optical network unit at the home.
- **Considerations:**
  - Requires fiber installation to each subscriber's home.
  - Video service deployment is required to maximize ARPU. There are various time-to-market factors that could delay mass video deployment, including:
    - RF video overlay deployment may require obtaining local TV franchise rights from each local governmental body.
    - Maturity of in-band IPTV video technology.
  - While in theory fiber can support more bandwidth than should ever be required, bandwidth upgrades may still require upgrades to ONT at the home and may also require upgrades at the serving office.
  - Initial costs can be higher depending on whether or not any part of the existing network infrastructure can be upgraded.

5.3 Brief Comments on Economics

In greenfield builds, the cost of deploying fiber has now reached parity with copper. It is less expensive given the longer lifetime of fiber and correspondingly lower operational costs. Some service providers in the United States are now targeting FTTP for new builds. SBC estimates that FTTP costs of $1,100 per household passed is at parity with traditional remote terminal deployment.

For brownfield deployment scenarios, the economics are more complicated because they are dependent on a mix of issues such as what bandwidth will be required for a given video service model, and whether the existing network infrastructure is capable of an incremental upgrade to support the required service bandwidth. SBC indicated that its cost to deploy FTTN could be as low as $250 per household passed. BellSouth has also indicated that it plans to upgrade its existing FTTC deployments to support higher bandwidth services. In most cases, incremental upgrades will be the lowest cost path. The real question is whether or not the FTTx solution can support the required bandwidth for video services today and tomorrow. The answer depends on how deep fiber is deployed into the network or conversely stated, keeping the copper loop as short as possible.

Summary and Conclusions

The "last-mile" has long been the final impediment to the deployment of end-user broadband services like video distribution. A single HDTV video stream can require 10 Mb/s per channel to retain the benefits of the higher resolution picture quality. A quantity of four video streams delivered at once with the addition of bandwidth for Internet access can put the total bandwidth requirement at more than 50 Mb/s needed for each home. Existing residential copper access networks cannot support this bandwidth requirement. Wireline service providers have moved aggressively toward mitigating this bottleneck through increased deep-fiber access penetration coupled with more efficient bandwidth usage with advanced compression algorithms.

The right FTTx solution choice depends on many factors, including service requirements, technological capabilities, regulatory requirements, existing installed infrastructure, capital and operational costs, and return on investment goals. In all cases, a deep fiber access solution like FTTC or FTTP that takes fiber to within at least 500 feet or all the way to the home will be the best alternative for deployment of video, data and voice triple-play services.

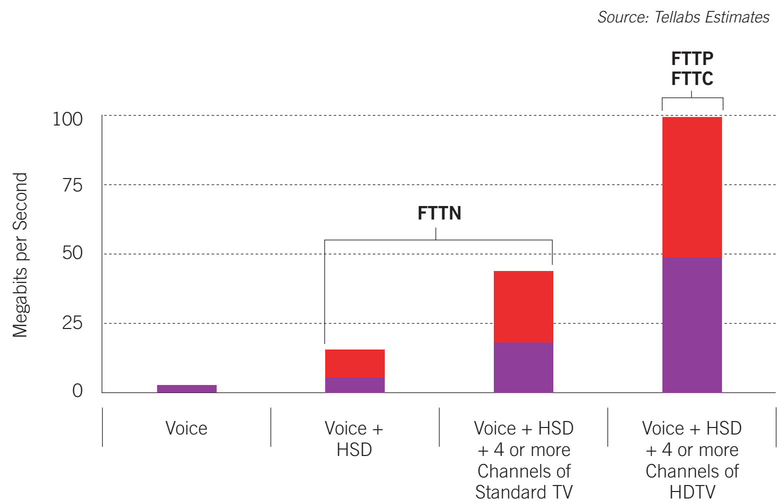

Figure 11. Optimal Solutions for Various Bandwidth Access Needs

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