Very-High-Data-Rate Digital Subscriber Line (VDSL)

Definition

The most promising technology capable of delivering full-service access is veryhigh-data-rate digital subscriber line (VDSL). VDSL is both symmetric and asymmetric and provides up to 52 Mbps of bandwidth over voice on a single twisted-pair copper loop.

Overview

This tutorial explores VDSL technology in detail, with emphasis on its potential benefits, existing standards, and deployment status. VDSL technology provides the telco with the ability to create the type of business that is critical for success in the new millennium. Those service providers that can deliver full narrowband and broadband services consisting of voice, data, and video will be the dominating forces in the industry today and tomorrow.

Topics

1. Introduction

Recent events in the telecommunications industry are giving rise to a new class of service providers, setting the stage for how this industry will appear in the new millennium. Telecom deregulation has sparked the emergence of the ever-growing competitive local exchange carrier (CLEC) industry segment, delivering a host of long-distance, cellular, and high-speed Internet services. In addition to new competitive entrants into this market, notable mergers and acquisitions combining telco and cable-television (CATV) operators have been influential. The demand for faster access to the Internet, coupled with this new competitive environment, has heightened the need for providers to offer more complete, more differentiated services and is accelerating the telecom industry's development of new technologies. Both consumers and businesses are utilizing the many benefits of the Internet, while innovative service providers are tapping into new convergent technologies to offer more complete and higher-speed services. As the Internet gains more users, the content becomes more graphical, and the delivery of services becomes more ubiquitous, demand for faster access and more bandwidth is certain. Those service providers who capitalize on this new environment by offering a full suite of narrowband and broadband services to deliver voice, data, and video will succeed in the new millennium.

In the quest to deliver broadband services over the existing narrowband network, most of the large North American carriers are engaged in various types of digital subscriber line (DSL) technology trials. Also, there is a new class of CLEC called the data CLEC, which utilizes DSL technology for inexpensive tier-1 (T1) replacements and high-speed Internet access. Today, several incumbent local exchange carriers (ILECs), independent LECs, CLECs, network services providers (NSPs), and Internet service providers (ISPs) have installed asymmetrical DSL (ADSL) trials, and some are beginning to roll out these services. The ADSL standard provides up to 6 Mbps downstream and 640 kbps upstream over voice and has a transmission loop distance of over 3 miles on copper wire. Most ADSL installations today support the G.lite standard rates of 1.5 Mbps downstream and 256 kbps upstream. While ADSL delivers high-speed Internet access over the existing narrowband network, it falls far short of being able to deliver full services that include video.

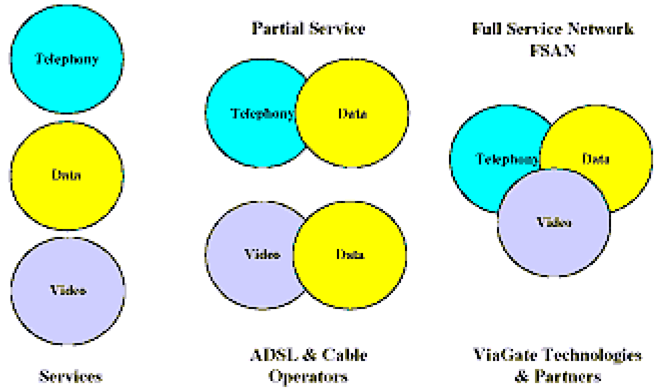
In addition to the emergence of DSL technology and a new class of telco, CATV companies are pursuing the telephony market by installing equipment to provide two-way communications over their existing cable installations. They are successfully rolling out Internet services with cable modems and hybrid fiber/coax (HFC) and are now developing new technology to add voice to their existing video services. Although deploying this new architecture is complicated, involves high costs, and will take several years to complete, cable companies will not be deterred and pose a significant threat to the traditional telco. Even though the cable industry appears to do well at providing broadcast video and Internet access, the key to success will be the integration of voice telephony services and broadband video (i.e., high-definition television [HDTV]), into their networks. Therefore, the cable companies will be limited in their ability to roll out full-service networks carrying video, data, and voice.

The most promising technology capable of delivering full service is very-high-data-rate DSL (VDSL). VDSL is both symmetric and asymmetric and provides up to 52 Mbps of bandwidth over voice on a single twisted-pair copper loop. VDSL technology provides the telco with the ability to create the type of business that is critical for success in the new millennium. Those service providers that can deliver full narrowband and broadband services consisting of voice, data, and video will be the dominating forces in the industry today and tomorrow.

2. Full-Service Broadband Network

There are three basic service types or classifications by which most communications can be categorized: voice, data, and video. Today, service providers (both telcos and cable companies) deliver only one or two out of the three. The telcos that will survive the new communications environment—and especially those that will dominate—will be the ones that learn how to deliver all three services over a single unified network. The basic architecture of this full-service network that will deliver both narrowband and broadband services is a fiber backbone coupled with the existing copper plant for the last mile. This architecture has been specified and is currently being built by the world's top sixteen telcos. The Full Service Access Network (FSAN) Consortium is actively pursuing the standardization and deployment of this narrowband and broadband full-service access network (see *Figure 1*).

Figure 1. Full-Service Network



3. FSAN

Since June 1995, an international initiative sponsored by the world's leading telecommunications operators and manufacturers has been underway to establish a consensus on system requirements for the local access network to deliver a full set of narrowband and broadband services. This initiative, led by FSAN, seeks to enable the large-scale introduction of broadband access networks through the definition of a basic set of common requirements. Although FSAN is not a standards body, this international consortium is working with the American National Standards Institute (ANSI), the European Telecommunications Standards Institute (ETSI), the International Telecommunications Union (ITU), the Digital Audio Video Council (DAVIC), the ADSL Forum, the VDSL Coalition, and other xDSL and asynchronous transfer mode (ATM) standards organizations. These groups seek to drive the establishment of technology standards that will satisfy system requirements for the new broadband, multiservice network. FSAN membership is restricted to the world's largest telco operators; *Table 1* lists the sixteen members of FSAN.

Table 1. FSAN Members

Member Partners	**Country**
Bell Canada	Canada
British Telecommunications	England
Deutsche Telekom	Germany
France Telecom	France
GTE	USA
NTT	Japan
Telecom Italia/CSELT	Italy
Telstra	Australia
Swiss PTT	Switzerland
Spain Telefonica	Spain
SBC	USA
Korea Telecom	Korea

Bell South	USA
Telecom Eirann Telefonica	Ireland
Dutch PTT	Netherlands
U S West	USA

The FSAN consensus specifies ATM as the primary transport technology, utilizing fiber in the core network and VDSL over copper in the last-mile access network. The architectures specified include fiber-to-the-cabinet (FTTCab) and fiber-to-the-building (FTTB).

4. Technology Standards

ATM is fast becoming the telco industry's preferred standard for the transmission of voice, data, and video services across its core networks, and ATM over VDSL is the preferred implementation method specified by the members of FSAN. Using ATM as the transport mechanism has the advantage of providing the following:

- guaranteed quality of service (QoS)
- multiple service classes support
- guaranteed bandwidth
- interconnects for different Internets and intranets
- interconnects for disparate systems
- interconnects for various media types such as wireless (terrestrial and satellite)
- extending the distance and interconnects without exceeding hops and dropping data
- integrated video and transmission control protocol (TCP)/Internet protocol (IP) applications
- multiple protocol support
- meeting future application requirements now

ATM standards are already well established, and VDSL standards are also well underway. The ANSI T1E1.4 and ETSI TM6 working groups, in cooperation with the VDSL Coalition and VDSL Alliance, have established recommended standards with contributions to the ITU in progress. It is expected that the ITU will adopt a VDSL standard by the end of 1999. Other standards that already exist or are emerging for the delivery format of services include MPEG audio and video, digital video disk (DVD), digital video broadcast (DVB), digital broadcast satellite (DBS), and HDTV, to name a few. *Table 2* lists the organizations developing or contributing to various standards that define the full-service access network of the new millennium.

Table 2. Relevant Standards Bodies and Working Groups

ANSI	**ETSI**	**ITU**
DAVIC	ISO/IEC	TIA
FSAN	VDSL Coalition	VDSL Alliance
ADSL Forum	ATM Forum	T1E1

5. VDSL Access Technology

VDSL is the highest-rate DSL technology available. Running at speeds of up to 52 Mbps, VDSL is the next generation of DSL, with higher throughput and simpler implementation requirements than ADSL. VDSL began its life being called VADSL but was renamed VDSL by the ANSI T1E1.4 working group. The principal reason T1E1.4 decided on VDSL over VADSL was that, unlike ADSL, VDSL is both symmetric and asymmetric. VDSL is nearly ten times faster than ADSL and is over thirty times faster than HDSL. The tradeoff for increased speed is loop length: VDSL has a shorter reach in the loop. *Table 3* provides a comparison of the various DSL technologies available today. We see that VDSL is the highest-bandwidth technology, supporting both asymmetric and symmetric applications, and is ideal for full-service broadband networks.

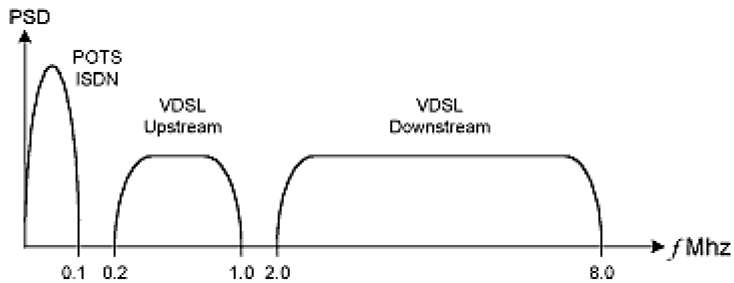
Table 3. xDSL Types

DSL Type	**Symmetric/ Asymmetric**	**Loop Range (kft)**	**Downstream (Mbps)**	**Upstream (Mbps)**
IDSL	symmetric	18	0.128	0.128
SDSL	symmetric	10	1.544	1.544
HDSL (2 pairs)	symmetric	12	1.544	1.544
ADSL G.lite	asymmetric	18	1.5	0.256

ADSL	asymmetric	12	6	0.640
VDSL	asymmetric	3	26	3
	asymmetric	1	52	6
	symmetric	3	13	13
	symmetric	1	26	26

Like other DSL technologies, VDSL uses the higher-frequency spectrum available over standard copper above the frequencies used for lifeline plain old telephone service (POTS) and integrated services digital network (ISDN) services. This is commonly referred to as data- and video-over-voice technology. This technology enables telcos to utilize existing copper infrastructure for the delivery of broadband services over the same physical plant. The VDSL spectrum is specified to range from 200 kHz to 30 MHz. Actual spectral allocation varies based on line rates and whether or not asymmetric or symmetric rates are being used. The baseband for lifeline POTS and ISDN service is preserved by using passive filters commonly known as splitters. *Figure 2* illustrates an example of spectral allocation for asymmetric VDSL running at 25.92 Mbps downstream and 3.24 Mbps upstream.

Figure 2. Example Single-Carrier VDSL Asymmetric Spectral Allocation



Asymmetric VDSL

VDSL has been designed to deliver a host of asymmetric broadband services, including digital broadcast TV, video on demand (VoD), high-speed Internet access, distance learning, and telemedicine, to name a few. Delivery of these services requires the downstream channel to have a higher bandwidth than the upstream channel and is thus asymmetric. For example, HDTV requires 18 Mbps for downstream video content. Upstream, however, it only requires the transmission of signaling information (i.e., channel changing or program selection), which is on the order of kbps. *Tables 4* and *5* clarify the VDSL line-rate standards established in the ANSI T1/E1.4 specification. Downstream rates are derived from submultiples of the synchronous optical network (SONET) and synchronous digital hierarchy (SDH) canonical speed of 155.52 Mbps, namely 51.84 Mbps, 25.92 Mbps, and 12.96 Mbps.

Table 4. Downstream Line Rates for Asymmetric VDSL Services (ANSI T1E1.4)

Typical Service Range	Bit Rate (Mbps)	Symbol Rate (Mbaud)	Comments
short range, 1 kft	51.84	12.96	baseline
	38.88	12.96	
	29.16	9.72	optional
	25.92	12.96	
medium range, 3 kft	25.92	6.48	baseline
	22.68	5.67	
	19.44	6.48	
	19.44	4.86	optional
	16.20	4.05	
	14.58	4.86	
	12.96	6.48	
long range, 4.5 kft	12.96	3.24	baseline
	9.72	3.24	optional
	6.48	3.24	

Table 5. Upstream Line Rates for Asymmetric VDSL Services (ANSI T1E1.4)

Typical Service Range	Bit Rate (Mbps)	Symbol Rate (Mbps)	Comments
short range, 1 kft	6.48	0.81	baseline
	4.86	0.81	optional
	3.24	0.81	
medium range, 3 kft	3.24	0.405	baseline
	2.43	0.405	optional
	1.62	0.405	
long range 4.5 kft	3.24	0.405	baseline
	2.43	0.405	optional
	1.62	0.405	

Symmetric VDSL

VDSL has also been designed to provide symmetrical services for small and medium business customers, the corporate enterprise, high-speed data applications, video teleconferencing and teleconsulting applications, and etc. Symmetric VDSL can be utilized to provide short-haul T1 replacements at nxT1 rates, plus support a host of other business applications. *Table 6* contains the VDSL line standards for symmetric service established in the ANSI T1E1.4 specification. At rates from 6.48 Mbps to 25.92 Mbps, it should be noted that VDSL provides symmetrical service between the standard T1 (1.536 Mbps) and T3 (44.376 Mbps) rates, bridging the gap over single twisted-pair copper. Although ANSI has not specified the distance and rates for long-range symmetric services, 6 Mbps to 1.5 Mbps over loops up from 3 kft to 10 kft are likely to be supported.

Table 6. Line Rates for Symmetric VDSL Services (ANSI T1E1.4)

Typical Service Range	Bit Rate (Mbps)	Downstream Symbol Rate (Mbps)	Upstream Symbol Rate (Mbps)
short range, 1 kft	25.92	6.48	7.29
	19.44	6.48	7.29
medium range, 3 kft	12.96	3.24	4.05
	9.72	3.24	2.43
	6.48	3.24	3.24

6. VDSL–Based Service Sets

VDSL technology offers a variety of simultaneous services never before possible, opening up the opportunity for service providers to deliver new subscription-based and multimedia services. Telco providers offering telephony and data services can now expand their businesses by offering full services and a host of video-centric applications (see *Table 7*). This enables telcos to compete with the encroaching CATV operators effectively.

Table 7. VDSL Applications

Full Service, One Network	True Multimedia	High-Speed Internet Access
Video on demand	broadcast digital TV	distance learning
Telemedicine	interactive video	video conferencing
HDTV	electronic commerce	electronic publishing
Intranet and telecommuting	video games	karaoke on demand

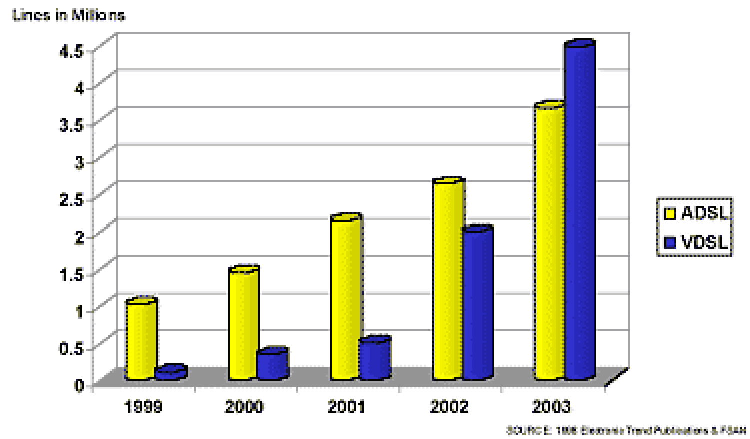
The original charter for ADSL was to deliver a full suite of broadband services to the residential consumer, so why the need for VDSL? The reality is that ADSL is an Internet-only technology. *Table 8* illustrates that, in the long run, ADSL is limited in its ability to deliver a full complement of broadband services. VDSL, on the other hand, is well suited to deliver these services today and tomorrow.

Table 8. Application Requirements: ADSL vs. VDSL

Application	Downstream	Upstream	ADSL	VDSL
Internet access	400 kbps–1.5 Mbps	128 kbps–640 kbps	yes	yes
Web hosting	400 kbps–1.5 Mbps	400 kbps–1.5 Mbps	today only	yes
video conferencing	384 kbps–1.5 Mbps	384 kbps–1.5 Mbps	today only	yes
video on demand	6.0 Mbps–18.0 Mbps	64 kbps–128 kbps	today only	yes
interactive video	1.5 Mbps–6.0 Mbps	128 kbps–1.5 Mbps	today only	yes
telemedicine	6.0 Mbps	384 kbps–1.5 Mbps	today only	yes
distance learning	384 kbps–1.5 Mbps	384 kbps–1.5 Mbps	today only	yes
multiple digital TV	6.0 Mbps–24.0 Mbps	64 kbps–640 kbps	today only	yes
telecommuting	1.5 Mbps–3.0 Mbps	1.5 Mbps–3.0 Mbps	no	yes
multiple VoD	18 Mbps	64 kbps–640 kbps	no	yes
high-definition TV	16 Mbps	64 kbps	no	yes
Note: based on ITU ADSL standard 6 Mbps, 640 kbps				

Figure 3 is a graph of the expected DSL market growth as a result of these factors and shows that the VDSL market is expected to overtake ADSL in a few years.

Figure 3. ADSL and VDSL Market Growth Projections



VDSL–Based Video Services

VDSL provides the operators with the ability to offer a host of digital video services that augment their current telephony and Internet service offerings. VDSL has the capacity to support digital broadcast TV, video-on-demand, and HDTV over standard twisted-pair copper. Head-end equipment can be centrally located or distributed across the network, transporting guaranteed bandwidth over ATM to the local access node. All programming channels are available and switched at the access node and are transported to the customer premises via VDSL. Today's existing cable plant delivers analog video, and the transition to digital is just beginning. These systems must also be upgraded to support VoD and require an overhaul to support HDTV. While DBS operators can offer digital video and HDTV services, their systems do not support VoD or Internet services. In addition to digital video and Internet services, VDSL also supports interactive video services, Web TV, e-commerce, video teleconferencing, and video games, representing a set of services currently not available from cable or DBS operators.

High-Speed Internet

Providing high-speed Internet access is an essential value for home users, small businesses, hotels, institutions, and other multidwelling buildings. The Internet is growing at a phenomenal rate, and along with this growth is an expansion of new and diverse applications to take advantage of the increased availability of equipment, software, access, and users. These new applications are requiring more resources than can be provided with the existing infrastructure, which is limiting the profit potential in providing these applications. While other DSL technologies, such as ADSL and G.lite, can satisfy the limited requirements of today's Internet applications, these systems will soon run out of bandwidth. In contrast, VDSL has the capacity to support today's applications with room to support the emerging applications of tomorrow, thus providing new opportunities for revenue growth while preserving the investment in DSL technology. As the Internet grows, more and more of the backbone architecture is being replaced by ATM. ATM is FSAN's preferred Internet backbone technology to handle the increasing load to support daily operations and mission-critical applications. The ATM architecture was chosen because it enables a single ATM network to be used to support all applications—carrying data, voice, and video—instead of delivering them in separate and incompatible networks. The combination of VDSL and ATM delivers the Internet services of today in an architecture that will support the emerging applications of tomorrow.

Telephony Services

A key service for every telco is the delivery of lifeline telephony services. One thing that has become universally expected is that no matter what, the telephone will work. VDSL, like other DSL technologies, supports a lifeline POTS connection. This is a basic requirement that must be met by any provider of telephony services. VDSL provides this functionality and gives the telco the opportunity to provide additional, derived voice channels over the same existing copper pair. Voice over IP (VoIP) and voice telephony over ATM (VToA) technologies are emerging to provide standard-quality telephony services over a digital network. Because ATM can also transport IP–based communications, ATM over VDSL will support both digital telephony standards. Although voice-over–DSL (VoDSL) initiatives seek to develop a standard for transport over all flavors of DSL, bandwidth is still the issue. Higher-bandwidth VDSL provides more derived voice channels. Cable operators are beginning to enter the voice market using such technologies, but they face a major obstacle in providing lifeline services. The ability of the new class of full-service telcos to provide lifeline POTS along with derived telephony, Internet access, and digital video services represents a key advantage over cable and DBS operators.

7. Deployment Scenarios

The deployment of the full-service access network is progressing along with the deployment of fiber-based networks. The ultimate architecture is fiber-to-the-home and business, but this will take a number of years and significant resources to be realized. Deployment scenarios for today are fiber-to-the-exchange (FTTEx), fiber-to-the-neighborhood (FTTN), FTTCab, and FTTB. VDSL is only appropriate for FTTEx, where the customers served are within close range of the central-office (CO) exchange. FTTN and FTTCab are appropriate for standalone VDSL switch deployments or as part of a next-generation digital loop carrier (NGDLC). FTTB would bring fiber directly into a building, such as a multidwelling unit (MDU) or enterprise business, and terminate at the VDSL access switch. *Figure 4* illustrates the FTTN and FTTCab deployment configuration.

Figure 4. Example FTTN and FTTCab Deployment

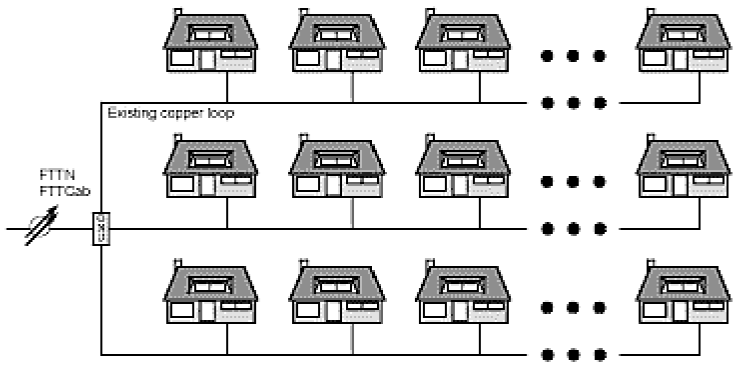
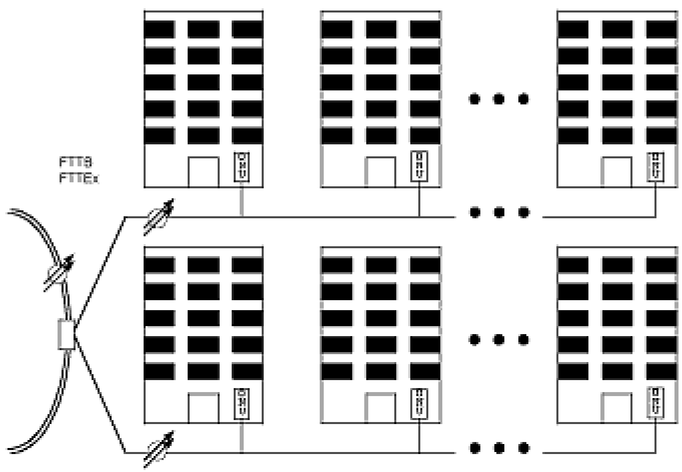


Figure 5 illustrates the FTTB deployment configuration.

Figure 5. Example FTTB Deployment



8. Summary and Conclusion

There is an ever-increasing demand for high-speed Internet access, rich entertainment, and cheap telephone service. There are currently only two industries that have the capability to profit from these market conditions: the telco and CATV industries. In addition, telecom deregulation has sparked the growth of the CLEC segment of the telco industry. Market conditions, coupled with this new competitive environment, have heightened the need for providers to offer more complete, more differentiated services and are accelerating the telecom industry's development of new technologies. Definite opportunities and technology are available to capitalize on this new environment, and there will be a new class of service providers emerging as the dominant force in this converging industry. Those telco service providers who can deliver a full suite of narrowband and broadband services to provide voice, data, and video are the communications companies that will be the dominant players in the market.

FSAN, made up of the world's 16 largest telcos representing over 50 percent of the world's phone lines, has been developing the requirements for the network that will deliver this rich set of services. The focus has been on technology and profitability. FSAN has chosen ATM and VDSL as the technology of choice for the full-service access network. The use of VDSL for businesses and residences will provide the badly needed increase in bandwidth that the market demands. By using ATM over VDSL, the systems will be reliable and can provide the required quality of service (QoS) that customers expect. By installing VDSL now, telcos need not go through a massive upgrade for more bandwidth in the near future. If the increase in demand for larger disk space and more memory in the personal computer (PC) business is anything like the future bandwidth demand in communications, ADSL will not last long. VDSL provides up to 52 Mbps of bandwidth over a single twisted-pair copper loop. Compared with other DSL technologies, VDSL is clearly the future of DSL, delivering a full-service access network. VDSL technology will be the solution for providing the market with required bandwidth now and into the future.

Self-Test

1. ADSL is able to deliver full Internet access service, including video.

    a. true

    b. false

2. The most promising technology capable of delivering full service is __________.

    a. HDSL

    b. ADSL

    c. VDSL

    d. DSL

3. At present, service providers are able to deliver all three basic service types or communications classifications (voice, data, and video).

    a. true

b. false

4. FSAN membership is open to all telco operators.

    a. true

    b. false

5. Which of the following statements about VDSL is not true?

    a. VDSL is both symmetric and asymmetric

    b. VDSL has a longer range in the loop

    c. VDSL is nearly ten times faster than ADSL

    d. VDSL is over thirty times faster than HDSL

6. Delivery of asymmetric broadband services requires the bandwidth of the downstream channel to be __________ the bandwidth of the upstream channel.

    a. higher than

    b. lower than

    c. equal to

7. ADSL is an Internet-only technology.

    a. true

    b. false

8. The combination of VDSL and ___________ delivers the Internet services of today in an architecture that is capable of supporting tomorrow's applications.

    a. X.25 packet switching

    b. frame relay

    c. Internet protocol

    d. ATM

9. VDSL is only appropriate for ___________.

    a. FTTEx

    b. FTTN

    c. FTTB

    d. FTTCab

10. VDSL provides 52 Mbps of bandwidth over a single twisted-pair copper loop.

    a. true

    b. false

Correct Answers

1. ADSL is able to deliver full Internet access service, including video.

    a. true

    b. false

    See Topic 1.

2. The most promising technology capable of delivering full service is __________.

    a. HDSL

    b. ADSL

    c. VDSL

    d. DSL

    See Topic 1.

3. At present, service providers are able to deliver all three basic service types or communications classifications (voice, data, and video).

    a. true

    b. false

    See Topic 2.

4. FSAN membership is open to all telco operators.

   a. true

   b. false

   See Topic 3.

5. Which of the following statements about VDSL is not true?

   a. VDSL is both symmetric and asymmetric

   b. VDSL has a longer range in the loop

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   d. VDSL is over thirty times faster than HDSL

   See Topic 5.

6. Delivery of asymmetric broadband services requires the bandwidth of the downstream channel to be __________ the bandwidth of the upstream channel.

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   See Topic 5.

7. ADSL is an Internet-only technology.

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   b. false

   See Topic 6.

8. The combination of VDSL and ___________ delivers the Internet services of today in an architecture that is capable of supporting tomorrow's applications.

   a. X.25 packet switching

   b. frame relay

c. Internet protocol

d. ATM

See Topic 6.

9. VDSL is only appropriate for ___________.

a. FTTEx

b. FTTN

c. FTTB

d. FTTCab

See Topic 7.

10. VDSL provides 52 Mbps of bandwidth over a single twisted-pair copper loop.

a. true

b. false

See Topic 8.

Glossary

ADSL
asymmetric digital subscriber line

ATM
asynchronous transfer mode

CLEC
competitive local exchange carrier

DBS
digital broadcast satellite

DSL
digital subscriber line

DVB
digital video broadcast

DVD
digital video disk

FSAN
full-service access network

FTTB
fiber-to-the-building

FTTCab
fiber-to-the-cabinet

HFC
hybrid fiber coax

ILEC
incumbent local exchange carrier

ISDN
integrated services digital network

NSP
network service provider

POTS
plain old telephone service

QoS
quality of service

SDH
synchronous digital hierarchy

VDSL
very-high-data-rate DSL

VoD
video on demand