Uni-DSL™: One DSL for Universal Service.

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DSL technology's history of rapid evolution has been rewarded with market success. Yet its greatest challenge lies ahead. New technologies must be developed to handle bandwidth-intensive, next-generation DSL services. The factors shaping new services include high-data-rate video delivery, infrastructure cost considerations, and competing broadband access technologies – especially in light of the triple-play video, data, and voice packages already being offered by some cable TV operators.

To meet the needs of DSL users and operators, TI is developing a next-generation DSL delivery platform called Uni-DSL. This white paper introduces Uni-DSL and its ability to provide one DSL for universal service. The paper has four main objectives:

1. To present the forces driving Uni-DSL development and to define Uni-DSL in terms of higher data rates and universal service.
2. To enumerate the technological advancements enabling Uni-DSL; and, to describe typical system configurations for end-to-end Uni-DSL service delivery.
3. To summarize the benefits to users in terms of new applications and services; and to operators in terms of increased revenue and decreased operating and infrastructure costs.
4. To explain how broadband silicon vendors can differentiate themselves in terms of performance, system integration and value-added applications; and, to show how Texas Instruments is uniquely qualified to deliver complete, best-in-class Uni-DSL silicon and software.

Introduction: The last-mile challenge

Delivering the data rates available within most of the Internet infrastructure to end users has always been hindered by the "last-mile" bottleneck – the connection of homes and businesses to the edge routers that reside in Internet access points or *points of presence* (PoPs). Broadband technologies such as DSL unplug this bottleneck by providing high-speed data connectivity from the PoPs to the customer premises.

Higher connection speeds enable multimedia applications such as listening to real-time Internet audio streaming from remote sources, viewing video news clips and movies, and posting and transferring still images.

Even though broadband has facilitated a wide range of new data services, new and more demanding services are taxing the broadband access infrastructure. Peer-to-peer file sharing, interactive gaming and VoIP telephony are three hot applications today.

In the near future, higher quality audio/video broadcast and conferencing, telecommuting with high-speed graphics transfer and other applications will become mainstream – as soon as they can be enabled.

The primary broadband growth drivers and their impacts are summarized in Texas Instruments' vision is that broadband multimedia – video, audio, voice, and data – will be delivered to and distributed within the home or business to personal endpoint devices. Services will be affordable and easy to use. They will be delivered quickly, securely and reliably. In the future, all things will be connected.

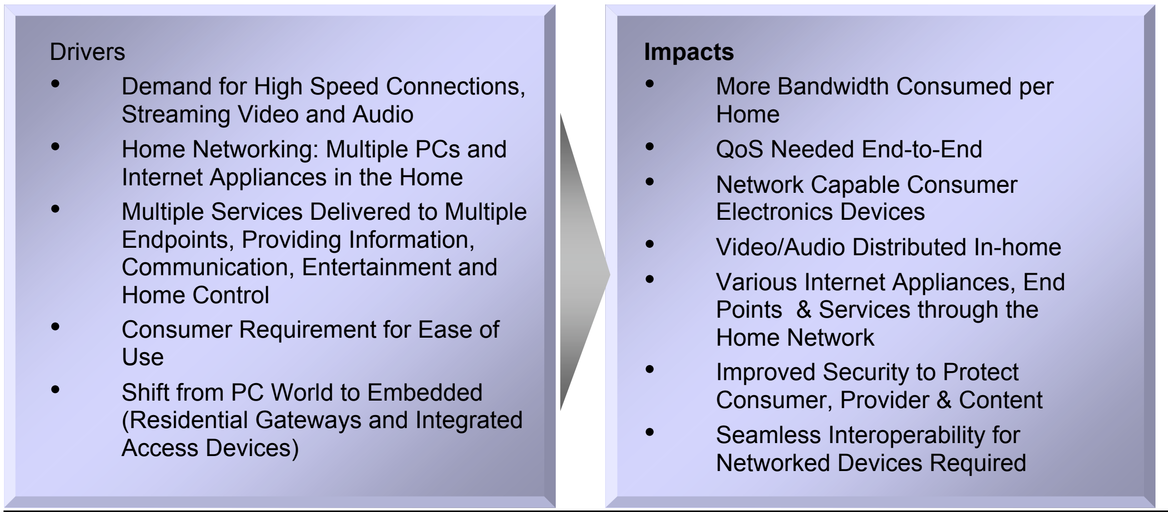

Figure 1: Drivers and Impacts of Broadband Growth

Accelerated evolution needed

DSL technology has evolved rapidly over the years. Present-generation Asymmetric DSL (ADSL) provides up to 8 Mbps from the network to the subscriber (downstream) and 1 Mbps from the subscriber to the network (upstream). The ADSL2 and ADSL2+ standards have been ratified. ADSL2+ enables downstream data rates up to 24 Mbps and upstream data rates up to 3 Mbps by doubling the line bandwidth to 2.2 MHz.

Very-high bit-rate DSL, or VDSL, can support asymmetric data rates of up to 52 Mbps on short (1-2 kft maximum) copper loops. But VSDL has not been widely adopted because of its short-loop limitation. The VDSL2 standard is currently advancing in the standards bodies and is expected to be ratified sometime in 2005.

For additional discussion of DSL evolution, see the sidebar article DSL: A History of Innovation.

Texas Instruments believes none of these developing standards alone will meet the demands of an increasingly competitive environment.

1. Factors driving Uni-DSL development

Uni-DSL – One DSL for Universal Service – is a new DSL delivery platform proposed by TI and enabled by TI's next-generation DSL modem integrated circuits and software.

Next-generation DSL equipment – and the systems based on this delivery platform – will support aggregate upstream plus downstream data rates up to 200 Mbps, including 100 Mbps symmetric, and will optimize the performance and service delivery for every local loop in the network.

The service is *Universal* because it takes advantage of both ADSL2+ and VDSL2 technology and supports a converged upgrade path that includes both ADSL/ADSL2 and VDSL1.

Specifically, Uni-DSL provides:

- Enriched and reliable service delivery to users – both home and business – including triple play data, voice and video services at data rates up to 200 Mbps aggregate
- Optimal performance and future-proof service delivery for each loop in the network.
- Unified, cost-effective network upgrade path as fiber is deployed further from the central office and closer to end users.
- Unified, cost-effective provisioning and management
- Backward compatibility with current infrastructure

DSL: A History of Innovation

The twisted-pair copper access network has been in place for more than a century and has well served the needs of voice telephony. Over the latter half of that century, however, the network has also evolved to support data communications, driving the development of Digital Subscriber Line (DSL) technology to carry high-speed data over twisted copper pairs.

The earliest type of DSL was basic rate ISDN, deployed in 1986, supporting two 64 kbps B channels and one 16 kbps D channel for a total of 144 kbps. High-data-rate DSL (HDSL), introduced in 1992, offered 1.5 Mbps symmetric service on a single pair to small and medium enterprise customers (SMEs) as a competitive alternative to T1/E1.

Various other forms of non-standard symmetric DSL (SDSL) were deployed by competitive service providers on leased copper pairs. SDSL standardization converged in the development of ITU standard G.991.2, known as G.shdsl, providing for a replacement SDSL service with data rates from 192 kbps to 2.3 Mbps.

These DSL technologies have shown continual growth in total deployment but they are tailored to the limited SME subscriber base and are expensive for residential users. It was not until cost-effective ADSL enabled the web browsing needs of residential users that DSL's explosive growth occurred.

Asymmetric DSL, or ADSL, provides up to 8 Mbps from the network to the subscriber (downstream) and 1 Mbps from the subscriber to the network (upstream). The asymmetry of ADSL has proved ideal for residential users because typical applications like web browsing and media streaming demand much higher data rates downstream than upstream.

Lower system costs

The popularity and standardization of ADSL have driven system costs low enough for the typical residential user to affordably subscribe, facilitating worldwide growth from 18M in 2001 to 110M in 2004, or 83% year-on-year growth. The ADSL2 and ADSL2+ standards have now been ratified, with ADSL2+ enabling downstream data rates up to 24 Mbps and upstream data rates up to 3 Mbps by doubling the line bandwidth to 2.2 MHz.

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Factors driving Uni-DSL development

Uni-DSL development is being driven by many important factors, as listed here and discussed below:

- DSL operators need to support competitive triple-play services, eventually including multiple channels of on-demand HDTV video delivery
- Appealing business case alternative to Fiber to the Home (FTTH)
- Advancements in DSL technology
- VDSL2 standards development
- Unique advantages over cable and other shared medium broadband services

One of the service providers' major concerns is the continuing loss of traditional analog telephony revenue from the copper infrastructure. This threat has two distinct aspects:

- The popularity of wireless phones means many people are substituting their traditional wire line phone service
- Other broadband service providers are adding telephony to their broadband offerings

It is estimated that service providers are losing 1-2 percent of their installed customer base per year to these alternative service options. Given that cable already provides video, telephony and high-speed data in much of its service area, the threat is quite real and the need to enable new services to extract more revenue from the existing copper base is obvious.

Very-high bit-rate DSL, or VDSL, can support asymmetric data rates of up to 52 Mbps on short (1-2 kft maximum) copper loops. However, since the line length (reach) between the central office (CO) or remote terminal (RT) modem and the customer premises equipment (CPE) for most users is greater than 1-2 kft, VDSL is not a viable service for these users.

In addition, VDSL standardization has lagged ADSL and available products are more proprietary and expensive, so at present VDSL service is primarily restricted to select businesses and residential users willing to pay a premium for these rates. The VDSL2 standard is currently advancing in the standards bodies.

Standards development status

The ADSL2+ standard is enabling a new wave of DSL equipment just coming to market to support up to 24 Mbps downstream, and deployment from the RT is expected to ramp over the next several years. The VDSL2 standard, however, is still in development and is expected to be ratified sometime in 2005.

TI is actively involved in the VDSL2 standards process and has already submitted a number of technical contributions. Some operators currently deploy VDSL1, but they are generally concerned with the lack of a unified, widely productized VDSL standard; other operators are simply waiting.

The ratification of VDSL2, with the involvement of operators, equipment vendors and silicon providers, will eliminate these concerns and open the gates for next-generation DSL deployment to proceed.

Fiber's unfulfilled promise

One solution is to overlay or replace the copper physical plant with fiber. Such a FTTH build-out is in the long-term strategic plan of many LECs, but at the same time it is recognized that deploying fiber all the way to every end user typically does not justify the capital cost of the upgrade, especially in developed areas that require significant retrenching and/or running of aerial fiber.

FTTH installations by LECs to date have been primarily in greenfield (new development) locations and in certain generally affluent areas with high expected take rates. The compromise to FTTH for most developed areas is, and will be, to expand fiber out from the central office gradually, stopping at several natural transition points in the copper plant. Mass deployment of FTTH is not envisioned for many years.

Uni-DSL Deployment Locations and Data Rate Tradeoffs

Possible locations for DSL equipment include the central office (CO), remote terminal (RT), cross-connect box, pedestal, curb, or basements and wiring closets of multi-dwelling units (MDUs) and enterprises.

Figure 2 depicts these locations and their respective upper-range distances from the customer premises as typically found in North America. In many countries loop lengths tend to be shorter, so this diagram somewhat represents worst case. DSL services that can be deployed from each location and the data rates expected from them are noted in the figure.

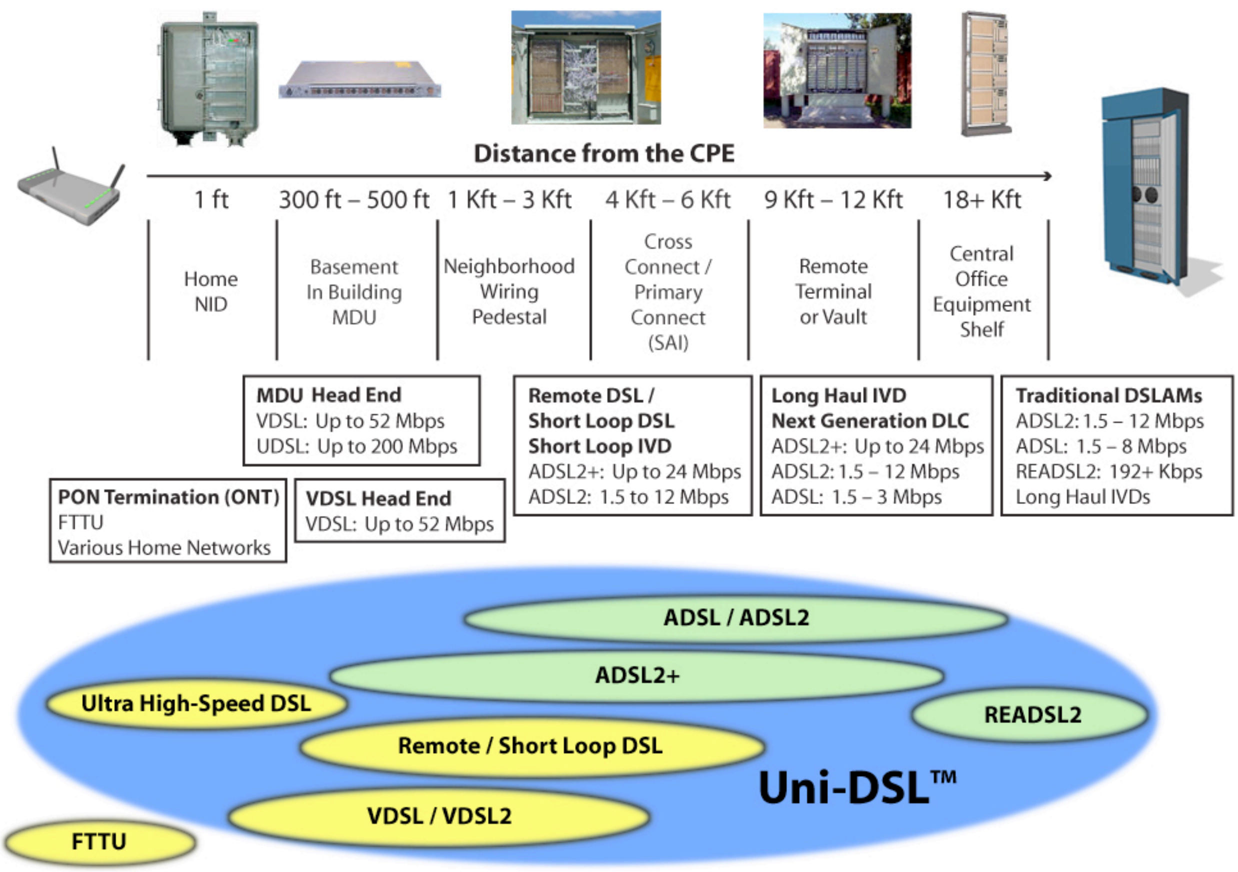

Figure 2: DSL Deployment points within the copper loop plant and the DSL services available from those points.

Most loop lengths from the central office (CO) or remote terminal (RT) are 6 kft or less, but depending on loop plant topology up to 30% are more than 6 kft and some approach the *carrier service area* (CSA) limit of 12 kft of 24 gauge wire or 9 kft of 26 gauge wire.

As shown in a comparison of the rate and reach performance of the various DSL standards, VDSL2 can provide >15 Mbps for those loop lengths in the 5-6 kft or less region. Assuming MPEG4 video at ~6-10 Mbps for HDTV, 2-4 Mbps for SDTV, data service at 1.5-3 Mbps, and voice service at several hundred kbps, this 15 Mbps will accommodate triple-play services to more than 70% of the service area.

In addition, since most users have two copper pairs already installed to the premises, two VDSL2 pairs can be bonded together into one logical data pipe for an aggregate downstream data rate of 30 Mbps.

Remote-terminal deployment

At present the most popular DSL upgrade path for service providers is to move deployment from the CO to the RT. Their primary motivation is to increase service availability and coverage area for high-speed Internet access at 1.5 Mbps or less.

But as shown in *Figure 2,* deploying Uni-DSL modems from the RT will in fact also enable a video delivery service to most of the subscriber base. Some providers have followed this path in select portions of their service area, using ADSL to deliver video broadcast and high-speed data.

Cross-connect box deployment

The next closest DSL deployment location to the user after the RT is the cross-connect box. The cross-connect is also called the *service area interface* (SAI), and the loop plant is typically designed such that 80-90% of users are within 3 kft of the SAI and virtually all users are within 6 kft. VDSL2 is well suited for up to 4 kft loop lengths, enabling approximately 25 Mbps to 95% of users.

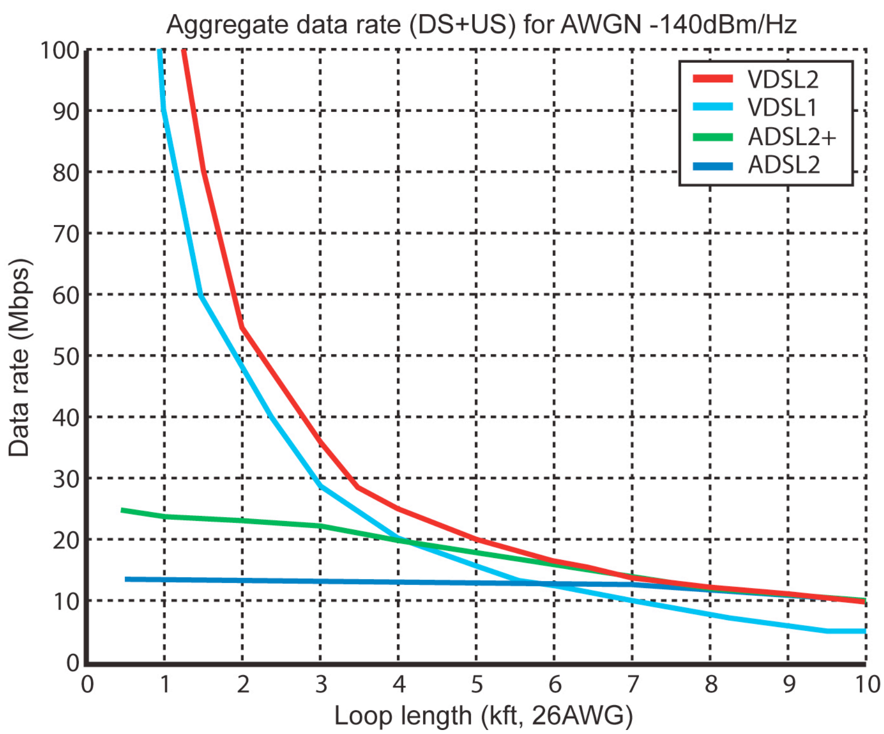

Figure 3

The middle image within shows a cross-connect box (SAI) with its doors open; the approximate dimensions are 4 feet (120 cm) wide, 3 feet (90 cm) tall and 1 foot (30 cm) thick. The SAI houses a wire-jumper panel that connects feeder cables from the central office, containing large bundles of twisted pairs, to distribution cables that contain smaller bundles of twisted pairs.

SAIs are passive devices and typically support 200-600 users. In most cases the feeder cables from the CO are run in conduit and the conduit is not full, allowing room to run fiber to the box without retrenching.

To handle the more extreme thermal characteristics of cross-connects compared to RTs, DSL equipment designed for the former is typically case-hardened, thermally-hardened and weatherproof. The main issues are expanding the size of the box to house the new equipment, supplying power, and of course actually rewiring the box.

Given the high capital costs of supplying local power, operators look to deploy equipment with low enough power consumption to be sourced from the CO or RT using existing copper pairs. Given the high operating costs of sending a technician to the SAI location each time a new subscriber requests DSL, operators look for equipment with appropriate size, cost and power to permit pre-provisioning of all potential subscribers. Uni-DSL's ability to address these needs is discussed later.

Limited DSL deployments to the cross-connect are already in service. Continued deployment will be gradual, but will be accelerated by Uni-DSL and its ability to meet the needs of operators to deploy a service platform that supports the existing DSL infrastructure and provides a seamless, cost-effective upgrade path to video data rates.

At 35 Mbps, several channels of HDTV video and several channels of high-quality audio, as well as telephony and data service, can easily be supported, providing DSL operators with a sufficient competitive weapon against CATV.

Pedestal or curb deployment

The next stop for running fiber and deploying DSL is the pedestal or curb, which will provide rates approaching 100 Mbps for all users. This effort typically requires trenching and/or other significant capital expense, but nonetheless installing DSL over the existing copper pair from the pedestal to the premises is still more cost-effective for many locations than running the fiber all the way to the home.

The same issues apply at the pedestal as at the cross connect: power must be supplied and the cabinet must be enhanced to adequately contain and protect the equipment.

Finally, for small business complexes and MDUs, fiber can be run all the way into the building and Uni-DSL can support 100 Mbps symmetric or more from the fiber termination to individual users over existing copper pairs in the building. For many buildings without Category-5 cable (CAT5) or fiber already installed within the building, extending Uni-DSL the last few hundred feet or less may be much less expensive than accessing walls and ceilings to run new cable.

2. Advancements in DSL technology

DSL technology advancements supported by standards include multiple latency paths, dynamic spectrum management (DSM), and channel bonding.

- Multiple latency paths permit multiple logical channels to share one physical DSL link with different latency and error protection tradeoffs per logical channel. Two-way interactive media and data traverse the low-latency path while distributed and broadcast media traverse the higher latency path with more error protection. QoS and security of DSL links and the access network will be much stronger in next-generation systems as multi-media data becomes richer in content and users focus on privacy.
- Dynamic Spectrum Management (DSM) techniques are used to improve utilization of network capacity, and are discussed in more detail in a later section.
- Bonding is the aggregation of multiple copper wire pairs, each with its own physical DSL connection, into one logical pipe with a total data rate equal to the sum of the individual connections – or more if vectoring. (discussed later). If any one connection fails, the remaining ones seamlessly adapt to maintain the channel at a lower rate.

A more detailed discussion of how these technologies will be implemented is presented later in this white paper. The remainder of this section will review the competitive landscape and suggest system configurations that are enabled by the technologies mentioned above.

Silicon advancements will play an important role by allowing for increased integration of features in a cost-effective manner, lower cost for a given feature set, and an increased variety of configuration possibilities. This is especially important in the CPE space, where a variety of devices will come to market to meet the specific needs of a multitude of user premise configurations, but is also important in the infrastructure space where factors such as modularity, scalability, advanced line testing and thorough but easy-to-use remote management are key considerations.

Advantages over other access technologies

The primary advantage of DSL over cable, satellite and Wi-MAX is its point-to-point topology rather than point-to-multipoint. A DSL link is dedicated entirely to a given user, thereby eliminating shared bandwidth, security or additional latency limitations.

DOCSIS 2.0, the data over cable standard, specifies 30 Mbps upstream and downstream but this is shared by up to 1000 homes passed by the coax distribution cable. Even with DOCSIS 3.0 targeting the 100-400 Mbps range and an additional fiber build-out such that only 50-100 homes share a cable, data rates could be constricted to a level that affects some applications.

Although DOCSIS has made advances in securing the privacy of user data, some users may be concerned that the shared coax medium is less secure than a dedicated twisted pair. Finally, the shared cable medium relies on a time division multiplexed downstream and a grant based upstream scheme. With many users, this can lead to inherent latency not present in DSL, which affects the response of interactive, high-data rate applications such as fast-action online gaming.

For more information on competing technologies, see the accompanying article, *Broadband Competitive Space.*

Uni-DSL system configurations

In the initial phase of ADSL deployment to residential customers, the customer premises system configuration was typically a DSL modem connected to one computer. If the link utilized a point-to-point authentication protocol such as PPP, the PPP client software was located on this computer. Soon thereafter, user demand to have multiple computers share one DSL line led to the development of low-cost, easy to use home routers.

The home router is a computer and Internet appliance in itself, taking care of PPP if required, providing firewall protection, tracking and emailing reports of web usage, etcetera. In 2003 approximately 28% of broadband users also had home networking, but by 2006 this is expected to grow to 50% for a total deployment of close to 100 million home routers.

Just as demand for home networking has driven development and deployment of cost-effective home routers, demand for computing mobility has led to the proliferation of Wireless LAN equipment. More than 30 million Wi-Fi devices were shipped as of 2003, and this number is expected to nearly triple by 2006.

VoIP gateways

The next feature wave now being added to CPEs is VoIP gateway functionality. The ability of broadband to replace residential and small-medium enterprise (SME) telephony using the digital bandwidth of the link for packet voice, while providing telephony features above and beyond the most expensive PBX systems of even five years ago, is driving a huge ramp in VoIP-enabled CPE. In fact, CPE equipment manufacturers are now producing cost-effective products that support all combinations of VoIP, Wi-Fi and home routing within one unit.

Figure 4 shows end-to-end connectivity of a Uni-DSL system. The edge router in the CO, typically referred to as a *broadband remote access server* (BRAS), authenticates and maintains the connection to a single user. Traffic through the BRAS may consist of data to/from the IP network, VoIP packets and signaling that are routed to/from a high-density VoIP access gateway and then to the public switched telephone network (PSTN), or data delivered to the user from local media stream servers or cache devices.

The media streams are carried on fiber to the RT or SAI and then over DSL to the CPE, a home router connected to a broad range of endpoints by either wireless or traditional LAN. These devices will include computers, PDAs, IP enabled home appliances and security systems, TVs and stereos, cameras and camcorders, etc. Bandwidth and QoS will be available to provide each of these devices with a logical link of appropriate data rate back to the server or peer device.

Broadband Competitive Space

The primary competition to ADSL in the broadband space today is cable modem service. Broadband over cable, or simply *Cable*, is delivered via the same Hybrid Fiber Co-axial (HFC) infrastructure that has delivered cable television for years.

From an established business of video delivery over an HFC infrastructure, CATV operators first expanded into broadband data service and now are rapidly deploying digital telephony service, all carried over the same HFC network.

This triple-play threat is the primary motivation for DSL operators to develop and execute their strategic plans for next-generation competitive broadband services. Cable currently accounts for roughly 60% of the U.S. broadband market and 35% of the worldwide market.

Fiber to the Home, or FTTH, is considered the holy grail of broadband last-mile access because of the seemingly unlimited data rates fiber can deliver. In actuality data rates depend on the topology of the fiber network and how much of it is active or passive, but aggregate data rates above 150 Mbps per user are easily supported.

Most DSL operators have strategic plans to upgrade their network to FTTH, but the cost of doing so has proven prohibitive. Some service providers have installed FTTH in new (greenfield) residential developments and some municipalities have installed fiber as a co-op initiative among residents, but to date this accounts for only a few hundred thousand homes in the US. Projected timeframes among industry visionaries for widespread FTTH deployment are in the 10-30 year range.

Broadband service can also be delivered via satellite or microwave. Satellite broadband service is typically used in locations too remote to be served by DSL or Cable. By nature it is a shared point-to-multipoint resource and upstream data rates are limited, sometimes requiring a phone line voice-band modem to establish the uplink. Downstream is a high data rate channel but must be shared between users, and latency is a significant issue for interactive services.

Wi-MAX, or Worldwide Interoperability for Microwave Access, is an initiative to standardize traditional point-to-multipoint Microwave data transmission technology. This standardization effort is advancing as IEEE 802.16, chartered to specify the wireless metropolitan area network air interface for wireless access.

Such standardization will allow metropolitan wireless access to undergo the same cost reductions and proliferation as DSL for broadband and WiFi for LAN access - good news for people who need mobile access anywhere in a city. However, residences and SMEs that do not need MAN mobility will get better service from DSL. Wi-MAX optimists expect the service to come to market in 1-2 years and proliferate by 2008.

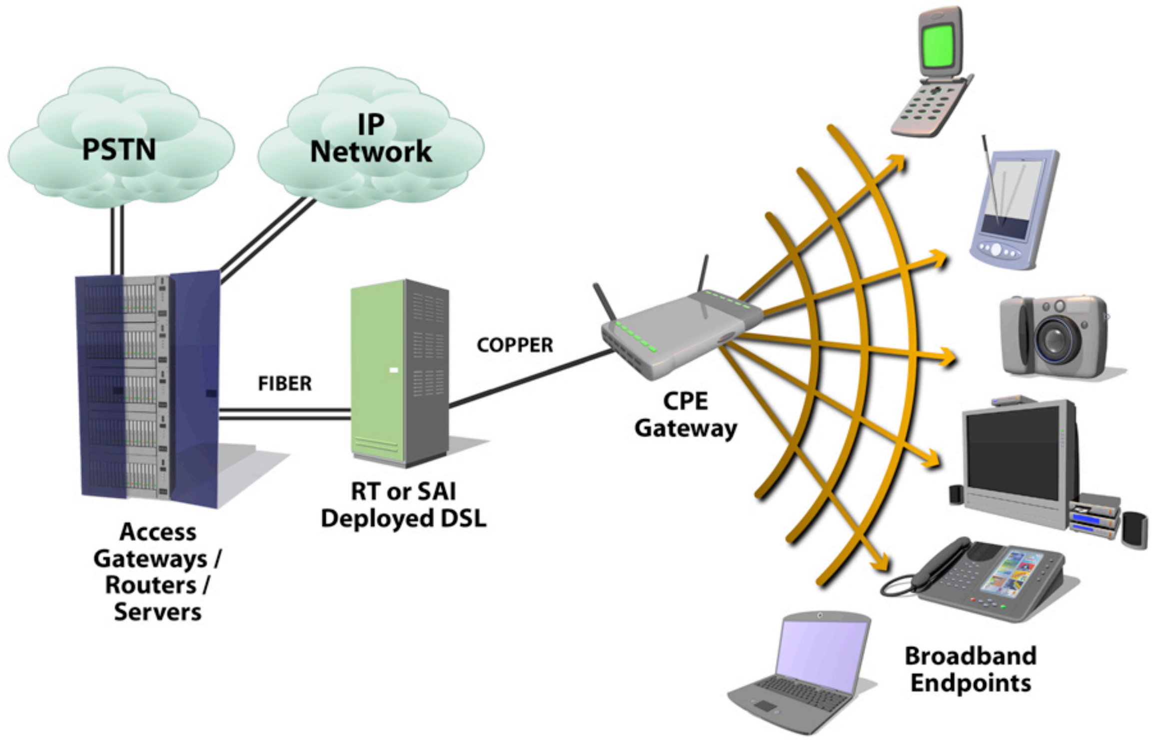

Figure 4: End-to-end Broadband Connectivity with Uni-DSL

3. Uni-DSL benefits for users and operators

For DSL users, Uni-DSL means enhanced, high-data-rate multimedia applications, better overall experience, more choices and less frustration. Enhanced multimedia applications will include all combinations of triple-play video, voice and data. The better user experience relative to today's broadband results from higher data rates and increased infrastructure maturity that will enhance and secure both existing and future applications.

More choices result from a wider selection of service packages as well as a wider selection of premises equipment, from bridging modems to full-blown Wi-Fi enabled home theater set-top boxes. Less frustration results from greater service coverage and reliability, and better remote diagnostics and test that allow providers to detect and fix problems quickly, possibly without the consumer even knowing.

In the broader sense, Uni-DSL in conjunction with the services and technologies it enables will facilitate advances in communication, computing and media delivery at least as revolutionary as those of the last 20 years.

Residential customers will enjoy new multimedia services such as

- Video broadcast: live or on-demand time-delayed.
- Streaming IP-video from the Internet
- On-demand movies and entertainment
- HDTV quality video
- Video conferencing

- Multiple telephone lines
- Fast, high-speed data service/internet access, both upstream and downstream.
- Home security and automation
- Telecommuting and enhanced productivity from home
- Gaming and virtual entertainment
- Interactive medical care, education, training
- Mobile and wireline convergence of telephone service

USDL benefits to business

Small/medium business users will have all of the above, as well as the following

- Ability to host their own web sites with their own high-speed servers and handle all web-based transactions on-site
- High-quality, hosted VoIP telephony with Computer-Telephony Integration (CTI) functionality equivalent to the highest-end PBX systems today.
- VPN tunnels between sites that are so fast they emulate LAN traffic
- Tunnels to hosted, leased SW application servers enabling all SW to be leased on-demand.

Video applications

As mentioned earlier, video is the most important new content enabled by Uni-DSL data rates and is the primary driver for next-generation DSL upgrades. In the future, at least three or four televisions in a house will each be able to receive on-demand video of HDTV quality and users will have movie or broadcast content at their fingertips. Wi-Fi enabled video cameras will finally make video conferencing and web-based live video streaming very high quality and very easy to use, to the point where almost anyone can set up a web-based “TV station”, and conferencing with remote family members really is almost like being there.

Audio applications include multi-channel Voice-over-IP telephony, multi-channel digital stereo broadcast, and audio on demand. One Uni-DSL connection can provide 4, 8, 24 or more telephone lines, which when coupled with *Computer-Telephony Integration* (CTI) application software, provides features previously found only on the most expensive enterprise PBX systems. Stereo systems connected to the Internet via Uni-DSL will be able to play virtually any broadcast content in the world, past or present, with very high sound quality.

Uni-DSL will enable new data applications requiring tens of megabits per second. For example, telecommuting with no perceived difference in access capability or experience whether at home or the office – or even the local coffee shop – will be possible. Online gaming will become more interactive and responsive, with participants spanning a neighborhood, metropolitan area or even the world. Smart appliances and home security systems now enabled by broadband will reach reliability and cost points that enable widespread adoption, just as wireless LAN proliferation has been driven by broadband growth and low cost points.

Wireless and wireline convergence

One of the more interesting advances enabled by Uni-DSL deployment - and upgrades to the mobile infractructure - is the convergence of wireless and wireline services. Mobile phones will register with a local Wi-Fi basestation upon entering a home or office, automatically registering location information if desired, and will receive a strong signal with no dropouts. In another example, vacationers could pan the home security camera and display the images on their cell phone screen – in near real time if they are at a Uni-DSL-enabled Wi-Fi hot spot.

Uni-DSL modems can also be set-up in a peer-to-peer configuration rather than an operator/user configuration any time a user needs to pass data from point to point over existing copper pairs. Several VDSL based peer-to-peer modems are in existence today, but Uni-DSL will support a bi-directional 100 Mbps Ethernet connection over CAT-3 copper according to the 802.3ah Ethernet First Mile (EFM) standard, resulting in better interoperability among vendors and lower costs for users. LECs may even use bonded Uni-DSL modems in this configuration to trunk data over copper pairs from the central office to the RT or cross connect when pulling new fiber is too costly.

Uni-DSL benefits operators

Key concerns of operators include reducing capital and operational costs, expanding service areas, adding new forms of revenue by providing enhanced services, and ultimately competing effectively with other types of broadband service providers.
Uni-DSL addresses these concerns in the following ways

- Provides a viable alternative to the tremendous capital expenditure of running fiber to every customer premises.
- Provides operators with a cost-effective means of generating new revenue and competing effectively with cable.
- Provides a unified upgrade path that can be deployed over time in stages.
- Reduces operational costs via unified network and system management for the entire service area, advanced single-ended (SELT) and dual-ended line testing (DELT) for diagnostics and repair, and the ability to pre-provision at selective locations.
- Enhances rate/reach performance through use of *dynamic spectrum management* and bonding.

North American operators typically estimate the cost of upgrading to FTTH at around $2,000 per user, not including CPE equipment. The portion of this that is saved by utilizing Uni-DSL from the SAI, pedestal, etc. varies by location and operator, but many operators have already analyzed the business case and stated their intent to use DSL for the last portion of the loop. As discussed throughout this paper, a deployment scheme using Uni-DSL still provides users with the data rates required to support feature rich triple-play services.

Uni-DSL provides a unified upgrade path that can be deployed over time in stages. For example, Uni-DSL infrastructure equipment can be deployed at the SAI (cross-connect box) to support a current ADSL user, and when that user wishes to upgrade to ADSL2+ or the highest Uni-DSL data rates, only the CPE equipment need be changed. The operator can remotely provision the SAI modem to increase its line bandwidth and enable the higher data rate requested.

By consolidating all loops and all DSL services on one platform, Uni-DSL enables operators to save significant network equipment and system management costs compared to deploying multiple platforms. Costs are also saved by enhanced SELT and DELT capability, coupled with enhanced network management features, such that problems or potential problems are detected and reported as soon as they occur. SELT and DELT can also be used to automatically test and adjust a line for optimal service and data rates.

For some locations and expected take rates, the costs and power consumption of Uni-DSL equipment will be low enough to facilitate pre-provisioning: installing a DSL modem for every potential user and making it ready to turn on remotely if and when each respective user requests service. For such deployments, the up-front capital costs are justified by the otherwise significant operational cost of sending a technician to the deployment site every time a new user requests service.

Uni-DSL technology enablers

A new approach to DSL is required in order to deliver the next-generation services to users within the cost constraints a highly competitive market imposes on operators. This section renews the discussion of a few of the technology advancements that will enable and drive Uni-DSL equipment and services.

- Higher bandwidth DMT
- Bonding
- Dynamic spectrum management

Discrete Multi-tone (DMT) is a modulation method in which the total available channel bandwidth is divided into multiple adjacent channels of equal bandwidth (tone spacing) each.

In ADSL and ADSL2, up to 256 channels (upstream plus downstream) with a bandwidth of 4312.5 Hz each are modulated at respective carrier frequencies N*4312.5 Hz, N=1 to 256, for a line bandwidth of 1.104 MHz. The elegance of DMT is that the modulation of all channels at once can be performed by a single IFFT transform, and demodulation can be performed by a single FFT transform.

ADSL2+ uses 512 tones for a line bandwidth of 2.208 MHz and a maximum downstream rate of 24 Mbps. VDSL2 standards, however, are targeting 4096 tones at 4312.5 Hz for a line bandwidth of 17.6 MHz, and possibly configurations that are even higher bandwidth.

The added tones and line bandwidth result in the data rates depicted in . Some VDSL1 modems deployed to date have implemented quadrature-amplitude modulation (QAM) instead of DMT, but the VDSL2 standards body is driving DMT for the line code choice due to its superior performance in maximizing the total channel signal-to-noise ratio, its ability to shape the transmission band very finely to avoid discrete interferers and noise sources, and its ability to flexibly and dynamically partition upstream and downstream channels.

Bonding is the grouping of multiple twisted pairs into one logical pipe. For customer locations with two or more pairs to the premises, a separate DSL modem pair (CO/CPE) can be placed on each of the lines and aggregated at the transport specific part of the modem data path. Uni-DSL silicon that supports multiple modems per chipset can therefore inherently support bonding, although an additional AFE may be required in the CPE and an additional port is used on the DSL access multiplexer.

The most prevalent form of bonding is expected to be ATM transport bonding of the two pairs already present at most customer premises. The data rate available is the sum of the individual lines, possibly more if using DSM in conjunction (see below).

For ADSL2+, this means two bonded loops can support more than 25 Mbps at a distance of up to 8 kft from the RT, enough to supply 90+% of residences with triple-play services. Enterprise locations and service provider uplinks will typically have four or more pairs available for bonding, allowing aggregate pipes approaching fast Ethernet rates at several thousand feet. Bonding can also be done when using Ethernet as the transport, as defined in the IEEE 802.3ah specification for Ethernet over twisted pair copper.

Dynamic Spectrum Management *(DSM)* refers to techniques applied to DSL systems that minimize the effects of crosstalk between copper pairs in the loop plant. A number of such techniques are being developed and implemented, and are generally categorized as Level 0 through Level 3.

In Level 0 DSM, each modem operates independently. Modems transmit as little power as needed to achieve their target transmission rate, resulting in lower overall crosstalk in the network such that total average power transmitted across all modems is minimized.

In Level 1 and 2 DSM, each modem reports line statistics to *a Network Management Entity* (NME) that then calculates the best parameters for each modem in the network and commands the modems to adjust their transmission characteristics accordingly. Adjustments are then made to band shaping, power per tone, bits per tone, etc. to minimize power consumption and crosstalk while maintaining necessary data rates. Level 1 and 2 differ in the amount of information that is reported to the NME and used to configure the system.

Level 3 DSM is also known as vectoring, which is analogous to the multiple-in multiple-out (MIMO) methods of Wireless LAN.

In vectoring, crosstalk between modems is cancelled by performing a complex matrix transformation on the received tones from the vectored modems. In addition, as the modems are decoded, the decision errors from the tone decoding of one modem are fed back to the other modems. The matrix multiply is referred to as the *feed-forward* stage and is used to cancel far end crosstalk (FEXT); the feedback stage is referred to as *noise de-correlation* since it is used to remove correlated noise components between modem lines. Matrix coefficients are calculated during initialization and updated during operation.

Figure 5 shows an example of the performance improvement that can be expected from vectored bonding versus simple bonding. Consider the 1000 ft loop length: without vectoring the two bonded pairs provide double the aggregate data rate of a single pair, or roughly 140 Mbps. When these two bonded modems are vectored to enable FEXT and noise cancellation, an additional 40 Mbps is added. Alternatively, at a data rate of 140 Mbps supported by two bonded pairs, vectoring increases the maximum loop length from 1000 to 2000 ft, a four times increase in service area.

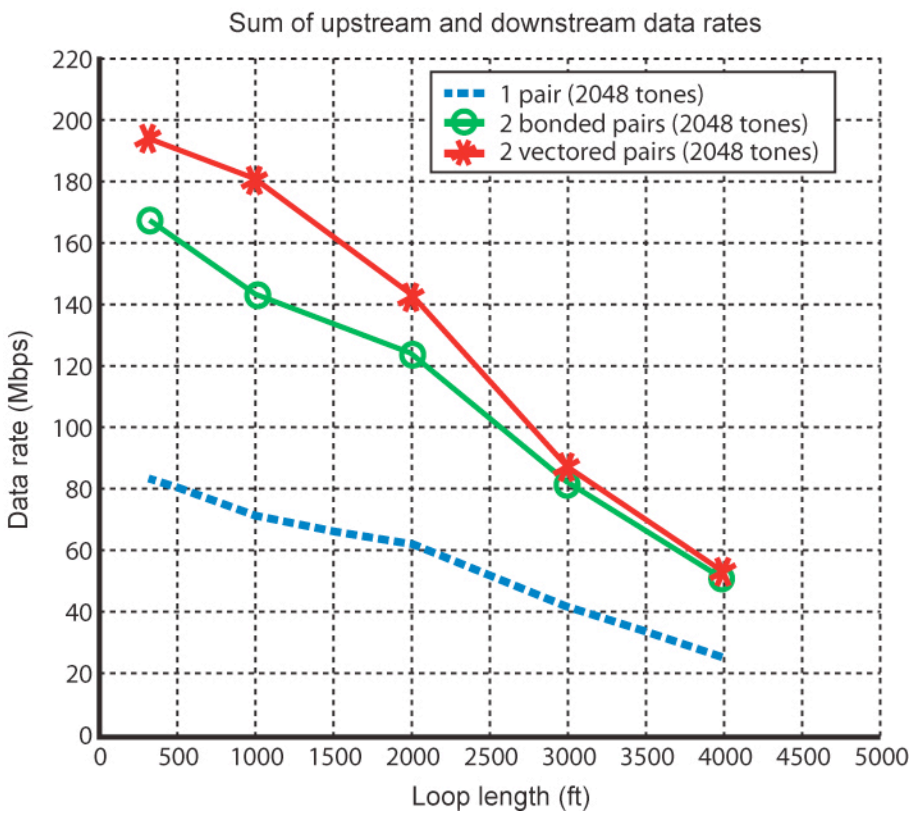

Figure 5: Performance of two bonded pairs without vectoring vs. two bonded pairs with vectoring

4. Product differentiation through silicon

Many aspects of Uni-DSL are or will be standardized, and history proves the value of such standardization efforts: enhanced interoperability and competition, leading to a wide range of cost-effective consumer choices, leading to widespread adoption of a new technology.

Beyond the standards, DSL chipset manufacturers differentiate themselves in the area of performance (rate/reach), interoperability with other vendors, enhanced data processing features to maximize the user experience, and enhanced OA&M features to minimize provisioning, maintenance and upgrade costs for operators.

Chipset manufacturers also differentiate themselves by supplying a wide breadth of complete broadband technology solutions from one source, and by providing a very reliable supply of cost-effective semiconductors at all stages of the product lifecycle.

TI's DSL interoperability and performance are known throughout the industry to be world class, helping drive TI's position as a market leader in both ADSL CO and CPE equipment. TI pioneered development of the first standardized ADSL (g.dmt) and is a leading contributor to the emerging VDSL2 standard. Other milestones include the first complete solutions for ADSL integrated access devices (IADs) and voice gateways and the first to integrate analog front end and processor into a single DSL router-on-a-chip.

Both the Uni-DSL platform and many of the broadband endpoints integrated with it (see) are enabled by TI's underlying semiconductor technology. Broadband endpoints, Uni-DSL premises access gateways, and Uni-DSL infrastructure gateways are all based on signal processing systems from TI. These signal processing systems are integrated, application specific systems consisting of DSPs, RISC processors, analog, mixed signal, power management and software, with industry leading level of system integration, power, footprint and cost.

TI designs these broadband systems in the context of the overall networked system in which they reside, taking into account overall system performance considerations like QOS, throughput and security. Trouble-shooting capabilities are designed into the systems to allow overall performance and diagnostic analysis.

TI builds its broadband solutions from a common modular architecture that provides a complete hardware and software solution with the versatility to serve as the basis for a full line of broadband products, saving development resources and reducing time-to-market for the manufacturer. Customers are able to build multiple solutions from a common architecture, speeding their time to market and lowering overall system cost.

Lastly, TI's manufacturing capacity provides quick ramp-to-volume and does not depend on third parties. From reference design to prototype to mass production, TI technology and products are readily available to help system vendors deliver winning products.

Summary

Texas Instruments is developing Uni-DSL, the next generation DSL delivery platform for deployment in fiber plus copper networks. Uni-DSL provides universal DSL service with data rates up to 200 Mbps, enabling feature-rich video, voice and data services for users. For operators, Uni-DSL provides a unified, cost-effective way to deliver these services in order to increase revenue and profit and compete effectively with other broadband service providers.

TI has a strong history in broadband and DSL and is currently a major supplier of DSL, Cable, wireless LAN, VoIP and video/audio silicon solutions. By possessing all the necessary technology, system expertise and manufacturing capability to provide equipment vendors with complete and innovative solutions for both infrastructure and end-point devices, TI is uniquely qualified to supply both Uni-DSL and all the surrounding broadband technology with which it integrates.

About the Author
Douglas Chrissan is the program manager for Uni-DSL central office systems within Texas Instruments' Broadband Communications Group. He has twelve years of industry experience in communications and embedded systems, including prior senior management and senior engineering positions at 8x8, Inc. and Hughes Aircraft Company. Mr. Chrissan received his B.S. and M.S. from the University of Southern California and a Ph.D. from Stanford University, all in electrical engineering.