STRATEGY WHITE PAPER

# Voice over DSL

## The Key to Next Generation Voice/ Data Services

Voice over DSL (VoDSL) allows the end user to consume voice-band telecommunications services via existing devices but using data access technology on copper wires, namely, digital subscriber line (DSL). End users can enjoy cost savings of combined voice and data access without having to replace existing devices.

VoDSL has been widely adopted in the telecommunications industry since its first appearance. This document will explore the key drivers of this technology in more detail and will examine some of the technical aspects of VoDSL and its main value proposition.

ARCHITECTS OF AN INTERNET WORLD ALCATEL

## Executive Summary


Voice over DSL (VoDSL) is being widely adopted in the telecommunications industry for the following reasons:

- The drive to voice/data convergence
- The success of DSL and other technologies that now allow "voice over" solutions
- The market opportunities created by new ways of doing business

### The Case for VoDSL

The main value proposition of VoDSL is this: It offers multiple voice connections simultaneously with data. This is particularly significant for small and medium-sized businesses where numerous voice lines are required. It will also be important for Small Office/Home Office (SOHO) customers and residential users who require a second line at the desktop.

### VoDSL Technology

VoDSL allows the end user to consume voice-band telecommunications services via existing devices but using data access technology on copper wires, namely, DSL. End users can enjoy cost savings of combined voice and data access without having to replace existing devices.

From a technology point of view, VoDSL is characterized by the fact that both voice and data are digitally combined and transported over the DSL access architecture. The IAD is used for mixing voice and data.

Moving from end user to the public network, the combining of voice and data occurs in the customer premises equipment (CPE), while the segregation occurs at the far end of the access network. At that point, data is fed into the edge of the Internet service provider's data network through a broadband remote access server (BRAS) and voice is fed into local existing switching equipment through a voice gateway.

### Future Developments

VoDSL architecture presents a compelling scenario for several independent future developments:

- All Digital Loop — ADSL's move toward packet-only access technology, in which a universal CPE will allow the provision of voice and data access to a mass market of mostly residential customers.
- Next Generation Networks — Convergence attained in both access and core networks, using a call server (softswitch) approach, leading to operational cost savings and new voice/data services.

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## Introduction

Voice over DSL (VoDSL) is a new service that has been widely adopted in the telecommunications industry. The following key drivers explain why:

- The continuing drive toward voice/data convergence, in order to reduce overall network usage costs and, indirectly, to reduce the cost of telecommunication services
- The success of digital subscriber line (DSL) technologies, combined with other technological evolutions, allowing for technical, cost-effective "voice over" solutions
- The market opportunities created by the changing way of doing business

This document will explore these drivers in more detail. To begin, however, we will examine the technical aspects of VoDSL and its main value proposition.

### What is VoDSL?

In today's telecom world, DSL is a well-known broadband access technology. More specifically, asymmetric DSL (ADSL) has gained considerable attention in both the residential and small and medium enterprise (SME) markets as a convenient way to gain access to high speed Internet services. It should be noted that the VoDSL concept is applicable to several DSL flavors, including single pair high bit rate DSL (SHDSL).

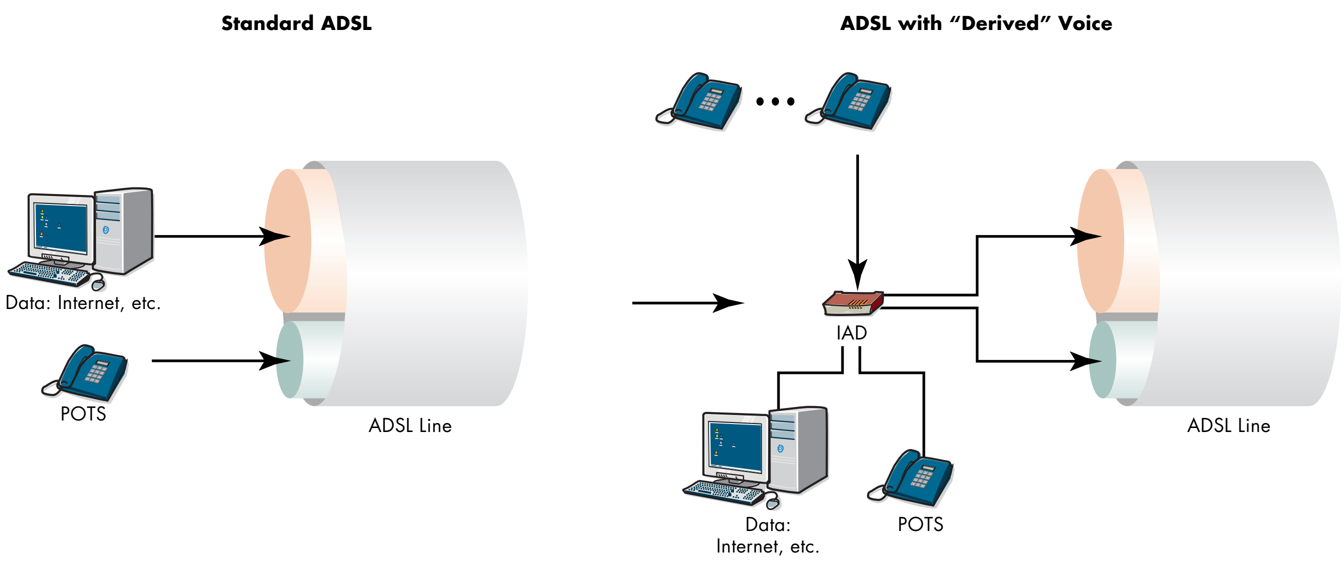
The ADSL case is particularly interesting as it also offers voice and data simultaneously, but in a different way than VoDSL. VoDSL and overlay POTS are quite different and are explained below.

The capability to overlay data services on existing POTS service, with minimal interference, has contributed to the success of ADSL. For the end user, this means:

- Always-on service capability — No need to dial up, because the Internet Protocol (IP) connection is always available, mirroring the office networking model, in which network resources are available all the time.
- Virtual second voice line — Unlike a modem connection, the voice line remains available for incoming and outgoing calls.

For the operator, the service overlay allows the installation of ADSL in the whole network, independent of the type of narrowband (NB) switches installed — ADSL works even with electro-mechanical voice switches. In Figure 1, the analog POTS overlay on the digital ADSL bit stream pipe is demonstrated by two different pipes contained in a single pipe, representing the copper line. The "analog POTS" pipe allows connection of just one telephone set (or any other device that hooks on an analog line, such as a fax or dialup modem). The digital pipe allows transmission of high speed Internet access via browsers running on the PC. The overlay POTS, however, only allows for a single voice line together with high speed data.

**Figure 1: Voice Overlay in ADSL vs. Voice Over DSL**



The VoDSL is depicted along the right-hand side of Figure 1: an Integrated Access Device, or IAD, multiplexes the traffic of both the PC and one or more telephone sets (or faxes or modems) onto the high speed digital pipe offered by ADSL. The number of telephone sets that can be handled is only limited by the bandwidth of the digital pipe. Each line is referred to as a “derived” line. Note that, at the same time, in the case of ADSL, the “overlay” line can remain.

Referring to the left-hand side of Figure 1, another device (the ADSL modem) is also required, but not drawn, as the traffic remains digital (from the Ethernet to the ADSL bit pipe). A conversion from analog to digital will take place in the IAD.

The main value proposition now becomes evident: VoDSL offers multiple voice connections simultaneously with data. This is particularly significant for small and medium-sized businesses where numerous voice lines are required. IADs, with up to 16 derived lines, are expected to be typical. A particular advantage, assuming an end user has the IAD installed, will be the ability of the service provider to “soft provision” voice lines. In other words, a few keystrokes in a management center will be enough to activate another derived line. This will save significantly on the truck rolls required to increase the number of external lines for a business user. However, from a business perspective, the revenue-generating capability offered by adding voice to data is the main reason a service provider would invest in and deploy DSL access.

### Voice/Data Convergence

Convergence of voice and data in telecommunications is not a new paradigm. Serious efforts at voice/data convergence were attempted with the introduction of ISDN. However, real data applications did not exist in the early days, so ISDN did not pay off. With the introduction of ATM the transport and switching of voice and data over the same infrastructure was again addressed. Indeed, even the cell length decision was based on the ability to transport good quality. However, it took several years before the equipment was available at acceptable prices. Today, both ATM and IP (or IP over ATM) are candidates as basic technologies for converged networking, as both allow a potential lower network cost as well as lower operation and maintenance costs.

Indeed, the same lines and equipment can be used for both services. This means that maintenance teams need experience in only one technology. Network extension can be realized using a single type of equipment. When dealing with only one type of bearer service, it is much easier to control the network. Lower costs will also result because line and equipment resources can be shared among voice- and data-based services. In many cases, statistical multiplexing can lead to serious bandwidth savings as well as network equipment savings.

The evolution to converged worldwide networking will not come overnight. The introduction of convergence in certain parts of the network will come first. Evidently, the access network is one area of focus. A service in which voice and data are combined at the customer premises, using an IAD, and are then separated at the access node (a DSLAM, for example), allows service providers to enjoy the significant cost savings that result from convergence.

The drive to voice and data convergence is also driving the development of control planes. The idea of softswitches is to move call and telecom service handling from today’s PSTN switches onto new servers hooked up to an all-packet network. The most promising aspect of this is that the servers will allow the easy creation of new services (at the speed data services are created on the Internet). Imagine the almost limitless combinations of PC and telephony applications that will be possible — unified messaging, that is, allowing access to e-mail, voice mail and faxes via a common interface on the computer or by telephone, being one example. However, there is a long way to go before the level of today’s PSTN services are reached. This is not surprising, if we consider how long telephony service has been deployed and evolving, meeting end user needs.

An architecture that makes use of the PSTN approach to services is therefore most welcome. VoDSL today, with an architecture similar to the PSTN, is a very promising first step to so-called next generation networks (NGNs).

### Changing the Way of Doing Business

Today's changing lifestyle will help stimulate the voice over DSL market.

Modern businesses need exactly what VoDSL brings in an integrated form: voice and data connectivity. In addition to the existing voice facilities, most businesses need the capability to exchange high amounts of data (e.g., an updated catalogue, a picture of a new engine, detailed product views, etc.). In addition, expectations for computer telephony integration are high (for example, the unified messaging or auto-attendant). Although, today, larger businesses have sophisticated infrastructures for both data and voice communication needs, smaller businesses are somewhat underserved. There is no doubt that heavy demand for data exists in the present e-business environment. Combining the data offer with the substitution or extension of voice access needs will be the main business proposal of VoDSL.

The residential user is at the other end of the spectrum. VoDSL can offer the residential customer a second or third line. Note that, recently, the demand for second lines has increased significantly, driven by the need for simultaneous voice and Internet access. ADSL can meet this need directly using the telephone line in overlay. Nevertheless, demand for extra telephone lines is expected to grow continuously as modern households require more simultaneous communications. A number of social and technological factors, including the growth of mobile, will drive this market. But for VoDSL to hit the residential market fully, cost-effective IADs tailored to the consumer market are needed.

## The Case for VoDSL

### The DSL Success Story

After the first successes of ADSL, it became apparent that even more extensive voice services could be offered on ADSL and, more generally, over xDSL targeted at specific markets. Recent evolutions in the technology enable new ways of providing access to both high speed data and voice services. This is driven by the intrinsic bandwidth capabilities of xDSL, as well as progress in voice compression, echo cancelling, DSP technology and silicon technology in general.

Indeed, DSL technology offers high data bandwidth capabilities, as well as the capability to offer additional voice services, integrated with the DSL data offering.

The VoDSL solution is independent of the DSL technology used to connect the end user. This will allow a wide application of VoDSL. Where ADSL is well suited for residential users and the lower end of the SMEs (i.e., single person businesses, small office/home office (SOHO) segments), SHDSL solutions best fit the requirements of most of the higher end SMEs. Note that "higher end" is relative here, as DSL bandwidth is restricted to serving telecommunication needs of enterprises that are telecom intensive and have approximately 50 employees or more. Clearly, fiber optics and VDSL will open new horizons.

Thinking longer term (a few years from now), ADSL will likely evolve to become a mass-market product incorporating several simplifications and cost reductions. For example, it will operate without overlay on an existing voice channel, and all voice will be carried in-band as data. It is thought that this all digital loop (ADL) will be used in a second wave of mass deployments for the residential market as it represents clean, high bandwidth data access for everyone. A customer needing just a telephone will also receive a DSL line, ensuring that the customer is prepared in case data is needed later. In fact, VoDSL deployment with ADL is a smart service for a provider to target right now.

All digital loop will make it possible to avoid using expensive and cumbersome POTS splitters, achieving a major breakthrough in ADSL density at the central office site, and allow the operator significant savings on the cost of ownership. Section 6.1 in this paper is devoted to ADL.

### Main Market Segments

For voice over DSL, two main market segments are the initial focus:

- Small and medium enterprise (SME) and small office/home office (SOHO) customers: A significant percentage of business customers have data connectivity needs in the order of 500 kb/s (mainly symmetric, but also asymmetric, in the case of Internet access needs). The voice needs are typically fulfilled with four to eight outgoing telephone lines. Using simple adaptive differential pulse code modulation (ADPCM) voice coding, these telephone lines consume, at peak usage, only 128 to "256 kb/s of the xDSL bandwidth resources (making an abstraction of overhead bandwidth). The total ADSL/ SHDSL bandwidth capacity is up to 8 Mb/s downstream and 800 kb/s upstream.
- Residential customers: High-end residential customers will appreciate the extra two to four voice lines that VoDSL can bring. For "average" residential users, a second line at the desktop, where the ADSL is terminated and the PC is positioned, is also compelling. This second voice line can be used for home office needs, while data connectivity to the corporate LAN with the PC is realized via the ADSL data capability.

Competition among service providers will accelerate the play in this market significantly. There is no doubt that the SME market will be targeted first. If SMEs are the object of "cherry picking", the SOHOs and high-end residential segments will represent another large group to be addressed in the next step.

## Benefits for the End User

Regardless of the benefits for a service provider, VoDSL will only succeed when benefits for the end user are compelling. This section discusses some of the major benefits for end users.

### *Single provider*

Voice and data convergence allows the "one-stop shopping" requirement that helps SMEs focus on their own business. Indeed, the end user can subscribe to data and voice services (one or more additional lines) at the same time, at a kiosk of the service provider. The service provider can then maximize this single interface with the customer, in order to handle questions and/or complaints. For business users, receiving a single bill will minimize the time required in verifying and tracking communication expenses.

In fact, this "outsourcing" is a general trend in support of a focus on the "core business". Note that this does not conflict with a parallel need for flexibility, which is under the control of the end user. The service provider should especially consider this when thinking in terms of differentiated services.

### *Lower costs*

Given the benefits of the VoDSL solution (see "Benefits for the Service Provider") to the service provider, a lower price point is expected, compared to traditional voice services. This is especially the case since the service provider will be able to sell both data and voice services in a bundled form. One would expect that costs of separate voice and data services to always be more expensive in total.

The pricing flexibility that bundled services offer will be a major tool in attracting the attention of the business end user.

***Voice quality***

VoDSL provides excellent voice quality that is the equal of digital telephony like ISDN. Indeed, impairments of analog lines are not encountered, as a digital transport is foreseen. The voice coding as traditional voice system, i.e., pulse code modulation (PCM or G.711), can be applied when needed. However, a code that uses half the bandwidth of PCM (ADPCM or G.726) can also be applied, without any loss of voice quality.

The reader should know that VoDSL goes together with echo cancellation techniques in both the IAD and voice gateway. A good design will make it possible to avoid quality impairments due to talker echo created in the existing analog PSTN network. The echo is particularly annoying when the delay is longer than 25 ms. Echo should be filtered out in a packet network, where additional delays are created, mostly due to packetization.

***Single communication box***

Advanced IADs meet the need for one single communication box to do it all. One box means minimal complexity in maintaining communication facilities. IADs are also able to adapt to meet a variety of service interface needs for the end user:

- Number of ports
- Types of WAN interfaces
- Functionality (firewall, bridge or router, VPN)
- Types of voice interfaces (ISDN, analog, T1/E1)
- Specific solutions addressing home/office wiring problems (HomePNA, wireless, Ethernet supporting VLANs)
- Combinations of dedicated voice and data interfaces (V.35 to interconnect with external routers)

The single IAD box, with its wide variety of capabilities, will also surely be under significant price reduction pressure.

***Fast service delivery***

With VoDSL, waiting to get a voice line enabled (or removed) will be history. Assuming that the customer has DSL access and a voice-enabled CPE installed, it is simply a matter of a few minutes to activate another voice line. The provisioning can be accomplished by an operator typing in a few commands on a management station that controls the interface with the PSTN. The operator is informed of the new request via a phone call. A more sophisticated process, known as "flowthrough provisioning", automates the entire process from subscriber registration to enabling the service.

Service enabling can be made even more flexible if the customer can type in a few commands on a web interface that automatically informs the management station. Self-provisioning will thus go hand in hand with VoDSL.

Short wait times for provisioning are a highly appreciated feature of voice services. One can state it also in the following way: end users are likely to change service providers if they are confronted with long wait times (longer than a day). For some businesses this facility — namely, the "just in time" provisioning of voice lines — can be extremely important. For example, a travel agency might want an additional line in the prime season, when people are planning their trips. An extra employee, hired just for that period, could use the extra line. Or, think of the florist that needs this extra employee just to cover a busy holiday, such as Mother's Day.

***New services***

Although VoDSL primarily replicates traditional voice access, new and interesting revenue-generating services will also be created. As indicated above, a service in which end users can fix their own profiles for voice lines (facilities on different numbers) might be of great interest. For example, an end user could order that a home office line be transferred to a colleague at work during holidays.

Another new type of service that is expected to attract attention is the ability to provide voice services to a company's PBX in order to allow home workers to recreate their working environment at home. In other words, the idea of data virtual private networks will be extended to voice VPNs.

Lesser known services, such as Centrex (providing PABX features from the local exchange), might also receive new market attention if the service mix and pricing are right. Centrex is somewhat limited outside the U.S., due to the subscription fees associated with each copper line. As this cost might vanish with VoDSL, a Centrex service could be an interesting alternative to buying a PABX.

## Benefits for the Service Provider

From the service provider's perspective, DSL offers considerable opportunities in terms of providing a source of incremental revenue and a way of reducing costs.

Both the incumbent operators, such as incumbent local exchange carriers (ILECs) and national telephone operators, as well as newcomers, such as competitive local exchange carriers (CLECs) and new operators will benefit from deploying VoDSL services. Each type of operator will have different priorities in terms of applications, and might deploy different network architectures. A closer look at these service provider benefits follows. (Note that an "out of region" ILEC is a special type of CLEC.)

The successful competitor is the one that owns the customer, that is, the one who serves all his or her communication needs.

### CLECs

***Revenue generation***

Voice over DSL is undoubtedly the killer application for new operators, or CLECs, trying to extend their customer base and revenues, either through voice or data applications.

Voice CLECs are confronted with high initial investments for PSTN equipment (i.e., the local exchange) as well as huge variable costs for hiring access facilities from the local incumbent. In order to maximize profits, CLECs are mainly serving the larger business subscribers (more than 50 employees). For these end users, a single access facility provides more than 12 voice lines, which generate sufficient monthly revenue. Access is typically realized via leased line using TDM technology (E1 or T1 circuits). Both voice and data requirements of these businesses are offered over TDM. Addressing smaller businesses (less than 50 employees) via partial-loaded leased facilities does not always lead to a profitable situation.

DSL, however, allows CLECs to profit from delivering data-only applications to small business and, in some cases, to residential users, as the demand for data is always increasing. Symmetric DSL (SDSL) and ADSL are the most popular versions. The so-called "data" CLECs (or DLECs) limit their business to this segment.

Voice CLECs are, in fact, best placed to diversify by offering DSL deployment for both data and voice, as they have the experience with the more complex part, that is, the voice. The complexity comes mainly from the fact that expectations of service capabilities are much higher for voice and because, over the many years legacy voice has existed, a multitude of new applications have been implemented and customers now want these new applications in their regular voice service. The VoDSL solution leverages existing telephony business in a transparent way over a data access infrastructure. It allows the voice CLEC to offer both voice and data, but now to a much larger potential customer base in the lower end of the SME segment.

From a data CLEC point of view, the picture is slightly different. By adding voice on the same infrastructure, the investments for data access can be leveraged for a new valuable source of revenue with a relatively small extra investment. Specifically, smaller business needs for voice are in the range of four to twelve voice lines, which can be integrated over the DSL high bandwidth pipe — be it ADSL or SHDSL — leaving sufficient extra bandwidth for data. The payback time for the necessary additional investments (for integrated access devices and the gateway) turns out to be well under six months. This is a compelling factor when addressing a market segment (i.e., small business) that has five to ten times as many customers as the larger enterprise market.

In order to address the SME segment, SHDSL might become the preferred option. Indeed, the high symmetric bandwidth capability of SHDSL access allows for a higher number of POTS lines (up to 16), leaving sufficient symmetric bandwidth for data.

It is not surprising, though, that mobile operators are also extremely interested in VoDSL, since the combined voice and data offering is seen as a possible source of revenue. The additional revenue from a few voice lines significantly improves the business case for DSL. It allows these operators to focus on the segment where they have experience, namely, the residential market. VoDSL will undoubtedly gain greater attention from exposure to this large segment of the market.

Competition between DSL providers and cable operators is expected to be another driver that opens the market to residential users. Many cable operators, today, offer both data and voice capabilities.

### ILECs

#### *Revenue generation for incumbents*

At present, it could be said that VoDSL "cannibalizes" the source of voice revenues of the incumbents. However, there are several good reasons that combined voice and data offerings will prove to be profitable.

Today, many SMEs struggle with a limited voice network, as the entry cost for new external lines is somewhat high and cumbersome to order. VoDSL can remove some of these obstacles (see "Benefits for the End User") and, therefore, can be easier to sell. The importance of bundled service cannot be overestimated. VoDSL will be extremely popular with small (and medium) businesses.

In today's fast growth business environment, the ability to sell easily extendable bundles of voice and data is quite ompelling. Service providers who can offer convenient bundles of voice and data will sell and increase their revenues.

The residential segment is also promising in terms of revenue for ILECs. If households can obtain additional voice lines easily, eventually they will be sure to add phones, thus creating new revenue. It is expected that higher standards of living, and competitive pressure leading to lower prices will result in greater telephony consumption. The phenomenon of Global System Mobile Communications (GSM) is typical. Numerous households have in this way increased their total telecom traffic.

It is believed that the residential subscriber will continue to opt for multiple voice lines combined with data access. This type of communication capability will eventually become the norm in every home.

#### *Market protection*

Clearly, the incumbent service provider will protect its current lucrative voice market. One of the best ways to fight back is by using the same weapons as the competition, that is, by delivering DSL not only for data but also for voice.

While new operators will focus first on the SME market, ILECs will also be able to service the SOHO and residential markets cost-effectively. Indeed, the ILECs are well positioned — they own the copper and the lines terminate in their central offices. Unlike CLECs, ILECs have no collocation costs and do not have to lease unbundled copper.

In this sense, VoDSL will undoubtedly have a strategic importance for ILECs. It is expected that many European ILECs are anticipating these market changes and are clearly interested in deploying VoDSL sooner rather than later.

#### *ISDN alternative*

VoDSL can be seen as a more interesting alternative for ISDN for the SOHO market, for high-end residential, as well as for the base residential subscriber. Indeed, a few simultaneous voice lines and data can be combined over a single copper access. Success in this market will depend on price levels. It is believed that high integration of CPE HW can sustain a slightly higher price point than the current ISDN offering over the long term. End user interest is expected to be high, as the customer will be offered, in addition to two simultaneous voice lines, data access that is superior to ISDN in terms of bandwidth.

#### *Copper savings*

Apart from bundled service offerings, ILECs may also be interested mainly in copper savings. Indeed, VoDSL provides a perfect alternative to traditional pair gain (or digital added main line (DAML)) systems. Service providers could invest in DSL technology especially for this purpose, that is, for subscribers demanding more voice lines. In this case, VoDSL can be seen as a "data-ready" solution. When the end user's interest in highspeed data access increases, the operator can, via soft provisioning, activate the service. This demonstrates its superior value to existing pair gain systems.

Copper shortage alone can be a driver for VoDSL. Although in several countries copper is not yet exhausted, a few additional considerations should be noted.

First, there is the cost associated with each copper line (mostly due to maintenance activities for maintaining accessibility to it at a given quality). It is expected that these costs are approximately equal to the monthly fee for unbundled copper (e.g., U.S. $20 per month). The bottom line for both ILECs and CLECs is the same: maximize revenue per copper line by squeezing different services over those lines.

Second, in many developed countries, copper is becoming a scarce resource in the competitive environment created by the unbundling of the local loop. Competition increases demand. Unused copper (the physical lines) should be seen as another source of revenue for the ILEC.

Third, copper needs will also increase with bonding, that is, increasing the total bandwidth by applying inverse multiplexing techniques.

Finally, upgrading investments can be postponed by optimizing the use of already existing copper.

### A Cost-effective Solution for any Type of Service Provider

The key goal of convergence is to reduce operation and maintenance costs. The most obvious cost reduction can be seen from the fact that VoDSL allows for voice and data services on a single network: no dedicated equipment is required for providing voice, nor any other for providing data. Only a single wire is required for multiple voice lines and data transport, another important factor in the total cost picture. Indeed, each wire is associated with some costs maintenance, wiring, repair), which the owner (in most cases, the incumbent service provider) has to bear. VoDSL will allow for copper recuperation that will pay back either in reduced costs or by reselling of copper to new operators.

Reduced wiring is another reason why VoDSL will decrease operation costs. At the customer premises network, for example, the existing public wiring to the office or home will be reused to connect a voice-enabled modem or IAD. At the central office, the VoDSL allows the adding of new voice lines without any wiring at all (provided DSL service has been installed).

Deployment of VoDSL, compared to a traditional voice network, will be cheaper as the number of truck rolls can be reduced, by using soft provisioning to add or remove voice lines for a VoDSL subscriber. Avoiding one truck roll can cover the costs of providing the “voice over” equipment for a single derived line.

The VoDSL solution also allows for optimized bandwidth usage as both voice and data are transported and switched in the same way, making dynamic bandwidth usage possible. If no voice calls are ongoing, the associated bandwidth on a DSL line (and also a fraction of the equipment) is freed up for data services.

From the point of view of a service provider who invests in DSL, the extra investments required on top of DSL infrastructure for providing voice are marginal compared to investments in traditional switching. Leveraging DSL platforms in this way can be seen as another major cost saver. Specifically, the integration of a DSLAM and a voice gateway is one compelling option for ILECs.

Finally, one should remember that VoDSL employs traditional access technologies (such as GR-303 and V5.2) that use lower cost access and switching equipment. Clearly, avoiding analog line circuits in the central office (CO) helps lower CO equipment costs (limited wiring in COs is due to the use of concentrated interfaces). Eventually, line circuits in the CPE will come at a lower cost, as only short-haul requirements exist, and high integration of voice and data circuits is expected.

## VoDSL Technology

### End-to-end Architecture for VoDSL

VoDSL allows the end user to consume voice-band telecommunication services via existing devices (e.g., plain old telephone, fax), but using the newly deployed data access technology on copper wires, namely, DSL. End users can enjoy the cost savings of the combined data and voice access without having to replace their existing devices.

From a technology point of view, VoDSL is characterized by the fact that both voice and data are digitally combined and transported over the DSL access architecture. The IAD is used for mixing voice and data. ATM AAL2 has been chosen as the transfer mode (DSL Forum and ATM Forum). Moving from end user to the public network, the combining of voice and data occurs in the CPE, while the segregation occurs at the far end of the access network. At that point, data is fed into the edge of the Internet service provider's (ISP's) data network through a broadband remote access server (BRAS) and voice is fed into local existing switching equipment (i.e., local exchanges or, in U.S. terminology, Class 5 switches) through a voice gateway (VGW).

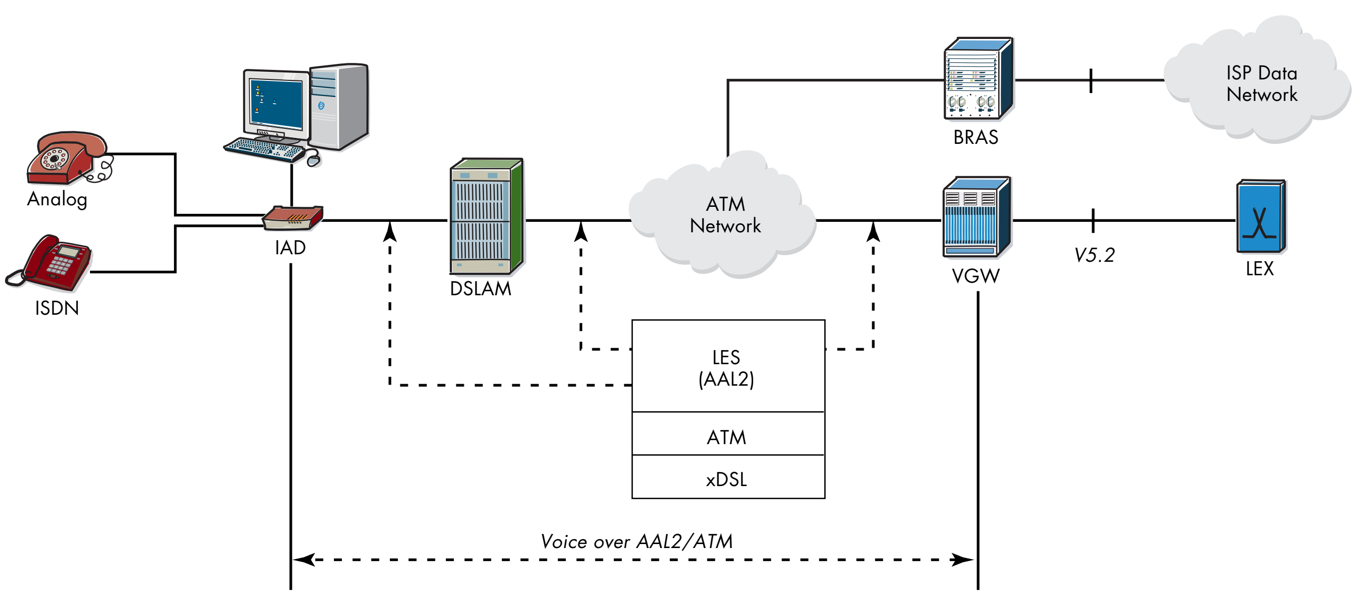
The architecture, depicted in Figure 2, complies with the loop emulation service (LES — AAL2) standardized by the ATM Forum.

From the customer premises to the PSTN point of presence, the following applies for VoDSL:

- On the CPE side, a built-in gateway function converts traffic from existing end user interfaces for voice band (e.g., POTS interface provided over RJ-11 connectors) to packetized voice (i.e., ATM) for transport over the xDSL transport facility, and vice versa. Multiple voice connections are multiplexed into a single virtual circuit using AAL2.
- The DSLAM performs its regular xDSL modem termination and traffic aggregation via ATM multiplexing. Any type of DSL can be used as the physical layer connecting the CPE.
- The "voice gateway" converts the packetized voice to existing interfaces (i.e., V5.2 or GR-303), connecting to the local exchange (LEX). Voice services delivered via the gateway functionality in "voice gateway" and CPE are called "derived voice services". At the CPE, the interfaces provided via RJ-11 jacks are correspondingly called "derived voice lines".

By adding gateway functionality to the CPE, the IAD provides the customer with multiple service interfaces. Later in this document the terms, CPE and IAD, are used interchangeably. The IAD performs the necessary functions to put voice band services from the user interfaces (POTS, ISDN) onto the xDSL line.

**Figure 2: VoDSL Reference Architecture**



The main functions of the IAD are:

- Termination of the voice user interfaces (POTS, ISDN)
- ATM AAL2 (de)multiplexing
- Voice handling function (compression, echo cancellation)
- Generation of signalling towards the voice gateway at input stimuli (POTS events) or just by relaying ISDN signalling
- Management from the gateway via an in-band interface

The gateway performs the necessary functions to interface in a correct format with the PSTN network. The main functions of the voice gateway are:

- Termination of the voice circuits
- ATM AAL2 (de)multiplexing (a single ATM VC carries all voice connections of one customer)
- Voice handling (compression, echo cancellation)
- IAD to voice gateway signalling termination and call control
- On-demand traffic concentration of the voice channels (a typical concentration for business subscribers being 4-to-1)
- Connectivity to a LEX via an open interface (e.g., V5.2 for ETSI market and GR-303 for the U.S. market)
- Management of the IADs via an in-band interface

The key element in the VoDSL architecture is that it allows for simultaneous voice and data services to the end user. It should be noted that the architecture allows centralization of the service handling part, namely, the LEX. This leads to stand-alone, centralized voice gateways. A typical case is when the ATM network is absent, that is, when the voice gateway is part of the DSLAM. By adding gateway functionality to the DSLAM, it is then leveraged to become more than just a DSLAM. Such devices should be referred to as integrated access platforms or multiservice access platforms.

## Network Configurations

A more detailed look at the network architecture for providing VoDSL follows, as well as a discussion of the evolution of VoDSL. Clearly, evolutionary factors may shape the decision on how to exploit voice and data from the beginning.

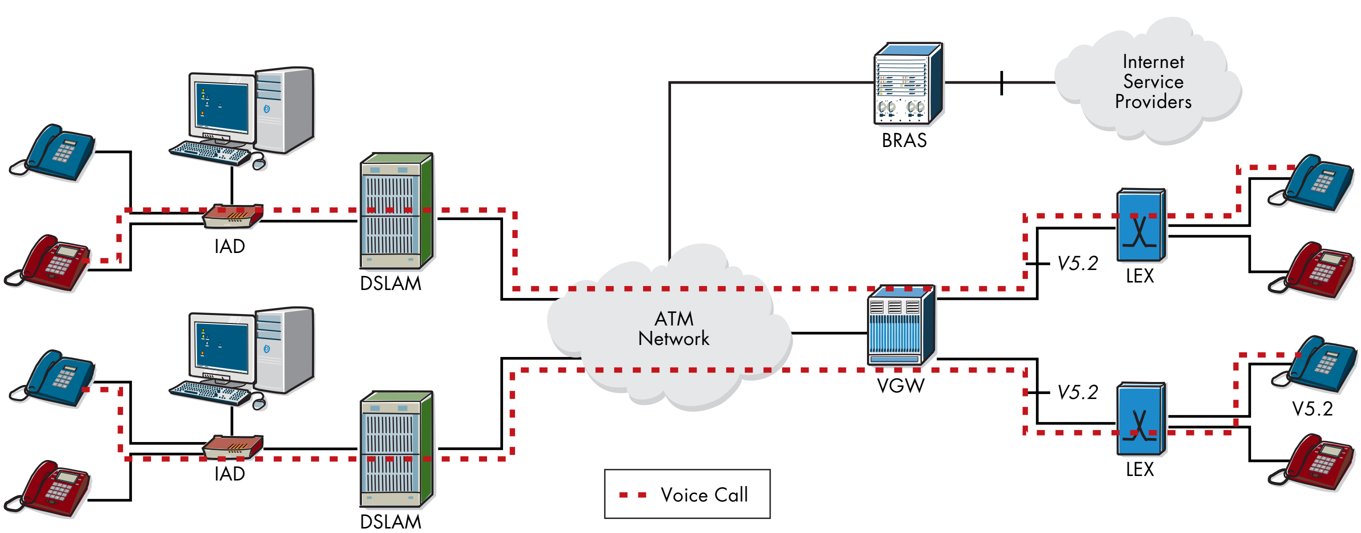
VGW functionality can be mapped on different network configurations. These configurations are illustrated below.

### *Standalone VoDSL gateways or centralized deployment*

Centralized VoDSL deployment is realized by using highly scalable VoDSL standalone gateways positioned at central locations in the network. This is shown in Figure 3.

Centralized deployment is mainly driven by initial cost considerations. Cost saving can be realized by sharing the common costs of the gateway itself and the concentrated interfacing (i.e., V5.2 in ETSI) at the local exchange, among a sufficient number of potential users. On top of these equipment costs, there are also costs associated with activating the service, where centralized operations tend

**Figure 3: Centralized VoDSL Deployment**



to be more efficient. For example, a distributed architecture would require that different experts visit the CO to install V5.2 interfaces and gateways.

As VoDSL evolves, decentralizing makes it possible to avoid some of the disadvantages associated with an overly centralized deployment. The most obvious disadvantage of centralizing is the need to backhaul a lot of traffic and hence consume large transport capacity. Imagine two neighboring VoDSL customers calling each other: The traffic travels from one IAD all the way over the DSL access network and an ATM network, up to the central gateway and across the narrowband switch (which is hardly a "local" exchange), and then the whole way back. This is necessary because the switching has to occur (by definition of the V5.2 interface) in the PSTN network.

For this reason, it is expected that CLECs will deploy in as decentralized a way as possible (except perhaps for the start-up of the service). In other words, a gateway will appear in every point of presence (PoP). Due to the huge costs of collocating narrowband switches, DSLAMs and gateways in the central office, CLECs are somewhat restricted in their ability to decentralize. Centralizing service deployment is added to the challenge of further centralizing customer administration, customer care, billing systems and network operations activities. In most cases this is not easy and, therefore, in order to minimize risk, further centralization will most probably not be coupled with new service deployments. For example, centralization will only be acceptable if number porting is implemented as well, which complicates the equation. Therefore, VoDSL is most easily deployed when leveraging the existing switches together with all operations and support systems. In other words, centralization or decentralization will depend on how centralized or decentralized the local exchanges are.

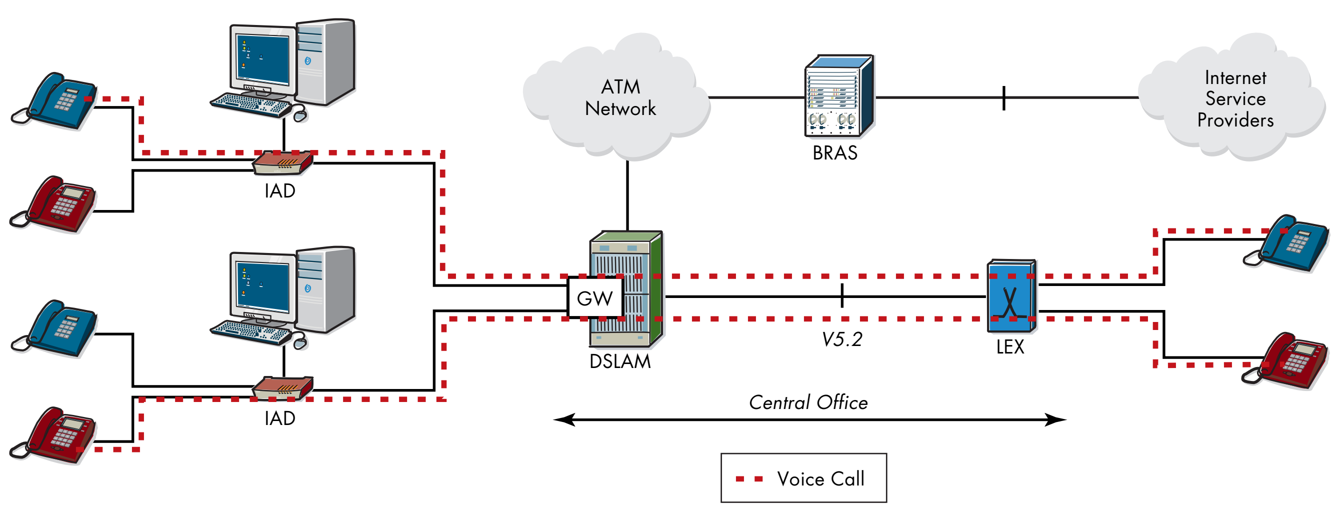
It should be noted that rolling out a centralized deployment might lead to scaling problems. Certain questions might need to be answered: Does the centralized local exchange have enough capacity? Is the gateway scalable enough? What is the cost of highly scalable systems?

Normally, an ILEC can decentralize up to the level of the central office. In fact, the choice is between a highly decentralized deployment or a more centralized deployment. CLECs, however, are somewhat limited to their points of presence (see "How the Landscape Will Evolve Over Time" for further detail on this option).

***Decentralized deployment and DSLAM and gateway integration***

Decentralized VoDSL deployment for an ILEC means that each central office gets voice gateway functionality. This can be realized cost-effectively by integrating the gateway inside the DSLAM. This is illustrated in Figure 4.

**Figure 4: Decentalized/Integrated Gateway Deployment**



By integrating the gateway inside the DSLAM, the operator can avoid the need for an ATM switch in each CO, hence significantly improving the total cost picture. There are a number of other reasons why this type of integration might be an advantage.

First, the integration allows for a cost-effective solution. This is mainly because common equipment (rack, power supply, processing power, ATM interfacing) can be shared with the DSLAM.

Further, the DSLAM becomes a single multiservice platform that requires single element management. In fact, the fewer the boxes, the easier it is to manage them. As described in the section on centralized deployment, it is evident that there is a huge advantage in leveraging existing narrowband switches together with back-end services. Existing operational support systems (OSSs) will typically be used for managing the narrowband switch. Evidently, in order to ensure smooth service activation, higher layer support systems linking both the narrowband exchange and the access network (including the voice gateway) are mandatory (independent of whether a centralized or decentralized architecture is used).

In a decentralized network, backhaul traffic is limited to a minimum, leading to significant cost savings on ATM switching and transmission equipment.

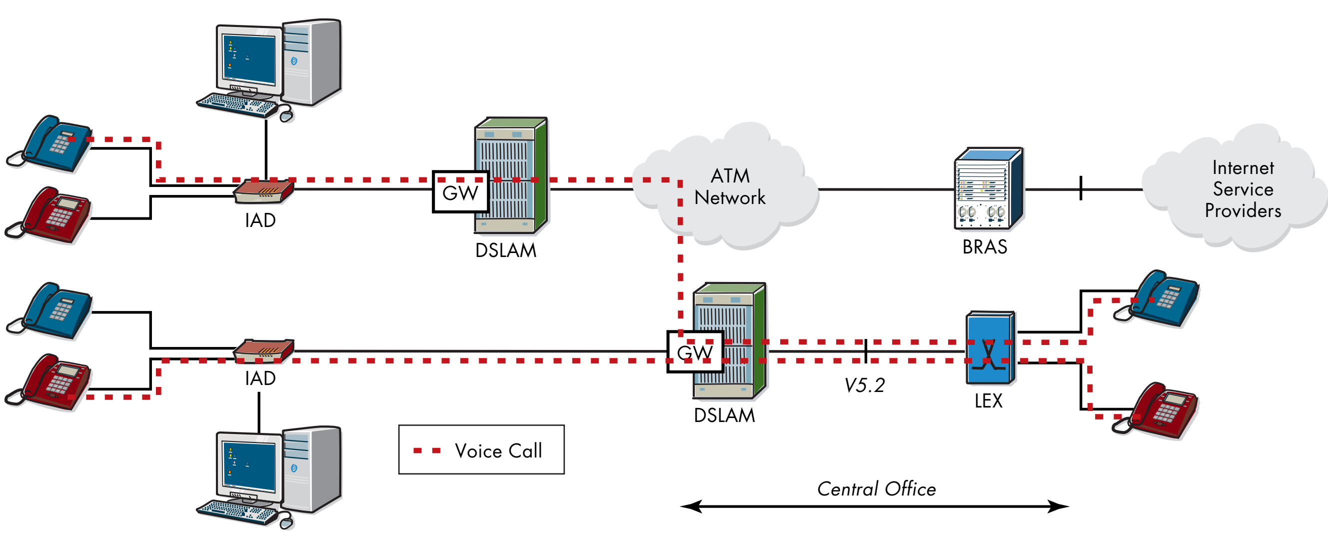
Note that a decentralized architecture also leads to savings on scaling costs. Initial VoDSL take-up may typically justify the addition of a small voice gateway within the DSLAM in the central office. This can include a moderate upgrade at the narrowband switch (concentrated interfaces are typically used). This could easily be accomplished in incremental stages as VoDSL take-up increases.

In the long term, it is expected that all investments in TDM switches will cease. Softswitches are expected to take control of voice gateways and/or new residential gateways (see “Toward Next Generation Networks”).

Softswitches, which are centralized servers, could handle the traffic from several central offices. Softswitches that can take over the traffic from highly centralized voice gateways could appear on the market. In many cases, it turns out that the existing PSTN is distributed in nature, and that new paradigms are adapting to this granularity.

Having said that, a decentralized architecture is, at least in the medium and long term, the most appropriate architecture. In order to lower the cost of introduction, initial deployments will tend toward centralization. A particularly interesting deployment scenario is one in which centralized deployment and gateway integration in DSLAMs are mixed.

**Figure 5: Mixed Use of Centralized and Distrinbuted Gateway**



***The best of both worlds: centralized and decentralized***
One interesting deployment option for an ILEC is to start up VoDSL using an integrated gateway in an area where large DSLAMs are deployed. Initially this gateway could also handle the voice traffic of other surrounding smaller DSLAMs. This approach could be used in cases where the cost of centralizing is less than the introductory cost of new gateways and V5.2 interfaces. This scenario is depicted in Figure 5 on page 12.

## How the Landscape Will Evolve Over Time

The VoDSL architecture presents a compelling scenario for future developments. Two main and independent evolutions are discussed:

> All digital loop: This represents the evolution of ADSL toward a packet-only access technology in which further improvements are realized with regard to performance, adapted to deliver all services and are much easier to operate. A universal CPE will allow the provision of voice and data access to a mass market of mostly residential customers.

> Toward next generation networks: In this architecture, convergence is attained in both access and core networks. A call server (also called a softswitch) approach will allow for additional operational cost savings and opens the way for a set of new voice/data services.

With both evolutions realized, multiple voice lines and data services will be equally accessible for all, independent of what service bundles they want and are willing to pay for.

The evolution of customer premises networks and new types of terminals is not discussed here, but will definitely be a part of future scenarios in which the line between voice and data services becomes more and more blurred and real multimedia services are offered.

### All Digital Loop

All digital loop is based on the fact that VoDSL allows for a digital integrated voice solution along with data services. Specifically, in the case of ADSL, overlay POTS can be replaced with derived voice. Loops will be exploited as fully digital high bandwidth access pipes, without any complications such as the need for cumbersome splitters, both at the central office and the customer premises.

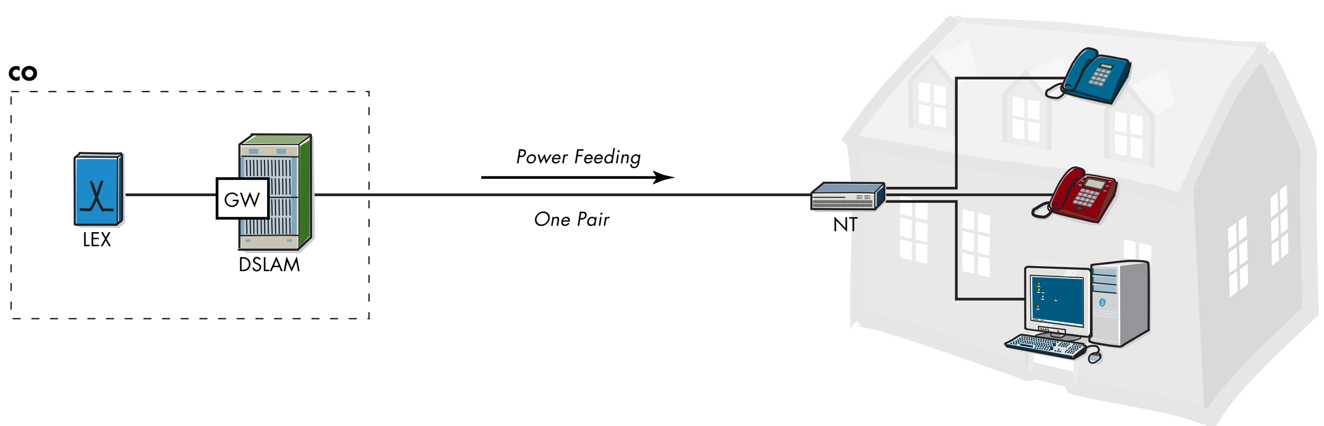
In the all digital loop scenario, as depicted in Figure 6, all voice is carried as digital in-band on the ADSL channel. Although a gateway and local exchange are depicted, the architecture beyond the access is irrelevant. Key features in the all digital loop include:

> The access is a full packet-based access technology.

> The ADSL technology is improved by extending the digital transmission to include the spectral bandwidth that was otherwise used by the overlay POTS or ISDN channel. The ADSL upstream bandwidth performance can be easily and significantly increased by bringing DMT coding down to DC frequencies.

> No splitters are needed on the CO side, lowering overall cost, and increasing the potential ADSL density further.

**Figure 6: All Digital Loop Reference Architecture**



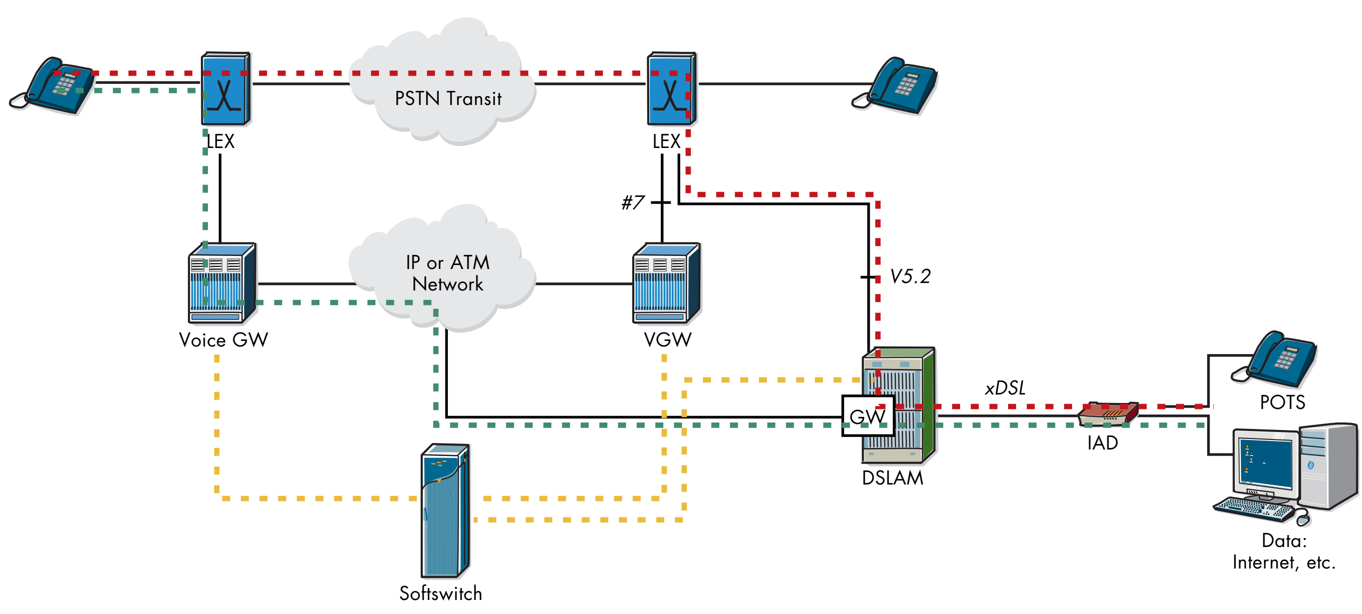
- A small voice gateway to an ISDN NT is needed at the CPE. In this case, the NT/gateway will typically offer an Ethernet and two analog short haul POTS interfaces. Because of the lack of splitters, this NT/gateway can be highly integrated. Other interfaces and architectures are possible for the CPE, including: ISDN S0 interfaces, wireless LAN interfaces (IEEE 802.11), HomePNA digital interfaces.
- For lifeline requirements, emergency power feeding will be an extremely interesting option for the residential user. Indeed, during emergency situations it is possible to dynamically limit the bandwidth of the ADSL signal to the minimum required (less than 100 kb/s), while other functions can be powered down (e.g., Ethernet driver), or operate in power saving modes. As a result, power consumption can be significantly reduced during power outages, and emergency remote powering becomes feasible.

Depending on the target ADSL penetration (greater than 20 percent), and depending on the network application (network growth, greenfield, residential areas, business parks, etc.), it will become economically attractive to implement data-only access networks based on pure ATM DSLAMs. In this end game architecture, voice-only services will also be offered over ADSL. The ADL becomes, in this case, the only (copper) loop for mass deployment to residential users. It is expected that this will be mixed with symmetric loops and bonded loops (i.e., combining the bandwidth of multiple copper loops) to serve small and medium, as well as large, enterprises. It is obvious that cost-effective IADs will be a condition for ADL to succeed in a serious way.

### Toward Next Generation Networks

Several benefits of the VoDSL solution outlined above are reinforced by a network solution, which brings about the convergence of voice and data in both the access and core networks. Several architectures have been proposed in the context of voice over Internet protocol (VoIP). Voice over Packet (VoP) is preferred as the term used to refer to these architectures since, in many cases, the top level features and advantages remain valid, whether voice and data are carried on ATM, IP frames or IP on top of ATM, in either the access or core network. Much of the final architecture at the transport level will depend on the deployment scheme (ATM vs. IP) followed by the service provider. Key for these fully packet-based next generation networks (NGNs), is that new services can easily be added by use of servers hooked up to the “all packet-based” network. The more the NGN is deployed, the more the gateways to the PSTN will disappear.

**Figure 7: VoDSL Evolution in Next Generation Networks**



Gateways are only needed at places where TDM is the only possible way to transport calls to their final destination. A next generation network is a network where handling of the voice calls is no longer performed by exchanges, but by centralized, high capacity call servers (CSs). The call server controls the gateways that perform the conversion to voice-over-packet, i.e., trunking gateways (TGWs).

Next generation network architectures are already being deployed in the core network. TGWs are typically positioned between the local exchange (Class 5) and a packet-based network (ATM or IP). In this way, the transit exchanges are replaced by more cost-effective router equipment. Call servers centralize the control, which leads to operational cost savings, while the use of voice compression permits bandwidth savings particularly on long-distance and intercontinental links.

The initial VoDSL scenario introduces gateway functionality at (or in) customer premises equipment and access nodes. The interface with the local exchange uses existing interfaces, that is, GR-303 for ANSI countries and V5.2 for ETSI countries. These interfaces are preferred, as they are interfaces over which calls are concentrated, and are open and standardized as well. The interfaces are characterized by the fact that PSTN service remains part of the local exchange, guaranteeing the same service transparency available in today's PSTN services.

In the near future, the VGW functionality can evolve to a real access gateway that connects the packet network and is controlled by call servers (e.g., the call server handles trunk traffic, now extended with local exchange functions). This guarantees that all installed IADs from initial VoDSL deployments remain unchanged when call servers start to take over from local exchanges. Ultimately, the end user will enjoy the existing bundled service offering, and will probably be keen on getting access to the new services that the NGN can offer.

In the future, the IAD could be directly controlled by the call server, so there is no longer any need for voice gateway functionality, except at the IAD itself, and at some points in the network where conversion to the PSTN is necessary in order to route the call to its final destination. This, too, is VoDSL.

## Conclusion

In conclusion, it is clear that VoDSL is a key step in the evolution of digital subscriber line technology. The advantages of VoDSL are apparent: The convergence of voice and data over a single line will lead to new revenues streams and numerous cost efficiencies for service providers of all types, including CLECs, ILECs and others.

Because VoDSL leads to so many benefits for end users, service providers will be able to increase revenue generation significantly from new converged voice and data services. New bundled services will be a paramount feature of this scenario.

IADs will be a key feature of VoDSL architecture. Their cost will have a significant impact on the ability of service providers to deliver competitive VoDSL.

VoDSL could quite likely be the killer application that drives the evolution of next generation networks.

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