Channelized Voice over Digital Subscriber Line

Ahsan Habib, Sprint Corp.

Hossein Saiedian, University of Kansas

ABSTRACT

The objective of this article is to present a promising voice over digital subscriber line (VoDSL) solution: an alternative method that uses physical layer transportation to provide channelized VoDSL (CVoDSL). This article also presents the advantages that the CVoDSL provides to the customers in terms of high-quality services and lower cost, and service providers in terms of market growth and success. It also offers a set of requirements, architectural design, and implementation scenarios that provide end-to-end solutions for CVoDSL.

INTRODUCTION

To survive the current telecommunications crisis, service providers need to attract more customers by implementing new and exciting network multimedia services and applications with careful planning and design. However, all the complicated calculations and amazing benefits will not mean much if the right technology is not used. Multiple service options is one way for carriers to generate business and increase profit.

Offering data or service alone will not get the carriers closer to their goals, but integrating them might. As enhanced services continue to expand, the rush to integrate voice and data is heating up. Multiservice access technology such as digital subscriber line (DSL) is capable of supporting more than one service (e.g., video, voice, and data) simultaneously over a shared access link. It is flexible enough to meet the high expectations set for both quality and quantity of services [1]. Its multiple service delivery capability allows service providers to cost effectively improve their local loop infrastructures and extend the economic and management benefits to the customer.

Being a scalable technology, DSL provides many advantages over other broadband technologies in network configurations. It is an efficient way to provide multimedia services. The idea of using physical layer transportation for voice has been around for a while. However, the potential for transporting both data and pulse code modulated (PCM) voice over the asymmetric DSL (ADSL) physical layer simultaneously has not been implemented yet. The uniqueness of the channelized voice over DSL (CVoDSL) solution lies in the fact that it transports voice over the physical layer, which eliminates voice packetization.

The voice bandwidth can be dynamically allocated in CVoDSL, so when voice lines are not in use, the bandwidth can be utilized for data traffic. CVoDSL coexists with plain old telephone service (POTS) by using frequency well above the POTS band, which means analog dialup and fax modem can be used at the same time. The CVoDSL method intends to replace existing VoDSL while offering superior voice quality, bandwidth efficiency, and architectural flexibility.

BACKGROUND OF DSL AND VoDSL

Legislators started deregulating the telecommunications market by breaking up AT&T in 1984 and introducing the 1996 Telecommunication Act. As a result competition stormed into the telecom market, and advanced technologies emerged. Market demands, such as increasing Internet access, also play a large role in advancing new technologies. Customers desire cost-effective, immediate, always available access to the Internet. ADSL technology utilizes the existing copper twisted pair to fulfill these demands and more.

Over the past few years various types of DSL have been introduced for different markets. These technologies are driven and supported by the industry, including service providers and vendors. Table 1 shows various DSL technologies and their data rate characteristics. ADSL has been chosen for CVoDSL transportation becaues of its popularity among small business and residential customers for asymmetric bandwidth characteristics.

ASYMMETRIC DIGITAL SUBSCRIBER LINE

ADSL is characterized by a different line rate from the service provider to the customer than that from the customer to the service provider. Its upstream and downstream data rates are documented in

Table 1. ADSL's frequency spectra range, from 30 kHz to 1.104 MHz, is shown in Fig. 1.

Each ADSL logical data channel can comprise four possible simplex and three duplex channels, which are known as bearer channels. The speed of the logical channel can actually vary but must be a multiple of 32 kb/s. The downstream data channel can be a combination of simplex and duplex channels, but only duplex can be used for the upstream channel [2]. Using PCM would allow up to 12 simultaneous voice channels over the upstream bandwidth, but for the simplicity of this article, voice lines have been limited to eight. However, any voice compression method listed in Table 2 can be used to reduce bandwidth consumption per voice line.

VoDSL

The feasibility of VoDSL technology brought a spurt into the DSL market in terms of revenue generation. The DSL Forum has wasted no time to initiate the specification for the VoDSL technique by identifying and documenting the VoDSL requirements in Technical Report TR-036. So far the DSL forum has recognized only two VoDSL technologies. One of the methods is known as multiservice broadband network (MBN). It supports new generation voice networks based on soft switching and VoIP standards developed by the Internet Engineering Task Force (IETF) and International Telecommunication Union — Telecommunication Standardization Sector (ITU-T). The second VoDSL technology is broadband loop emulation services (BLES). It uses an asynchronous transfer mode (ATM) loop emulation method based on ATM Forum work. These methods have already been implemented in the DSL network. There are many disadvantages in these methods. Some of their drawbacks are inefficient use of bandwidth, network complexity, undesirable end-to-end delays, and poor voice quality.

DELAYS IN THE EXISTING VoDSL

Delay causes echo and talker overlap in the voice network. Echo starts annoying users when the signal's round-trip delay become greater than 50 ms. On the other hand, talker overlap becomes significant if the one-way delay is greater than 150 ms. Highly interactive applications may experience degradation for any delay well below the standard's acceptable one-way delays (150 ms). Therefore, keeping the transmission delay at its lowest is encouraged. But there are many reasons to believe that existing VoDSL technologies often exceed delay limits [3].
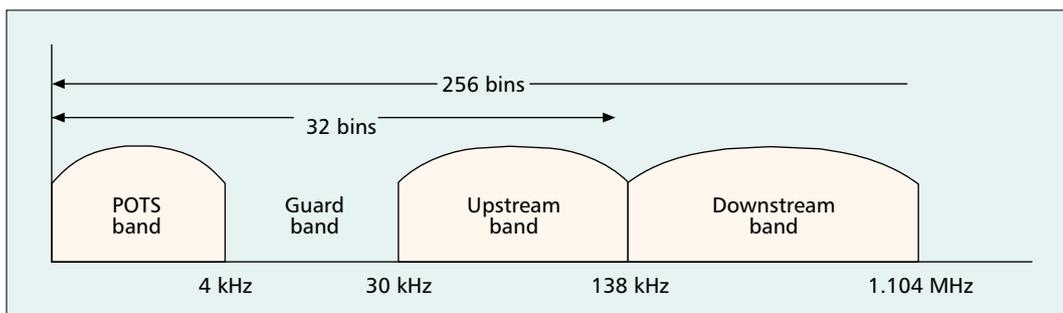
First of all, there is voice coding delay introduced by the analog-to-digital (A/D) conversion and digital coding, which is inevitable. The need to collect frames of voice samples to be processed by the voice coder introduces this delay. It also depends on the coding mechanism. A list of their delays appears in Table 2.
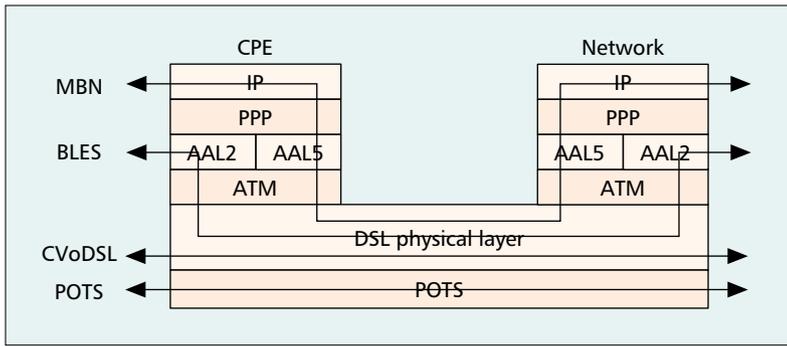
Then there is voice packetization delay. This delay is caused by the need of sufficient sample accumulation to fill the ATM or IP frame. Packetization delay accounts for more than 15 percent of the entire delay budget for PCM encoding and 30 percent for adaptive differential PCM (ADPCM) encoding method and it also limits quality of service (QoS) [4].

Network processing delay is introduced by cell delineation, switching, queuing, and cell rate decoupling. It also depends on the speed of the trunks, the amount of congestion, the number of nodes in the connection path, and so on. Furthermore, propagation delays are also experienced in the network. The echo canceller is used to eliminate echoes in the existing VoDSL, which adds more delays to the VoDSL network. The average echo cancellation delay is about 0.5 ms [3].

There is another kind of delay known as interworking function (IWF) delay. These delays depend mainly on DSL bit rates. A worst case situation for the IWF delay will occur when transporting a single voice channel over an

DSL types	Rates	
	Upstream	Downstream
ADSL	100–800 kb/s	1–8 Mb/s
HDSL	Fixed 784, 1544, 2048 kb/s	Fixed 784, 1544, 2048 kb/s
IDSL	128 kb/s	128 kb/s
SDSL	64–200 kb/s	800–2000 kb/s
VDSL	Up to 25 Mb/s	Up to 25 Mb/s

■ **Table 1.** *DSL technologies.*

Compression method	Data rate	Delay
PCM (G.711)	64 kb/s	0.75 ms/0 ms
ADPCM (G.726)	32 kb/s	1 ms/0 ms
LD-CELP (G.728)	16 kb/s	3–5 ms/0 ms
CS-ACELP (G.729)	8 kb/s	10 ms/5 ms

■ **Table 2.** *Codec delays.*

■ **Figure 1.** *The ADSL frequency spectrum.*

■ Figure 2. *A layer diagram for various VoDSL methods.*

ADSL link. The worst-case delay is assumed to be approximately 19 ms.

Finally, there are component delays, which also contribute to the degradation of the voice quality. Rigorous demands on end-to-end delays that allowed in the PSTN are not defined in standards. However, ITU-T Recommendation G.114 gives guidance by defining the following delay ranges that include both public and private network contributions [5]:

• 0–25 ms: no echo cancellation needed
• 25–150 ms: echo cancellers needed
• 150 ms–400 ms: risk for disruption of service even with properly installed echo cancellers
• > 400 ms: these connections should be avoided

By no means CVoDSL will eliminate all of these delays. But it will improve the voice quality by eliminating several of these delays. To do so, simplification in the network architecture is required, and CVoDLS has managed to do that.

TYPICAL CVoDSL ARCHITECTURE

CVoDSL came into the picture because of its architectural simplicity. But simple architecture would not mean anything if it does not concur with the existing and future technolo-

gies. In fact, services and devices that add values to CVoDSL networks are still evolving. In the CVoDSL model, legacy equipment and services are fully supported. All the PSTN's service qualities are maintained in the CVoDSL by supporting CLASS features and CENTREX services. CVoDSL uses the physical layer to transport voice traffic over subscriber line, which eliminates the packetization process and associated delays. This also allows CVoDSL to be more bandwidth-efficient. Figure 2 shows layer diagram for different VoDSL methods.

CVoDSL architecture provides a clear evolution path of services and supports infrastructure as the network evolves into the next-generation networks. At the same time, the architecture also maintains backward compatibility. CVoDSL makes customer premises equipment (CPE) circuitry much more simple and reliable by delivering end-to-end PCM voice. The architecture of the existing VoDSL and proposed CVoDSL is presented in Fig. 3a. It shows that CVoDSL trims the hardware requirement of the CPE by half. In CVoDSL, voice needs to propagate through only the subscriber loop interface card (SLIC), codec, and ADSL physical layer to the transmission line.

The SLIC is similar to any other telco interface cards such as foreign exchange station (FXS) that has RJ-11 jacks for multiple voice lines and RJ-45 for data services. It is located in the integrated access device (IAD). The codec performs A/D conversion and voice compression for transmission. Codecs used in CVoDSL should be fully compatible with at least G.711 or G.726 standards. Support of μ-law and A-law is also necessary. CVoDSL's functional block is diagram shown in Fig. 3b. The ADSL physical layer defined the mechanical and electrical connections and also regulates the transmission of bitstreams.

Less CPE hardware requirements and simple CVoDSL architecture leads to a simple network model, which is presented as a reference model.
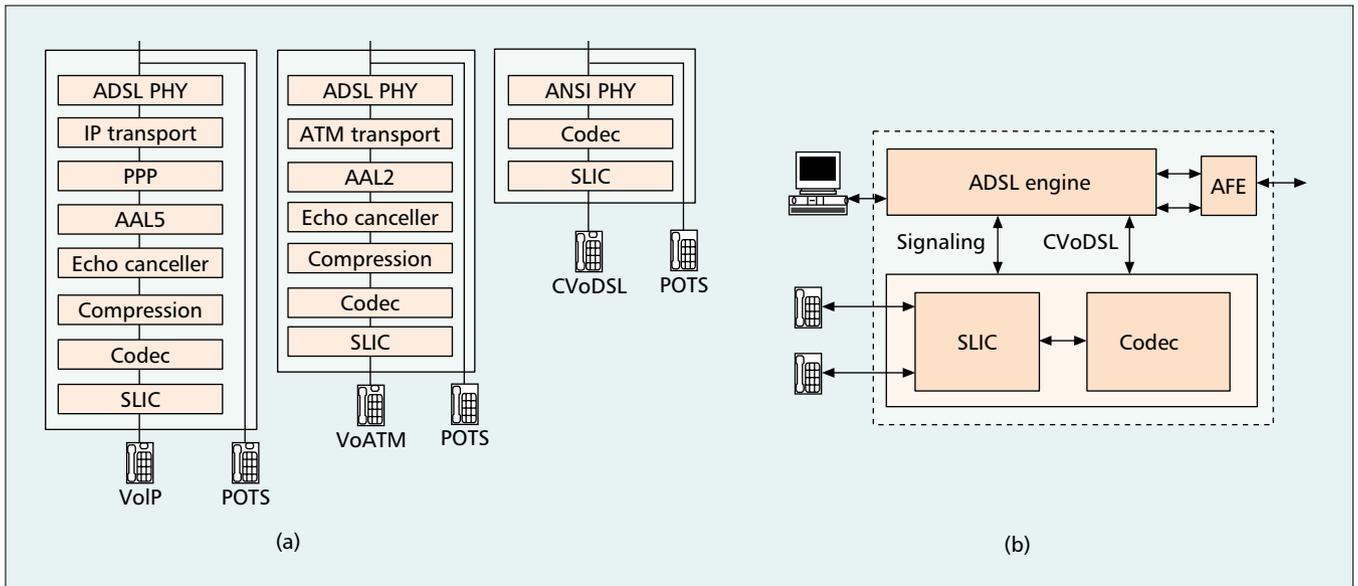
■ Figure 3. *The architecture of VoDSL services.*
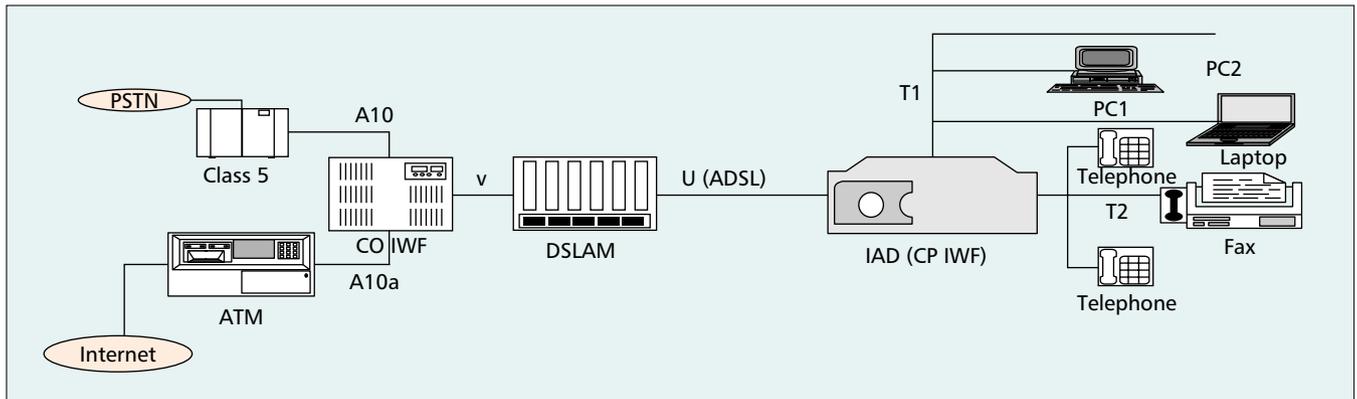
■ **Figure 4.** *The CVoDSL reference model.*

THE CVoDSL REFERENCE MODEL

The general reference model for a CVoDSL network is described in Working Text WT-043. Figure 4 shows the proposed CVoDSL reference model. Nevertheless, all CVoDSL networks will have almost the same arrangement with minor exceptions and changes. The entire CVoDSL network can be divided into equipment, IWF (located in the central office, CO, and at the customer premises), and interface sections.

ADSL technology has inspired many vendors to build advanced equipment that performs faster services over the existing copper lines. The latest round of product innovation has made VoDSL easier to deploy. This equipment is designed to support any kind of access services.

THE SERVICE PROVIDER'S EQUIPMENT

Class 5 and ATM switches are examples of service provider equipment. A Class 5 switch provides telephony services to subscribers, including regular telephony services, custom calling features, CLASS features, and CENTREX services. It is directly connected to the end user's equipment. On the other hand, an ATM switch supports communication between different types of traffic via integrated access. In the CVoDSL environment, an ATM switch aggregates traffic from multiple COs and sends them to the ISP network.

CENTRAL OFFICE EQUIPMENT

This aggregates multiple services from different locations. Service providers can have various kinds of equipment in the central office including ATM switch, router, aggregator, and DSLAM. Central office equipment also performs authentication, billing, signaling control, and other management tasks. It also acts as a voice gateway and separates data from voice. The CO IWF also resides in the central office equipment, and performs the translation of signaling and bearer methods used by the existing telephony equipment to the signaling and bearer methods for ADSL and vice versa.

DSL ACCESS MULTIPLEXER

This is usually located in either CO or local exchange area. This equipment terminates multiple ADSL lines and aggregates traffics from them into uplink ports to V interface. It also it distributes traffic from the uplink to the appropriate ADSL port. It also supports all DSL standards to give the service providers the flexibility to offer multiple services.

INTEGRATED ACCESS DEVICE

CVoDSL requires more sophisticated IAD to handle the multiplexing of multiple voice channels and data traffic. It is located in the customer premises, which deliver bundled voice, data, and video services. It performs the functions of terminating the DSL signal entering the customer premises. CP-IWF resides in the IAD, which performs the translation of signaling and bearer methods used by the existing telephony equipment, to the signaling and bearer methods of ADSL and vice versa. All IAD should support the functionality of dynamic bandwidth allocation for voice channels. It should also support or transparent to all traditional CLASS and CENTREX features. Supporting of DMT line encoding is essential for the IAD.

CUSTOMER PREMISE EQUIPMENT

Examples of CPE include phones, key systems, answering machines, fax machines, dialup modems, and so on.

The delivery of CVoDSL service requires coordination of more sophisticated interfaces throughout the network. The physical interface is a data transmission regulator that manages the exchange of data between two devices. CVoDSL uses various types of interfaces to communicate from one device to another.

CVoDSL REQUIREMENTS

CVoDSL networks are expected to operate in environments that integrate voice channels with traditional data services at the T interface. CVoDSL implementation requires support of CVoDSL IWF-IWF, dynamic rate repartitioning (DRR), signaling, transporting, and encoding.

CVoDSL IWF-IWF

The CVoDSL service can generally be defined as an interface between two inter-working functions, one at the central office known as CO-IWF and other one located in the IAD, known as CP-IWF. The interoperability and transparency of CVoDSL with the existing telephony

service is maintained by IWF. CVoDSL IWF-IWF communication transparently transports the telephony signaling and bearer traffic between the service provider switching equipment and the CPE.

Each CP-IWF must communicate with the CO-IWF for signaling and management over a physical layer overhead channel. Since the line capacity for ADSL is allocated in 32 kb/s blocks, two blocks are allocated for each active voice channel. This allows the maximum bandwidth on the CVoDSL channel for bearer services. The CP-IWF translates signaling from the customer premises equipment into the CVoDSL signaling methods. It also performs multiplexing functions when more than one voice channel is supported. CVoDSL networks support QoS by providing a dedicated channel for these services.

The CO IWF translates signaling and management messages from the CP IWF, and converts them to signaling and management messages for the service provider network. The CO IWF also provides cross-connect and multiplexing functions between the service provider switching equipment and the CVoDSL network [6].

DYNAMIC RATE REPARTITIONING

CVoDSL uses DRR technology to provide an effective priority mechanism to support QoS for voice. Dynamic bandwidth allocation is highly desirable in CVoDSL networks since multiple voice channels can use a substantial fraction of DSL upstream bandwidth. DRR is used in CVoDSL to allocate bandwidth for an active voice channel from the total available upstream bandwidth.

DRR partitions the ADSL upstream link capacity into guaranteed and non-guaranteed resources, where the non-guaranteed resource such as data bandwidth is subject to change as needed. When a voice channel activation request arrives, the event is communicated over the signaling channel and to the DRR protocol to allocate necessary dedicated bandwidth for voice. When voice calls are not active, DRR reallocates that bandwidth to the data channels. The rate repartitioning may be performed with a maximum of 125 ms of service interruption as per T1.413 Annex K and ITU G.992.1.

SIGNALING

No telephone system would survive without an underlying signaling mechanism, and the fundamental requirement for any new signaling system is the ability to emulate the existing signaling scheme to ensure flawless compatibility. CVoDSL relies on the DRR mechanism that requires a signaling system to perform dynamic bandwidth allocation. To maintain an acceptable voice quality for multiple connections it requires much higher level of signaling support than traditionally required for call setup, supervision, configuration, network management, control, fault reporting, and so on [7]. CVoDSL signaling also needs to extract bit codes from the PSTN bitstream and reformulate them for the CVoDSL network. Signaling for a CVoDSL network can be transported either in band with the bearer channel or out of band.

IN-BAND SIGNALING

This signaling scheme is also known as dual tone multifrequency (DTMF) signaling. It uses overhead in the same path as the PCM data to transport the channel associated signaling (CAS) information. This is done by stealing a bit from a PCM byte, which is known as a robbed bit. As a result, it does not require any extra bandwidth. This signaling has exactly the same delay as the PCM samples. Frame synchronization is achieved quickly this way. However, it is unable to control remote functions such as voice mail.

OUT-OF-BAND SIGNALING

The out-of-band channel may be in the overhead of the framing structure or a physically separate network such as SS7. It requires less than 16 kb/s for eight CVoDSL channels. Since current ADSL standards allocate bandwidth in 32 kb/s increments, out-of-band signaling using overhead channels would provide more efficient transportation of signaling information than establishing additional channels in the data stream. There are two types of out-of-band signaling that can be implemented in CVoDSL.

The first method is known as message-based signaling. It can communicate complex events using a single encoded message across the interface. It uses operational sequences to communicate with the CPE and can provide the deterministic end-to-end two-way communication for DRR enabled network. It also provides assured transmission and automatic retransmission of any lost message. It uses common channel signaling (CCS) to efficiently implement system-enhancing mechanisms such as automated status reporting and software upgrade.

The second method is known as state or bit based signaling. It uses either 2 (AB) or 4 (ABCD) bits to represent up to 4 or 16 possible signaling states respectively. In this method, signaling information is refreshed every 3 ms. It uses very short messages to communicate state events to and from the CPE. In general, state-based signaling requires less processing at the CPE side than message-based signaling but it is a one-way communication mechanism, which lacks the best possible robustness and provides only minimal capabilities for acknowledgment, retransmission, and problem logging [7].

TRANSPORTING

The downstream and upstream data channels are synchronized to a 4 kHz symbol rate in ADSL technology. CVoDSL uses upstream logical channels for voice transmissions. These channels are dynamically allocated by the DRR mechanism.

ENCODING

Encoding refers to the class of signal transformations. It is designed to improve communications performance by enabling the transmitted signals to better withstand the effects of various impairments.

LINE ENCODING

ADSL products can use carrierless amplitude/phase modulation (CAP), quadrature amplitude modulation (QAM), and discrete multitone (DMT) technology as line coding tech-

niques. However, American National Standards Institute (ANSI) T1.413 defined DMT as the official line coding technique for ADSL because it can easily adjust to changing line conditions such as interferences. It is also resistant to noise and crosstalk. DMT has a number of distinct advantages over other line coding technologies such as superior noise immunity, active monitoring, rate flexibility, rate-adaptive, and maximum loop variation coverage. In addition, DMT is an open standard, so chipsets can be developed by anyone.

DMT divides the entire ADSL bandwidth range into a number of equally spaced channels called bins (Fig. 1), and each bin occupies 4.3125 kHz to achieve robust throughput [8]. Some of these channels are reserved for management purposes. Each channel employs its own QAM coding technique. QAM utilizes amplitude and phase modulation to transmit multiple bits per transition. DMT allows a communication system to be very flexible by optimally utilizing each channel. DMT devices can measure the gain in each channel and adjust the actual number of bits per second per channel to reflect the actual line gain profile.

SPEECH ENCODING

The manner in which encoded voice is multiplexed before transmitting via an ADSL connection needs careful consideration to ensure excellent quality. Multiplexing of voice channel implementation will significantly depend on the voice source coding technique. Any of the existing speech coding techniques such as PCM, ADPCM, LD-CELP, or CELP can be used for CVoDSL, but this article is limited to PCM to minimize the end-to-end delays.

IMPLEMENTATION OF CVoDSL

Service providers are deploying new broadband infrastructures with new protocols and signaling and management techniques as customers are demanding advanced features, but legacy equipment and services will continue to exist. For a CVoDSL solution to be realistic, it must take advantage of existing facilities, services, and customer equipment and integrate them seamlessly with new broadband network infrastructures. One of the basic requirements of CVoDSL is to provide voice services that are virtually indistinguishable from existing ones using new infrastructure.

CVoDSL is extremely flexible in its implementation and fits perfectly into the existing network architectures. It supports traditional circuit- and packet-based networks and facilitates migration from one type of network to another. CVoDSL can also be successfully implemented into BLES, NGDLC, NGN, or a legacy network. Implementation of CVoDSL into these networks has been reserved for future discussion.

WHY CVoDSL?

Service providers can deliver multimedia services to their customers using CVoDSL technology. This creates a larger and more profitable market for service providers. Support of standards-based telephony network interfaces allows customers to utilize existing or new equipment. All advanced telephone services, such as CENTREX services, caller ID, call forwarding, and voice mail, are available because CVoDSL systems transparently derive voice services from Class 5 switches [4]. A CVoDSL system is also future-proof since any new features provided by a Class 5 switch will be supported.

CVoDSL solutions will benefit customers and service providers equally by leveraging existing equipment and utilizing new technologies to deliver better quality of services at lower cost. Carriers can roll out their own DSL facilities and take direct control of both voice and data services down to the customer premises.

VOICE PERFORMANCE

The true measure of quality for voice is transparency of services, features, and speech. Service and feature intelligibility of CVoDSL depends on precisely carrying signaling information across the ADSL network. The goal of CVoDSL is to ensure that subscribers will not notice any degradation but improvement in multimedia services. Control of delay is necessary to maintain superior voice quality. Using the same analysis used in TR-036, it is easy to show that, by eliminating packetizing delays and avoiding link queuing delays, CVoDSL can achieve an end-to-end delay of 7 ms, which is well below the ITU-T's recommendation (50 ms). Thus, CVoDSL provides significant improvement of voice quality over existing VoDSL technologies.

NETWORK MIGRATION

When deploying a new technology, a service provider needs to consider eventual migration strategies. A successful migration strategy is one that can introduce a new technology at low introduction cost and at the same time guarantee continuity without any major service disruption. The migration path from the current circuit-switched network to the future CVoDSL network can be achieved successfully by using the same CPE with minor changes to provide better quality service.

LOW LATENCY

CVoDSL avoids latency associated with packetization (IP or ATM) by transporting voice over the physical layer over the local loop. Echo cancellation circuitry in the ATU-R is also eliminated. Voice quality for common call scenarios in a CVoDSL network have been improved by eliminating these latencies.

BANDWIDTH EFFICIENCY

The avoidance of packetization eliminates cell overhead for voice, making more bandwidth available for data transportation. In fact, a CVoDSL voice channel uses only 80 percent of BLES and 50 percent of an MBN voice channel. CVoDSL requires 64 kb/s of bandwidth for each uncompressed voice line, whereas BLES requires about 80 kb/s, and MBN 120 kb/s [9].

LOWER COST

Lower end-to-end delays in the CVoDSL network removes the need for an echo canceler and several other processing engines in the CPE, thereby significantly reducing size, power, and complexity of CPE devices. As a result, equip-

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ment functionality at the CO is also reduced. Less complexity and fewer functionalities drive down the cost of the equipment.

NETWORK ARCHITECTURE FLEXIBILITY

Avoiding packetization over the local loop allows flexible implementation of CPE. CVoDSL can be integrated into a variety of access network architectures and products, including DSLAM, DLC, integrated access platforms, and DSL-enabled switches.

REDUCTION OF COMPLEXITY

CVoDSL offers significant advantages and benefits to service providers and customers. The use of CVoDSL reduces the functionality of the CPE significantly by simplifying the CP IWF. By using a separate non-ATM channel for voice, the number of virtual channel connections (VCCs) associated with a subscriber becomes dependent on the data applications only. This saves the service provider the time and effort required to provision the virtual circuits and improve network scalability.

BUNDLED SERVICE

CVoDSL method enables providers to generate more revenue by offering bundled services such as voice, data, and video using the existing copper line. As a result production costs will go down and customers will get cheaper services. Moreover, everyone will enjoy the simplicity of a single contact point for telephone and high-speed Internet service.

MARKET OPPORTUNITY

CVoDSL is still in its early stage of growth, but its compelling technology and economic benefits will push it toward a multibillion-dollar market quickly. To capture this market, service providers need to act quickly and target the appropriate customers. CVoDSL will attract small business and residential customers who need multiple voice lines with data services. By combining voice and data, voice carriers can extend both services over single copper telephone lines. The ability to offer multiple voice lines over a single connection greatly leverages the providers with more service capacity across the final mile of copper. Thus, they will be able to cost effectively address the needs of the huge market for residential and small business customers.

CVoDSL technology is the road to a larger and more profitable market for both service providers and customers. The economics and tight integration of CVoDSL enables service providers to fulfill the desire of customers to purchase telecommunication services from a single provider. Service providers can pass these cost savings benefits to their customers to create a larger market. Customer benefits include a single bill with discounted rates for services, and a single point of contact for installation, customer service, technical support, and other value-added services. As long there is demand for bundled communication services, CVoDSL will do just fine.

CONCLUDING REMARKS

CVoDSL technology represents a tremendous opportunity for customers and service providers in the telecommunications market. It offers an exciting next step in the development of bundled services. Customers will benefit from its bundled high-quality voice, high-speed data, and streaming video services offered by competitive service providers with better price plans and single-point-of-contact customer service.

A critical aspect of any technology deployment involves ensuring that it does not interfere with the existing system. CVoDSL supports it and maximizes equipment investment by being compatible with current and future networks. Service providers will be able to offer a complete solution to a larger market and attain greater profits, which will be passed onto their customers.

A detailed examination of the exciting features of CVoDSL would demonstrate that it enjoys clear superiority over the existing VoDSL methods, but still it is too early to predict the pace at which this new technology will be accepted.

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BIOGRAPHIES

AHSAN HABIB [M] is a network engineer for Sprint Customer Systems Development Lab, where he is involved in IP, xDSL, and ATM technologies. He evaluates and certifies network elements for Sprint networks. He obtained his B.S. in electrical engineering from the University of Missouri and his M.S.E.E. from University of Kansas.

HOSSEIN SAIEDIAN [SM] (saiedian@eecs.ukans.edu) (Ph.D, Kansas State University, 1989) is a professor of software engineering in the Department of Electrical Engineering and Computer Science and a member of the ITTC at the University of Kansas. His primary area of research is software engineering, in particular models for quality software development, both technical and managerial. He is also interested in certain aspects of computer networks and communication. He has over 100 publications on a variety of topics in software engineering, computer science, and computer networking. His research in the past has been supported by NSF as well as regional organizations.