Symmetric DSL White Paper

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Abstract

SHDSL (ITU Rec. G.991.2) represents the best of several symmetric DSL technologies that have been combined into a single industry standard providing rate adaptation, greater reach, spectral compatibility, low power, and application flexibility. SHDSL (Symmetric High-Speed Digital Subscriber Line) is emerging as the access technology of choice for high-speed symmetric service offerings by the service providers for businesses and Small Office Home Office (SOHO) customers. The technology is very well suited for high-speed symmetric data, digital voice transport, and real-time video conferencing. Since the various services are handled in the digital domain, bandwidth can be dynamically allocated between voice, video and data. By supporting a variety of line rates and payload configurations, SHDSL allows various service applications to be customized to meet the needs of small, medium, and home office environments. It is expected to become the most common solution for symmetric access by the major service providers worldwide in 2003.

Introduction

Digital Subscriber Line (DSL) technology opened a new frontier recognizing that bandwidth on the local copper loops did not have to be limited by the application, voice or Plain Old Telephony Service (POTS). While the voice speech path uses frequencies under 4 kHz, greater bandwidth can be achieved with the application of new line codes and Digital Signal Processor (DSP) techniques. The amount of usable bandwidth available over a loop is dependent on a number of factors, including loop length, impedance, signal power, frequency and line coding techniques. The higher the frequency, the greater the attenuation, and the smaller the signal becomes when it is received at the far end. This is illustrated in Figure 1 by the curve showing the strength of the received signal decreasing as the frequency increases.

There are two general categories of DSL: symmetric and asymmetric. Symmetric DSL provides the same service bit-rate in both upstream and downstream direction. Asymmetric DSL (ADSL) provides more downstream bit-rate (from the network to the user) than upstream bit-rate.

From the start, ADSL technology was developed to coexist simultaneously with POTS or ISDN voice service. This is achieved by transmitting the data signal at higher frequencies than is used for POTS or ISDN. This type of transmission is referred to as passband transmission. By transmitting a signal at the higher frequencies and avoiding the voice band frequencies, broadband data can be sent simultaneously with voice on the same copper loop. Today, ADSL is the most commonly deployed type of DSL for the residential customer. However, SHDSL will emerge as a preferred technology for the high-speed symmetric business environment, and some predict that it will be used for selected residential customers as well.

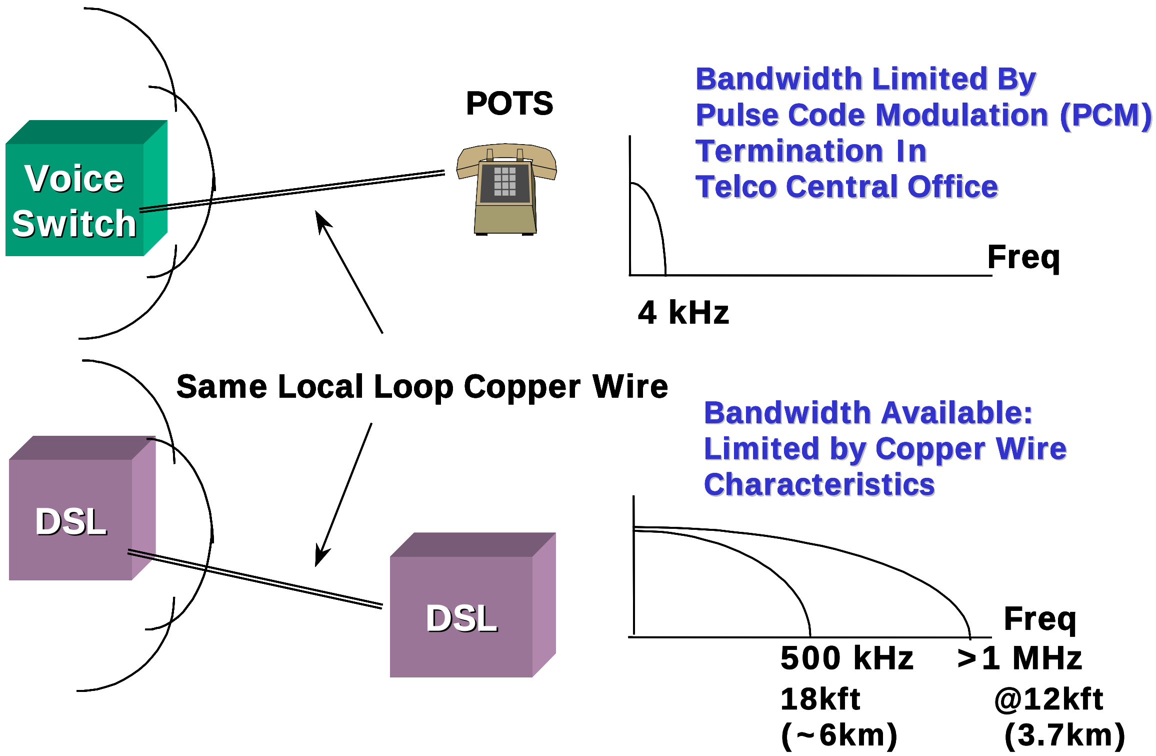

Figure 1
Bandwidth on Copper Loops

Background

There have been many advances in symmetric DSL technology since its first introduction in the early 90's. Symmetric DSL was initially developed as a more economic way of providing equivalent E1 (2.048 Mb/s) or T1 (1.544 Mb/s) service. The Alternate Mark Inversion (AMI) line coding used on E1/T1 lines uses two pairs of copper loops (also called 4-wire). The symmetric DSL line codes were developed to go longer distances without the need for repeaters that are required for E1/T1 service. As a replacement for E1/T1, Symmetric DSL has a number of advantages. For example, E1/T1 transmission requires two wire pairs, where Symmetric DSL techniques have been developed to operate over one pair. This frees up a copper pair, which can be used to either support a different subscriber or can be "bonded" together to essentially double the bandwidth delivered to a customer. Two specialized types of symmetric DSL are used for DS1 (1.544 Mb/s) transmission: HDSL2 utilizes one pair of wires, and HDSL4 achieves greater loop reach using two pairs of wires.

E1/T1 transmission systems were developed as a method of multiplexing many voice channels over one transmission path. Consequently, voice or POTS is not carried in the lower 4 kHz of bandwidth as it is with ADSL. Instead, POTS and voice band modem traffic is carried in accordance with the multiplexed channel structure within the E1/T1 signal. The new single pair DSL technologies such as SHDSL frees up the use of the entire frequency spectrum for data as well as digital voice. The ability to use the complete bandwidth is referred to as baseband transmission. Because signal transmission is more efficient at the low frequencies, and more robust with respect to noise, symmetric DSL is able to achieve a given reach with lower power. The advantage of lower power is that in addition to less energy and heat, symmetric DSL generates less signal noise or cross-talk, thereby improving spectral compatibility. In other words, SHDSL does not disturb other forms of communications carried in the same cable bundle enabling support of SHDSL customers in the same cable binder as other services.

Problems of today

However, symmetric DSL standards were slow to emerge and resulted in a number of line coding techniques being used today. (Line codes are essentially signal conversion algorithms that allow for reliable transmission of data across copper wire.) These include Carrierless Amplitude & Phase Modulation (CAP), Two Binary one Quaternary (2B1Q) line coding which is also used for Integrated Services Digital Network (ISDN), and Pulse Amplitude Modulation (PAM) that can be found in network deployments today. These line codes, combined with other techniques, reduce power, achieve longer reach, improve performance, encode more data within the frequency spectrum, resulting in a new line code technology called Trellis Coded PAM (TC-PAM). Line codes use either echo cancellation (EC) or frequency division multiplexing (FDM) transmission schemes to separate downstream (received) data from the central office (CO) to the customer premises equipment (CPE) and upstream (sent) from the CPE to the CO.

DSL	Linecode	# of pairs	Payload per pair	Standards
HDSL	2B1Q or CAP	1, 2 or 3	776, 1160 or 2312 kbps	ETSI TS101135 ITU G.991.1 ANSI T1.4-TR28
SDSL	2B1Q or CAP	1	384 to 2312 kbps	Proprietary
HDSL-2	TC-PAM	1	1544 kbps	ANSI T1.418
HDSL-4	TC-PAM	2	776 kbps	ANSI T1.418
SHDSL	TC-PAM	1 or 2	192 to 2312 kbps	ITU G.991.2 ETSI TS102524 T1.422

Table 1
Symmetric DSL Technologies

With symmetric standards slower to emerge than asymmetric, the result was the development of a family of symmetric DSL devices, such as Symmetric DSL, High-bit-rate DSL (HDSL) with single pair or 2-wire (HDSL2) and dual pair or 4-wire (HDSL4) identified in Table 1 respectively. This proliferation of DSLs raises two challenges: 1) interoperability, since both ends need to operate using the same techniques, and 2) spectral compatibility. These will be discussed later in this paper.

A final consideration, legacy services such as E1/T1 require the use of many repeaters, approximately every 1000m or 3 – 4 kft, which is complicated to deploy, power and maintain. Figure 2 shows the rates and distances that can be achieved by a number of DSL technologies and illustrates how SHDSL provides full symmetric service rates at distances greater then other DSLs, and without repeaters to 4 km.

It is also important to note that symmetric DSL standards were developed to support a repeater mode. By using SHDSL as a repeater technology for really long loops, not only are fewer repeaters required for a given distance but also the reach of DSL service is nearly unlimited.

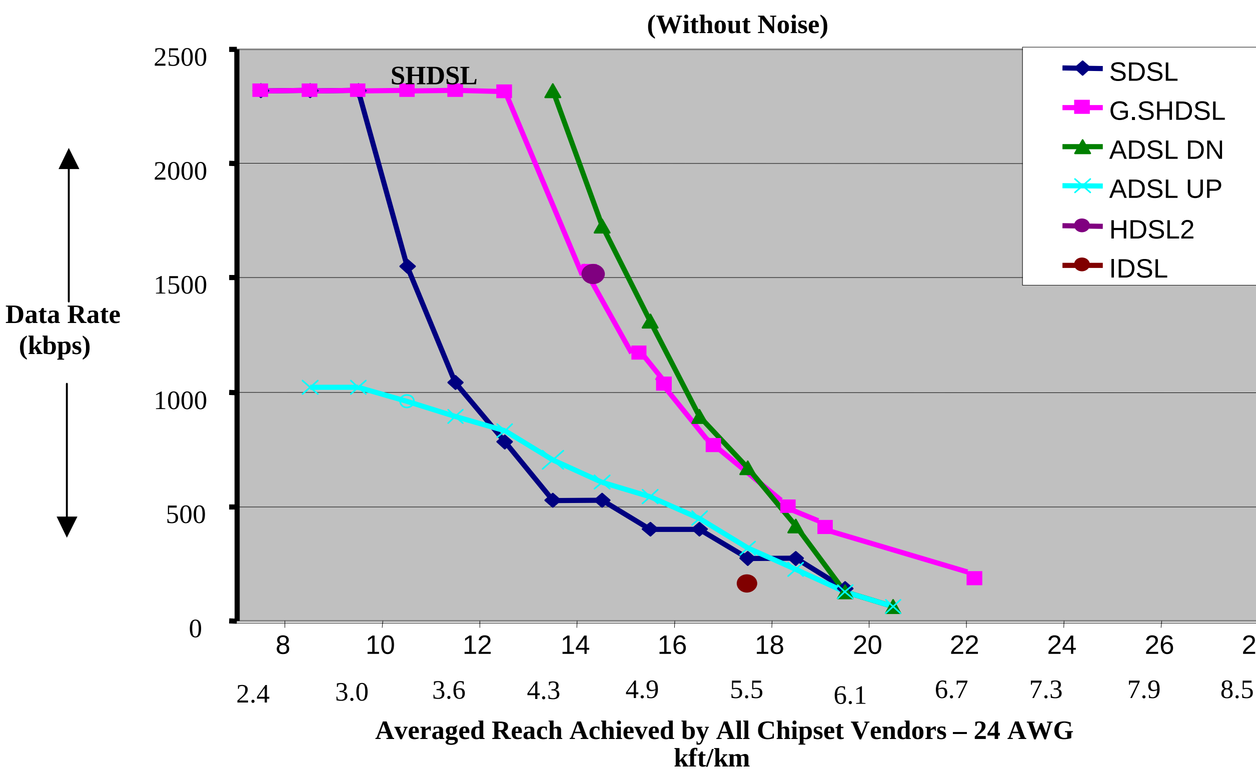

Figure 2
Rate and Reach Comparison

What is SHDSL?

SHDSL (Symmetric High-speed Digital Subscriber Line) was based on HDSL and is specified in the International Telecommunications Union (ITU) recommendation number G.991.2 titled *Single-Pair High-Speed Digital Subscriber Line Transceivers.* Today SHDSL can operate at data rates from 192 kbps to 2.312 Mbps (in a 2-wire mode) and 384 Kbps to 4.624 Mbps (in a 4-wire mode) with higher rates under development, and is spectrally compatible to all other DSL technologies with the use of TC-PAM line coding. SHDSL combines the best of the legacy services into a single, robust technology that can be used for both full and fractional E1/T1 lines, Digital Added Main Lines (multiple voice channels), and video conferencing applications using a single twisted pair of wires.

Why symmetric?

Where Internet access is by nature a more asymmetric service, there is a growing need for symmetric types of applications, particularly in the SOHO and telecommute environments:

- Voice
- Peer-to-peer file sharing (e.g. – collaborative projects between a satellite office location and a main office of an organization or consumer file swapping)
- Business data traffic (E-Mail, LAN)
- Leased line replacement (T1, E1)

Example applications using SHDSL are discussed in more detail in later sections of this white paper.

SPECTRAL COMPATIBILITY

The spectral compatibility of two DSL transmission systems is defined by the effect of the crosstalk that one system has on another in the same cable. Cables are made up of many copper wire pairs that are bundled together. With this close proximity, some signal energy being transmitted on one pair is going to be induced into pairs that are in the adjacent area. Because DSL service is not introduced to all customers simultaneously, over time and as technology matures and standards emerge, it is possible to have a mix of DSL techniques in use even in the same bundle. From experience, it is known that some techniques generate more interference or crosstalk than others.

Different types of DSL in a cable utilize different bandwidth. Depending on the energy of the signals and the spectral placement, the different types of DSL systems may or may not be compatible with each other. The crosstalk effect that one DSL system has on another in the cable defines the spectral compatibility.

In the design of DSL systems, spectral compatibility is important because the deployment of any new DSL services should not degrade the performance of other services in the cable. Likewise, the existing services in the cable should not prevent the new DSL from meeting its performance objectives.

Spectral compatibility is a function of the degree of overlap between the received signal and the crosstalk signal, and the relative strengths of the signals. A number of factors influence the severity of crosstalk on a pair of wires and in effect, interfere with the desired signal. Factors such as loop length, the effect of echo cancellation (EC) versus frequency division multiplexing (FDM) transmission schemes goes beyond the scope of this white paper.

The SHDSL standard was developed not only to address interoperability issues but also took into consideration the spectral characteristics of the existing line coding and transmission techniques in common use within the existing networks. SHDSL or G.991.2 is based on modifications to HDSL2 and uses TC-PAM, providing 16 levels of encoding rather then the 4 levels provided by 2B1Q and thereby improving spectral efficiency. Trellis coding, Viterbi decoding and Tomlinson precoding provide improved bit error rates and SNR (Signal Noise Ratio).

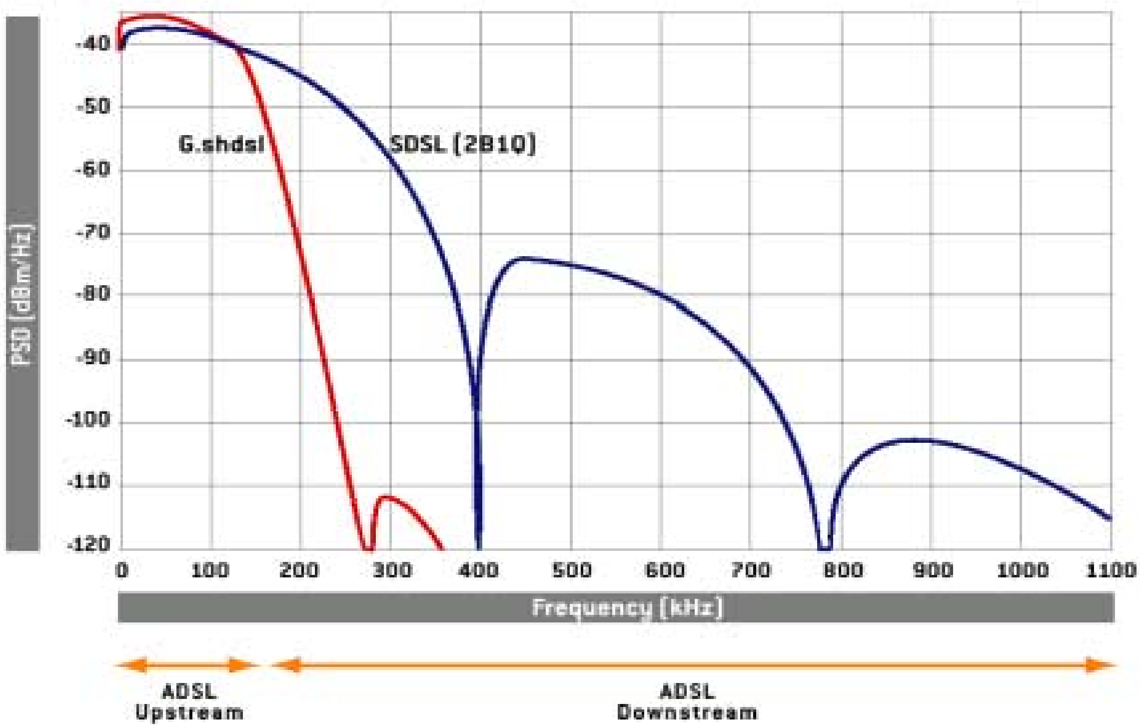

Figure 3
SHDSL Spectral Efficiency at 768 kbps

Figure 3 illustrates the improved power spectral density (PSD) characteristics and efficiency of SHDSL. The PSD represents the amount of energy required to send information. With a reduced amount of energy across a band of frequencies, the potential for interference with an ADSL customer is greatly reduced while requiring less power. Therefore SHDSL presents less of a disturbance to ADSL equipped loops, and ensures overall spectral compatibility with existing deployments.

HANDSHAKE

Another advantage that SHDSL has over earlier symmetric DSL approaches includes the use of the signaling standard, G.994.1, "Handshake Procedures for DSL Transceivers", frequently referred to as G.hs for short. G.hs defines signals, messages and procedures for exchange between DSL equipment. The use of this signaling capability occurs after the DSL equipment has gone through its power initialization phase and enters the mode where it needs to automatically establish certain operational characteristics before signals can be exchanged.

For example, G.hs procedures are utilized to enable rate adaptation. The bandwidth and therefore data rate that can be supported on that particular copper loop can be adjusted to attain a certain bit error rate based on a Service Level Agreement (SLA), or achieve longer loop lengths or reach. In this manner, rate adaptive operation and power adjustments are made automatically. At the completion of initialization and handshake procedures, the DSL equipment enters SHOWTIME. SHOWTIME is used to describe the mode where the user and network can begin communications over the access network.

Carrier Advantages

While the demand for greater communication access speeds continues to grow, service providers/carriers are also beginning to place new importance on flexibility and programmability. For ISPs, ILECs, and CLECs, the goal is to increase revenue by adding new services and applications to their current portfolio of existing services, and expanding their Internet access. DSL technology is evolving to meet these needs.

Service Providers/Carriers are embracing new standards for expanded distances, adaptive rates, lower power, ease of deployment and revenue generating capabilities. SHDSL offers a wide range of benefits in deploying advanced services.

- Deploy new high-value business services out of existing installed base of DSLAMs – leverage current Capex investment
- Symmetric bandwidth supports applications that require high performance in both directions
- Single pair design with dual pair option, and rate-adaptive capability provides network design and deployment flexibility
- Eliminates need for E1/T1 repeaters on loops under 18 kft.
- Enhanced reach capabilities allow an offering of consistent services to a wider range of customers
- Superior spectral compatibility with other transmission technologies eases deployment limitations, reduces criticality of accurate loop records and eliminates the need for troublesome binder group segregation
- Transport cost savings for existing services such as leased or private lines
- Worldwide standard drives wider availability of fully interoperable equipment

Target applications for SHDSL

Systems that utilize SHDSL can support numerous types of symmetric access applications. While SHDSL has been targeted primarily as the high-speed symmetric service for business and SOHO customers, it is also applicable for selected applications in the residential market. Since services are handled in the digital domain, bandwidth can be dynamically allocated between voice, data and video applications.

Figure 4 is an illustration of the service provider/carrier network and the access application environment that SHDSL can support. It is significant to note that globally, starting in 2002, there were approximately 196 million E1/T1 subscriber access lines in use according to Cahners In-Stat. In the future, the majority of these lines are candidates for upgrade with SHDSL to leverage ability to support new or higher speed applications than can be supported over E1/T1 lines, and to lower operational costs. These are discussed below.

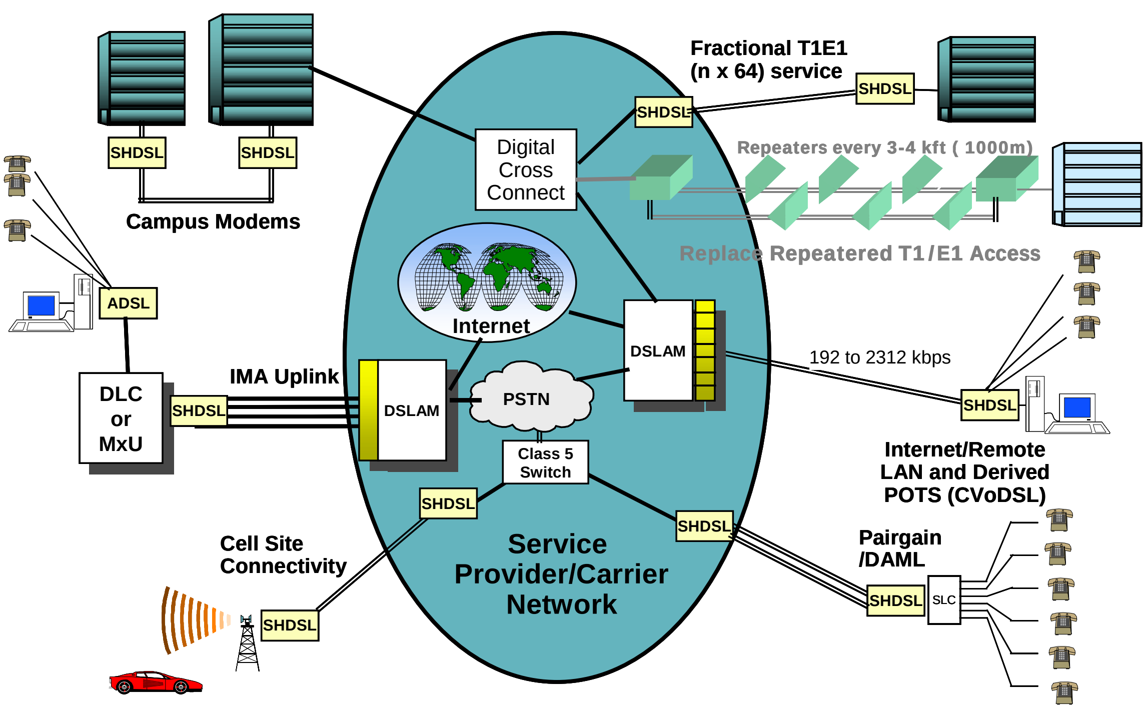

Figure 4
Symmetric DSL Applications

1. Business Users[1]

SHDSL is suited to voice and data applications that need high upstream and downstream bit-rates and is well matched to the following business services/applications.

- ✓ Multi-line Voice over DSL (VoDSL)
  - A Voice over DSL service requires the use of a CPE / IAD (Integrated Access Device) that typically provides 4-16 voice ports in addition to the data port(s) on the unit.
  - VoDSL with multiple voice channels places stringent requirements on the upstream link, requires guaranteed bandwidth (QoS) and is better suited to a symmetric connection than to an asymmetric to operate successfully.
- ✓ Web hosting
  - Application where a web server is located at subscriber's premises, and is connected to the Internet via the DSL link
  - Requires a high bandwidth connection in the upstream direction
- ✓ Videoconferencing
  - A videoconferencing service can run data, text and video over (typically) an ISDN link. DSL has the capability to offer the same service but with a higher data rate hence giving improved video quality and/or multiple videoconferences on the same line.
  - As the videoconference service is usually two way, symmetric DSL service (SHDSL) is best suited to this application
- ✓ VPN Services
  - A virtual private network (VPN) is a private data network that makes use of the public telecommunication infrastructure, maintaining privacy through the use of a tunneling protocol and security procedures.
  - SHDSL is well suited to the provision of VPN services interconnecting smaller branch offices where higher speed access provided by E3/T3 or fiber access is either not available or too expensive when copper pairs are readily available
- ✓ Remote LAN Access
  - Remote LAN (Local Area Network) Access is typically used by telecommuters and in the SOHO environment to access the corporate network. This technology is also applicable to campus locations to interconnect between buildings such as hospitals, universities, and airports. In these applications, data packets are exchanged symmetrically in both directions.
  - SHDSL is well suited for Remote LAN Access because it enables end-users to upload information as fast as it can be downloaded. Rates range from 192Kbps to 4.6Mbps depending on the service ordered and/or the reach. The SOHO environment within the USA is typically characterized as having 8 – 16 lines, and in Europe typically 6-8 lines. Symmetric

[1] SHDSL does not support POTS, and thus does not provide Lifeline (e.g. E-911 in US) support. However, digital voice can be supported using VoDSL techniques.

access using just one or two pairs can support the same number of POTS and ISDN channels while using the remaining bandwidth to provider even higher speed corporate data or Internet access.

2. Residential Users

The following points highlight attributes making SHDSL applicable for certain residential users. Because SHDSL uses the POTS bandwidth, alternative mechanisms have been developed to support voice (details go beyond the scope of this paper). In the event of the loss of power, emergency Lifeline service (e.g E-911 in US) is generally not supported. However, SHDSL provides a remote powering option and it can be utilized to provide one emergency line.

- ✓ Extended reach for remote customers
  - Unlike ADSL, SHDSL technology can achieve higher rates at longer distances, and also supports the use of signal repeaters. This enables users outside the range of ADSL to be offered DSL service where in the past service could not be provided.
  - On average, SHDSL provides 3 – 4 kft increased reach over previous symmetric technologies such as SDSL (2B1Q). When this is put into perspective of the serving area, this translates to approximately 40 % increase in coverage area. More serving area, more customers served, more revenue opportunities for service providers.
- ✓ Residential Gateway Access
  - A residential gateway is a term used to describe Customer Premises Equipment (CPE) installed in a home that provides access to/from the home for multiple services (Internet access, home video surveillance, home automation, etc.)
- ✓ Internet Gaming
  - Internet gaming is driven by client-server architecture, targeted marketing, and the Web's global reach
  - Internet gaming is convenient for end users since it can be done from the comfort of their own homes. In this competitive application environment, one user is competing against a game server (or another player in the future). In the gaming community where ranking levels are used, every 5 ms (milliseconds) of delay or slower packet transmission response results in a lower ranking level. Asymmetric service where the upstream link speed is much slower than the downstream link skews the player's performance ranking due to the slower upstream speed. Symmetric service is required for successful Internet gaming.
  - Start-up costs are relatively low including a cheap server and some unsophisticated interactive software on the client side, which can be licensed from many sources.
- ✓ Peer-to-Peer Services

- Someone who runs a business from their home and needs to share information with clients would fall into the category of Peer-to-Peer Services e.g. media file sharing
- SHDSL is best-suited for these types of services in that it enables the user to share large files with clients and receive large files from clients – SHDSL enables smooth two-way communication

3. MxU Feeder Applications

✓ The multi-unit building market, generically identified as MxU stands for Multiple Dwelling Unit (MDU) and Multiple Tenant Unit (MTU).

✓ MDUs include apartment houses, condominiums, and commercial multi tenant office buildings. The customers that benefit include tenants, IT service providers, NSPs (Network Service Providers), and ISPs (Internet Service Providers). Tenants benefit by receiving Internet services more conveniently at faster speeds. IT service providers benefit by expanding end-user services such as video and virtual gaming in conjunction with billing services. NSPs and ISPs benefit by expanding service boundaries for community applications like E-commerce and local network applications.

✓ MTUs consist of mainly hotels. The customers that benefit from SHDSL deployment within hotels include hotel operators that can sell new services over existing cabling without compromising revenues from voice services and guests, especially business travelers, who can access corporate Intranets and use e-mail over much more convenient connections than currently possible.

✓ SHDSL with Inverse Multiplexing over ATM (IMA) fills an important void by enabling SHDSL over multiple lines multiplexed together to offer higher speed service rates between the MxU location and the network without installing E3/T3 line or constructing fiber to the building. The advantages include:
  - Minimize time to market by reusing the existing copper wiring already connected to the customer location;
  - Minimize disruptions to tenants in the MxU because no new cable construction is necessary;
  - Enable the use of SHDSL technology across different MxU segments, residential versus business
  - Lower deployment costs with the MxU representing a converged communication platform, and lower maintenance costs with new support tools.
  - Provides higher reliability and redundancy with multiple copper pairs back into the network.

4. E1/T1 Replacement

✓ Price is one reason DSL is taking the commercial market by storm. DSL is available at a fraction of the cost of E1/T1 service, which generally is not affordable for most small businesses. The primary reason why SHDSL service is more economical is related to the fact that there is no need for repeaters approximately every 1000 meters or every 3 – 4 kft, which is required with E1/T1. To order a new E1/T1 line, there is significant delay and costs because the service provider must install these repeaters in the outside plant and involves multiple truck rolls. SHDSL does not require repeaters under 18 kft and can be installed on existing copper loops thereby significantly reducing time to service as well as being a lower cost technology. Furthermore, SHDSL only uses one copper pair to provide equivalent E1/T1 service rates where E1/T1 service requires two pairs.

✓ The SHDSL standard includes a provision for carrying E1/T1 within the SHDSL payload, thus SHDSL is able to provide E1/T1 type services. CPE vendors have developed CPE units are available on the market today.

✓ Some carriers/service providers are still using E1/T1 equipment from the 1980s, which is quickly becoming obsolete. SHDSL provides these carriers with a cost reduced and simplified alternative solution for providing equivalent service and/or can provide higher-speed, higher-bandwidth intensive service rates up to 4.6Mbps. Figure 5 shows how the use of SHDSL can simplify the network architecture.

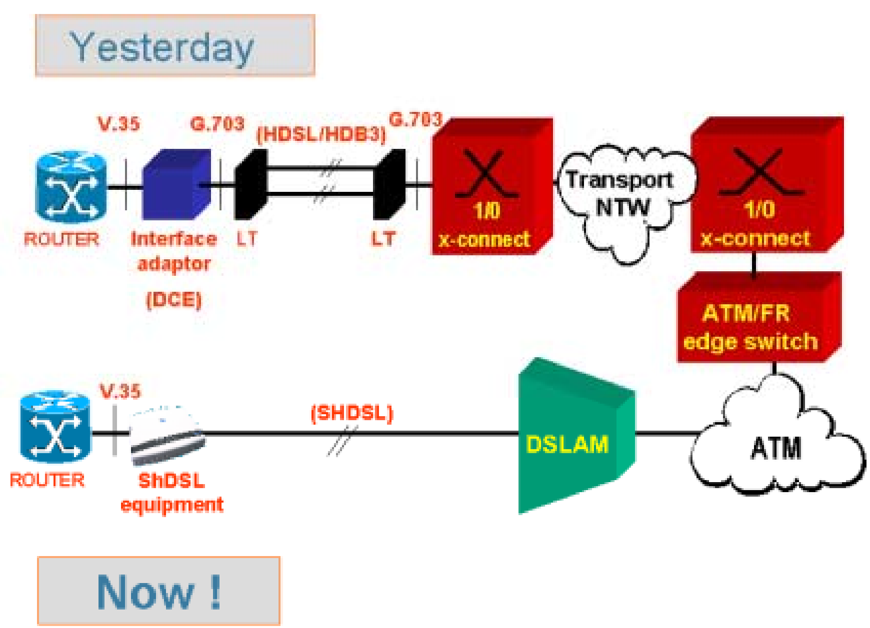

Figure 5

Simplifying the Leased Line Network with SHDSL

5. Migration path for HDSL2

✓ HDSL2 or advanced High bit rate Digital Subscriber Line is a T1 transport service replacement transmitting at 1.5 Mbps T1 rates over 2-wire or single pair for distances of about 4 km (or CSA - Carrier Service Area) in the United States. The HDSL2 line coding scheme is a precursor to SHDSL.

- ✓ HDSL2's primary benefit is that it requires only a single twisted copper pair to transmit the same distance and data rate as regular HDSL on two pairs. This is a distinct advantage in certain areas where unused copper pairs are becoming a rare commodity. HDSL2 will allow telecom service providers to meet rapidly increasing demands for high-speed transmission services in areas where copper pair shortages exist.
- ✓ In places where the length of the loop is the most critical factor and not the number of loops, a version of HDSL2 named HDSL4 has been created. Two pairs are used at speeds of 776 kbps to get T1 speed but at much greater distances.
- ✓ HDSL2 has built-in flexibility that enables it to be used for a wider range of applications and to reach a larger target market than today's HDSL. In addition to all the typical T1 transmission applications such as cellular base stations and leased lines, HDSL2 can be targeted to a wider range of data access applications such as fast access to the Internet for residential or business customers, voice pair gain systems, or even video conferencing. Due to the specified bit rates of up to 2.312 Mbps, SHDSL can also transport E1 services. However the SHDSL standard has an option to support T1 traffic using the same line coding techniques as HDSL2

6. Migration path for VoDSL

   Even without compression, a large number of voice channels can be placed on DSL channels, which makes the technology very attractive. For example, up to 24/32 voice channels can be transmitted over 1.5/2.0 Mbps DSL. DSL signals at the customer side are delivered into an integrated access device (IAD), which forwards them over twisted pair to the carrier. The signals go to the carrier's DSLAM and then to an access switch that forwards voice via a voice gateway to the Public Switched Telephony Network (PSTN) and data to the appropriate data network.

7. Repeater Technology – Greater Reach

   - ✓ SHDSL provides the greatest reach of all DSL technologies and is illustrated in Figure 2.
   - ✓ The SHDSL standard supports the use of line powered repeaters, therefore allowing very long DSL customer reach. Multiple repeaters (up to 7) can be used to achieve extremely long distances. DSL services can be provided to customers well beyond 30 kft.

8. High Bandwidth alternative to Fiber

   SHDSL is an excellent high bandwidth alternative to Fiber for many reasons, including:

- ✓ DSL is comparatively inexpensive because it runs over copper networks that are already in place. Service providers can avoid the expense of laying fiber, enabling the operator to offer high-speed services at a lower price than if they had to invest and deploy new transmission facilities.
- ✓ As noted previously, techniques such as bonding and IMA enable higher data rates to be supported. Bonding generally involves the use of a second pair. When an E1/T1 (which is 4-wire or two pair) customer is upgraded, only one pair is required with SHDSL to support the equivalent service rates. By utilizing the "spare" pair, the service rate to that customer can be doubled with bonding. With IMA, many pairs can be multiplexed together to support even higher rates to the customer. Copper loops to customer locations are far more prevalent than T3/E3 or fiber. SHDSL provides an important new tool in the service provider/carrier service portfolio.

Interoperability

Organizations such as Independent Testing Laboratories (ITLs) allow vendors to share test facilities in a neutral, non-competitive environment and organize "plugfests" which bring together engineers and researchers for a week or more to tackle any outstanding interoperability issues. Through ongoing testing and plugfests, potential bugs are discovered and resolved in the lab. These activities help avoid the burden of costly and time-consuming truck rolls after installation.

By consolidating expensive testing facilities in one spot and bringing the best minds of the industry together to use them, the ITLs speed the process that enables different silicon and system vendor's products to achieve interoperability while saving companies massive capital overhead. Particularly important in today's economy, overall system costs are reduced and time to market is significantly shortened. In addition, interoperability will foster mass deployment, as companies leverage the work that has taken place with all of the other flavors of DSL.

Future Outlook

Though the SHDSL standard has reached a mature status, there is always room for new ideas. The main standardization bodies like ITU, Committee T1 and ETSI are currently working on the next generation of their respective standards. In order to widen the possible field of application, higher data rates, multi channel bonding and new payload classes such as Packet Transport are being addressed. Moreover new applications like Ethernet in the first mile based on extended 10 Mbps SHDSL are currently under discussion.

Summary

By utilizing SHDSL technology, service providers can offer services that combine greater reach performance and spectral compatibility with other transmission technologies in the same binder, as well as lower power and rate adaptation within their respective networks for high-speed symmetric service offerings. Until recently, most of the current deployments of Symmetric DSL (SDSL) have been proprietary and based on two-binary one-quaternary (2B1Q) modulation over a single twisted pair. SHDSL provides both equipment manufacturers and service providers with a shared common definition for a worldwide multi-rate symmetric service, and provides greater deployment and service flexibility for service providers.