**Broadband Access: G.SHDSL: Reaching the Access Network**

Jim Quilici - January 10, 2001

The G.SHDSL standard, now in the final stages of definition by the ITU, is a new international standard for symmetric DSL (SDSL). Also known by its official moniker of G.991.2, G.SHDSL is designed for businesses that require high-speed data transfer in both directions. The new standard moves data farther and faster than earlier solutions, while improving spectral compatibility to pre-existing and emerging services. Once the final standard is published in April of 2001, operators around the world will have a common definition for a worldwide multi-rate SDSL spec.

DSL deployment is now in full swing in North America and other regions of the world, with tremendous growth projected during the next five years. While asymmetric DSL (ADSL) is targeted at consumer Internet access, where upstream data rates are of less importance, SDSL is emerging as the business DSL. By supporting equal two-way data rates, SDSL better enables LAN remote access, Web hosting, and the ability to combine multiple voice and data channels within the DSL payload.

Primarily driven by competitive local-exchange carriers (CLECs), the SDSL systems currently under deployment have been derived from high-bit-rate DSL (HDSL). Developed in the early 1990s, HDSL uses 2B1Q modulation and two twisted-pair cables to deliver T1 service at 1.544 Mbps. To date, most SDSL systems have been proprietary and based on two-binary one-quaternary (2B1Q) modulation over a single twisted pair. While some CLECs are building a healthy subscriber base using SDSL technology, spectral compatibility concerns and a lack of standards have caused many incumbent local exchange carriers (ILECs) to hesitate in deploying SDSL services. When the ITU gives final approval to G.SHDSL, that hesitation will evaporate as operators and equipment manufacturers share a common definition for a worldwide multi-rate SDSL.

For many users in small and medium-sized business environments, dial-up modem speed is quickly becoming inadequate for day-to-day transactions. Consequently, business users have driven much of the early DSL deployment.

The asymmetric upstream and downstream data rates of ADSL are fine for Internet surfing, yet insufficient for applications that require large file transfers in both directions. Although it is possible to deploy ADSL in a symmetric fashion, the technology has never been optimized for symmetric operation. Under best-case conditions, a user might only achieve a 784-kbps symmetric service. G.SHDSL has been designed specifically for symmetric data transfers, allowing upstream and
downstream data transfers in excess of 2 Mbps over a single pair of copper wires.

**Consistency**

A more subtle issue is consistency of service. ADSL was designed to be a "best-effort" service, in which the user's data rate can vary, depending on noise conditions and distance from the operator's equipment. G.SHDSL, on the other hand, has been developed as a guaranteed service. The technology delivers a 10^-7 bit error rate (BER) to a specified distance under worst-case noise conditions. The subscriber can count on a guaranteed bandwidth and a certain quality of service for important transactions.

Finally, ADSL provides a single analog voice connection along with a broadband data channel (see Figure 1). While the analog connection supports continued use of an existing phone line, G.SHDSL's digital technology allows business users to have multiple phone connections combined with a fax and broadband data channel. With G.SHDSL, multiple voice and video channels can be embedded in the data payload. The difference resides in the transmission latency. ADSL uses Reed-Solomon forward error correction (FEC) coding, resulting in a relatively large transmission latency of 20 ms.

This latency makes it difficult to transport time-sensitive voice and real-time video within the ADSL payload. Although the ADSL FEC can be turned off to bring transmission latency to acceptable levels, this action ultimately reduces the performance margin and BER of the line.

By comparison, the latency of G.SHDSL is less than 1.2 ms, which is suitable for 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, G.SHDSL allows different service applications to be tailored for medium-sized businesses, small businesses, telecommuters, and home offices.

**Designed for the access network**

While the American National Standards Institute (ANSI) has recently developed HDSL2, a successor to HDSL, this technology was primarily designed for the feeder networks of North America. G.SHDSL was primarily developed for the access network.

Feeder cables are generally arranged in large binder groups and normally extend along major corridors from the telephone company central office (CO) to distribution frames. At the distribution frame, the cables then branch out into the access network, which extends to individual subscribers. Often, large bundles of feeder cables are deployed directly into large corporations and industrial centers. Feeder lines are also used for internetworking wireless base stations, or connecting an ISP to the CO.

In North America, 90 percent of feeder network loops reside within 12,000 feet of the central office, and generally have a healthy mix of T1 and HDSL services within the cable binder groups. In
contrast, the access network generally has shorter loops (under 6,000 feet) with the cables carried in smaller binder groups. Also, there is a lower incidence of T1 and E1 service, which can often be dominant sources of noise.

From the distribution frames, the access network carries service directly to business and residential users. Often, the services in the access network are deployed from DSL access multiplexers (DSLAMs) at the CO or digital loop carrier (DLC) equipment at the street curb. Both types of equipment feature a high concentration of ports, which makes heat dissipation and cooling a major concern. The power consumption of the DSL transceivers often determines how many ports can be implemented on a DSLAM or DLC line card.

**Power concerns**

Power is also a concern when providing voice service. Many operators are required by their regional regulators to provide a minimum of one voice circuit in the event of a power outage at a customer’s premises. This implies that a customer modem must be powered over the twisted-pair cable. For safety reasons, industry regulators limit the voltage and current that can be delivered on the line.

On longer loops, more than half of the delivered power is dissipated in the resistance of the twisted-pair cable. Considering that power at the remote end of the line must be budgeted between the DSL modem, voice codec, and telephone ringer, it becomes clear why span powering places tight constraints on modem power consumption. Ultimately, the power budget restricted the modulation technique and degree of DSP processing that could be employed for G.SHDSL.

Spectral compatibility was another key factor in defining the modulation technique for G.SHDSL. In entering the access network, G.SHDSL must be spectrally friendly to new and existing services. The access network is dominated currently by POTS, ISDN, and a growing percentage of ADSL. ADSL is particularly sensitive to background noise. This concern ultimately limited the power used in the G.SHDSL transmission.

**HDSL2 derivative**

Improved spectral compatibility was one of the key drivers for the new standard. The 2B1Q modulation used in proprietary SDSL systems begins to severely interfere with ADSL when deployed at data rates above 784 kbps. ANSI's new HDSL2 technology, on the other hand, uses advanced modulation and coding techniques to limit the transmit spectrum and assure spectral compatibility with ADSL. ANSI’s criteria for developing HDSL2 included the requirement that degradation to ADSL should be no worse than the pre-existing and widely-deployed HDSL service. However, HDSL2 is not entirely appropriate for access networks. First, HDSL2 was primarily developed for North American feeder networks. It utilizes a shaped power spectral density (PSD) mask that has been optimized for noise conditions in North America.

Additionally, loop conditions and noise environments in Europe and the rest of the world are significantly different, and therefore require different shaping characteristics. In addition, HDSL2
employs a signal boost in the 200- to 300-kHz region of the upstream spectrum to overcome the
strong T1 background noise. One result of PSD shaping is that the signal characteristic takes on a
large peak-to-average ratio (PAR).

As the PAR increases, so does the power consumption of the line driver (check out the companion
article, "Peak-to-Average Ratio and Its Effect on DSL System Power Consumption," at
www.csdmag.com/main/2001/12/sidebar.htm). Furthermore, the ANSI HDSL2 standard defines only
a single rate, which is 1.544 Mbps. When the shaped PSD is scaled to other data rates, all
performance and spectral compatibility benefits are lost. Clearly, operators need a multi-rate
solution that provides good spectral compatibility with other services and is able to operate at power
levels comparable to the 2B1Q SDSL systems.

**G.SHDSL solutions to fit regional conditions**

Recognizing the need for a simplified symmetric service prompted the initiation of an SDSL project
in the ITU. In the fall of 1998, the G.SHDSL project was launched. After evaluating the alternatives,
the ITU determined that G.SHDSL would use the same advanced signal modulation and data
encoding techniques as HDSL2. Carrierless amplitude/phase (CAP) and discrete multitone (DM)
modulation schemes were also investigated, yet pulse amplitude modulation (PAM) 16 proved to be
the best alternative in terms of complexity, performance, and latency.

Most HDSL2 silicon solutions have flexible DSP cores. One of the ITU’s objectives was to define the
standard in such a way that HDSL2 silicon could be re-used for multi-rate applications. However, to
minimize power consumption, the signal shaping needed to be simplified.

Across the Atlantic, Committee TM6 of the European Technical Standards Institute (ETSI) had also
begun the work of defining a multi-rate SDSL for business and residential use. ETSI wanted to take
advantage of the foundation established by HDSL2, and based their system on trellis coding and
PAM 16 modulation. While Europe and North America share many service requirements, the noise
and loop conditions of each region are different. Consequently, the two regions require slightly
different standards. Ultimately, the ITU adopted the ETSI work for the European environment and
then produced a North American version.

**Two annexes**

G.SHDSL has been organized into a base document with two regional annexes (see Figure 2). The
base document describes fundamental modem start-up and operation. Annex A describes
transmission and performance requirements for North America, and annex B describes performance
and transmission requirements for Europe. For annex B, the ITU has adopted ETSI’s draft SDSL
standard. Annex A utilizes the basic PSD defined by ETSI, yet specifies a different set of loop
conditions and performance requirements.

The basic G.SHDSL PSD is shown in Figure 3. Much simplified from HDSL2, the PSD is flat and
symmetric in the upstream and the downstream directions.
The transmit power is much lower as well. While HDSL2 has a maximum transmit power of 16.5 dBm, the power of G.SHDSL is 13.5 dBm up to 2.048 Mbps. At and above the 2.048-Mbps data rate, the power may be increased to 14.5 dBm, if required. The PSD template scales with the data rate, and the -3-dB lowpass cut-off is placed at half the baud rate. A sixth-order Butterworth filter roll-off attenuates the out-of-band noise and provides good spectral compatibility with ADSL.

At the 2.048-Mbps data rate and under worst-case conditions, G.SHDSL can reach 2.4 km and still provide 6 dB of margin and a 10e-7 BER.

While the primary objective of the G.SHDSL standard was to produce a multi-rate symmetric solution for access networks, both annexes include optional PSDs for DS1 transport in feeder networks. The optional PSD in annex A is essentially the HDSL2 solution. ETSI defined two optional PSDs: one for E1 transport and the other for carrying synchronous digital hierarchy (SDH) tributary payloads. The optional PSDs in the G.SHDSL standard use higher transmit power to provide added performance in severe noise conditions.

To compensate for the higher transmit levels, the optional PSDs also use excess bandwidth as well as asymmetric upstream and downstream PSD characteristics (see Figure 4). The asymmetric configuration also improves spectral compatibility to ADSL. The faster roll-off of the asymmetric PSDs results in a higher PAR, and consequentially higher power consumption in the line driver.

**PSD comparison**

A comparison of the PSD options indicates that the symmetric spectrum used in the base configuration is spectrally benign to other services and consumes less power. This equates to less noise in the system, more channels per line card in the DSLAM and DLC equipment, and lower cost. The primary use for the asymmetric PSDs will be long-reach applications in feeder networks.

Table 1 compares the various options. Performance varies with noise conditions and line characteristics, yet the G.SHDSL solution generally provides longer reach than its 2B1Q predecessor. For instance, at 1.544 Mbps, G.SHDSL can reach over 2.4 km (8 kft) on 0.4-mm (26 AWG) cable and under self-near-end-crosstalk (self-NEXT) conditions. By comparison, single-pair HDSL merely reaches 1.8 km (5.8 kft) under similar conditions.

While G.SHDSL uses a much-simplified PSD and lower transmit power than HDSL2, many of the functional blocks are the same. Most HDSL2 implementations have been designed with flexible DSP cores and may be re-used for G.SHDSL. Figure 5 shows a block diagram of a G.SHDSL transceiver.

The core of the transceiver consists of the scrambler, 16-level symbol mapper, transmit precoder, and transmit filter. These blocks carry over directly from HDSL2 to G.SHDSL, given that the transmit filter is programmable and can realize the different PSD shapes. The analog functions also carry over. However, the lower transmit level of G.SHDSL allows the line driver to be optimized for lower power consumption.
New functions

Even with the ability to re-use some HDSL2 technology, G.SHDSL still required new functions to enhance its multi-rate capability. In most instances, modems must be able to negotiate line rate and configuration details. In access networks, loop lengths and noise conditions differ significantly from pair to pair. While 13.5-dBm transmit power is required for worst-case noise conditions, many lines will not require such power levels. G.SHDSL includes a power back-off algorithm that enables modems to adjust transmit power according to conditions on the line. Operators can use this feature to manage and reduce crosstalk noise on the network.

To negotiate these features, G.SHDSL adopted the ITU G.994.1 handshake procedure, which allows modems at either side of the line to trade configuration and line-rate details prior to activation. In most applications, the operator will dictate the line rate. However, G.SHDSL does have provisions for automatic rate negotiation. G.994.1 uses narrowband frequency tones and differentially encoded phase-shift-keying (DPSK) modulation to trade this information. This signaling technique is spectrally benign to other services.

Probing the line

During preactivation, a broadband line probe is used to characterize the line attenuation and signal-to-noise ratio (SNR). When activating, the modems first use G.994.1 signaling to determine the rate, power, pulse duration, and PSD of the line probe.

Next, the line-probe sequence begins. The modem at the remote end will first send out a series of pulses. The duration of the line-probe pulses can range from 0.5 to 3.1 sec, depending on implementation. On completion of remote-end signaling, the CO side sends and completes its probe sequence. The modems return to the G.994.1 signaling and trade attenuation as well as SNR details.

Based on this information, the modems then determine full-activation line rate and power levels, and proceed to full activation. In all, the preactivation and probe sequence may add 10 to 20 sec to the activation time. Depending on the data rate, another 15 to 30 sec may be needed to train the equalization and echo cancellers and fully activate the modems at each end of the line. While use of the handshake and line probe is optional, most manufacturers will use this capability to implement power back-off and achieve interoperability.

Another G.SHDSL function for the access network is warm start. Operators and users alike prefer that modems go into low-power mode when not in use. As mentioned earlier, modems require 15 to 30 sec to fully train the equalizers and echo cancellers.

However, in a warm-start application, the modem will save the equalizer coefficients prior to going into an idle state. In this case, the modem can undergo a fast retrain upon receiving a wake-up signal locally or from the other end of the line. The stored DSP coefficients are reloaded and the modem's clock recovery mechanism will then resynchronize with the incoming signal. The warm-start requirement comes from ETSI SDSL, which has set a reactivation requirement of less than 500 ms.
Payloads and payoffs

Traditionally, HDSL and HDSL2 have been used for channelized DS1 transport, with the payload being chopped into synchronous 64-kbps time slots and mapped to and from the DSL line. Today, access networks are moving quickly to an asynchronous, cell-based transport. G.SHDSL has provisions for mapping ATM cells into the DSL channel.

A transmission-convergence (TC) function has been defined to perform the functions of header-error checking (HEC), rate decoupling, and cell delineation. Essentially, the TC function maps the asynchronous cell traffic to and from the synchronous DSL channel. Cells are mapped byte-wise into a clear G.SHDSL payload.

If there are gaps in the transmission and cells are not coming from the ATM layer, the TC function will insert IDLE cells into the G.SHDSL transmit path.

The TC also performs the function of cell delineation, allowing ATM traffic to be handed to the higher layer through a cell-based handshake. The cell delineation is based on the HEC algorithm. The HEC is also used to filter corrupted cells rather than pass them up to the higher layer. Packet transport is also possible with G.SHDSL, although the ITU specifications simply document how the packet-based data will be mapped to the payload. Error checking and rate decoupling are defined in higher-layer specifications (Internet Engineering Task Force [IETF] document RFC1661, "PPP in HDLC-like Frames").

Finally, the G.SHDSL standard defines provisions for combining synchronous narrowband DS0 channels with a broadband data channel (see Figure 1). This capability allows for multiple voice lines, either ISDN or traditional POTS, to be combined with a data service. Depending on the application, the bandwidth for voice channels may be set up dynamically in the event of a call. The bandwidth can then be returned to the data channel once the call session is over.

The G.SHDSL standard brings a common definition for symmetric DSLs, to which manufacturers worldwide can build interoperable equipment. In the past, interoperability was not critical for telephone operators. But with deregulation and increased competition, network requirements are changing. Because interoperability helps minimize cost and deployment time, issues that are critical to the success of new services, operators have now made interoperability a key selection criterion for new DSL systems.

Interoperability testing

A G.SHDSL consortium has been formed at the University of New Hampshire and will begin testing interoperability in the first quarter of 2001. With better bandwidth efficiency and an international standard behind it, G.SHDSL should replace nonstandard SDSL systems to become the service of choice.
## TABLE 1: Comparison of SDSL Technologies

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<thead>
<tr>
<th>ITU G.991.1, HDSL</th>
<th>ANSI T10418, HDSL2 (Option under G.SHDSL annex A)</th>
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<td>Data rate (Mbps)</td>
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<td>2.048</td>
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<td>2.304</td>
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<td>2B1Q</td>
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<td>Trellis coded PAM 16</td>
<td>Trellis coded PAM 16</td>
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<tr>
<td>Transmit power</td>
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<td>13.5 dBm (basic)</td>
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<tr>
<td></td>
<td>16.5 dBm</td>
<td>14.5 dBm</td>
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<td></td>
<td>(optional PSD)</td>
<td>(2.048, 2.304 Mbps)</td>
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<td>PAR</td>
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<td>3.8 (optional PSD)</td>
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<td>DS1 ATM cells packets ISDN BA</td>
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Editor's note: Read the sidebar to this article, entitled **Peak-to-Average Ratio and Its Effect on DSL System Power Consumption**.

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### About the Author

**Jim Quilici** is a technical manager for DSL access operations at Intel. He holds a BSEE from the University of Santa Clara and MSEE from the University of Arizona. Jim has more than 12 years' experience developing products for LAN and telecom applications. He has been an active participant of the ANSI, ETSI, and ITU standardization process for SDSL technology and can be reached at [james.e.quilici@intel.com](mailto:james.e.quilici@intel.com)

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**Illustrations**
- Figure 1: Combined voice and data services.
- Figure 2: The ITU family of SDSL standards.
- Figure 3: Basic G.SHDSL PSD for North America, Europe, and the rest of the world.
- Figure 4: Optional asymmetric PSD for Europe and the rest of the world.
- Figure 5: G.SHDSL transceiver block diagram.