HDSL4

Reliable, Longer Reach, Spectrally Compliant T1 Transport

white paper

Abstract

Using two pairs of copper wires to provide T1 transport delivery, HDSL4 maintains spectral compatibility beyond the carrier service area (CSA) range as well as on repeatered loop applications. Service providers can realize numerous benefits by deploying this latest advancement in symmetric DSL services. For instance, the technology offers extended reach and spectral compatibility with ADSL. In order to make optimal DSL technology deployment choices, though, service providers need to carefully analyze the application before selecting technologies and the associated equipment.

HDSL4 is the latest advancement in symmetric digital subscriber line (DSL) solutions for T1 delivery. In February 2002, the T1E1.4 committee approved the T1.418 Issue 2 HDSL2 standard, which includes HDSL4 as a 4-wire, symmetric, 1.544-Mbps T1 transport solution.

HDSL4 offers the same robust performance as HDSL and HDSL2, providing a maximum bit-error-rate (BER) of 10e-7 with 5 dB of margin over a 1% worst-case mixed crosstalk environment. What makes HDSL4 unique is that it is a spectrally compliant T1 transport solution that extends the "repeaterless" reach to 16kft (24 AWG) and the "repeatered" reach to up to 46kft (24 AWG). When used with repeaters, HDSL4 is the only T1 transport technology that meets spectral compatibility requirements with ADSL per the ANSI T1.417 spectrum management standard.

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What are the Benefits of HDSL4?

HDSL4 offers considerable cost savings and better utilization of local loop bandwidth. The advantages of using HDSL4 products include spectral compatibility with ADSL, extended reach using fewer repeaters, and cost savings in installation and power consumption.

Spectral Compatibility with ADSL

With the variety of xDSL technologies being deployed in the same copper binders, spectral compatibility is becoming extremely important to limit crosstalk noise interference between the pairs and to achieve performance targets.

In 2001, ANSI published the T1.417 spectrum management standard. Unfortunately, traditional DS-1 repeaters and HDSL technology were often found incompatible with ADSL when carried in the same cable bundle. As a result, HDSL2 was developed to eliminate this spectral interference with ADSL, but its reach was limited to a Carrier Service Area (CSA) range of 12kft on 24 AWG. This short range was not sufficient to reach an optimal number of customers.

HDSL4 is spectrally compatible with ADSL when used with up to two repeaters, and it is the first and only T1 transport technology spectrally compatible with ADSL when deployed beyond 12kft on 24 AWG.

HDSL4's exceptional range eliminates regulatory concerns for service providers, especially when leasing unbundled copper. The technology also reduces circuit problems on both DS-1 and ADSL circuits because it improves performance, provides reliability, and guarantees supported data rates—all of which improve customer satisfaction.

Extending Reach with Fewer Repeaters

While traditional repeaterless HDSL and HDSL2 deployments are limited to CSA range, HDSL4 extends this range by 30% to 16kft on 24 AWG, and maintains the same robust performance without the use of repeaters. This increase in reach means more customers are accessible without installing additional repeaters. In fact, data shows that 11% more customers can be reached with HDSL4 without the use of expensive outside plant repeater installations . Research shows that:

- 80% of HDSL/HDSL2 applications are repeaterless.
- 15% of HDSL/HDSL2 applications require a single repeater.
- 70% of those single repeater HDSL/HDSL2 applications can be covered with repeaterless HDSL4.
- 91% of all HDSL2/HDSL4 circuits can be repeaterless.

In multiple span applications, repeatered HDSL4 extends the per-span reach from 12kft in HDSL to 16kft (or 15kft depending on the number of spans) in HDSL4. The HDSL4 standard enables the use of up to two repeaters, yielding a maximum spectrally compatible reach of 46kft on 24 AWG.

Cost Savings in Installation and Power Consumption

In long loop applications with repeaters, HDSL4 provides cost savings because fewer repeaters are used. For example, in a 46kft application, HDSL4 uses two repeaters while HDSL technology requires three. Because of greater equipment requirements, the HDSL approach has a more complex installation process, which increases installation planning time and costs. Actual cost savings in equipment and installation from HDSL4 can range from $410 to $650 per circuit.

Reducing the number of repeaters used in a circuit also translates into cost savings due to lower power consumption from the network battery. Most of the HDSL/HDSL2/HDSL4 repeaters and remote units are line-powered by the Central Office unit, which is powered by a –48VDC battery in the Central Office bay.

The most significant savings is realized in 12kft to 16kft (both in 24 AWG) deployment applications, where a repeaterless HDSL4 circuit is used instead of a single-repeater HDSL circuit. Using HDSL4 transceiver chipsets that were developed with the latest low-power microelectronics technology, it is reasonable to estimate power consumption savings of up to 30% in a repeaterless HDSL4 deployment scenario.

As an additional benefit, heat dissipation within the CO unit can also be reduced by up to 20% in these circuits, increasing the density of circuits that can be deployed per bay while maintaining NEBS compliance.

How Does HDSL4 Offer These Advantages?

The signal processing blocks to implement equalization, modulation, coding, and decoding are all the same in both HDSL4 and HDSL2, so HDSL4 operates similarly to HDSL2 at the physical layer (PHY).

HDSL4's benefits of spectral compliance and extended reach are due to careful design choices when using bandwidth and limiting transmit power. Specifically, HDSL4 technology uses transmission over two pairs of wire, Trellis Line Coding techniques, lower transmit power levels, spectrum shaping, and power back-off to provide extended reach in a spectrally compliant solution.

Two-pair Transmission

Generally speaking, reducing the line rate transmitted on a pair will result in a gain in loop reach. Using 16 level Trellis Coded Pulse Amplitude Modulation (TCPAM), HDSL2 has a loop reach of 12kft when transmitted on a single pair of copper at a line rate of 1552kbps. By halving the line rate to 784kbps and transmitting over two pairs of copper, HDSL4 extends the loop reach on a single span to 16kft. The DS-1 payload is split using bit interleaving over the 2 pairs of copper, and the aggregate payload rate of 1.544Mbps is maintained with a low latency optimized for voice service delivery. Combined with spectral shaping of the Power Spectral Density (PSD) (see "Spectral Shaping" below), this reduction in signaling bandwidth allows HDSL4 to be spectrally compatible with ADSL when deployed in the same cable binder.

Trellis Line Coding

HDSL technology uses 2B1Q as the transmission line code, in which two information bits are transmitted per symbol in the physical layer. This is a four-level code without redundancy and is limited in capacity advancement. HDSL2 and HDSL4 use 16-level TCPAM, which is an error-correcting code with performance that approaches the theoretical limit of channel capacity.

The 16-level Trellis encoder transmits three information bits and one redundant coding bit per symbol. The redundancy added in the Trellis encoder, together with the Viterbi decoder implemented at the receiver, allows erroneous bits to be recovered, which results in 5dB of coding gain. This enables HDSL2 and HDSL4 to overcome local loop impairments and maintain a 5dB noise margin over HDSL under worst-case conditions, even on longer loops.

Lower Transmit Power

The transmit power level of a symbol determines the signal energy that the analog front end transmits to the physical wire. While higher transmit power means longer reach, that energy must be balanced with minimizing crosstalk. For instance, a higher transmit power allows the receiver to enjoy a higher signal-to-noise ratio (SNR) after the signal travels through the attenuation of the copper wire, but it will adversely affect spectral compatibility as more crosstalk noise is induced to the adjacent pairs. An HDSL4 signal has a maximum transmit power level of +14.1dBm, which is lower than the HDSL2 maximum power of +16.5 to +16.8dBm. With HDSL4, crosstalk to other cable pairs is minimized while maintaining performance targets.

Higher transmit power levels typically limit the ability to deploy repeaters because more power would be required to operate the analog front-end circuit. This would increase the power consumption per network element and the power loss on the cable. Lower transmit power levels in HDSL4 reduces the power consumption per network element. As a result, line powering of two network elements per circuit over the maximum reach per span is possible with the HDSL4 maximum voltage limit of 200V.

Spectral Shaping of Asymmetric Spectrum

The Power Spectral Density (PSD) of a signal determines how signal energy is distributed when transmitted across the frequency bandwidth. ADSL service is upstream limited by the signal noise crosstalk from other technologies occupying the upstream frequency passband below 138kHz.

HDSL4 uses spectral shaping to address this problem and reduce degradation to ADSL service. This means that some of the HDSL4 downstream signal energy (that can affect upstream ADSL performance) is relocated to a higher bandwidth region **(Figure 1)**. As a result, the HDSL4 downstream

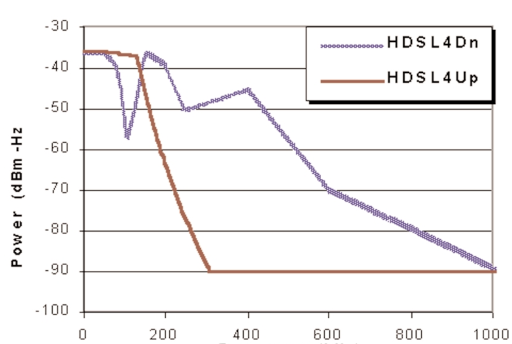

Figure 1. HDSL4 Asymmetric PSD Plots

PSD has a "notch" at approximately 138kHz so near-end crosstalk (NEXT) induced from the HDSL4 Central Office Transmitter into the ADSL Central Office receiver is reduced, and ADSL upstream performance capacity can be maintained.

Although HDSL4 is a symmetric data service (delivering the same data rate of 1.544 Mbps in the up and downstream), the PSD spectrum it uses to deliver this data rate is NOT symmetric. This use of asymmetric spectrum offers HDSL4 better reach performance than symmetric spectrum—which has limited reach in typical self-NEXT scenarios. In fact, an asymmetric HDSL4 spectrum reduces both upstream ADSL service degradation and self-NEXT degradation. This increases the potential reach of both HDSL4 and ADSL in typical deployment scenarios even while achieving spectral compatibility.

Since repeaters are usually deployed closer to the ADSL customer remote equipment, downstream ADSL performance using the higher bandwidth needs to be "protected" at the ADSL remote. Thus, it becomes necessary to use a lower bandwidth symmetric spectrum at the HDSL4 repeaters so the NEXT at the higher frequency bandwidth induced to the ADSL remote is minimized.

So, while asymmetric spectrum is used on the first span in HDSL4 to provide a maximum reach of 16kft (in both repeaterless and repeatered applications), symmetric spectrum is used on the second and third repeatered spans, with a maximum reach of 15kft per span. Though there is a slight reduction of reach, use of symmetric spectrum at the repeaters is necessary for spectral compliance with ADSL.

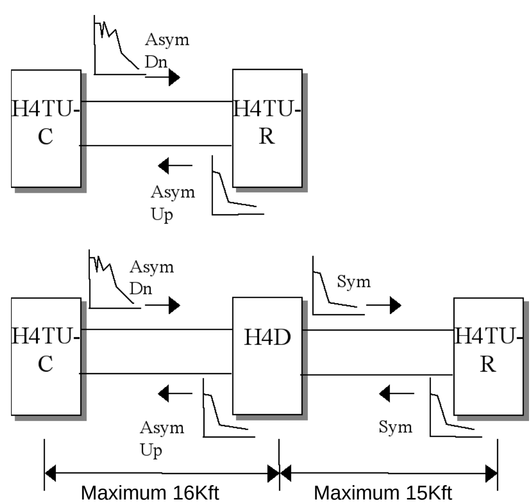

Figure 2. HDSL4 Spectra used in 1-span and 2-span circuits

Power Back-off

In order to reduce crosstalk interference into other DSL pairs and to achieve spectral compatibility, HDSL4 systems reduce the transmit power of the signal down from its maximum level power. This is known as power back-off.

The specific power back-off level required depends on the equivalent working length (EWL) of the cable pair. For instance, the shorter the loop, the higher the power back-off level required. The power back-off level is determined automatically by the transceiver at the beginning of each start-up activation cycle. The receiver estimates the EWL of the cable pair from the received power level and determines the power back-off level from a look-up table. The transmitter then sends the signal using this lower power, which allows spectrum compliance to ADSL.

If the first span of the HDSL4 deployment is less than 16kft (24AWG), such as in a mid-span repeater application deployed in a 20kft loop, power back off has to be implemented on the first span to be compatible with ADSL. This is necessary because the repeater is now closer to the ADSL Central Office Unit than if it were installed at the maximum 16kft, and the already limited upstream ADSL performance would be further impaired by far-end crosstalk (FEXT) induced by the repeater. As a result, the HDSL4 power back-off scheme reduces the transmit power in both the Central Office and repeater in this scenario in order to accomplish ADSL spectral compatibility.

Characteristics	HDSL	HDSL2	HDSL4
Standard	TR-28	T1.417	T1.417 Issue, 2
Number of Pairs	2 Pairs	1 Pair	2 Pairs
Line Rate	784 kbps x 2 Pair	1.544 Mbps	784 kbps x 2 Pair
Line Code	2B1Q	16-TCPAM	16-TCPAM
Transmit Power	+13.5dBm	+16.8dBm Downstream +16.5dBm Upstream	+14.1 dBm
Spectrum Mask	Symmetric	Asymmetric	Asymmetric on 1st span Symmetric on 2nd/3rd span
Power Back-Off	None	Yes	Yes
Maximum Reach without Repeaters	12kft	12kft	16kft
Maximum Reach with Repeaters	60kft w/4 repeaters	N/A	46kft w/2 repeaters
Spectral Compatibility without Repeater	Yes	Yes	Yes
Spectral Compatibility with Repeaters	No	No	Yes
Support Interoperability	No	Yes	Yes
Span Powering Voltage	Across Loop 1 & 2	Across TIP & RING	Across Loop 1 & 2

Table 1. Comparison of HDSL, HDSL2 and HDSL4 Technologies

Deployment Guidelines for HDSL4

To ensure compliance to the T1.417 standard, the following deployment guidelines for HDSL4 should be followed (all specified using 24 AWG copper):

- Maximum first span reach is 16kft
  (equivalent to maximum of 47dB of insertion loss @ 196kHz)

- With repeater(s), the maximum second span and third span reach is 15kft (equivalent to maximum of 43dB of insertion loss @ 196kHz)

- With repeater(s), the minimum first span reach is 5kft (equivalent to 16dB insertion loss @ 196kHz)

Which DSL Technology Should Be Used?

While HDSL4 demonstrates many benefits, it does not completely eliminate the deployment of HDSL2 and HDSL for T1 transport. In fact, HDSL4 is considered as a complementary technology for service providers to use for different deployment scenarios. The following deployment guidelines help to determine the type of DSL technology for optimal service coverage (see **Figure 3**):

- HDSL2 without repeater on circuits out to 12kft
  → Single pair, interoperable, spectrally compliant

- HDSL4 without repeater on circuits from 12kft to 16kft
  → 2-pair, interoperable, spectrally compliant

- HDSL4 with repeaters on circuits from 16kft to 46kft
  → 2-pair, interoperable, spectrally compliant

- HDSL with repeaters on circuits from 46kft to 60kft
  → 2-pair, fewer spectrum concerns than repeatered T1

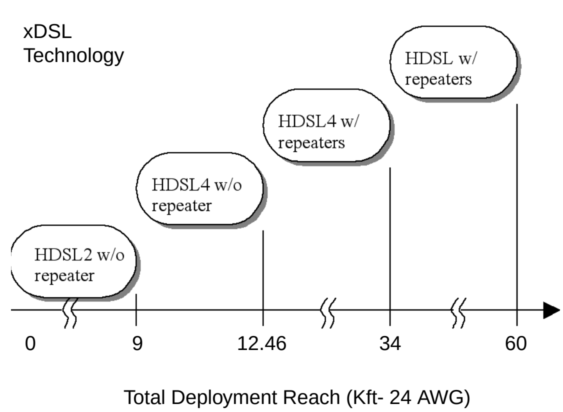

Figure 3. HDSLx Technology vs. Reach

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