

-ZyXEL White Paper-

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An introduction to VDSL2 and VDSL2 deployment options

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Table of Contents

1.	INTRODUCTION.....	3
2.	HISTORIC BACKGROUND	4
2.1	ADSL	5
2.2	ADSL2 / ADSL2+	6
2.3	VDSL	6
3.	INTRODUCTION TO VDSL2	8
3.1	BANDPLANS AND PROFILES	8
3.2	VDSL2 FEATURES.....	10
3.2.1	<i>Link stability / On-Line Reconfiguration</i>	<i>10</i>
3.2.2	<i>Support for TEQ/Echo canceller</i>	<i>10</i>
3.2.3	<i>RFI Notching and PSD Shaping</i>	<i>10</i>
3.2.4	<i>Extended frequency profiles</i>	<i>11</i>
3.2.5	<i>Coding and error correction</i>	<i>11</i>
3.2.6	<i>Framing</i>	<i>12</i>
3.2.7	<i>ADSL2+ Fallback.....</i>	<i>12</i>
3.3	VDSL2 DEPLOYMENT SCENARIOS AND RELATED PROFILES	13
3.3.1	<i>Fiber to the Exchange (FTTEx).....</i>	<i>14</i>
3.3.2	<i>Fiber to the Cabinet (FTTCab).....</i>	<i>14</i>
3.3.3	<i>Fiber to the Basement/Building (FTTB).....</i>	<i>15</i>
4.	ZYXEL VDSL2 PRODUCT PORTFOLIO.....	17
4.1	COE PRODUCTS	17
4.1.1	<i>Pizzabox.....</i>	<i>17</i>
4.1.2	<i>Chassis-based.....</i>	<i>18</i>
4.2	CPE PRODUCTS	18
4.2.1	<i>P-870M-I V2 series.....</i>	<i>18</i>
4.2.2	<i>P-2802HWL-I series.....</i>	<i>19</i>

1. Introduction

This presentation provides the reader with a brief overview of the VDSL2 technology, and deployment options. The historic evolution of xDSL from IDSL to VDSL2 is briefly described, and the new features of VDSL2 are described. The new band plans and profiles are described, and put in relation to different deployment scenarios.

Finally ZyXEL's VDSL2 product portfolio is presented.

2. Historic background

DSL means Digital Subscriber Line, and is the successor to the analogue modems of the eighties. When speaking of DSL in general, the DSL term is often prefixed with an ‘x’ to indicate that several flavors are in question. The xDSL technology offer higher bandwidth compared to analogue modems and is typically ‘always on’. One of the major reasons why xDSL technology is so popular is that it uses the good old PSTN copper pairs for the last-mile transmission of data between the subscriber and the exchange making for an economically efficient deployment compared to e.g. fiber installations where new infrastructure must be established. See Figure 1 for an overview of the evolution of xDSL and an indication of the deployment of DSL lines.

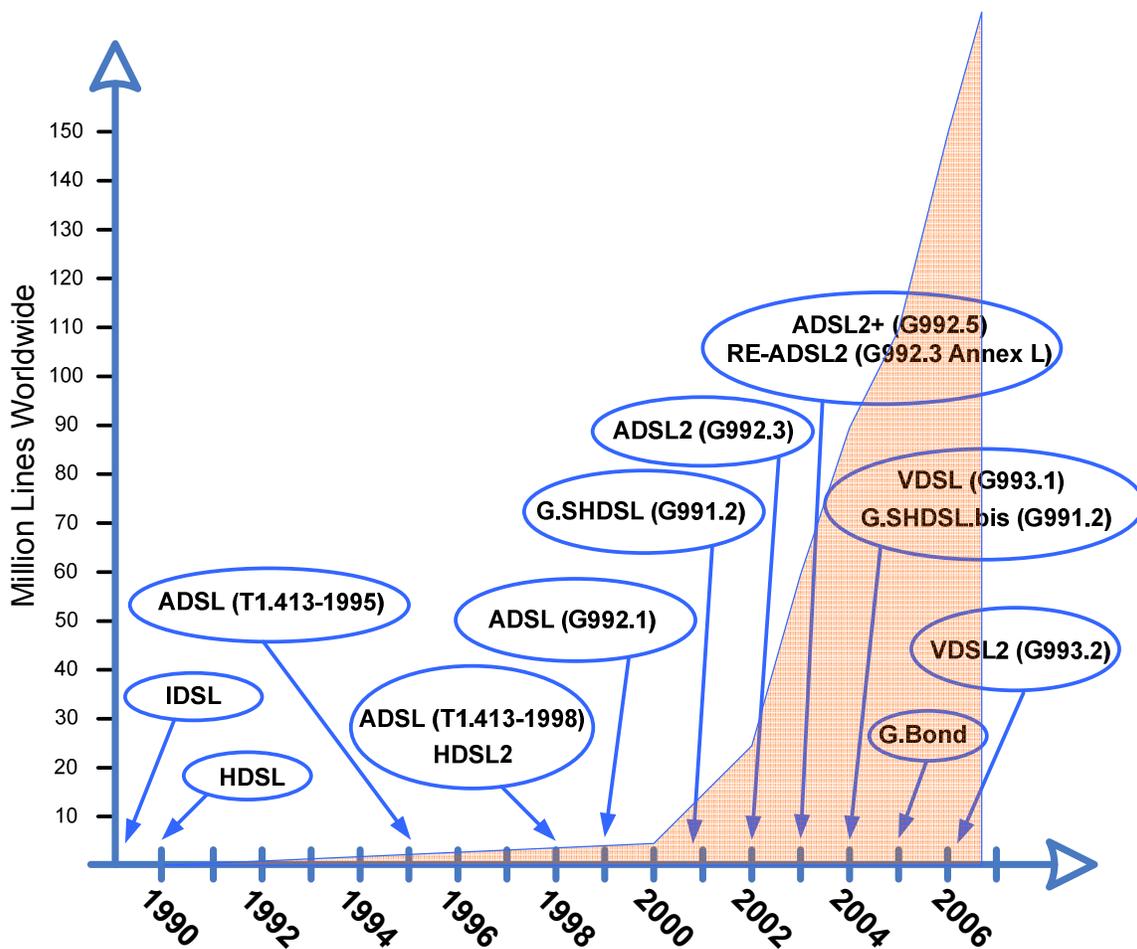


Figure 1: Historic overview of the evolution of DSL standards, and the global market penetration of DSL lines.

All the different flavors of xDSL technologies can be grouped into two basic families of technologies, which differ on two interesting properties:
Asymmetric bit rates versus symmetric bit rates

MCM (Multiple Carrier Modulation) versus SCM (Single Carrier Modulation) types of modulation technique.

The asymmetric family (ADSL, ADSL2(+), VDSL¹, VDSL2) are all pass-band technologies, i.e. the lowest frequency in use $f_0 > 0$ Hz, thus allowing a base-band service like POTS or ISDN to co-exist on the same copper-pair. Furthermore the ADSL-family all utilize variants of the same MCM modulation technology, DMT (Discrete Multi-Tone). Central office side transceiver is different from customer premises transceiver.

The symmetric DSL-family (IDSL²(IDSL (based on ISDN) is arguably not really a DSL-technology in peoples mind due to the low bit rates, but is still mentioned since I see it as the starting point of digital services for the end-user.), HDSL, SHDSL) are all base-band services, i.e. the lowest frequency in use $f_0 = 0$ Hz, and different variants of SCM is used (2B1Q, QAM, PAM ...). Due to their symmetric properties, and the fact that overlapped spectrum is used (upstream and downstream use same frequencies) the central office side transceiver and the customer premises transceiver can be the same hardware type, so you can connect two CPE's back-to-back.

Since VDSL2 is the main topic of this paper, the symmetric types of xDSL will not be described in further detail.

2.1 ADSL

ADSL was developed by Stanford University and AT&T Bell Labs in the period from 1990 to 1992 where the first prototype was tested. After three years of field trials and revising, the first ADSL standard was issued by ANSI (American National Standards Institute) in 1995 (T1.413-1995). ANSI released a second issue in 1998 (T1.413-1998) which addressed ambiguities and leftouts in the first edition to increase the interoperability between chipsets from different vendors.

In the early days of ADSL the modulation to be used was fiercely discussed: SCM (single-carrier modulation) or MCM (multiple-carrier modulation). Some of the very early versions used a SCM technology called CAP (Carrierless Amplitude and Phase), and others used the MCM technology called DMT (Discrete Multi Tone) which is the technology that was eventually chosen as the standard.

In 1999 ITU (International Telecommunication Union) released the first international ADSL standard (ITU-T G992.1), largely based on the ANSI standards. This made for much better interoperability between chipsets, and the market began to see the first mass deployments of ADSL.

¹ The VDSL specification includes both a DMT/MCM, and a QAM/SCM modulation (i.e. base band) version, but only the MCM version is mandated.

² IDSL (based on ISDN) is arguably not really a DSL-technology in peoples mind due to the low bit rates, but is still mentioned since I see it as the starting point of digital services for the end-user.

2.2 ADSL2 / ADSL2+

While ADSL have been a tremendous success with more than 60 million lines deployed, it suffers from a number of shortcomings and lack of features that needed addressing. Therefore work on a successor to ADSL was started in the ITU Study Group 15.

The requests for a new ADSL standard were primarily longer reach, better stability of the link, and better diagnostic tools as well as higher upstream bit rates. In 2001 ADSL2 was ratified by the ITU (ITU-T G992.3), constituting an entirely new transceiver design. The underlying DMT modulation and the power spectral properties is the same as for ADSL, but the framing mechanism was revised, and now with support for PTM (Packet Transfer Mode), which enable a pure IP solution instead of the ATM layer from the traditional ADSL systems. This feature was not widely used, but can be seen as a step in the direction of the VDSL2 PTM which is the preferred transport convergence layer used in VDSL2 deployments today.

To improve long-term link stability ADSL2 introduced some new On-Line Reconfiguration (OLR) tools that enable the system to adapt to changing loop conditions without interrupting the data flow. A novel DELT (Dual Ended Loop Testing) functionality called Loop diagnostics Mode was introduced, enabling much more accurate loop estimation.

Furthermore the initialization procedures in ADSL2 are much different from the procedures in ADSL, where the COE decided all parameters. Now the CPE is to a much higher degree involved in this decision. The benefit is that the link can be trained to more optimal settings, compared to ADSL.

To address the higher upstream bit rate requirement ADSL2 introduced a new annex M where the annex A (ADSL over POTS) and annex B (ADSL over ISDN) sub carriers are combined, which in effect doubles the attainable upstream bit rate.

In 2003 the annex L for ADSL2 was added to G992.3, which provides a better long reach performance. This is achieved by making some modifications to the PSD mask reducing the number of sub carriers, and increasing the power on the remaining sub carriers. Furthermore 1-bit constellation sizes are allowed, making more sub carriers useable at the very long loop lengths (traditionally 1-bit constellations are not allowed, since the power required for generating 1 and 2-bit constellations is equal).

In 2003 ITU also ratified the G992.5 standard (ADSL2+) standard that doubles the number of sub carriers, and thus increases the downstream attainable bit rate to approximately 25 Mbps on short loops. Apart from the number of sub carriers (and subsequently the larger frequency band required by the service) the ADSL2+ and ADSL2 standards are very similar.

2.3 VDSL

Work on VDSL started in 1995 where the need for higher bit rates was recognized. ANSI, ETSI and ITU had projects ongoing simultaneously targeting a new standard

capable of higher rate but the work was slowed much down because of disagreements on which line coding that should be used. Just as with ADSL the discussion was between SCM and MCM types of line coding.

Furthermore the effort of completing the ADSL2 and ADSL2+ standards took major parts of the focus, and work on the VDSL standard was down prioritized. Still chipset and system vendors continued working on VDSL-type of products, and as a result of the lacking standard, a number of proprietary implementations were developed and deployed - primarily in Asia.

In 2003 as the workload on ADSL2(+) standards decreased, the VDSL specification work gained pace by a joined statement from 11 major DSL equipment/chipset manufacturers stating their support for DMT line coding. Their rationale was:

Greater interoperability

Much better spectral compatibility to existing ADSL/ADSL2(+) installations

Simpler implementation of frequency notching to minimize RF interference

To cut through all the discussions it was decided to facilitate “VDSL Olympics” events labs run by British Telecom in the UK and Telcordia Technologies in the USA. The purpose of these events was to once and for all decide which line coding technology to use for VDSL. The DMT version of VDSL outperformed the SCM version of VDSL and was thus adopted by IEEE and ANSI. Due to already existing implementations ITU-T chose to make a compromise and included both QAM and DMT in the VDSL standard but at the same time stipulated that all future evolutions of VDSL technology would be based on DMT, and that a new standard, VDSL2, should be defined.

3. Introduction to VDSL2

VDSL2 was ratified by ITU (G993.2) in February 2006, and is based on both the ADSL2(+) and VDSL specification. DMT is chosen as the sole line code technology, which makes VDSL2 spectrally compatible with existing ADSL and ADSL2(+) deployments. Furthermore VDSL2 support multimode operation with ADSL2+. Compared to VDSL the scope of the VDSL2 specification is quite broad. It aims to increase the maximum attainable bit rate on short loops, as well as increasing the performance on longer loops, making it more widely useable compared to both ADSL2+ and VDSL.

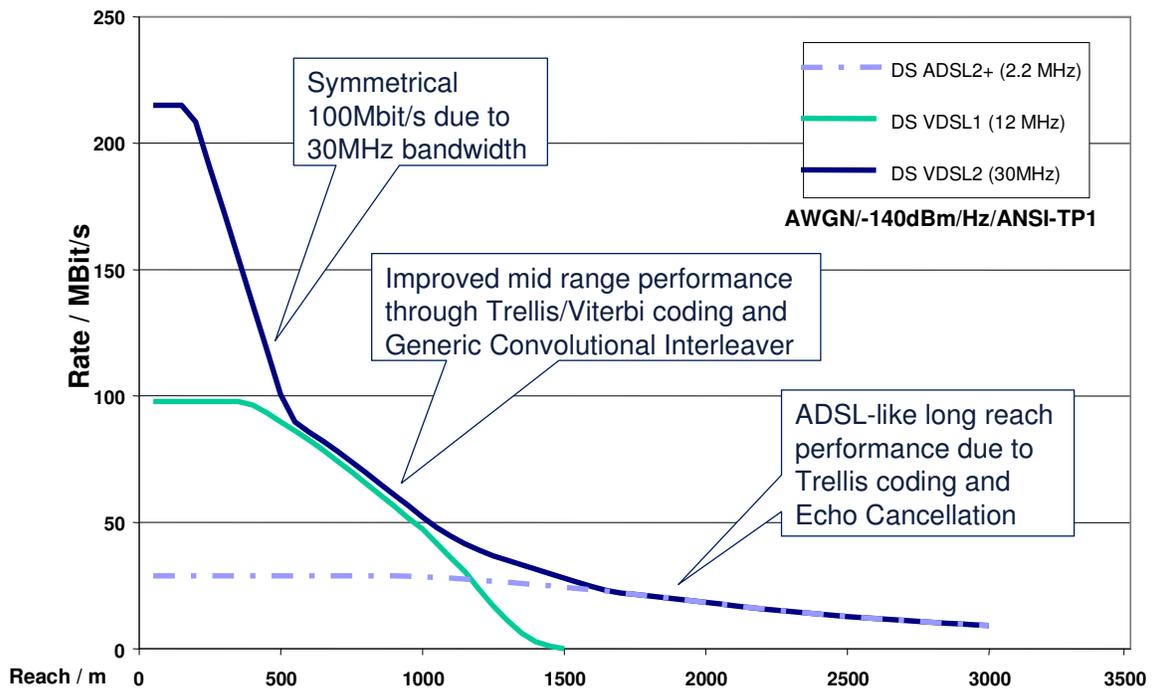


Figure 2: VDSL2 attainable downstream bit rates compared to ADSL2+ and VDSL (Source: DSL Forum)

3.1 Bandplans and profiles

ADSL and ADSL2 can be considered as two-band systems (one frequency band used for upstream transmission and one frequency band for downstream). VDSL2 however offer multiple up- and downstream bands, making VDSL2 very configurable in order to meet the spectral requirements from different deployment options.

For the western market two primary band plans were defined in 2000:

- 997 – Optimized for symmetric services
- 998 – Optimized for asymmetric services

VDSL supports up to 12 MHz bandwidth, which in the VDSL2 specification is extended to 30 MHz bandwidth, enabling a net bit rate of 200 Mbps on short loops. VDSL2 is based on band plan 998, but the upper frequency limit is extended to 30 MHz and a new upstream band (US0) is introduced to increase the long reach capabilities of VDSL2. Extending the upper frequency to 30 MHz makes room for one more set of US/DS bands: US3 and DS3. The frequency division between US3 and DS3 are still under discussion, but so far a proposal based on plan 998 has been adopted by most European countries as well – see Figure 3.

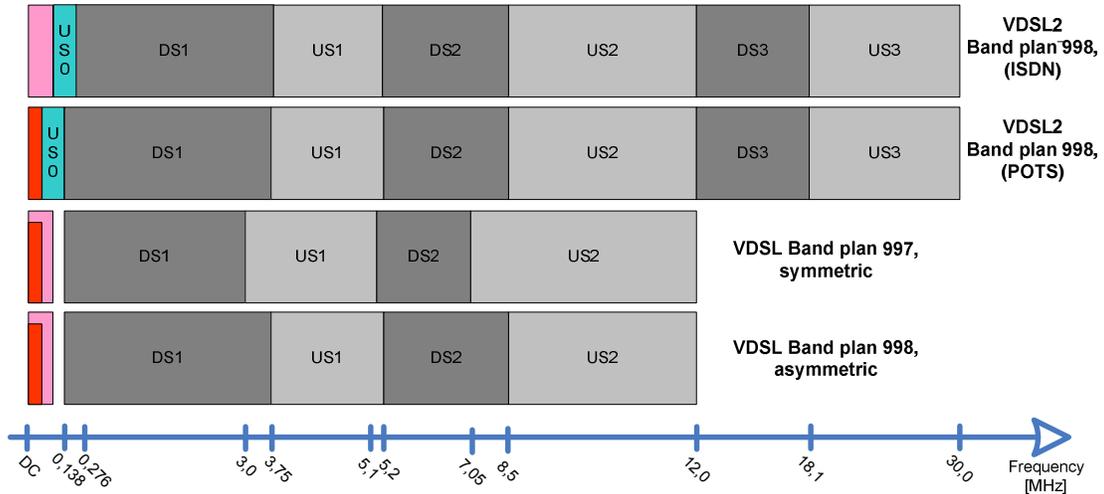


Figure 3: VDSL and VDSL2 band plans. Red color denominates POTS and pink denominates ISDN base band service.

Within the band plans a number of profiles are defined with various combinations of transmit power and allocated frequency bandwidth optimized to different deployment scenarios, e.g. FTTE_x and FTTcab (more on deployment types in section 3.3).

The profiles 8a, 8b, 8c, 8d are designed for long reach applications with a maximum attainable net data rate of 50 Mbps. The difference between the 8a, 8b and 8d profiles is the maximum transmit power limitation, to address corresponding regional requirements. For all the 8x profiles support for the US0 band is mandatory.

Profiles 12a and 12b use the US2 at full bandwidth band hence providing significantly higher upstream bit rates, compared to the 8x profiles.

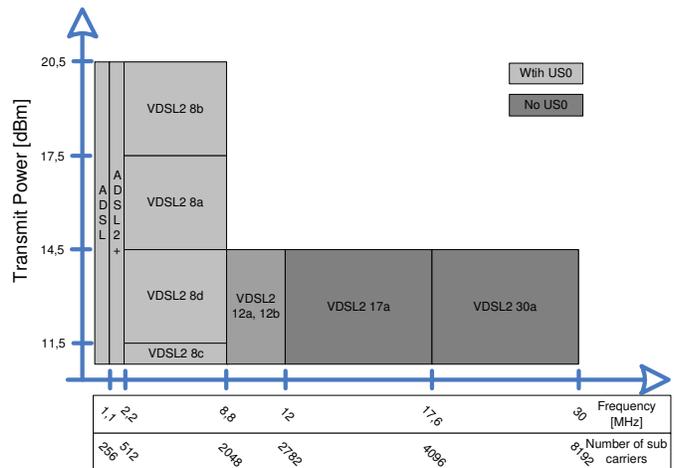


Figure 4: Frequency versus transmit power.

The maximum supported net data rate for profiles 12a and 12b is 68 Mbps. Support for US0 is optional for the 12x profiles.

Profile 17a addresses a medium loop length scenario, such as FTTcab, by extending the frequency range to 17 MHz. The added bandwidth is used for the DS3 band and provides a higher downstream bit rate for a total of 100 Mbps downstream and 50 Mbps upstream. Since profile 17a is not meant for long-reach deployment US0 is not supported.

Profile 30a is designed for short-loop deployments such as FTTB, where the loop length does not exceed a few hundred meters. The full bandwidth of 30 MHz is used for this profile by including the US3 band and consequently providing up to 200 Mbps net data rate. The US0 band is not supported for profile 30a.

3.2 VDSL2 features

The subsections in this chapter provide the reader with a brief walkthrough of the new features in VDSL2 and their impact on functionality/performance.

3.2.1 Link stability / On-Line Reconfiguration

One of the major shortcomings in VDSL was the lack of the basic OLR technologies from ADSL2. This is introduced in VDSL2, which support SRA, DRR and bit swapping³ providing tools for a much better link stability. For details regarding OLR techniques, see the ZyXEL whitepaper “Dynamic adaptation to varying loop conditions” (http://www.ZyXEL.dk/isp_link).

3.2.2 Support for TEQ/Echo canceller

Sequence in initialization procedure added to provide chipsets the possibility to train any TEQ (time-domain equalizer) and echo cancellers will provide a better loop reach performance. It is up to the chipset vendor whether to implement TEQ and EC algorithms, but adding the possibility to train the algorithms will significantly improve the performance on e.g. Broadcom chipsets, since these have a history of combining the FDD PSD with echo cancellers, which enable very good performance. Especially upstream performance will benefit from this.

3.2.3 RFI Notching and PSD Shaping

The DMT line coding technology makes it possible to enable notching of 16 arbitrary RFI bands simultaneously. This is required in some regions to address potential RF interference from VDSL2 installations.

³ DRR and SRA was for further study in the 2006 version of the VDSL2 specification, but has been introduced with amendment 1 (April 2007). Full chipset support is expected during 1H'08.

As in ADSL2(+) TSSi (Transmit Spectrum Shaping) shaping is supported basically making it possible to completely customize the PSD mask of a VDSL2 system. This is used to address regional requirements, and can also be used to minimize crosstalk in a mixed loop-length environment. See Figure 5, where some of the copper loops pass through the cabinet from the CO, causing the other lines to see unnaturally strong far-end crosstalk (FEXT) since the induced signal is not attenuated by the full loop length.

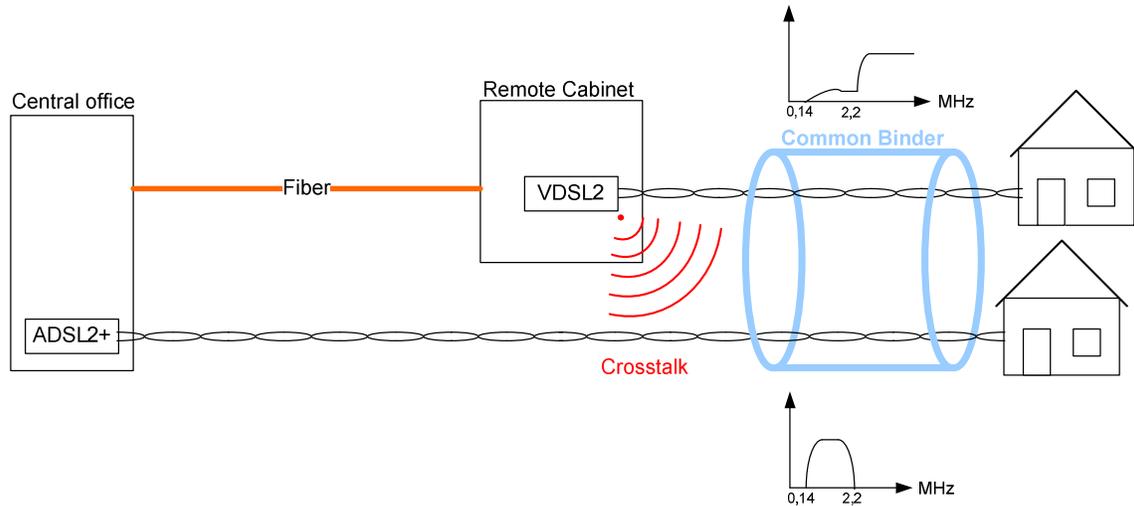


Figure 5: Transmit Spectrum Shaping (TSSi) makes it possible to reduce the transmit spectrum in bands where a Cabinet installation would severely impact the performance of existing DSL installations in same binder.

3.2.4 Extended frequency profiles

New extended frequency profiles provides the option for up to 200 Mbps net data rate for FTTB type of installations, as well as introduction of a low-frequency US0 band to provide longer loop reach at FTTEEx type of installations. See section 3.1 for details on VDSL2 profiles.

All Digital Mode (optional) is currently not supported by chipsets, but provides the potential for even better loop reach.

3.2.5 Coding and error correction

VDSL2 has mandatory support for Trellis coding (a convolutional code that improves the receivers ability to retrieve correct data from noisy QAM constellations) is mandatory is VDSL2, providing a coding gain of up to 3 dB. This provides a better loop reach performance, especially on medium-length loops.

The Forward Error Correction capabilities are also improved by supporting INP (Impulse Noise Protection) up to 16 symbols (INP=16 symbols mean that errors due to transient noise of up to 2,75 ms duration can be corrected).

As in ADSL2(+) a Loop Diagnostics mode is introduced making it possible to do more accurate loop estimation and fault diagnosis.

3.2.6 Framing

The VDSL2 specification support dual latency and dual bearer, facilitating triple-play types of configurations, where the service require a combination of strong impulse noise protection (low bit error rate) for IP-TV and low latency for gaming type of service.

New PTM Transport Convergence layer based on IEEE802.3ah 64/65 octet encapsulation mean that ATM is no longer the base protocol on the last mile. This provides for more efficient use of the data rater, since the payload overhead is greatly reduced. Furthermore this simplifies the backend providing “pure Ethernet” all the way to the subscriber.

3.2.7 ADSL2+ Fallback

The fact that major parts of the ADSL2 specification is inherited by the VDSL2 specification makes for a big improvement in long reach performance compared to VDSL. A further advantage from this is that due to the analog similarities it is relatively easy for VDSL2 chipsets to also support ADSL2+ fallback mode. This makes it much cheaper and easier for ISP’s to start deploying VDSL2 in an environment where lots of ADSL2+ products are already deployed (Figure 6, phase 1).

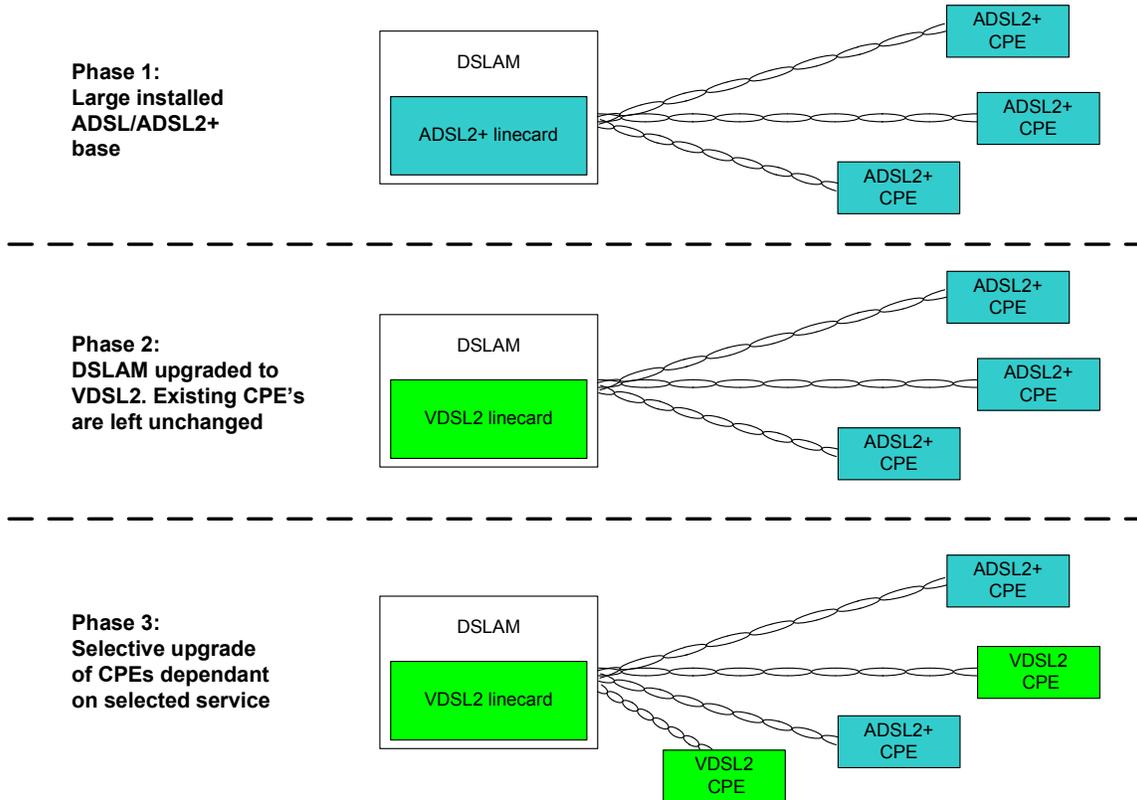


Figure 6: Phase-split deployment of VDSL2 in an ADSL2+ environment.

Using the ADSL2+ fallback capabilities of the VDSL2 linecard it is feasible to start exchanging the old ADSL2+ linecards on CO's connected to existing ADSL2+ customers, where the link will simply train into ADSL2+ mode (Figure 6, phase 2). As new customers are connected a VDSL2 CPE can be connected to the DSLAM, and existing customers opting for a new higher-rate service can be upgraded simply by exchanging the CPE to a new VDSL2 CPE, and not needing a technician to visit the CO (Figure 6, phase 3).

3.3 VDSL2 deployment scenarios and related profiles

Compared to ADSL ADSL2+ and older xDSL standards one of the novel features in VDSL and VDSL2 is the profiles, that makes the same technology suited for a number of different deployment scenarios.

Traditional xDSL have been deployed from the central office providing a net data rate of 0,5 – 25 Mbps, but as the requirements for more bandwidth increases and technologies such as fiber challenges the xDSL role as last-mile medium the need arises for 30-100 Mbps net data rates, or even higher. These data rates can be achieved using VDSL2, but in order to achieve the high performance the copper loop must not exceed a few hundred meters. This can be achieved by moving the DSLAM from the central office closer to the subscribers. The backhaul from the remote DSLAM to the aggregation network is usually taken care of using a fiber link, but still the last stretch from the DSLAM to the customers is still using the traditional copper infrastructure. The benefit from this approach is that the cost of digging fibers to every house can be avoided, while “fiber-like” speeds are still achieved.

A number of scenarios can be described under the term FTTx (Fiber-To-The-x) and is briefly described in the following sections. Figure 7 depicts the different FTTx scenarios applied to a user that live at a distance of 2500 meters to the central office.

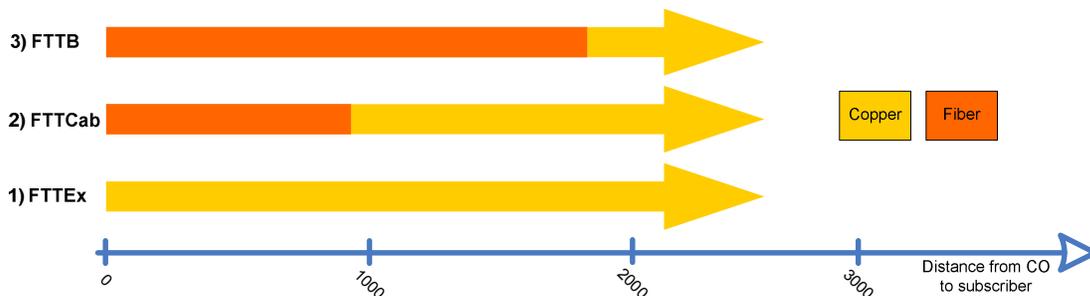


Figure 7: Example: A subscriber living at a distance of 2500 meters from the central office can get a VDSL2 based service based on FTTx scenarios using a mixture of fiber and copper to transport the data.

3.3.1 Fiber to the Exchange (FTTEx)

In densely populated areas the local loop length is sufficiently short to facilitate VDSL2 deployment from the central office. FTTEx serve VDSL2 the traditional way leveraging the copper loop all the way from the central office to the subscriber, see Figure 7, part1. The attainable bit rates are at 2500 meters similar to ADSL2+ bit rates. For VDSL to exhibit significantly better performance compared to ADSL2+ the local loop length should not exceed 1500-2000 meters in this scenario.

The profiles 8a-d and 12a-b are designed specifically for FTTEx deployments offering best possible bit rates on longer loop lengths at the expense of lower possible bit rate on shorter loops. The choice between profile 8x and 12x depend on the type of service to be offered, and the actual loop environment. In a nutshell 8x gives higher priority to extended-loop performance where 12x prioritizes the medium and short loop performance.

	8a	8b	8c	8d	12a	12b
Minimum net data rate [Mbps]	50	50	50	50	68	68
Transmit power [dBm]	17,5	20,5	11,5	14,5	14,5	14,5
Bandwidth [MHz]	8,5	8,5	8,5	8,5	12	12

Table 1: Basic parameters for profiles 8x and 12x

3.3.2 Fiber to the Cabinet (FTTCab)

Where a higher bit rate is required, or in e.g. rural areas where a neighborhood is located far from the central office exchange an FTTCab solution can be used. This scenario is sometimes also called FTTC (Fiber To The Curb). In this scenario the DSLAM is moved from the CO to the street cabinet aggregating all the local copper loops. The backhaul from the cabinet to the CO is usually a fiber connection.

For this kind of deployments it is recommended to use profile 17a which offer >100 Mbps net data rate, or even profile 30a offering >200 Mbps net data rate.

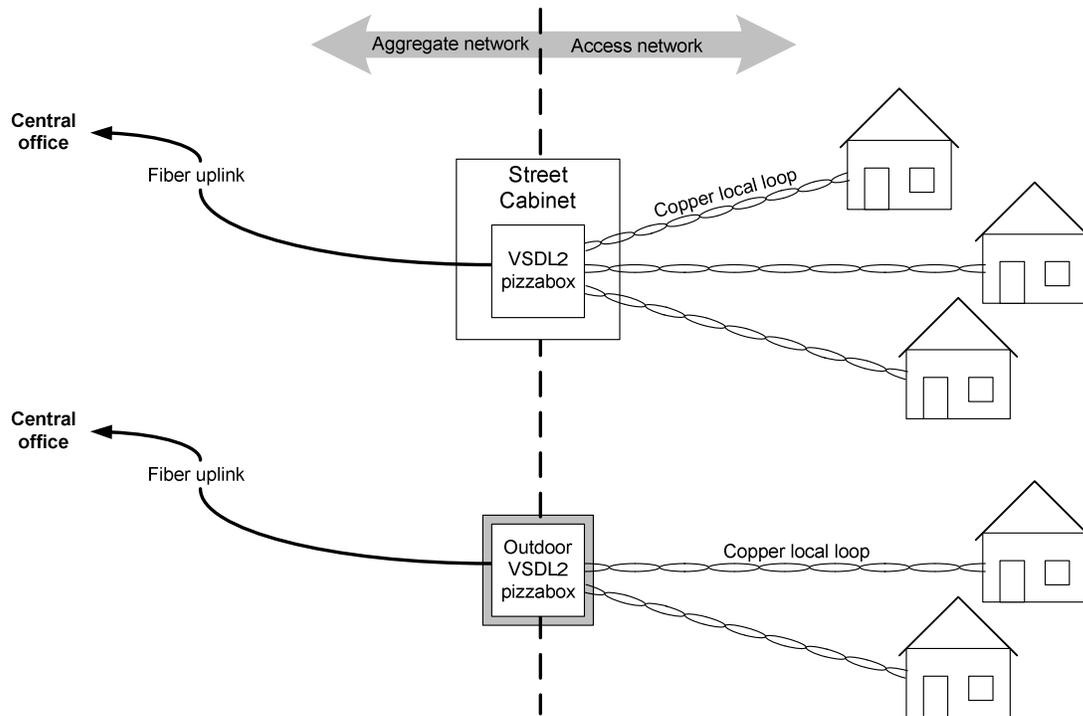


Figure 8: In a Fiber To The Cabinet deployment a fiber is used to connect a remote cabinet to the CO. From the cabinet, the last stretch to the subscribers consists of copper. A VDSL2 pizzabox handles this last-mile connection. ZyXEL also offer outdoor models of the VDSL2 pizzabox that can function in harsh conditions due to the environmentally hardened design.

In some cases the street cabinet is not big enough to contain the DSLAM, or for some other reason it is desirable to deploy an FTTCab solution outside the cabinet. For this purpose an outdoor version of the pizzabox is offered, which is environmentally hardened to sustain rain, snow, dust, etc.

3.3.3 Fiber to the Basement/Building (FTTB)

Apartment buildings can leverage on the existing copper infrastructure of the building to provide very high speed internet services to the sub tinders by installing a DSLAM in the basement. This scenario is typically denominated Fiber To The Basement or Fiber To

The Building (FTTB), and using the profile 30a is recommended providing as much as 100 Mbps symmetrical data rate on 0-300 meter copper.

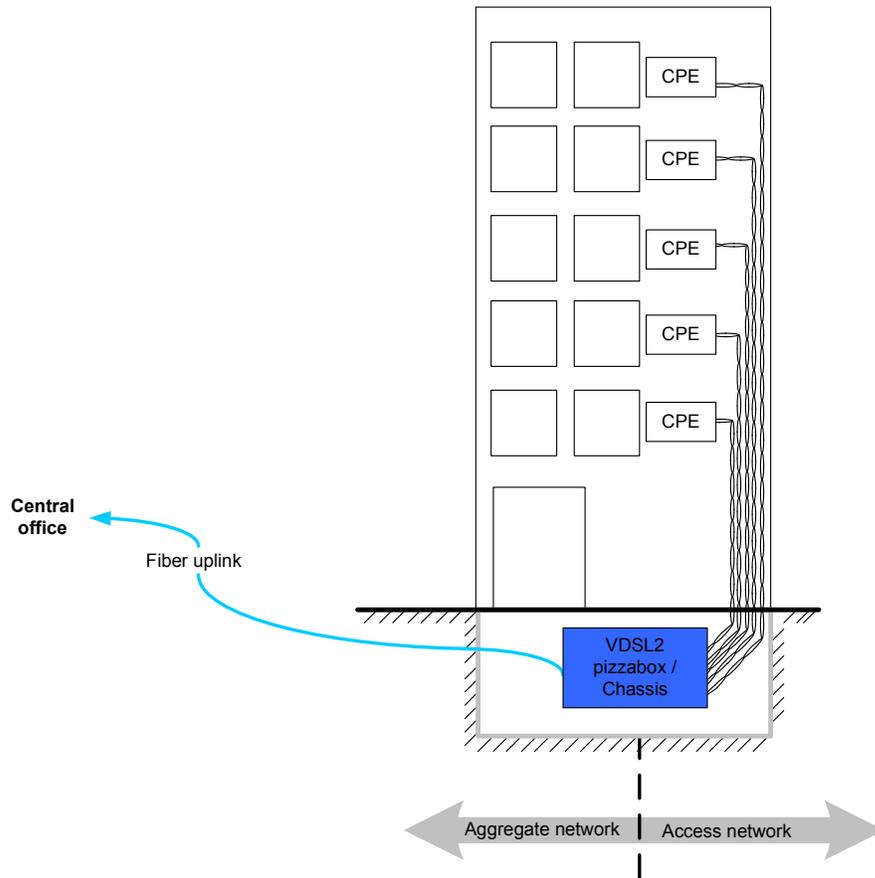


Figure 9: Fiber To The Basement consist typically a fiber connection endpoint in the basement of an apartment building where the existing PSTN wiring is reused for the data connection. Due to the short loop lengths a high bit rate can be offered. This scenario also applies to hotels wishing to provide (wired) internet connectivity to their guests. Both pizzaboxes and chassis types of equipment can be used for this purpose depending on the required port-density.

For this kind of deployment both pizzabox and chassis types of equipment can be used, depending on the number of VDSL2 lines required. This type of set is also often used by e.g. hotels to offer internet services for their guests.

4. ZyXEL VDSL2 product portfolio

ZyXEL offer a broad portfolio of VDSL2 products to meet any need a customer might have for deployment scenarios and service types. See <http://www.ZyXEL.dk> for product details.

4.1 COE products

For Central Office applications ZyXEL offer both chassis based solutions (line cards) for the deployment-from-the-CO type of scenarios, and pizzaboxes for remote deployment types of scenarios.

4.1.1 Pizzabox

The pizzaboxes are all temperature hardened to ensure a stable performance in an enclosed environment.



Figure 10: 24-port VDSL2 switch

Indoor versions of the pizzabox design are available with 16-24 lines to best fit the specific need in a particular installation.



Figure 11: Outdoor version of the pizzabox.

A 48-port version of the indoor pizzabox is planned for release end of 2008. The outdoor version of the VDSL2 switch is offered to address the deployment scenario where no street cabinet is available to house the VDSL2 switch. The outdoor version is contained in an extremely sturdy housing that can easily sustain the beatings of the Nordic climate, as well as a number of ingenious details to ease the installation and O&M of the product – even when situated on top of a pole.

Currently only an 8-port and a 16-port version are available in the outdoor design.

4.1.2 Chassis-based

For the CO based installations a 24-port VDSL2 linecard is currently available. The VLC1224G-51 support ADSL2+ fallback to address the phase-split deployment scenario mentioned in section 3.2.7.

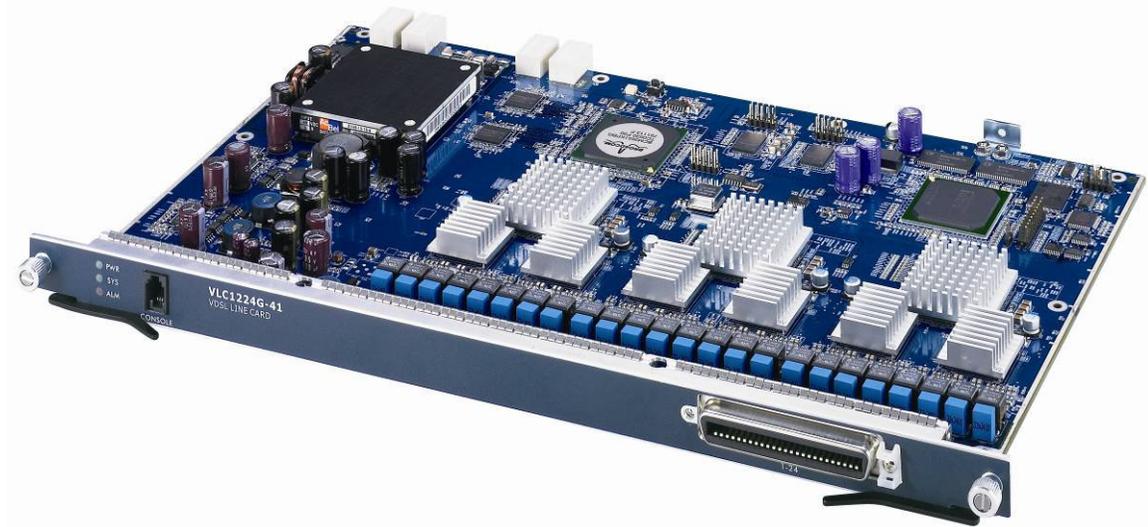


Figure 12: 24-port VDSL2 linecard

A 48-port version of the VDSL2 linecard is scheduled for release in Q2 2008. The linecards fit into the IES5000/5 and IES6000 IP-DSLAM chassis solutions, and support up to profiles 8x, 12x and 17a, suitable for the FTTE_x scenario described in section 3.3.1.

4.2 CPE products

The VDSL2 standard is still relatively young, and as a consequence the chipset-to-chipset interoperability can still cause problems. This is not a problem when using ZyXEL COE products, since ZyXEL can offer CPE's to fit the COE thereby forming an end-to-end solution.

Both simple bridge-type devices and full-featured IAD devices are available to fit the need for any service offering that an operator might wish to deploy.

4.2.1 P-870M-I V2 series

P-870M-I V2 series is a “plug-and-play“ hostless VDSL2 Modem. Through the high data rate, up to 100/100Mbps, the **P-870M-I V2 series** takes the advantages of faster and more stable data transfer over the existing copper line. Designed to support the wide deployment of Triple Play services such as voice, video, data, high definition television (HDTV) and interactive gaming, VDSL2 enables operators and carriers to gradually, flexibly, and cost efficiently upgrade existing xDSL-infrastructure.

To provide VDSL2 service to end users, Telecoms in different areas may have different deployment strategies unique to their existing and future network. **P-870M-I V2 series**



Figure 13: P-870 series CPE

support numerous configuration profiles to meet regional service provider requirement. **P-870M-I V2 series** are also integrated with advanced Quality of Service (QoS) features to manage the Triple Play Services.

4.2.2 P-2802HWL-I series

ZyXEL's P-2802HWL-I series is the VDSL integrated access device (IAD) that offers the highest performance that is available today over existing copper telephone lines. The P-2802HWL is designed for small office, home office, and residential users. It can provide a wide-range of applications such as VoIP, Enhanced Complementary Gaming, Security/VPN, Video Surveillance, and Real-Time Video Conferencing.

Key features :

- IP-based VDSL2 High-Speed Internet Access
- Multiple SIP Numbers and Voice Channels Enabling Feature-rich Phone Services over Internet Connection.
- New QoS with More Powerful Functionalities to Prioritized the Traffics for Better Bandwidth Utilization.
- Firewall Protection and IPSec VPN Security
- Easy Installation and TR-069/TR-104 Compliance



Figure 14: P-2802 series IAD