TELECOMMUNICATIONS STANDARDS ADVISORY COMMITTEE

Overview of Very High Speed Digital Subscriber Line 2 (VDSL2)

甚高速數碼用戶線路2的概覽

Introduction

ADSL (Asymmetric Digital Subscriber Line) technologies have been used to provide satisfactory broadband Internet services over existing copper pairs running from local exchanges to user premises at speed in excess of 20 Mbit/s. Yet development efforts to boost the speeds further up to support more versatile and bandwidth-intensive services do not end. In June 2004, ITU-T published the G.993.1 recommendation for VDSL, offering downstream speed up to 52 Mbit/s for video delivery over copper pairs.

2. The standardization work of the next version VDSL, VDSL2, started in January 2004 with major technical development in ITU-T. In February 2006, ITU-T approved the G.993.2 recommendation for VDSL2. This paper gives an overview on G.993.2 VDSL2.

Technology Overview

General

3. G.993.2 VDSL2 is an enhancement to G.993.1 VDSL that supports asymmetric and symmetric transmission at a bi-directional (upstream + downstream) net data rate up to 200 Mbit/s on twisted copper pairs. G.993.2 VDSL2 can be deployed from central offices, from fibre-fed cabinets located near the customer premises, or within buildings. While band plans in G.993.1 VDSL uses only 12 MHz spectrum of the copper pairs, G.993.2 VDSL2 includes definition of band plans allowing use of spectrum up to 30 MHz. This allows high data rate operation on short loops and makes the provision of the so-called Triple Play services - high-speed Internet, multi-channel television, and telephone - over a single broadband connection possible. When deployed from central offices (longer loops), VDSL2 can provide reliable operation up to about 2500 metres over 26 AWG (0.4 mm) loop at reduced data rates.

<u>Initialization</u>

4. Initialization is required to establish a physical connection between the VDSL2 transceiver at the customer side and that at the network side. Like the previous ADSL, ADSL2, ADSL2+ and VDSL recommendations, G.993.2 VDSL2 follows the handshake procedures as specified in ITU-T recommendation G.994.1 to initialize the transceivers after power-up, loss of signal, or recovery from errors, and to exchange information about the capabilities of the transceivers, and to select the appropriate modes of operation. After handshaking, additional initialization will be carried out to determine the characteristics of the communications channel and specific operational parameters.

<u>Band Plans</u>

5. G.993.2 adopts frequency division duplexing to separate upstream and downstream transmissions. For frequencies below 12 MHz, VDLS2 uses the 5-band plan as shown in Figure 1 below. US0, US1 and US2 are upstream bands whereas DS1 and DS2 are downstream bands, with band separating frequencies f_{0L}, f_{0H}, f_1, f_2, f_3, f_4 and f_5 where $f_{0H} \leq f_1$. For frequency band between 12 MHz and 30 MHz, VDSL2 uses one or more upstream and downstream bands. G.993.2 defines band plans for three regions - Region A (North America), Region B (Europe) and Region C (Japan), each with specific values assigned to f_{0L} to f_5. The upper band edge for band plans of Regions A and B is 12 MHz. For Region C, additional upstream and downstream bands from 12 MHz to 30 MHz have been defined.

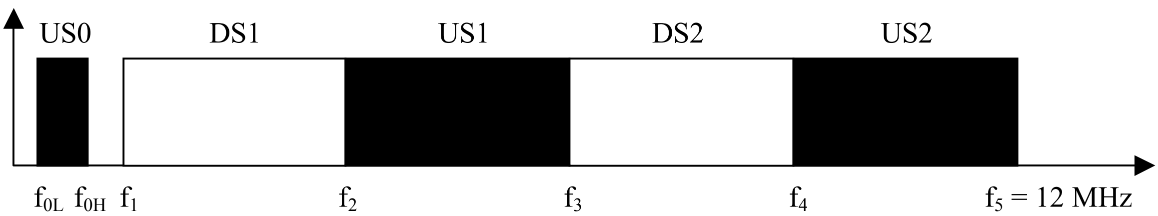

Figure 1 - Band Plan in frequency range up to 12 MHz

6. The band plan for Region A (North America) has band separating frequencies given in Table 1 below (based on band plan configuration in Figure 1).

Band Plan for Region A (North America)	Band separating frequencies (as defined in Figure 1)						
	f_{0L}	f_{0H}	f_1	f_2	f_3	f_4	f_5
	kHz	kHz	kHz	kHz	kHz	kHz	kHz
	4 to 25*	138 to 276*	138 or 276**	3750	5200	8500	12000

* If US0 is present, f_{0L} can vary from 4 kHz (without plain old telephone service (POTS)) to 25 kHz (with POTS), and f_{0H} can vary from 138 kHz to 276 kHz.

** f_1 can take two values, either 138 kHz or 276 kHz.

Table 1 - Band separating frequencies of Band Plan for Region A

7. Two different band plans are defined for Region B (Europe), which are based on G.993.1 band plans previously known as Plan 997 and Plan 998. Two variants are defined for Plan 997, and four for Plan 998, to accommodate different underlying services such as POTS (plain old telephone service) and ISDN-BA (ISDN Basic rate Access), and different US0 bandwidth. The band separating frequencies for the Region B band plans are given in Table 2 below which is based on band plan configuration in Figure 1 with f_{0H} equals to f_1. Additional band plans for using frequencies above 12 MHz are for further study.

Band Plans for Region B (Europe)	Band separating frequencies (as defined in Figure 1)					
	f_{0L}	$f_{0H} = f_1$	f_2	f_3	f_4	f_5
	kHz	kHz	kHz	kHz	kHz	kHz
Plan 997	25	138	3000	5100	7050	12000
	25	276				
Plan 998	25	138	3750	5200	8500	12000
	25	276				
	120	276				
	N/A*	138				

* N/A means upstream band US0 is not used.

Table 2 - Band separating frequencies of Band Plans for Region B

8. The band plan for Region C (Japan) as defined in G.993.2 is given in Figure 2 below. For VDSL2 system operating above POTS, frequencies above 25 kHz are used for VDSL2 but the use of the upstream band US0 is for further study, and DS1

starts at the nominal value of 138 kHz. For VDSL2 system operating above TCM-ISDN (Time Compression Multiplex-ISDN), frequencies above 640 kHz are used for VDSL2 (with DS1 starting at 640 kHz) and US0 is not used. Compared with the band plans for Regions A and B, the Region C band plan includes the additional downstream band DS3 and upstream band US3 in the 12 - 30 MHz range.

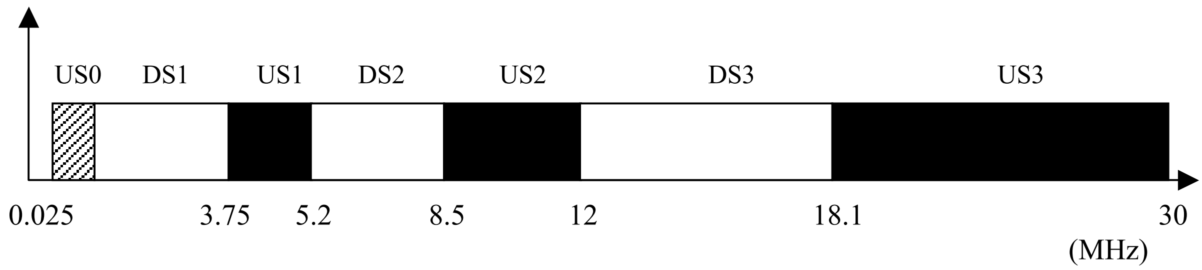

Figure 2 - Band Plan for Region C (Japan)

Modulation

9. In G.993.1 VDSL, two types of modulation, QAM (quadrature amplitude modulation) which uses single carrier, and DMT (discrete multi-tone) which uses multiple carriers, are specified. In G.993.2 VDSL2, only DMT modulation is specified.

10. The number of sub-carriers N used in G.993.2 DMT modulation shall not exceed 4096. G.993.2 specifies a tone spacing Δf (i.e. the frequency spacing between two adjacent sub-carriers) of 4.3125 kHz and 8.625 kHz. Each sub-carrier is centred at an integer multiple of the tone spacing, i.e. $k\Delta f$ where k is the tone index which takes values from 0 to $N-1$. Tone index 0 represents the DC component and is not used (i.e. frequency domain value for the corresponding sub-carrier equal to 0). The sub-carriers which will be used depend on the direction of transmission (upstream or downstream, which use different frequency bands), presence of POTS or ISDN-BA services, and bandwidth available (e.g. 12 MHz for Regions A and B band plans, or 30 MHz for Region C band plan). For example, for downstream transmission under Region A band plan, sub-carriers within 3.75 - 5.2 MHz and 8.5 - 12 MHz (assigned for upstream US1 and US2) and beyond 12 MHz (not used in Region A Plan) will not be used. The exact subsets of sub-carriers which will be modulated by data bits are determined during initialization. Two disjoint subsets of sub-carriers will be used, one for upstream, one for downstream.

11. Like the previous DSL technologies, data bits are assigned to the usable sub-carriers using the QAM modulation scheme. The number of bits to be assigned to a sub-carrier depends on the signal-to-noise ratio (SNR) of the corresponding sub-channel, and are negotiated during initialization. The frequency-domain values of the DMT symbol (consisting of QAM symbols of the usable sub-carriers, and the sub-carriers not used which have frequency-domain values zero) are inverse Fourier transformed to obtain the time domain values which is then further processed (e.g. digital-to-analogue converted) for transmission over the copper wire. At the receiving side, the time signal is processed and converted to digital form, and then Fourier transformed to recover the frequency-domain values from which the data bits are extracted.

Profiles

12. G.993.2 covers a wide range of settings and parameters (e.g. maximum aggregate transmit power, index of highest supported data-bearing sub-carrier) that could potentially be supported by a VDSL2 transceiver for wide range of deployment scenarios (e.g. fibre-to-the-exchange, fibre-to-the-cabinet, fibre-to-the-building). A set of eight profiles (8a, 8b, 8c, 8d, 12a, 12b, 17a, and 30a) are defined in G.993.2, each covers certain settings and parameters. VDSL2 transceivers compliant with G.993.2 shall comply with at least one profile, but compliance with more than one profile is not prohibited. This could allow vendors to limit implementation complexity and develop implementations that target specific service requirements.

Spectral Compatibility

13. Like other DSL technologies, VDSL2 is designed to co-exist with the narrowband POTS and ISDN-BA service on the same copper pair. And group of copper pairs providing both broadband and narrowband services would run within a multi-pair cable (the binder). There would be potential interference between the broadband signals and the narrowband signals within a copper pair, and crosstalk between copper pairs within the same binder.

14. To combat such interference and crosstalk, G.993.2 specifies a set of PSD (power spectral density) masks (referred to as the Limit PSD masks), limiting the PSD of the VDSL2 transmitters at both downstream and upstream, for each of the band plans described in para. 5 to 8 above to meet the specific requirements of different regions. In addition to the Limit PSD masks, G.993.2 also allows operator-specified

PSD mask intended to shape the mask below the applicable Limit PSD mask. Like G.993.1, G.993.2 also defines upstream power back-off to mitigate far-end crosstalk caused by upstream transmissions from shorter loops onto longer loops.

15. G.993.2 also specifies the maximum aggregate transmit power for VDSL2 transmissions. In the upstream, the maximum aggregate transmit power is 14.5 dBm irrespective of the profile. In the downstream, the aggregate transmit power ranges from 11.5 dBm to 20.5 dBm, depending on the profile used.

<u>Splitter</u>

16. A splitter consists of a low-pass filter and a high-pass filter required for separating the low frequency POTS or ISDN-BA signals and the high frequency VDSL2 signals carried on the same copper pair. G.993.2 requires a splitter at the network end of the copper loop, but allows application models with or without a splitter at the customer side. At the customer side, G.993.2 allows flexible use of splitter / filters. A splitter can be used at the customer end of the copper loop as shown in Figure 3 below. Alternatively, in the splitterless application model as shown in Figure 4, high-pass filter (which may be integrated with the VDSL2 transceiver) and <u>optional</u> low-pass filter can be used to provide the necessary separation of the broadband and the narrowband signals. The location of the filters shown in Figures 3 and 4 below is functional only. G.993.2 does not specifies the physical location of the filters which may be regional specific.

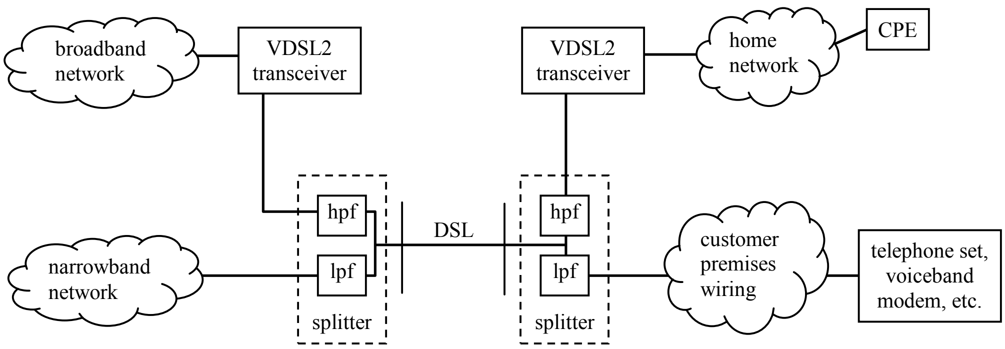

Figure 3 - VDSL2 Application Model with Splitter

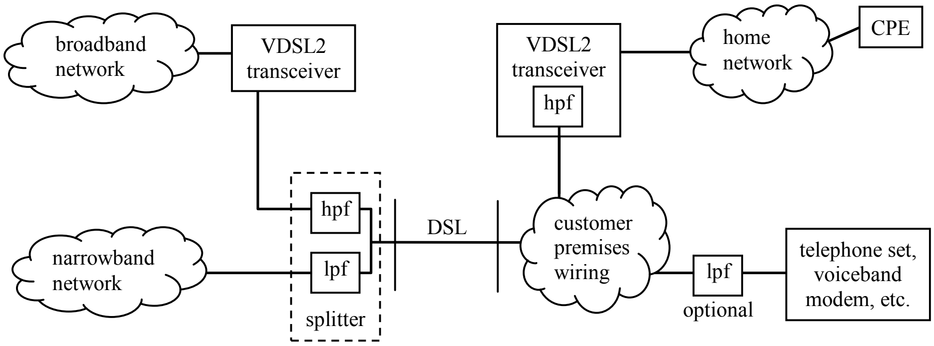

Figure 4 - Splitterless VDSL2 Application Model

17. When the VDSL2 operation is suspended due to abnormalities like power outage or equipment failure, the narrowband services shall not be affected. That means the splitter or filters installed shall be of a passive nature. The POTS service, if present, shall continue to be powered from the exchange node.

Performance

18. The actual data rates supported by VDSL2 depend on several factors, including length and gauge of the copper wire, band plans and profiles selected, etc. VDSL2 is designed to provide higher speed than VDSL for short reach copper loops of a few hundred metres, and speeds comparable to ADSL2+ for long reach copper loops of a few kilometres.

19. Some general indications on the performance of VDSL2 in terms of bit rate against length of copper loop are given in Figure 5 below (based on information from the DSL Forum[1]). It can be seen that, taking advantage of 30 MHz bandwidth (region and profile dependent), VDSL2 can offer a bi-directional net data rate of 200 Mbit/s for copper loops up to about 300 metres in length. Yet the bit rate drops quickly to 100 Mbit/s at about 0.5 km and to 50 Mbit/s at about 1 km, offering mid-range performance similar to that of VDSL. Beyond this point, VDSL2 performance degrades at a slower rate than VDSL. Between 1 km and 1.5 km, the VDSL2 performance is better than that of VDSL and ADSL2+. Starting from about 1.5 km, VDSL2 performance is similar to ADSL2+.

[1] DSL Forum is a consortium of about 200 industry players covering telecommunications, equipment, network, service providers. The Forum, established in 1994, aims at advancing the worldwide deployment of DSL. The Forum develops technical reports on the capabilities, testing, management and network architecture for effective deployment and operation of DSL, as well as providing inputs to standards bodies.

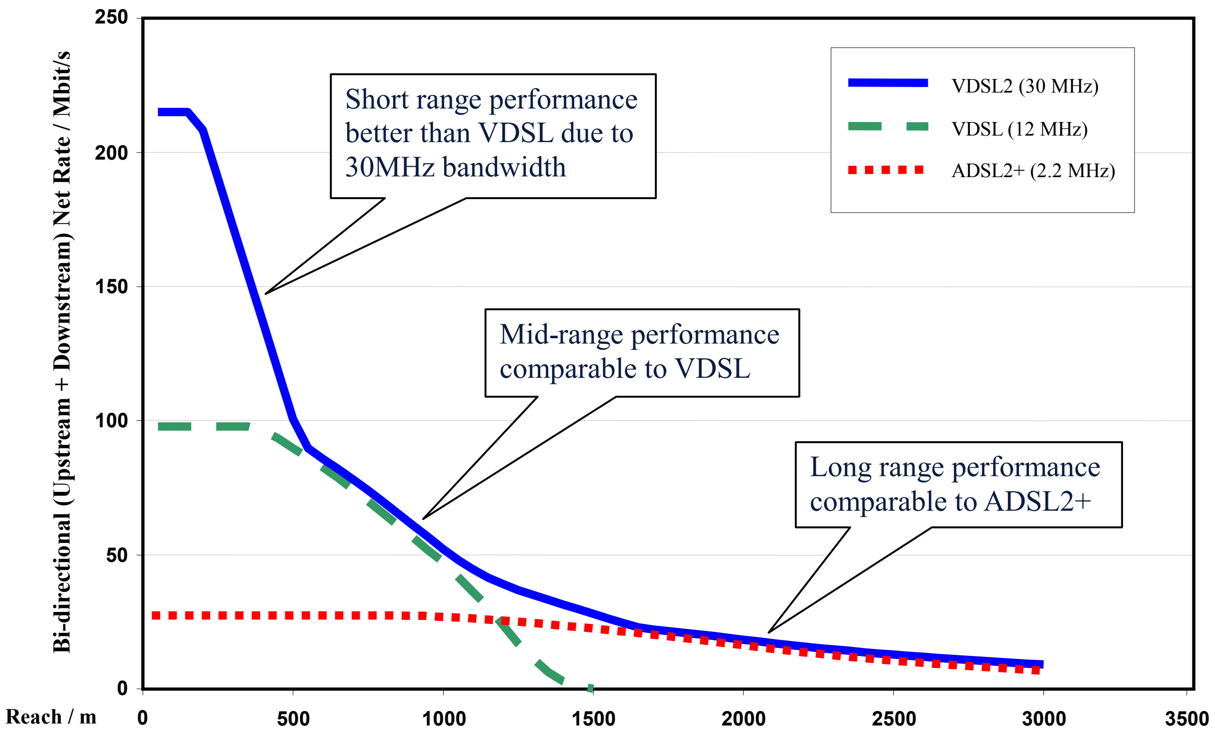

Figure 5 - VDSL2 Performance
(based on information from the DSL Forum available at http://www.dslforum.org/learndsl/ppt/VDSL2_Tutorial-2005.ppt with remarks in the textboxes modified)

ADSL Compatibility

20. With the use of DMT modulation and the ADSL-like functionalities, VDSL2 includes all technical prerequisites to address the ADSL backward compatibility issues. Interoperability of VDSL2 with installed ADSL infrastructure still needs to be achieved through field experience and collaboration between equipment/component vendors, but it is expected that VDSL2 devices eventually will achieve interoperability with ADSL/2/2+. This enables operators a gradual transition towards VDSL2 with a single technology to cover all xDSL implementations. That means, operators can upgrade their line cards at the network side to VDSL2 without affecting existing subscribers using ADSL. The subscribers, if so desire, can upgrade to VDSL2 to take advantage of its higher performance.

Development

21. At present, consumer type equipment based on G.993.2 is not yet available off the shelf. Yet chips based on G.993.2 VDSL2 have been available and some

manufacturers already have produced VDSL2 equipment (although such equipment is not yet available off the shelf). Deployment of VDSL2 network has also started in Europe[2]. In January and early May 2006, the DSL Forum hosted two VDSL2 chip tests, allowing VDSL2 chip vendors to test the interoperability of their implementations based on G.993.2. Besides the chip tests, the DSL Forum is also working on the G.993.2 VDSL2 performance and functionality test plans to prepare for tests to be conducted later. These activities will help identify interoperability issues and, along with the G.993.2 recommendation, will provide chip vendors and equipment manufacturers with the information required to produce fully interoperable and standard-compliant products. This process is expected to take some years to complete.

22. With the continuous effort of the carriers to upgrade and develop their networks, the penetration of fibre-to-the-cabinet (FTTcab) or fibre-to-the-building (FTTB) is constantly increasing. There will be more and more subscribers connected with short copper loops and eligible for the full advantages of VDSL2. With more bandwidth available, business opportunities will be created to service providers for offering more versatile services (e.g. simultaneous viewing of two or more high quality TV channels, interactive gaming, peer-to-peer file sharing, video conferencing) to the subscribers.

Consultation in CCS-WG

23. An overview of VDSL2 was presented to CCS-WG members at the meeting of 11 April 2006. Members noted ITU's approval of the ITU-T recommendation G.993.2 on VDSL2, and discussed the necessity of adopting the standards for VDSL2 and other DSL technologies including ADSL2, ADSL2+ and VDSL in Hong Kong. Members had raised concerns about interference/crosstalk between copper pairs in the same cable binder, band plans to be used, etc. Discussion will continue at the next CCS-WG meeting.

[2] Deutsche Telekom is deploying a G.993.2 VDSL2 solution in 10 cities in Germany, offering video at 50 Mbit/s downstream and 10 Mbit/s upstream. The service will be available from May or June this year onwards.

Advice Sought

24. Members are invited to provide additional information and comments on the above note on VDSL2, and to advise on the need and timing for the adoption of technical specifications for VDSL2 as well as other DSL technologies including ADSL2, ADSL2+, and VDSL in Hong Kong to ensure interoperability of the DSL equipment at the customer side and the network side. Members are also invited to comment on the need for adoption of standards to cover the deployment issues such as crosstalk/interference between copper pairs within the same cable binder in the local access loop, and between copper pairs running within the in-building cabling systems.

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