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Overview of digital subscriber line (DSL) Recommendations

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Supplement 50 to ITU-T G-series Recommendations

Overview of digital subscriber line (DSL) Recommendations

Summary

Supplement 50 to ITU-T G-series Recommendations provides an overview of the family of DSL Recommendations. It describes how the various DSL Recommendations are related. This Supplement also defines a generic system reference and a protocol reference configuration for DSL Recommendations and relates it to the system reference models of the DSL Recommendations.

This Supplement integrates and replaces Recommendation ITU-T G.995.1(2001) and its Amendment 1. It also includes more clauses and text with regard to Recommendations ITU-T G.992.3, ITU-T G.992.4, ITU-T G.993.2, ITU-T G.993.5, ITU-T G.998.1, ITU-T G.998.2, ITU-T G.998.3 and ITU-T G.998.4.

Supplement 50 to ITU-T G-series Recommendations

Overview of digital subscriber line (DSL) Recommendations

1 Scope

This Supplement provides an overview of the family of DSL Recommendations. It describes how the various DSL Recommendations are related. This Supplement also defines a generic system reference and a protocol reference configuration for DSL Recommendations and relates it to the system reference models of the DSL Recommendations. This Supplement is of informative nature and does not imply any specific requirements.

2 Revision history

This Supplement integrates and replaces Recommendation ITU-T G.995.1(2001) and its Amendment 1. It also includes more clauses and text with regard to Recommendations ITU-T G.992.3, ITU-T G.992.4, ITU-T G.993.2, ITU-T G.993.5, ITU-T G.998.1, ITU-T G.998.2, ITU-T G.998.3 and ITU-T G.998.4.

3 Definitions

This Supplement defines the following terms:

3.1 DSL Recommendations: The family of ITU-T Recommendations G.991.1, G.991.2, G.992.1, G.992.2, G.992.3, G.992.4, G.992.5, G.993.1, G.993.2, G.993.5, G.994.1, G.995.1, G.996.1, G.996.2, G.997.1, G.998.1, G.998.2, G.998.3, G.998.4, and G.999.1.

3.2 XDSL: Any of the various types of digital subscriber lines.

4 Abbreviations

This Recommendation uses the following abbreviations:

2B1Q	2 Binary 1 Quaternary
ADSL	Asymmetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
ATU	ADSL or ADSL2 Transceiver Unit
ATU-C	ATU-Central Office End
ATU-R	ATU-Remote Terminal End
C	Common circuitry
CAP	Carrier-less Amplitude and Phase
CO	Central Office
CPE	Customer Premises Equipment
DLL	Digital Local Line
DSL	Digital Subscriber Line
GII	Global Information Infrastructure
H	HDSL transceiver

HDSL	High Bit Rate Digital Subscriber Line
h-p	high-pass
HSS-TC	Handshake Specific-Transmission Convergence
HSTU	Handshake Transceiver Unit
HSTU-C	Handshake Transceiver Unit-Central office end
HSTU-R	Handshake Transceiver Unit-Remote terminal end
I	Interface
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
l-p	Low-pass
LTU	Line Termination Unit
M	Mapping
MPS-TC	Management Protocol Specific-Transmission Convergence
NT1	Network Termination 1
NT2	Network Termination 2
NTU	Network Termination Unit
PHY	Physical Layer
PMD	Physical Media Dependant
PMS-TC	Physical Media Specific-Transmission Convergence
POTS	Plain Old Telephony Service
REG	Regenerator
SM	Service Module
SNI	Service Node Interface
STM	Synchronous Transfer Mode
TA	Terminal Adapter
TC	Transmission Convergence
TCM	Time Compressed Multiplex
TPS-TC	Transport Protocol Specific-Transmission Convergence
VDSL	Very-High Speed Digital Subscriber Line
VTU	VDSL or VDSL2 Transceiver Unit
VTU-O	VTU at the ONU (or central office, exchange, cabinet, etc., i.e., operator end of the loop)
VTU-R	VTU at the remote site (i.e., subscriber end of the loop)
XNI	Access Network Interface
XTU	xDSL Transceiver Unit

XTU-C	xDSL Transceiver Unit-Central Office End
XTU-R	xDSL Transceiver Unit-Remote Terminal End

5 Overview of the Family of DSL Recommendations

The family of DSL Recommendations includes 19 Recommendations: ITU-T G.991.1, G.991.2, G.992.1, G.992.2, G.992.3, G.992.4, G.992.5, G.993.1, G.993.2, G.993.5, G.994.1, G.996.1, G.996.2, G.997.1, G.998.1, G.998.2, G.998.3, G.998.4, and G.999.1. ITU-T G.991.1, G.991.2, G.992.1, G.992.2, G.992.3, G.992.4, G.992.5, G.993.1, G.993.2 have developed techniques for transmitting a range of bit rates over the existing copper local network from relatively short distances at high bit rates, and to long distances at relatively lower bit rates. ITU-T G.994.1, G.996.1, G.996.2, and G.997.1 support ITU-T G.992.1, G.992.2, G.992.3, G.992.4, G.992.5, G.993.1, G.993.2 by providing common handshake, management and testing procedures. ITU-T G.998.1, G.998.2, and G.998.3 define various types of bonding functionality to be used in conjunction with XDSL. ITU-T G.998.4 defines retransmission functionality to be used in conjunction with XDSL. ITU-T G.993.5 defines self-FEXT cancellation functionality to be used in conjunction with G.993.2. ITU-T G.999.1 defines the interface between the link layer and physical layer for XDSL transceivers. These Recommendations include mandatory requirements, recommendations and options; these are designated by the words "shall", "should" and "may", respectively. The word "will" is used only to designate events that take place under some defined set of circumstances.

In clauses 5.1-5.19, the DSL Recommendations have been introduced. In clause 5.20, the relationship of these Recommendations with each other is described.

5.1 ITU-T G.991.1: High bit rate digital subscriber line (HDSL) transceivers

ITU-T G.991.1 describes a transmission technique called High Bit Rate Digital Subscriber Line (HDSL), as a means for the transportation of several types of applications. The Recommendation defines the requirements for the individual HDSL transmission system, the transmission performance, the HDSL maintenance requirements and procedures.

An individual HDSL transceiver system is a two-wire bidirectional transceiver for metallic wires using the echo cancellation method. Three systems may be utilized, one transporting a bit rate of

784 kbit/s over each of two or three pairs used in parallel, a second with an increased bit rate of 1168 kbit/s and two pairs in parallel only and a third with a more increased bit rate of 2320 kbit/s on one pair only.

The line code of systems specified in ITU-T G.991.1 is 2B1Q and CAP. The implementers may choose the one or the other of these alternatives, only one line code has to be realized in a transmission system.

In the main body of ITU-T G.991.1, systems with 2B1Q for 2048 kbit/s applications are described. In Annex A/G.991.1, the G.704 frame structure for 1544 kbit/s applications on two pairs is described. Systems using a CAP line code are covered in Annex B/G.991.1.

ITU-T G.991.1 defines the common circuitry for combining and controlling one, two or three HDSL transceiver systems, depending on the bit rate of the transceiver system used. The common circuitry and the necessary number of HDSL transceiver systems form the HDSL core, which is independent from the possible applications.

ITU-T G.991.1 does not specify all the requirements for the implementation of NTU, LTU or REG. It serves only to describe the functionality needed.

Appendices in ITU-T G.991.1 describe examples of a number of telecommunication services that may be supported.

5.2 ITU-T G.991.2: Single-pair High-speed Digital Subscriber Line (SHDSL) transceivers

ITU-T G.991.2 describes a symmetric transmission method for data transport in telecommunications access networks. G.991.2 transceivers are designed for duplex operation over mixed gauge two-wire twisted metallic pairs. Four-wire operation is optionally supported for extended reach applications. Optional signal regenerators for both single-pair and two-pair operation are also specified. G.991.2 transceivers are capable of supporting selected symmetric user data rates in the range of 192 kbit/s to 2312 kbit/s in increments of 8 kbit/s and an optional four-wire operational mode that is capable of supporting user data rates from 384 kbit/s to 4624 kbit/s in increments of 16 kbit/s, using a Trellis Coded Pulse Amplitude Modulation (TC-PAM) line code. Regional requirements may limit the specific user data rates for use within particular regions. G.991.2 transceivers are designed to be spectrally compatible with other transmission technologies deployed in the access network, including other DSL technologies specified in ITU-T G.991.1, G.992.1 and G.992.2. G.991.2 transceivers do not support the use of analogue splitting technology for coexistence with either POTS or ISDN. Regional requirements, including both operational differences and performance requirements, are specified in separate annexes. Symmetric transmission method for data transport in networks with existing TCM-ISDN service (as specified in Appendix III/G.961) is specified in Annex H/G.992.1 and is referenced in Annex C/G.991.2.

The principal characteristics of ITU-T G.991.2 may be summarized as follows:

- provisions for duplex operation over mixed gauge two-wire or optional four-wire twisted metallic pairs;
- specification of the physical layer functionality, e.g. line codes and forward error correction;
- specification of the data link layer functionality, e.g. frame synchronization and framing of application and OAM data;
- provisions for optional use of repeaters for extended reach;
- provisions for spectrum compatibility with other transmission technologies deployed in the access network;

- provisions for regional requirements, including functional differences and performance requirements.

5.3 ITU-T G.992.1: Asymmetric Digital Subscriber Line (ADSL) Transceivers

ITU-T G.992.1 specifies the physical layer characteristics of the Asymmetric Digital Subscriber Line (ADSL) interface to metallic loops. ITU-T G.992.1 has been written to help ensure the proper interfacing and interworking of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C) and also to define the transport capability of the units. Proper operation is to be ensured when these two units are manufactured and provided independently.

A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g. crosstalk and noise). The transmission system is designed to operate on two-wire twisted metallic cable pairs with mixed gauges. ITU-T G.992.1 is based on the use of cables without loading coils, but bridged taps are acceptable in all but a few unusual situations.

An ADSL transmission unit can simultaneously convey all of the following: downstream simplex bearers, duplex bearers, a baseband analogue duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance. ITU-T G.992.1 supports a minimum of 6.144 Mbit/s downstream and 640 kbit/s upstream net data rate.

Two categories of performance are specified. Category I performance is required for compliance with ITU-T G.992.1; performance enhancement options are not required for category I equipment. Category II is a higher level of performance. Category II performance and characteristics are not required for compliance with ITU-T G.992.1.

ADSL provides a variety of bearer channels in conjunction with other services:

- ADSL transmission on the same pair with voiceband transmission (including POTS and voiceband data services).
- ADSL transmission on the same pair with ISDN, as defined in Appendices I and II/G.961. The ADSL occupies a frequency band above the ISDN, and is separated from it by filtering.
- ADSL transmission on the same pair with voiceband transmission (including POTS and voiceband data services), and with ISDN in an adjacent pair as defined in Appendix III/G.961.
- In the direction from the network operator to the customer premises (i.e. downstream) the bearer channels may consist of full duplex low-speed bearer channels and simplex high-speed bearer channels; in the other direction (i.e. upstream) only low-speed bearer channels are provided.

Specifically, ITU-T G.992.1:

- defines the combined options and ranges of the simplex and full-duplex bearer channels provided;
- defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;
- specifies the transmit signals at both the ATU-C and ATU-R;
- describes the electrical and mechanical specifications of the network interface;
- describes the organization of transmitted and received data into frames;
- defines the functions of the operations channel;
- defines the ATU-R to service module(s) interface functions;

- defines the Transmission Convergence Sub-layer for ATM transport.

In separate annexes it also:

- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex and duplex bearer channels;
- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of ISDN services as defined in Appendices I and II/G.961, and both simplex and duplex bearer channels;
- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex and duplex bearer channels when they are subject to cross-talk from ISDN as defined in Appendix III/G.961;
- describes those specifications that are unique to Synchronized Symmetric Digital Subscriber Line (SSDSL) transceivers for use in the same cable binder as TCM-ISDN defined in ITU-T Appendix III/G.961. This SSDSL transmission method allows symmetric data rates in the range of 192 kbit/s to 1.6 Mbit/s with 32 kbit/s granularity using a scheme synchronized with TCM-ISDN. The 1.544 Mbit/s STM data transport capability is optionally supported.

ITU-T G.992.1 defines several optional capabilities and features:

- echo cancellation;
- trellis coded modulation;
- loop timing at either the ATU-C or the ATU-R;
- dual latency;
- transport of a network timing reference;
- transport of STM and/or ATM;
- reduced overhead framing modes.

By negotiation during initialization, G.992.1 in combination with G.994.1 provides for U-interface compatibility and interoperability between transceivers complying with ITU-T G.992.1 and between those transceivers that include different combinations of options.

5.4 ITU-T G.992.2: Splitterless asymmetrical digital subscriber line (ADSL) transceivers

ITU-T G.992.2 describes a transmission system that interfaces the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of ITU-T G.992.2 apply only to a single asymmetric digital subscriber line. ITU-T G.992.2 allows the provision of simultaneous voiceband transmission, including POTS and V-series data transmission, and a number of digital channels.

A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g. crosstalk and noise). The transmission system is designed to operate on two-wire twisted metallic cable pairs with mixed gauges and over the customer premises wiring. ITU-T G.992.2 is based on the use of cables without loading coils, but bridged taps are acceptable in all but a few unusual situations.

G.992.2 transmission unit can simultaneously convey a downstream and upstream simplex bearer, a baseband analogue duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance. ITU-T G.992.2 supports a maximum of 1.536 Mbit/s downstream and 512 kbit/s upstream net data rates.

Specifically, ITU-T G.992.2:

- defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;
- specifies the transmit signals at both the ATU-C and ATU-R;
- describes the electrical specifications of the network interface;
- describes the organization of transmitted and received data into frames;
- defines the functions of the operations channel;
- defines the ATU-R to service module(s) interface functions;
- defines the Transmission Convergence Sub-layer for ATM transport;
- defines the fast retrain procedure for use in the presence of non-linear off-hook phones in a splitterless environment;
- defines the power saving procedures for CPE and CO equipment;
- loop timing at the ATU-R.

In its separate annexes it also:

- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex upstream and downstream bearer channels;
- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex upstream and downstream bearer channels when they are subject to cross-talk from TCM-ISDN as defined in Appendix III/G.961;
- description of the transmission technique to support the simultaneous transport on a single twisted-pair of ISDN services as defined in Appendices I and II/G.961, and both simplex upstream and downstream bearer channels has been left for future study.

ITU-T G.992.2 defines several optional capabilities and features:

- transport of a network timing reference.

By negotiation during initialization, ITU-T G.992.2 provides for U-interface compatibility and interoperability between transceivers complying with ITU-T G.992.2 and between those transceivers that include different combinations of options.

5.5 ITU-T G.992.3: Asymmetric Digital Subscriber Line transceivers 2 (ADSL2)

Summary

Recommendation ITU-T G.992.3 describes asymmetric digital subscriber line (ADSL) transceivers on a metallic twisted pair that allows high-speed data transmission between the network operator end (ATU-C) and the customer end (ATU-R). It defines a variety of frame bearers in conjunction with one of two other services, or without underlying service, dependent on the environment:

- 1) ADSL transmission simultaneously on the same pair with voiceband service.
- 2) ADSL transmission simultaneously on the same pair with integrated services digital network (ISDN) (Appendix I or II of Recommendation ITU-T G.961) services.
- 3) ADSL transmission without underlying service, optimized for deployment with ADSL over voiceband service in the same binder cable.
- 4) ADSL transmission without underlying service, optimized for deployment with ADSL over ISDN service in the same binder cable.

- 5) ADSL transmission with specific requirements for Reach Extended ADSL2, simultaneously on the same pair with voiceband service.
- 6) ADSL transmission with extended upstream bandwidth, simultaneously on the same pair with voiceband service.
- 7) ADSL transmission on the same pair with voiceband services and operating in an environment with TCM-ISDN (Appendix III of Recommendation ITU-T G.961) services in an adjacent pair.

This Recommendation specifies the physical layer characteristics of the asymmetric digital subscriber line (ADSL) interface to metallic loops.

This Recommendation has been written to help ensure the proper interfacing and interworking of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C), and also to define the transport capability of the units. Proper operation is ensured when these two units are manufactured and provided independently. A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g., crosstalk and noise).

An ADSL transmission unit can simultaneously convey all of the following: a number of downstream frame bearers; a number of upstream frame bearers; a baseband plain old telephone service (POTS)/ISDN duplex channel; and ADSL line overhead for framing, error control, operations, and maintenance. Systems support a net data rate ranging up to a minimum of 8 Mbit/s downstream and 800 kbit/s upstream. Support of net data rates above 8 Mbit/s downstream and support of net data rates above 800 kbit/s upstream are optional.

This Recommendation defines several optional capabilities and features:

- transport of STM and/or ATM and/or Packets;
- transport of a network timing reference;
- multiple latency paths;
- multiple frame bearers;
- short initialization procedure;
- dynamic rate repartitioning;
- seamless rate adaptation;
- extended impulse noise protection;
- erasure decoding;
- virtual noise;
- impulse noise monitor.

It is the intention of this Recommendation to provide, by negotiation during initialization, for U-interface compatibility and interoperability between transceivers complying with this Recommendation and between transceivers that include different combinations of options.

This Recommendation describes the second generation of ADSL, based on the first generation Recommendation ITU-T G.992.1. It is intended that this Recommendation be implemented in multi-mode devices that support both Recommendations ITU-T G.992.3 and ITU-T G.992.1.

This Recommendation has been written to provide additional features, relative to Recommendation ITU-T G.992.1. Recommendation ITU-T G.992.1 was approved in 1999. Since then, several potential improvements have been identified in areas such as data rate versus loop reach performance, loop diagnostics, deployment from remote cabinets, spectrum control, power control,

robustness against loop impairments and radio frequency interference (RFI), and operations and maintenance. This Recommendation provides a new ADSL U-interface specification, including the identified improvements, which ITU-T believes will be most helpful to the ADSL industry.

Relative to Recommendation ITU-T G.992.1, the following application-related features have been added:

- Improved application support for an all-digital mode of operation and voice-over-ADSL operation.
- Packet TPS-TC function, in addition to the existing STM and ATM TPS-TC functions.
- Mandatory support of 8 Mbit/s downstream and 800 kbit/s upstream for TPS-TC function #0 and frame bearer #0.
- Support for inverse multiplexing over ATM (IMA) in the ATM TPS-TC.
- Improved configuration capability for each TPS-TC with configuration of latency, bit error ratio (BER) and minimum, maximum and reserved data rates.

Relative to Recommendation ITU-T G.992.1, the following PMS-TC-related features have been added:

- A more flexible framing, including support for up to 4 frame bearers, 4 latency paths.
- Parameters allowing enhanced configuration of the overhead channel.
- Frame structure with receiver-selected coding parameters.
- Frame structure with optimized use of Reed-Solomon (RS) coding gain.
- Frame structure with configurable latency and bit error ratio.
- Operations, administration and management (OAM) protocol to retrieve more detailed performance monitoring information.
- Enhanced on-line reconfiguration capabilities, including dynamic rate repartitioning.

Relative to Recommendation ITU-T G.992.1, the following PMD-related features have been added:

- New line diagnostics procedures available for both successful and unsuccessful initialization scenarios, loop characterization and trouble-shooting.
- Enhanced on-line reconfiguration capabilities including bitswaps and seamless rate adaptation.
- Optional short initialization sequence for recovery from errors or fast resumption of operation.
- Optional seamless rate adaptation with line rate changes during showtime.
- Improved robustness against bridged taps with receiver-determined pilot tone.
- Improved transceiver training with exchange of detailed transmit signal characteristics.
- Improved SNR measurement during channel analysis.
- Subcarrier blackout to allow RFI measurement during initialization and showtime.
- Improved performance with mandatory support of trellis coding.
- Improved performance with mandatory one-bit constellations.
- Improved performance with data modulated on the pilot tone.
- Improved RFI robustness with receiver-determined tone ordering.
- Improved transmit power cutback possibilities at both the central office (CO) and remote side.
- Improved initialization with receiver- and transmitter-controlled duration of initialization states.
- Improved initialization with receiver-determined carriers for modulation of messages.
- Improved channel identification capability with spectral shaping during channel discovery and transceiver training.
- Mandatory transmit power reduction to minimize excess margin under management layer control.
- Power saving feature for the central office ATU with new L2 low power state.
- Power saving feature with new L3 idle state.
- Spectrum control with individual tone masking under operator control through the CO-MIB.
- Improved conformance testing, including increase in data rates for many existing tests.

Through negotiation during initialization, the capability of equipment to support this Recommendation and/or Recommendation ITU-T G.992.1 is identified. For reasons of interoperability, equipment may support both Recommendations such that it is able to adapt to the operating mode supported by the far-end equipment.

Annex C to this Recommendation has been published independently due to its size and its specific structure.

5.6 ITU-T G.992.4: Splitterless Asymmetric Digital Subscriber Line transceivers 2 (splitterless ADSL2)

This Recommendation describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. G.992.4 allows the transmission of POTS and V-series data services simultaneously with a digital channel over a single

mixed gauge twisted metallic pair. Operation in a TCM-ISDN noise environment is for further study. This Recommendation is structured as a delta document to ITU-T Rec. G.992.3.

This Recommendation includes procedures to allow provisioning without the need for "splitters", typically installed at the ingress to the customer premises. Additionally, power management procedures and link states are specified to achieve power savings at the central office and customer premises.

This Recommendation describes the second generation of splitterless ADSL, based on the first generation ITU-T Rec. G.992.2. This Recommendation may be easily implemented in multi-mode devices that support both G.992.4 and G.992.2 with the following major additions and revisions:

- Improved application support for an all digital mode of operation and voice over ADSL operation.
- A new packet TPS-TC function and a STM TPS-TC function in addition to the existing ATM support.
- Support for IMA in the ATM TPS-TC.
- Improved configuration capability for each TPS-TC with configuration of latency, BER and minimum, maximum and reserve data rate.
- New line diagnostic procedures available for both successful and unsuccessful initialization scenarios.
- Enhanced on-line reconfiguration capabilities including bit-swaps, dynamic rate repartitioning, and seamless rate adaptation.
- A more flexible TPS-TC function including support for up to 4 frame bearers, 4 latency paths, and control parameters allowing enhanced configuration of the overhead channel.
- Performance improvements including mandatory support for R = 16, one-bit constellations, and trellis coding.
- A more robust initialization procedure that includes splitterless capability features of the G.992.2 fast retrain procedure, CO and CP controlled adaptive signal durations, receiver determined adaptive frequency modulation for data exchange, and an optional adaptive length fast start-up procedure.
- Improved RFI and spectrum management tools including transmit power cutback at both ends of the line, spectrum shaping, sub-carrier black-out lists to avoid RFI, and improved sub-carrier ordering to help mitigate the propagation of RFI from sub-carrier to sub-carrier.
- Power saving features including mandatory reduction of excess margin under management layer control and a new L2 power management link state with low power features for the central office.

5.7 ITU-T G.992.5: Asymmetric Digital Subscriber Line transceivers 2 (ADSL2) – Extended bandwidth (ADSL2plus)

Recommendation ITU-T G.992.5 describes asymmetrical digital subscriber line (ADSL) transceivers on a metallic twisted pair that allows high-speed data transmission between the network operator end (ATU-C) and the customer end (ATU-R), using extended bandwidth. This Recommendation defines a variety of frame bearers in conjunction with one of two other services, or without underlying service, dependent on the environment:

- 1) ADSL transmission simultaneously on the same pair with voiceband service.
- 2) ADSL transmission simultaneously on the same pair with integrated services digital network (ISDN) (see Appendix I or II or Recommendation ITU-T G.961) services.

- 3) ADSL transmission without underlying service, optimized for deployment with ADSL over voiceband service in the same binder cable.
- 4) ADSL transmission without underlying service, optimized for deployment with ADSL over ISDN service in the same binder cable.
- 5) ADSL transmission with extended upstream bandwidth, simultaneously on the same pair with voice band service.

ADSL transmission on the same pair with voiceband services and operating in an environment with TCM-ISDN (see Appendix III of Recommendation ITU-T G.961) services in an adjacent pair is for further study.

This Recommendation specifies the physical layer characteristics of the extended bandwidth asymmetric digital subscriber line (ADSL) interface to metallic loops. As compared to the ADSL2 transceiver defined in Recommendation ITU-T G.992.3, the operating modes use double the downstream bandwidth. When operating on the same pair with voiceband services, an additional operating mode is defined, using the double upstream bandwidth.

This Recommendation has been written to help ensure the proper interfacing and interworking of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C) and also to define the transport capability of the units. Proper operation is ensured when these two units are manufactured and provided independently. A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g., crosstalk and noise).

An extended bandwidth ADSL transmission unit (ADSL2plus transceiver) can simultaneously convey all of the following: a number of downstream frame bearers; a number of upstream frame bearers; a baseband plain old telephone service (POTS)/ISDN duplex channel; and ADSL line overhead for framing, error control, operations and maintenance. Systems support a net data rate ranging up to a minimum of 16 Mbit/s downstream and 800 kbit/s upstream. Support of net data rates above 16 Mbit/s downstream and support of net data rates above 800 kbit/s upstream are optional.

This Recommendation defines several optional capabilities and features:

- transport of STM and/or ATM and/or Packets;
- transport of a network timing reference;
- multiple latency paths;
- multiple frame bearers;
- short initialization procedure;
- dynamic rate repartitioning;
- seamless rate adaptation;
- extended impulse noise protection;
- erasure decoding;
- virtual noise;
- impulse noise monitor.

It is the intention of this Recommendation to provide, by negotiation during initialization, for U-interface compatibility and interoperability between transceivers complying with this Recommendation, and between transceivers that include different combinations of options.

This Recommendation describes the operation with extended bandwidth, based on the ITU-T Rec. G.992.3. This Recommendation is easily implemented in multi-mode devices that support both G.992.5 and G.992.3 with the following additions:

- The downstream PSD mask in the CO-MIB (exchanged between NMS and access node over the Q reference point) is specified through the downstream power back-off-shaped (DPBOSHAPED) or through a set of breakpoints (PSDMASKds).
- In the downstream direction, the ATU-C transmitter may apply windowing. The windowing allows to control the out-of-band PSD without the need for filtering in the analog front end.

5.8 ITU-T G.993.1: Very high speed digital subscriber line transceivers (VDSL)

ITU-T G.993.1 VDSL (Very high speed Digital Subscriber Lines) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. While POTS uses approximately the lower 4 kHz and ADSL/HDSL use approximately 1 MHz of the copper wire spectrum, G.993.1 uses up to 12 MHz of the spectrum. G.993.1 includes worldwide frequency plans that allow asymmetric and symmetric services in the same group of wire pairs (known as a binder). This is accomplished by designating bands for the transmission of upstream and downstream signals.

G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power transmission levels have been designed to minimize potential egress interference into other transmission systems.

As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

ITU-T G.993.1 supports a Fibre to the Node deployment architecture with an Optical Network Unit (ONU) appropriately placed in the existing metallic access network and the Local Exchange or Central Office deployment architecture without an ONU. The first architectural model covers Fibre-to-the-cabinet (FTTCab) type of deployment; the second one is Fibre-to-the-exchange (FTTEx) type of deployment. Existing unscreened twisted metallic access wire-pairs are used to convey the signals to and from the customer's premises.

ITU-T G.993.1 provides two or four data paths with bit rate under the control of the network operator, consisting of one or two downstream and one or two upstream data paths. A single path in each direction can be of high latency (with lower BER expected) or lower latency (with higher BER expected). Dual paths in each direction provide one path of each type. The dual latency configuration is thought to be the minimum that is capable of supporting a sufficient full service set, although it is possible to support both the single latency model with programmable latency, or two paths/latencies. The model assumes that Forward Error Correction (FEC) will be needed for part of the payload and that deep interleaving will be required to provide adequate protection against impulse noise.

G.993.1 provides for service-splitter functional blocks to accommodate shared use of the physical transmission media for VDSL and either POTS or ISDN-BA. The rationale behind this is to provide network operators freedom to evolve their networks in one of two ways: complete change out or overlay. Support for active Network Termination (NT) in G.993.1 provides termination of the point-

to-point VDSL transmission system and presents a standardized set of User Network Interfaces (UNI) at the customer's premises. The NT provides the network operator with the ability to test the network up to the UNI at the customer's premises in the event of a fault condition or via nighttime routine checks. The home wiring transmission system is outside the scope of G.993.1.

It is envisaged that G.993.1 will find applications in the transport of various protocols. For each transport protocol, different functional requirements must be developed for the Transport Protocol Specific – Transmission Convergence Layer (TPS-TC). This specification covers the functional requirements for the transport of Asynchronous Transfer Mode (ATM) and Packet Transfer Mode (PTM). However the G.993.1 core transceiver would be capable of supporting future additional transport protocols.

VDSL service would non-invasively coexist with the narrow-band services on the same pair. Failure of power to the VDSL NT or failure of the VDSL service does not affect any existing narrow-band services. This may imply that the splitter filter is of a passive nature not requiring external power in order to provide frequency separation of the VDSL and existing narrow-band signals. POTS, if present, continues to be powered from the existing exchange node and a DC path is required from the local exchange to the customer telephone. Similarly a DC path is required for ISDN-BA in order to provide remote power feeding to the ISDN-BA NT.

POTS and ISDN-BA cannot exist simultaneously on the same pair at present. Network Operators may provide one or the other but not both over a single wire-pair. Network Operators may choose to provide VDSL on access lines without any narrow-band services.

The VDSL NT is not required to be powered remotely. Also, repeatered operation is not required for G.993.1.

ITU-T G.997.1 specifies the physical layer management and the clear embedded operations channel for ADSL transmission systems based on the usage of indicator bits and eoc messages defined in ITU-T G.992.x. It specifies Network Management Elements and their content for configuration, fault and performance management. ITU-T G.997.1 does not preclude the use of eoc as currently defined in ITU-T G.992.1 and G.992.2. All the network elements may not be relevant to a particular ITU-T G.992.x Recommendation (e.g. fast data stream management elements for ITU-T G.992.2).

5.9 ITU-T G.993.2: Very high speed digital subscriber line transceivers 2 (VDSL2)

This Recommendation is an enhancement to ITU-T Rec. G.993.1 [1] that supports transmission at a bidirectional net data rate (the sum of upstream and downstream rates) up to 200 Mbit/s on twisted pairs. This Recommendation is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS (plain old telephone service).

This Recommendation specifies only discrete multi-tone (DMT) modulation and incorporates components from ITU-T Rec. G.993.1 (VDSL) [1], ITU-T Rec. G.992.3 (ADSL2) [10], and ITU-T Rec. G.992.5 (ADSL2 plus) [11].

Whilst POTS uses approximately the lowest 4 kHz and ADSL uses approximately 2 MHz of the copper wire spectrum, this Recommendation is defined to allow the use of up to 30 MHz of the spectrum. This Recommendation can be deployed from central offices, from fibre-fed cabinets located near the customer premises, or within buildings.

The availability of bandwidth up to 30 MHz allows G.993.2 transceivers to provide reliable high data rate operation on short loops. Without the use of the US0 band, this Recommendation should operate reliably over loop lengths that are similar to those of ITU-T Rec. G.993.1 [1], or slightly longer lengths due to the mandatory support of trellis coding. The addition of the US0 band and means to train echo cancellers and time-domain equalizers (TEQs) also allows this

Recommendation to provide reliable operation on loops up to approximately 2500 metres of 26 AWG (0.4 mm).

This Recommendation defines a wide range of settings for various parameters (such as bandwidth and transmitter power) that could potentially be supported by a transceiver. Therefore, this Recommendation specifies profiles to allow transceivers to support a subset of the allowed settings and still be compliant with the Recommendation. The specification of multiple profiles allows vendors to limit implementation complexity and develop implementations that target specific service requirements. Some profiles are better suited for asymmetric data rate services, whereas other profiles are better for symmetric data rate services.

The annexes of this Recommendation include band plans and power spectral density (PSD) masks that address region-specific requirements.

Like ITU-T Rec. G.993.1 [1], this Recommendation defines upstream power back-off (UPBO) to mitigate far-end crosstalk (FEXT) caused by upstream transmissions on shorter loops to longer loops. The mechanism is the same as in ITU-T Rec. G.993.1 [1].

As do other ITU-T Recommendations in the G.99x series, this Recommendation uses ITU-T Rec. G.994.1 [2] to initiate the transceiver training sequence.

Changes in this Recommendation relative to ITU-T Rec. G.993.1 [1] include:

- The definition, in annexes, of band plans up to 30 MHz to support a bidirectional net data rate up to 200 Mbit/s;
- Support for extension of the upper band edge of the US0 band to as high as 276 kHz (based on Annex M/G.992.3 [10]);
- The definition of means to improve the performance of US0 (specifically, support in initialization for training of time domain equalizers and echo cancellers);
- A requirement for downstream and upstream transmitters to notch, simultaneously, 16 arbitrary operator-defined RFI bands;
- The definition of profiles to support a wide range of deployment scenarios (e.g., central offices, fibre-fed cabinets located near the customer premises, and within buildings);
- A requirement to support the US0 band in the upstream direction for some profiles;
- Support for downstream maximum transmit power (profile dependent) of up to 20.5 dBm;
- Support for a MIB-controlled PSD mask mechanism to enable in-band spectrum shaping (based on ITU-T Rec. G.992.5 [11]);
- Mandatory support of trellis coding (based on ITU-T Rec. G.992.3 [10]);
- The definition of receiver-determined tone ordering (based on ITU-T Rec. G.992.3 [10]);
- Mandatory support of all integer-bit constellations from 1 bit to 15 bits;
- Support for optional cyclic extension (CE) lengths as large as $\frac{1}{4}$ of a symbol period;
- The definition of VTU-R receiver-selected pilot tone(s), including the option not to select a pilot tone;
- Support of all integer values of impulse noise protection (INP) up to 16 symbols;
- Insertion of a sync symbol after every 256 data symbols to signal on-line reconfiguration (OLR) transitions;
- Improved OLR mechanisms (based on ITU-T Rec. G.992.3 [10]);
- Improved framing (based on ITU-T Rec. G.992.3 [10]);
- Improved overhead channel;

- Improved interleaving;
- Improved FEC capabilities, including a wider range of settings for the Reed-Solomon encoder and the interleaver;
- The definition of two latency paths and two bearer channels;
- Improvements to initialization, including the definition of a channel discovery phase, a training phase, and a channel analysis & exchange phase;
- Support for a VTU-R lineprobe stage during initialization;
- Support for a wide range of test parameters (based on ITU-T Rec. G.992.3 [10]);
- The definition of a loop diagnostic mode;
- Support for STM interfaces;
- Support for PTM interfaces based on IEEE 802.3ah 64/65 octet encapsulation;
- Support for an optional all-digital mode;
- Support for an optional impulse noise monitor function;
- Support for an optional equalized FEXT UPBO method;
- Support for the emergency rate adjustment (SOS) functionality;
- Specification of accuracy of test parameters;
- Specification of longitudinal conversion loss (LCL) above 12 MHz;
- Support for transmitter and receiver referred virtual noise;
- Support for downstream and full vectoring (G.993.5) friendly operation;
- Support for transport of Time-of-Day from central office end to remote end.

The ITU-T G.993.2 Recommendation defines a wide range of settings for various parameters that could potentially be supported by a VDSL2 transceiver. Profiles are specified to allow transceivers to support a subset of the allowed settings and still be compliant with this Recommendation. The specification of multiple profiles allows vendors to limit implementation complexity and develop implementations that target specific service requirements. VDSL2 transceivers compliant with this Recommendation comply with at least one profile specified in this Recommendation. Compliance with more than one profile is allowed. In addition to complying with at least one profile, VDSL2 transceivers comply with at least one annex specifying spectral characteristics. The eight VDSL2 profiles are commonly referred to as 8a, 8b, 8c, 8d, 12a, 12b, 17a, and 30a.

5.10 ITU-T G.993.5: Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Vectoring is a transmission method that employs the coordination of line signals for reduction of crosstalk levels and improvement of performance. The degree of improvement depends on the channel characteristics. Vectoring may be for a single user or for multiple-users' benefit.

The scope of this Recommendation is specifically limited to the self-FEXT (far-end crosstalk) cancellation in the downstream and upstream directions. This Recommendation defines a single method of self-FEXT cancellation, in which FEXT generated by a group of near-end transceivers and interfering with the far-end transceivers of that same group is cancelled. This cancellation takes place between VDSL2 transceivers, not necessarily of the same profile. This Recommendation is intended to be implemented in conjunction with [ITU-T G.993.2]. Multi-pair digital subscriber line (DSL) bonding ([b-ITU-T G.998.1], [b-ITU-T G.998.2] and [b-ITU-T G.998.3]) may be implemented in conjunction with vectoring.