International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series G
Supplement 50
(09/2011)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Overview of digital subscriber line Recommendations

ITU-T G-series Recommendations – Supplement 50

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Supplement 50 to ITU-T G-series Recommendations

Overview of digital subscriber line Recommendations

Summary

Supplement 50 to ITU-T G-series Recommendations provides an overview of the family of digital subscriber line (DSL) Recommendations. It describes how the various ITU-T Recommendations on DSL are related. This Supplement also defines a generic system reference and a protocol reference configuration for ITU-T Recommendations on DSL 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.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G Suppl. 50	2011-09-16	15

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this publication, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this publication is voluntary. However, the publication may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the publication is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the publication is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this publication may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the publication development process.

As of the date of approval of this publication, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this publication. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Page

Supplement 50 to ITU-T G-series Recommendations

Overview of digital subscriber line Recommendations

1 Scope

This Supplement provides an overview of the family ITU-T Recommendations on digital subscriber line (DSL). It describes how the various ITU-T Recommendations on DSL are related. This Supplement also defines a generic system reference and a protocol reference configuration for ITU-T Recommendations on DSL and relates it to the system reference models of the ITU-T DSL Recommendations. This Supplement is of an 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 ITU-T Recommendations on DSL – see clause 5.

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 ITU-T Recommendations on digital subscriber line (DSL)

The family of ITU-T Recommendations on DSL includes the following 19 ITU-T Recommendations:

ITU-T G.991.1, ITU-T G.991.2, ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.1, ITU-T G.993.2, ITU-T G.993.5, ITU-T G.994.1, ITU-T G.996.1, ITU-T G.996.2, ITU-T G.997.1, ITU-T G.998.1, ITU-T G.998.2, ITU-T G.998.3, ITU-T G.998.4, and ITU-T G.999.1.

ITU-T G.991.1, ITU-T G.991.2, ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.1, and ITU-T 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, ITU-T G.996.1, ITU-T G.996.2, and ITU-T G.997.1 support ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.1, and ITU-T G.993.2 by providing common handshake, management and testing procedures.

ITU-T G.998.1, ITU-T G.998.2, and ITU-T 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 ITU-T 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 ITU-T Recommendations on DSL 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

Recommendation 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 of ITU-T G.991.1, the ITU-T 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 of ITU-T 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 telecommunication access networks. ITU-T 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. ITU-T 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. ITU-T 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, ITU-T G.992.1 and ITU-T G.992.2. ITU-T 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 of ITU-T G.961) is specified in Annex H of ITU-T G.992.1 and is referenced in Annex C of ITU-T 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 of ITU-T 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 of ITU-T 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 sublayer 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 of ITU-T 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 of ITU-T 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 of ITU-T 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, ITU-T G.992.1 in combination with ITU-T 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 asymmetric 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.

ITU-T 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 sublayer 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 of ITU-T 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 of ITU-T 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)

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 Recommendation ITU-T G.992.1 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)

Recommendation ITU-T G.992.4 describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. ITU-T 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 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 G.992.2. This Recommendation may be easily implemented in multi-mode devices that support both ITU-T G.992.4 and ITU-T 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 ITU-T 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, subcarrier black-out lists to avoid RFI, and improved subcarrier ordering to help mitigate the propagation of RFI from subcarrier to subcarrier;
– 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 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 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 ITU-T G.992.3. This Recommendation is easily implemented in multi-mode devices that support both ITU-T G.992.5 and ITU-T 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 control the out-of-band PSD without the need for filtering in the analogue front end.

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

Recommendation ITU-T G.993.1 permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. ITU-T 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, ITU-T G.993.1 uses up to 12 MHz of the spectrum. ITU-T 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.

ITU-T 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, ITU-T 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 ITU-T G.99x-series, ITU-T G.993.1 uses ITU-T G.994.1 to handshake and to 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.

ITU-T 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 ITU-T 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 night-time routine checks. The home-wiring transmission system is outside the scope of ITU-T G.993.1.

It is envisaged that ITU-T 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 (TPS-TC) layer. This specification covers the functional requirements for the transport of asynchronous transfer mode (ATM) and packet transfer mode (PTM). However the ITU-T 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, a repeater operation is not required for ITU-T 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.992x. 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 ITU-T 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 G.993.1 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 G.993.1 (VDSL), ITU-T G.992.3 (ADSL2) and ITU-T G.992.5 (ADSL2 plus).

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 ITU-T 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 G.993.1, 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 G.993.1, 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 G.993.1.

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

Changes in this Recommendation relative to ITU-T G.993.1 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 of ITU-T G.992.3);
– 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 G.992.5);
– mandatory support of trellis coding (based on ITU-T G.992.3);
– the definition of receiver-determined tone ordering (based on ITU-T G.992.3);
– mandatory support of all integer-bit constellations from 1 bit to 15 bits;
– support for optional cyclic extension (CE) lengths as large as ¼ 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 G.992.3);
– improved framing (based on ITU-T G.992.3);
– 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 G.992.3);
– 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 (ITU-T G.993.5) friendly operation;
– support for transport of time-of-day from central office end to remote end.

Recommendation ITU-T G.993.2 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

ITU-T G.993.5 describes vectoring as 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 (ITU-T G.998.1, ITU-T G.998.2 and ITU-T G.998.3) may be implemented in conjunction with vectoring.

The techniques described in this Recommendation provide means of reducing self-FEXT generated by the transceivers in a multi-pair cable or cable binder. Self-FEXT cancellation techniques are particularly beneficial with short cable lengths (< 1 km) and limited near-end crosstalk (NEXT), background noise, and FEXT from systems which are not a part of the vectored group (alien noise). The level of non-self-FEXT noise sources relative to that of self-FEXT sources determines the degree to which self-FEXT reduction can improve performance. Another significant factor is the degree to which the self-FEXT cancelling system has access to the disturbing pairs of the cable. Maximum gains are achieved when the self-FEXT cancelling system has access to all of the pairs of a cable carrying broadband signals. For multi-binder cables, significant gains are possible when the self-FEXT cancelling system has access to all of the pairs of the binder group(s) in which it is deployed and has the ability to cancel at least the majority of dominant self-FEXT disturbers within the binder. When multiple self-FEXT cancelling systems are deployed in a multi-binder cable without binder management, gains may be significantly reduced.

A reference model for a vectored system is illustrated in Figure 5-1. In a vectored system, the access node (AN), located at a central office (CO) or remote terminal (RT) or other location, transmits to and receives from a number of network terminations (NTs). The common element of all forms of vectoring is coordinated transmission (downstream vectoring) or coordinated reception (upstream vectoring) of signals from lines in the vectored group at the AN. Thus, the signals may be represented as a vector where each component is the signal on one of the lines. This coordination is made possible through an interface between a VTU-O (here called VTU-O-1) and all other VTU-Os (here called VTU-O-*n*, *n*=2…*N*, where *N* denotes the number of lines in the vectored group), which is here called ε-1-*n* to indicate that the coordination takes place between line 1 and line *n*.

Coordinated management of the lines is performed by the network management system (NMS), passing management information to the management entity (ME) through the Q-interface. Both the NMS and the ME are defined in ITU-T G.997.1. Inside the AN, the ME further conveys the management information for a particular line (over an interface here called ε-m) to the vectoring control entities (VCEs) of the vectoring group that line belongs to. Each VCE controls a single vectored group, and controls VTU-O-*n* (connected to line *n* in the vectored group) over an interface here called ε-c-*n*. Pre-coder data are exchanged between VTU-O-*n*1 and VTU-O-*n*2 over an interface here called ε-*n*1-*n*2.

Figure 5-1 shows the reference model for a vectored system (only line 1 out of a vectored group of *N* lines is shown). The PHY blocks represent the physical layer of the AN interface towards the network and of the NT interface towards the customer premises (CP). These blocks are shown for completeness of the data flow but are out of scope of this Recommendation. The L2+ blocks represent the Ethernet Layer 2 and above functionalities contained in the AN and NT. These blocks are shown for completeness of the data flow but are out of scope of this Recommendation, except for the encapsulation (at NT) and decapsulation (at AN) of the backchannel.

Using ITU-T G.998.1, ITU-T G.998.2, and ITU-T G.998.3, data rates can be increased by deploying multiple lines to the same customer premises – a technique known as bonding.

NOTE – Vectoring is not another name for bonding; bonding may be used with or without vectoring. The use of vectoring over bonded lines is often defined as bonded vectoring or as multiple input multiple output (MIMO) DSL.

The focus of this Recommendation is the use of vectoring over lines that are not bonded, although it does not preclude the use of vectoring over bonded lines.

A vectored VDSL2 system improves its performance from the use of joint signal processing in the downstream direction (coordinated transmission), or from the use of joint signal processing in the upstream direction (coordinated reception) which allows cancelling of self-FEXT (i.e., FEXT generated by the lines of the vectored group). The noise sources which are external to the group of vectored pairs in the vectored system (for example, alien crosstalk from lines operated by another service provider, interference from AM broadcast channels or interference from amateur radio transmitters (above the AM broadcast band) (HAM)) reduce the benefits of FEXT cancellation and reduce the performance enhancement provided by a vectored system.

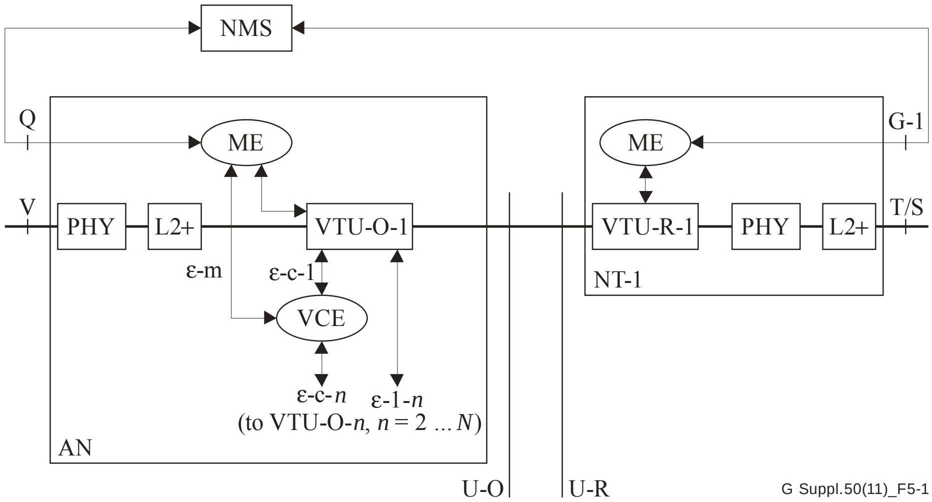


Figure 5-1 – Reference model for a vectored system (shown for line 1 in a vectored group of *N* lines)

For relatively short lines and high-bandwidth systems such as VDSL, self-FEXT is the limiting factor for downstream data rates. This Recommendation defines multi-line pre-coding at the AN to mitigate FEXT in the downstream direction, based on "pre-subtraction" or "pre-compensation" of the FEXT, while meeting transmitted power constraints. To accommodate for such pre-coding, the ITU-T G.993.2 PMD layer is modified as shown in Figure 5-2 (adapted from Figure 10-1 of ITU-T G.993.2, with differences shown shaded). Figure 5-2 shows the VTU-O functional model for line 1 out of a vectored group of *N* lines. For each line in the vectored group, the PMD sublayer includes an $N \times 1$ pre-coder. Over the vectored group, the *N* pre-coders for each of the *N* lines constitute the FEXT cancellation pre-coder.

NOTE – The precoder may or may not be implemented in the same physical device as the other functional blocks shown in Figure 5-2.

The VTU-R functional model of PMD sublayers is as shown in Figure 10-1 of ITU-T G.993.2, with an addition of vectoring-related control signals applied to the sync symbol encoder and initialization symbol encoder to provide pilot sequence modulation on sync symbols, similar to those shown in Figure 5-2.

Upstream vectoring is mainly a receiver function at the CO-side, and therefore its implementation is vendor discretionary. This Recommendation only defines the VTU-R transmitter requirements to facilitate upstream FEXT cancellation at the CO-side (e.g., transmission of upstream pilot sequence with timing and content under VCE control).

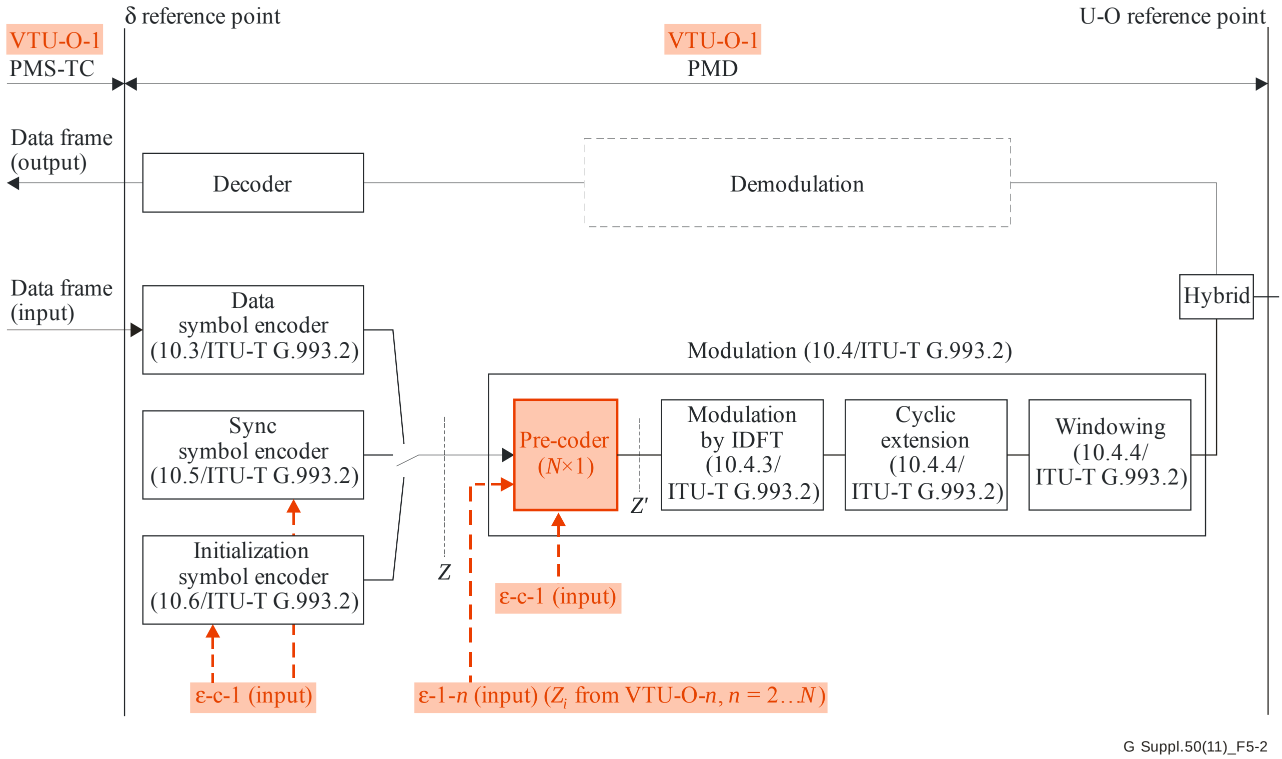


Figure 5-2 – VTU-O functional model of PMD sublayer using N×1 pre-coder for downstream vectoring (shown for line 1 in vectored group of N lines)

5.11 ITU-T G.994.1: Handshake procedures for digital subscriber line (DSL) transceivers

ITU-T G.994.1 defines signals, messages and procedures for exchanging these between digital subscriber line (DSL) equipment, when the modes of operation of the equipment need to be automatically established and selected, but before signals are exchanged which are specific to a particular DSL Recommendation.

The principal characteristics of ITU-T G.994.1 are as follows:

a) use over metallic local loops;

b) provisions to exchange capabilities information between DSL equipment for identifying common modes of operation;

c) provisions for DSL equipment at either end of the loop to select a common mode of operation or to request the other end to select the mode;

d) provisions for exchanging non-standard information between DSL equipment;

e) provisions to exchange and request service and application related information;

f) support for both duplex and half-duplex transmission modes.

5.12 ITU-T G.996.1: Test procedures for digital subscriber line (DSL) transceivers

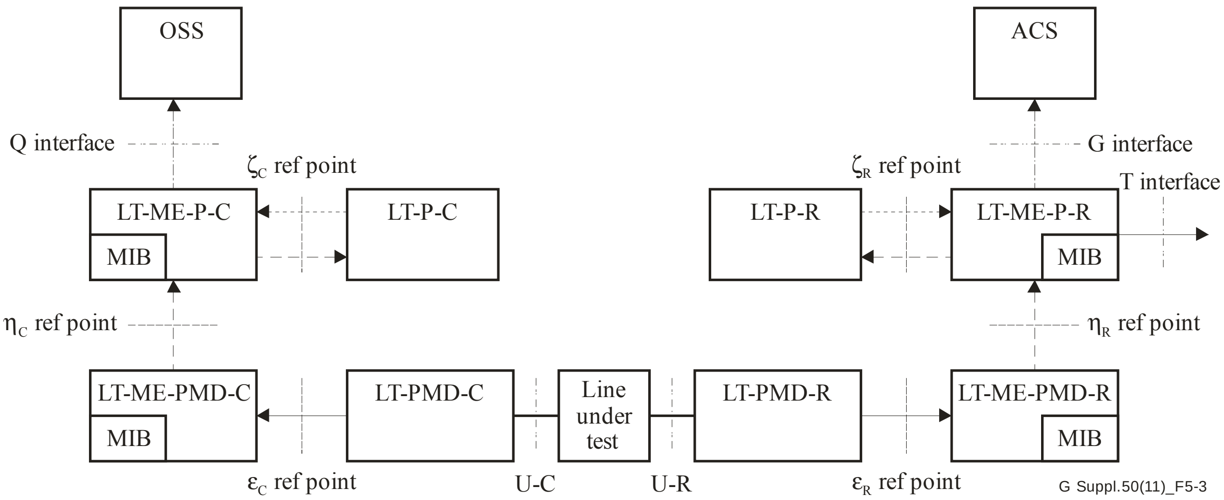
ITU-T G.996.1 describes the testing procedures for ITU-T G.99x-series Recommendations. ITU-T G.996.1 provides descriptions of the test procedures, test configurations, test loops, crosstalk models. ITU-T G.992.1 and ITU-T G.992.2 reference ITU-T G.996.1 for testing procedures and configurations. Performance requirements for ITU-T G.992.1 and ITU-T G.992.2 are outlined in each of the respective Recommendations.

5.13 ITU-T G.996.2: Single ended line testing for digital subscriber lines (DSL)

ITU-T G.996.2 specifies line testing for use on xDSL lines. The Recommendation contains annexes that describe specifications for single ended line testing (SELT), dual ended line testing (DELT) and metallic line testing (MELT). Separate annexes describe physical medium dependent (PMD) and processing functions for SELT, DELT and MELT. An informative appendix is also included describing SELT application models. In this Recommendation, one or more of the line testing (LT) functional blocks may, but are not required to, be the same as the xDSL transceiver unit (xTU) functional block.

Line test involves the measurement of electrical signals on a line with or without a stimulus applied to the near end or the far end of the loop. These measurements are used to determine measurement parameters which are the basic parameters that characterise the loop and its noise environment. Derived parameters are derived from the measurement parameters and provide specific features of the loop and the noise environment.

In order to produce the parameters to be delivered to the management system from observations of the loop connected at one termination side to the U-C interface and at the other side to the U-R interface, a number of distinctive functions can be identified. Each of these functions is represented by a functional block (rectangle) in the functional reference model. Reference points are introduced into the model. Some reference points correspond to functional interfaces. Figure 5-3 depicts the functional reference model.



NOTE: arrows show flow of data elements only; flow of control elements are bi-directional (not shown).

Figure 5-3 – Functional reference model

There are four functional blocks that exist at each end of a line. The following general descriptions of the functionality of each block apply at both ends of the line but the detail of their functionality may be different at each end.

The first functional block is called the LT-PMD (line test – physical medium dependent). The LT-PMD function performs measurements on the physical medium to which the line test device is connected. The result of a measurement is a quantity represented as a parameter (one or more dimensional, discrete or continuous). From these parameters, measurement parameters are derived, usually through multiple measurements.

The fact that the functional block is connected to the physical medium motivates calling it 'PMD'. The prefix LT indicates that this functional block is specific to line testing. However, in some instantiations, this may be the same as, or nearly the same as, instantiations of an xTU-PMD functional block.

The second functional block is called the LT-P (LT – processing). The LT-P function transforms the measurement parameters into derived parameters. These derived parameters directly reflect the characteristics of the loop under test.

The third functional block is denoted LT-ME-P (LT – management entity – P) and has the following functionalities:

A. Data Plane:

– to provide an interface point to the OSS, ACS or User for access to both derived and measurement parameters across the Q, G or T interfaces respectively;

– to access the measurement parameters in the LT-ME-PMD across the η reference point.

B. Management Plane:

– to manage the LT-P-MIB;

– to control the functionality of the LT-P across the ζ reference point;

– communicate with the far end LT-ME-P across the U interface to coordinate testing and exchange derived and measurement parameters.

The fourth functional block is denoted LT-ME-PMD (LT – management entity – PMD) and has the following functionalities:

A. Data-plane:

– to provide to the LT-ME-P access to measurement parameters.

B. Management-plane:

– to manage the LT-PMD-MIB;

– to control the measurements performed by the LT-PMD across the ε reference point.

The term "LT" in the Line Test Reference Model refers to all forms of Line Test (i.e., SELT, DELT and MELT). In Annexes A and B, which contain SELT requirements, the term "SELT" is used in place of the term "LT". In Annexes C and D, which contain DELT requirements, the term "DELT" is used in place of the term "LT". In Annexes E and F, which contain MELT requirements, the term "MELT" is used in place of the term "LT".

The test measurements are fundamental electrical measurements. Three types of measurements can be distinguished:

1. Measurements at the near end that are associated with an excitation of the physical medium from the PMD block at the near-end.
2. Measurements at the near end that are associated with an excitation of the physical medium from the PMD block at the far-end.
3. Measurements that do not require any excitation.

A sequence of measurements of the first two measurement types are defined as the measurements associated with a sequence of corresponding excitations. For the third measurement type the PMD blocks at either end do not inject any signal on to the line.

5.14 ITU-T G.997.1: Physical layer management for digital subscriber line (DSL) transceivers

Recommendation ITU-T G.997.1 specifies the physical layer management for ADSL and VDSL2 transmission systems. It specifies means of communication on a transport transmission channel defined in the physical layer Recommendations ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5 and ITU-T G.993.2. It specifies network elements content and syntax for configuration, fault and performance management.

This Recommendation includes the MIB elements for the physical layer management of ITU-T G.993.2 and additional MIB elements for the physical layer management of ITU-T G.992.3 and ITU-T G.992.5. It specifies network management elements content for configuration, fault and performance management.

The mechanisms to provide OAM functions and to generate OAM flows F1, F2 and F3 will depend on the transport mechanism of the physical layer transmission system as well as on the supervision functions contained within the physical layer termination functions of equipment. This Recommendation only specifies flow F3 – transmission path level.

5.15 ITU-T G.998.1: ATM-based multi-pair bonding

The purpose of this Recommendation is to assist manufacturers, providers, and users of products on how to use multiple DSL lines to carry a single ATM payload stream. In order to satisfy this purpose, requirements and guidelines are provided. This Recommendation is written to satisfy the following bonding objectives:

1) bonding supports dynamic removal and restoration of pairs without human intervention;
2) bonding supports disparate data rates, up to a ratio of 4-to-1 (fastest to slowest), amongst its pairs;
3) the protocol allows bonding of 2-32 pairs;
4) the protocol permits bonding of randomly assigned ports on an access node;
5) the protocol is PHY independent;
6) the protocol incurs a maximum overall one-way bonding delay of 2 ms.

In order for implementations compliant to this Recommendation to be interoperable between vendors, an initialization procedure, a payload tagging method, and OAM capability are provided.

The applications supported within this Recommendation relate to bonding of multiple DSL loops to deliver ATM payload beyond the rate/reach capability of a single DSL loop. Each ATM TPS-TC (assuming multiple bearer channels) operates in an independent bonded group. As described within this Recommendation, the customer premises equipment (CPE) represents the User-Network Interface (UNI) to the ATM network.

An illustration of the bonding system for transport of an ATM payload across several DSL lines with disparate data rates is provided in Figure 5-4 below. In traditional inverse multiplexing over ATM (IMA) as specified in the ATM Forum document, Inverse Multiplexing for ATM (IMA) Specification, Version 1.1 [B1], it is assumed that all bonded links operate at the same nominal rate. The original cells are not modified, and control (ICP) cells are inserted for OAM communication between the two ends. In this Recommendation, each cell is tagged with a Sequence ID (SID). The transmitter may place any cell on any link, and the receiver can reassemble the original sequence.

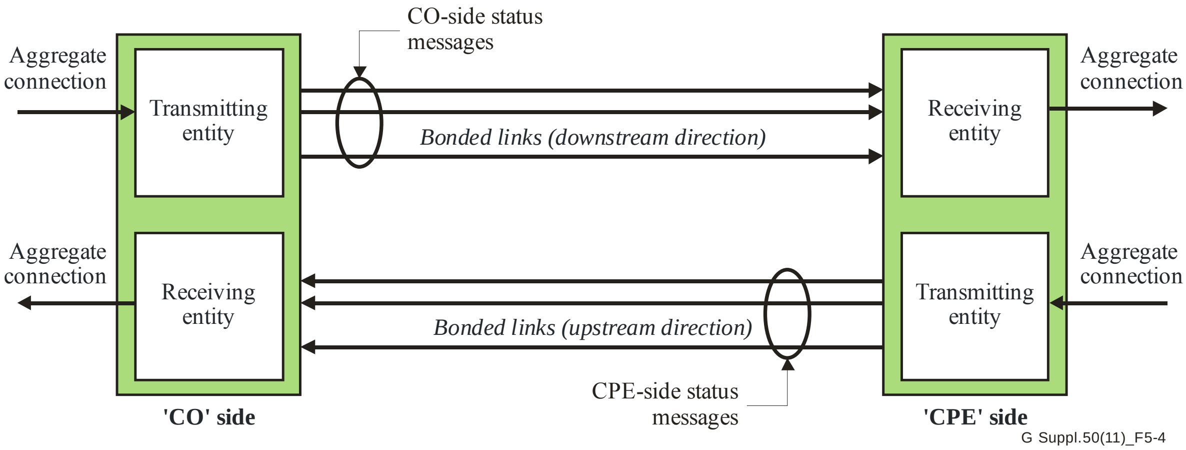


Figure 5-4 – Status message flow. Each transmission direction is treated independently

A bonding group is defined as a bidirectional ATM stream transported by multiple bidirectional bearers across multiple physical media in both upstream and downstream directions. A single bonding group cannot span multiple CPE entities or CO-side access nodes. As a consequence, the control channel is also a bidirectional ATM stream, consisting of ATM messages called autonomous status messages (ASMs). The content and sequence of these messages defines a control protocol between the two bonding entities in both directions. Some implementations may support multiple bearers on each physical link. Different bearers on the same line are never bonded together into the same group.

NOTE – The upstream and downstream rates may be different.

The control protocol communicates the status of each link in the bonding group. The way a bonding group is defined at start up, maintained during operation, and put out of service, is discussed below.

The underlying bit rate of the individual links within a bonded group may be freely and independently changed by their respective PHY layers. It is the responsibility of the transmitter not to overrun PHY transmit buffers, nor add delay created by excess buffering (by either carefully controlling the PHY bit rate itself, by allowing the PHY bit rate to "float" and then honouring back pressure, or by monitoring instantaneous bit rate and rate shaping its transmissions, matching multiplex ordering to rates, etc.).

NOTE – Resultant changes in bit rate are subject to constraints of buffer size, number of lines, and differential delay. The 4-to-1 ratio is not a hard limit, and may be violated provided these other constraints are satisfied.

5.16 ITU-T G.998.2: Ethernet-based multi-pair bonding

Recommendation ITU-T G.998.2 specifies portions of clause 61 of IEEE Standard 802.3 (Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specification) as a normative reference and identifies the requirements for multi-pair bonding in IEEE Standard IEEE 802.3. Further, this Recommendation specifies the requirements for extending the bonding methods in IEEE 802.3ah-2004 to xDSL technologies other than VDSL and SHDSL.

The following are the objectives this Recommendation:

a) To provide support for operation of xDSL technologies on multiple pairs of voice grade twisted pair cable.

b) To provide 100 Mbit/s burst data rate at the Ethernet media independent interface using Rate Matching.

c) To provide full duplex operation.

d) To provide a communication channel with a mean BER at the α/β service interface of less than 10^{-7}.

Large portions of this Recommendation reference the IEEE Standard 802.3. A cross-reference to the technology nomenclature, and a reference to the relevant Recommendations, are given in Table 1.

Table 1 – Technology nomenclature

Reference in this Recommendation	IEEE 802.3ah-2004 Reference	Relevant Recommendation
VDSL	10PASS-TS	T1.424
SHDSL	2BASE-TL	ITU-T G.991.2
ADSL	N/A	ITU-T G.992.1

As shown in the table, the IEEE reference to 10PASS-TS is the IEEE 802.3 standard for transporting Ethernet using a MCM-VDSL-based PHY. Likewise, 2BASE-TL is the IEEE 802.3 standard for transporting Ethernet using a SHDSL-based PHY. There is no IEEE standard for transporting Ethernet over ADSL, though that operation is clarified in this Recommendation.

The Copper PHYs addressed by this Recommendation are only defined for full duplex operation as defined in the IEEE 802.3 specification.

The physical coding sublayer (PCS) contains two functions: MAC-PHY rate matching and PME aggregation. The functional position of the PCS is shown in Figure 5-5.

The γ-interface and the α(β)-interface are generic interfaces used in various xDSL specifications. The α(β)-interface is a simple octet-synchronous date interface; the γ-interface add protocol-awareness.

Note that the bit rates in the shaded area labelled "PMD rate domain" are derived from the DSL bit rates. Data is transferred across the γ-interface at the rate imposed by the lower layers. The bit rates in the shaded area labelled "100 Mbit/s rate domain" are synchronous to the MII rate. Data is transferred across the MII at the rate of one nibble per MII clock cycle. The MAC-PHY rate matching function adjusts the inter-packet gap so that the net data rate across this interface matches the sum of rates across the γ-interface.

NOTE – Bit domains and physical clock domains do not necessarily coincide. The TC sublayer receives as clock signal from the PMA via the α(β)-interface, and a clock signal from the optional PAF or the MAC-PHY Rate Matching function via the γ-interface. The TC provides matching between the two clock domains.

In the transmit direction, frames are transferred from the MAC to the PCS across the MII when the MAC-PHY rate matching function allows this. In the PCS, preamble and SFD octets are removed. The data frame is fragmented by the PAF, and fragments are forwarded, optionally through a flexible cross-connect, towards each of the aggregated PME instances via the γ-interface. The TC sublayer accepts data from the MAC-PHY rate matching function or the PAF, at the rate at which it can be processed by the TC sublayer, by asserting Tx-Enbl on the γ-interface.

The optional flexible cross-connect function may be present to provide access from a centralized bonding function (PAF) to TCs on lines distributed throughout a system. The method by which frames are transferred between the bonding function and the various TCs in the bonded group is outside the scope of this Recommendation.

In the receiver direction, the TC sublayer pushed data to the PAF (if present) or the MAC-PHY rate matching function by asserting Rx_Enbl on the γ-interface. The PAF reassembles the received fragments into data frames. Preamble and SFD octets are generated and prepended to the data frame prior to passing it up to the MAC across the MII. The MAC-PHY Rate Matching function may delay the transfer of the frame to avoid simultaneous transfer of transmit and receive frames if required.

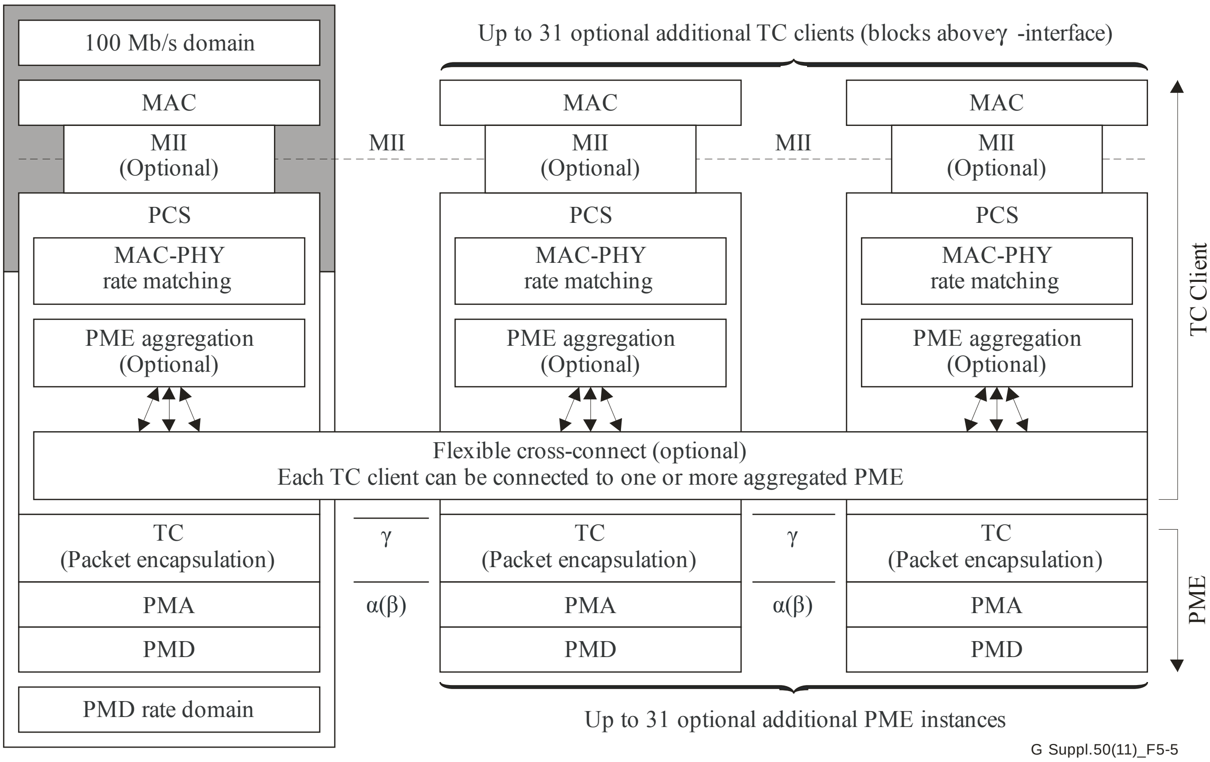


Figure 5-5 – Overview of PCS functions

Figure 5-6 compares the ITU layering with the IEEE layering by showing the relative positions of the γ and α(β) interfaces and the relevant architectural blocks. Some things to note include:

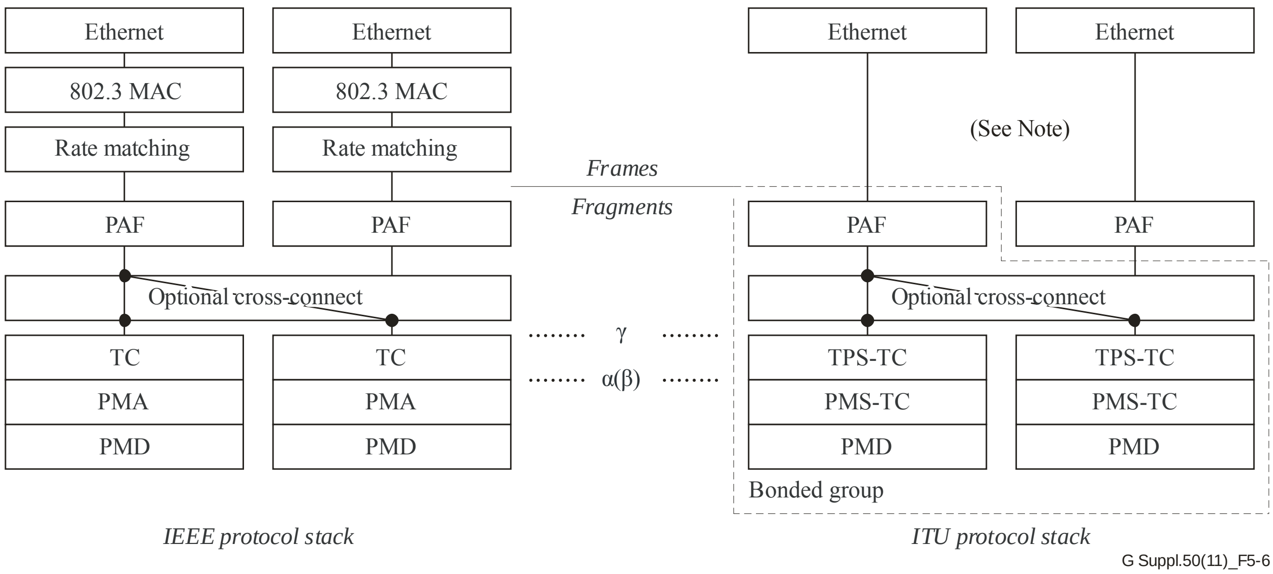
1) In IEEE 802.3ah-2004, the entire function of a bonded group (taking in/out frames, fragmenting/reassembly across multiple lines, encapsulating fragments on a line, etc.) is referred to as the PCS function. In Figure 5-6, two lines are shown being aggregated into the leftmost PAF function in both protocol stacks.

2) Since IEEE 802.3ah-2004 has only a single TPS-TC (it defines only 64/65-octet encapsulation as the TPS-TC), the TPS-TC function is abbreviated TC.

3) IEEE 802.3ah-2004 requires a rate matching function to provide an interface between the well-defined 100 Mbit/s Ethernet MAC and the variable rate aggregation function. The ITU protocol stack does not require the use of the standard Ethernet MAC, and thus, no rate matching function is required.

As can be seen from the diagram, the protocol stacks are very similar, but have terminology and architectural differences related to the historical terminology and architecture of the individual standards organization.

For physical layers that support multiple bearers, the methods of this Recommendation can be applied to one or multiples of those bearers independently. As each bearer can independently carry individual fragments, multiple bearers can be aggregated across multiple lines. Multiple bearers on the same line should not be aggregated.



NOTE – A rate matching algorithm may be implemented somewhere above the PAFT. The IEEE rate matching algorithm is specifically designed for the Ethernet MAC.

Figure 5-6 – Comparison of IEEE and ITU protocol stacks

5.17 ITU-T G.998.3: Multi-pair bonding using time-division inverse multiplexing

This Recommendation defines the bonding function for the TDIM-based bonding method, the purpose of which is to provide inverse multiplexing of various service data streams (Ethernet, ATM, and TDM) over multiple DSL physical links and to retrieve the original stream at the far-end from these physical links.

This Recommendation is a detailed specification of the TDIM protocol in sufficient detail to allow development and testing of interoperable implementations for both transmitter and receivers. It includes:

1) Multi-pair synchronization frame format.
2) Bonding communication channel (BCC).
3) Dispatching algorithm.
4) Hitless addition and removal of pairs.
5) Fast removal of pair upon pair failure.
6) Using IEEE 802.3ah handshake for pair discovery, parameter negotiation and set up.

This Recommendation defines a new TPS-TC for DSL transceivers. Architecturally, this TPS-TC should be placed above the PMS-TC (at the alpha/beta-interface) of existing or future DSL transceivers. Practically, the exact same result can be obtained by stacking the new TPS-TC defined in this Recommendation on top of the clear channel or STM TPS-TC, as defined in existing ITU-T Recommendations on DSL.

Figure 5-7 represents the data flow model which is defined in this proposed text. Data from a mix of services is encapsulated into a single data stream. The data stream can then optionally pass through forward error correction and interleaving, and then be dispatched (inverse multiplexed) over multi-pair modems.

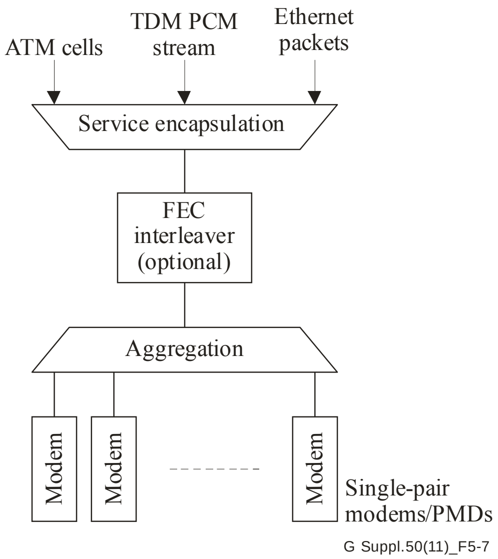


Figure 5-7 – Data flow model

5.18 ITU-T G.998.4: Improved impulse noise protection for DSL transceivers

This Recommendation specifies techniques beyond those defined in the existing ITU-T digital subscriber line (DSL) Recommendations ITU-T G.992.3, ITU-T G.992.5, and ITU-T G.993.2 to provide enhanced protection against impulse noise or to increase the efficiency of providing impulse noise protection (INP).

Impulse noise is a noise event of limited duration that can degrade one or more transmitted symbols. Unlike the various types of continuous noise found on DSLs, impulse noise has a short duration and may repeat, either randomly or periodically. Impulse noise that does not appear to repeat periodically but occur as unpredictable events is termed SHINE (single high impulse noise event). Impulse noise caused by noise from electrical mains and thus repeats at a constant period related to the local AC power frequency is termed REIN (repetitive electrical impulse noise).

Impulse noise protection techniques are, in general, techniques used by a DSL transceiver to protect against the effects of impulse noise on the transmitted signal. Existing ITU-T Recommendations on DSL specify techniques to ameliorate impulse noise effects. Among these methods are the use of forward error correction (FEC) coding and interleaving.

This Recommendation specifies a physical layer retransmission method for enhancing INP, with annexes specifically providing the details required for implementation of these techniques for transceivers supporting Recommendations ITU-T G.992.3, ITU-T G.992.5 and ITU-T G.993.2. Methods for enhancing INP by techniques other than physical layer retransmission are for further study.

This Recommendation is implemented in conjunction with one of the following ITU-T Recommendations, referred to as "associated Recommendations": ITU-T G.992.3 (ADSL2), ITU-T G.992.5 (ADSL2plus), or ITU-T G.993.2 (VDSL2).

The main body specifies the elements that are independent of the associated Recommendations that include:

– data path and the retransmission return channel for the transmission direction for which retransmission is enabled;
– management and control of the retransmission function.

The annexes specify the elements that are dependent on the associated Recommendations that include:

– requirements on the data path specific to the associated Recommendation;

– changes to the initialization of the associated Recommendation;

– changes to the EOC messages.

A transceiver compliant with this Recommendation supports the main body, one of the associated Recommendations and the respective annex.

Figure 5-8 shows the functional reference model for the case where retransmission is enabled in both transmission directions.

In the forward direction, only one bearer channel (#0) is active. Octets from the bearer channel are encapsulated in data transfer units (DTUs). DTUs are stored in a retransmission queue after transmission. A DTU multiplexer will select either a new DTU or a DTU from the retransmission queue for transmission over the α2-reference point.

The PMS-TC contains two latency paths and a retransmission request channel (RRC). Latency path 0 contains only overhead data, while latency path 1 contains only DTUs (i.e., octets coming over the α2-reference point). The RRC carries acknowledgments for received DTUs. The latency paths are scrambled and encoded using a Reed-Solomon code. The RRC is encoded using an extended Golay code. The output bits from the latency paths and the RRC are multiplexed into a data frame that is transferred to the PMD over the δ-reference point.

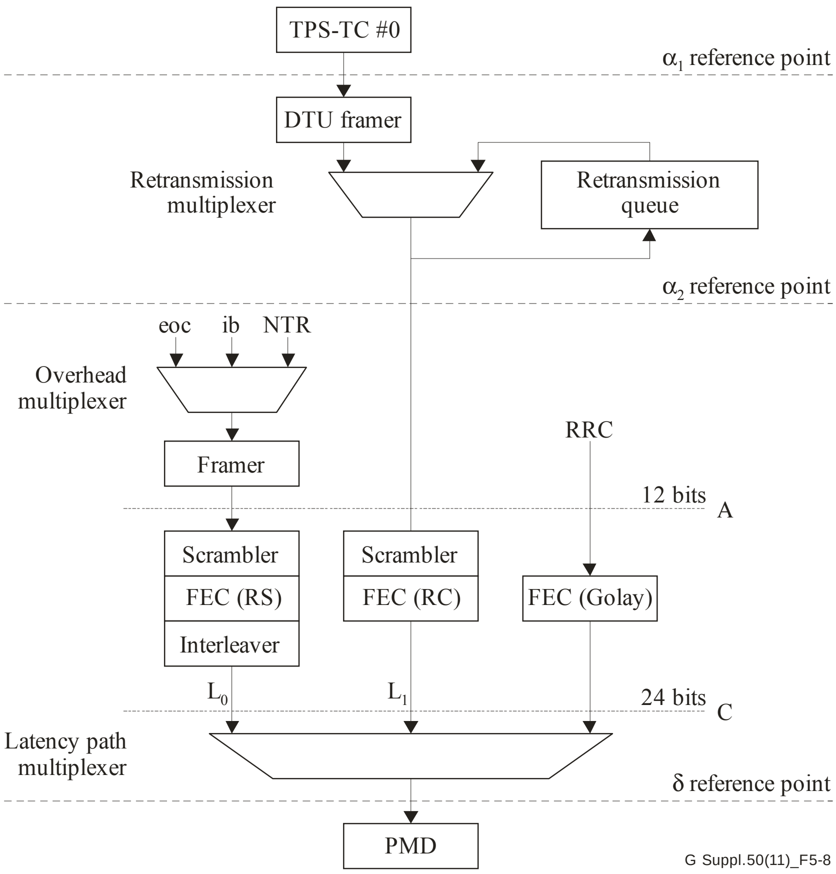


Figure 5-8 – Reference model when retransmission is enabled in both directions

Figure 5-9 shows the functional reference model in the forward direction when retransmission is enabled in a single direction. This functional reference model is identical to the one described in Figure 5-8, with the exception that there is no RRC.

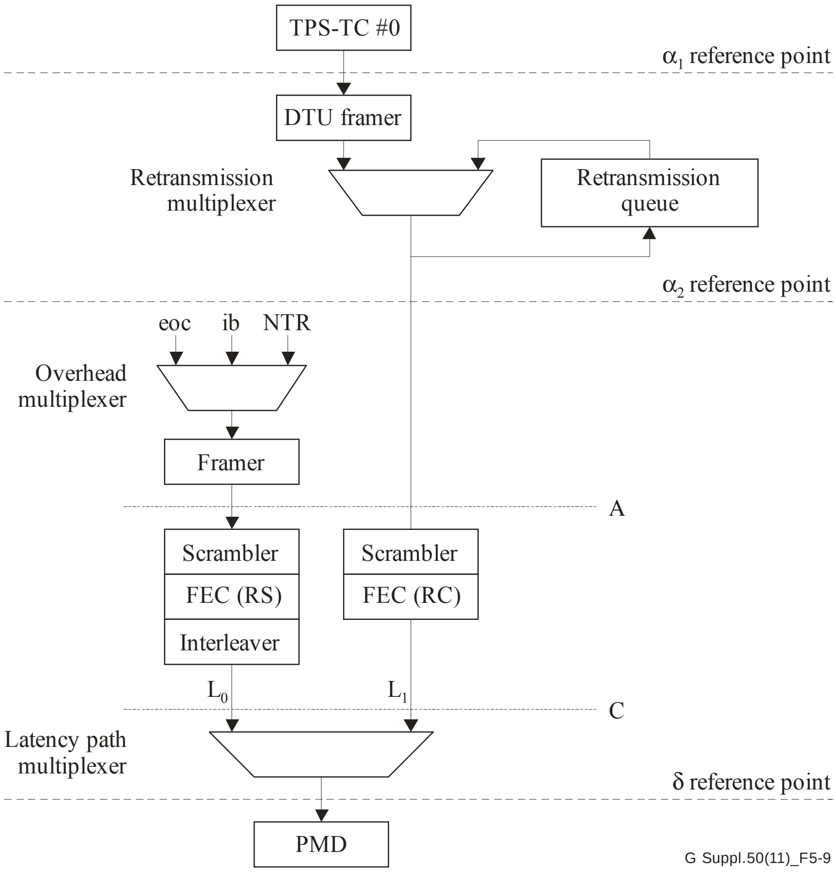


Figure 5-9 – Reference model in the forward direction when retransmission is enabled in a single direction

Figure 5-10 shows the functional reference model in the return direction when retransmission is enabled in a single direction. The functional reference model for the TPS-TC is identical to the TPS-TC functional model in the applicable associated ITU-T Recommendation (ITU-T G.992.3, ITU-T G.992.5 or ITU-T G.993.2). The PMS-TC consists of one latency path and the RRC. The functional model of the latency paths is identical to that in the applicable associated ITU-T Recommendation (ITU-T G.992.3, ITU-T G.992.5 or ITU-T G.993.2). The RRC is multiplexed with the output of the latency paths into a data frame that is transferred to the PMD over the δ-reference point.

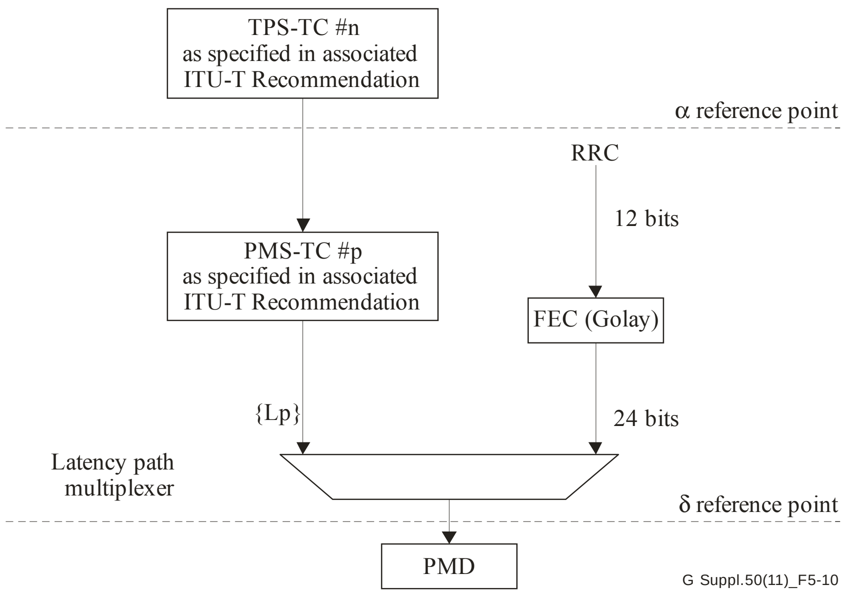


Figure 5-10 – Reference model in the return direction when retransmission is enabled in a single direction

In the reference model of Figure 5-8 and Figure 5-9, the retransmission queue is shown to be located between the TPS-TC and scrambler only for the purpose of defining the data transmission unit (DTU) frame structure. It is noted that the DTU frame structure is defined such that it is transparent to the location of the retransmission queue where the queue may be placed at one layer in the transceiver structure and interoperate with another device having the queue located in a different layer.

5.19 ITU-T G.999.1: Interface between the link layer and the physical layer for digital subscriber line (DSL) transceivers

This Recommendation defines an interface between a LINK device and a PHY device. The interface is a single point-to-point interconnection from the LINK layer device to a PHY device, and it is intended for use with all current and developing ITU-T Recommendations on DSL (e.g., ADSL2, VDSL2, SHDSL, etc.).

The LINK/PHY interface reference model is shown in Figure 5-11. This reference model shows the following primitives defined in Annex K of ITU-T G.992.3 and Annex K of ITU-T G.992.5. Primitives are labelled *n*, where *n* corresponds to an individual stream, with $n = 0..N - 1$ for a LINK/PHY interface transporting N streams.

– Stream(n).request: This primitive is used by the transmit PHY port to request one or more data units from the transmit LINK layer function to be transported. By the interworking of the request and confirm, the data flow is matched to the PHY port configuration (and underlying functions).
– Stream(n).confirm: The transmit LINK layer function passes one or more data units to the PHY port to be transported with this primitive.
– Stream(n).indicate: The transmit PHY port passes one or more data units to the receive LINK layer function that have been transported with this primitive.

The data unit is a block of data consisting of an integer number of octets for transport between a PHY port and a link port. The contents of a data unit is vendor discretionary and outside the scope of this Recommendation. For example, a data unit may contain an Ethernet frame, an Ethernet bonding fragment, one or more ATM cells or an ATM AAL5 PDU.

The LINK/PHY interface reference model adds the following blocks:

– frag: Fragmentation of each data unit, with a tag control identification (TCI) field added to each fragment, and with each fragment not to exceed the configured maximum fragment length;
– tag: Identification of fragments through insertion of a data stream or pause identification tag into the TCI field;
– ETH: Ethernet adaptation by adding fields for compliance with the IEEE 802.3 frame format; the ETH block is configurable to be used or not;
– FCS: Error detection through addition of frame-check-sequence;
– PAUSE: Data flow control through a single PAUSE unit containing the data flow control states of all N streams;
– dec: Decapsulation to recover data units (confirm and indicate primitives) and data flow control states (request primitives), comprising the reverse operation of the frag, tag, and ETH blocks.

Data unit encapsulation is defined as the cascade of the frag, tag, ETH and FCS blocks. Pause init encapsulation is defined as the cascade of the PAUSE, ETH and FCS blocks. Encapsulation overhead depends on whether or not the ETH block is used.

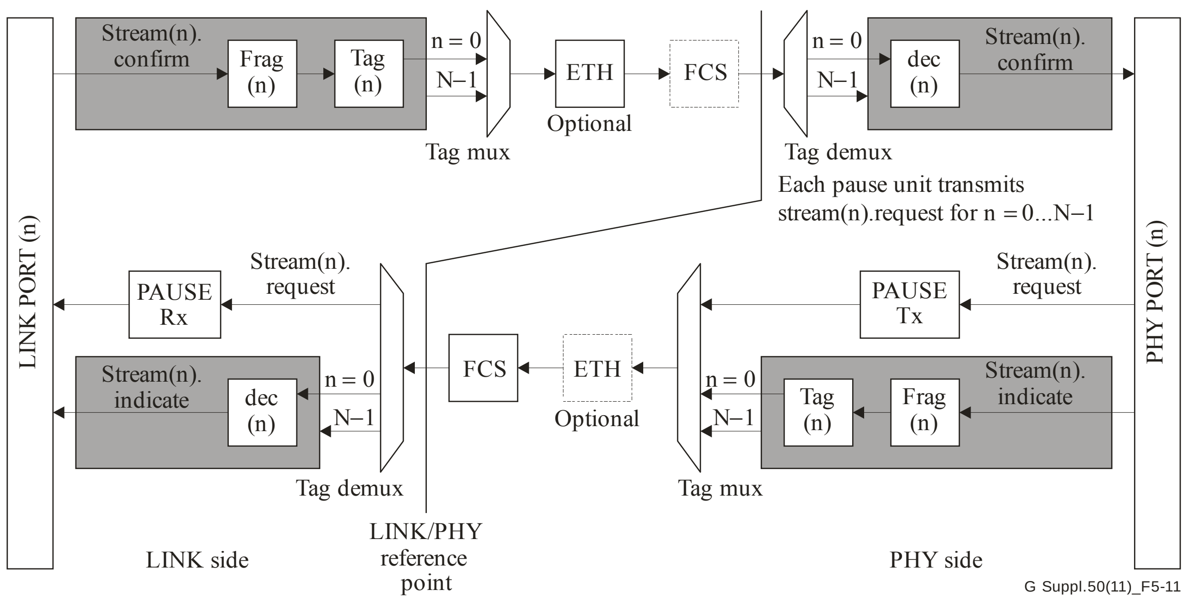


Figure 5-11 – Reference model for the LINK/PHY interface

The LINK device and PHY device use a physical point-to-point interconnection. The LINK/PHY interface supports a data rate of at least 1 Gbit/s for the encapsulated data units. The minimum required bit rate at the LINK/PHY reference point may be higher (e.g., 1.25 Gbit/s if 8B/10B encoding is used).

5.20 Relationship among the ITU-T Recommendations on DSL

The ITU-T Recommendations on DSL are related to each other as explained below.

VDSL (ITU-T G.993.2, and ITU-T G.993.1), ADSL (ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5), HDSL (ITU-T G.991.1) and SHDSL (ITU-T G.991.2) are metallic digital physical layer interface specifications for use over the twisted copper pair plants. All of them are for transmission of digital data over the copper pair. However, the type of applications, range of date rates, symmetry or asymmetry in the two directions, and the loop plant coverage, and the linecode technologies are what differentiate one from the other. From the perspective of symmetry, ITU-T G.991.1 and ITU-T G.991.2 provide symmetric data rates whereas ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5 provide asymmetric data rates in the upstream and the downstream direction.

ITU-T G.991.1 and ITU-T G.991.2 do not allow simultaneous transmission of ITU-T G.991.1 or ITU-T G.991.2 and the voiceband transmissions. A fully equipped ITU-T G.991.1 consists of one 2320 kbit/s, two 1168 kbit/s or two or three 784 kbit/s symmetric data rate service. ITU-T G.991.2 supports a range of symmetric user data rates from 192-2312 kbit/s over a single twisted copper wire pair. The ITU-T G.992.1 systems support a minimum of 6.144 Mbit/s downstream and 640 kbit/s upstream data rate. In the case of ITU-T G.992.2, systems support a maximum of 1.536 Mbit/s downstream and 512 kbit/s upstream data rate. The data rates for both ITU-T G.992.1 and ITU-T G.992.2 are asymmetrical. ITU-T G.992.1 has higher downstream to upstream asymmetry ratio than ITU-T G.992.2. From the loop plant coverage perspective, ITU-T G.991.1 has shorter loop length compared to ITU-T G.991.2, ITU-T G.992.1 and ITU-T G.992.2. The length of ITU-T G.991.1 may be increased through the use of regenerators. Regenerators are not specified on the ITU-T G.992.1 and ITU-T G.992.2 loops. Bridge taps are allowed on the ITU-T G.991.1, ITU-T G.992.1 and ITU-T G.992.2 loops. From the applications perspective, ITU-T G.991.1 is most often used for the business application. ITU-T G.992.1 may be used for both business and home applications. The large downstream bandwidth in ITU-T G.992.1 is suitable for facilitating some of the broadcast applications such as video-on-demand. The other data centric applications are possible under the constraint of lower upstream data rates when compared to ITU-T G.991.1. ITU-T G.992.2 main focus is simplified installations. It is suitable for high speed Internet access when compared to the voiceband data transmission. ITU-T G.991.1, ITU-T G.992.1 and ITU-T G.992.2 specify the achievable or target bit rates and are accordingly suitable for numerous applications. ITU-T G.992.2 and G.992.1 use the same DMT line code principles. ITU-T G.991.1 provides a choice of a 2B1Q or CAP linecode.

In some respects, ITU-T G.992.1 and ITU-T G.992.2 are closely related. There are other aspects that differentiate them. The close relation of the two lies in the use of the same core DMT line code and its associated parameters. ITU-T G.992.2 has been developed with considerations for possible interoperability with ITU-T G.992.1. ITU-T G.992.2 is based on modifications to ITU-T G.992.1 to meet the key objectives of lower equipment complexity, lower power consumption and splitterless operation. Extended reach ITU-T G.992.2 is under consideration for future revisions or modifications of ITU-T G.992.2. Some of the differentiating features of ITU-T G.992.2 are the reduced IDFT size for the downstream transmitter, smaller parameter set for the FEC coding and the Interleaving and the simpler reduced overhead framing structure. Other ITU-T G.992.2 specific features are the fast retrain and the power saving mechanisms. The fast retrain procedure is used to cater for those situations in which a non-linear phone goes off hook, thus changing the channel characteristics in a significant manner in a splitterless environment.

When a twisted pair is subject to crosstalk from TCM-ISDN, as defined in Appendix III of ITU-T G.961, both ITU-T G.992.1 and ITU-T G.992.2 provide Annex C which describes the asymmetric transmission techniques synchronized with TCM-ISDN. The symmetric transmission technique when they are subject to cross-talk from TCM-ISDN is described in Annex H of ITU-T G.992.1. Annex H of ITU-T G.992.1 specifies DMT line code synchronized with TCM-ISDN as a symmetric extension of Annex C of ITU-T G.992.1. Annex C of ITU-T G.991.2 is a pointer to Annex H of ITU-T G.992.1.

ITU-T G.991.1 and ITU-T G.991.2 are related in that both address transmission of symmetric user data over metallic copper wires, support T1 and E1 replacement and other business applications on two pairs of metallic copper wires and do not support the use of analogue splitting technology for coexistence with either POTS or ISDN. However, ITU-T G.991.2 is different from ITU-T G.991.1 in that it supports a range of user data rates from 192-2312 kbit/s over a single twisted copper wire pair, while ITU-T G.991.1 supports only 2048 and 1544 kbit/s user data. The transmission technologies are also different in that ITU-T G.991.2 employs trellis coded pulse amplitude modulation (TC-PAM), while the 2B1Q and CAP line codes are specified in ITU-T G.991.1.

ITU-T G.992.3 (ADSL2) and ITU-T G.992.4 (splitterless ADSL2) are second generation versions of ITU-T G.992.1 and ITU-T G.992.2 respectively. ITU-T G.992.5 (ADSL2plus) is an extended bandwidth version of ITU-T G.992.3. The ITU-T G.992.1 systems support a minimum of 8 Mbit/s downstream and 800 kbit/s upstream data rate. In the case of ITU-T G.992.2, systems support a maximum of 1.536 Mbit/s downstream and 512 kbit/s upstream data rate. The ITU-T G.992.5 systems support a minimum of 16 Mbit/s downstream and 800 kbit/s upstream data rate. The data rates for ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5 are asymmetrical. ITU-T G.992.5 has higher downstream to upstream asymmetry ratio than ITU-T G.992.3, which has a higher downstream to upstream asymmetry ratio than ITU-T G.992.4. ITU-T G.992.3 and ITU-T G.992.5 may be used for both business and home applications. The large downstream bandwidth in ITU-T G.992.3 is suitable for facilitating some of the IPTV broadcast applications, where ITU-T G.992.5 is suitable for facilitating multichannel IPTV. The main focus of ITU-T G.992.4 is simplified installations. It is suitable for high speed Internet Access when compared to the voiceband data transmission. ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5 use the same DMT line code principles.

For service flexibility, central office implementations may choose to include one or more than one DSL scheme as specified in ITU-T G.992.x-series Recommendations, or elsewhere. Details of these implementations, whether in hardware or software, are beyond the scope of these Recommendations.

Recommendations ITU-T G.991.x and G.992.x facilitate transmission of digital data over the copper pair. ITU-T G.993.1 (VDSL) provides for transceivers that may support both asymmetric and symmetric operations at much higher data rates when compared to ITU-T G.991x for symmetric date rates and ITU-T G.992x for asymmetric data rates. The ITU-T G.993.2 (VDSL2) is a second generation version of ITU-T G.993.1. In the fibre-to-the-exchange (FTTEx) type of deployment, ITU-T G.993.x transceivers would provide less loop plant coverage than the ITU-T G.991.x and ITU-T G.992.x transceivers. The coverage can however be increased using the fibre-to-the-cabinet (FTTCab) type of deployment. ITU-T G.993.x based transceivers would be able to coexist with underlying narrow-band POTS or ISDN services, as is the case with ITU-T G.992.x. The network operators would also be able to choose to provide VDSL2 on access lines without any narrow-band services. Recommendation ITU-T G.993.2 defines various profiles to allow vendors to limit implementation complexity and develop implementations that target specific service requirements. The eight VDSL2 profiles are commonly referred to as 8a, 8b, 8c, 8d, 12a, 12b, 17a, and 30a. The 8a, 8b, 8c, 8d profiles define a minimum aggregate of downstream and upstream data rates of 50 Mbit/s, where the 12a, 12b, 17a, and 30a profiles define a minimum aggregate of 68, 100 and 200 Mbit/s respectively. Actual data rates will be up to these values, depending on loop characteristics and noise conditions.

ITU-T G.994.1 provides a common mode of automatic selection and operation of the ITU-T G.991.2, ITU-T G.992.x, and ITU-T G.993.x equipment. ITU-T G.994.1 messages signals and procedures take place before those signals are exchanged which are specific to a particular DSL Recommendation. The use of ITU-T G.994.1 is an integral part of the ITU-T G.991.2, ITU-T G.992.x and ITU-T G.993.x. ITU-T G.991.1 does not support ITU-T G.994.1. ITU-T G.994.1 is expected to be used in future ITU-T Recommendations on DSL and the future revision of current Recommendations. ITU-T G.994.1 has no implications for ITU-T G.997.1 and ITU-T G.996.1.

ITU-T G.996.1 provides a common resource of test procedures, loop specifications and noise models to facilitate the performance testing of the G.99x-series Recommendations. Both ITU-T G.992.1 and ITU-T G.992.2 use the test procedures, loop specifications and noise models in ITU-T G.996.1 when the performance requirements are specified. ITU-T G.991.1 is self-contained in this regard. More recently, their performance requirements are specified in Technical Reports of the Broadband Forum (e.g., TR-100, TR-105, TR-114, and TR-115).

6 The reference configuration for ITU-T G.99x-series Recommendations

Two generic reference configurations are used to relate the ITU-T G.99x-series Recommendations. First reference configuration is based on the reference configuration used for the N-ISDN in ITU-T I.410 and described in 6.1. The other reference configuration is a protocol reference configuration to provide a view of the ITU-T G.99x-series Recommendations from the protocol architecture point of view and is described in clause 6.2.

6.1 Generic reference configuration

Figure 6-1 depicts a generic reference configuration for a generic xDSL system based on the reference configuration used for N-ISDN in ITU-T I.411.

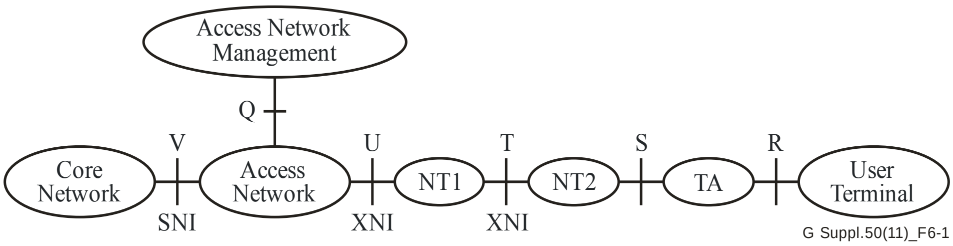


Figure 6-1 – A reference configuration for a generic ITU-T G.99x system

This reference configuration identifies the reference points in the context of access network.

The generic reference configuration consists of seven elements:

1) Core network.
2) Access network.
3) Network termination 1 (NT1).
4) Network termination 2 (NT2).
5) Terminal adapter (TA).
6) User terminal.
7) Access network management.

Core network and access networks are separated at the V interface. The access network management element depicts the management functionalities. The access network and the access network management elements are separated at the Q reference point. The NT1 makes a physical connection to the access network at the U reference point, and provides service presentation to a customer on a logical or physical interface at the T reference point. The NT1 terminates the access digital section of the broadband connection allowing management and performance monitoring. An NT1 may not terminate the transport protocol (e.g., ATM) for user traffic, but may implement transport protocol functions such as rate adaptation required to support different T/U reference point/interface characteristics. An NT2 connects to the network at the T reference point, may connect to multiple user terminals on S reference point interfaces. The NT2 terminates the transport protocol (e.g., ATM) for user traffic, and may implement switching/routing functions. The NT2 may be integrated with an NT1 to form an NT1/2. The NT term is used for generic network termination for various services. For some services it could be part of the access network, and for others not. The inclusion of the NT in the access network and vice versa does not necessarily imply the ownership. A TA adapts the transport protocol to the specific requirements of a user terminal.

One or more of the elements in the reference configuration may be null in some scenarios; therefore, one or more of these reference points may be merged. The reference points may also correspond to the functional interfaces, although, existence of a physical interface is not implied. Some of these reference point/interface are the subject of ITU-T G.99x-series Recommendations, whether by inclusion or by reference to other Recommendations or specifications. When two or more functional groupings are present in a real device, the interface between them need not be exposed, even if it is the subject of these Recommendations.

There may be more than one interface specification for each of these reference points. The exact interpretation at these reference points will depend upon the local network architecture and regulatory environment.

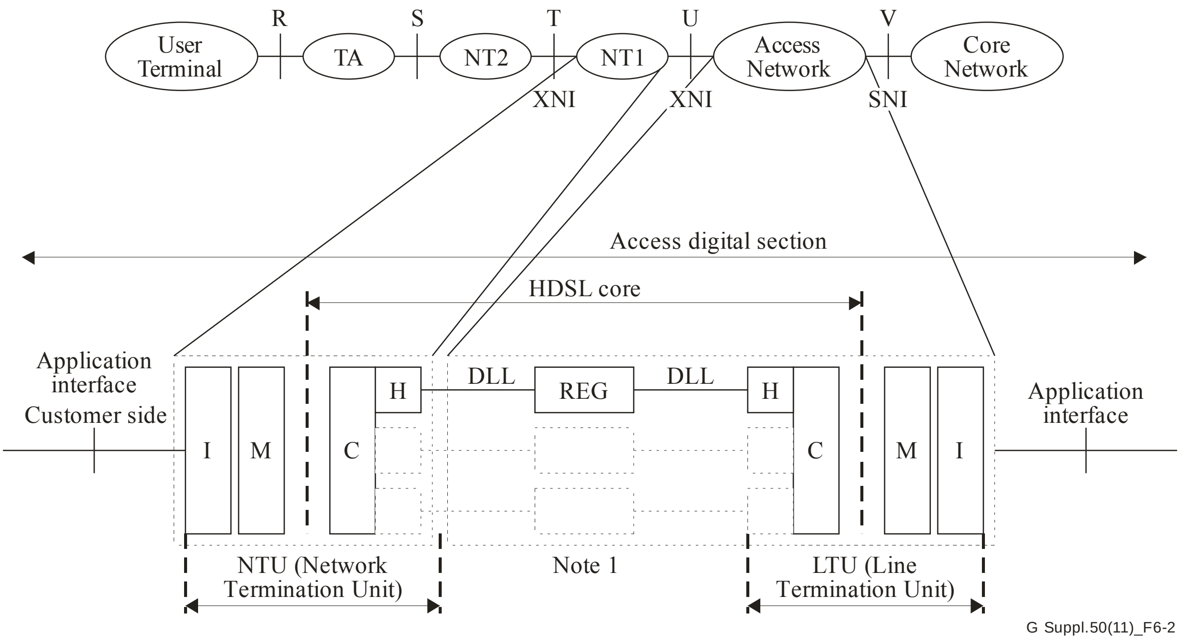
The reference configurations in this clause show abstract functional groupings, which may or may not correspond to real devices. Real devices may comprise one abstract functional grouping, more than one abstract functional grouping or a portion of an abstract functional grouping.

6.1.1 Relation of the generic reference configuration to the ITU-T G.99x-series Recommendations

The reference models of the ITU-T Recommendations on DSL may be viewed with respect to the generic reference configuration described in clause 6.1.

6.1.1.1 Relation with ITU-T G.991.1

Figure 6-2 illustrates the ITU-T G.991.1 system reference model aligned with the reference configuration shown in Figure 6-1.



Description of functional blocks:

C Common circuitry
H HDSL transceiver
I Interface
M Mapping
REG Regenerator
DLL Digital Local Line

NOTE 1 – A fully equipped HDSL core consists of one, two or three H, REG and DLL combinations depending on ITU-T G.991.1 data retransmission rate.
NOTE 2 – REGs are optional.

Figure 6-2 – ITU-T G.991.1 system reference model and its alignment with the generic reference configuration

An access digital section which uses HDSL technology can be considered as a number of functional blocks as shown in Figure 6-2. Depending upon the HDSL transceiver (H) transmission rate, a fully equipped HDSL core consists of one 2320 kbit/s, two 1168 kbit/s or two or three 784 kbit/s HDSL transceiver pairs connected by digital local lines (DLLs) (which are linked by some common circuitry (C)). The HDSL core is application independent. Operation with a non-fully equipped HDSL core is also permitted.

If enhanced transmission range is required the HDSL core may contain optional regenerators (REGs). The regenerator may be inserted at any convenient intermediate point in the HDSL core with the appropriate insertion loss consideration. In addition there may be further restrictions in line length due to power feeding.

An application is defined by the interface (I) and mapping and maintenance (M) functionalities.

The functionalities at the exchange side constitute the line termination unit (LTU) and act as master to the (slave) customer-side functionalities, which collectively form the network termination unit (NTU) and the REGs where applicable.

While aligning the HDSL functional model with the generic reference configuration, the access network comprises the line termination unit and the loop plant including the repeaters. The NT1 comprises the HDSL network termination unit with the functionality described above.

6.1.1.2 Relation with ITU-T G.991.2

Figure 6-3 illustrates the ITU-T G.991.2 system reference model aligned with the reference configuration shown in Figure 6-1.

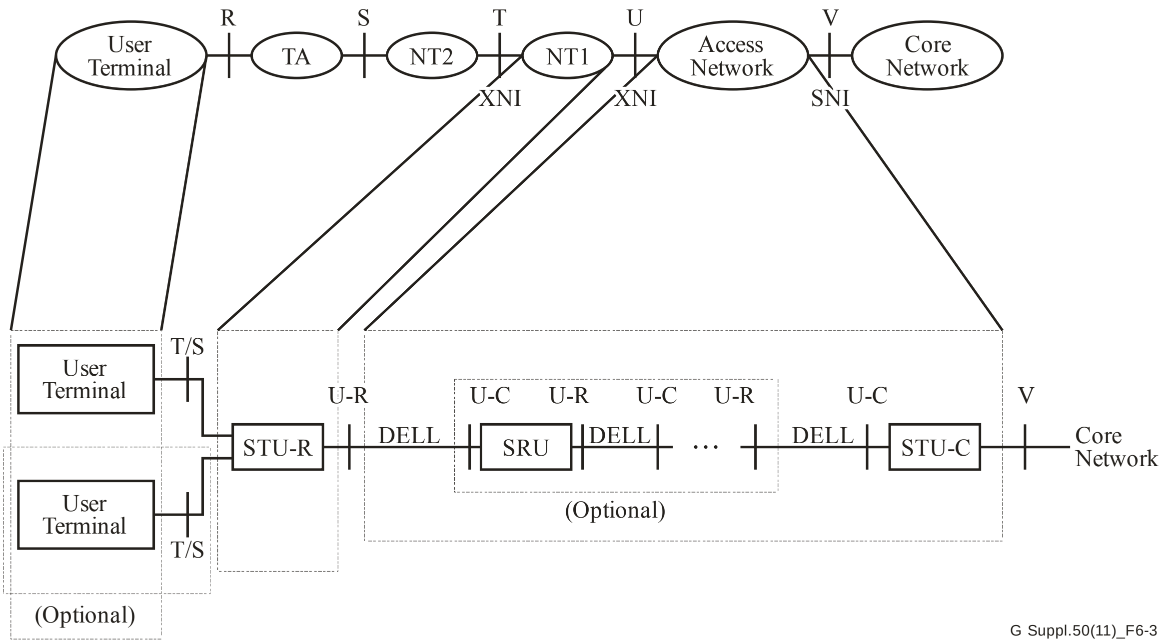


Figure 6-3 – ITU-T G.991.2 system reference model and its alignment with the generic reference configuration

The ITU-T G.991.2 system reference model shows the functional blocks necessary to illustrate an SHDSL transmission system. When aligned with the reference configuration, the core network functionalities, which are not shown here, include central office equipment connected to the access network through V interface. The access network comprises DLL, SHDSL repeater units (SRU) and the STU-C. The connection between STU-R and STU-C may optionally contain one or more SHDSL signal regenerators (SRUs). The connections to the DLLs that interconnect STUs and SRUs are designated U reference points. For each STU-x and SRU, the network side connection is termed the U-R interface and the customer side connection is termed the U-C interface. The STU-C typically connects to a central office equipment at the V reference point. The NT1 comprises the STU-R functions. Alternatively, the NT2, terminal adapter and user terminal may share some or all of the NT1 functionalities. An STU-R will typically connect to one or more user terminals, which may include data terminals, subtended telecommunications equipment, or other devices. These pieces of terminal equipment are connected to the access network through T/S reference points.

6.1.1.3 Relation with ITU-T G.992.1

Figure 6-4 illustrates the ITU-T G.992.1 system reference model aligned with the reference configuration shown in Figure 6-1.

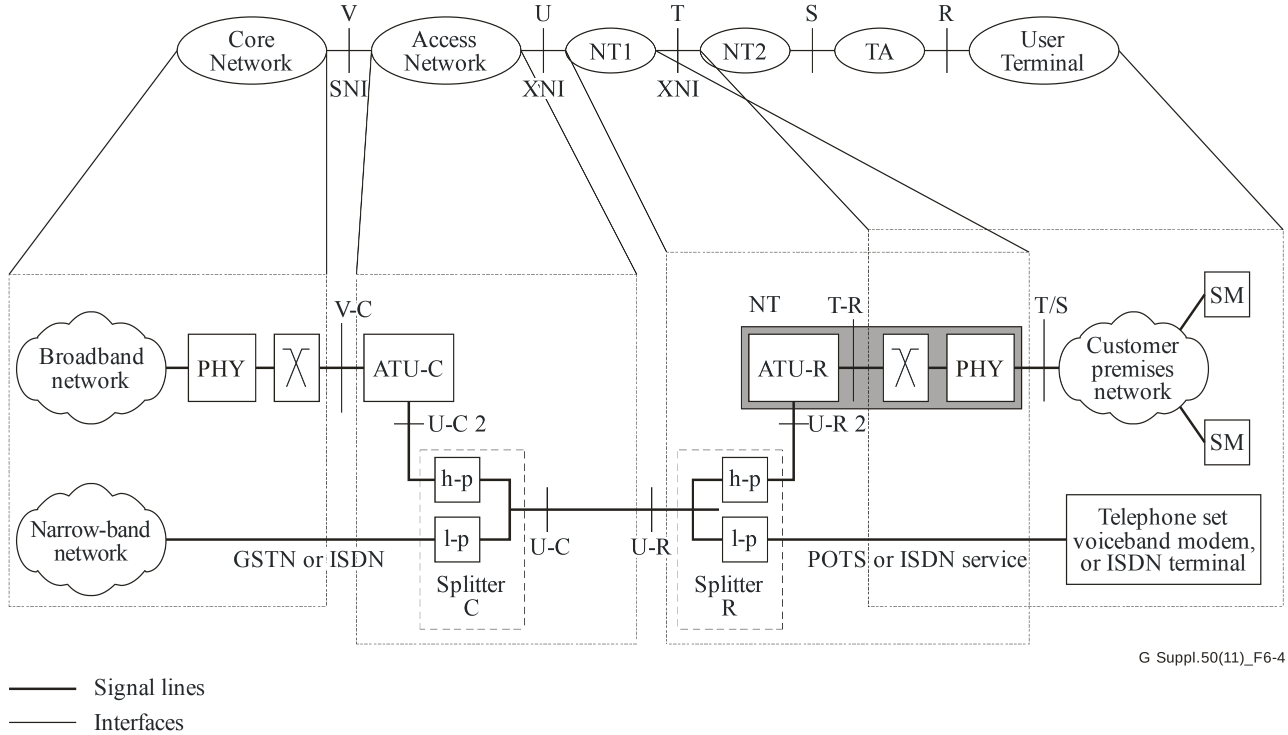


Figure 6-4 – ITU-T G.992.1 system reference model and its alignment with the generic reference configuration

The ITU-T G.992.1 system reference model shows the functional blocks necessary to illustrate an ADSL transmission system. With reference to the alignment with the generic reference configuration, the core network may contain the following functions:

1) Concentrator and/or switch.
2) Interface to the broadband and narrow-band network.

The ADSL access network consists of the following:

1) ADSL transceiver unit-central office end (ATU-C).
2) POTS splitter to separate the POTS and ADSL channels.
3) Copper loop plant.

The ADSL-NT1 may consist of the following functions:

1) ADSL transceiver unit-remote terminal end (ATU-R).
2) Multiplexer/Demultiplexer.
3) Higher layer functions.
4) Interface to the user terminal or a home network.

The ADSL-NT2, the terminal adapter and the user terminal may share some or all of the NT1 functionalities.

In ITU-T G.992.1, interfaces are defined at the V, U and T reference points namely U-C, U-R, V-C and T-R interfaces.

The U-C and U-R interfaces are fully defined in ITU-T G.992.1. Due to the asymmetry of the signals on the line, the transmitted signals are distinctly specified at the U-R and U-C reference points.

The V-C and T-R interfaces are defined only in terms of logical functions. The V-C interface may consist of interfaces to one or more (STM or ATM) switching systems. Implementation of the V-C and T-R interfaces is optional when interfacing elements are integrated into a common element. One or other of the high-pass filters, which are part of the splitters, may be integrated into either of the ATU-C or ATU-R; if so, then the U-C2 and U-R2 interfaces become the same as the U-C and U-R interfaces, respectively. A digital carrier facility (e.g., SONET/SDH extension) may be interposed at the V-C.

The T/S interface is not defined in ITU-T G.992.1. The nature of the customer installation distribution and customer premise network may be varied, e.g., bus or star, or type of media. Therefore, more than one type of T-R interface may be used, and more than one type of T/S interface may be provided from an ADSL NT (e.g., NT1 or NT2 types of functionalities).

6.1.1.4 Relation with ITU-T G.992.2

Figure 6-5 illustrates the ITU-T G.992.2 system reference model aligned with the reference configuration shown in Figure 6-1.

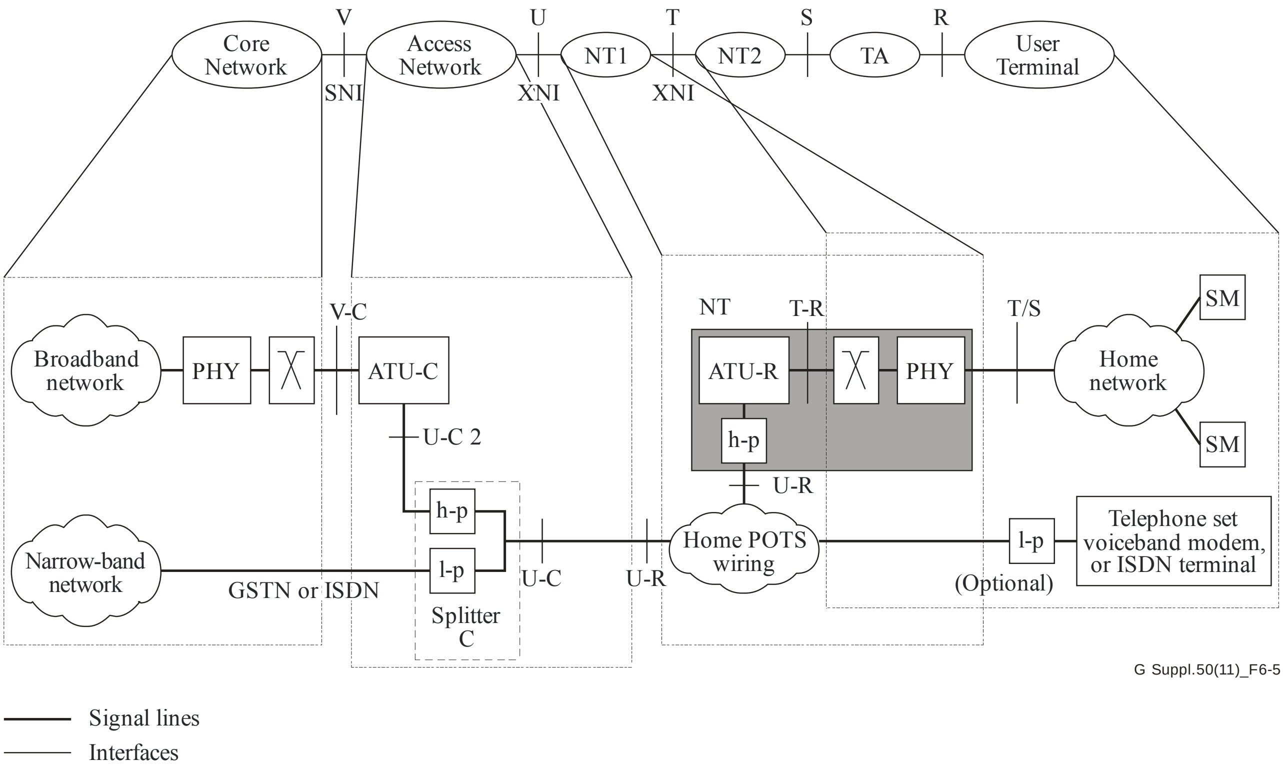


Figure 6-5 – ITU-T G.992.2 system reference model and its alignment with the generic reference configuration

The ITU-T G.992.2 system reference model shows the functional blocks useful to illustrate an ITU-T G.992.2 transmission system. When comparing Figure 6-5 to the Figure 6-4 in clause 6.1.1.3, it may be observed that the main difference in the system reference model pertains to the absence of a separate POTS splitter functionality. The POTS splitter functionalities have now been distributed. The high pass filter functionality has been shown integrated in the NT1 and an optional low pass filter is depicted next to the POTS, ISDN or user terminal. This does not preclude the use of ITU-T G.992.2 transmission system with splitter, as shown in ITU-T G.992.1. The U-R2 interface does not exist in ITU-T G.992.2. The remaining discussion of clause 6.1.1.3 also applies here.

6.1.1.5 Relation with ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5

The application models for ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5 are based upon the generic reference configuration described in Figure 6-1. Two generic application models for ITU-T G.992.3, ITU-T G.992.4 and ITU-T G.992.5 exist. The application model for remote deployment with splitter is shown in Figure 6-6.

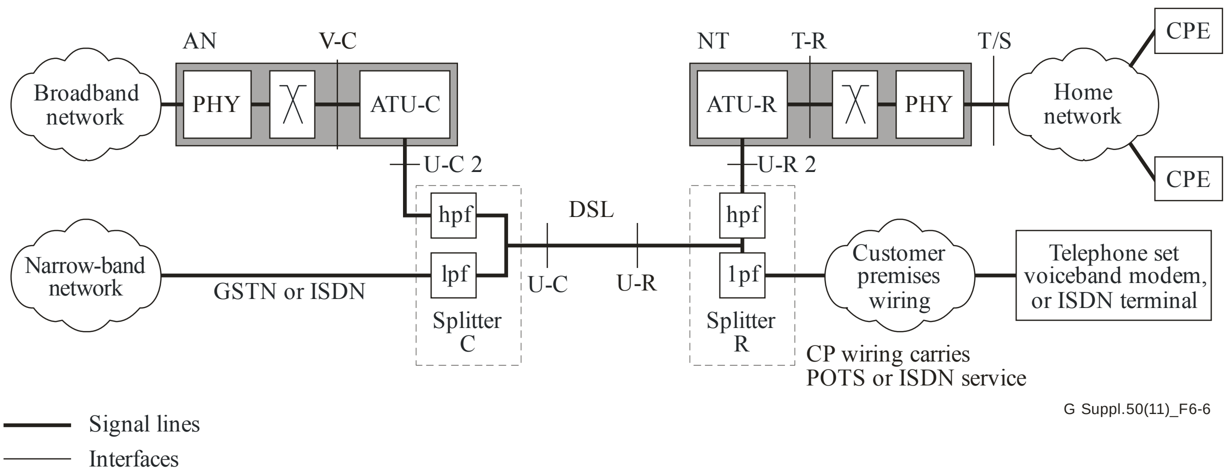


Figure 6-6 – Generic application reference model for remote deployment with splitter

The application model for splitterless remote deployment is shown in Figure 6-7. This application model is intended to be used more prevalently with ITU-T G.992.4. An optional low-pass filter may be included to provide isolation and protection of telephone sets, voiceband modems, ISDN terminals and the ATU-R. The location of filters in all application model diagrams is intended to be functional only. The specific functions of the filter may be regionally specific. The filter may be implemented in a variety of ways, including splitters, in-line filters, integrated filters with ATU devices, and integrated filters with voice equipment.

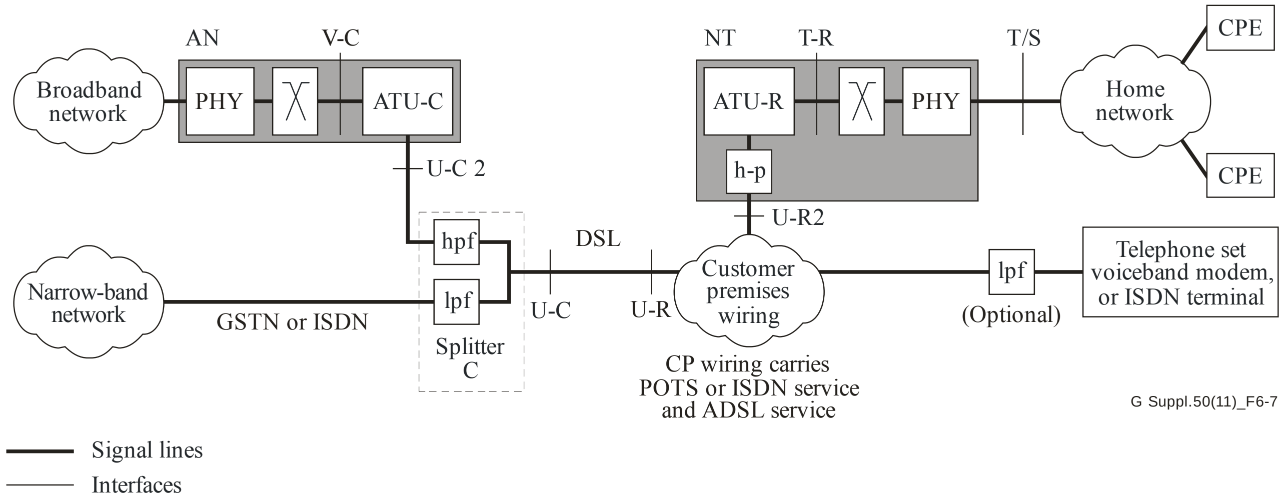


Figure 6-7 – Generic application reference model for splitterless remote deployment

6.1.1.6 Relation with ITU-T G.993.1

Figure 6-8 illustrates the ITU-T G.993.1 system reference model aligned with the reference configuration shown in Figure 6-1.

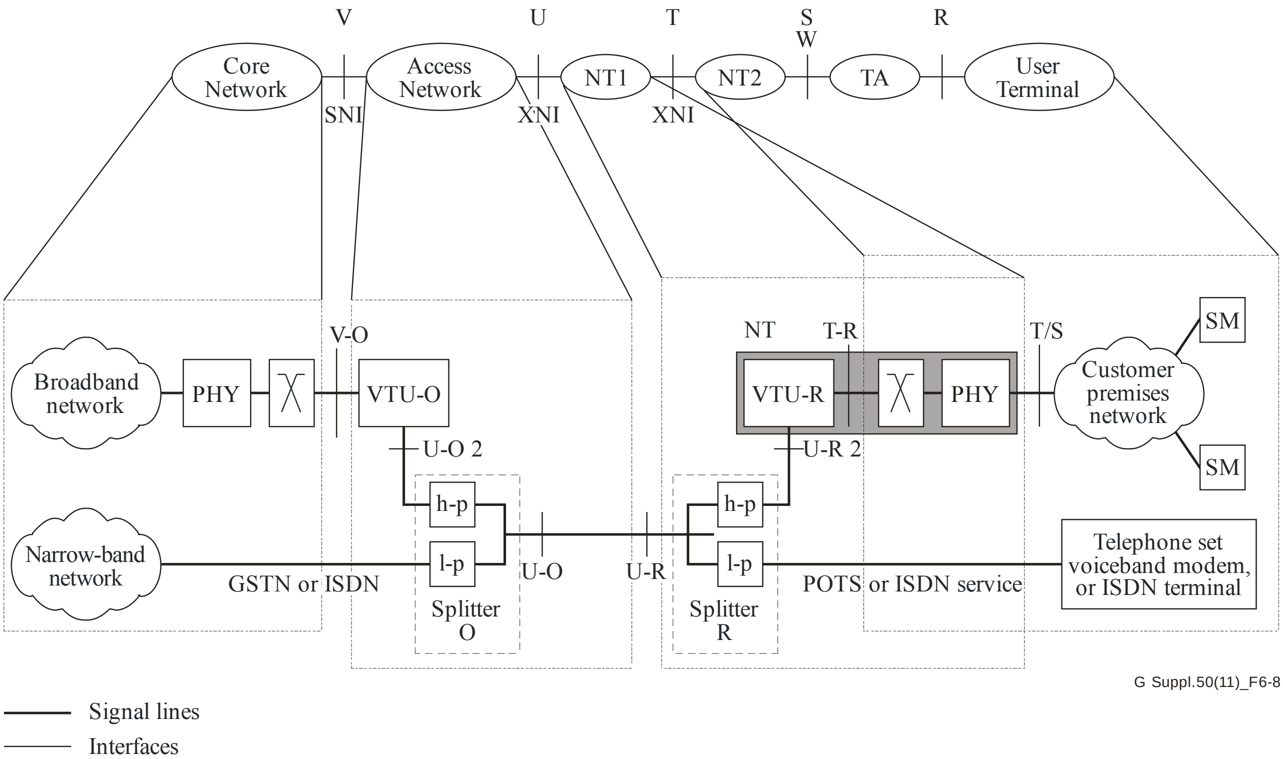


Figure 6-8 – ITU-T G.993.1 system reference model and its alignment with the generic reference configuration

The ITU-T G.993.1 system reference model shows the functional blocks necessary to illustrate a VDSL transmission system. With reference to the alignment with the generic reference configuration, the core network may contain the following functions:

– concentrator and/or switch;

– interface to the broadband and narrow-band network.

The VDSL access network consists of the following:

- VDSL Transceiver Unit-ONU (VTU-O);
- POTS splitter to separate the POTS and VDSL channels;
- copper loop plant.

The VDSL-NT1 may consist of the following functions:

- VDSL Transceiver Unit – Remote Terminal end (VTU-R);
- multiplexer/Demultiplexer;
- higher layer functions;
- interface to the user terminal or a home network.

The VDSL-NT2, the terminal adapter and the user terminal may share some or all of the NT1 functionalities.

In ITU-T G.993.1, interfaces are defined at the V, U and T reference points namely U-O, U-R, V-O, and T-R interfaces.

The U-O and U-R interfaces are fully defined in ITU-T G.993.1. Due to the potential asymmetry of the signals on the line, the transmitted signals are distinctly specified at the U-R and U-O reference points.

The V-O and T-R interfaces are defined only in terms of logical functions. The V-O interface may consist of interfaces to one or more (PTM or ATM) switching systems. Implementation of the V-O and T-R interfaces is optional when interfacing elements are integrated into a common element. One or other of the high-pass filters, which are part of the splitters, may be integrated into either of the VTU-O or VTU-R; if so, then the U-O2 and U-R2 interfaces become the same as the U-O and U-R interfaces, respectively.

The T/S interface is not defined in ITU-T G.993.1. The nature of the customer installation distribution and customer premises network may be varied, e.g., bus or star, or type of media. Therefore, more than one type of T-R interface may be used, and more than one type of T/S interface may be provided from a VDSL NT (e.g., NT1 or NT2 types of functionalities).

6.1.1.7 Relation with ITU-T G.993.2

The application models for ITU-T G.993.2 are based on the generic reference configuration described in Figure 6-1. There are three separate application models:

- data service only;
- data service with underlying POTS service; and
- data service with underlying ISDN service.

The application reference model for remote deployment with POTS or ISDN service facilitated by a splitter is shown in Figure 6-9. The application model for splitterless remote deployment is shown in Figure 6-10. An optional low-pass filter may be included to provide additional isolation between the VTU-R and narrow-band network CPE such as telephone sets, voiceband modems, or ISDN terminals.

The location of the filters (HPF and LPF) in application models presented in Figures 6-9 and 6-10 is functional only; the physical location and specific characteristics of splitters and the filter may be regionally specific. The filters at the CPE side shown in Figure 6-9 may be implemented in a variety of ways, including splitters, and in-line filters, and filters integrated with VTU devices, and filters integrated with narrow-band network CPE.

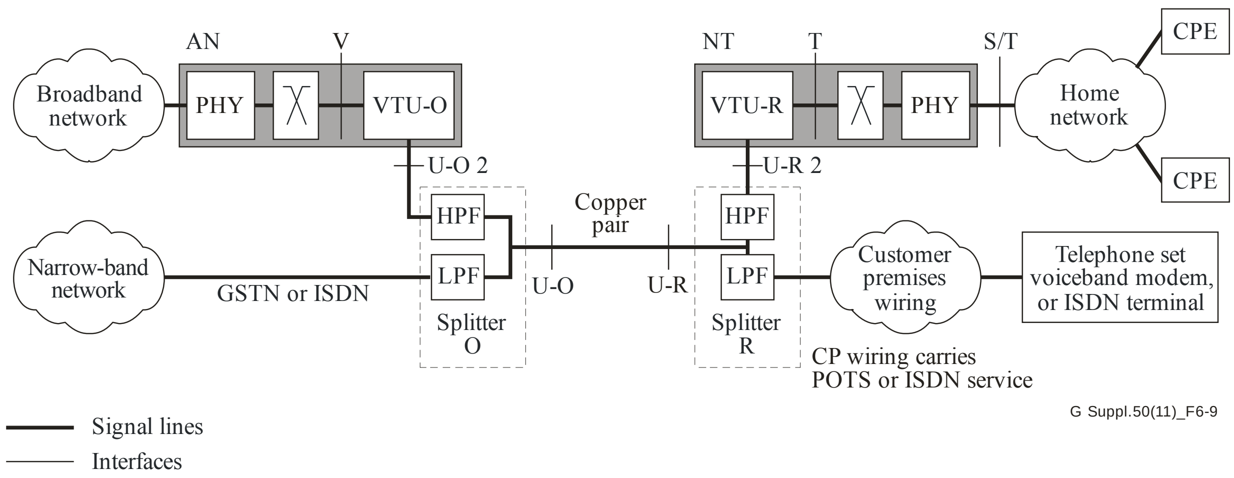


Figure 6-9 – Generic application reference model for remote deployment with splitter

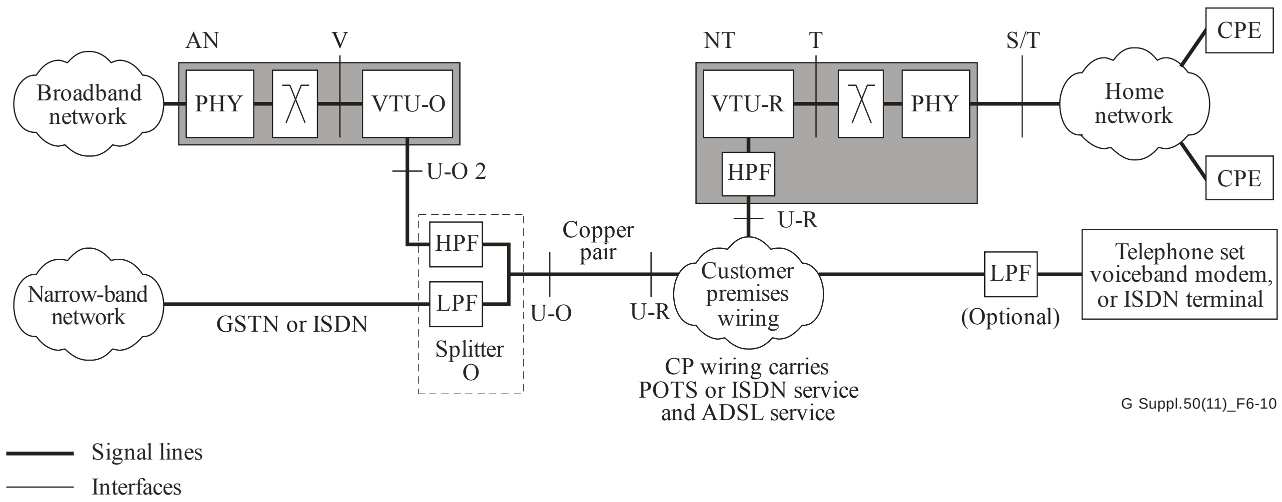


Figure 6-10 – Generic application reference model for splitterless remote deployment

NOTE – VDSL2 operating in the splitterless remote deployment mode is highly likely to suffer severe service impairments due to the topology and uncertain quality of the in-premises wiring. Star topology wiring practices, in particular, will lead to deep notches in the frequency response of the transmission path due to multiple signal reflections. In addition, poor balance, routing close to sources of electrical noise, and exposure to strong radio signals can all lead to high levels of RFI.

6.1.1.8 Relation with ITU-T G.994.1

Figure 6-11 illustrates the ITU-T G.994.1 system reference model aligned with the reference configuration shown in Figure 6-1.

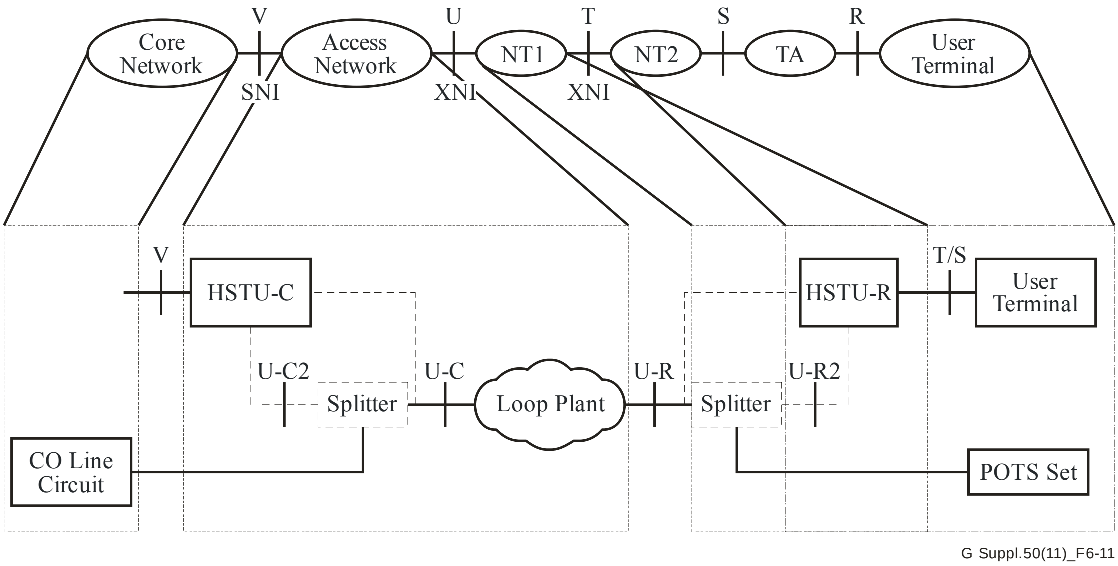


Figure 6-11 – ITU-T G.994.1 system reference model and its alignment with the generic reference configuration

ITU-T G.994.1 system reference model is a simplification of the ITU-T G.992.1 and ITU-T G.992.2 reference model that attempts to identify the necessary functional blocks and the reference points and/or interface points that may be used or have implications in ITU-T G.994.1. The handshake transceiver unit (HSTU) is used to signify that the ITU-T G.994.1 transceiver function is different from ITU-T G.992.1 and ITU-T G.992.2.

When aligned with the reference configuration, the access network comprises the HSTU-C, splitter and the loop plant. The NT1 comprises the splitter and the HSTU-R. Alternatively, the NT1 functionality may just contain the splitter whereas the NT2, TA and user terminal may collectively contain the HSTU-R and other user terminal functionality.

6.1.1.9 Relation with ITU-T G.996.1

Figure 6-12 illustrates the ITU-T G.996.1 system reference model aligned with the reference configuration shown in Figure 6-1.

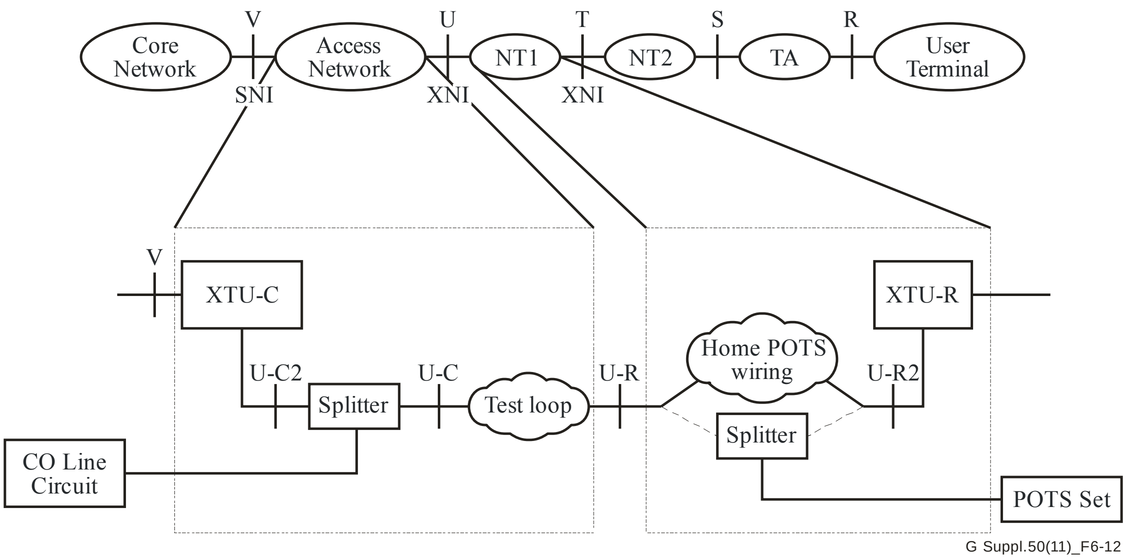


Figure 6-12 – ITU-T G.996.1 system reference model and its alignment with the generic reference configuration

The ITU-T G.996.1 system reference model is a simplified test system version of the ITU-T G.992.1 and ITU-T G.992.2 system reference models to show the general arrangement for testing of the compliant modems. The terminology XTU refers to the fact that this model is to be used for ITU-T G.992.1, ITU-T G.992.2 and also any new future G.99x Recommendations.

The following potential sources of impairment are simulated in a laboratory set-up that includes test loops, test sets, and interference injection equipment, as well as the test system itself:

– crosstalk coupling from other systems;
– background noise;
– impulse noise;
– POTS signalling.

The crosstalk and impulse noise interfering signals are simulations that are derived from a consideration of real loop conditions and measurements. The test procedure is to inject the interference into the test loops and measure the effect on system performance by a bit error test simultaneously run on the system information channels.

When aligned to the reference architecture, only two elements apply to ITU-T G.996.1, i.e., access network and NT1. Access network comprises of the XTU-C, POTS splitter, and test loops. The NT1 comprises of the home POTS wiring or POTS splitter and the XTU-R.

6.1.1.10 Relation with ITU-T G.997.1

Figure 6-13 illustrates the ITU-T G.997.1 system reference model aligned with the reference configuration shown in Figure 6-1.

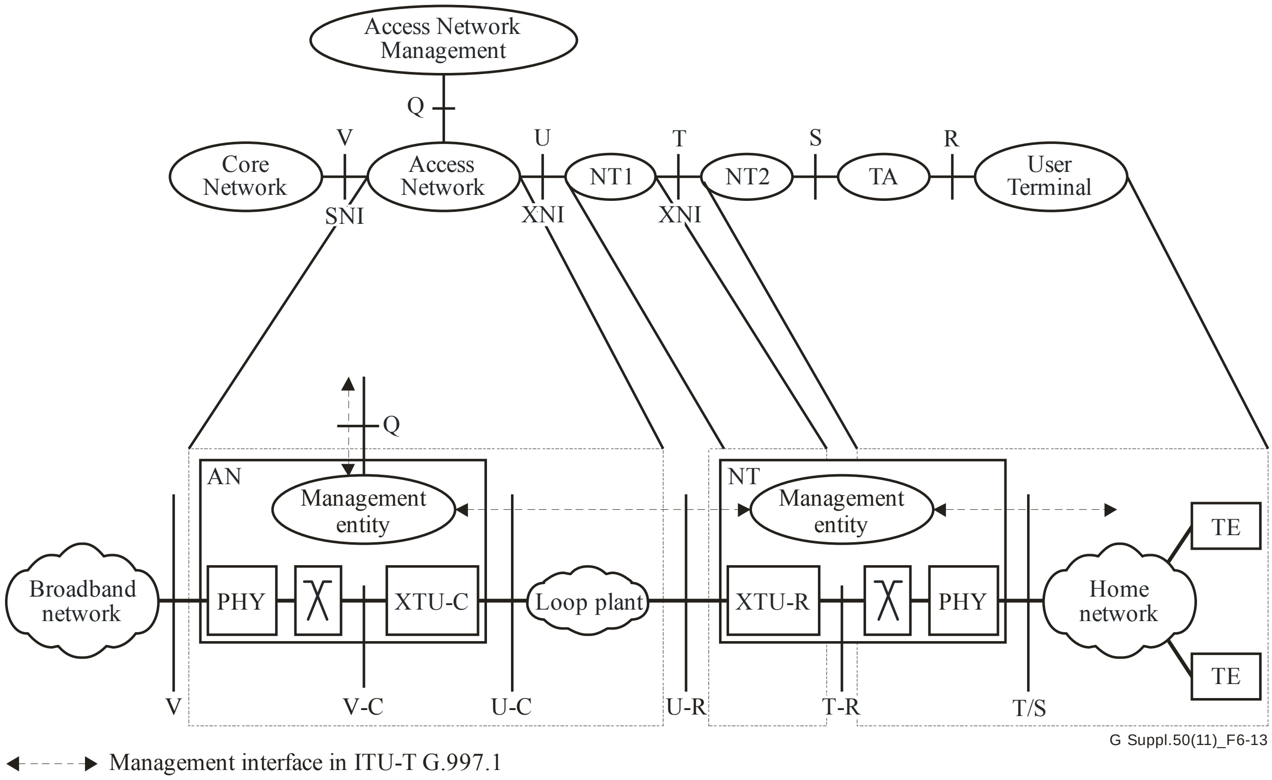


Figure 6-13 – ITU-T G.997.1 system reference model and its alignment with the generic reference configuration

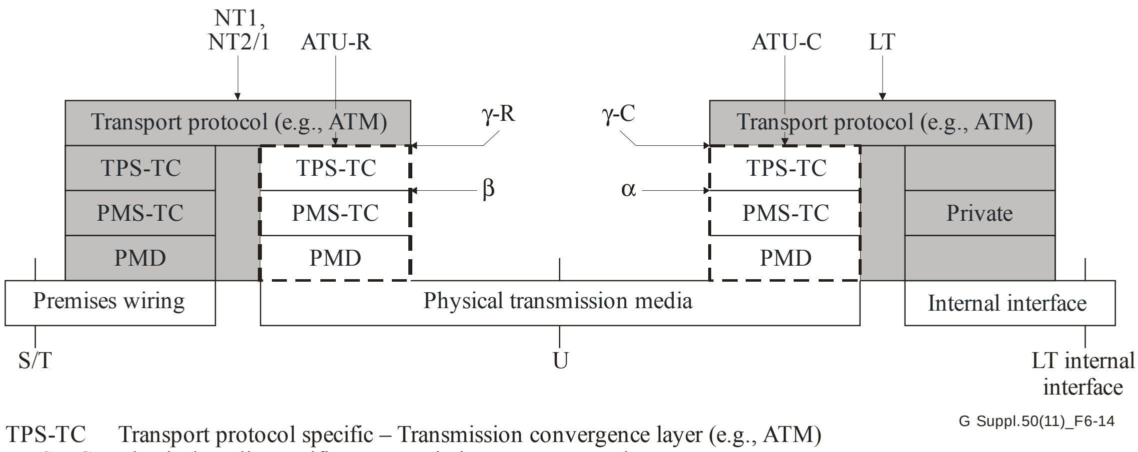
The ITU-T G.997.1 reference model, similar to the ITU-T G.994.1 system reference model, is a simplification of the ITU-T G.992.1/ITU-T G.992.2 reference model that attempts to identify the necessary functional blocks and the reference points and/or interface points. The xDSL transceiver unit (XTU) is used to signify that the ITU-T G.997.1 transceiver function is applicable for both ITU-T G.992.1 and ITU-T G.992.2. A management entity functional block is added in both access node (AN) and the NT to depict the management functionalities. A new reference point Q has been added.

When aligned with the reference configuration, the core network functionalities are the broadband network or other functionalities that are not shown here. The access network comprises AN, and the loop plant. The NT1 comprises the NT functions. Alternatively, the NT1 functionality may just contain the XTU-R whereas the NT2, TA and User terminal may contain the remaining user terminal functionalities.

6.2 Reference layered protocol architecture for ITU-T G.99x Recommendations

In this clause, a reference layered protocol architectural view of the ITU-T G.99x-series Recommendations is presented in user and management planes as appropriate.

Figure 6-14 depicts the user plane protocol reference architecture that may apply in general to ITU-T Recommendations on DSL.



TPS-TC Transport protocol specific – Transmission convergence layer (e.g., ATM)
PMS-TC Physical media specific – Transmission convergence layer
LT Line terminal
γ-R, γ-C xDSL transport protocol reference point (e.g., ADSL T-R, V-C)
α, β Hypothetical application (transport protocol) independent reference points

Figure 6-14 – User plane protocol reference architecture

Both ATU-C and ATU-R are encapsulated in a dashed box and comprise of PMD, TPS-TC and PMS-TC. From the perspective of the OSI layered stack, all of the three may be considered as sublayers of the physical layer.

Line terminal is shown as a shaded box and includes ATU-C. NT1 or combined NT2/1 are also shown dashed and include the ATU-R.

The U, T/S reference points/interfaces are shown here. The V reference point/interface has been shown as an LT internal interface and may not need elaboration as being implementation dependent and private to service providers. On the remote side, T reference point/interface may be assumed if an NT1 is assumed to have implemented the shown layered functions. Under the assumption that both NT1 and NT2 share the shown layered functions, an S reference point/interface may be assumed at the remote side.

Figure 6-15 depicts the user plane protocol layered protocol architecture for both ITU-T G.992.1 and ITU-T G.992.2.

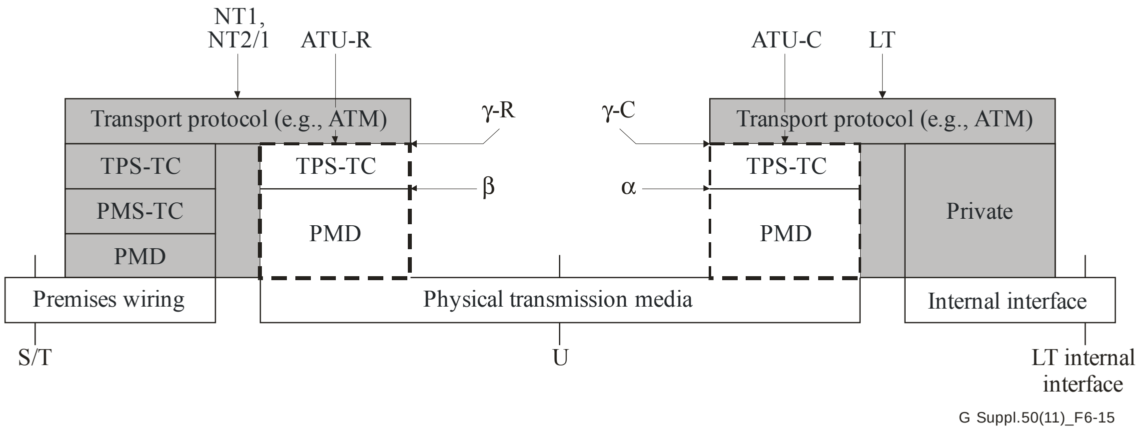


Figure 6-15 – User plane protocol reference architecture for ITU-T G.992.1 and ITU-T G.992.2

Both ITU-T G.992.1 and ITU-T G.992.2 do not clearly define the functional separation between the PMD and PMS-TC sublayers. As a result, the two sublayers are merged into one and is referred to as the PMD sublayer. The term PMD is used in both ITU-T G.992.2 and ITU-T G.992.1.

For ITU-T G.991.1, that contains two line code specifications, Figure 6-16 is an appropriate representation of the layered protocol architecture.

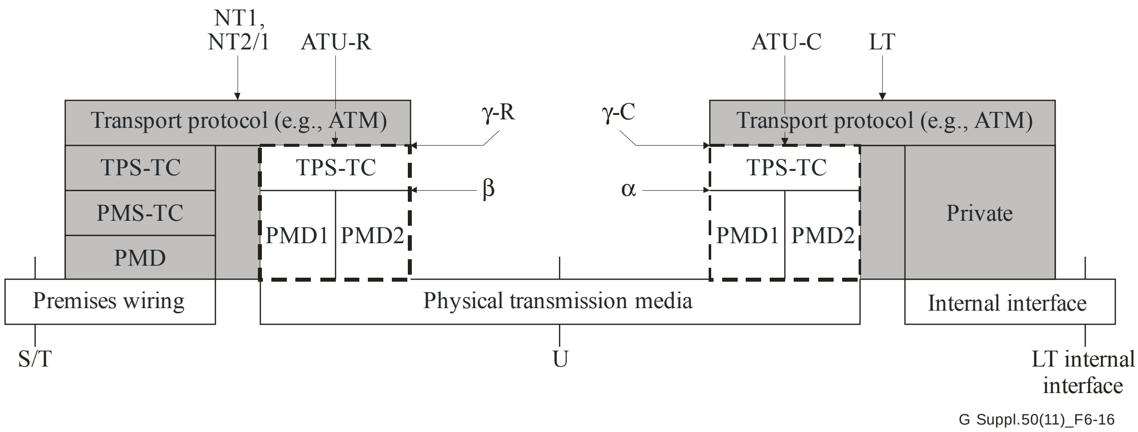


Figure 6-16 – User plane protocol reference architecture for ITU-T G.991.1

Two PMDs are shown to reflect the choice of one of the two line codes.

Figure 6-17 depicts the user plane protocol layered protocol architecture for ITU-T G.991.2.

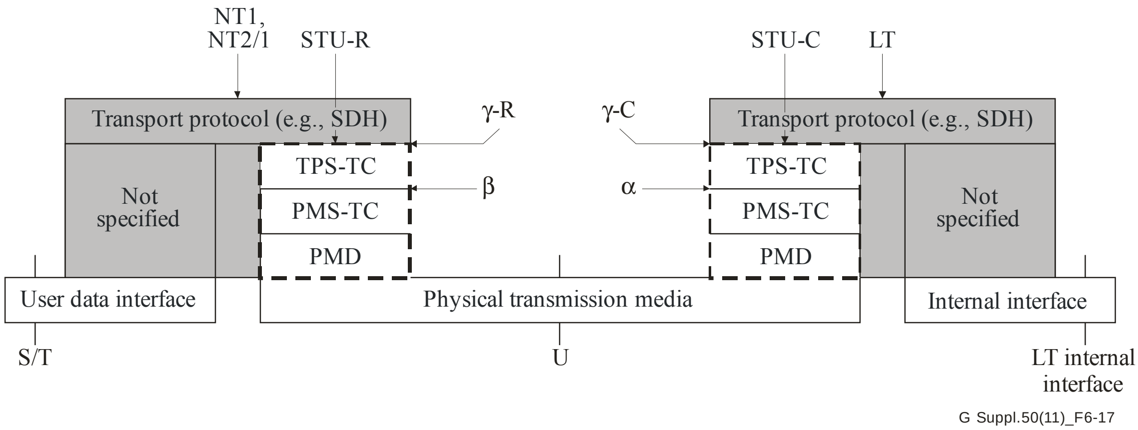


Figure 6-17 – User plane protocol reference architecture for ITU-T G.991.2

The principal functions of the ITU-T G.991.2 PMD layer are symbol timing generation and recovery, coding and decoding, modulation and demodulation, echo cancellation, line equalization, and link activation.

The PMS-TC layer contains the framing and frame synchronization functions, as well as the scrambler and descrambler. The PMS-TC is connected across the α and β interfaces in the STU-C and STU-R, respectively, to the TPS-TC layer. The TPS-TC is application specific and consists largely of the packaging of user data within the SHDSL frame. This may include multiplexing, demultiplexing, and timing alignment of multiple user data channels.

The TPS-TC layer communicates with the interface blocks across the γ_r and γ_c interfaces. Depending upon the specific application, the TPS-TC layer may be required to support one or more channels of user data and associated interfaces. The definition of physical interfaces is beyond the scope of this Recommendation.

The α, β, γ_r, and γ_c interfaces are only intended as logical separations and need not be physically accessible.

Figure 6-18 depicts the user plane protocol layered protocol architecture for ITU-T G.992.3, ITU-T G.992.4, and ITU-T G.992.5. It emphasizes the layered nature of these Recommendations and provides a view that is consistent with the generic xDSL models shown in Figure 6-1.

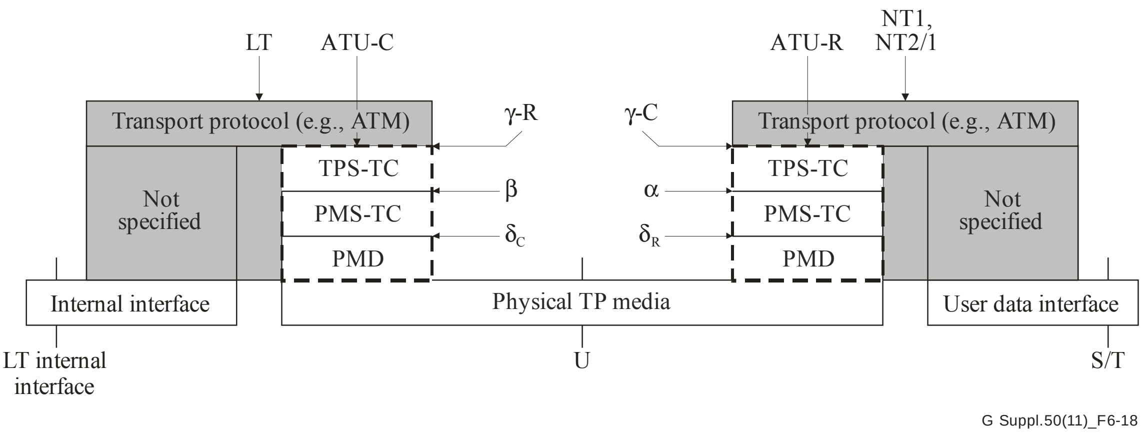


Figure 6-18 – User plane protocol reference architecture for ITU-T G.992.3, ITU-T G.992.4, and ITU-T G.992.5

The user plane protocol reference model for ITU-T G.993.1 and ITU-T G.993.2 is shown in Figure 6-19. The user plane protocol reference model is included to emphasize the layered nature of this Recommendation and to provide a view that is consistent with the generic xDSL protocol reference model shown in Figure 6-1.

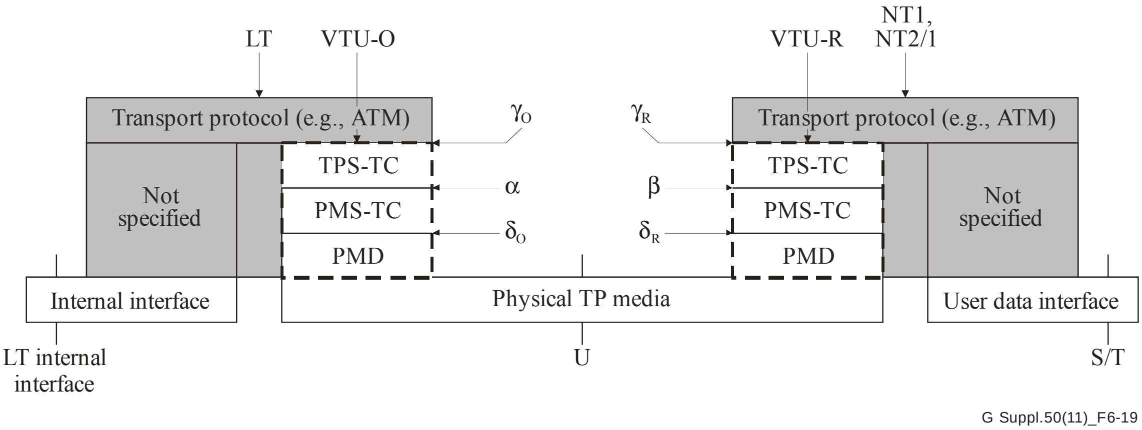


Figure 6-19 – User plane protocol reference model for ITU-T G.993.1 and ITU-T G.993.2

ITU-T G.994.1 may be viewed from the perspective of user plane layered protocol architecture as shown in Figure 6-20.

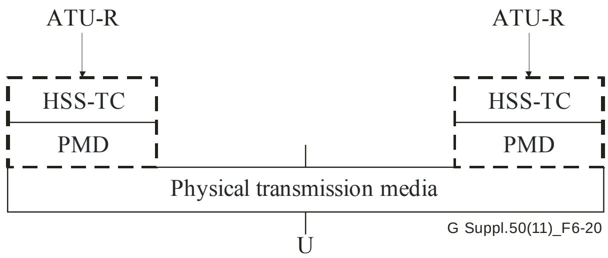


Figure 6-20 – User plane protocol reference architecture for ITU-T G.994.1

The simplicity of Figure 6-20 is reflective of the limited layered protocol architectural scope for ITU-T G.994.1. ITU-T G.994.1 uses a different modulation format and transmissions convergence function when compared to ITU-T G.992.1 or ITU-T G.992.2. Therefore, Figure 6-20 signifies that the PMD function and the "Handshake Specific-Transmission Convergence (HSS-TC)" is not the same as that of ITU-T G.992.1 or ITU-T G.992.2.

As the handshake procedure takes place before the initialization and showtime of ITU-T G.992.1 and ITU-T G.992.2, ITU-T G.994.1 compliant modem may be viewed to have changed its layered protocol architecture from that in Figure 6-13 to that in Figure 6-15 in continuous time.

Figure 6-21 depicts the management plane protocol reference architecture for ITU-T G.99x Recommendations that may be considered appropriate for ITU-T G.997.1.

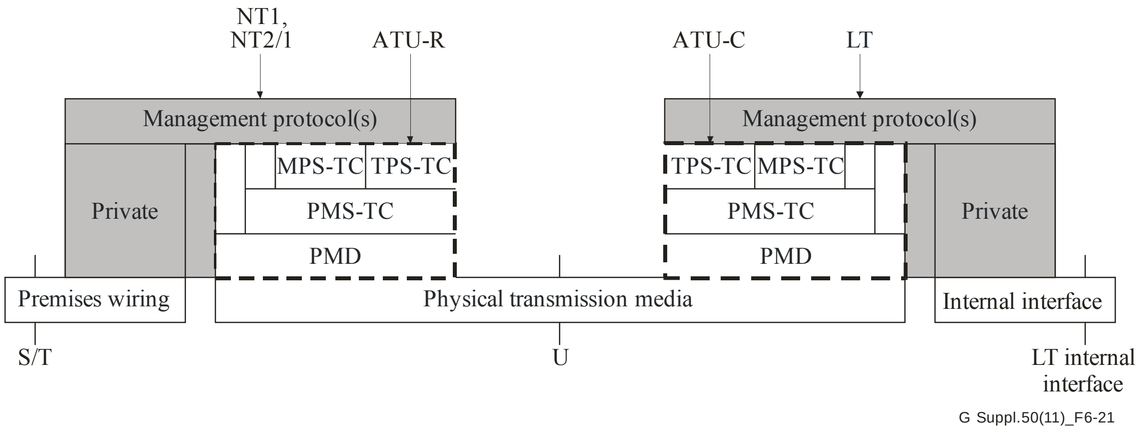


Figure 6-21 – Management plane protocol reference architecture for ITU-T G.99x Recommendations

In Figure 6-21, MPS-TC stands for management protocol specific – transmission convergence. This figure attempts to depict four ways the management plane functions may be implemented by the management protocol. A combination of them may be used in some implementations. It must be noted that management protocol may have direct access to the PMD management functions, or through the PMS-TC (e.g., AOC, EOC), or it may have access through a management protocol specific transmission convergence layer or MPS-TC (e.g., SNMP), or management may be part of the normal user plane functions through TPS-TC (e.g., ATM).

ITU-T G.996.1 need not be viewed from the layered architecture perspective.

7 Illustration of data service using ITU-T Recommendations on DSL

A data-centric connection is described by reference to the ISDN reference configuration and its standard R, S, T, U and V reference points. It includes CPE to ISP connections and by reflection also includes CPE-CPE connections. GII reference points are also shown for comparison.

There are apparently two key network connection options; the customer's terminal or home network can be connected to the public network either via separate network termination (NT1) equipment, by using a network interface card plugged into a terminal equipment incorporating an embedded NT1, or by a "home gateway" incorporating both NT1 and NT2 functionality.

7.1 End-to-end data-centric connection

Figure 7-1 shows the relationship between reference points from the generic reference configuration and equivalent reference points from the ITU-T G.902 GII model in the context of end-to-end data centric reference connection. It illustrates the scope of ITU-T G.992.2 and ITU-T G.992.1 in relation to an overall broadband system reference model.

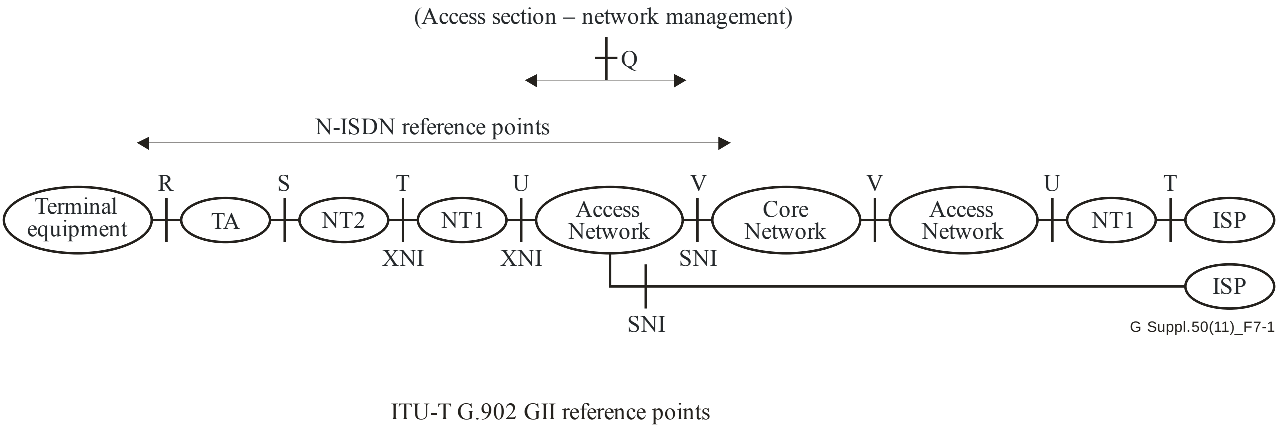


Figure 7-1 – Illustration of a generic xDSL data connection

7.2 Illustration of service presentation options

In the following subclauses several potential service presentation options are described.

7.2.1 Service presentation at the T interface

Service presentation at a T interface is shown in Figure 7-2.

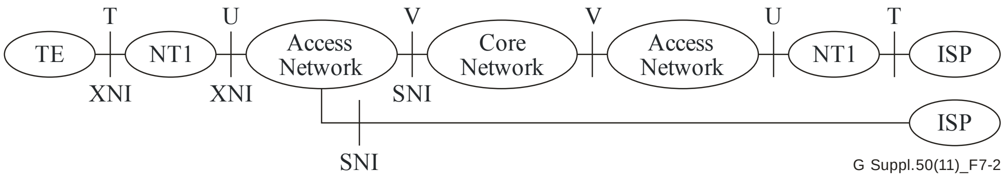


Figure 7-2 – Data service presentation at the T interface

In the case of ITU-T G.992.1, the NT1 may be provided as a separate box owned by the network operator or the customer as in North American and European narrow-band ISDN practice, respectively. The user network interface is expressed at the T reference point on a physical interface. TE may implement NT2 and TA functions for connection to a home network. Figure 7-3 depicts a separate NT1 model for ITU-T G.992.1. The same considerations are valid for ITU-T G.993.1 and for full-splitter deployment of ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.2.

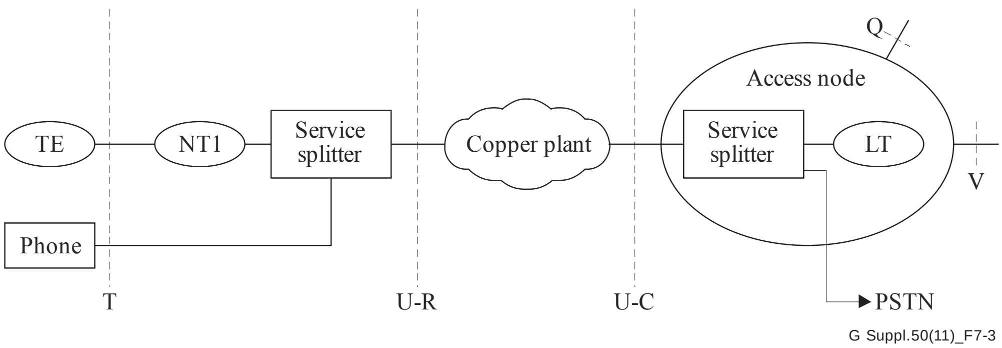


Figure 7-3 – ITU-T G.992.1 data service presentation at the T interface

In the case of ITU-T G.992.2, the above is true except that the service splitter between copper plant and the NT1 is not present, as shown in Figure 7-4. The same considerations are valid for splitterless deployment of ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, and ITU-T G.993.2.

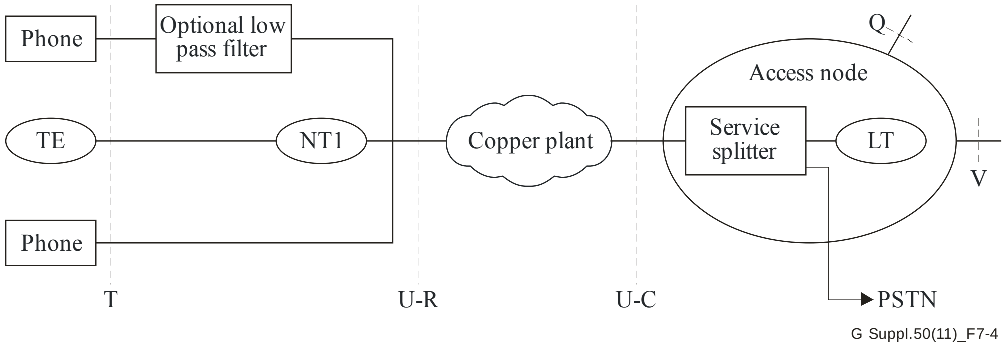


Figure 7-4 – ITU-T G.992.2 data service presentation at the T interface

7.2.2 Service presentation at the U interface

Service presentation at a U interface is shown in Figure 7-5.

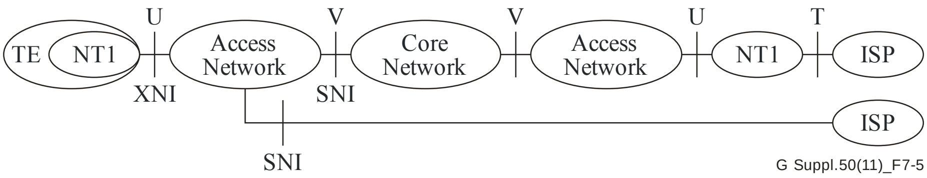


Figure 7-5 – Data service presentation at the U interface

When NT1 is embedded on a TE interface card for ITU-T G.992.1, NT1 may be part of the network operator's access network management domain. The user network interface is expressed physically at the U reference point (equivalent to GII XNI), and logically inside the TE at a hypothetical T reference point. The TE may implement NT2 and/or TA functions. Figure 7-6 depicts an integrated NT1 model for ITU-T G.992.1. The same considerations are valid ITU-T G.993.1 and for full-splitter deployment of ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, and ITU-T G.993.2.

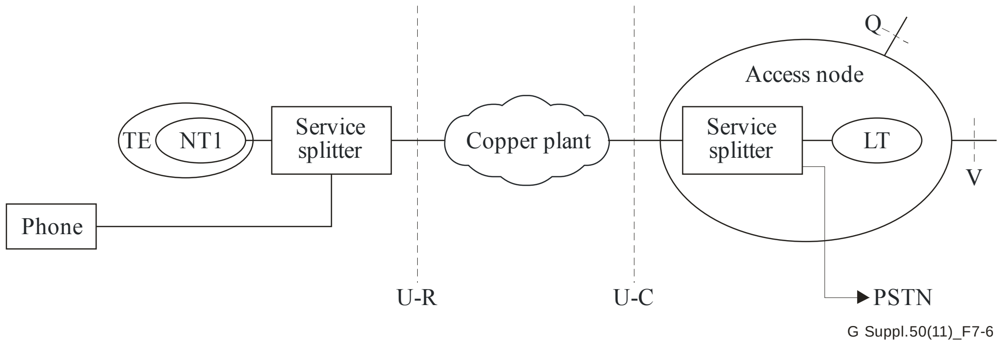


Figure 7-6 – ITU-T G.992.1 data service presentation at the U interface

When NT1 is embedded on a TE interface card for ITU-T G.992.2, NT1 may still be part of the network operator's access network management domain. The user network interface may be expressed physically at the U reference point (equivalent to GII XNI), and logically inside the TE at a hypothetical T reference point. The TE may implement B-NT2 and/or TA functions. Figure 7-7 depicts an integrated NT1 model for ITU-T G.992.2. The same considerations are valid for splitterless deployment of ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.1 and ITU-T G.993.2.

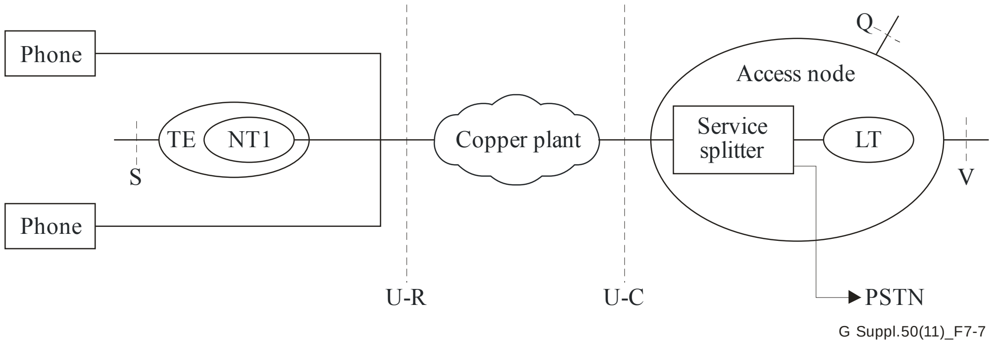


Figure 7-7 – ITU-T G.992.2 data service presentation at the U interface

Other data service presentations are also possible but are not shown here for brevity. The options shown here are for illustration purposes only and are not endorsed for implementation.

8 Glossary of terms in ITU-T Recommendations on DSL

The following terminology is used in the ITU-T Recommendations on DSL:

α	Hypothetical application (transport protocol) independent reference points/interfaces.
β	Hypothetical application (transport protocol) independent reference points/interfaces.
γ-C	ADSL transport protocol reference point (e.g., ADSL T-R, V-C).
γ-C	VDSL transport protocol reference point (e.g., VDSL T-R, V-C).
γ-R	xDSL transport protocol reference point (e.g., ADSL T-R, V-C).
ADSL system overhead	All overhead needed for system control, including crc, eoc, aoc synchronization bytes, fixed indicator bits for OAM, and FEC; that is, the difference between total data rate and net data rate.
Aggregate data rate	Data rate transmitted by an ADSL system in any one direction; it includes both net data rate and data rate overhead used by the system for crc, eoc, synchronization of the various bearer channels, and fixed indicator bits for OAM; it does not include FEC redundancy.
AS0	The ADSL data channel from the ATU-C to the ATU-R.
Bearer channel	A user data stream of a specified data rate that is transported transparently by an ADSL(2) or VDSL(2) system.
Bridged taps	Sections of unterminated twisted-pair cables connected in parallel across the cable under consideration.
Category I	Basic category of ADSL transceivers with no performance-enhancing options, which meet a basic set of performance requirements.
Category II	Category of ADSL transceivers with performance-enhancing options which meet an expanded set of performance requirements.
Channelization	Allocation of the net data rate to bearer channels.
Data Frame	A frame of bytes that compose part of the superframe.

DMT symbol	A set of complex values $\{Z_I\}$ forming the frequency domain inputs to the inverse discrete Fourier transform (IDFT). The DMT symbol is equivalently the set of real valued time samples, $\{x_n\}$, related to the set of $\{Z_I\}$ via the IDFT.
Data symbol rate	The net average rate (after allowing for the overhead of the synchronization symbol) at which symbols carrying user data are transmitted (= 4 kbaud for ITU-T G.992x).
Downstream	ATU-C to ATU-R direction, VTU-O to VTU-R direction.
ITU-T Recommendations on DSL	The family of ITU-T Recommendations : ITU-T G.991.1, ITU-T G.991.2, ITU-T G.992.1, ITU-T G.992.2, ITU-T G.992.3, ITU-T G.992.4, ITU-T G.992.5, ITU-T G.993.1, ITU-T G.993.2, ITU-T G.993.5, ITU-T G.994.1, ITU-T G.995.1, ITU-T G.996.1, ITU-T G.996.2, ITU-T G.997.1, ITU-T G.998.1, ITU-T G.998.2, ITU-T G.998.3, ITU-T G.998.4 and ITU-T G.999.1.
Dual latency	Simultaneous transport of multiple data bearer channels in any one direction, in which user data is allocated to both the fast and interleaved paths; that is for ADSL, $\text{sum}(B_f) > 0$ and $\text{sum}(B_i) > 0$.
FEC output frame	A frame of data presented to the constellation encoder after Reed Solomon encoding.
Indicator bits	Bits used for OAM purposes; embedded in the synchronization bytes.
Initiating signal	A signal that initiates an ITU-T G.994.1 transaction.
Initiating station	The station that initiates an ITU-T G.994.1 transaction.
Loading coils	Inductors placed in series with the cable at regular intervals in order to improve the voiceband response; removed for DSL use.
LS0	The ADSL data channel from the ATU-R to the ATU-C.
Message	Framed information conveyed via modulated transmission.
Net data rate	Data rate that is available for user data in any one direction; for the downstream direction this is the sum of the net simplex and duplex data rates.
Responding signal	Responding signal: A signal that is sent in response to an initiating signal.
Responding station	Responding station: The station that responds to initiation of an ITU-T G.994.1 transaction from the remote station.
Showtime	The state of either ATU-C or ATU-R – reached after all initialization and training is completed – in which user data is transmitted.
Signal	A collection of one or more carriers from within a given signalling family.
Signalling family	A group of carriers which are integral multiples of a given carrier spacing frequency.
Single latency	Simultaneous transport of one or more bearer channels in any one direction, in which all user data is allocated to either the fast or the interleaved path; that is for ADSL, either $\text{sum}(B_f) > 0$ or $\text{sum}(B_i) > 0$.
Service node Interface (SNI)	SNI is the interface between the access network and the core network.

Splitter	Filter that separates the high frequency signals (ADSL) from the voiceband signals; (frequently called POTS splitter even though the voiceband signals may comprise more than POTS).
Subcarrier	A particular complex valued input, Z_i, to the IDFT.
Superframe	A data entity consisting of 68 data frames and one Sync frame.
Symbol rate	The rate at which all symbols, including the synchronization symbol, are transmitted (for ITU-T G.992.x that is (69/68)*4.0 = 4.0588 kbaud); contrasted with the data symbol rate.
Sync byte	A byte of data in the ADSL mux data frame that contains either AOC, eoc or IB bits.
Sync frame	A frame of bytes that compose part of the superframe.
Sync symbol	A DMT symbol modulated with a constant data pattern.
Total data rate	Aggregate data rate plus FEC overhead.
Transaction	A sequence of ITU-T G.994.1 messages, terminating with either a positive acknowledgement (ACK(1)), a negative acknowledgement (NAK), or a time-out.
Upstream	ATU-R to ATU-C direction, VTU-R to VTU-O direction.
Vectored group	The set of lines over which transmission from the AN is eligible to be coordinated by pre-compensation (downstream vectoring), or over which reception at the AN is eligible to be coordinated by post-compensation (upstream vectoring), or both. Depending on the configuration of the vectored group, downstream vectoring, upstream vectoring, both or none may be enabled.
Vectoring	The coordinated transmission and/or coordinated reception of signals of multiple DSL transceivers using techniques to mitigate the adverse effects of crosstalk to improve performance.
Voiceband	0 to 4 kHz; expanded from the traditional 0.3 to 3.4 kHz to deal with voiceband data services wider than POTS.
Voiceband services	POTS and all data services that use the voiceband or some part of it.
xDSL	Any of the various types of digital subscriber lines.
XNI	Access network interface is the interface between the access network and the user premises.

Bibliography

ITU-T G.704 (1998), *Synchronous frame structures used at 1544, 6312, 2048, 8448 and 44 736 k/bits hierarchical levels.*

ITU-T G.961 (1993), *Digital transmission system on metallic local lines for ISDN basic rate access.*

ITU-T G.991.1 (1998), *High bit rate digital subscriber line (HDSL) transceivers. System On Metallic Local Lines.*

ITU-T G.991.2 (2001), *Single-pair high-speed digital subscriber line (SHDSL) transceivers.*

ITU-T G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers.*

ITU-T G.992.2 (1999), *Splitterless asymmetric digital subscriber line (ADSL) transceivers.*

ITU-T G.992.3 (2009), *Asymmetric digital subscriber line transceivers 2 (ADSL2).*

ITU-T G.992.4 (2002), *Splitterless asymmetric digital subscriber line transceivers 2 (splitterless ADSL2).*

ITU-T G.992.5 (2005), *Asymmetric digital subscriber line transceivers 2 (ADSL2) – Extended bandwidth (ADSL2plus).*

ITU-T G.993.1 (2005), *Very high speed digital subscriber line transceivers (VDSL).*

ITU-T G.993.2 (2006), *Very high speed digital subscriber line transceivers 2 (VDSL2).*

ITU-T G.993.5 (2010), *Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers.*

ITU-T G.994.1 (2001), *Handshake procedures for digital subscriber line (DSL) transceivers.*

ITU-T G.996.1 (2001), *Test procedures for digital subscriber line (DSL) transceivers.*

ITU-T G.996.2 (2009), *Single ended line testing for digital subscriber lines (DSL).*

ITU-T G.997.1 (1999), *Physical layer management for digital subscriber line (DSL) transceivers.*

ITU-T G.998.1 (2005), *ATM-based multi-pair bonding*.

ITU-T G.998.2 (2005), *Ethernet-based multi-pair bonding*.

ITU-T G.998.3 (2005), *Multi-pair bonding using Time-Division Inverse Multiplexing*.

ITU-T G.998.4 (2010), *Improved impulse noise protection for DSL transceivers*.

ITU-T G.999.1 (2009), *Interface between the link layer and the physical layer for digital subscriber line (DSL) transceivers*.

ITU-T I.411 (1993), *ISDN user-network interfaces – Reference configurations*.

Broadband Forum TR-100 (2007), *ADSL2/ADSL2plus Performance Test Plan*. Issue: 1.0.

Broadband Forum TR-105 (2011), *ADSL2/ADSL2plus Functionality Test Plan*. Issue: 2.

Broadband Forum TR-114 (2010), *VDSL2 Performance Test Plan*. Issue 1: Corrigendum 2.

Broadband Forum TR-115 (2011), *VDSL2 Functionality Test Plan*. Issue: 1 Corrigendum 2.

Committee T1, T1.424 (2002), *Trial Use Interface between Networks and Customer Installations – Very-high Speed Digital Subscriber Lines (VDSL) Metallic Interface (Trial Use Standard)*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Terminals and subjective and objective assessment methods
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2012