ETSI TS 103 430 V1.1.1 (2016-05)

TECHNICAL SPECIFICATION

PowerLine Telecommunications (PLT); Specification on coexistence of VDSL2 and PLT modems in customer premises; Spectral management of PLT and VDSL2 transceivers

Reference
DTS/PLT-00042

Keywords
powerline, VDSL2

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Sous-Préfecture de Grasse (06) N° 7803/88

Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

The present document is a deliverable covering the coexistence of Powerline Telecommunication transceivers with Very high speed Digital Subscriber Line transceivers in customer premises.

The present document on coexistence of VDSL2 and PLT is aligned on Recommendation ITU-T G.9979 Amendement 1 [i.5].

Executive summary

The overlapping of frequency bands between DSL and PLT is causing mutual interferences raising the issue of EMC.

The present document specifies reference models and functionality of a mechanism to mitigate interference caused by in-home powerline devices to xDSL (implementing access Recommendations like Recommendation ITU-T G.993.2 [2] and Recommendation ITU-T G.9701 [i.4]) and vice versa. It is defined as a pointer document to the Recommendation ITU-T G.9977 (2016) [1].

Addressing the coexistence problems of PLT and DSL operating in customer environments, the present document describes a coordination of both the xDSL access and in-home powerline transmission by an arbitration function (AF) which allows optimizing the performance of each part of the system in order to meet the throughput requirements to the end customer across both in-home and xDSL access networks by appropriately configuring parameters of xDSL and/or PLC devices based on a coordination policy whenever this policy is available.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

Over the past decades, broadband technologies for access networks and home networking have seen an increasing level of improvements to meet consumers expectations in speed and services.

The demand for higher bit rate data services from customer side is promoted by high-speed Internet access and many forthcoming innovative services as UHD video streaming. This demand become possible with the deployment of DSL technology as well as the extension to DSL vectoring and bonding.

Recent advances in power line communications (PLT) have made it popular for in-home networking. This makes PLT a source of interference for digital subscriber line (DSL) networks within the home environment.

The present document proposes interference mitigation solutions that allow the coexistence of in-home PLT and DSL networks.

In addition, the present document proposes two interference mitigation solutions that enhance the coexistence of in-home PLT and DSL networks.

The interactions between a Digital Subscriber Line (DSL) access network and Home Networks based on Powerline Telecommunication (PLT) have been reported during past years as PLT modems are widely used for IPTV distribution in a home.

PLT networks and DSL networks use some of the same frequencies in the unlicensed band from 2 - 88 MHz. PLT devices and DSL devices may often be placed in relative proximity to each other and there are concerns that this could present interference.

1 Scope

The present document defines a method to improve the coexistence by mitigating the interference between the DSL transceiver and PLT transceiver operating in overlapping frequency band but on different cables.

In-home PLT networks operate over the same spectrum as DSL networks. This increases the likelihood of crosstalk between PLT and DSL communications systems. For instance, two home networks that operate at the same frequency range, one over copper twisted-pairs (138 kHz - 30 MHz) and the other over power lines (1,8 MHz - 30 MHz), would interfere with each other.(ETSI TR 102 930 [i.1]).

The DSL and PLT interference environment is discussed in more detail. Communication standards for PLT, have been developed with mechanisms that prevent any interference between various systems within the home environment.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] Recommendation ITU-T G.9977 (02-2016): "Mitigation of Interference between DSL and PLC".

[2] Recommendation ITU-T G.993.2 (01-2015): "Very high speed digital subscriber line transceivers 2 (VDSL2)".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 102 930 (V1.1.1): "PowerLine Telecommunications (PLT); Study on signal processing improving the coexistence of VDSL2 and PLT".

[i.2] ETSI-PLUGTEST (May 25-29, 2009): "DSL and in-door PLT coexistence Tests Report" from LANPARK.

[i.3] BroadBand ForumTR-069: "CPE WAN Management Protocol".

NOTE: Available at http://www.broadband-forum.org/cwmp.php.

[i.4] Recommendation ITU-T G.9701: "Fast access to subscriber terminals (G.fast) - Physical layer specification".

[i.5] Recommendation ITU-T G.9979 (2014) Amendment 1 (02-2016): "Implementation of the generic mechanism in the IEEE 1905.1a - 2014 Standard to include applicable ITU-T Recommendations".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Arbitration Function (AF): entity that facilitates coordination between the DSL and PLC systems in order to reduce interference on the basis of coordination policy by appropriately configuring parameters of the DSL and PLC devices

NOTE: The coordination policy is expected to be determined and provided by the operator. In case such policy is not determined or provided by the operator, the AF works according to a predefined default policy.

Customer Premises Equipment (CPE): customer premises equipment implementing xDSL functionality that is compliant with at least one of the Recommendation ITU-Ts of G.99x and G.970x series

Centralized Control Mode (CCM): mode of a PLC network in which devices do not exchange information directly with the AF but via the PLC-NC

Distributed Control Mode (DCM): mode of a PLC network in which PLC devices exchange information directly with the Arbitration Function

PLC Network Controller (PLC-NC): in CCM, one of the PLC devices in the PLC network that is assigned to control all other devices in the network

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AF	Arbitraty Function
CPE	Customer Premises Equipment
DMT	Discrete MultiTone
DSL	Digital Subscriber Line
DSM	Dynamic Spectrum Management
EMC	ElectroMagnetic Compatibility
FDD	Frequency Division Duplexing
IPTV	Internet Protocol TeleVision
ITU-T	International Telecommunication Union - Telecommunication
LAN	Local Area Network
MAC	Medium Access Controler (Layer 2)
MIMO	Multiple Input Multiple Output
NMS	Network Management System
NT	NeTwork
OFDM	Orthogonal Frequency Division Multiplexing (multi-carrier transmission)
OPCODE	OPeration CODE
PHY	PHYsical layer /transmission (Layer 1)
PLC	PowerLine Communication
PLT	PowerLine Telecommunication
RGW	Residential GateWay
TV	TeleVision
UHD	Ultra High Definition (4K video)
VDSL2	Second generation of Very high speed Digital Subscriber Line

4 Configuration of VDSL2 gateway and PLT network in customer premise

4.1 Introduction

DSL and PLT technologies are based on OFDM transmission and both PLT and DSL modems operate in the frequency range from 2 MHz to 30 MHz, although on different cables.

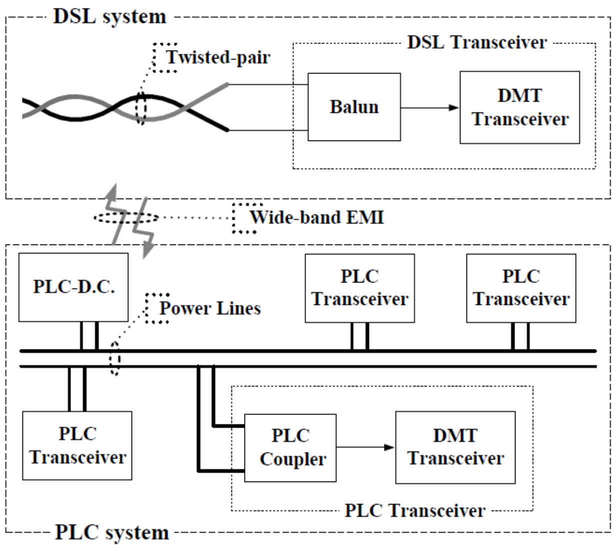

Figure 1: Interaction between DSL and PLT

The cross-channel coupling depends on the type of cables (twisted or untwisted) used for DSL transmission as well as on the following parameters (length, space/distance, type):

- Length of co-localized cables: 1 m, 5 m, 20 m.
- Space between cables: Contact, 1 cm, 6 cm, 20 cm.
- DSL cables: untwisted, CAT3, CAT5.
- Power cables: 3G2.5.

The cross-channel coupling occurs when cables are co-localized (telephone and electrical), this configuration includes customer premise equipments as residential broadband gateway, set-top-box and connected TV.

Under real life tests [i.2] with several PLT technologies allowed the following conclusions: the confirmation of DSL and PLT signals in-door coupling, depending on the quality (twisted or not twisted) of cables, the distance between the telephone and electrical cables.

4.2 DSL and PLT Channel Coupling Model

The DSL and PLT channels are usually modelled separately, for our purpose of coexistence of these two transceivers, a MIMO channel model of dimension using matrix H (2 x 2) was introduced to take into account the channel coupling and this is illustrated in figure 2).

In this MIMO model, coefficient h1,1 represents the DSL channel model, and coefficient h2,2 the PLT channel model.

This MIMO model exhibit also channel coupling coefficients as coefficient h2,1 from PLT to DSL and coefficient h1,2 vice-versa (i.e. from DSL to PLT).

The complete model also include additive noises (n1,n2) on each channel as depicted in figure 2.

In figure 2, the input signals are: X1 for DSL and X2 for PLT and output signals (the ones actually received by the modems) are Y1 for DSL modem and Y2 for PLT modem.

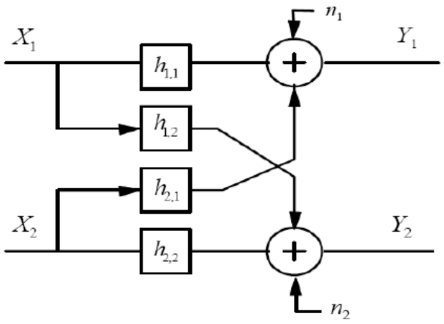

Figure 2: DSL and PLT channel coupling MIMO model

The coexistence between these two transceivers could be solved at different layers levels: Both PLT and VDSL2 modems operate in the frequency range from 2 MHz to 30 MHz, although on different cables.

The coupling factor is increasing as a function of frequency; this observation is correlated to the coupling factor between DSL lines in a same cable. H(f) is the transfer function, based on the PLT and DSL channel coupling model expressed as a matrix.

In the following, a MIMO transfer function is defined as H(f) based on the PLT and DSL channel coupling model as a matrix H where X1 represent DSL signal and X2 the PLT signal with additive Gaussian noises (n1, n2) as given by the equation (1):

$$\begin{aligned} Y_1 &= h_{11}X_1 + h_{12}X_2 + n_1 \\ Y_2 &= h_{21}X_1 + h_{22}X_2 + n_2 \end{aligned} \qquad (1)$$

It has been validated by real measurements [i.2] that interferences from a PLT modem to a DSL modem can reach -90 dBm/Hz, this crosstalk interference from PLT is affecting more the downstream of DSL received at the customer premises than the upstream. Under such conditions impacted DMT carriers may not be able to carry any data.

To solve the coexistence of PLT with DSL, the following MIMO [i.1] channel model was used in description of the coupling of telephone wires channels and electrical wires channels.

The PLUGTEST report [i.2] on PLT-DSL coexistence confirms the risk of potential interferences when the cables are very close to each other:

1) The dominating part of the interference above certain frequency is due to electromagnetic emission (radiation).

2) The interference (or the coupling) will increase with frequency up to a certain cut-off frequency.

3) The conducted field interference is not so strong as would generally be perceived.

In real customer premise, many wiring rules are adopted for electrical networks and telephone in home networks, the resulting coupling between the two wiring is unknown.

Depending on this coupling, the interferences from PLT signal on DSL signal is strong when the two wires are close.

4.3 Analysis of the PHY layers of PLT and DSL

The physical layer of PLT modem (PHY) is based on windowed OFDM as the basic modulation technique. The physical layer of VDSL2/ modem (PHY) is also based on windowed OFDM.

The separation of upstream and downstream transmissions by FDD is defined by the band plans [2].

The VDSL2 signal can potentially use the frequency range up to 35 MHz, although the maximum frequency used by a modem to transmit data depends on the selected band plan and the conditions of telephone line.

The VDSL2 transceiver may select one or more sub-carriers to use for timing recovery, called Pilot Tones. Pilot tones are selected separately for initialization and showtime. For VDSL2, two sub-carrier spacing are available: 4,3125 kHz and 8,625 kHz.

Table 1: VDSL2 transmission parameters (PHY) corresponding to different profiles

Profile	Upper band edge frequency for e.g. bandplan 998ADE (MHz)	Index of highest supported carrier for e.g. bandplan 998ADE	Carrier spacing (kHz)	Max. aggregate downstream transmit power (dBm)	Min. bidirectional net data rate (Mbit/s)
8a	8,5	1 971	4,3125	+17,5	50
8b	8,5	1 971	4,3125	+20,5	50
8c	8,5	1 971	4,3125	+11,5	50
8d	8,5	1 971	4,3125	+14,5	50
12a	8,5	1 971	4,3125	+14,5	68
12b	8,5	1 971	4,3125	+14,5	68
17a	17,66	4 095	4,3125	+14,5	100
30a	24,89	2 885	8,625	+14,5	200
35a	35,32	8 191	4,3125	+17,5	250

5 Reference models

5.1 Generalized reference model

The generalized reference model addressing the coexistence mechanism is presented in figure 3. The Arbitration Function (AF) facilitates resource allocation between the PLC network and the xDSL NT. The communication between PLC and AF and the xDSL NT and AF are defined using a generic reference model presented in figure 3, over logical interfaces ΦP and ΦC, respectively, while the operator may control the AF using the logical interface ΦA. The operator's control on AF, as well as other elements of the customer premises network, is usually implemented via the Network management system (NMS). In case operator control of AF is not established by certain reasons, the AF may use its internal arbitration and coexistence policies to facilitate xDSL-PLC coordination (e.g. the default policies or those downloaded during previous session). This includes the cases in which:

- xDSL line is inactive and thus no connection to the NMS is available;
- xDSL line is active, but no connection to the NMS is established or NMS is unavailable.

In these cases the AF should be able to function without operator control.

NOTE: To support coexistence mechanism during the time when operator control is not available, the AF may the AF may (either partially or entirely)reside inside the RGW.

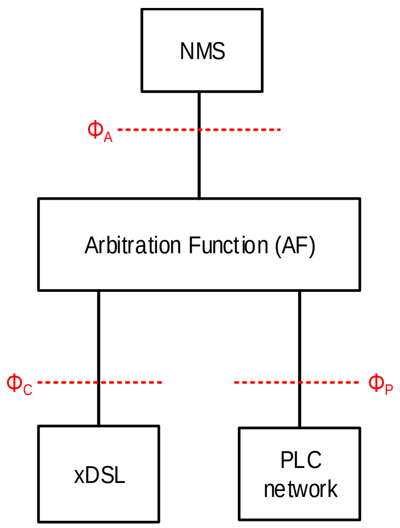

Figure 3: Generalized reference model

An application of the generalized reference model showing more details of the xDSL and the PLC network is presented in figure 4.

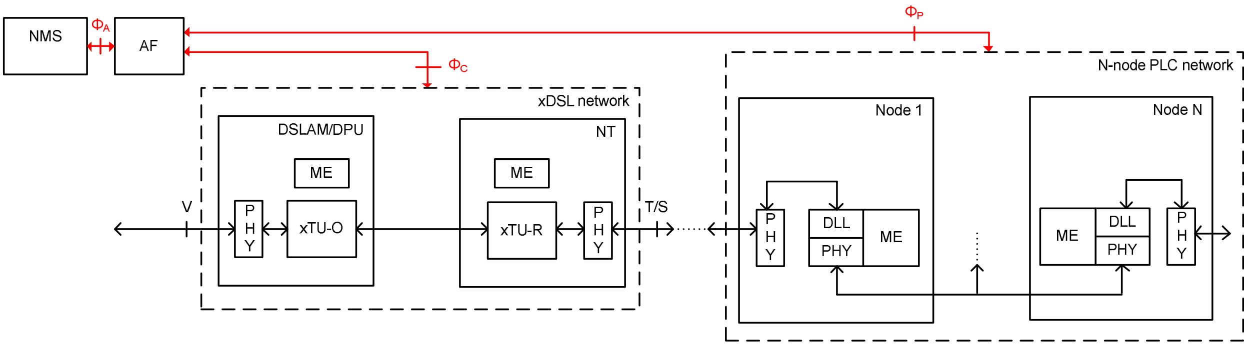

Figure 4: Reference model

First example of a system functional model corresponding to the reference models in figure 4 is presented in figure 6-3 in Recommendation ITU-T G.9977 [1]. It represents the case in which the AF resides in the Residential Gateway (RGW). To address a generic case of user installation, both PLC network and xDSL NT are connected to the RGW using 802.3 LAN interfaces (RGW is stand-alone device).

Second example of a system functional model corresponding to the reference models in figure 4 is presented in figure 6-4 in Recommendation ITU-T G.9977 [1]. It represents the case in which the AF resides in the Residential Gateway (RGW) and a PLC device is also part of the RGW. The xDSL NT is connected to the RGW using 802.3 LAN interfaces.

Third example of a system functional model corresponding to the reference models in figure 4 is presented in figure 6-5 in Recommendation ITU-T G.9977 [1]. It represents the case in which the AF resides in the Residential Gateway (RGW) and the xDSL NT is also part of the RGW. The PLC network is connected to the RGW using 802.3 LAN interfaces. In this case, the CPE functionalities are integrated into the RGW.

5.2 Details of the interfaces

1) The defined interfaces of the generic reference model (Φ_C, Φ_P, and Φ_A, figure 3) are logical, which means:

   - the interface is defined by sets of primitives to be exchanged (see clause 7.5 in Recommendation ITU-T G.9977 [1]);

   - no L1-layer protocol (physical signals) is specified.

2) The Φ_C, Φ_P, and Φ_A interface primitives are exchanged by using protocols and message formats defined in Recommendation ITU-T G.9977 [1].

6 General approach

6.1 Overview of PLC the interference mitigation mechanism

6.1.1 Overview

The coexistence mechanism defined in Recommendation ITU-T G.9977 [1] provides mitigation of the PLC interference into xDSL line and mutual optimization of the performance of the xDSL line and PLC network. It facilitates normal initialization and stable steady-state operation of a xDSL line within the QoS requirements defined by the operator, in the presence of PLC, while also providing minimum performance degradation for PLC devices and seamless PLC operation (i.e. no service disruption during xDSL initialization).

The mitigation of PLC interference shall be accomplished by an AF implementing the following AF Device Discovery, AF Coordination and AF Policy functionalities:

AF Device Discovery functionality includes the following actions:

- Discovery of the MAC addresses of the xDSL NT and PLC devices.
- Identification of the type and status of each device.
- Monitoring of device presence and status changes.

AF Coordination functionality includes the following actions:

- Establish communication with PLC devices and xDSL NT.
- Coordinate interference measurement, i.e. trigger measurement modes and retrieve results.
- Collect interference data and report it to the AF.
- Coordinate start-up procedure of xDSL and PLC devices.
- Coordinate parameter reconfiguration of PLC devices and xDSL to mitigate interference based on AF policy.

AF Policy functionality includes the following:

- The AF implements a provided coordination policy from an operator. In case such a policy is not provided or available the AF will work according to a predefined (default) policy.
- The coordination policy may be provided through a static definition (autonomously implemented within the unit embedding the AF) or a dynamic definition using a remote management protocol (e.g. BBF TR-069 [i.3]).

Operator control of the AF and the applied coexistence policies prevent conflicting goals that PLC devices and xDSL NT may have, while the goal is to optimize the overall performance.

The coexistence mechanism defined in this Recommendation facilitates operation for the following cases:

1) When xDSL line is inactive, the PLC devices should be allowed to use all network resources.
2) When xDSL line starts initialization, the PLC network and/or devices should facilitate xDSL initialization such that the QoS targets defined by the operator are achieved at the transition to showtime.
3) When xDSL line is active, the xDSL line in showtime should maintain the QoS targets set by the operator and should not be disrupted by reconfiguration of the PLC network (e.g. when new PLC devices are added to the network or PLC devices are moved to another location).

6.1.2 Scenarios

This clause provides an overview of the operation of the overall system under different coexistence scenarios:

- Scenario #1: PLC is active while xDSL is OFF.
- Scenario #2: xDSL line turns active in presence of an active PLC network.
- Scenario #3: Steady-state operation of xDSL in the presence of a PLC network.
- Scenario #4: PLC devices initializing in presence of an active xDSL network.

The details of the different mechanisms that are used are explained in clauses 7.2, 7.3 and 7.4 in Recommendation ITU-T G.9977 [1].

6.2 Device discovery

6.2.1 Overview

The discovery mechanism provides the AF, the xDSL NT, and the PLC devices a procedure to announce themselves and become aware of the existence of devices that are relevant for the coexistence procedure. The discovery mechanism provides the tools that:

- Allow the AF, the xDSL NT and PLC network devices to announce their presence, address, and main properties.
- Allow the xDSL NT and PLC network devices to discover the AF.
- Allow the AF to routinely monitor the status of the devices relevant for the interference mitigation procedure.
- Allow the AF to be informed on new devices added to or leaving the network.

The specified discovery mechanism addresses operation of the PLC networks in both DCM and CCM. It is defined in clause 7.2 in Recommendation ITU-T G.9977 [1].

6.3 Device measurement

6.3.1 Overview

The AF is in charge of coordinating the measurement of the interference between xDSL and PLC network devices. For this, AF may request corresponding time windows. As a result of these measurement procedures, AF can obtain measurement data and use it to facilitate coexistence between xDSL NT and PLC network devices, and optimize end-to-end throughput. The defined measurement mechanism provides the tools that:

- Allow the AF to initiate a measurement procedure that evaluates the impact of transmission of each PLC device on the xDSL access system.
- Allow the AF to retrieve the measurement data (measurement results) from xDSL NT.

Measurement of impact from PLC devices into xDSL is defined in clause 7.3.2 in Recommendation ITU-T G.9977 [1]. Measurement of impact from xDSL transmission on the PLC devices is for further study.

6.4 Device configuration

6.4.1 Overview

The device configuration procedure allows changing transmission parameters of PLC network devices and xDSL line (xDSL NT) necessary to facilitate coexistence between the PLC network and the xDSL and optimize the overall end-to-end service delivery to the customer. The procedure is managed by the AF and performed under control of the operator.

The configuration procedure provides the tools that:

- Allow reconfiguration of selected transmission parameters of the PLC network devices.
- Allow reconfiguration of selected transmission parameters of the xDSL line (xDSL NT).
- Facilitates a capability for both PLC devices and xDSL NT to negotiate configuration with the AF in case a compromise is necessary.

Configuration of PLC devices is defined in clause 7.4.2 in Recommendation ITU-T G.9977 [1]. Configuration of xDSL line is defined in clause 7.4.3 in Recommendation ITU-T G.9977 [1].

6.5 Primitives supporting coexistence protocol

The list of coordination primitives between xDSL NT and PLC network for the logical interfaces Φ_P, Φ_C, and Φ_A is defined in table 7-4 in Recommendation ITU-T G.9977 [1].

6.6 Description of primitives

The primitives exchange across Φ_P, Φ_C, and Φ_A interfaces shall have the following properties:

- the exchange contains a set of request - response pairs of messages (except for indication messages);
- each primitive may carry one or more primitives;
- the type of the primitive is determined by the OPCODE that indicates the interface across which this primitive is exchanged, whether the primitive is a request, or a response, or an indication and specific parameter(s) carried by this primitive.

The entity initiating the primitive transaction (e.g. AF or PLC or xDSL NT) shall send a request (a ".request primitive") and wait for a response (a ".confirm primitive"). If no response is received during the defined timeout, depending on the type of the request, the request primitive may be either retransmitted or abandoned. A timeout of two seconds should be used if no specific timeout is defined for a particular primitive exchange. A mandatory requirement is for further study.

The list of request primitives and corresponding response primitives, and indication primitives is shown in table 7-5 in Recommendation ITU-T G.9977 [1]. An indication (an ".ind primitive") is considered as a request with no response required. If after an indication is sent, no expected activity is detected within 10 seconds, it may imply that the indication is lost. In this case, the indication shall be sent again with any updates. A response (a ".confirm primitive") may include no parameters associated (simple acknowledgement).

Whenever the entities exchange primitives across the Φ_P, Φ_C, or Φ_A interfaces over Layer 2, the primitives shall be mapped into messages using protocol formats defined in annex A, clause A.1.1 in Recommendation ITU-T G.9977 [1].

History

Document history		
V1.1.1	May 2016	Publication