ETSI TR 101 830-2 V1.2.1 (2008-07)

Technical Report

Transmission and Multiplexing (TM); Access networks; Spectral management on metallic access networks; Part 2: Technical methods for performance evaluations

Reference

RTR/ATTM-06004-2

Keywords

access, ADSL, HDSL, ISDN, VDSL, xDSL, local loop, modem, network, POTS, SDSL, spectral management, transmission, unbundling

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document is part 2 of a multi-part deliverable covering Transmission and Multiplexing (TM); Access networks; Spectral management on metallic access networks, as identified below:

Part 1: "Definitions and signal library";

Part 2: "Technical methods for performance evaluations";

1 Scope

The present document gives guidance on a common methodology for studying the impact of noise on xDSL performance (maximum reach, noise margin, maximum bitrate) when changing parameters within various Spectral Management scenarios. These methods enable reproducible results and a consistent presentation of the assumed conditions (characteristics of cables and xDSL equipment) and configuration (chosen technology mixture and cable fill) of each scenario.

The technical methods include computer models for estimating:

- xDSL receiver capability of detecting signals under noisy conditions;
- xDSL transmitter characteristics;
- cable characteristics;
- crosstalk cumulation in cables, originating from a mix of xDSL disturbers.

The objective is to provide the technical means for evaluating the performance of xDSL equipment within a chosen scenario. This includes the description of performance properties of equipment.

Another objective is to assist the reader with applying this methodology by providing examples on how to specify the configuration and the conditions of a scenario in an unambiguous way. The distinction is that a configuration of a scenario can be controlled by access rules while the conditions of a scenario cannot.

Possible applications of the present document include:

- Studying access rules, for the purpose of bounding the crosstalk in unbundled networks.
- Studying deployment rules, for the various systems present in the access network.
- Studying the impact of crosstalk on various technologies within different scenarios.

The scope of the present document is explicitly restricted to the methodology for defining scenarios and quantifying the performance of equipment within such a scenario. All judgement on what access rules are required, what performance is acceptable, or what combinations are spectral compatible, is explicitly beyond the scope of the present document. The same applies for how realistic the example scenarios are.

The models in the present document are not intended to set requirements for DSL equipment. These requirements are contained in the relevant transceiver specifications. The models in the present document are intended to provide a reasonable estimate of real-world performance but may not include every aspect of modem behaviour in real networks. Therefore real-world performance may not accurately match performance numbers calculated with these models.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
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2.1 Normative references

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Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

SpM

[i.1] ETSI TR 101 830-1: "Transmission and Multiplexing (TM); Access networks; Spectral management on metallic access networks; Part 1: Definitions and signal library".

[i.2] ANSI T1E1.4, T1.417-2003: "Spectrum Management for loop transmission systems".

ISDN

[i.3] ETSI TS 102 080: "Transmission and Multiplexing (TM); Integrated Services Digital Network (ISDN) basic rate access; Digital transmission system on metallic local lines".

HDSL

[i.4] ETSI TS 101 135: "Transmission and Multiplexing (TM); High bit-rate Digital Subscriber Line (HDSL) transmission systems on metallic local lines; HDSL core specification and applications for combined ISDN-BA and 2 048 kbit/s transmission".

SDSL

[i.5] ETSI TS 101 524: "Transmission and Multiplexing (TM); Access transmission system on metallic access cables; Symmetric single pair high bitrate Digital Subscriber Line (SDSL)".

[i.6] ITU-T Recommendation G.991.2: "Single-Pair High-Speed Digital Subscriber Line (SHDSL) transceivers".

ADSL

[i.7] ETSI TS 101 388: "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Asymmetric Digital Subscriber Line (ADSL) - European specific requirements [ITU-T Recommendation G.992.1 modified]".

[i.8] ITU-T Recommendation G.992.1: "Asymmetric digital subscriber line (ADSL) transceivers".

[i.9] ITU-T Recommendation G.992.3: "Asymmetric digital subscriber line (ADSL) transceivers - 2 (ADSL2)".

[i.10] ITU-T Recommendation G.992.5: "Asymmetric digital subscriber line (ADSL) transceivers - extended bandwidth ADSL2 (ADSL2plus)".

VDSL

[i.11] ETSI TS 101 270-1: "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements".

[i.12] ETSI TS 101 271: "Access Terminals Transmission and Multiplexing (ATTM); Access transmission systems on metallic pairs; Very high speed Digital Subscriber Line system (VDSL2)". [ITU-T Recommendation G993.2, modified].

[i.13] ITU-T Recommendation G993.2: "Very High Speed Digital Subscriber Line 2 (VDSL2)".

SPLITTERS

[i.14] ETSI TS 101 952-1-3: "Access network xDSL transmission filters; Part 1: ADSL splitters for European deployment; Sub-part 3: Specification of ADSL/ISDN splitters".

[i.15] ETSI TS 101 952-1-4: "Access network xDSL transmission filters; Part 1: ADSL splitters for European deployment; Sub-part 4: Specification of ADSL over "ISDN or POTS" universal splitters".

OTHER

[i.16] ITU-T Recommendation G997.1: "Physical layer management for digital subscriber line (DSL) receivers".

3 Definitions and abbreviations

3.1 Definitions

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

access port: physical location, appointed by the loop provider, where signals (for transmission purposes) are injected into the local loop wiring

access rule: mandatory rule for achieving access to the local loop wiring, equal for all network operators who are making use of the same network cable that bounds the crosstalk in that network cable

cable fill (or degree of penetration): number and mixture of transmission techniques connected to the ports of a binder or cable bundle that are injecting signals into the access ports

Cable Management Plan (CMP): list of selected access rules dedicated to a specific network

NOTE: This list may include associated descriptions and explanations.

deployment rule: voluntary rule, irrelevant for achieving access to the local loop wiring and proprietary to each individual network operator

NOTE: A deployment rule reflects a network operator's own view about what the maximum length or maximum bitrate may be for offering a specific transmission service to ensure a chosen minimum quality of service.

disturber: source of interference in spectral management studies coupled to the wire pair connecting victim modems

NOTE: This term is intended solely as a technical term, defined within the context of these studies, and is not intended to imply any negative judgement.

downstream transmission: transmission direction from port, labelled as LT-port, to a port, labelled as NT-port

NOTE: This direction is usually from the central office side via the local loop wiring, to the customer premises.

Echo Cancelled (EC): term used within the context of ADSL to designate ADSL (FO) systems with frequency overlap of downstream and upstream signals

NOTE: In this context, the usage of the abbreviation "EC" was only kept for historical reasons. The usage of the echo cancelling technology is not only limited to FO systems (frequency overlapped), but can also be used by FDD systems (frequency division duplexing).

local loop wiring: part of a metallic access network, terminated by well-defined ports, for transporting signals over a distance of interest

NOTE: This part includes mainly cables, but may also include a Main Distribution Frame (MDF), street cabinets, and other distribution elements. The local loop wiring is usually passive only, but may include active splitter-filters as well.

loop provider: organization facilitating access to the local loop wiring

NOTE: In several cases the loop provider is historically connected to the incumbent network operator, but other companies may serve as loop provider as well.

LT-access port (or LT-port for short): access port for injecting signals, designated as "LT-port"

NOTE: Such a port is commonly located at the central office side, and intended for injecting "downstream" signals.

max data rate: maximum data rate that can be recovered according to predefined quality criteria, when the received noise is increased with a chosen noise margin (or the received signal is decreased with a chosen signal margin)

network operator: organization that makes use of a local loop wiring for transporting telecommunication services

NOTE: This definition covers incumbent as well as competitive network operators.

noise margin: ratio (P_{n2}/P_{n1}) by which the received noise power P_{n1} may increase to power P_{n2} until the recovered signal no longer meets the predefined quality criteria

NOTE: This ratio is commonly expressed in dB.

NT-access port (or NT-port for short): is an access port for injecting signals, designated as "NT-port"

NOTE: Such a port is commonly located at the customer premises, and intended for injecting "upstream" signals.

performance: is a measure of how well a transmission system fulfils defined criteria under specified conditions

NOTE: Such criteria include reach, bitrate and noise margin.

power back-off: is a generic mechanism to reduce the transmitter's output power

NOTE: It has many purposes, including the reduction of power consumption, receiver dynamic range, crosstalk, etc.

power cut-back: specific variant of power back-off, used to reduce the dynamic range of the receiver, that is characterized by a frequency independent reduction of the in-band PSD

NOTE: It is used, for instance, in ADSL and SDSL.

PSD mask: absolute upper bound of a PSD, measured within a specified resolution band

NOTE: The purpose of PSD masks is usually to specify maximum PSD levels for stationary signals.

PSD template: expected average PSD of a stationary signal

NOTE: The purpose of PSD templates is usually to perform simulations. The levels are usually below or equal to the associated PSD masks.

signal category: is a class of signals meeting the minimum set of specifications identified in TR 101 830-1 [i.1]

NOTE: Some signal categories may distinct between different sub-classes, and may label them for instance as signals for "downstream" or for "upstream" purposes.

signal margin: ratio (P_{s1}/P_{s2}) by which the received signal power P_{s1} may decrease to power P_{s2} until the recovered signal no longer meets the predefined quality criteria

NOTE: This ratio is commonly expressed in dB.

spectral compatibility: generic term for the capability of transmission systems to operate in the same cable

NOTE: The precise definition is application dependent and has to be defined for each group of applications.

spectral management: art of making optimal use of limited capacity in (metallic) access networks

NOTE: This is for the purpose of achieving the highest reliable transmission performance and includes:

- Designing of deployment rules and their application.
- Designing of effective access rules.
- Optimized allocation of resources in the access network, e.g. access ports, diversity of systems between cable bundles, etc.
- Forecasting of noise levels for fine-tuning the deployment.
- Spectral policing to enforce compliance with access rules.
- Making a balance between conservative and aggressive deployment (low or high failure risk).

spectral management rule: generic term, incorporating (voluntary) deployment rules, (mandatory) access rules and all other (voluntary) measures to maximize the use of local loop wiring for transmission purposes

transmission equipment: equipment connected to the local loop wiring that uses a transmission technique to transport information

transmission system: set of transmission equipment that enables information to be transmitted over some distance between two or more points

transmission technique: electrical technique used for the transportation of information over electrical wiring

upstream transmission: transmission direction from a port, labelled as NT-port, to a port, labelled as LT-port

NOTE: This direction is usually from the customer premises, via the local loop wiring, to the central office side.

victim modem: modem, subjected to interference (such as crosstalk from all other modems connected to other wire pairs in the same cable) that is being studied in a spectral management analysis

NOTE: This term is intended solely as a technical term, defined within the context of these studies, and is not intended to imply any negative judgement.

3.2 Abbreviations

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

2B1Q	2-Binary, 1-Quaternary (Use of 4-level PAM to carry two buts per pulse)
ADSL	Asymmetric Digital Subscriber Line
BER	Bit Error Ratio
CAP	Carrier less Amplitude/Phase modulation
CMP	Cable Management Plan
DFE	Decision Feedback Equalizer
DMT	Discrete MultiTone modulation
EC	Echo Cancelled
EPL	Estimated Power Loss

FBL	Fractional Bit Loading
FDD	Frequency Division Duplexing/Duplexed
FO	Frequency Overlap, previously referred to as Echo Cancelled (EC)
FSAN	Full Service Access Network
GABL	Gain Adjusted Bit Loading
HDSL	High bitrate Digital Subscriber Line
ISDN	Integrated Services Digital Network
LT-port	Line Termination - port (*commonly at central office side*)
LTU	Line Termination Unit
MDF	Main Distribution Frame
NT-port	Network Termination - port (*commonly at customer side*)
NTU	Network Termination Unit
PAM	Pulse Amplitude Modulation
PBO	Power Back-Off
PSD	Power Spectral Density (single sided)
QAM	Quadrature Amplitude Modulation
RBL	Rounded Bit Loading
SDSL	Symmetrical (single pair high bitrate) Digital Subscriber Line
SNR	Signal to Noise Ratio (*ratio of powers*)
TBL	Truncated Bit Loading
TRA	TRAnsmitter
UC	Ungerboeck Coded (also known as trellis coded)
VDSL	Very-high-speed Digital Subscriber Line
xDSL	(all systems) Digital Subscriber Line

4 Transmitter signal models for xDSL

A transmitter model in this clause is mainly a PSD description of the transmitted signal under matched conditions, plus an output impedance description to cover mismatched conditions as well.

PSD *masks* of transmitted xDSL signals are specified in several documents for various purposes, for instance in TR 101 830-1 [i.1]. These PSD masks, however, cannot be applied directly to the description of a transmitter model. One reason is that masks are specifying an upper limit, and not the expected (averaged) values. Another reason is that the definition of the true PSD of a time-limited signal requires no resolution bandwidth at all (it is defined by means of an autocorrelation, followed by a Fourier transform) while PSD *masks* do rely on some resolution bandwidth. They describe values that are (slightly) different from the true PSD; especially at steep edges (e.g. guard bands), and for modelling purposes this difference is sometimes very relevant.

To differentiate between several PSD descriptions, *masks* and *templates* of a PSD are given a different meaning. Masks are intended for proving compliance to standard requirements, while templates are intended for modelling purposes. This clause summarizes various xDSL transmitter models, by defining *template* spectra of output signals.

In some cases, models are marked as "default" and/or as "alternative". Both models are applicable, but in case a preference of either of them does not exist, the use of the "default" models is recommended. Other (alternative) models may apply as well, provided that they are specified.

4.1 Generic transmitter signal model

A generic model of an xDSL transmitter is essentially a linear signal source. The Thevenin equivalent of such a source equals an ideal voltage source U_s having a real resistor R_s in series. The output voltage of this source is random in nature (as a function of the time), and occupies a relatively broad spectrum. Correlation between transmitters is taken to be negligible. The autocorrelation properties of a transmitter's signal are taken to be adequately represented by a PSD template.

This generic model can be made specific by defining:

- The output impedance R_s of the transmitter.
- The template of the PSD, measured at the output port, when terminated with an external impedance equal to R_s. This is identified as the "matched condition", and under this condition the output power equals the maximum power that is available from this source. Under all other (mis-matched) termination conditions the output power will be lower.

4.2 Transmitter signal model for "ISDN.2B1Q"

The PSD template for modelling the "ISDN.2B1Q" transmit spectrum is defined by the theoretical sinc-shape of PAM encoded signals, with additional filtering and with a noise floor. The PSD is the maximum of both power density curves, as summarized in expression 1 and the associated table 1. The coefficient q_N scales the total signal power of $P_1(f)$ to a value that equals P_{ISDN}. This value is dedicated to the used filter characteristics, but equals q_N=1 when no filtering is applied ($f_L \to 0$, $f_H \to \infty$). The source impedance equals 135 Ω.

$$P_1(f) = P_{ISDN} \times \frac{2 \times q_N}{f_X} \times \text{sinc}^2\left(\frac{f}{f_X}\right) \times \frac{1}{1+\left(f/f_H\right)^{2 \cdot N_H}} \times \frac{1}{1+\left(f_L/f\right)^2} \quad [W/Hz]$$

$$P_2(f) = \frac{10^{(P_{floor\_dBm}/10)}}{1000} \quad [W/Hz]$$

$$P(f) = \max\left(P_1(f), P_2(f)\right) \quad [W/Hz]$$

Where:

$P_{ISDN} = \left(10^{P_{ISDN\_dBm}/10}\right)/1000$ [W]

R_S = 135 [Ω]

sinc(x) = sin($\pi \cdot x$) / ($\pi \cdot x$)

Default values for remaining parameters are summarized in table 1.

Expression 1: PSD template for modelling "ISDN.2B1Q" signals

Different ISDN implementations, may use different filter characteristics, and noise floor values. Table 1 specifies *default* values for ISDN implementations, in the case where 2nd order Butterworth filtering has been applied. The default noise floor equals the maximum PSD level that meets the out-of-band specification of the ISDN standard (TS 102 080 [i.3]).

Table 1: Default parameter values for the ISDN.2B1Q templates, as defined in expression 1

Type	*f*X [kHz]	*f*H [kHz]	*f*L [kHz]	NH	*q*N	*P*ISDN_dBm [dBm]	*P*floor_dBm [dBm/Hz]
ISDN.2B1Q	80	1×f_x	0	2	1,1257	13,5	-120

NOTE: These default values are based on 2nd order Butterworth filtering.

4.3 Transmitter signal model for "ISDN.2B1Q/filtered"

When ISDN signals have to pass a low-pass filter (such as in an ADSL splitter) before they reach the line, the disturbance caused by these ISDN systems to other wire pairs will change, as well as their performance. SpM studies should therefore make a distinction between crosstalk generated from ISDN systems connected directly to the line and filtered ISDN systems.

The PSD template for modelling a "ISDN.2B1Q/filtered" transmitter signal that has passed a low-pass splitter/filter, is defined in table 2 in terms of break frequencies. It has been constructed from the transmitter PSD template, filtered by the low-pass transfer function representing the splitter/filter.

The values are based on filter assumptions according to splitter specifications in TS 101 952-1-3 [i.14] and TS 101 952-1-4 [i.15]. The associated values are constructed with straight lines between these break frequencies, when plotted against a *logarithmic* frequency scale and a *linear* dBm scale.

Table 2: PSD template for modelling "ISDN.2B1Q/filtered" signals

ISDN.2B1Q/filtered	(135Ω)
f [Hz]	PSD [dBm/Hz]
1 k	-32,1
10 k	-32,3
20 k	-33,1
30 k	-34,5
40 k	-36,6
50 k	-39,8
60 k	-44,5
65 k	-47,8
70 k	-52,2
75 k	-59,3
80 k	-126,5
85 k	-61,9
90 k	-57,4
100 k	-55,2
110 k	-57,9
115 k	-62,9
120 k	-68,2
125 k	-79,3
130 k	-90,8
135 k	-104,1
140 k	-117,9
145 k	-132,8
150 k	-136,9
160 k	-140,0
170 k	-140,0
180 k	-136,2
190 k	-135,2
200 k	-135,8
210 k	-137,8
220 k	-140,0
30 M	-140,0