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TITLE **Generic detection models for performance modeling**

PROJECTS Spectral Management, part 2

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STATUS for Decision

ABSTRACT Part 2 of SpM requires a range of calculation blocks, to enable performance evaluations. One of them is a model for the detection block that evaluates the noise margin when the effective SNR is known of a received signal. This contribution provides the text for three generic detection models, based on (a) Shannons capacity limit, (b) PAM encoded signals and (c) CAP/QAM encoded signals. A DMT model is left for further study.

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1. Rationale behind this proposal

Part 2 of the Spectral management report requires the description of performance models consisting of a range of individual calculation blocks. All these blocks together are to enable reproducible and well-defined performance evaluations under (noisy) conditions. The models of the building blocks that are proposed in this contribution are a few out of many building blocks that are required for part 2.

The models proposed here, are based on the expressions, published in the ANSI Spectral Management report. The theory behind these models can be found in various textbooks, dedicated to this subject.
The evaluation of these models is quite straight-forward. The formulas are written as the solution of an equation; solving this means an iterative approach, which is easy to program.

A similar expression will hold for modelling DMT encoded signals, but for the time-being this has been left for further study.

2. Literal text proposal

The text below refers to TD 35 from the previous meeting (021t35) that has been copied into the living list. That text illustrates how Expression 1 defines the shortcuts formats of the effective SNR, which is used to simplify the description of the detection model.

5.1 Basic model for the input block

<……….>

$SNR_{ofs,N}(m,f)$ = …..

$SNR_{ofs,S}(m,f)$ = …..

Expression 1*: Shortcuts for SNR, resulting from the basic model of the input block, using offset formats.*

<……….>

The text below proposes literal text for inclusion in clause 5 of the Spectral Management draft, part 2.

5.2 Generic detection models

This clause identifies several generic (sub) models for the detection block: one linecode independent model derived from the Shannon capacity limit, and various linecode dependent models dedicated to PAM, CAP/QAM or DMT linecoding.
Table 1 summarizes the naming convention for input and output quantities.

Input quantities	***linear***	***In dB***	***remarks***
Signal to Noise Ratio	SNR	$10\times\log_{10}(SNR)$	Ratio of powers (frequency dependent)
Output quantities			
Noise margin	m_n	$20\times\log_{10}(m_n)$	Ratio of amplitudes
Signal margin	m_s	$20\times\log_{10}(m_s)$	Ratio of amplitudes

Table 1. *Symbols used for input and output quantities of detection models*

On input, the detection block requires an effective SNR, as provided by the input block. This SNR is a function of the frequency *f*. When the offset format is used for describing the SNR (see expression 1), it will also be a function of the offset parameter *m.*

On output, the detection block evaluates a signal margin m_n (or a noise margin m_s when more appropriated). This margin parameter is a dominant measure for the transport quality that is achieved under noisy conditions.

- The *Noise Margin* m_n indicates how much the received noise can increase before the transmission becomes unreliable.
- The *Signal Margin* m_s indicates how much the received signal can decrease before the transmission becomes unreliable.

Unless explicitly specified otherwise, the word *margin* refers in this document to *noise margin*.

NOTE From an xDSL deployment point of view, analyzing the noise margin is preferred over signal margin, since the (crosstalk) noise is the quantity that may increase when more systems are connected to the same cable. Many xDSL implementations, however, do report margin numbers that are not exactly equal to this noise margin, since the detection circuitry cannot make a distinction between external noise (due to crosstalk) and internal noise (due to imperfect electronics). These margins are often an estimate closer in value to the signal margin then the noise margin.

5.2.1 Generic Shannon detection model

The calculation of the margin *m* using the generic Shannon detection model, is equivalent with solving the equation in expression 2. The associated parameters are summarized in table 2. Depending on what offset format is used for the SNR expression (see expression 1), the calculated margin *m* will represent the noise margin m_n or the signal margin m_s.

$$f_b = \int_{f_c-B/2}^{f_c+B/2} \log_2\left(1+\frac{SNR_{ofs}(m,f)}{\Gamma^2}\right)\cdot df$$

Expression 2*: Equation of the Shannon detection model, for solving the margin m.*

Model Parameters	***linear***	***In dB***	***remarks***
SNR gap	Γ	$20\times\log_{10}(\Gamma)$	
Data rate	f_d		all payload bits that are transported in 1 sec
Line rate	f_b		= DateRate + overhead bitrate
Bandwidth	B		Width of relevant spectrum

Table 2. *Parameters used for Shannon detection models.*

The various parameters used within this generic detection model are summarized in table 2. The model can be made specific by assigning values to all these model parameters.

- The SNR-gap (Γ) is a performance parameter that indicates how close the detection approaches the Shannon capacity limit.
- The linerate is usually higher then the datarate (0…30%) to transport overhead bits for error correction, signaling and framing.
- The Bandwidth is a parameter that indicates what portion of the received spectrum is relevant for data transport. The model assumes that this portion passes the receive filters.

5.2.2 Generic PAM detection model

The calculation of the margin *m* using the generic PAM detection model is equivalent with solving the equation in expression 3. The associated parameters are summarized in table 3. Depending on what offset format is used for the SNR expression (see expression 1), the calculated margin *m* will represent the noise margin m_n or the signal margin m_s.
This model assumes optimal decision feedback equalizer (DFE) margin calculations.

$$SNR_{req} = \Gamma^2 \times \left(2^{2\cdot b} - 1\right) = \exp\left(\frac{1}{f_s} \times \int_0^{f_s} \ln\left(1 + \sum_{n=N_L}^{N_H} SNR_{ofs}\left(m, f + nf_s\right)\right) \cdot df\right)$$

Expression 3*: Equation of the PAM-detection model, for solving the margin m.*

Model Parameters	***linear***	***In dB***	***remarks***
SNR gap	Γ	$20\times\log_{10}(m)$	$= \sqrt{(SNR_{req} / (2^{2\cdot b}-1))}$
Required SNR	SNR_{req}	$10\times\log_{10}(SNR_{req})$	$= \Gamma^2\times(2^{2\cdot b}-1)$
Data rate	f_d		all payload bits that are transported in 1 sec
Line rate	f_b		= DateRate + overhead bitrate
Symbol rate	f_s		$= f_b / b$
Bits per symbol	b		$= f_b / f_s$ (can be non-integer)
Summation range	N_L, N_H		On default: N_L=–2 and N_H=+1

Table 3. *Parameters used for PAM detection models.*

The various parameters in table 3 used within this generic detection model have the following meaning:

- The SNR-gap (Γ) and required SNR (SNR_{req}) are similar parameters and can be converted into each other. The advantage of using Γ over SNR_{req} is that Γ can be defined with similar meaning for all theoretical models in the frequency domain (Shannon, CAP, PAM, DMT). The advantage of using SNR_{req} over Γ is that this quantity is closer related to the SNR observed at the decision point of the detection circuitry.
- The linerate is usually higher then the datarate (0…30%) to transport overhead bits for error correction, signaling and framing. The symbol rate is usually significantly lower when multiple bits are packed together in a single symbol.
- The summation range for *n* is from $n=N_L$ to $n=N_H$, and this range has to be defined to make this generic model specific. Commonly used values for PAM, using oversampling, are N_L=–2 and N_H=+1, but wider ranges are not excluded.

5.2.3 Generic CAP/QAM detection model

The calculation of the margin *m* using the generic CAP/QAM detection model is equivalent with solving the equation in expression 4. The associated parameters are summarized in table 4. Dependening on what offset format is used for the SNR expression (see expression 1), the calculated margin *m* will represent the noise margin m_n or the signal margin m_s.
This model assumes optimal decision feedback equalizer (DFE) margin calculations.

$$SNR_{req} \equiv \Gamma^2 \times \left(2^b - 1\right) = \exp\left(\frac{1}{f_s} \times \int_0^{f_s} \ln\left(1 + \sum_{n=N_L}^{N_H} SNR_{ofs}\left(m, f + nf_s\right)\right) \cdot df\right)$$

***Expression 4**: Equation of the CAP/QAM-detection model, for solving the margin m.*

Model Parameters	***linear***	***In dB***	***remarks***
SNR gap	Γ	$20\times\log_{10}(\Gamma)$	$= \sqrt{}(SNR_{req} / (2^{-b}–1))$
Required SNR	SNR_{req}	$10\times\log_{10}(SNR_{req})$	$= \Gamma^2\times(2^{-b}–1)$
Data rate	f_d		all payload bits that are transported in 1 sec
Line rate	f_b		= DateRate + overhead bitrate
Symbol rate	f_s		$= f_b / b$
Bits per symbol	b		$= f_b / f_s$ (can be non-integer)
Summation range	N_L, N_H		On default: N_L=0 and N_H=+3

***Table 4.** Parameters used for CAP/QAM detection models.*

The various parameters in table 4 used within this generic detection model have the following meaning:

- The SNR-gap (Γ) and required SNR (SNR_{req}) are similar parameters and can be converted into each other. The advantage of using Γ over SNR_{req} is that Γ can be defined with similar meaning for all theoretical models in the frequency domain (Shannon, CAP, PAM, DMT). The advantage of using SNR_{req} over Γ is that this quantity is closer related to the SNR observed at the decision point of the detection circuitry.
- The linerate is usually higher then the datarate (0..30%), to transport overhead bits for error correction, signaling and framing. The symbol rate is usually significantly lower when multiple bits are packed together in a single symbol.
- The summation range for *n* is from $n=N_L$ to $n=N_H$, Commonly used values for CAP/QAM systems using oversampling are N_L=0 and N_H=+3. This holds when the carrier frequency positions the spectrum low in the frequency band (e.g. CAP-based HDSL). Other values may be more appropriated when the carrier frequency moves the spectrum to higher frequencies (e.g CAP based VDSL).

5.2.4 Generic DMT detection model

<left for further study>

End of literal text proposal