TITLE **Generic DMT detection model**

PROJECTS Spectral Management, part 2.

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AUTHORS: Rob van den Brink
Bas Gerrits

CONTACT: Rob F. M. van den Brink,
TNO Telecom
P.O. Box 421
2260 AK Leidschendam
The Netherlands

tel +31 70 4462389
fax: +31 70 4463166 (or +31 70 4463477)
e-mail: R.F.M.vandenBrink@telecom.tno.nl
the above numbers and e-mail address are changed since 1 jan 2003!

STATUS for Decision

ABSTRACT Part 2 of SpM requires a range of individual calculation blocks, including a generic DMT detection block that evaluates the noise margin when the effective SNR is known of a received signal. The model, modelling DMT encoded signals, is based on expressions, published in the ANSI Spectral Management report.

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.

This contribution proposes the model for a generic DMT detection block that evaluates the noise margin when the effective SNR is known of a received signal. The model, modelling DMT encoded signals, is based on 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 straightforward. The formulas are written as the solution of an equation; solving this means an iterative approach, which is easy to program.

2. Literal text proposal

The text below proposes literal text for inclusion in clause 5.2.4 of the Spectral Management draft, part 2.

5.2.4 Generic DMT detection model

The calculation of the margin m using the generic DMT detection model is equivalent with solving the equations in expression 1, for a given line rate f_b. The associated parameters are summarized in Table 1, and function *bitload* is specified by the chosen bit-loading algorithm. The effective SNR is to be evaluated by using one of the input models described in clause 5.1. Depending on what offset format is used for the SNR expression, the calculated margin m will represent the noise margin m_n or the signal margin m_s.

$$\Delta b_k = \int_{(k-½)\bullet f_c}^{(k+½)\bullet f_c} \log_2\left(1 + \frac{SNR_{ofs}(m,f)}{\Gamma}\right)\cdot df$$
$$f_b = f_s \times b = f_s \times \sum_{k \in tones} bitload(\Delta b_k)$$

Expression 1: Equation of the DMT-detection model, for solving the margin m for a given line rate f_b.

Bit-loading algorithm

The DMT carriers are all positioned at a multiple of the carrier frequency f_c, and each carrier may carry a fraction of the symbol by means of a few bits. The way this bit space is used to load each carrier with bits is implementation dependent.

Bit-loading algorithms do commonly use masking. Masking means skipping carriers for bit-loading when their bit space Δb_k is below some predefined minimum value Δb_{min}, and limiting the bit-loading to some pre-defined maximum when the bit space Δb_k exceeds some predefined maximum Δb_{max}.

When data transport has been pushed to its limits (zero margin), the following bit-loading algorithms may apply, in addition to masking:

- *Fractional bit-loading* is a pure theoretical approach enabling to load even (non-integer) fractions of the bit space Δb_k on carrier *k*. This maximizes the use of the available capacity, but is unpractical to implement.

$(\Delta b_k < \Delta b_{min})$	$\Rightarrow$	$bitload(\Delta b_k) \equiv 0$
$(\Delta b_k \geq \Delta b_{min})$ and $(\Delta b_k < \Delta b_{max})$	$\Rightarrow$	$bitload(\Delta b_k) \equiv \Delta b_k$
$(\Delta b_k > \Delta b_{max})$	$\Rightarrow$	$bitload(\Delta b_k) \equiv \Delta b_{max}$

- *Truncated bit-loading* is a more feasible in practice, and loads each carrier *k* to a number of bits equal to the largest non-negative integer *below* the bit space Δb_k.
- *Rounded bit-loading* is also feasible in practice, and loads each carrier *k* to a number of bits equal to the nearest non-negative integer of bit space Δb_k.
- *Gain adjusted bit-loading* is a sophisticated combination of rounded bit-loading and adjustment of powers to each of the tones, so that each individual bit space Δb_k approaches a rounded value (minimizes the loss of capacity), while the total transmit power is kept unchanged on average.

Studies have shown that the capacity of well-designed *gain adjusted* bit-loading algorithms closely match those achieved by *fractional* bit-loading. For reasons of simplicity, and for making capacity calculations in this document less implementation dependent, the fractional bit-loading algorithm is used as default for DMT calculations all over this document, unless specified explicitly otherwise.

SNR-Gap

The (effective) SNR gap Γ, being used in the above expression 1, is a combination of various effects. This Γ parameter is often split-up into the following three parts:

- Its theoretical value Γ_{DMT} (in the order of 9.75 dB at BER = 10^{-7})
- A theoretical coding gain $\Delta\Gamma_{coding}$ (usually in the order of 3 - 5 dB), to indicate how much additional improvement is achieved by the chosen coding mechanism.
- An empirical adjustment for all *unidentified* implementation losses $\Delta\Gamma_{impl}$ (usually a few dB as well), indicating how much overall performance degradation is caused by implementation dependent imperfections (e.g. echo cancellation and equalization).

When Γ is split-up into the above three parts, its value shall be evaluated as follows:

SNR gap (linear): $\Gamma = \Gamma_{DMT} \;/\; \Delta\Gamma_{coding} \;\times\; \Delta\Gamma_{impl}$

SNR gap (in dB): $\Gamma_{\_dB} = \Gamma_{DMT\_dB} \;-\; \Delta\Gamma_{coding\_dB} \;+\; \Delta\Gamma_{impl\_dB}$

Involved parameters

Input quantities	***linear***	***In dB***	***remarks***
Signal to Noise Ratio	SNR	$10\times\log_{10}(SNR)$	Frequency dependent ratio of powers
Model Parameters	***linear***	***In dB***	***remarks***
SNR gap (effective)	Γ	$10\times\log_{10}(\Gamma)$	$= SNR_{req} / (2^{2\cdot b}-1)$
SNR gap in parts:	Γ_{DMT} $\Delta\Gamma_{coding}$ $\Delta\Gamma_{impl}$	$10\times\log_{10}(\Gamma_{DMT})$ $10\times\log_{10}(\Delta\Gamma_{coding})$ $10\times\log_{10}(\Delta\Gamma_{impl})$	*Theoretical linecode value* *Coding gain* *Implementation loss*
Symbol rate		f_s	The DMT symbol rate
Data rate		f_d	All payload bits that are to be transported in 1 sec
Line rate		f_b	= Date rate + overhead bitrate
Available set of tones		*tones*	Can be a subset of all possible tones. (e.g. *tones* = [7:255])
Carrier frequency (*of tone k*); $k \in$ tones		$k\times f_c$	
Bits per symbol		b	$= f_b / f_s$ Bits of each symbol are spread out over all used carriers.
Bit-loading algorithm			Can be one of: ▪ *Fractional* ▪ *Truncated* ▪ *Rounded* ▪ *Gain adjusted*
Minimum bit-loading		Δb_{min}	
Maximum bit-loading		Δb_{max}	
Output quantities			
Noise margin	m_n	$10\times\log_{10}(m_n)$	
Signal margin	m_s	$10\times\log_{10}(m_s)$	

Table 1: Parameters used for DMT detection models.

The various parameters in Table 1 used within this generic detection model have the following meaning:

- The SNR-gap (Γ) is a parameter indicative for how close the Shannon capacity limit can be approached.
- The line rate is usually higher then the data rate (0…30%) to transport overhead bits for error correction, signaling and framing.
- The symbol rate is usually significantly lower then the line rate since multiple bits per symbol are packed together, and spread-out over many carriers.
- The available tones are a list of integers that indicate what frequency band can be occupied by individual carriers. For instance all tones from tone 7 to tone 255.
- The carrier frequency is the frequency of the first non-zero carrier.
- The minimum and maximum bit-loading specify in what range the bit space of each carrier is loaded. Bit loading is skipped when the bit space is below Δb_{min}, and limited when the bitspace exceeds Δb_{max}.

End of literal text proposal

5. References

[1] ETSI WG TM6, permanent document TM6(01)21: ETSI document M01p21r3, “, Living List for SpM part 2”, Oct 25, 2002.