Project:	Spectrum Management
Title:	Generic detection model for DMT based modems
Source:	FTW

Authors: Driton Statovci, Rickard Nilsson, and Tomas Nordström

Contact: Tomas Nordström
Forschungszentrum Telekommunikation Wien (FTW),
Donau-City-Strasse 1/3
AT-1220 Wien, Austria
Telephone: +43 1 5052830-22
Fax: +43 1 5052830-99
Email: Tomas.Nordstrom@ftw.at

Abstract: The aim of this contribution is to improve and make some corrections to the proposed text "5.2.4 Generic DMT detection model" in the "Living List for SpM part 2".

This revision (2) contains updates reflecting the discussions after the presentation.

Distribution:	ETSI WG TM6 working group members
Status:	For discussion

1. Introduction

The aim of this contribution is to improve and make some corrections to the contribution entitled “5.2.4 Generic DMT detection model” in [1]. In order to do so a short background is given in this introduction to support the proposed changes to “5.2.4 Generic DMT detection model” in [1].

All current DMT based xDSL systems use QAM constellations. For QAM constellations, the number of bits that can be transmitted on a given subcarrier *k* is computed by

$$b_k = \log_2\left(1+\frac{SNR_k}{\Gamma}\right) \qquad [\text{bit}], \qquad (1)$$

where SNR_k is the average Signal to Noise Ratio on subcarrier *k* and Γ is the SNR gap. For a certain bit error rate, the SNR gap reflects the how far a DMT xDSL modem is operating from the optimal Shannon capacity limit. The average SNR for each subcarrier, SNR_k, is calculated as the ratio between the average received signal power and the average noise power at the input of the decision device.

Due to the constraints of the real transmit signal, for the first subcarrier $k = 0$ (at DC) and for the last subcarrier (at the Nyquist frequency), only real valued symbols, such as PAM, can be used. However, they are not used in the current DMT based systems.

Based on the assumption of flat received signal and noise power within each subcarrier, the SNR for each subcarrier can be approximated with

$$SNR_k \cong SNR(f_k)$$

where $SNR(f_k)$ is the SNR value of subcarrier *k* operating at the centre frequency f_k. This is only one the possible approximation of SNR_k and it does not take into account windowing and side-lobe pickup.

We conclude that a suitable approximation for SpM work is to write Equation (1) as:

$$b_k = \log_2\left(1+\frac{SNR(f_k)}{\Gamma}\right) \qquad [\text{bit}]. \qquad (2)$$

From Equation (2) we find that the number of bits transmitted on a given subcarrier does not depend on the subcarrier bandwidth. The subcarrier bandwidth determines only the number of symbols per time interval that can be transmitted over a certain channel.

The total number of bits that can be transmitted over all used subcarriers is

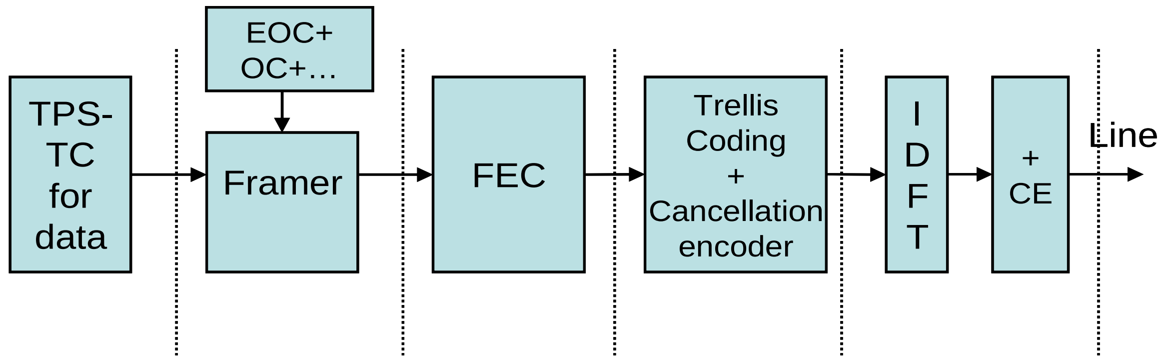
$$b = \sum_{k \in tones} b_k = \sum_{k \in tones} \log_2\left(1+\frac{SNR(f_k)}{\Gamma}\right) \qquad [\text{bit}], \qquad (3)$$

where *tones* is the set of all used subcarriers for a given transmission direction.

All DMT based xDSL systems use some form of bit-loading algorithm to determine how many (integer) number of bits that should be assigned to each subcarrier. Two forms of bit-loading algorithms are commonly used:

- Rate adaptive, which maximizes the supported data rate for the following fixed parameters: margin, PSD-mask, and total power allowed to be used
- Margin adaptive, which maximizes the margin for the following fixed parameters: supported data rate, PSD-mask, and total power allowed to be used.

For performance evaluation purposes also fractional bit-loading (sometimes referred to as a water-filling algorithm) can be used. This algorithm can assign any real number of bits to each subcarrier. For example, in searching for the system margin (a performance parameter) margin adaptive bit-loading algorithm can be used. For dynamic spectrum management this can be refined further, by using fixed margin bit-loading algorithm, which uses only the power needed to support a given data rate for a fixed margin.



T1E1 ADSL Issue 2	Net data rate	Aggregate data rate	Total data rate	Line rate (excluding data in synchronization symbol)	?
ITU G.992.1	Net data rate	Aggregate data rate	Total data rate	Line rate (excluding data in synchronization symbol)	?
ITU G.992.3	Net data rate	Aggregate data rate	Total data rate	Line rate (excluding data in synchronization symbol)	?
ETSI VDSL	Payload bit rate	Aggregate data rate	Line rate		?
ANSI VDSL	Payload bit rate	Aggregate data rate	Line rate		?
Our Proposals	Net data rate	Aggregate data rate	Total data rate (for the systems that use trellis coding)	Line rate (excluding data in synchronization. symbol if it is present)	To be defined (if relevant)

Figure 1: Structure of generic DMT transmitter. TPS-TC: Transmission Protocol Specific - Transmission convergence (sublayer), FEC: Forward Error Correction, IDFT: Inverse Discrete Fourier Transform, CE: Cyclic Extension, EOC: Embedded operation channel, OC: Overhead control.

With the aim to describe the different rates used in the “Generic detection model for DMT based modems” we use the generic DMT transmitter structure shown in Figure 1. It shows the names of data rates used in various standards and our names proposals to be used in the generic detection model.

The “TPS-TC for data” block in Figure 1 refers only to the TPS-TC sublayer interfaces that are used to transport the data of the upper layers and it excludes all the overhead used for management of the TPS-TC sublayer. All data used for management of the TPS-TC sublayer are added by “Framer” in this generic transmitter model.

The total number of DMT symbols transmitted over the line can be higher than the number of DMT symbols used for data. In ADSL, for example, 4000 DMT data symbols per second are transmitted. However, after 68 DMT data symbols one additional DMT *synchronization* symbol is transmitted. Thus, the total symbol rate for ADSL is therefore $69/68 \times 4000$ baud.

Hence, in order to avoid confusion we propose the usage of two *different* terms for describing the different *symbol* rates:

1. *Data DMT symbol rate*, $f_{DMT-dsr}$ [baud] referring to the symbol rate associated with symbols carrying data frames,

2. *Line DMT symbol rate*, $f_{DMT-lsr}$ [baud] referring to the total symbol rate including all synchronization symbols.

For example in VDSL the *Data DMT symbol rate* and *Line DMT symbol rate* are equal as there is no extra synchronization symbol, as in ADSL.

In Figure 1 we show that various standards defines different data rates (bit rates), but for performance evaluations we need only the data that comes into the framer and the data that goes out over the line. Therefore we propose to use the following terms for the data rates:

3. *Line rate*, f_b [bit/s] referring to the data rate associated to the *Data DMT symbol rate.* The line rate does not include the bit rate contained in the overhead due to the cyclic extension.

Additionally, instead of using the term *data rate* as in [1], we propose to use the term

4. *Net data rate*, f_n [bit/s] is the *Line rate* excluding the overhead bits that are used for synchronization, all types of coding, the embedded operation channel, etc in a specific DMT system.

The *line rate* is computed by

$$f_b = f_{DMT-dsr} \times b \qquad \left[\frac{\text{bit}}{s}\right],$$

where $f_{DMT-dsr}$ is the *data DMT symbol rate* and b is calculated as in Equation (3). The *net data rate* depends on the particular DMT system and the user supported data rate.

If other data rates shown in Figure 1 are relevant for performance evaluation they can be defined and included in the standard text proposal.

Another point we would like to make is that there are two forms of coding gain Γ_{coding} in use, one is a *net coding gain* which is the gain after accounting for bandwidth penalties (i.e. the Aggregate data rate is the same as the Total data rate or Line rate) and a "*raw coding gain*" excluding the overhead (i.e., the Aggregate data rate is different from the Total data rate or Line rate, due to error correction overhead).

Our text proposal for the "**Generic DMT detection model"** is given in Section 2. For the sake of consequence it based on [1], by only making changes and notation clarifications based on the explanations in this introduction text.

2. Text proposed for inclusion in Section 5.2.4

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 2, for a given line rate f_b. The associated parameters are summarized in Table 6, and function *load* is specified by the chosen bit-loading algorithm. The offset SNR, $SNR_{ofs}(m, f_k)$, should be evaluated by using one of the input models described in Clause 5.1. Depending on the offset format used for the SNR expression, the calculated margin m will represent the noise margin m_n or the signal margin m_s.

$$b_k = \log_2\left(1 + \frac{SNR_{ofs}(m, f_k)}{\Gamma}\right) \quad [\text{bit}]$$

$$f_b = f_{DMT-dsr} \times b = f_{DMT-dsr} \times \sum_{k \in tones} load(b_k) \quad \left[\frac{\text{bit}}{s}\right]$$

Expression 2: Equation of the DMT-detection model, for solving the margin m for a given line rate f_b and a given data DMT symbol rate $f_{DMT\text{-}dsr}$.

Bit-loading algorithms

The DMT subcarriers are all positioned (centred) at a multiple of the subcarrier spacing Δf, and each subcarrier theoretically may carry any number of bits. The way this bit space is used to load each subcarrier with bits is implementation dependent. Bit-loading algorithms used in DMT systems do commonly use masking. Masking means skipping carriers for loading when their bit space b_k is below some predefined minimum value b_{min}, and limiting the bit-loading to some pre-defined maximum when the bit space b_k exceeds some predefined maximum value b_{max}. This masking process is summarized in Expression 3:

$$\begin{array}{lcl} b_k < b_{\min} & \Rightarrow & load(b_k) \equiv 0 \\ b_{\min} \le b_k \le b_{\max} & \Rightarrow & load(b_k) \equiv b_k \\ b_k > b_{\max} & \Rightarrow & load(b_k) \equiv b_{\max} \end{array}$$

Expression 3: The bit space used in bit-loading algorithms.

When the data transport is operating on its limits (margin $m = 0$ [dB]), the following bit-loading algorithms may apply, in addition to masking:

- *Fractional bit-loading* (FBL) sometimes referred to as *water-filling* – is a theoretical approach enabling loading of any real number of bits in any subcarrier k. This maximizes the use of the available capacity, but is unpractical to implement.
- *Truncated bit-loading* (TBL) – is a more feasible in practice, and loads on each subcarrier k a number of bits equal to the largest non-negative integer below the bit space b_k.
- *Rounded bit-loading* (RBL) – is also feasible in practice, and loads on each subcarrier k a number of bits equal to the nearest non-negative integer of bit space b_k.
- *Gain adjusted bit-loading* (GABL) – is a sophisticated combination of rounded bit-loading and adjustment of powers to each of the subcarriers, so that each individual bit space b_k approaches a rounded value (minimizes the loss of capacity), while the total transmit power is kept unchanged on average.

In various applications, it may be assumed that the capacity of well-designed *gain adjusted bit-loading* algorithm closely match those achieved by the *fractional bit-loading* algorithm. For the sake of simplicity, and for making capacity calculations in this document less implementation dependent, the *fractional bit-loading* algorithm with constraint number of bits per subcarrier, as in Expression 3 is used as default for DMT calculations all over this document, unless specified explicitly otherwise.

Note that when calculating the bit-loading the used total power needs to be reduced by the amount of power spent on the cyclic extension.

SNR-Gap

The (effective) SNR gap, Γ, used in Expression 2, is a combination of various effects. This Γ parameter is often split-up into the following three parts:

- A modulation gap Γ_{DMT} (in the order of 9.75 dB at BER = 10^{-7})
- A theoretical coding gain Γ_{coding} (usually in the order of 3 - 5 dB), to indicate how much additional improvement is achieved by using channel coding.
- An empirical adjustment for all *unidentified* implementation losses Γ_{impl} (usually a few dB as well), indicating how much overall performance degradation is caused by implementation dependent imperfections (e.g., echo cancellation, analogue front end realization, etc).

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

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

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

The margin value, which can be either noise margin or signal margin, is not included in the equations for SNR gap as it is contained in the offset SNR expression as described in Clause 5.1.

Involved parameters

Input quantities	Linear	In dB	Remarks
Signal to Noise Ratio	SNR	10×log10(SNR)	Frequency dependent Signal to Noise ratio
Model Parameters	Linear	In dB	Remarks
SNR gap (effective)	Γ	10×log10(Γ)	= SNR_{req} / (2^b–1)
SNR gap in parts:	Γ_{DMT} Γ_{coding} Γ_{imp}	10×log10(Γ_{DMT}) 10×log10(Γ_{coding}) 10×log10(Γ_{impl})	Modulation gap Coding gain Implementation loss
Line DMT symbol rate	$f_{DMT-lsr}$		The number of DMT symbols transmitted in 1 sec.
Data DMT symbol rate	$f_{DMT-dsr}$		The number of DMT symbols used for data transmission in 1 sec.
Net data rate	f_n		All net data bits that are to be sent in 1 sec.
Line rate	f_b		All bits sent in one sec. on line that are contained in data DMT symbols
Available set of tones	*tones*		A subset of all available tones. (in ADSL a subset of [7:255])
Centre frequency location of tone *k*, $k \in$ tones	f_k		$f_k = k \times \Delta f$, Δf = 4.3125 kHz in all current DMT systems
Bits per DMT symbol	b		= f_b / $f_{DMT-dsr}$
Bit-loading algorithms	FBL TBL RBL GABL		Can be one of: • Fractional bit-loading (a.k.a water-filling) • Truncated bit-loading • Rounded bit-loading • Gain adjusted bit-loading
Minimum bits	$b_{\min}$		Minimum number of bits per subcarrier
Maximum bits	$b_{\max}$		Maximum number of bits per subcarrier
Output quantities			
Noise margin	m_n	10×log10(m_n)	
Signal margin	m_s	10×log10(m_s)	

Table 6: Parameters used for DMT detection models.

The various parameters in Table 6, used within this generic detection model, have the following meaning:

- *Data DMT symbol rate*, $f_{DMT-dsr}$ [baud] referring to the symbol rate associated with symbols carrying data frames,
- *Line DMT symbol rate*, $f_{DMT-lsr}$ [baud] referring to the total symbol rate including all synchronization symbols,
- *Line rate*, f_b [bit/s] referring to the data rate associated to the *Data DMT symbol rate.* The line rate does not include the bit rate contained in the overhead due to the cyclic extension,
- *Net data rate*, f_n [bit/s] is the *Line rate* excluding the overhead bits that are used for synchronization, all types of coding, the embedded operation channel, etc in a specific DMT system,
- *SNR-gap*, Γ, is a parameter that shows how far from the Shannon capacity limit a modem is performing at a certain bit error rate,
- The line rate is higher then the net data rate to transport overhead bits for error correction, signalling, and framing,

- The available set of tones is a list of integers that indicate what frequency band can be occupied by individual subcarriers. For instance in ADSL it can contain any of the tones from tone 7 to tone 255,
- The centre frequency of a subcarrier *k*, is $k\Delta f$ where Δf is the subcarrier spacing,
- $b_{\min}$ and $b_{\max}$ are the minimum and maximum number of bits, respectively, used in the bit-loading.

3. References

[1] ETSI WG TM6, permanent document TM6 (01)21: ETSI document M01p21r6 "Living List for SpM part 2", Aug 29, 2003.