Project	IEEE 802.16 Broadband Wireless Access Working Group <**http://ieee802.org/16**>
Title	**Improved method for using EESM for CINR Measurements**
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Source(s)	Kevin Baum Yufei Blankenship Brian Classon Mark Cudak Philippe Sartori Motorola Labs 1301 E. Algonquin Road Schaumburg, IL 60196 [mailto: Mark.Cudak@motorola.com]
Re:	IEEE P802.16e/D6, sponsor ballot
Abstract	This contribution comments on the limitations of a recently proposed design for using EESM to provide CINR measurement and proposes an improved design.
Purpose	Adoption of proposed changes into P802.16e
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Comments on the Use of EESM method for CINR Measurements

Kevin Baum, Yufei Blankenship, Brian Classon, Mark Cudak, Philippe Sartori
Motorola Labs

Introduction

In [1], a modification of the SINR reporting process is proposed in order to use the Exponential ESM (EESM) method. Recent publications have shown that the EESM method is a very useful method to predict the frame error rate (FER) for multicarrier modulation systems in a frequency selective channel ([2], [3]). Using the EESM method for link adaptation has the potential to significantly improve system performance: as illustrated in [1], the prediction error with the EESM is lower than 1 dB, whereas the prediction error using only the mean SNR typically ranges between 3 dB and 6 dB (and in some cases the error is much larger). It is therefore expected that a properly configured EESM estimator will improve the system capacity given that currently the standard uses the average SINR based method.

However, the simplified version of the EESM solution provided in the proposed text of [1] appears to be based on an assumption that the relationship between the effective SNR (dB) and _ (dB) is linear over the range of _ (dB) values of interest. In this contribution, it is shown that the linear behavior assumed in [1] is quite limited, especially for practical frequency-selective channels. Therefore, while the EESM method holds promise, the specific solution proposed in [1] should be improved to provide better estimation accuracy over a wider range of _ values.

Simplification suggested in [1]

In [1], a linear dependency between the effective SNR (dB) and _ (dB), _ < 15dB, is hypothesized. However, this hypothesis is based on observations over a very limited set of simulation conditions. The example given in [1] assumes that the channel is independently Rayleigh faded on every subcarrier and the only SNR considered is 10 dB.

In the following, various channel types were studied to check the validity of the linear assumption. The plots are shown with _ in the range of 0 dB to 15 dB, since for modulation and coding schemes defined in the standard, the _ value (linear) ranges roughly from 1 (close to _ of QPSK, rate 1/2) to 30 (close to _ of 64-QAM, rate 3/4). As a check of our simulation setup, we first show our simulation results with exactly the same assumptions for a single channel realization[1] in Figure 1. As it can be observed from Figure 1, a more or less linear dependency is observed up to a _ value of 15 dB, although there is some degradation for _ larger than 9 dB.

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[1] In order to make the figures easy to read, only a single channel realization is presented on each plot. The channel sample was chosen randomly and is representative of the channel conditions one might expect for a given channel type.

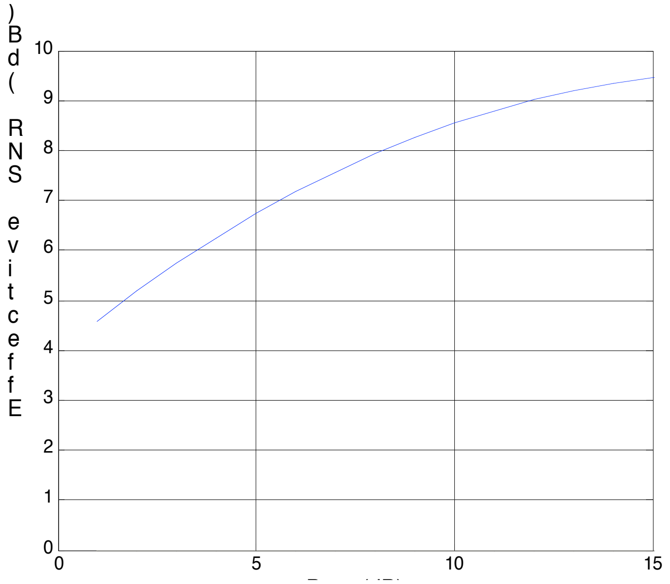

Figure 1. Effective SNR (dB) as a function of _ (dB) (independent Rayleigh fading, average SINR of 10 dB).

However, it should first be noted that the range on which the linear approximation is valid is fairly limited. As an example, Figure 2 shows the effective SNR vs. _ for Rayleigh fading and a lower average SINR of 6 dB. These results show an approximately linear relationship for a small region of _ between 1 dB and 5 dB. When considering the _ > 5 dB region as well, the nonlinearity becomes significant.

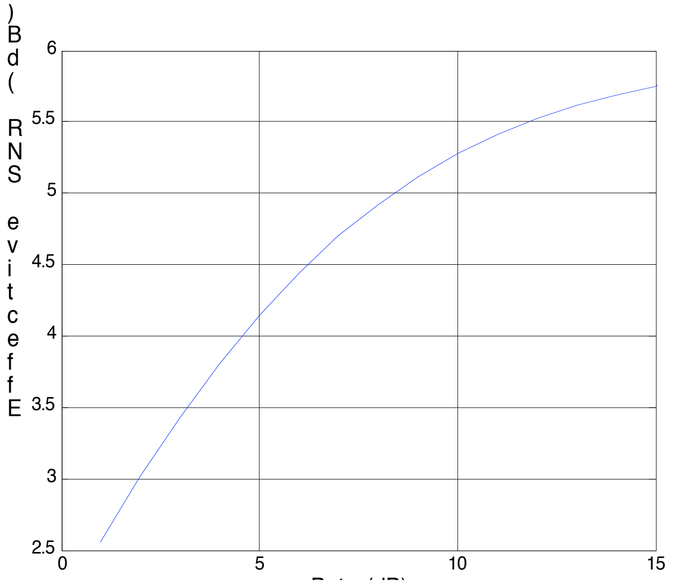

Figure 2. Effective SNR as a function of _ (independent Rayleigh fading average SINR of 6 dB.

Next, we investigate the characteristics over a more realistic channel model rather than the simplified model used above. In practice, the frequency response of the channel is correlated over several subcarriers. It is therefore important to look at the effective SNR vs. _ for channels having such correlation. One channel often used for the 3G evaluation is the 3GPP Pedestrian A (Ped A) channel. Figure 3 and Figure 4 depict the effective SNR (dB) as a function of _ (dB) for the Ped A channel, for an average SINR of 10 dB and 5 dB, respectively.

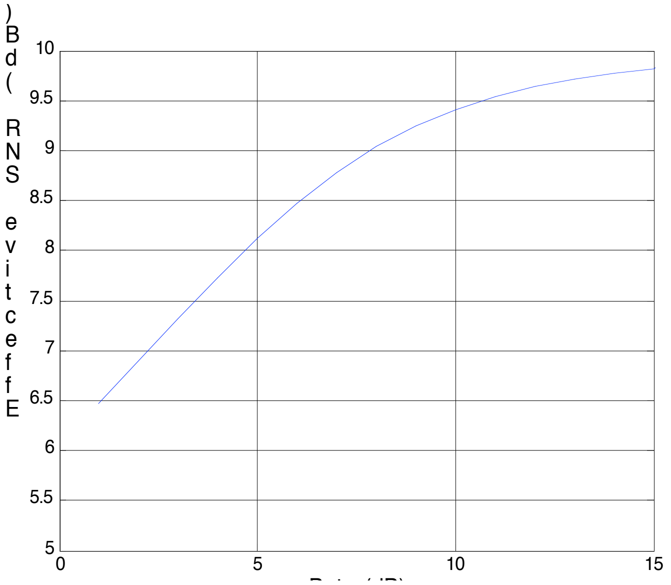

Figure 3. Effective SNR (dB) as a function of _ (dB) (Ped A channel, average SINR of 5 dB).

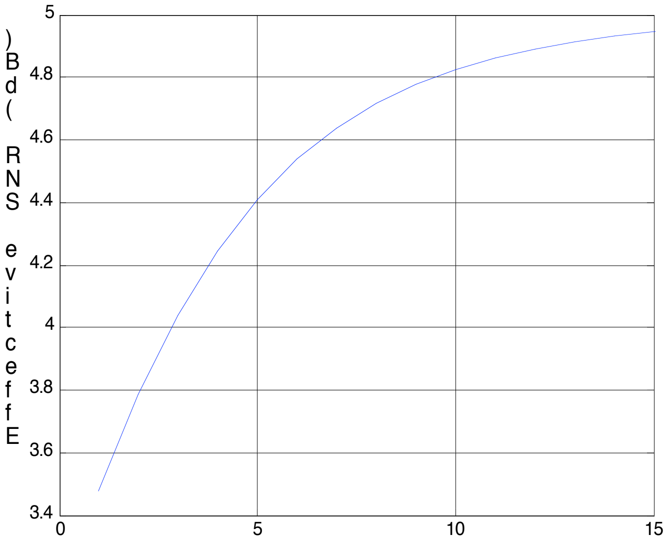

Figure 4. Effective SNR (dB) as a function of _ (dB) (Ped A channel, average SINR of 10 dB).

Clearly, for the Ped A channel, it is inaccurate to consider that the dependency between the effective SNR and _ (dB) is linear for the entire range of 0 dB < _< 15 dB. For instance, for a received average SINR of 10 dB, the curve appears linear only over a couple of dB width at a time. For a system like 802.16 where 16-QAM and 64-QAM are defined, the _ difference for two consecutive Modulation/Coding Schemes (MCS) is larger than 2 dB.
In conclusion, though the EESM method is promising for improving MCS selection, the feedback method proposed in [1] should be improved to provide better accuracy over a wider range of _ values.

Generalized Method

The method presented in [1] can easily be generalized by using a better curve fitting. First, from link-level simulations (not presented here), it appears that the [0 dB, 15 dB] range for _ is sufficient to cover modulation levels up to 64-QAM for the coding schemes used by 802.16e. Therefore, the focus of the curve fitting will be the [0 dB, 15 dB] range.

Although many type of curve fitting, $\mathrm{SNR}_{\mathrm{eff}}$=F(_) where F(_) is an nonlinear function of _, could be used in theory, it is necessary to limit the amount of feedback the mobile has to send to the BS. As an example of the function F(_),a quadratic curve fitting can be employed to provide very good accuracy. The SNR_{eff} (dB)- _ (dB) relationship can be approximated by:

$$\mathrm{SNR}_{\mathrm{eff}}\ (\mathrm{dB}) = a+b\ \_{\mathrm{dB}}+c\ \_{\mathrm{dB}}^{2}, \qquad (1)$$

Where a, b, and c are coefficients that need to be determined for the current channel realization. Note that, when compared to the method presented in [1], only one additional coefficient is needed. Note also that a is the effective SNR value for _=0 dB (i.e., _=1). Obviously, a different reference point for _ could be chosen.

These three parameters, a, b and c may vary at a different rate. For instance, a varies at the same rate as the instantaneous CINR (with different amplitude), whereas link simulations have shown that b and c are heavily dependent on the channel type, but do not necessarily vary significantly for two different realizations of the same channel type. Thus, it is more efficient to send a more frequently (for instance using a CQI report), and b and c at a slower rate. Alternatively, a simpler but less efficient approach is to send these three coefficients in every CQI report. In addition, only three variables of the four, $\{\mathrm{SNR}_{\mathrm{eff}}, a, b, c\}$ need to be provided to fully construct the relationship of (1), if the _ value is known. Thus variations of the protocol based on (1) can be used. For example, $\{\mathrm{SNR}_{\mathrm{eff}}, b, c\}$ may be sent back from the subscriber to the basestation instead of $\{a, b, c\}$, while a is derived based on (1). In this case, $\{b, c\}$ can be updated less frequently than $\{\mathrm{SNR}_{\mathrm{eff}}\}$.

It should also be noted that although the curve fitting function above focus on approximating the relationship of SNR_{eff} (dB) - _ (dB), it is equivalently valid to approximate the relationship of SNR_{eff} (dB) - _ (linear scale), or SNR_{eff} (linear scale) - _ (dB).

The fading channel curves shown in Figure 5 and Figure 6 illustrate that the quadratic approximation is more accurate than the linear approximation in the β (dB) range of interest. In fact, the quadratic approximation leads to an almost perfect curve fitting (a few hundredths of a dB, not noticeable when practical limitations are taken into account). It is important to minimize the curve-fitting error, because this easily controllable error is in addition to the EESM method error which is very difficult to further reduce. Since the EESM method error is less than 0.5 dB for all the 802.16 MCS, the advantage of using EESM will be lost if the curve-fitting error is more than a fraction of 0.5 dB. Note that in Figure 5 and Figure 6, the slope of the linear approximation was selected to minimize the mean-square error (under the linear curve constraint) over the entire β range of [0 dB, 15 dB]. If the slope local to a specific β value was used instead (as suggested in [1]), then errors on the order of several dBs may occur.

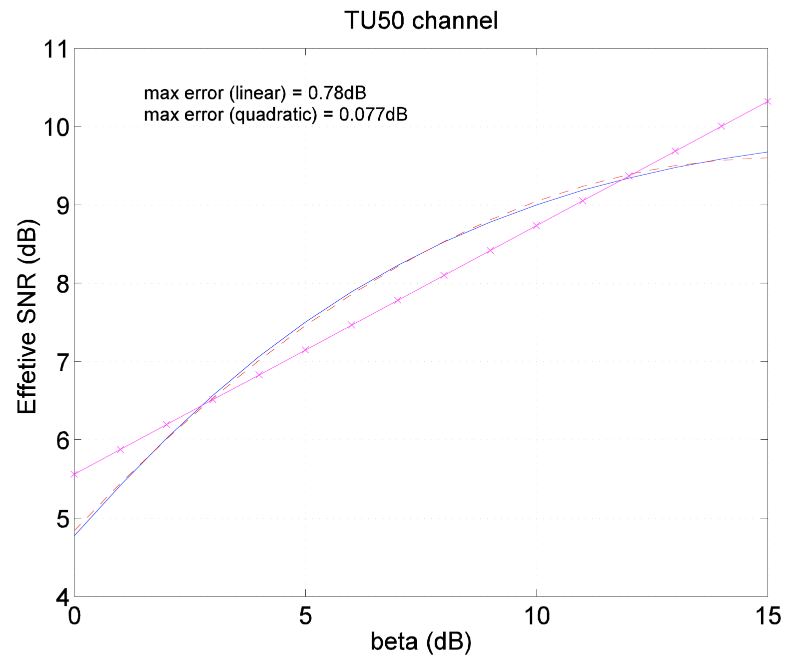

Figure 5. Quadractic (dashed line) vs. linear (cross) curve fitting for the GSM TU channel.

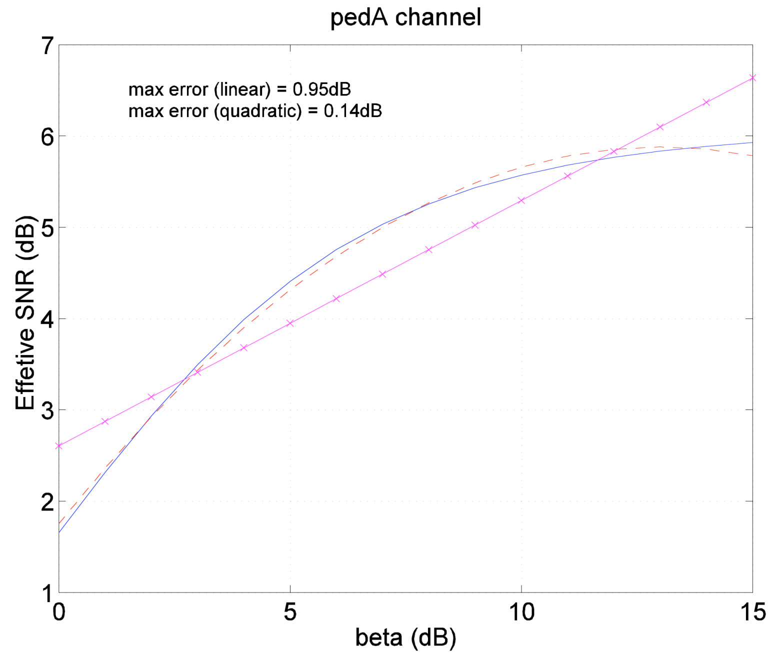

Figure 6. Quadratic (dashed line) vs. linear (cross) curve fitting for the Ped A channel.

Detailed Text Changes

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[Add the following entries to table 14, page 34:]

Type	Message name	Message description	Connection
...			
66	CINRMODE_REQ	CINR measurement mode change request message	Basic
67	CINRMODE_RSP	CINR measurement mode change response message	Basic
~~66~~ 68-255		*Reserved*	

[Add the following new section 6.3.2.3.63:]

.3.2.3.63 CINR measurement mode change request (CINRMODE_REQ) message

The BS may decide to change the CINR measurement mode of an MSS that supports EESM CINR measurement by sending a CINRMODE_REQ message, to which the MSS shall respond with a CINRMODE_RSP message. This message only applies to OFDMA PHY mode.

Table WWW – CINRMODE_REQ message format

Syntax	Size	Notes
CINRMODE_REQ {		

Management Message Type=66	8 bits	
CINR measurement mode	1 bit	0b0-Regular CINR measurements 0b1-EESM CINR measurements
If (CINR measurement mode ==0b1)		
{		
CINR reference FEC type	2 bits	Indicates the FEC type for which the normalized C/N and _ values apply: 0b00=CC 0b01=CTC 0b10=BTC 0b11=LDPC
Information data bytes	8 bits	Indicates the number of information data bytes a packet carries
}		
Start_frame	7 bits	6 LSBs of the frame number in which the new measurement mode is activated
}		

CINR measurement mode
Indicates the new measurement mode that is activated from the frame specified by 'start frame' field. The MSS shall reset all message time indices related to CINR measurement (see sections 8.4.11.3 and 8.4.11.4) upon activation of the new CINR measurement mode.

[Add the following new section 6.3.2.3.64]

6.3.2.3.64 CINR measurement mode change response (CINRMODE_RSP) message

The CINRMODE_RSP message shall be used by the MSS to acknowledge receipt of the CINRMODE_REQ message and to send relevant parameters. The MSS shall send its response prior to the frame number in which the new measurement mode is activated, as specified in the 'start frame' field of the received CINRMODE_REQ message. The MSS may also send a CINRMODE_RSP message in an unsolicited fashion to notify the BS of a change in the CINR vs. β curve fitting parameters.

Table UUU – CINRMODE_RSP message format

Syntax	Size	Notes
CINRMODE_RSP message format {		
Management Message Type-67	8 bits	
Linear _ parameter	8 bits	Curve fitting parameter for the CINR (dB) vs. β (dB) curve. See section 8.4.11.4.
Quadratic _ parameter	8 bits	Curve fitting parameter for the CINR (dB) vs. β (dB) curve. See section 8.4.11.4.
}		

[Add the following new section 8.4.11.4]

.4.11.4 Optional EESM CINR measurement mode

The EESM method for computing effective CINR provides the BS with a tool to better estimate the optimal MCS and/or boosting level for the MSS by accounting for the frequency selectivity of the signal and the noise. The BS may switch the CINR measurement mode of the MSS to EESM by sending a CINRMODE_REQ message. Following activation of this mode, CINR mean shall be computed using the EESM method.

$$CINR_{\beta} = EESM\left[\{\gamma_1,\ldots,\gamma_N\},\beta\right]$$

where $EESM\left[\{\gamma_1,\ldots,\gamma_N\},\beta\right] = -\beta.\ln\left(\frac{1}{N}\sum_{i=1}^{N}\exp\left(-\frac{\gamma_i}{\beta}\right)\right)$, $\{\gamma_1,\ldots,\gamma_N\}$ are the set of per-subcarrier CINR values (in linear scale) and _ is a weighting coefficient in linear scale.

In addition, the MSS shall compute the quadratic approximation of CINR vs. _$_{dB}$=10.log(_) and update its parameters using the CINRMODE_RSP message according to the following procedure. After the quadratic curve fitting, CINR can be approximated as:

CINR (dB) = $a+b$ _$_{dB}$ +c _$_{dB}{}^{2}$

In Table UUU, parameter *b* is called the 'linear _ parameter' and *c* is the 'quadratic _ parameter'. Parameters *b* and *c* are sent in the CINRMODE_RSP message. Parameter $a=CINR_0$ is reported in the CQI_feedback.

The method to determine *b* and *c* are left to individual implementation.

The CINR value shall not include the SNR improvement resulting from repetition.

The reported CINR shall include all receiver implementation losses.

When a linear approximation is good enough, the MSS shall set the quadratic _ parameter *c* to 0.

References

[1] IEEE C802.16e-05/141, "CINR measurements using the EESM method," Alvarion Ltd, March 2005.

[2] "OFDM EESM simulation results for system-level performance evaluations," Nortel Networks, R-1-04-0089, January 2004.

[3] Y. Blankenship *et al*, "Link error prediction methods for multi-carrier systems," *in Proc. VTC fall 2004*, Los Angeles, Sept. 2004.