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Abstract	
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CINR measurements using the EESM method

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1 Introduction

The current 802.16e SINR reporting mechanism requires the MSS to report a straightforward CINR measurement. This mechanism does not provide the BS with any knowledge on the frequency selectivity of the channel and noise (especially prominent with partially loaded cells and with multipath). This knowledge is important since, contrary to the AWGN channel, in a frequency selective channel there is no longer a 1 to 1 relation between amount of increase in power and amount of improvement in "effective SINR" [1]. Furthermore, the relation is dependent on MCS level. This lack of knowledge in the BS side results in larger fade margins, which translates directly to reduction in capacity.

In this contribution we propose a mechanism based on the EESM model that provides the BS with sufficient knowledge on the channel-dependent relationship between power increase, MCS change and improvement in effective SINR. The EESM method is a well known SINR predictor in the context of OFDM/A [1][2][3][4].

The contribution is organized as follows: in section 2 we introduce the EESM method. Section 3 discusses the accuracy of the EESM model. Section 4 gives an outline of the proposed solution, followed by a detailed description of the text changes.

2 Exponential Effective SIR Mapping (SIR)

To estimate demodulator performance in a channel with frequency selective signal and/or noise, a known method is the so-called "exponential effective SIR mapping" (EESM) [1][3][4]. In a sense, the EESM is a channel-dependent function that maps power level and MCS level to SINR values in the AWGN channel domain. This allows using this mapping along with AWGN assumptions (such as effect of increase in power, CINR/MCS threshold tables) in order to predict the effect of MCS and boosting modification. The method has been shown to yield an accurate estimation of

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[1] Effective SINR = AWGN-equivalent SINR, i.e. Equivalent SINR in AWGN channel that results in the same error rate.

the AWGN-equivalent SINR (henceforth referred to as "effective SINR") for frequency selective channels. Section 3 discusses the accuracy of the EESM model.

The EESM method estimates the effective SINR using the following formula:

$$\gamma_{eff} \equiv EESM(\tilde{\boldsymbol{a}},\beta) \equiv -\beta \cdot \ln\left(\frac{1}{N}\cdot\sum_{i=1}^{N} e^{-\frac{\gamma_i}{\beta}}\right)$$

where $\tilde{\boldsymbol{a}}$ is a vector $[\gamma_1,\gamma_2,...,\gamma_N]$ of the per-tone SINR values, which are typically different in a selective channel.

In general, we would like the MSS to report the effective SINR to the BS, and have the BS decide what modulation and coding to use and with what power boosting. However, as stated earlier, this is complicated by the fact that the relationship between increase in power and increase in effective SINR is both channel-dependent and MCS-dependent. **In contrast to the AWGN channel case, 1dB increase in transmit power does *not* translate to 1dB increase in effective SINR**.

In context of EESM, this implies that for each MCS a different β should be utilized, and for each such β , different boosting should be considered. As a result, the BS is required to know the dependence of effective SINR on β and power increase; thus computation of equivalent SNR can no longer remain solely in the MSS's territory.

The increase of γ_{eff} due to boosting is β dependent, as can be seen below (where B denotes the boost ratio)

$$EESM(\tilde{\boldsymbol{a}}\cdot B,\beta) \equiv -\beta \cdot \ln\left(\frac{1}{N}\cdot\sum_{i=1}^{N} e^{-\frac{\gamma_i\cdot B}{\beta}}\right) \neq EESM(\tilde{\boldsymbol{a}},\beta)\cdot B$$

This implies that EESM is a two-dimensional mapping of boost level and an MCS-dependent quantity (β) to effective SINR. However, we can simplify by observing that

$$EESM(B\cdot\tilde{\boldsymbol{a}},\beta) \equiv -\beta \cdot \ln\left(\frac{1}{N}\cdot\sum_{i=1}^{N} e^{-\frac{\gamma_i\cdot B}{\beta}}\right) = B\cdot\left(-\frac{\beta}{B}\right)\cdot\ln\left(\frac{1}{N}\cdot\sum_{i=1}^{N} e^{-\frac{\gamma_i}{\beta/B}}\right) = B\cdot EESM(\tilde{\boldsymbol{a}},\beta/B)$$

which shows that given an SINR-per-tone vector it is sufficient for the BS to know the MSS-specific curve relating EESM to β . Both boosting and rate adaptation can be done based on the same curve, thus reducing the mapping problem to one dimension.

2.1 Linear approximation

In Figure 1 we plot EESM as function of β , for different cases. The first graph plots EESM for 4 different $\tilde{\boldsymbol{a}}$ vectors, drawn from 24 independent Rayleigh distributions. Both EESM and β are plotted in dB. It can be seen that the graphs can be approximated locally as linear (in dB=>dB), and have overall a linear shape with saturation at β >15dB. Saturation occurs for practically unachievable β values. This linear shape may be used for compressing the curve for transmission to the BS.

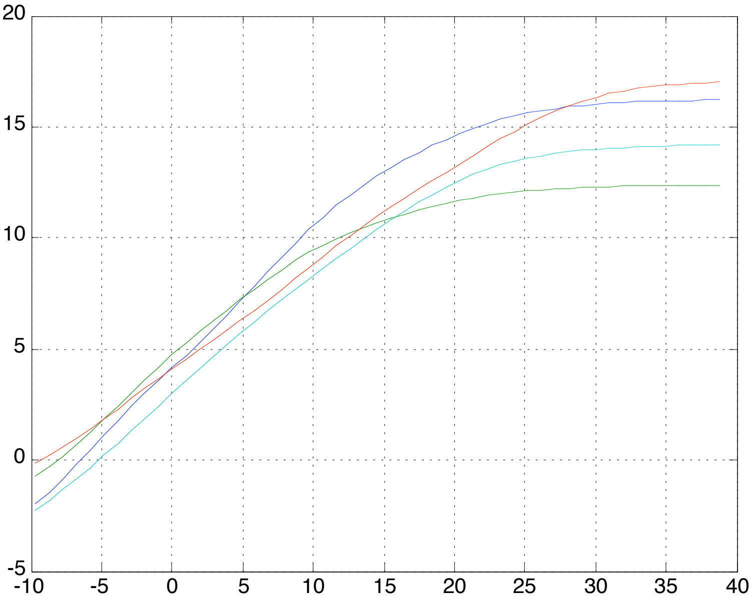

Figure 1 – EESM as a function of β for 4 channel realizations drawn from 24 independent Rayleigh distributions.

For the purpose of fast rate adaptation or Hybrid ARQ, the MSS needs to provide instantaneous SINR and BS may decide rate and boosting, according to MSS instantaneous SINR. However the number of relevant rates is limited and their β values are close. Furthermore, the boosting range is limited, so we are typically interested in a narrow region of the β axis. Thus a local linear approximation suffices, and the graph may be compressed effectively. This implies one straightforward solution – the MSS can initially (e.g. on handover to a new cell) send a table of EESM SINR thresholds and β values for each MCS, and then at a higher speed transmit a local linear approximation for the EESM(β) curve. A more simplified solution is described in section 4.

2.2 Quadratic approximation

The fading channel curves shown in Figure 2 and Figure 3 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 2 and Figure 3, 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, then errors on the order of several dBs may occur.

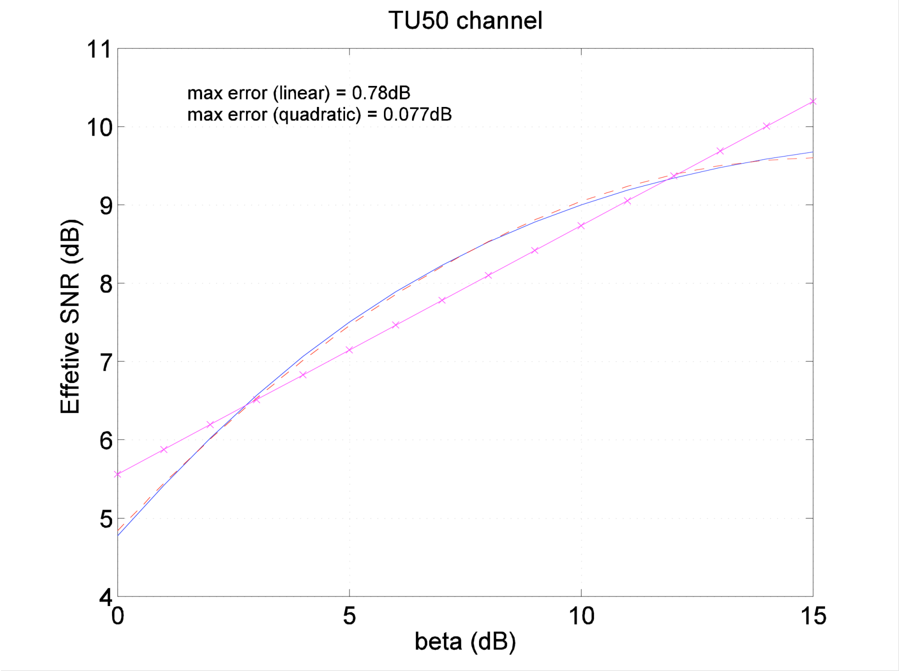

Figure 2. Quadractic (dashed line) vs. linear (cross) curve fitting for the GSM TU channel.

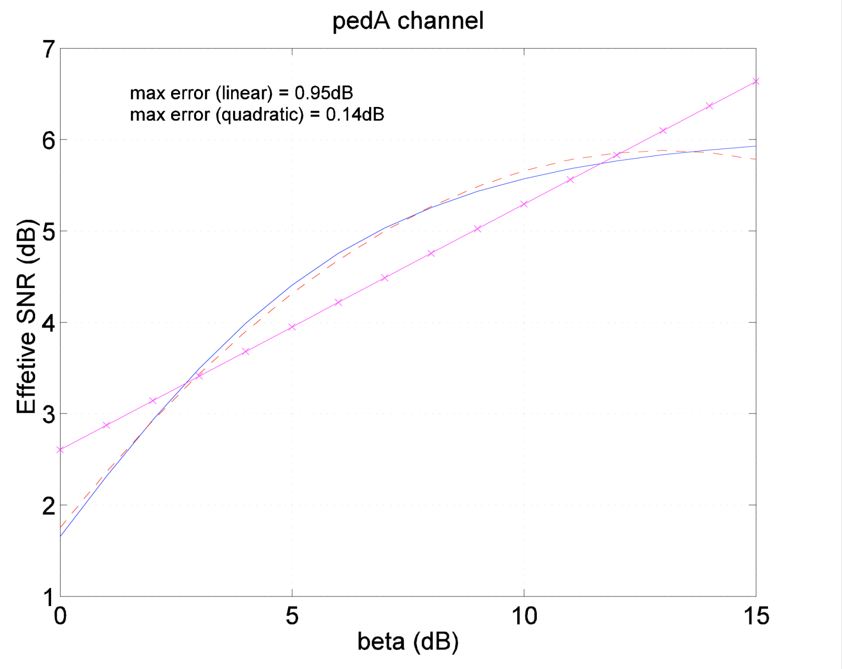

Figure 3. Quadratic (dashed line) vs. linear (cross) curve fitting for the Ped A channel.

3 Accuracy of the EESM method

The accuracy of the EESM modeling technique as a predictor for the AWGN-equivalent SINR was analyzed extensively for OFDM in [1][2][3].

In addition, we performed a short examination in order to validate the accuracy of EESM for 802.16. The following methodology was used.

(A) First, optimal β values were estimated for each MCS level as follows:

- A reference PER(SNR) for AWGN conditions was generated for each MCS.
- N multi-path channel realizations (SUI3 profile) were generated at random.
- For each channel realization, a PER(SINR) curve was generated for all MCS types through simulation.
- For each MCS, a β estimate was obtained such that the mean square error between the (AWGN-equivalent) EESM SINR and the true AWGN SINR was minimized.

(B) Then, the accuracy of EESM was evaluated:

- K other multi-path channel realizations were generated.
- For each channel realization, a PER(SINR) curve was generated for each MCS type through simulation.
- For each MCS, we compared the AWGN-equivalent SINR obtained using EESM (with the estimated β value) and the AWGN-equivalent SINR obtained from the simulation.

The following scenario was examined:

- DL PUSC zone, full bandwidth.
- CTC encoding.
- 120 byte payload, various MCS levels.
- SUI3 multi-path channel.
- β fit optimized for PER=1e-2.

The following figures show, for each MCS (QPSK _, QPSK _, 16-QAM _, and 16-QAM _), the distribution of the EESM fit error (on the left) and the mean SINR vs. EESM prediction error (on the right) for the channel realizations tested in step (B).

As can be observed, all EESM prediction errors fall within a +/-0.5dB range for QPSK and within a +/-1dB range for 16-QAM.

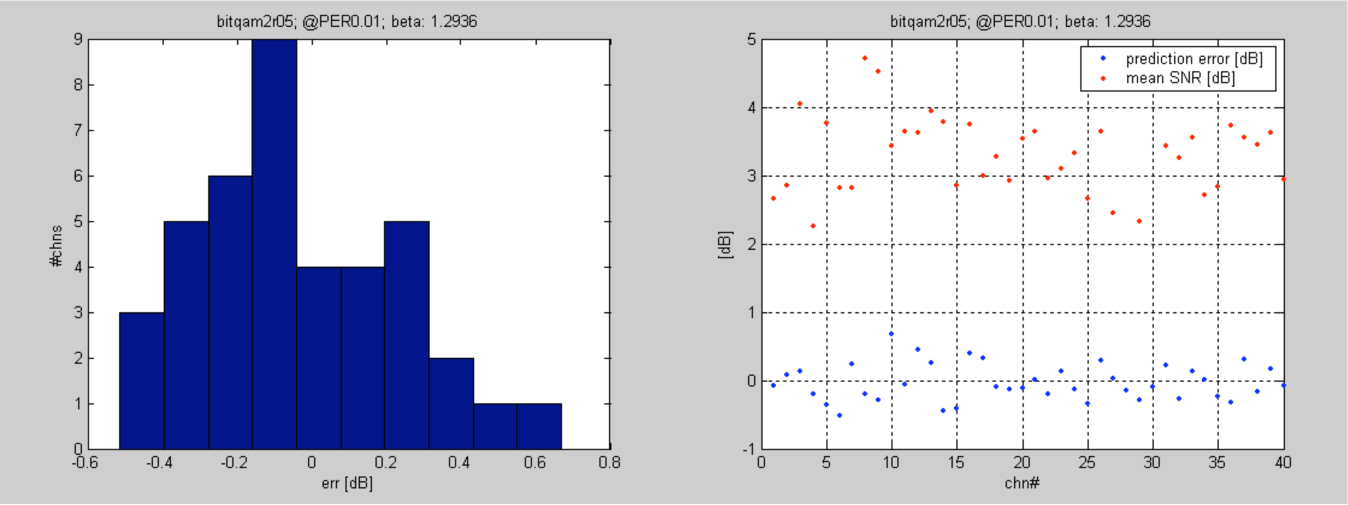

Figure 4 – QPSK _: (left) EESM fit error, (right) mean SINR and prediction error per channel realization

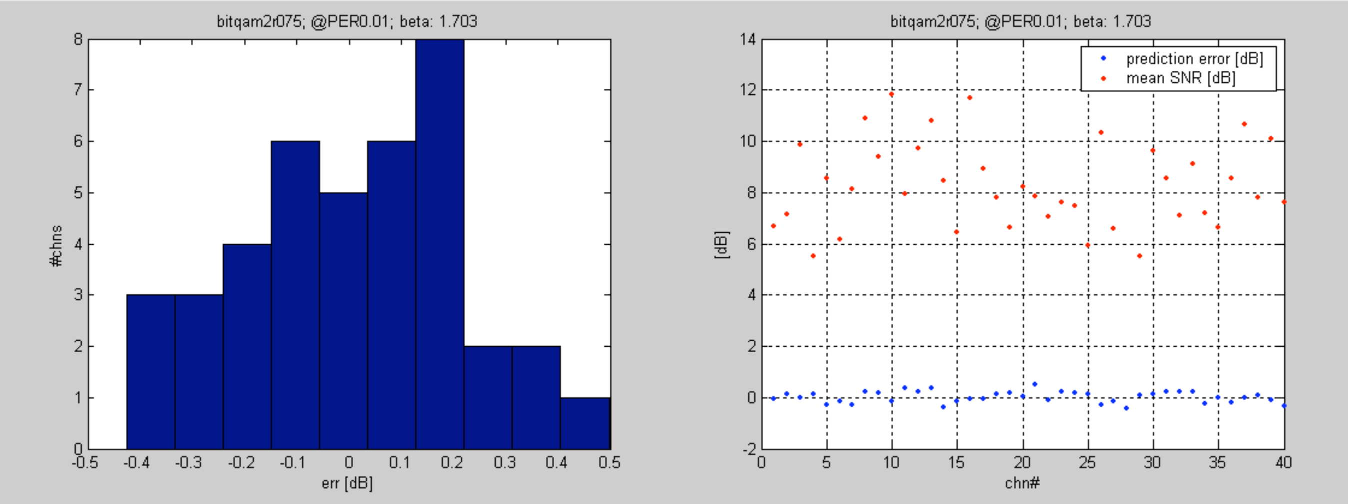

Figure 5 - QPSK _: (left) EESM fit error, (right) mean SINR and prediction error per channel realization

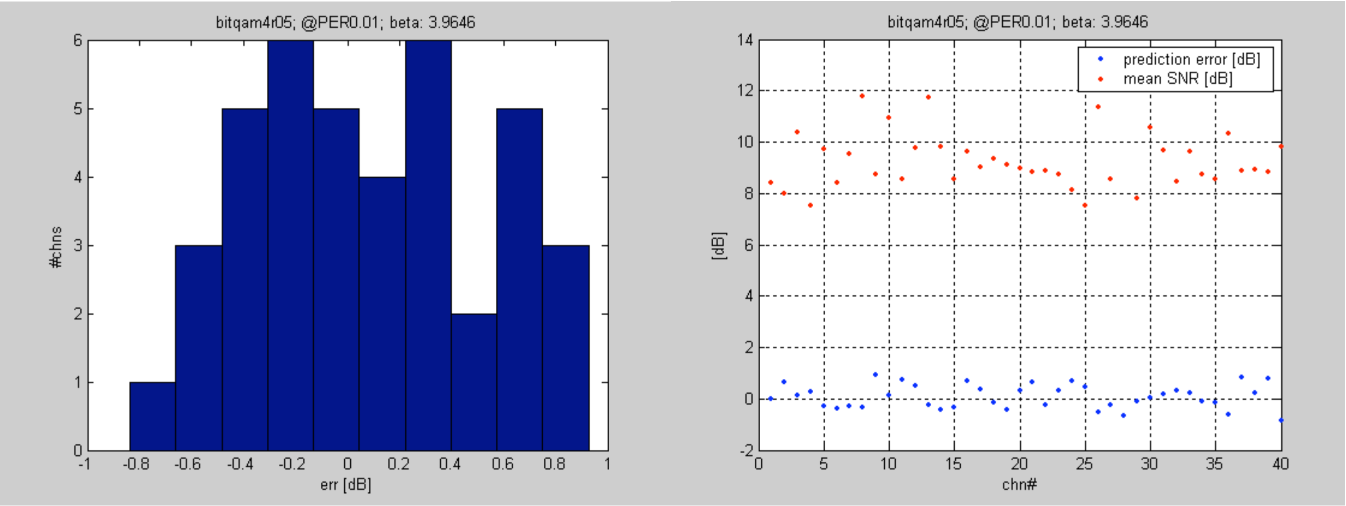

Figure 6 – 16-QAM _: (left) EESM fit error, (right) mean SINR and prediction error per channel realization

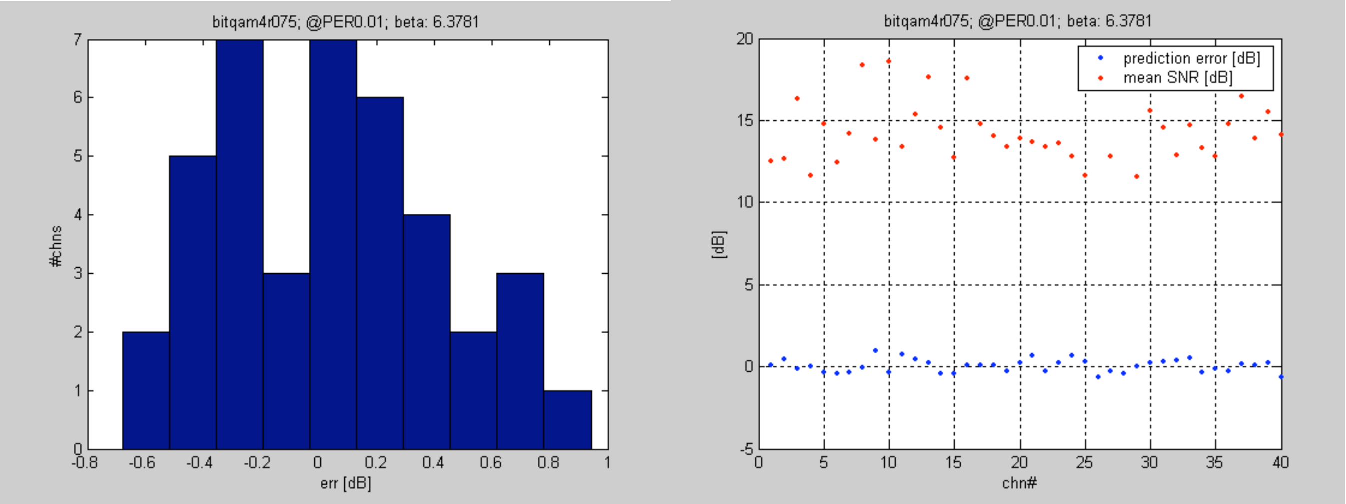

Figure 7 – 16-QAM _: (left) EESM fit error, (right) mean SINR and prediction error per channel realization

4 Outline of the proposed solution

In section 2.1 we showed that the relationship between EESM and β can be expressed as a linear approximation. The proposed mechanism is as follows:

- MSS computes SINR-per-tone vectors for the purpose of EESM.
- MSS computes the curve parameters of EESM(β) in the β range of interest. Curve parameters consist of a linear parameter (slope) or both linear and quadratic parameters. The range of interest depends on current MCS level, for example, an MSS that operates in the QPSK area should compute the local slope for the QPSK range of βs rather than the local slope for the QAM-64 range of β s.
- MSS sends the curve parameters to the BS, and updates the BS whenever these parameter change (due to change in channel conditions) – slow update.
- MSS uses β values from a table of β per MCS (provided by the BS) to compute CINR measurement based on the EESM formula. These measurements are averaged.
- The MSS compensates for implementation losses so that the transmitted CINR values are aligned with normalized threshold levels supplied by the BS.
- A CINR report consists of a single CINR value. The MSS sends the CINR measurement that corresponds to one of the βs; this β is selected using a rule, which ensures that the BS knows its value.

The BS now has all needed information (EESM CINR value, β for which it was computed, local linear approximation of EESM(β)) in order to predict the effect of boosting and change of MCS level with the MSS's current channel conditions.

5 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]

[Note to editor: the correct table number should replace XXX]

6.3.2.3.63 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 message format }		
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 β values in section 8.4.11.4, table XXX, apply: 0b00 = CC 0b01 = BTC 0b10 = CTC 0b11 = LDPC
}		
Start frame	5 bits	6 LSBs of the frame number in which the new measurement mode is activated; at least 2 frames ahead of the current frame.
}		

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 parameters of the CINR (dB) vs. β (dB) curve.

Table UUU – CINRMODE_RSP message format

Syntax	**Size**	**Notes**
CINRMODE_RSP message format }		
Management Message Type = 67	8 bits	
Beta parameters included	1 bit	
If (Beta parameters included == 1) {		
Linear _parameter	8 bits	Curve fitting parameter for the CINR (dB) vs. β (dB) curve for EESM-based measurements, in units of 0.01. See section 8.4.11.4.
Quadratic _parameter	8 bits	Curve fitting parameter for the CINR (dB) vs. β (dB) curve for EESM-based measurements, in units of 0.01. See section 8.4.11.4.
}		
}		

[Add the following new section 8.4.11.4]

[Note: the correct table number should replace XXX]

8.4.11.4 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 and/or standard deviation (reported either through REP-REQ/RSP or through fast-feedback channel) shall be computed using the EESM method. In this mode, the MSS measures SINR per subcarrier on a subchannel indicated by the BS. The BS shall facilitate this by maintaining constant output power on the indicated subchannel (specified in the latest CINRMODE_REQ message) throughout the duration of the zone specified in the CINRMODE_REQ message.

The EESM CINR estimate of a single message k shall be derived as a function of the weighting factor β using

$$CINR_{\beta}[k] = EESM(\{\gamma_1,\ldots,\gamma_N\},\beta)$$

Where:

$$EESM(\{\gamma_1,\ldots,\gamma_N\},\beta) = -\beta\cdot\ln\left(\frac{1}{N}\sum_{i=1}^{N}\exp\left(-\frac{\gamma_i}{\beta}\right)\right)$$

$\{\gamma_1,\ldots,\gamma_N\}$	are the set of per-subcarrier CINR values (in linear scale) corresponding to the subcarriers of the message (the manner in which these are derived is left to individual implementation). The CINR values shall not include the effects of data boosting.
β	is a weighting coefficient,

In addition, the MSS shall compute the linear or quadratic approximation of CINR (dB) vs. $_{dB}$=10log( ) and update its parameters using the CINRMODE_RSP message according to the following procedure. After the quadratic curve fitting, CINR can be approximated as:
EESM (dB) = a+b $_{\mathrm{dB}}$ +c $_{\mathrm{dB}}{}^{2}$
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.

$EESM(\{\gamma_1,\ldots,\gamma_N\},\beta)$ shall be derived with a relative accuracy of +/-1dB and an absolute accuracy of +/-2dB. The mean CINR statistic (in dB) shall be derived, for each β defined in table XXX, from a multiplicity of single messages using

$$\hat{\mu}_{CINR\_dB,\beta}[k] = 10\log\left(\hat{\mu}_{CINR,\beta}[k]\right),$$

where

$$\hat{\mu}_{CINR,\beta}[k] = \begin{cases} CINR_{\beta}[0] & k=0 \\ \left(1-\alpha_{avg}\right)\hat{\mu}_{CINR,\beta}[k-1]+\alpha_{avg}\cdot CINR_{\beta}[k] & k>0 \end{cases}$$

k	is the time index for the message (with initial message being index by k=0, the next message by k=1, etc.)
α_{avg}	is an averaging parameter specified by the BS.

The standard deviation statistic (in dB) shall be derived, for each β defined in table XXX, from a multiplicity of single messages using

$$\hat{\sigma}_{CINR\_dB,\beta}[k] = 5\log_{10}\Big(\hat{x}^{2}_{CINR,\beta}[k]-\hat{\mu}^{2}_{CINR,\beta}[k]\Big|\Big)$$

where

$$\hat{x}^{2}_{CINR,\beta}[k] = \begin{cases} \left|CINR_{\beta}[0]\right|^{2} & k=0 \\ \left(1-\alpha_{avg}\right)\hat{x}^{2}_{CINR,\beta}[k-1]+\alpha_{avg}\cdot\left|CINR_{\beta}[k]\right|^{2} & k>0 \end{cases}$$

The MS reports the mean and standard deviation of CINR for a single value of β in the vicinity of the MS's operation region. In order to resolve ambiguity, the mean and standard deviation of CINR shall be reported for the value of β that corresponds to the highest MCS in table XXX for which

$$\hat{\mu}_{CINR\_dB,\beta(MCS)}[k] > \text{Normalized C/N}\left(MCS\right).$$

Table XXX – normalized C/N and β per MCS

MCS	**Normalized C/N [dB]**	**10log$_{10}$(β) [dB]**
QPSK _	5dB	1.3
QPSK _	6.5dB	1.7
16-QAM _	11dB	3.6
16-QAM _	14dB	6.5
64-QAM _	16dB	11.5
64-QAM 2/3	17.5dB	23
64-QAM _	19dB	27
64-QAM 5/6	21dB	35

The BS may choose to provide other values for table XXX for specific FEC types or block sizes, by overriding the default values using dedicated UCD message TLVs.

In addition, the MSS shall compute the linear approximation of the $\hat{\mu}_{CINR\_dB}\left(10\log(\beta)\right)$ curve and update it's parameters using EESM_RSP messages as channel conditions change. The manner in which the linear and quadratic parameters are computed is 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 so that an MSS reporting EESM-based CINR value higher or equal to a C/N value appearing in table XXX is able to demodulate data in the respective modulation and coding rate, in the current selective channel conditions, with BER equal to 1e-5 using the FEC indicated in the CINRMODE_REQ message. For example, a SS reporting CINR=6dB should be able to decode QPSK rate 1/2 with BER equal to 1e-5.

[Add the following entries to the end of table 353, section 11.3.1]

[Note: the correct table number should replace XXX]

EESM Normalized C/N override for CC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.25. The bytes correspond in order to the list defined by table XXX, starting from the second line. The number encoded by each byte represents the difference in normalized C/N relative to the previous line in the table, for CC FEC.

EESM β override for CC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.1. The bytes correspond in order to the list defined by table XXX, starting from the first line. The number encoded by each byte represents the value of $10\log_{10}(\beta)$ for CC FEC.
EESM Normalized C/N override for BTC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.25. The bytes correspond in order to the list defined by table XXX, starting from the second line. The number encoded by each byte represents the difference in normalized C/N relative to the previous line in the table, for BTC FEC.
EESM β override for BTC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.1. The bytes correspond in order to the list defined by table XXX, starting from the first line. The number encoded by each byte represents the value of $10\log_{10}(\beta)$ for BTC FEC.
EESM Normalized C/N override for CTC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.25. The bytes correspond in order to the list defined by table XXX, starting from the second line. The number encoded by each byte represents the difference in normalized C/N relative to the previous line in the table, for CTC FEC.
EESM β override for CTC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.1. The bytes correspond in order to the list defined by table XXX, starting from the first line. The number encoded by each byte represents the value of $10\log_{10}(\beta)$ for CTC FEC.
EESM Normalized C/N override for LDPC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.25. The bytes correspond in order to the list defined by table XXX, starting from the second line. The number encoded by each byte represents the difference in normalized C/N relative to the previous line in the table, for LDPC FEC.
EESM β override for LDPC FEC	ZZZ	8	This is a list of numbers, where each number is encoded by one byte, and interpreted as a signed value in units of 0.1. The bytes correspond in order to the list defined by table XXX, starting from the first line. The number encoded by each byte represents the value of $10\log_{10}(\beta)$ for LDPC FEC.

[Add the following new section 11.8.3.7.X]

11.8.3.7.X Optional CINR measurement mode support

These fields indicate the support of optional CINR measurements, by a WirelessMAN-OFDMA PHY MSS. These field are not used for other PHY

specifications. The first bit indicates the capability to perform optional CINR measurements. A value of 0 indicates not supporting CINR measurement. A value of 1 indicates supporting the CINR measurement.
The second bit indicates approximation level of the optional CINR measurement. A value of 0 indicates linear approximation. A value of 1 indicates both linear and quadratic approximation.

Type	Length	Value	Scope
XXX	1	Bit #0: EESM CINR measurement. Bit #1: EESM CINR measurement approximation capability	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

===

6 References

[1] “Considerations on the System-Performance evaluation of HSDPA using OFDM modulation”, Ericsson, 3GPP TSG_RAN WG1 #34, R1-030999, October, 2003.

[2] “System-level evaluation of OFDM – further considerations”, Ericsson, 3GPP TSG_RAN WG1 #35, R1-031303, November, 2003.

[3] “OFDM EESM simulation Results for System-Level Performance Evaluations, and Text Proposal for Section A. 4.5 of TR 25.892”, Nortel Networks, R1-04-0089, January, 2004

[4] “Feasibility Study for OFDM for UTRAN enhancement, Release 6”, 3GPP TSG RAN, TR 25.892 v1.1.0, March 2004.