Modified EESM Based Link Adaptation Algorithm for Multimedia Transmission in Multicarrier Systems

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Abstract

The previous link adaptation algorithms on ofdm based systems use equal modulation order for all sub carrier index within a block. For multimedia transmission using ofdm as the modulation technique, unequal constellation is used within one ofdm subcarrier block, a set of subcarriers for audio and another set for video transmissions. A generic model has been shown for such a transmission and link adaptation algorithm has been proposed using EESM (Effective Exponential SNR mapping) method as basic method. Mathematical model has been derived for the channel based on bivariate Gaussian distribution in which the amplitude varies two dimensionally in the same envelope. From the Moment generating function of bivariate distribution, Probability of error has been theoretically derived. Results have been shown for BER performance of an ofdm system using unequal constellation. BER performances have been shown for different values of correlation parameter and fading figure.

Keywords: 802.16, OFDM, link adaptation EESM

1. Introduction

Next generation cellular systems support multiple transmission modes, which can be used to improve the performance of such systems by adapting to current channel conditions. This process is referred to as link adaptation. Typically, these transmission modes include different modulation and coding, schemes (MCS) and different multiple antenna arrangements modes – such as beam-forming, space-time coding and spatial multiplexing – as the transmission becomes multidimensional in space, time, and frequency domain. Orthogonal Frequency Division Multiplexing (OFDM) is the air interface for 802.11, 802.16 (WiMAX), and 3GPP Long Term Evaluation (LTE) systems. The resources typically referred to as subcarriers, available in an OFDM frame, can be defined on a time frequency grid [1]. The performance of a binary code depends on the channel condition obtained over the allocated subcarriers. Typically, the channel is frequency selective,
2. EESM for Unequal Constellation in OFDM Block

The proposed structure [15] transceiver structure consists of data compressor, unequal adaptive modulator and channel estimator. Multimedia data is compressed using a source coder based on discrete wavelet transformation, in wavelet analysis we represent low frequency information by approximation coefficients cAn an high pass spatial frequency data by horizontal, vertical and diagonal signal by cHn,cVn,cDn. To achieve a target SNR we allocate approximate coefficients with low modulation order and detail coefficients with high modulation order based on the channel estimation feedback message from the receiver.

EESM method has been identified as one of the fast link adaptation technique for multicarrier based systems. For a fast link adaptation of multimedia transmission where the audio and video are transmitted in different constellations on the same OFDM block, the EESM method has been modified and used for performance prediction (e.g., the FER metric) for the current channel conditions. In the subcarrier block with two modulation order are taken such a way that low frequency components (Audio) are transmitted with low modulation order and high frequency components (video) with high modulation order. This method maps a set of per subcarrier SNRs \( \{ \gamma_1 \ldots \gamma_N \} \) to a single effective SNR (SNReff):

\[
\gamma_{\text{eff}} = -\beta.\ln \left( \sum_{i=1}^{N_1} e^{-\gamma_i/\beta_1} + \sum_{i=N_1+1}^{N_2} e^{-\gamma_i/\beta_2} \right) / (N_1 + N_2)
\]

Where \( N_1 \) & \( N_2 \) is the number of sub-carriers used by a codeword, for 1 to \( N_1 \) subcarriers \( \beta_1 \) is the calibration parameter and from \( N_1+1 \) to \( N_2 \) subcarriers \( \beta_2 \) is used as the calibration parameter that is typically different for each MCS. The procedure used to link adaptation with EESM is listed herewith.

1. Obtain the parameters \( a,b,c \) from quadratic equation

   \[
   \text{SNR}_{\text{eff}}(\beta) = a + b\beta + c\beta^2
   \]

   Where \( a,b,c \) are \( y \)-intercept, linear and quadratic parameters.

2. Sent \( a,b,c \) as Channel quality indicator to BTS.

3. BTS receiving the parameters will update it and select the appropriate \( \beta \) for the required SNR_{eff}.

4. Based on current \( \beta \) value the modulation order is selected.

\[
16QAM \\
4QAM \\
quadratic
\]

3. Vertical Shift Method

Enabling the method described above it would require the approximation of the SNR_{eff} vs. \( \beta_1 \) and curve to SNR_{eff} vs. \( \beta_2 \) have to be sent potentially as often as every frame, in order to track changes in the SNR due to fading. This represents less feedback than sending the entire channel response \( \{ \gamma_1, \ldots, \gamma_N \} \), but is still a significant amount of data to be sent.

\[
\gamma_{\text{eff}} = -\beta.\ln \left( \sum_{i=1}^{N_1} e^{-\gamma_i/\beta_1} + \sum_{i=N_1+1}^{N_2} e^{-\gamma_i/\beta_2} \right) / (N_1 + N_2)
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For the quadratic approximation, three coefficients \((a, b, c)\) for two different modulation orders would have to be fed back every frame. A first possible approach to eliminate the frame-by-frame feedback of curve parameters is to assume that the shape of the \(\beta\) curve does not change significantly with changes in band-average SNR as long as the channel power-delay profile does not change.

More specifically, this method consists of sending infrequently the instantaneous SNR eff vs. \(\beta_1\) curve only as a reference SNR value (reference curve) instead of transmitting two curves. The SNR eff vs. \(\beta_2\) curve for the current channel is then obtained by a simple vertical (1-dimensional) shift of the reference curve by 3dB. This first order approximation will be referred to as the vertical shift method.

3. Unequal Modulations – Bivariate Distribution

The two dimensional amplitude variations within same channel envelope can be modeled as bivariate Gaussian distribution. The purpose of such a multilevel modulation is that the carriers in an OFDM block which can withstand deep fading can be allotted a low modulation order and the others high level modulation and as the result the SNR performance can be improved much better than equal modulation. From theory two univariate marginal distributions following Gaussian distribution can be modeled as under the same roof as bivariate joint distribution given [3] by

\[
F(x_1, x_2) = \frac{(x_1 x_2)^{\alpha - 1/2}}{\Gamma(\alpha \| \beta_1 \| \beta_2 \| 1 - \rho \| -1 \rho \|)} \exp \left( \frac{x_1 | \beta_1 + x_2 | \beta_2}{1 - \rho} \right) I_{\alpha - 1/2} \left( \frac{2 \rho | x_1 + x_2 |}{1 - \rho} \right) f(x_1) f(x_2)
\]

(2)

Where \(f(.)\)is gamma function and \(I(.)\) is a modified Bessel function of first kind \(\beta_1\) and \(\beta_1\) are scaling parameters, \(x_1\) and \(x_2\) are random variables for different marginal distributions, and \(\rho\) is the correlation coefficient .When \(\rho \rightarrow 0\) the joint pdf tends to product of two univariate gamma distribution . Consider two OFDM modulation techniques 16QAM and 64QAM and the joint probability distribution for them is given below,
figure and moments. It has the inherent advantage of versatility and covers a wide range of fading channel scenarios. The m-distributed pdf of the envelope is taken as [2].

\[ P(R) = \frac{2m^m R^{2m-1}}{\Gamma(m)\Omega^m} \exp\left(-\frac{mR^2}{\Omega}\right), R \geq 0 \]

where \( \Omega = E(R^2), m = \frac{\Omega^2}{E[(R^2 - \Omega^2)]}, m \geq 1/2 \) \hspace{1cm} (3)

\( \Gamma(\cdot) \) represents the average and \( \Omega(\cdot) \) represents the gamma function, \( \Omega/2 \) is the average power of the signal, ‘m’ is named fading figure, parameter related to fading range. In the case of M-distributed correlated nonidentical fading Nakagami-\( m \) channels PDF of the combined signal envelope[14] is given by

\[ p_a(r_i) = \frac{2r_i \sqrt{\pi}}{\Gamma(m)\left[\sigma_1\sigma_2(1 - \rho)\right]^m} \left[\frac{r_i^2}{2\beta}\right]^{m-1/2} I_{m-1/2}\left(\frac{r_i^2}{2\beta}\right)e^{-\sigma_{\rho}^2}, r_i \geq 0 \]

(4)

where \( I_m(\cdot) \) denotes the \( m \)th-order modified Bessel function

\[ \rho = \frac{\text{cov}(r_1^2, r_2^2)}{\sqrt{\text{var}(r_1^2)\text{var}(r_2^2)}}, 0 \leq \rho < 1 \]

(5)

is the envelope correlation coefficient [3] between the two signals[6] and the parameters \( \sigma_d \) \( (d = 1, 2) \), \( \alpha \), and \( \beta \) are defined as follows:

\[ \sigma_d = \frac{\Omega_d}{m}, \quad d = 1, 2 \]

\[ \alpha' = \frac{\alpha}{E_s/N_0} = \frac{m(\bar{\gamma}_1 + \bar{\gamma}_2)}{2\bar{\gamma}_1\bar{\gamma}_2(1 - \rho)} \]

\[ \beta' = \frac{\beta}{E_s/N_0} = \frac{m((\bar{\gamma}_1 + \bar{\gamma}_2)^2 - 4\bar{\gamma}_1\bar{\gamma}_2(1 - \rho))^{1/2}}{2\bar{\gamma}_1\bar{\gamma}_2(1 - \rho)} \]

(7)

and finally the equation reduces to

\[ p_a(\gamma_1) = \frac{1}{2\sqrt{\rho\gamma}} \left\{ \exp\left[\frac{\lambda_1}{(1 + \sqrt{\rho\gamma})\gamma}\right] - \exp\left[\frac{-\gamma_1}{(1 - \sqrt{\rho\gamma})\gamma}\right] \right\} \]

(8)

Using the Laplace transform it can be shown after some manipulations that the MGF \( p_a(\gamma_1) \) of is given by [5]

\[ M_a(s) = 1 - \frac{(s - \bar{\gamma}_1\bar{\gamma}_2)}{m}s + \frac{(1 - \rho)\bar{\gamma}_1\bar{\gamma}_2}{m^2} s^2 \]

(9)
The average error probability \[14\] in general is given by

\[
P_e = 1 - \int_{-\infty}^{\infty} p(\theta) d\theta
\]

where \(P(\theta) = \int_{0}^{\infty} f(\theta/R)p_o(R) dR.\)

\[
P_e = \frac{\Gamma(2m+1/2)}{e^{\omega \alpha^2} \Gamma(2m+1)} \left( \frac{1}{(\gamma/m) \sin^2 \left( \frac{\pi}{m} \right)} \right)^{2m}
\]

\[\text{[10]}\]

\[
f(\theta/R) \text{ is the p.d.f of the detection error, } p_o(R) \text{ is the pdf of the envelope of the fading signal. After approximation [14]}
\]

\[
P_e = \frac{\Gamma(2m+1/2)}{e^{\omega \alpha^2} \Gamma(2m+1)} \left( \frac{1}{(\gamma/m) \sin^2 \left( \frac{\pi}{m} \right)} \right)^{2m}
\]

\[\text{[11]}\]

\(K\) is the power correlation coefficient of the two set of fading from the above formulas the moment generating function is dependent upon the correlation coefficient

4. Simulation Results

| SIMULATION PARAMETERS | DETAILS |
|-----------------------|---------|
| Order of the system (M) | 4, 16 and 64 |
| Types of Modulation | QPSK, QAM |
| Data rate (Max.) | 50 Mbps |
| Coding rates | 1/2, 2/3, 3/4 |
| Subcarriers for audio transmission | 52 |
| Subcarriers for video transmission | 256 |
| Number of pilot carriers | 4, 8 |
| Guard interval | 800 ns |
| OFDM symbol duration | 4 \(\mu\)s |
| Channel bandwidth | 20MHz |

Table 1 Simulation parameters for unequal modulation

For the above mentioned parameters in a rayleigh channel the simulation has been conducted for unequal modulation orders. The resultant shows the unequal ber performance is better compare to high modulation order to all subcarriers.

![Fig. 5 Ber results for equal and unequal modulation](image)

![Fig. 6 Performance of SNR vs BER for different values of \(\rho\)](image)

The above graph is plotted for different values of \(\rho\) for 16 qam modulation. The plot shows that as the \(\rho\) value increases the ber increases as the fading profile increases with \(\rho\).
5. Conclusion

The paper proposes an EESM based link adaptation algorithm in which unequal constellation orders has been used for the same sub-carrier block of an OFDM system. Simulation results have been shown for bit and fading margin with unequal constellation size. The result shows performance enhancement over equal constellation orders in OFDM system.

References

[1] Sayana K, Zhuang J, Stewart K. Motorola Inc. Short term link performance modeling for ml receivers with mutual information per bit metrics June 2002.
[2] 3GPP2, TSG-C WG3.3GPP TS 25.321 v 5.5.0, Medium Access Control (MAC) protocol specification.
[3] IEEE 802.16 Broadband Wireless Access Working Group, Sayana K, Zhuang J, Stewart K, Motorola Inc. Link performance abstraction based on mean mutual information per bit (MMIB) of the llr channel Nov 2006.
[4] Brueninghaus K, Astely D. Salzer T, Visuri S. Link performance models for system level simulations of broadband radio access systems, IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) Sept 2005.
[5] Wan L, Tsai S, Almgren M. A fading- insensitive performance metric for a united link quality model. Proceedings of WCNC 2006;2110-2114.
[6] Wang TR, Proakis JG, Masry E, Zeidler JR. Performance Degradation of OFDM Systems Due to Doppler Spreading Sept 2004.
[7] Kim J, Ashkhamin A, Wijngaarden A, Soljanin E. Reverse link hybrid ARQ link error prediction methodology based on convex metric. Lucent Technologies Jan 2007.
[8] IEEE 802.16m-07/031, IEEE 802.16 Broadband Wireless Access Working Group: RBIR MLD PHY Abstraction for HARQ IR/CC,03/10/2007.
[9] Simon MK, Alouin MS. Digital communication fading channels –A unified approach to performance analysis. John Wiley and Sons:2000.
[10] Sayana K, Zhuang J. Link performance abstraction based on mean mutual information per bit (MMIB) of the LLR channel. IEEE Contribution, C802.16m-07/097; May 2007.
[11] Ericsson, System-level evaluation of OFDM – further considerations, 3GPP TSG-RAN WG1, No. 35 R1-031303; 2003. [12] Baum, Kevin, L., Blankenship, Yufei, W., Classon, Brian, K.,Sartori. : US251180 (2006).
[13] IEEE802.16m-07/031, IEEE 802.16 Broadband Wireless Access Working Group: RBIR MLD PHY Abstraction for HARQ IR/CC,03/10/2007.
[14] Yoshiyamagaki, Norihiko, Toshihiko namekawa “Error probability characteristics for c-psk signal Through m-distributed fading channel” IEEE Transactions on communication, vol.com26,NO.1,January 1978
[15] Tasso Athanasias, Kevin H.Lin, and Zahir M.Hussain, “An Unequal modulation scheme for the transmission of compressed multimedia data over adaptive mimo ofdm systems”, TENCON 2006:2006 IEEE Region 10th conference 14-17 Nov 2006 pages:1-4

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