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Analytical Frame Work for MIMO-OFDMA With Non-Stationary Interference

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ABSTRACT: MIMO OFDMA system is used for high data rate services in wireless communication networks. Here multi cell systems developed based on broadband wireless standards such as Wi-MAX and 3GPP LTE. Beam forming systems with Coordinated Scenario is used for mitigation of stationary interference and Diversity model with Randomized interference is used for Non-Stationary interference. The analytical frame work for bit error probability of multi cell bit interleaved convolution coded system.

KEYWORDS: BER,BICM,MVDR,MVDR.

I. INTRODUCTION

OFDMA used for next generation wireless systems for its flexibility and scalability. OFDMA-MIMO system used for efficient solution for high spectral efficiency requirements. Nowadays, COFDM represents the core of the physical layer of many communication standards such as Wi-Fi, Wi-MAX and LTE. For high data rate systems are expected for different applications maximize capacity, mitigation of interference and channel aware scheduling algorithms. Performance evolution of propagation interference scenario and cellular deployments makes complex task by reducing computational burden of extensive simulations are analytical modal. Bit interleaved coded modulation of OFDMA system over space frequency selective fading channels. Cellular systems are suffering by non stationary inter cell interference due to fluctuations of the traffic load over the cells. Performance analysis has interference mitigation techniques and adaptive modulation coding schemes. Performance assessment for system settings and the wide range of propagation scenarios and cellular development makes this evaluation complex task. The analytical models for physical layer performance are relevant to reduce the computational burden of extensive simulations. The analytical frame work has multi cell scenarios with practical multi user access policies and realistic channel models, multi antenna links with BICM OFDM Over space frequency selective fading channels. Performance analysis should include interference mitigation techniques and adaptive modulation coding schemes.

II.BACKGROUND

The historical roadmap dates back from the early60s with the idea of using frequency division multiplexingwith overlapping sub channels to the OFDM system as we refer to nowadays. During the 80s and 90s codedOFDM (COFDM) has been investigated for Digital Video Broadcasting (DVB) as first massive application. COFDM for cellular mobile radio systemswith pilot based correction has been proposed bygeneral framework for performance evaluation of BICM was first given in following an information-theoretical analysis based on channel capacity and cutoff rate. The average and outage performances for a wide spectrum of digital communication systems have been presented as where in multi-antenna combining techniques and fading propagation environments have been considered. Furthermore, the effects of impairmentfluctuations due to non-stationary noise have been treated. The uncoded slot error rate over non-linear frequency-selective fading channels has been derived for DVB systems. In the analytical study has been adapted to provide the bit error rate for DVB coded systems. For frequency-selective channels, the

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effective signal-to-noise-ratio (SNR) has been introduced as the SNR of an equivalent frequency-flat additive white Gaussian noise (AWGN) channel yielding the same performance. The idea of the effective SNR is simple but still powerful to adapt modulation and coding to the instantaneous channel conditions (and service requirements), or to assess the average error rate for a given transmission mode. The approach recently evolved into the exponential effective SNR mapping (EESM) that provides a semi-analytical model for link-layer performance of COFDM systems; extensions to Wi-MAX and LTE. The EESM and mutual information based ESM methods provide the instantaneous performance of such systems, for a given frequency-selective channel response and interference configuration, without averaging over the fading and interference statistics. The statistics of the effective SNR has been derived for multi antenna WiMAX systems in fading environments in order to evaluate the average error rate without these heuristic adjustments. This paper extends the analysis to systems with multiple antennas at both links, non-stationary inter cell interference and higher order modulations.

III. IMPLEMENTING METHOD

The performance of the MIMO-OFDMA system over space frequency selective channels and non-stationary interference. The performance is evaluated average bit error rate by using union bound approach with convolution codes. The transmission of a codeword over parallel sub channels. The performance of coded MIMO OFDMA system can be analyzed by deriving the pair wise error probability by using union bound approach $p(c)$. the error event 'c' depend on statistics of signal to interference noise ratio changes over the sub channels, due to multipath propagation and time varying interference from nearby cells, the signal to interference noise ratio values are correlated random variables, whose statistical properties are fading channels and interference levels observed along the sub channels. In this paper the derivation of the average bit error probability

$$P(c) = E_{\gamma}[P(c|\gamma)] = E_I[E_H[P(c|H, I)]] \quad (1)$$

The average is first performed with respect to the space time correlated channel $E_H[\]$ through derivation of the effective signal to interference noise ratio probability density function and average with respect to the interference $E_I[\]$. The analysis focus on two types of fading and interference mitigation strategies i.e., closely spaced apart antennas paired with beam forming processing for attenuation of the out of cell impairments and widely spaced apart antennas with orthogonal space time block coding for gaining spatial diversity .A multicell scenario has been considered for inter-cell interference based on either coordinated or randomized multi-user access. The analytical formulation accounts for the spatial-frequency selectivity of the fading channel and possible non-stationary interference due to subcarrier randomization. Both beam forming and diversity schemes have been considered as multi-antenna systems. The analysis has been carried out for convolutional coded BICM systems with BPSK modulation.

a) *ofdma cellular layout:*

MIMO OFDMA multicell system is developed based on broadband wireless standards such as WIMAX, 3GPP LTE. In every cell base station is $N_R \geq 1$ antennas & each subscriber

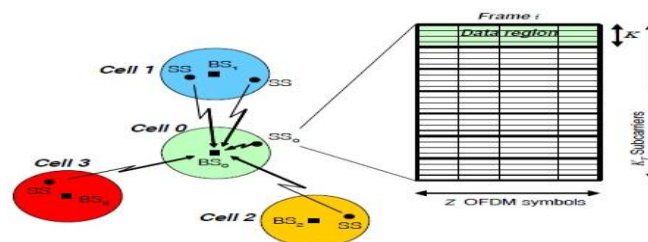


Fig 1: interference scenario in a multi-cell system

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station antennas $N_T \geq 1$. the traffic load is denotes the number of active subcarriers out of the total number .the line between SS0 to bso,interference is Ni SS's in nearby cells that share part of the time frequency resources used by SS0.

b) multi user access scenarios:

The mapping rule between the logical data regions and physical resources to cope with time varying fading and interference based on conventional scheduling techniques adopted in OFDMA system. In the coordinated method, the data is sent over the channel with adjacent, or piecewise-adjacent Subcarriers which make the inter channel interference pattern to be constant over the whole channel region. The MIMO-OFDMA system applied here is for two dimensions that can be employed for reduction of ICI: the frequency domain of the OFDM signaling and the spatial domain offered by the array processing. To improve the ICI rejection capability, system adopt a uniform linear antenna array (ULA) with closely spaced antennas and a beam forming processing over every subcarrier.

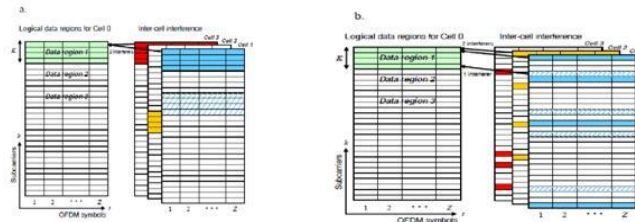


Fig 2 : multi user access scenario

In randomized method, diversity is artificially introduced through the randomized multi-user access approach which provides ICI fluctuations over the codeword. Here any interference mitigation techniques is unfeasible due to the unpredictability of the impairments configuration and so the receiver is based on coherent maximum likelihood (ML) OSTBC detector.

c) signal model:

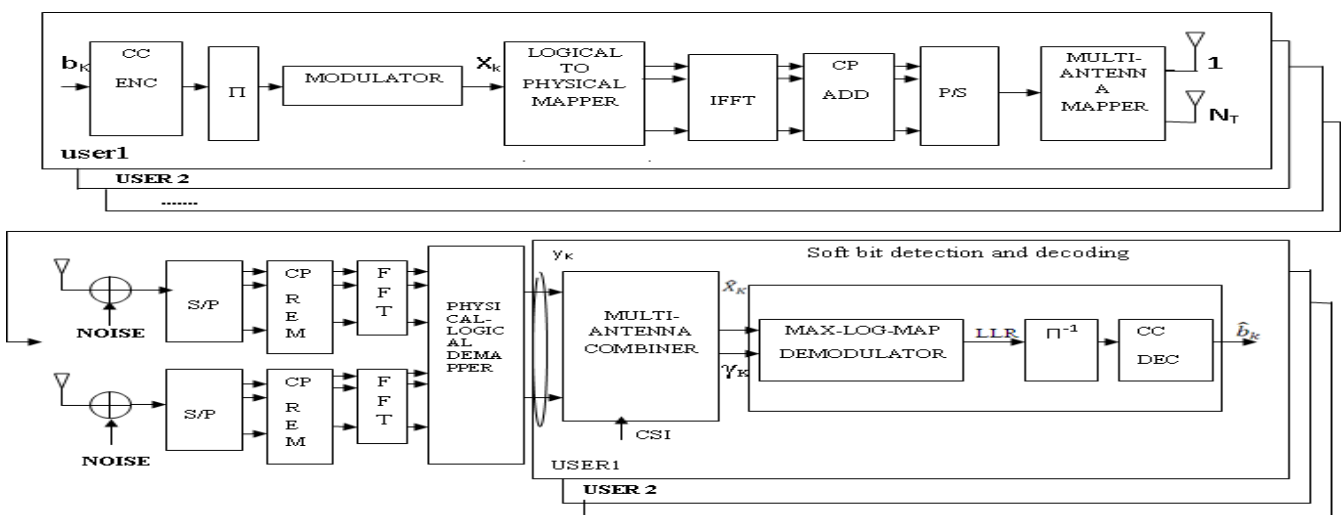


Fig3: Block diagram of proposed method

A sequence of bits are coded by a Convolution code with rate RCC .The code word is then interleaved and mapped onto complex valued symbols that are defined in a modulation set S the modulated signals are assigned to the logical data region allocated to the user and then mapped over the physical resources of the frame according to the coordinated or randomized scheduling strategy. Each OFDM symbols of the frame is transmitted by the multi antenna system over a

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frequency selective fading channel and interference are assumed to be constant within one frame but varying from frame to frame. Without loss of generality, we now focus on a single OFDM symbol of the frame. The baseband signal obtained on the subcarrier is modelled as H

$$y_k = \sqrt{P_0} H_k x_k + n_k \quad (2)$$

Where the transmitting power is indicated with, the MIMO matrix gathers the complex channel gains and the $N_T \times 1$ vector x_k collects the transmitted symbols mapped over the antennas with normalized energy $E[\|X_k\|^2] = 1$.

The subcarrier index $k \in \mathcal{K}$ ranges over the K allocated subcarriers. The $N_R \times 1$ vector $n_k \sim \mathcal{CN}(0, Q_k)$ models the background noise and the co-cell interference on the k th subcarrier as Gaussian with spatial correlation

$$Q_k = \sum_{i \in I_k} P_i Q_{k,i} + \sigma_{bn}^2 I_{N_R} \quad (3)$$

Background noise has power σ_{bn}^2 . The interfering signal from the i th cell is characterized by a transmitting power P_i and a spatial covariance Q_k , i that remains the same over a number of frames since it is related to the spatial position of the interfering users. The covariance matrix is normalized with $[Q_{k,i}]_{n_R, n_R} = 1$ for $n_R = \{1, \dots, N_R\}$. Let us label with index $i = 1, \dots, N_I$ the interfering cells; the set $I_k \subseteq \{1, \dots, N_I\}$ denotes the group of cells that are using the same k th subcarrier as SSO. The cardinality $v_k = |I_k| \in \{0, 1, \dots, N_I\}$ gives the number of active interferers while the set J_k depends on the index k as the configuration of the interferers varies along the subcarriers according to the adopted interference management policy. After physical-logical demapping, the received signals y_k are processed by the multi-antenna combiner according to the channel state information (CSI) that includes both channel and interference conditions. The combiner provides the estimates \hat{x}_k of the transmitted symbols paired with the corresponding SINR values $\gamma_k = \gamma_k(H_k, I_k)$. Max-Log-Map demodulation is carried out to provide the log-likelihood ratios (LLR) to the Viterbi decoder. For LLR computation the instantaneous channels H_k are assumed to be perfectly known while the interference levels I_k (that may rapidly vary with k due to subcarrier permutation) are known either perfectly or in average only.

d) *Channel and interference model:*

The spatial correlation of the fading channel is kronecker product of spatial covariance transmitting antenna and spatial covariance receiving antenna

$$R_{s,r} = R_{TX,r} \otimes R_{RX,r} \quad (4)$$

Here two different models that are beam forming model and diversity model. Beam forming model: the antenna arrays with closely spaced apart elements. Over all interference

$$Q_k = \sum_{i \in I_k} P_i \sum_{r=1}^{W_1} \rho_{i,r} a_R(\theta_{i,r}^{(R)}) a_R^H(\theta_{i,r}^{(R)}) + \sigma_{bn}^2 I_{N_R} \quad (5)$$

Diversity model: the array elements that are sufficiently far apart. the received fading signals are un correlated among the antennas. the total interference power

$$\sigma_k^2 = \sum_{i \in I_k} P_i + \sigma_{bn}^2 = v_k P_1 + \sigma_{bn}^2 \quad (6)$$

IV. ANALYTICAL FRAME WORK FOR BIT ERROR RATE MIMO- OFDMA SYSTEM

Mimo-ofdma system performance in terms of average bit error probability. it is evaluated through the union bound.

$$\begin{aligned} \bar{P}_b &\leq \frac{1}{k_{cc}} \sum_{d \geq d_{free}} \sum_{c \in \mathcal{E}(d)} \beta(c) P(c) \\ &= \frac{1}{k_{cc}} \sum_{d \geq d_{free}} \sum_{c \in \mathcal{E}(d)} \beta(c) E_\gamma [P(c|\gamma)] \quad (7) \end{aligned}$$

Averaging the conditioned pair wise error probability

$$P(c|\gamma) = P(c|H, I) = Q(\sqrt{2\gamma_{eff}}(H, I)) \quad (8)$$

a) *Average over the fading:*

The average of the conditioned PEP with respect to the fading is $P(c|I) = E_H [P(c|H, I)]$

$$= \int Q(\sqrt{2\gamma_{eff}}) p(\gamma_{eff}|I) d\gamma_{eff} \quad (9)$$

The probability density function can be simplified according.

$$p(\gamma_{eff}|I) = \sum_{i=1}^{d N_R N_T} \frac{A_i}{\lambda_i} \exp(-\gamma_{eff}/\lambda_i) \quad (10)$$

Hence, after straightforward algebraic manipulations, the average PEP can be written as

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$$P(c|I) \leq \frac{1}{2} \sum_{i=1}^{dN_{RN_T}} \frac{A_i}{1+\lambda_i} \quad (11)$$

b) *Code word bound:*

To evaluate the bit error probability (7) we have to account for all the possible code words of the set $\mathcal{E}(d)$ for a given d . The cardinality of $\mathcal{E}(d)$ varies with respect to the specific CC and it usually grows for increasing Hamming distance. Notice also that interleave and scheduler scramble the bits of each code word in different ways giving rise to a large number of patterns of subcarriers carrying the unmatched bits. Due to the selectivity of the channel, each configuration experiences a different degree of diversity. For example, let us consider the CC with generator polynomials [171, 133]: at the free distance $d_{free} = 10$ the set $\mathcal{E}(d_{free})$ is composed by 11 possible error paths. Hence the computation of (7) requires the evaluation of at least these 11 configurations.

To avoid the exhaustive computation of all the error events for a given set $\mathcal{E}(d)$, in the high SINR region we simplify the bound by upper bounding each PEP with the PEP of the Code word $c_{w,d}$ associated to the configuration of d bits that achieves the minimum degree of diversity (or equivalently, the maximum correlation of the SINR values over \mathcal{F}) at the output of the scrambling process, thus leading to $P(c) \leq P(c_{w,d})$. In this way the system performance (7) is further bounded as

$$\tilde{P}_b \leq \frac{1}{k_{cc}} \sum_{d \geq d_{free}} \beta_d P(c_{w,d}) \quad (12)$$

With $\beta_d = \sum_{c \in \mathcal{E}(d)} \beta(c)$. Hence, the worst error event $c_{w,d}$ is the one that yields the highest PEP:

$$c_{w,d} = \arg \max_{c \in \mathcal{E}(d)} \{P(c|I)\} \quad (13)$$

For the maximization we use the expression

$$P(c|I) = \frac{1}{\pi} \int_0^{\pi} \prod_{i=1}^{dN_{RN_T}} \left(1 + \frac{\lambda_i}{\sin^2 \theta}\right)^{-1} d\theta \quad (14)$$

for the conditioned PEP, upper-bounded with $\sin^2(\theta) \leq 1$ (see also, i.e.:

$$P(c|I) \leq \frac{1}{2} \prod_{i=1}^{dN_{RN_T}} \frac{1}{1+\lambda_i} \quad (15)$$

c) *Co-ordinated interference scenario:*

The data regions in all cells are mapped over adjacent or piecewise adjacent subcarriers which make the interference pattern to be constant over the whole data region. The stationary interference allows for an accurate estimate of the impairment covariance which can efficiently be exploited for interference mitigation. To enhance the interference rejection capability use uniform linear antenna array (ULA) with closely spaced apart antennas and beamforming processing over each subcarrier. The SINR depends only on the channel variations over K , whereas the interference pattern I does not vary along the data region. The minimum variance distortion less receiver is used to combine the signals received at different antennas, by using Viterbi decoder. The Viterbi decoder is used to get the constant interference covariance.

d) *Randomized interference scenario:*

The maximum diversity provided by the fluctuations of both channel and impairments. Diversity is artificially introduced through the randomized multi user access approach which provides interference fluctuations over the codeword. Interference mitigation is unfeasible due to unpredictability of the impairments configuration. To exploit the diversity provided by the MIMO channel we adopt an OSTBC with antennas sufficiently spaced apart. The receiver is based on coherent maximum likelihood (ML) OSTBC detector. The Viterbi convolutional decoder exploits the knowledge of the average noise power over the whole data region and Viterbi genie decoder for instantaneous signal to interference noise ratio. The randomized approach the permutation of the subcarriers makes the interference scenario

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randomly fluctuate along k and the average PEP has to account for all the possible levels of interference. The overall noise power depends on the number of interferers $V_k = |I_k|$ superimposed on the k th subcarrier. The interference power pattern over the error event \mathcal{C} can be fully described by the vector of cardinalities the average of the conditioned PEP can be calculated as

$$P(c) = E_I[P(c|I)] = \sum_v P(c|v)P_r(v) \quad (16)$$

The number of interferers can be considered as a random variable independent from subcarrier to subcarrier, so that

$$P_r(v) = \prod_{k=1}^d P_r(v_{fk}) \quad (17)$$

The binomial distribution

$$P_r(v) = \binom{N_I}{v} \eta^v (1 - \eta)^{N_I - v} \quad (18)$$

V. PERFORMANCE ANALYSIS FOR BROADBAND STANDARDIZED OFDMA SYSTEMS

The performance analysis of Sections V-VI is here configured for the assessment of the following standard-based wireless technologies: the WiMAX standard IEEE 802.16-d for fixed or nomadic SSs, the WiMAX standard IEEE 802.16-e for mobility scenarios and the 3GPP LTE recommendations (downlink only). The analytical performance is validated by Monte-Carlo simulation of the OFDM/OFDMA PHY layer of each standard, whose main parameters are summarized in Table I. Details on the adopted CC are specified in Table II. Both the interference randomization and coordination policies are considered using for simulation the two scenarios described in Sec. III. The performance is evaluated with respect to the average SINR defined as

$$\text{SINR} = \frac{P_0}{\sigma_n^2 + \sum_{i=1}^{N_I} P_i} = \left(\frac{1}{\text{SNR}} + \frac{1}{\text{SIR}} \right)^{-1} \quad (19)$$

Where $\text{SNR} = P_0/\sigma_{\text{bn}}^2$ denotes the background signal-to-noise ratio, while $\text{SIR} = P_0/\sum_{i=1}^{N_I} P_i$ is the signal-to-interference ratio. All SSs are assumed to transmit at the same power level. According to the path-loss law, the SIR depends only on the ratio between the distances $\text{SS}_i\text{-BS}_0$ (ℓ_i) and $\text{SS}_0\text{-BS}_0$ (ℓ_0), for $i = 1, \dots, N_I$: $\text{SIR} = \frac{P_0}{\sum_{i=1}^{N_I} P_i} = \frac{1}{\sum_{i=1}^{N_I} (\ell_0/\ell_i)^\eta}$ for path-loss exponent $\eta = 3$. For simulation of the coordinated scenario, at the BS we consider an antenna array with inter-element spacing 1.4λ (where λ is the carrier wavelength) according to the optimized antenna array deployment, which provides a spatial resolution of $\Delta\theta = 3.4\text{deg}$. Channels are simulated using the beamforming model, with a separable space-time structure defined as follow. The multipath pattern is composed of $W = W_c W_m$ paths, grouped into W_c clusters of W_m paths each. All paths within a cluster have the same DOA,

TABLE I
MAIN PARAMETERS OF THE SIMULATED STANDARD-COMPLIANT SYSTEMS.

Feature	IEEE 802.16d	IEEE 802.16e	3GPP LTE
Carrier frequency f_c	3.5GHz	3.5GHz	2GHz
Sampling frequency $1/T$	4MHz	11.5MHz	15.36MHz
N. of subcarriers N	256	1024	1024
N. of data subcarriers K_T	192	841	601
N. of data region subcarrier K	192	192	200
Cyclic prefix length W_m (samples)	64	64	128
N. of antennas (N_T, N_R)	(1, 4)	(1, 1)	(2, 2)
Antenna spacing Δ	1.4λ	-	10λ
Considered std compliant CCs	WiMAXcc1-2	WiMAXcc1	LTec

TABLE II
PARAMETERS OF THE SIMULATED CONVOLUTIONAL CODES.

Code Label	R_{cc}	Perforation	Native g	C. length	d_{free}	d	β_d
WiMAXcc1	1/2	no	{171, 133}	7	10	{10, 12}	{36, 211}
WiMAXcc2	2/3	yes	{171, 133}	7	6	{6, 7, 8}	{3, 70, 285}
LTec	1/2	no	{561, 753}	9	12	{12, 14}	{33, 281}

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Which is $\theta_p = (p - (Wc + 1)/2)\Delta\theta + \theta_0$ for the p th cluster, $p = 1, \dots, Wc$. The TOAs in each cluster are defined as multiple integers of the sampling interval, i.e.

$\tau_r = (r - 1)TW$ with $r = 1, \dots, Wm$. The value of the parameter Wm is chosen so that the resulting channel impulse response duration, $(Wm - 1)T$, equals the cyclic prefix length in Table I (i.e., the TOAs span the whole maximum allowed channel duration). The power-delay-angle profile is defined as:

$$\rho_r = \rho_d(\tau_r)\rho_a(\theta_r, \theta_0) \quad (20)$$

With exponential profile over the delays

$$\rho_d(\tau) = \rho_d(0) \exp\left(-\frac{\tau}{\sigma_\tau}\right) \quad (21)$$

And Laplacian (double exponential) profile over the angles

$$\rho_a(\theta, \theta_0) = \rho_a(0, \theta_0) \exp\left(-\frac{|\theta - \theta_0|}{\sigma_\theta}\right) \quad (22)$$

Parameters σ_τ and σ_θ represent, respectively, the delay and angle spreads, θ_0 is the main DOA connecting SS0 and BS0, while $\rho_d(0)$ and $\rho_a(0, \theta_0)$ are factors employed to normalize the overall profile so that $\sum_{r=1}^W \rho_r = 1$. Signals from the three interferers are simulated with main DOAs (with respect to the BS array): $\theta_1 = -46.1$ deg, $\theta_2 = 0$ deg and $\theta_3 = 46.1$ deg. The interference generated by the i th SS is temporally uncorrelated but spatially correlated with spatial covariance, for $i = 1, 2, 3$. Similarly to the SS0 channel, the multipath structure of each interferer shows $W_i = W_c$ paths with DOAs $\{\theta_p\}_{p=1}^{W_c}$ as defined above and Laplacian power-angle profile $\rho_{i,r} = \rho_a(\theta_p, \theta_i)$. The frequency-flat (FF) channel where the channel gains are constant over the whole bandwidth, i.e., $H_k = H, \forall k$ (as for a frequency-flat channel with delay spread $\sigma_\tau = 0$). The maximum frequency diversity (MaxFD) channel where the channel gains are i.i.d. over the subcarriers (as for the ideal case of a maximum delay spread $\sigma_\tau \rightarrow \infty$).

A. Modeling the WiMAX IEEE 802.16 multi-cell scenario:

We first consider the uplink of a WiMAX system conforming to the IEEE 802.16-d standard. This is an OFDM system where the active SS in each cell transmits using all the available subcarriers: $K = K_T = 192$ (full traffic load $\eta = 1$). We assume a coordinated scenario with each SS employing a single antenna ($N_T = 1$) and the BS using an ULA of $N_R = 4$ elements for interference cancellation. The single-input-multiple-output (SIMO) channels are simulated according to the beamforming model described above with $W_c = 35$ clusters of $Wm = 64$ multipath components each.

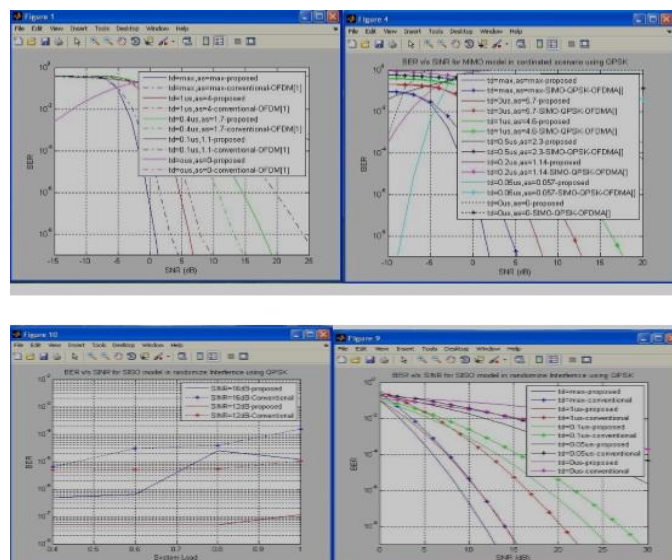


Fig. 4. Analytic and simulated BER vs SINR in coordinated interference scenario.

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Performance of a SIMO IEEE 802.16-d system with (A) 16QAM, convolutional code WiMAXcc1, interference cancellation with MVDR filtering and full traffic load ($\eta=1$). (B) QPSK, convolutional code WiMAXcc2, interference cancellation with MVDR filtering and full traffic load $\eta=1$. (C) Randomized interference scenario with ideal genie decoder. Performance of a SISO IEEE 802.16-e system with QPSK, convolutional code WiMAXcc1, PUSC randomization and traffic load $\eta=1/3$. (D) Analytic and simulated BER vs traffic load η in randomized interference scenario with ideal genie decoder. Performance of a SISO IEEE 802.16-e system with QPSK, convolutional code WiMAXcc1, Interference randomization with PUSC strategy and fixed delay spread $\sigma_\tau = 1\mu s$.

Fig. 4(A) compares the simulated and the analytical BER vs the SINR, for 16-QAM modulation and code WiMAXcc1 in Table II. The user in cell 0 transmits from the main DOA $\theta_0=5\text{deg}$ with $\text{SNR} = 20\text{dB}$. The analytical BER is evaluated using the union bound with PEP and SINR distribution (16). The union bound is truncated to either the free distance term $d_f=10$ or the two first minimum distances $d_m=\{10, 12\}$. The worst error event configurations, $c_{w,d}$, are identified using the specific code and interleaver scheme prescribed by the standard. Multipath channels are simulated with delay spread $\sigma_\tau \in \{0.1; 0.4; 1\}$ and angular spread $\sigma_\theta \in \{1.1; 1.7; 4\}$ deg. The two extreme cases of frequency selectivity MaxFD and FF are evaluated as well to get lower and upper performance bounds. The numerical results in Fig. 4(A) show that the system performance improves when increasing the channel spread σ_θ and/or σ_τ . As a matter of fact the more uncorrelated are the channel gains in space frequency, the higher is the diversity gain provided to the BICM. As expected, the best performance is achieved with the MaxFD case (channel gains are uncorrelated over the subcarriers and thus the diversity degree is $d_f=10$), while the worst performance is obtained with the FF channel which does not provide any diversity gain (the channel is constant over the whole codeword). In all cases, the analytical BER accurately fits the simulated results over the whole range of SINR values and space-frequency selectivity degrees.

Fig.4 (B) draws the simulated and analytical performance for the same system of the previous simulation but with QPSK modulation and punctured convolutional decoder WiMAXcc2

(see Table II). Multipath channels are simulated with delay spread $\sigma_\tau \in \{0.05; 0.2; 0.5; 1; 3\}$ s and angular spread $\sigma_\theta \in \{0.57; 1.14; 2.3; 4.6; 5.7\}$ deg. Simulated results show that the proposed analytical tool offers a tight performance bound even in this scenario. We point out that, compared to the previous case, here more error events (with $d_f=6, 7, 8$) have been included in the computation of the union bound since the path at the free distance is not enough to represent the statistics of the error events. We now investigate the performance provided by interference randomization simulating the IEEE 802.16-e standard with the PUSC permutation rule. For this scenario we consider a single-input-single-output (SISO) communication link ($M_T=M_R=1$) and an ideal genie decoder. The total data subcarriers for each OFDM symbol is $K_T=841$. The PUSC approach prescribes a division of the spectrum into 35 subchannels of 6 tiles each. A tile is a group of 4 consecutive subcarriers repeated for 3 OFDM symbols. The data region is formed by a number of subchannels of 48 data subcarriers each. The user SS0 requests 4 subchannels and adopts QPSK modulation with WiMAXcc1 code (see Table II). The interleaving and the PUSC permutation rules are applied according to the standard specifications. At the receiver, we assume $\text{SNR} = 30\text{dB}$.

Fig. 4(C) draws the simulated and analytical BER vs the SINR for the considered system with traffic load $\eta=1/3$ and $\sigma_\tau \in \{0.05; 0.1; 1\}$ μs . Notice that, in this SISO scenario, for decreasing values of the delay spread the analytical curves obtained with only the free distance ($d_f=10$) do not closely fit the performance. The same result has been observed for SISO systems with constant interference pattern. The basic principle behind this behavior is that in a strongly correlated channel (without spatial diversity provided by multiple antenna), an unfavorable channel realization affects the whole codeword, the interleaver is less effective and the error event can be easily longer than the free distance. The analytical Performance computation should include error events with longer distances. An investigation of the analytical performance for varying system load η .

Fig. 4 (D) for a selective channel with delay spread $\sigma_\tau = 1\mu s$, average SINR $\in \{12, 16\text{dB}\}$ and $\text{SNR} = 30\text{dB}$. As expected, performance degradation is experienced as the cell load increases since the interference power grows providing less interference diversity. We can notice that the analytic bound fits all the considered traffic load situations, ranging from light load ($\eta=0.4$) to full load ($\eta=1$, i.e., for constant interference level).

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B. Modeling the 3GPP LTE multi-cell scenario:

The downlink of a 3GPP LTE system is here simulated in a randomized interference scenario. We consider a MIMO link of $N_R = N_T = 2$ antennas, with Alamouti code and maximum ratio combining (MRC) at the receiver. The diversity channel model is adopted with $\sigma_\tau \in \{0.5; 1.5\}$ s and channel length $Wm = 128$ taps. The main 3GPP LTE system parameters are reported in Table I while the subcarrier permutation policy is modeled as described in . The data region assigned to the user of interest is a time-frequency grid composed of 25 subcarriers and 8 consecutive OFDM time symbols, yielding an overall number of $K = 200$ subcarriers. These subcarriers are employed to transmit 400 coded bits, using the LTEcc code in Table II and QPSK modulation. The traffic load is set to $\eta = 0.4$, while the signal-to-noise ratio is $SNR = 20$ dB.

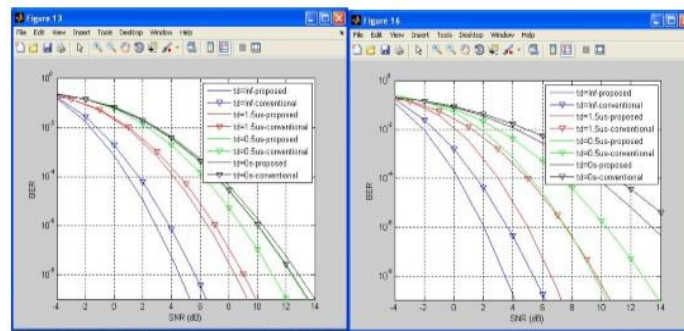


Fig. 5. Analytic and simulated BER vs SINR in randomized interference scenario with (A) conventional decoder.

Performance of a MIMO LTE system with QPSK, CC LTEcc, traffic load $\eta = 0.4$. (B) Ideal genie decoder. Performance of a MIMO LTE system with QPSK, CC LTEcc, interference randomization with traffic load $\eta = 0.4$.

Figures 5(A) and 5(B) show the BER performance vs the average SINR for the conventional and the genie decoder, respectively. The analytical BER is evaluated according to the union bound truncated to the first two error events with Hamming distances $d = \{12, 14\}$, using for the average with respect to the random interference and for the average with respect to the fading channel. Simulation results show that the performance bound is tight over a large SNR range and for different degrees of channel correlation. With this system set up, however, the analytical bound turns out to be less accurate for small delay spread (e.g., for $\sigma_\tau = 0.5\mu s$). This is the most crucial range of operation as error events with large Hamming distance (not taken into account here) are more likely to occur in highly correlated channels. The performance gain of the genie receiver with respect to the conventional one is approximately 1dB.

C. Performance comparison with the EESM methodology:

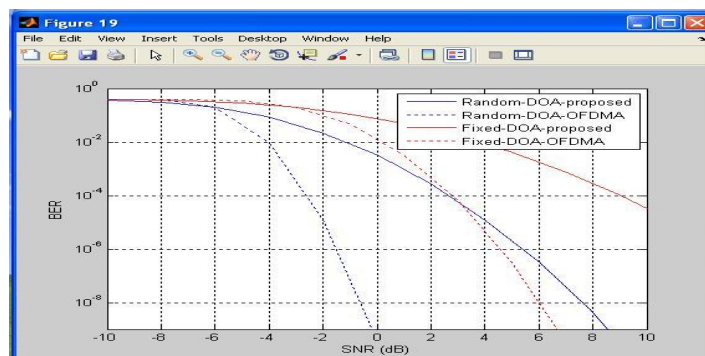


Fig. 6. BER vs SINR in coordinated interference scenario with 3GPP SCM Model III for the proposed analytical bound and the EESM method.

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SIMO IEEE 802.16-d system with QPSK, convolutional code WiMAXcc1, interference cancellation with MVDR filtering and full traffic load

The performance provided by the proposed method is compared here to the EESM approach. Fig. 6 shows the comparison between the two methods for the IEEE 802.16-d beamforming scenario with QPSK modulation and code WiMAXcc1 in Table II. Both the EESM and the proposed analytical methods provide a good matching with the simulated BER performances. However, the two methods require substantially different approaches for implementations discussed below. The EESM is an empirical method to assess the performance of the OFDM communication over a given realization of the frequency-selective fading channel. In order to obtain the average performance, we need to average the outcome of the EESM over a number of channel and interference realizations as in a common link level simulator. Therefore, the lower is the BER that we want to assess; the higher is the number of channel and interference realizations that we have to simulate to obtain reliable performance estimation. On the other hand, the proposed method provides directly the performance averaged over the fading, using the with which is based on the eigenvalue decomposition of the space-frequency channel covariance R_d . Monte Carlo averaging is used in only for handling the non-stationary of the interference (by including all the possible interference structures), and it can also be adopted in case the channel is modelled with a stochastic process. Usually, the number of iterations required for such an average is meaningfully lower than for link level simulators, or EESM method. It is important to notice that numerical averaging is independent on the BER target. Therefore the proposed framework provides accurate performance at any BER values with low computational complexity, and it can be cast easily for a wide range of propagation environments avoiding any kind of empirically tuned parameters.

VI. CONCLUSIONS

This paper an analytical framework for the performance assessment of bit-interleaved coded multi-antenna OFDMA systems over space-frequency selective fading channels with application to practical 4G broadband wireless standards. The proposed analytical method provides a direct average fading and interference.

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