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Performance of MMSE Receiver based Multi Input Multi Output-Interleave Division Multiple-Access System with Multi-user Detection over Frequency Selective Wireless Communication Channel

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Abstract: Problem statement: This study presents the performance analysis of turbo assisted Interleave Division Multiple-Access (IDMA) system with Multi Input Multi Output (MIMO) support for multi user scenario over correlated frequency selective and uncorrelated frequency selective channel. **Approach:** The key principle of IDMA is that interleaver unique which distinguishes the users in contrast to spreading sequence in Code Division Multiple Access System (CDMA). **Results:** In this work, we assume that Interleavers are generated independently and randomly. At the receiver, we employed Ordered SIC (OSIC) technique using ZF and MMSE criterion to combat Inter Antenna Interference (IAI) and Multi User Interference (MUI) problem along with iterative decoding to improve the performance in terms of BER. The performance of system has been discussed for different channel conditions with realistic channel model using extensive simulation runs based on Monte Carlo simulation trials. We have exhibited the flexibility and robustness provided by MIMO-IDMA. **Conclusion/Recommendations:** It has been proved from the results that IDMA principle can be applied to realize many potential performance gains highlighted by information theory, including coding gain multiplexing gain and multi-user gain. Simulation results presented to demonstrate the benefits of IDMA with MUD and iterative decoding. It is discerned that IDMA performs better than CDMA in frequency selective channel for high load conditions which is assessed through computer simulation results.

Key words: Multi-User Interference (MUI), Multiple Antenna Interference (MAI), Code Division Multiple Access (CDMA), Stanford University Interim (SUI), channel capacity, iterative decoding, Log-Likelihood Ratio (LLR), Multi Input Multi Output (MIMO)

INTRODUCTION

Code division multiple access system is the most widely used system for multi-user communications. But the performance of CDMA (Sreedhar and Chockalingam, 2006) is limited by multiple access interference and inter symbol interference. With CDMA fading is circumvented by the use of interleavers placed between FEC and spreading. After the invention of joint Turbo type receivers, extensive studies have been made to mitigate MAI and ISI (Schoeneich and Hoeher, 2004; Telatar, 1999; Nagaradjane *et al*., 2009a; 2009b) employing joint detection and decoding. But high complexity of optimal detection precludes its implementation for signal detection. Recently asynchronous multiple access scheme called interleave Division Multiple-Access (IDMA) (Novak *et al*., 2007) system have been widely studied the use of random sequences (i.e., random coding) for Communication forms the core of information theory. The framework of Interleave-Division Multiple-Access (IDMA) is closely related to random coding. In an IDMA scheme, different interleavers are used to distinguish users as against different codes in a conventional Code Division Multiple Access (CDMA) system. These interleavers are selected randomly and orthogonality propertry need not be essential. In a conventional CDMA scheme, interleavers are placed before the spreaders and they are effective only when used in conjunction with channel coding (Ping *et al*., 2003; Schoeneich and Hoeher, 2004). Recently, a very interesting technique using chip-level interleavers was addressed in (Novak *et al*., 2007), which aims at mitigating Intersymbol Interference (ISI) in multipath fading environments. Many works have discussed the role of interleavers in

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multiple access systems (Novak *et al*., 2007; Schoeneich and Hoeher, 2004). IDMA inherits many benefits of CDMA; in particular, path diversity and mitigation of intra cell interference. Also all the users employ a common spreading sequence.

MATERIALS AND METHODS

The Shannon's capacity theorem states that $C = W\log_2(1+SNR)\text{bits/sec}$ Where *C*-capacity, W-Bandwidth, SNR-signal to noise ratio. For fixed bandwidth, capacity can be increased by means of multiple antennas both at the transmitter and receiver:

$$C = MW\log_2(1+SNR)\text{bits/sec}$$

where, M= min (N_t, Nr) where N_t-transmitter antenna and N_r-receiver antenna. Hence Use of MIMO (Multiple-Input Multiple-Output) (Novak *et al*., 2007; Sayadi *et al*., 2009; Muthaiyah, 2004) systems which employ multiple antennas at the transmitter and receiver to multi-user environments can provide higher throughput and error performance (less error probability) without any additional expenditure in bandwidth or transmitted power. MIMO system with appropriate processing can provide spatial multiplexing to achieve high data rate communications or diversity to overcome multipath effects. So combining MIMO with the IDMA system can result in MIMO-IDMA that can offer bandwidth efficiency (Prabagarane *et al*., 2008), space multiplexing and lower speed parallel type of signal processing and interference rejection capability (ISI reduction) in high data-rate transmission.

Multi-user Detection (MUD) (Prabagarane *et al*., 2008; Verdu, 1998) is based on the idea of detecting interference and exploiting the resulting knowledge to mitigate its effect on the desired signal. Prabagarane *et al*. (2008) several low cost detection algorithm for IDMA scheme have been addressed. Also a semi analytical treatment to estimate the BER performance of several less complex detection algorithm based on SNR evolution is addressed in (Telatar, 1999). Non iterative MUD for dealing with MAI problem have been widely addressed. Brink (2001) iterative MUD based on turbo principle and its potential merits is considered.

In this study, we investigate the performance of the MIMO assisted Interleave Division Multiple Access (MIMO-IDMA) scheme with multi-user detection and iterative decoding over both correlated and uncorrelated frequency selective fading channel aided by sub-optimal detector such as zero forcing and MMSE algorithm for three types of delay spread based on SUI channel model (Table 1).

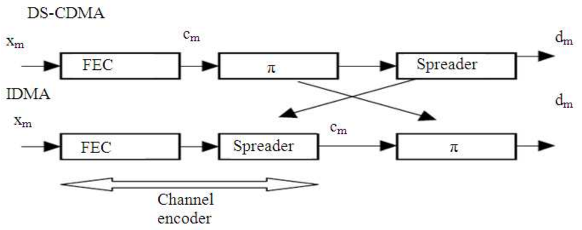


Fig. 1: Comparison of conventional DS-CDMA with IDMA

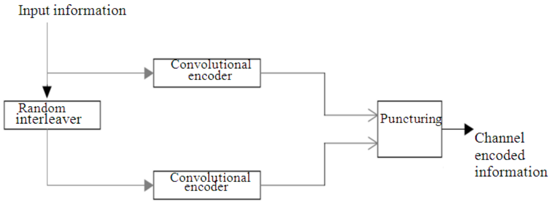


Fig. 2: Structure of turbo encoder

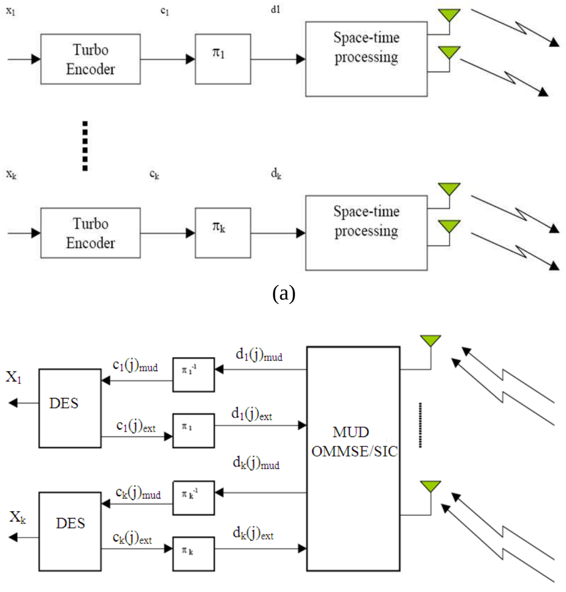
The rest of the study is organized as follows-. System model is presented in section II. Section III gives the essence of signal detection techniques. Section IV illustrates chip-by-chip detection. Performance results are presented in section V to validate analytical results and section VI concludes our study.

System model: The data sequence of the m-th layer is denoted as x_m and the corresponding encoded and interleaved sequence is denoted as d_m.

A DS-CDMA system is illustrated where interleaver is closely attached to the FEC encoder and the use of signature sequences for user separation is a characteristic feature for a conventional CDMA system (Brink, 2001). Interleaving, which is usually placed between Forward Error Correction (FEC) coding and spreading, is employed to combat fading effect. The arrangement of interleaving (π) and spreading(C) is reversed in IDMA and a single low-rate encoder, subsequently denoted bychannel encoder may do FEC encoding and spreading jointly Fig. 1. Now, different interleavers distinguish distinct data streams. Furthermore, it is important to note that interleaving is done on a chip-by-chip basis. This special case of DS-CDMA is called code-spread CDMA, chip-interleaved CDMA (cI-CDMA), or interleave-division multiple access (IDMA) inthe turbo codes are typically generated with parallel-concatenated convolutional encoder with large interleavers which is indicated in the Fig. 2.

Table 1: Channel model parameters for SUI and rayleigh channel

	SUI-1		SUI-3		SUI-5		Rayleighfading channel	
Path number (l)	Delay (ms)	Power (dB) $\Psi(\tau)$	Delay (ms)	Power (dB) $\Psi(\tau)$	Delay (ms)	Power (dB) $\Psi(\tau)$	Delay (ms)	Power (dB) $\Psi(\tau)$
1	0	0	0	0	0	0	0.1	2
2	0.4	-15	0.4	-5	4	-5	0.2	3
3	0.9	-20	0.9	-10	10	-10	0.3	4



(a)

(b)

Fig. 3: System overview of (a) transmitter and (b) (iterative) receiver structures of an MIMO-IDMA scheme for Up Link communication

Figure 3 shows the block diagram of IDMA system. In this contribution, we consider K-user up-link communication with each mobile station equipped with 2 transmitter antenna and the base station equipped with 2 receiver antenna .Let Nt X 2 component transmitted vector of k^{th} user be denoted by $d_k = [d_1(1), \ldots d_{Nt}]^T$.

This dk will be transmitted to M base station.

In this contribution, we assume that channel matrix that connects K_{th} user and M_{th} base station is frequency selective. The channel model (Sayadi *et al*., 2009) assumed in our work is based on SUI with rich spatial scattering. The channel profile are detailed in Table 1.

With the help of the parameter defined in Table 1, the impulse response from ith transmitter antenna to jth receiver antenna may be defined as:

$$h_{ji}(t) = \sum_{l=1}^{L} h_{ji}^{l} \partial(t - \tau_l) \qquad (1)$$

where, h_{ji}^{l} is a complex zero-mean Gaussian random process with variance $\Psi(\tau_l)$. Also, h_{ji}^{l} is correlated with other paths and channels. L denotes the total number of paths between the i $_{th}$ transmit and the j_{th} receive antenna.

The N_r length Up Link received vector y at the m_{th} base station can be expressed as:

$$y = \sum_{k=1}^{K} H_k d_k + n \qquad (2)$$

$$= \underbrace{H_k d_k}_{\substack{\text{Desired}\\ \text{SIgnal}}} + \underbrace{\sum_{i=1, i\neq k}^{K} H_k d_i}_{\text{MAI}} + n \qquad (3)$$

$$k = 1, 2, \ldots, K$$

Signal detection technique:

AV-BLAST-Zero forcing/OSIC detector: For user-k, the corresponding ESE outputs $\{L(d_k(j)), j = 1, 2, \ldots J\}$ are de-interleaved to form $\{L(d_k(j)), j = 1,2,\ldots J\}$ and delivered to the DES for user-k. The DES performs a soft-in/soft-out chip-by-chip de-spreading operation as detailed below. For simplicity, we focus on the chips related to d1(k), the first bit of user-k. The treatment for other chips is similar.

The V-BLAST detection algorithm (Nagaradjane *et al*., 2009a) is a recursive procedure that extracts the components of the transmitted vector d according to a certain ordering $(k_1, k_2 \ldots k_M)$ of the elements of d, where, $(k_1, k_2 \ldots k_M)$ is a permutation of (1… M). In VBLAST, this permutation depends on H (which is known at the receiver by assumption) but not on the received vector r. in this study, we have considered sub-optimal detector such as ZF and MMSE to realize the performance. The VBLAST/ZF algorithm is a variant of VBLAST derived from ZF rule. The algorithm determines the order of layers to be detected performs nulling and computes the decision statistics. It then slices the computed decision statistics and yields the decision by performing cancellation with the help of decision feedback and finally computes the new pseudo-inverse for the next iteration. V-BLAST/ZF may be seen as a successive-cancellation scheme derived from the ZF scheme:

$$W_1 = H^+ \tag{4}$$

where, W is the weight matrix that depends on the channel fading H.

i=1

Recursion:

$$k_i = \underset{j \notin \{k_1 \ldots k_{i-1}\}}{\arg\max} \; \| (W_i)_j \| \tag{5}$$

$$\begin{aligned} Y_{k_i} &= (W_i)_{k_i} r_i \\ \hat{a}_{k_i} &= Q(Y_{k_i}) \end{aligned} \tag{6}$$

$$r_{i+1} = r_i - \hat{a}_{k_i} (H)_{k_i} \tag{7}$$

$$W_{i+1} = H^+_{\bar{k}_i} \tag{8}$$

where, H^+ is the Moore-Penrose pseudo-inverse of H, the channel matrix. $(W_i)_j$ is the j^{th} row of W_i Q(.) is a quantizer to the nearest signal point, $(H)_{k_i}$ denotes the k_i th column of H. $H \pm_{k_i}$ denotes the matrix obtained by zeroing the columns k_1 k_2……... k_i of H.. In the above algorithm, zf-1 determines the order of the channels to be detected. This is done by choosing the channels with the smallest noise variance. Using Eq. 4 the corresponding layer is decided based on the smallest noise variance and quantization is performed with the help of the Eq. 6. In Eq. 7 interference mitigation is performed through decision feedback. Equation 8 calculates the weight matrix for the next iteration. The ZF creates set of sub-channels by forming:

$$\hat{a}_{zf} = (H^+H)a + H^+v \tag{9}$$

The order selection rule prioritizes the sub-channel with the smallest noise variance.

V-BLAST-MMSE/OSIC detector: The V-BLAST/MMSE algorithm is a variant of V-BLAST/ZF where the Weight matrix is chosen based on the MMSE rule:

$$W_1 = (H^H H + \sigma^2 I_{nT})^{-1} H^H \tag{10}$$

i=1

Recursion:

$$k_i = \underset{j \notin \{k_1 \ldots k_{i-1}\}}{\arg\max} \; \| (W_i)_j \| \tag{11}$$

$$Y_{k_i} = (W_i)_{k_i} r_i, \hat{a}_{k_i} = Q(Y_{k_i}) \tag{12}$$

$$r_{i+1} = r_i - \hat{a}_{k_i} (H)_{k_i} \tag{13}$$

$$\begin{aligned} W_{i+1} &= H^+_{\bar{k}_i} \\ i &= i+1 \end{aligned} \tag{14}$$

$$W_{i+1} = (H_{\bar{k}i}{}^H H_{\bar{k}i} + \sigma^2 I_{nT})^{-1} H_{\bar{k}i}{}^H \tag{15}$$

The MMSE Interference cancellation receiver suppresses both interference and noise component (Sreedhar and Chockalingam, 2006; Almutairi *et al.*, 2003), which means that the mean square error or variance between the transmitted symbols and the estimate is reduced.

Chip by chip detection: The a posteriori LLR for $x_k(j)$ can be computed using $\{L_k(c(j))\}$ as:

$$\begin{aligned} L(x_k(j)) &\equiv \log\left[\frac{\Pr(x_k(j) = +1 \mid r)}{\Pr(x_k(j) = -1 \mid r)}\right] \\ &= \sum_{j=1}^{S} s_k(j) L(c_k(j)) \end{aligned} \tag{16}$$

The extrinsic LLR for a chip cj(k) within d1(k)s(k) is defined by:

$$(c_k(j))_{Ext} \equiv \log\left[\frac{\Pr(c_k(j) = +1 \mid r)}{\Pr(c_k(j) = -1 \mid r)}\right] - L(c_k(j)) \tag{17}$$

The extrinsic LLRs $\{(c_k(j)_{Ext})\}$ form the outputs of the DES and are fed back to the ESE after interleaving. In the next iteration, $\{Ext(d_k(j))\}$ are used to update $\{E(d_k(j))\}$ and $\{var\ d_k(j))\}$as:

$$\begin{aligned} E(d_k(j)) &= \frac{\exp((d_k(j))_{Ext}) - 1}{\exp(Ext(d_k(j))) + 1} = \tanh\left[\frac{(d_k(j))_{Ext}}{2}\right] \\ Var(d_k(j)) &= 1 - E(d_k(j))^2 \end{aligned} \tag{18}$$

The iterations are carried out until mean=1 and variance = 0.

RESULTS AND DISCUSSION

In this section, we present the simulation results of our analysis. Table 2 summarizes the simulation parameters.

Table 2: Simulation parameter

Parameter	Attributes
Modulation technique	BPSK
Channel spacing	20MHz
Sampling frequency	22.5 MHz
Number of transmitter antenna	2
Number of Receiver antenna	2
Channel Model	SUI-1, SUI-2, SUI-3 channel model, Frequency selective fading channel
Channel coding	Turbo

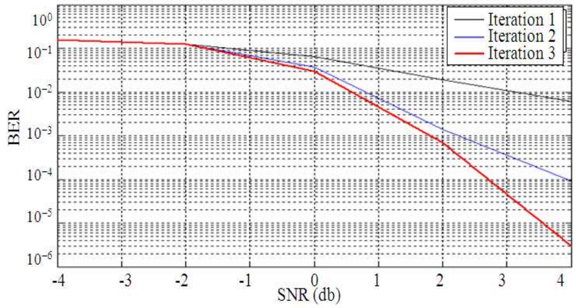


Fig. 4: Bit Error Rates (BER) performance of coded IDMA-MIMO MMSE with 50 users for Rayleigh fading channel

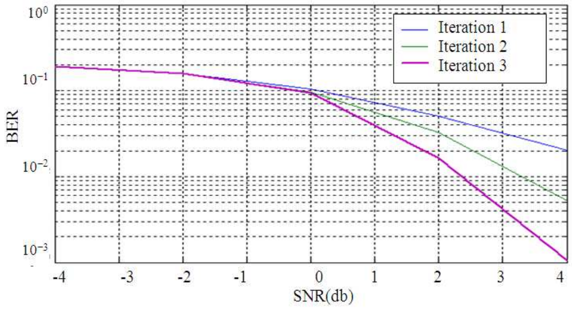


Fig. 5: Bit Error Rates (BER) performance of coded IDMA-MIMO MMSE with 50 users over correlated Rayleigh fading channel

The Fig. 4 expounds MIMO-IDMA System with MMSE Detector for 50 users employing MUD with 3 iteration. The Fig. 5 indicates MIMO-IDMA System with MMSE Detector for 50 users employing MUD with 3 iteration over correlated channel. The Fig. 6 and 7 shows the comparison of ZF and MMSE detector for rayleigh fading channel over correlated and uncorrelated channel. The Fig. 8 evince the effect of correlation on the MIMO channel for MMSE Detector. The Fig. 9 evince comparison results for an MIMO-IDMA System and MIMO-CDMA system with MMSE detector for Rayleigh fading channel. The Fig. 10-12 elucidate the results for an MIMO-IDMA system with ZF detector for SUI 1, 3, 5 channel model.

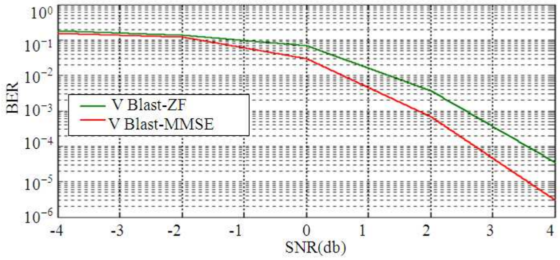


Fig. 6: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA with ZF and MMSE for 50 users over rayleigh fading channel

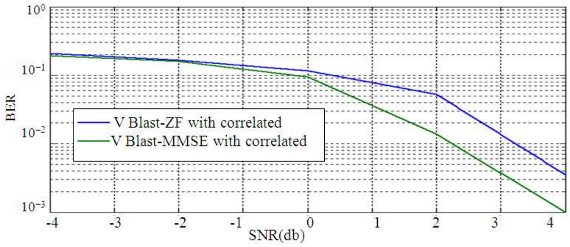


Fig.7: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA ZF and MMSE for 50 users over correlated channel

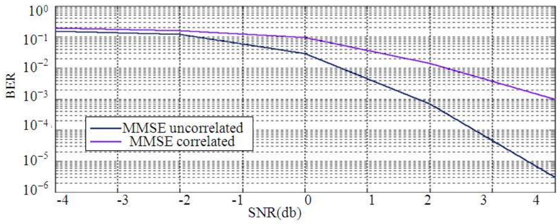


Fig. 8: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA with MMSE over correlated and uncorrelated channel for 50 users

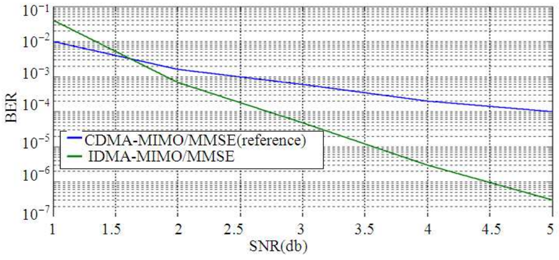


Fig. 9: Bit Error Rate (BER) performance of turbo coded MIMO-CDMA and MIMO-IDMA with MMSE detector over Rayleigh fading channel

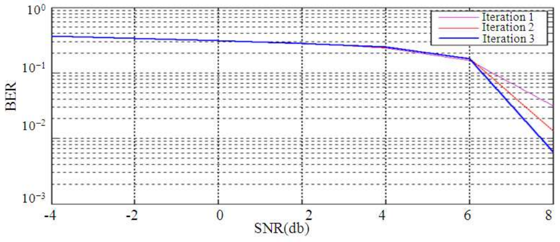


Fig. 10: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA with ZF detector for SUI-1 channel model

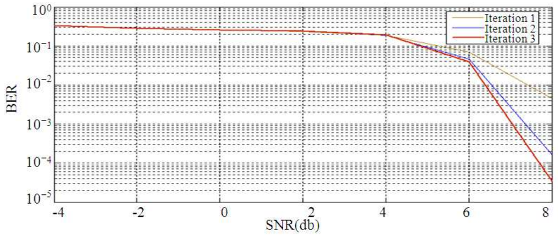


Fig. 11: Bit Error Rate (BER)performance of turbo coded MIMO-IDMA with ZF detector for SUI-3 channel model

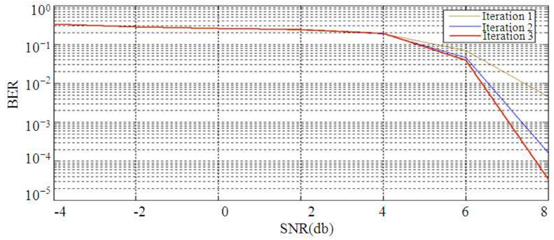


Fig. 12: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA with ZF detector for SUI-5 channel model

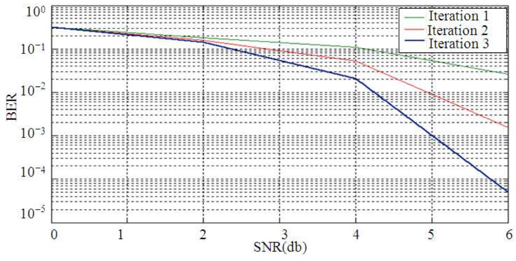


Fig. 13: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA with MMSE detector for SUI-1 channel model

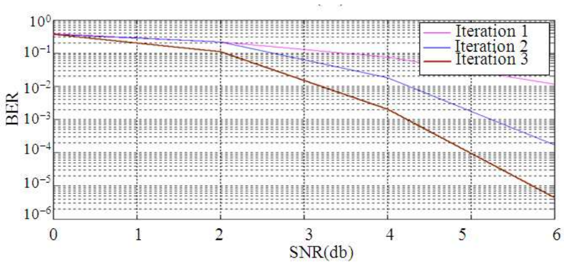


Fig.14: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA MMSE for 50 users over SUI channel model-3

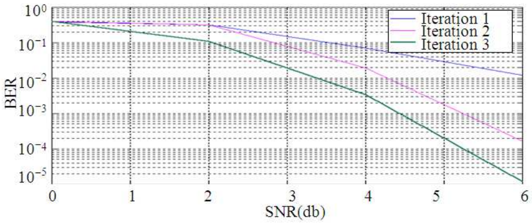


Fig. 15: Bit Error Rate (BER) performance of turbo coded MIMO-IDMA MMSE for 50 users over SUI channel model-5

The Fig. 13-15 shows the results for an MIMO-IDMA System with MMSE detector for SUI 1,3,5 channel model. The Fig. 16-18 shows the omparison of MIMO-IDMA ZF MUD and MMSE MUD for SUI 1, 3, 5 channel model. From the analysis it has been observed that MIMO-IDMA outperform MIMO-CDMA System with MMSE MUD and with MMSE MUD, we can achieve superior performance interms of BER as compared to ZF MUD.

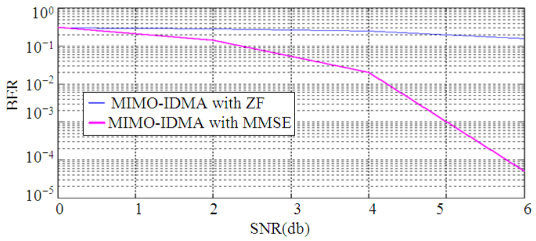


Fig.16: Comparison of Bit Error Rate (BER) performance of coded MIMO-IDMA with ZF and MMSE MUD for SUI model-1(50 users)

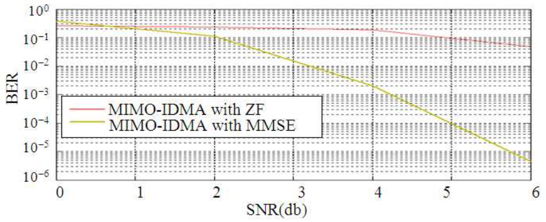


Fig.17: Comparison of Bit Error Rate (BER) performance of coded MIMO-IDMA with ZF and MMSE MUD for SUI channel model-3 (50 users

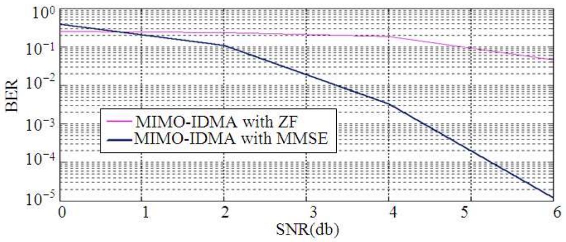


Fig. 18: Comparison of BER performance of coded MIMO- IDMA with ZF and MMSE MUD for SUI channel model-5(50 users)

CONCLUSION

In this article, we evaluated the performance of turbo assisted MIMO -IDMA system with sub-optimal MUD. It is discerned from the analysis that multipath can severely degrade the system performance. Also, MUI can result in further degradation in terms of achievable BER. It is shown through simulation that, in the context of multi-user scenario, MIMO-IDMA system with MUD can mitigate multi-user interference and inter antenna interference with less detection complexity. Further our analysis show that MIMO-IDMA can support more number of users there by resulting in higher capacity. Furthermore, MIMO-IDMA system aided by iterative decoding algorithm and MMSE MUD results in significant performance improvement compared to ZF MUD.

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