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 property 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...
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

\[ C = W \log_2(1 + \text{SNR}) \text{bits/sec} \]

where, \( C \) = capacity, \( W \) = Bandwidth, \( \text{SNR} \) = signal to noise ratio. For fixed bandwidth, capacity can be increased by means of multiple antennas both at the transmitter and receiver:

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

where, \( M = \min(N_t, N_r) \) 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).
Table 1: Channel model parameters for SUI and Rayleigh fading channel

<table>
<thead>
<tr>
<th>Path number</th>
<th>Delay (ms)</th>
<th>Power (dB)</th>
<th>Delay (ms)</th>
<th>Power (dB)</th>
<th>Delay (ms)</th>
<th>Power (dB)</th>
<th>Delay (ms)</th>
<th>Power (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>-15</td>
<td>0.4</td>
<td>-5</td>
<td>4</td>
<td>-5</td>
<td>0.2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>-20</td>
<td>0.9</td>
<td>-10</td>
<td>10</td>
<td>-10</td>
<td>0.3</td>
<td>4</td>
</tr>
</tbody>
</table>

where, $h_{ji}^l$ is a complex zero-mean Gaussian random process with variance $\Psi(\tau)$. 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 $N_t$ length Up Link received vector $y$ at the $m_{th}$ base station can be expressed as:

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

$$= H_k d_k + \sum_{i=1,i \neq k}^{K} H_i d_i + n$$  \hspace{1cm} (3)

$k = 1, 2, ..., K$

**Signal detection technique:**

**AV-BLAST-Zero forcing/OSIC detector:** For user-$k$, the corresponding ESE outputs $\{L(d_k(j)), j = 1, 2, ..., J\}$ are de-interleaved to form $\{L(d_k(j)), j = 1, 2, ..., J\}$ 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 $d_1(k)$, 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 $(k_1, k_2, ..., k_M)$ of the elements of $d$, where, $(k_1,k_2,..,k_M)$ 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:

\[ W_i = H^+ \]  

(4)

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

Recursion:

\[ k_i = \arg \max_{j \in \{k_1, \ldots, k_{i-1}\}} \| (W_i)_j \| \]  

(5)

\[ Y_{k_i} = (W_i)_{k_i} \hat{r}_{k_i} \]  

(6)

\[ \hat{r}_{k_i} = \hat{a}_{k_i} (H)_{k_i} \]  

(7)

\[ W_{i+1} = H^+_{k_i} \]  

(8)

where, \( H^+ \) is the Moore-Penrose pseudo-inverse of \( H \), the channel matrix. \((W_i)_j\) is the \( j^{th} \) row of \( W \). \( Q(.) \) is a quantizer to the nearest signal point, \( (H)_{k_i} \) denotes the \( k_i \)th column of \( H \). \( H(\pm) \) denotes the matrix obtained by zeroing the columns \( k_1, k_2, \ldots, k_i \) 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:

\[ \hat{a}_{st} = (H^+ H)a + H^+ v \]  

(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:

\[ W_i = (H^+ H + \sigma^2 I_{n_r})^{-1} H^+ \]  

(10)

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:

\[ L(x_k(j)) = \log \frac{\Pr(x_k(j) = +1 | r)}{\Pr(x_k(j) = -1 | r)} = \sum_{j=1}^{s} s_k(j) L(c_k(j)) \]  

(16)

The extrinsic LLR for a chip \( c_j(k) \) within \( d_1(k)s(k) \) is defined by:

\[ (c_k(j))_{\text{Ext}} = \log \frac{\Pr(c_k(j) = +1 | r)}{\Pr(c_k(j) = -1 | r)} - L(c_k(j)) \]  

(17)

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

\[ E(d_k(j)) = \frac{\exp(\text{Ext}(d_k(j))_{\text{Ext}}) - 1}{\exp(\text{Ext}(d_k(j))_{\text{Ext}}) + 1} = \tanh \left( \frac{(d_k(j))_{\text{Ext}}}{2} \right) \]  

(18)

\[ \text{Var}(d_k(j)) = 1 - E(d_k(j))^2 \]
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>
<thead>
<tr>
<th>Parameter</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation technique</td>
<td>BPSK</td>
</tr>
<tr>
<td>Channel spacing</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>22.5 MHz</td>
</tr>
<tr>
<td>Number of transmitter antenna</td>
<td>2</td>
</tr>
<tr>
<td>Number of Receiver antenna</td>
<td>2</td>
</tr>
<tr>
<td>Channel Model</td>
<td>SU1-1, SU1-2, SU1-3 channel model, Frequency selective fading channel</td>
</tr>
<tr>
<td>Channel coding</td>
<td>Turbo</td>
</tr>
</tbody>
</table>

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. 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 comparison 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 in terms of BER as compared to ZF MUD.
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.

REFERENCES


