Capacity Enhancement of MCCDMA Systems through MAI Cancellation Using Switched Interleaving Technique and Correlation Reconstruction based MRC with Diversity Gain

G.Senthilkumar, R.Amutha

Abstract**—*****The multi-carrier code division multiple access (MCCDMA) is a attractive choice for the future wireless systems where multiplexing and diversity in space, time and frequency are joined together through multiple input multiple output (MIMO) and space time block coding (STBC) in order to increase user capacity. In this study, the orthogonal complete complementary (OCC) spreading codes are employed along with unique spreading modulation for synchronous downlink transmission of MCCDMA systems. However, MC-CDMA suffers from multiple access interference (MAI) due to frequency-selective fading and multipath effects. To mitigate this MAI effect and achieve diversity gain, adaptive switched interleaving technique is proposed based on the concept of Minimum Distance Conditional Bit Error Rate (MDCBER) criterion. Furthermore, simple correlation reconstruction based maximal ratio combing (CRMRC) scheme is introduced at the receiver to compensate the diversity fading and suppress the effect of MAI at the receiver. The proposed technique modifies interleaving pattern adaptively for STBC encoded sequence of the users to reconstruct the orthogonality among the users to counteract the fading and multipath effects. For this purpose only a quantized detail of the Squared Minimum Distance Estimation (SMDE) is enough at the users such that the associated overhead is nominal compared to perfect channel state information (CSI) at the users. The simulation result shows that the MCCDMA system using switched interleaving technique along with CRMRC scheme achieves significant performance improvement in terms of BER. It also shows that the proposed technique reduces the MAI and increases user capacity.***

Index Terms**— *****multicarrier code division multiple access (MCCDMA), multiple access interference (MAI), switched interleaving, combining schemes, orthogonal complete complementary (OCC) Codes***

I. INTRODUCTION

With growing requirements on recent wireless systems and multimedia services, a capacity enhancement technique has captivated researchers in recent years for facilitating multimedia communications among multiple users. MCCDMA systems become a promising candidate to future wireless communication systems. Among its many advantages, it is worth mentioning the high spectral efficiency due to the use of orthogonal frequency division multiplexing (OFDM) and the potential of collecting the received signal energy of numbers of sub-carriers scattered in the frequency domain, which results into a significant frequency diversity gain [1] to diminish fading effect.

In a MCCDMA system, the user's data symbols are spread in the different sub-carriers using orthogonal spreading codes. After passing through a frequency selective fading channel and multipath, however, the received codes are no longer orthogonal due to imperfect correlation properties of orthogonal spreading codes and MAI will arise [2]. Therefore, the user capacity of MCCDMA system is effectively limited by the MAI.

As an efficient technique to remove the effects of fading and to increase the diversity gain, transmit diversity has been studied. The MCCDMA with STBC [3] provides full diversity gain as well as full rate without consuming extra spectrum in order to counteract multipath fading effects when approached for multipath fading channels. The MCCDMA with Space-time (S-T)-coding based MIMO systems [4] have emerged as key technologies for 4G wireless to offer best detection efficiency and system throughput by exploiting its unique spatial diversity gain and spatial multiplexing capability and does not sacrifice bandwidth efficiency. The multiuser interference (MUI) is increased owing to the symbols overlapping throughout the subcarriers. In the literature, many works have been reported to approach the issues on design and applications of different types of orthogonal spreading codes, whose correlation properties can be utilized to mitigate the interferences such as multipath interference (MI) and MAI. The spreading code scheme based on the complementary code was proposed in [5] to design an MAI-free CDMA system. This scheme along with offset stacked spreading modulation [6] achieves higher spectrum efficiency than conventional CDMA system. In order to exploit the maximum channel diversity and to mitigate the MAI effect, MCCDMA system using OCC codes is developed here for capacity enhancement by combining those technologies [3-6].

Even though, the MCCDMA system can completely exploit frequency diversity and correlation properties among the subcarriers, the performance of MCCDMA is still limited by MAI at particular channel conditions. Interference cancellation is traditionally practiced at the receiver side by resorting to familiar multiuser detection schemes [7]. Due to heavy processing load as the number of users increases, these schemes may be restricted to some applications. Moreover, the perfect channel state information (CSI) about subcarriers is necessary for the realization of multiuser detection (MUD) techniques. Alternately, suboptimum linear MUD techniques such as Minimum Mean Square Error (MMSE)

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MUD [8] techniques are investigated. Even though MMSE allows a simple realization, this demands maximum Signal to Noise plus Interference Ratio (SINR), instead of minimization of the BER that is the objective of a good receiver. Under considering the MAI cancellation, a pre-filtering technique at the transmitter and equal gain combing (EGC) or MRC combining schemes at the receivers are proposed [9] to suppress the effect of MAI. However, the estimated signal weights for each receiver are not optimum to cancel MAI using pre-filtering technique and it is computations dependent. The Adaptive Threshold Orthogonality Restoring (TORC) has been proposed [10] based on minimum BER for increased diversity gain for MCCDMA. This is obtained at the cost of an increased system receiver complexity. The minimum BER strategy is further investigated for the computationally affordable signal detection optimization [11] and its application to multiuser detection. The iterative multi-user detection schemes [12] based on interleave-division multiple access (IDMA) is proposed for reduced complexity of receivers which is independent of the number of users but increasing with the path number.

Thus, a switched interleaving technique at the transmitter and a CRMRC scheme at the receiver are proposed to eliminate MAI with diversity gain and for affordable complexity based on the above discussion. For this, the concept the MDCBER criterion is introduced to based on the squared minimum distance between the combined transmitted data and its candidate at receiver and minimization of probability of error conditionally for near-optimum multiuser detection. Here, the receiver perfectly estimates the CSI using a training symbol and only quantized detail of the SMDE is enough at the users such that the associated overhead is nominal compared to perfect CSI at the users. Thus, to restore the correlation among the users at the transmitter to counteract the effect of bad channel conditions, the proposed technique modifies the interleaving pattern adaptively by the switched interleaver with respect to correlation of M element sequences whenever SMDE value below the threshold value δ in order to satisfy MDCBER criterion. To obtain a frequency diversity gain and MAI cancellation at the receiver, CRMRC scheme compensates the diverse fading based on optimum combining of gain vectors estimated from the outputs of M chip matched-filters.

The rest of this paper is organized as follows: Section II illustrates the signal description of MCCDMA system using OCC codes. Section III describes switched interleaving technique and CRMRC scheme to achieve an MAI-free system with diversity gain. Section IV presents simulation results to demonstrate the performance improvement in terms of BER and finally the conclusion is given in Section V.

II. SYSTEM DESCRIPTION

Figure1 describes a transceiver structure of MCCDMA system model. The data source signal spectrum is modulated by an OCC code set, which is unique for each user. The group of M element codes, $\{c_{k,1}, c_{k,2},.. , c_{k,M}\}$ are assigned to K users. Each element code $c_{k,m}$ consists of N chips where $k \in (1,K)$ and $m \in (1,M)$. The source information symbols are space-time block-encoded into P parallel independent symbol streams. Based on the Alamouti STBC algorithm [3], an STBC encoded signal block for the m^{th}-element code of the k^{th} user in this system can be written as,

$$s_{1,k,m} = \left(b_{1,o}\, c_{o\,k,m} + b_{1,e}\, c_{e\,k,m} \right), \qquad (1)$$

$$s_{2,k,m} = (b_{1,e}\, c_{o\,k,m} - b_{1,o}\, c_{e\,k,m}), \qquad (2)$$

The proposed switched interleaving technique modifies the interleaving pattern adaptively with respect to interleaved mapping function (IMF) which finds correlation of m element sequences and changed by switched interleaver according to SMDE value and the MDCBER criterion so as to minimize the correlation among the users. Thus, the STBC coded sequence is then dispersed as per modified interleaving pattern by switched interleaver (π_s) producing $b_k \equiv [b_k(1), \ldots, b_k(l), \ldots, b_k(L)]T$. The P parallel symbol streams are sent into OCC encoding module [6] that consists of M OCC encoding branches, each of which has P OCC slices. In this way, M replicas of P parallel symbol streams are encoded by different OCC code sets to realize diversity order of P and parallel transmission order of M. Therefore, the family size of the OCC must be at least MP.

This MCCDMA combines its OCC spread-coded bits together using offset stacked modulator [6] to improve the spectral efficiency. The input bit sequence $b_k = (b_{k1}, b_{k2},. b_{kj})$ of each user is spread with the element code $c_{km} = (c_{1km}, c_{2km}. \ldots c_{Nkm})$. Also, each information bit is shifted by one chip offset to one another and then combined. The OCC encoded output of user k is expressed as,

$$d_K(t) = \sum_{i=0}^{\infty} \sum_{n=0}^{N-1} b_{K,i\, C_{m,n}}\; C_{m,n} \prod \frac{(t-\left(i+n+\frac{1}{2}\right)Tc}{Tc}\, X \prod \frac{(t-\left(\frac{T}{2}\right)-iTc}{T}, \qquad (3)$$

$$\text{Where} \quad \prod\left(\frac{t}{T\omega}\right) = \begin{cases} 1, & t \in \left(-\frac{T\omega}{2}, \frac{T\omega}{2}\right) \\ 0, & \text{otherwise,} \end{cases} \qquad (4)$$

where $d_K(t)$ represents the OCC encoded output of user K, $b_{K,i}$ denotes the i^{th} information bit from user K, $C_{m,n}$ denotes the n^{th} chip of the m^{th} element code, t and Tc and T denote chip and bit duration, respectively. Each element code, c_{km} is then carrier modulated by sub-carrier, fm. This forms spreading of data information in both the time and frequency domains. Then, the output of offset stacked modulator is modulated by a quadrature amplitude modulation (QAM) map to transmit the $L= (N-1)$ different levels in symbol duration which results in improved detection efficiency. The output of the m^{th} OCC encoder is expressed (5) as the sum of all users spread streams,

$$s_m(t) = \sum_{k=0}^{M-1}, d_{K,m}(t), \qquad (5)$$

The MCCDMA system will share the same M sub-carriers which carry the same data information but encoded by different element codes belonging to the same code group. For hardware realization simplification, OFDM architecture is used. It is assumed to use only two antennas ($n_t = P = 2$) to achieve transmitter diversity. It is also assumed that signals from different antennas in a transmitter experience independent Rayleigh fading and additive white Gaussian noise (AWGN).

At a receiver, the carrier demodulation is carried and then, correlation between local sub-codes and the incoming signals in the M sub-channels takes place. The M filtered signals which are used to extract symbol streams can be written as,

$$y_m^{(u)}(l) = h_m^{(u)} \sum_{k=1}^{K} b^{(k)}(l) Corr_{k,u}^{(m)} + n_m, \qquad (6)$$

where $h_m^{(k)}$ is the channel coefficient of subband m from base station to the receiver of user u, $Corr_{k,u}^{(m)}$ is the correlation value of the mth element sequences of users k and u and n_m is zero mean white Gaussian noise. These M correlation outputs are then combined together to obtain the decision variable. The receiver performs decoding using perfect or estimated CSI and the i^{th} demodulated information bit of user K is written as,

$$b_{K,i}(t) = sgn(y_m^{(u)}(l)), \quad (7)$$

where *sgn(.)* denotes signum function.

III. PROPOSED TECHNIQUE

A. Correlation Reconstruction Based MRC (CRMRC) Scheme

A MCCDMA system is viewed as an M-branch diversity system, as it transmits M replicas of signals. Here, the M filtered signals are combined with combining coefficient w_m to extract symbol streams. When EGC [13] is employed as M element sequences weighted with same channel gain, the performance is poor due to its loss of orthogonality under the frequency selective fading. When MRC is employed [14] as M element sequences weighted in proportion to the signal to noise ratio (SNR)s, it achieves the maximum SNR before decision after deinterleaving and space-time decoding. The output of MRC combiner is written as,

$$\hat{b}_{mrc}^{(u)}(l) = \sum_{m=1}^{M} h_m^{(u)} * y_m^{(u)}(l) = N\sum_{m=1}^{M} h_m^{(u)} b^{(u)}(l) + I_{mrc} + n_{mrc}, \quad (8)$$

The signal of (8) consists the three terms: the desired signal, the MAI caused by loss of spreading code orthogonality among the users, and the residual noise. The MAI term is written as,

$$I_{mrc} = \sum_{k=1,k\neq u}^{K} b^{(k)}(l) \sum_{m=1}^{M} | \left[h_m^{(u)}\right]^2 | \; Corr_{k,u}^{(m)}, \quad (9)$$

In order to cancel the MAI component, the CRMRC scheme is used here to compensate the diverse fading of unequal channel coefficients by making $Corr_{k,u}^{(m)} = 0$. For this, the MDCBER criterion is formulated for the reduction of the probability of error conditionally based on the estimation of MAI through squared minimum distance between the symbols [15] and concept of conditional mBER [11]. This leads to the computation of the couple of optimum receiver gain vectors

$$w_m^{(OPT)} = C_{k,m}\,(h_{em}^{(k)*}) / \, h_{em}^{(k)}, \quad (10)$$

where $h_{em}^{(k)}$ is the estimated channel gain. It is observed that phase of the filtered signal on each subcarrier is compensated individually and so error rates are reduced. This CRMRC detector reduces the computational burden and increasing linearly with number of users.

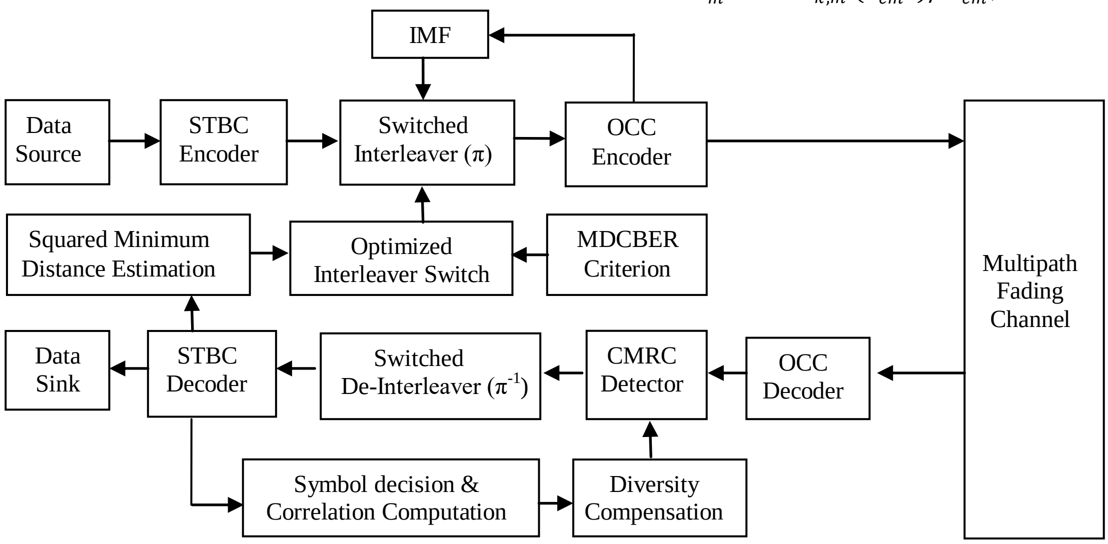

Fig:1 MCCDMA Systems for capacity enhancement through MAI Cancellation using Switched Interleaving Technique & correlation based MRC with Diversity Gain

B. SWITCHED INTERLEAVING TECHNIQUE

In order to counteract the effects of bad channel condition, the switched interleaving technique is proposed to modify the interleaving pattern adaptively. This reconstructs the correlations of subcarriers and restores the orthogonality of the spreading codes among users and consequently, it eliminates the MAI from other users. For this, Squared Minimum Distance between the combined transmitted data $(s_A, s_B)_{ADD}$ and its candidate $(s'_A, s'_B)_{ADD}$ is estimated to find the magnitude of error at the destination and it is written as,

$$SDME = E\{d^2_{(Sk,Sj)\leftrightarrow(S'k,S'j)} = |\,(S_K - S'_k) + \gamma e^{j\theta}\,(S_j - S'_j)|^2\}, \quad (11)$$

where γ and Θ are channel factors which causes poor values of Squared Minimum Distance due to MAI at particular channel conditions[16]. The information of all possible distances based on MDCBER criteria and channel coefficients are needed at the transmitters to reformulate [17] the correlation among the users using switched interleaving technique at the transmitter. In practice, transmitter is difficult to obtain CSI perfectly. For this purpose only a quantized detail of the SMDE is enough at the users such that the associated overhead is nominal compared to perfect CSI at the users. In order to satisfy the MDCBER criterion, the switched interleaver chooses the optimal interleaving pattern adaptively whenever SMDE is below minimum distance threshold of $\delta = (S_{uk} - S'_{uk})\,|\gamma e^{j\theta} \; - \gamma_m\, e^{j\theta_m}|$. The quantized detail of SMDE, whether below δ is indicated to the users by a feedback. In order to find the optimum interleaving pattern, it is necessary to compute the value of interleaved mapping function (IMF) where IMF finds values of correlation among the users for this new modified interleaving pattern with respect to correlation of m element sequences. The switched interleaver assigns another interleaving pattern adaptively based on the values of IMF and SMDE and MDCBER criterion until IMF =0.

IV. SIMULATION RESULTS

Based on the discussion given in the earlier sections, the performance of MCCDMA systems using OCC codes in terms of BER are evaluated using MATLAB with respect to SNR for downlink frequency selective Rayleigh fading channel with AWGN floor with and without the proposed techniques switched interleaving technique and CRMRC scheme. The proposed CRMRC scheme is compared with existing combining schemes at the receiver, including MRC, ORC, and EGC. In the simulations, three different scenarios including *K =1, K = 4, and K = 8* users are considered under a two-ray multipath channel with its delay profile being *[1/2, 0, 1/2]* and one chip inter path delay. It is assumed that the path components are different and independent for all paths. The receiver had perfect knowledge of the CSI and only quantized detail of the SMDE is feedback to transmitter instead of perfect CSI. The data packet of 256 symbols, the modulation of 4-QAM, and the following key parameters of OCC codes used in the simulations are,

OCC: flock size (M) = 4, element code length (G) = 16, Sequence length N = 64,

In Figure 2, the simulation results of different combining schemes in MCCDMA system employing OCC codes are compared in terms of BER under frequency selective fading channels for $k=8$ users. The EGC fails to work in frequency selective fading due to its loss of orthogonality. Observing the curves, a cancellation of MAI is realized to compensate the loss of orthogonality in a MCCDMA system with ORC even in a frequency selective fading multipath channel. On the other hand, ORC enhances the noise and require large weights over low SNR. It is observed that, MRC outperforms ORC with a frequency diversity gain but it needs more number of receivers in the MCCDMA system for good performance. The performance of MRC is degraded by both the detrimental effects of MAI and the multipath fading channel. The proposed CRMRC scheme gives best performance in terms of BER than the above combing schemes after being compensated with optimal diversity combining.

BER performance of MCCDMA system using OCC codes is compared for MAI robustness with and without proposed switched interleaving technique along with CRMRC scheme for $k=8$ users in figure 3. The performance of MRC scheme degrades as the number of receivers in the system increases where as the proposed technique switched interleaving technique along with CRMRC scheme influences the performance due to its maximum diversity gain and MAI cancellation. Thus, the MCCDMA using the proposed technique outperforms the MRC and CRMRC schemes due to formatting of the signals among the users through modified interleaving pattern. The extra performance gain is achieved by mitigating the detrimental effects of MAI.

Figure 4 compares BER performance of MCCDMA system using OCC code for different number of users with and without proposed switched interleaving technique. The BER curves for the MRC scheme deteriorate obviously as number of user increases due to increased MAI, whereas proposed switched interleaving technique performs nearly the same as that in the single user scenario. These simulation results concludes that performance is not affected by the number of increased receivers and the number of increased users, because CRMRC optimum combing compensates the diverse fading and modified interleaving pattern formats the signals among the users so that it retains the orthogonality of the spreading codes that are not destroyed by frequency-selective fading.

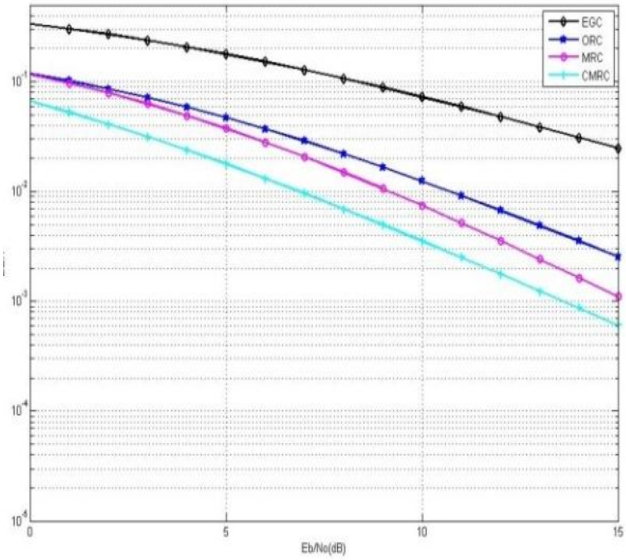

Fig. 2. BER of a MCCDMA system employing OCC codes with different combining schemes under frequency selective fading channels for k=8 users

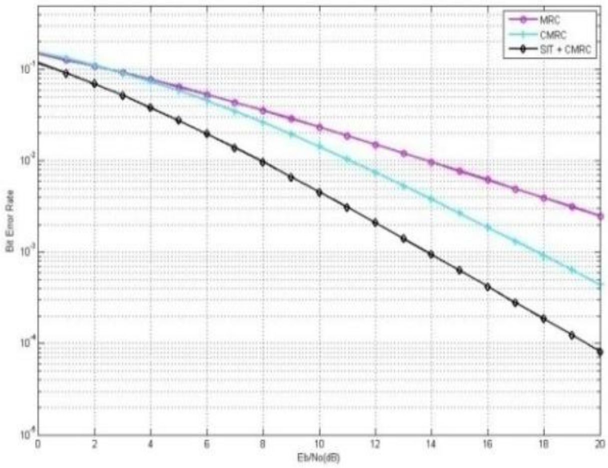

Fig.3. BER comparison for MAI robustness of a MCCDMA system employing OCC codes with and without proposed switched interleaving technique with CRMRC scheme for k=8 users

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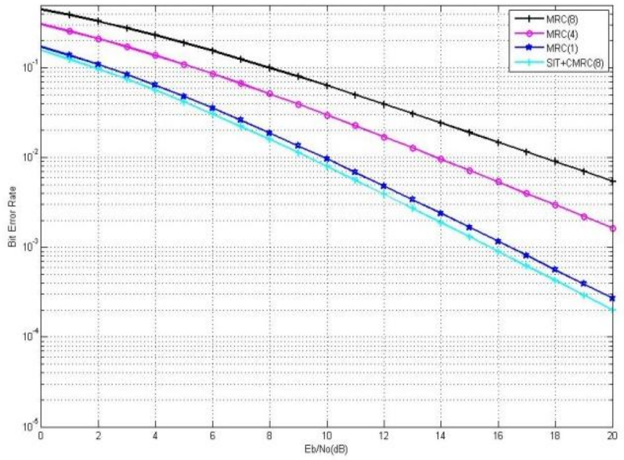

Fig. 4. BER of a MCCDMA system compares proposed switched interleaving technique along with CRMRC combining scheme and MRC for different number of users

V.CONCLUSION

In this paper, the MCCDMA system using OCC codes is studied to combine with MIMO and STBC techniques for the capacity enhancement. The different combining schemes are analyzed and CRMRC scheme is developed for compensating the diversity fading and suppress the effect of MAI at the receiver while keeping the simple receiver structure. In addition, the adaptive switched interleaving technique is proposed at the transmitter based on MDCBER criterion to exploit the maximum possible channel diversity and mitigate the MAI effect. The detrimental effects of MAI are counteracted through orthogonality reconstruction by selecting the optimal interleaving pattern in the switched interleaver by comparing the values of IMF which is calculated for minimum correlation among the users and SMDE which estimates the detrimental effects of MAI at the receiver. The quantized detail of SMDE is sufficient at the users to reduce the complexity of the feedback from the receiver instead of perfect CSI. The performance of CRMRC in terms of BER is better than the other combing schemes after being compensated with optimal diversity combining. The simulation results lead to the conclusion that the MCCDMA system using switched interleaving technique along with CRMRC scheme increases the diversity gain and cancels the detrimental effects of MAI. It also shows that the proposed technique increases the user capacity due to MAI robustness.

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