Performance of Blind Successive Interference Canceller for Multi-Carrier CDMA Systems

P A HARIS, E GOPINATHAN and C K ALI
Department of Electronics and Communication Engineering,
National Institute of Technology, Calicut, Kerala, INDIA.
E-mail: harisabdul_k@yahoo.com, gopie@nitc.ac.in, cka@nitc.ac.in

Abstract-An efficient multiple user access over the wireless channel necessitates a communication system design that can overcome the adverse impact of multipath propagation such as Inter Symbol Interference (ISI) and Multiple Access Interference (MAI). This being the objective, a Multi Carrier Code Division Multiple Access (MC-CDMA) communication system is considered in this paper. MC-CDMA, being a combination of DS-CDMA and OFDM converts a frequency selective fading channel into multiple flat fading channels thereby mitigating ISI. To overcome the effect of MAI, Multi User Detection (MUD) based receiver is addressed. The performances of Blind successive Interference Cancellation (BIC) techniques are compared with Matched filter receiver and BMMSE receiver by simulating the entire system. The BIC is a multi-user detection technique that uses knowledge of only the desired user's signature sequence and his timing to estimate his information. This is done by executing interference cancellation in a successive manner, starting from the most dominant component and successively canceling the weaker ones. Simulation results show that BIC scheme outperforms conventional MF receiver and BMMSE receiver.

***Index Terms*—** Inter symbol interference, Multiple Access interference, Multi user detection, Single user lower bound, Maximum mean energy.

1. INTRODUCTION

Multi-carrier CDMA [1, 2, 3, 4] is a promising candidate to the challenge of providing high data rate wireless communication. It is a combination of two distinct techniques namely OFDM [5] and CDMA. MC-CDMA systems combine features of these two technologies to provide a communication system that has the advantages of both. MC-CDMA can have synergistic effects such as enhancement of robustness against frequency selective fading and high scalability in possible data transmission rate.While DS-CDMA spreads in the time domain, MC-CDMA applies the same spreading sequences in the frequency domain. While the performance of MC and DS-CDMA is identical in an additive white Gaussian noise (AWGN) channel, MC-CDMA has been shown to out-perform DS-CDMA in multipath channels. In a DS-CDMA system, a single fade or interferer can cause the entire link to fail, but in an MC-CDMA system, only a small percentage of subcarriers will be affected. MC-CDMA system is considered to be one of candidates as a physical layer protocol for 4G mobile communications, because 4G systems require high scalability and adaptability in the possible transmission rate and the MC-CDMA has the potential.

MC-CDMA is a digital modulation technique where a single data symbol is transmitted at multiple narrowband sub carriers with each sub carrier encoded with a phase offset of 0 or π based on the signature sequences. This modulation scheme is also a multiple access technique in the sense that different users will use the same set of sub carriers but with different signature sequences that is orthogonal to the code of all other users. Thus, it is essential to point out that there exist two levels of orthogonality. While the sub carriers frequencies are orthogonal to each other, and the signature sequences are also orthogonal to each other. Firstly, an OFDM system is used to provide a number of orthogonal carriers, free from ISI. The narrowband sub carriers are obtained by using BPSK modulated signals [6], each at different frequencies which at base band are at multiples of a harmonic frequency. Thus, the sub carriers are orthogonal to each other at base band, and the component at each sub carrier may be filtered out by modulating the received signal with the frequency corresponding to the particular sub carrier of interest and integrating over a symbol duration. The orthogonality between sub carrier frequencies is obtained if the sub carrier frequencies are spaced apart by multiples of F/Tb, where F is an integer. The phase at each sub carrier corresponds to one element of the signature sequences. For signature sequences of length N, there are N sub carriers. Secondly, each carrier is modulated by an individual code chip, in order to provide a spread spectrum system. Different users transmit over the same set of sub carriers but with signature sequences that is orthogonal to the codes of other users. The signal obtained has an orthogonal code structure in the frequency domain. If the number and spacing between sub carriers is correctly chosen, all of the sub carriers will not be located in a deep fade.

MC-CDMA systems mitigate the inter-chip-interference (ICI) problem by transmitting the same data symbol over a large number of narrowband orthogonal carriers, without spectrum spreading per carrier, and make it possible for multiple users to communicate through the same channel. MC-CDMA signals can be easily transmitted and received using the Fast Fourier Transform (FFT) without increasing the transmitter and receiver complexities and have the attractive feature of high spectral efficiency due to minimally densely sub carrier spacing. The major advantage of MC-CDMA is that it can lower the symbol rate in each subcarrier so that longer symbol duration makes it easier to quasi-synchronize the transmission.

Section 2 and 4 presents MC-CDMA transmitter and receiver models. Section 3 presents the channel model. Section 5 presents an overview of multi user detection. Section 6 presents BIC-MME crieterion. Section 7 briefly reviews the MMSE criterion. Simulation results are presented in section 8 and section 9 contains our conclusion.

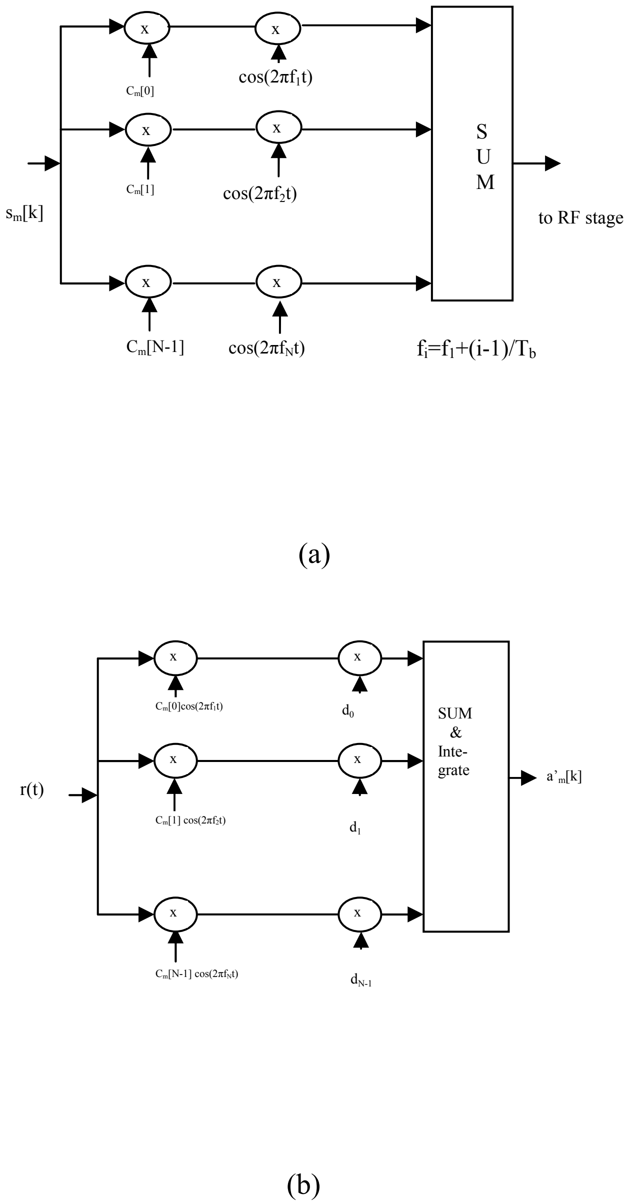

Fig.1. Block diagram for MC-CDMA communication systems (a) Transmitter (b) Receiver

2. MC-CDMA Transmitter

The description of MC-CDMA system in this paper here focuses on the downlink system. A quasi-synchronous downlink system is assumed for simplicity of the system model. Fig.1 shows a model of the transmitter for one possible implementation of an MC-CDMA system. The input data symbols, $s_m[k]$, are taken to be binary antipodal where k denotes the kth bit interval and m denotes the mth user. In the analysis, it is assumed that $s_m[k]$ takes on values of -1 and 1 with equal probability. The generation of an MC-CDMA signal can be described as follows. A single data symbol is converted into n parallel copies. The ith branch (sub carrier) of the parallel stream is multiplied by a chip, from a pseudo-random (pn) code or some other orthogonal code of length n and then bpsk modulated to a sub carrier spaced apart from its neighboring sub carriers by F/Tb where F is an integer number. The transmitted signal is the sum of the outputs of these branches. This process results a multi carrier signal with the sub carriers containing the pn-coded data symbol. However, for the case of F = 1, the MC-CDMA signal shares the same signal structure as OFDM. The analysis of OFDM results that the discrete-time version of the OFDM transmitter is simply a Discrete Fourier Transform (DFT). Thus, the transmitter model of MC-CDMA shown in Fig.1 may simply be replaced by an FFT operation for F = 1. As illustrated in Fig.1, the transmitted signal corresponding to the kth data bit of the mth user is

$$X_m(t)=\sum_{j=0}^{N-1} c_m(j)a_m(k)\cos(2\pi f_c t+2\pi i\frac{F}{T_b}t)P_{T_b}(t-kT_b)$$

C

$_m(j)\in\{-1,1\}$ (1)

where c_m [0], c_m [1], .. c_m [N-1] represents the signature sequences of the mth user and $P_{Tb}(t)$ is defined to be a unit amplitude pulse that is non-zero in the interval of [0, T_b].

3. Channel Model

In this paper, we assume a frequency selective channel with 1/ T_b << Bc where Bc is the coherence bandwidth. Here each modulated subcarrier with transmission bandwidth of 1/ T_b does not experience significant dispersion. As Doppler shifts are very small, it is also assumed that the amplitude and phase remain constant over the symbol duration, T_b. Multipath propagation in time translates into frequency selectivity in the frequency domain. While there is frequency selectivity over the entire bandwidth, each subcarrier experiences a flat fade. The transfer function of the continuous time fading channel assumed for the mth user can be represented as

$$H_m(f)=\rho_{m,i}\, e^{j\theta_{m,i}}$$

where $\rho_{m,i}$ and $\theta_{m,i}$ are random amplitude and phase of the channel of the mth user. For downlink transmissions a terminal receives interfering signals through the same channel as the wanted signal

4. MC-CDMA Receiver

When there are M active users, the received signal is

$$r(t)=\sum_{m=0}^{M-1}\sum_{i=0}^{N-1}\rho_{m,i}c_m(i)a_m(k)\cos(2\pi f_c t+2\pi i\frac{F}{T_b}t+\theta_{m,i})+n(t) \tag{2}$$

Where the effects of the channel have been included in and n(t) is additive white Gaussian noise (AGWN) with a one-sided power spectral density of No. For the transmitter model of Fig.1, a possible implementation of the receiver is shown in Fig.2 below where it has been assumed that m = 0 corresponds to the desired signal. In this model, there are N matched filters with one matched filter for each sub carrier. The output of each filter provides one component to the decision variable; each matched filter consists of an oscillator with a frequency corresponding to the frequency of the particular BPSK modulated sub carrier that is of interest and an integrator. Also a phase offset equal to the phase distortion introduced by the channel, is included in the oscillator to synchronize the receiver to the desired signal in time. To obtain the desired signal's component, the orthogonality of the codes is used. For the ith sub carrier desired signal, the corresponding chip, from the desired user's code is multiplied with it to nullify the code. If the signal is undistorted by the fading channel, the interference terms will cancel out in the decision variable due to the orthogonality of the codes. As the fading channel will distort the sub carrier components, an equalization gain, may be included for each matched filter branch of the receiver.

Applying the receiver model of Fig.2 to the received signal given in equation provides the following decision variable for the k th data symbol assuming the users are synchronized in time.

$$v_0 = \sum_{m=0}^{M-1}\sum_{i=0}^{N-1}\rho_{m,i}c_m(i)d_{0,i}a_m(k)\frac{2}{T_b}\times \int_{kT_b}^{(k+1)T_b}\cos(2\pi f_c t + 2\pi i\frac{F}{T_b}t + \theta_{m,i})\times \cos(2\pi f_c t + 2\pi i\frac{F}{T_b}t + \hat{\theta}_{0,i})dt + \eta \tag{3}$$

where $d_{0,i}$ denotes the receiver's estimation of the phase at the ith sub carrier of the desired signal and the corresponding AWGN term, is given as.

$$\eta = \sum_{i=0}^{N-1}\int_{kT_b}^{(k+1)T_b} n(t)\frac{2}{T_b}d_{0,i}\cos(2\pi f_c t + 2\pi i\frac{F}{T_b}t + \hat{\theta}_{0,i})dt \tag{4}$$

For perfect phase correction, the decision variable reduces to

$$v_0 = a_0(k)\sum_{i=0}^{N-1}\rho_{0,i}d_{0,i} + \sum_{m=1}^{M-1}\sum_{i=0}^{N-1}a_m(k)c_m(i)c_0(i)\rho_{m,i}d_{0,i}\cos\hat{\theta}_{m,i} + \eta \tag{5}$$

Thus the decision variable consists of three terms. The first term corresponds to the desired signal's component, the second corresponds to the interference and the last corresponds to a noise term.

5. Multi User Detection

The goal of multiuser detection is to correctly demodulate the transmitted symbols of mutually interfering users in a multiple-access communication system. In MC-CDMA system using single user detectors each user is detected separately without regard for the other users. The code orthogonality among users in MC-CDMA systems is highly distorted by the instantaneous frequency response of the channel. The MAI due to the frequency selectivity in fading channels degrades the performance of MC-CDMA systems. Multi-user detection [7] and related signal-processing techniques are developed for mitigating MAI. In multi-user detectors, the information about multiple users is used to improve detection of each individual user. MAI is caused by the cross correlation of user's signature sequences. MAI can be eliminated by making the spreading sequences orthogonal to each other. But multi-path components and asynchronous transmission make them non-orthogonal again. In order to overcome this problem, interference cancellation techniques are proposed. MUD techniques are combination of Linear Detectors and Interference Cancellation. Linear detectors apply linear transform to the outputs of the matched filters and thereby removing the multiple access interference. Interference cancellation, estimate MAI first and then subtract it from the received signal. A hierarchy of various MUDs are shown in Fig.10 and a small description of each are given below.

5.1.Maximum Likelihood Sequence Estimation (MLSE) Detector

The objective of an MLSE detector is to find the input sequence which maximizes the conditional probability or maximum likelihood of the given output sequence. The MLSE detector computes the correlation metrics for each possible sequence, and selects the sequence that has the largest correlation metric. The complexity of MLSE grows exponentially with the number of users. In the asynchronous transmission Viterbi algorithm can be applied to reduce the complexity. Unfortunately, the computational complexity of the Viterbi algorithm is still exponential in terms of the number of users. Despite the great performance and capacity gains over the conventional detection, such a high complexity makes the MLSE detector impractical. Another disadvantage of the MLSE detector is that it requires knowledge of received amplitudes, phases and propagation delays. These parameters are not available in the receiver a priori, and must be estimated accurately .

5.2 Decorrelating Detector

The decorrelating detector applies the inverse of the correlation matrix to the outputs of the matched filter bank. Thus, the detector completely decorrelates the multiuser interference and results in elimination of MAI. No knowledge of the received amplitude is required; hence it reduces the burden of the channel estimator. The computational complexity is reduced to linear in terms of the number of users, which is significantly lower than that of the MLSE detector. A disadvantage of this detector is that it causes noise enhancement, since the power is associated with the noise term at output of the decorrelating detector is always greater than or equal to the noise power at the output of the matched filter bank. Another disadvantage of the decorrelating detector is that the computations needed to invert the correlation matrix are difficult to perform in real time.

53 MMSE Multiuser Detection

The Minimum Mean Square Error (MMSE) detector is a linear detector which takes into consideration the background noise and MAI at the same time. The detector implements the linear mapping which minimizes the mean-squared error between the actual data and the weighted soft output of the matched filter bank. The solution to this optimization problem shows that the MMSE detector implements a partial or modified invers of the correlation matrix. Because it takes the background noise into account, the MMSE detector generally provides a better probability of error performance than the decorrelating detector. As the background noise goes to zero, the performance of the MMSE detector converges to the decorrelating detector. On the other hand, as the MAI goes to zero, the performance of the MMSE detector approaches to the conventional single user detector. A disadvantage of the MMSE detector is that, unlike the decorrelating detector, it requires the training sequence and estimation of the received amplitude. Another disadvantage is that the performance depends on the energies of the interfering users, which causes some loss of the near-far resistance.

5.4 Multistage Multiuser Detector

The multistage detector is analogous to the parallel interference canceller. Each stage takes as its input the data estimates of the previous stage, and produces a new set of estimates at its output. Due the delay constraint it is desirable to limit the number of stages to two or three. As in the case of the MLSE detector, the multistage detector requires knowledge of the signal amplitude and code timing. The computational complexity of this algorithm is linear in terms of the number of users. Too many incorrect initial data estimates may cause the performance to degrade relative to the conventional detector. Therefore, using a decorrelating detector at the first stage significantly improves the performance of the detector and simplifies the analysis of error probability.

5.5 Decision Feedback (DF) Multiuser Detector

The decision feedback detector can be viewed as the combination of decorrelating detector and a Successive Interference Cancellation (SIC) detector. The linear operation of a decorrelating detector partially decorrelates the users without enhancing the noise, then the SIC operation decisions subtract the interference from one additional user at a time in descending order of signal strength. An important difficulty with DF detector is the need to compute the Cholesky decomposition of the correlation matrix and the whitening filter, like the other nonlinear detectors, the DF detector has the disadvantage of requiring channel parameter estimation. If the channel estimates are more reliable than those produced by the decorrelating detector, the DF detector performs better than the decorrelating detector. If the estimates are less reliable, the performance will degrade greatly.

5.6 Successive Interference Cancellation (SIC) Detector

The main idea of the SIC is to consider what would be the simplest augmentation to the conventional detector which would provide some benefits of multiuser detection. That is how to improve the traditional detector such that it performs reasonably well in near-far environment. This goal can be achieved by successively cancelling the interference generated from the other users. Bearing this concept in mind, it is important to cancel the strongest signal before detecting the other signals because it has the most negative effect. Also, the best estimate of the signal is from the strongest, since the strongest signal has the minimum MAI. Therefore, there are two reasons for doing successive cancellation in order of signal strength. First, it is easiest to achieve acquisition and demodulation on the strongest user. Secondly, the removal of the strongest signal gives the most benefits for the remaining users. The successive cancellation must operate fast enough to keep with the bit rate and not introduce intolerable delay. For this reason, it will be necessary to limit the number of cancellation. The disadvantage of the SIC is that an accurate channel estimate is required for successively cancelling the interference from the received signal. Another potential problem with the SIC detector occurs if the initial data estimates are not reliable. Thus, a certain minimum performance level of the conventional detector is required to yield the improvements.

Due to various disadvantages of the MUDs described above and the complexity involved in their implementation and also considering the various features of Blind Successive interference cancellation (BSIC), we have chosen to implement BSIC to overcome MAI.

6. MC-CDMA with Blind Successive Interference Cancellation

We now present a blind successive interference cancellation scheme [8,9,10,] where we incorporate the MME criterion [11] and realize the blind interference cancellation-maximum mean energy (BIC-MME) receiver. In order to set a basis for BIC receiver we adopt the following well known results from linear algebra[12]

Result 1: The eigenvector of Rr (covariance matrix of the received vector r) that corresponds to the maximum eigen value (λ_{max}) is the vector that maximizes the mean energy

Result 2: If the contribution of v_{max} is removed from the matrix R_r, as follows:

$$R^{`}_r = R_r - \lambda_{max} v_{max} v^T_{max} \qquad (6)$$

then the eigenvector v_{max} that corresponds to the maximum eigenvalue of R_r is the same as the eigenvector that corresponds to the second largest eigenvalue of R_r.

The receiver executes the following steps:

Step 1: Estimate the covariance matrix R_r of the received vector r.

$$\hat{R}_r(i) = \frac{1}{n} \sum_{k=i-n+1}^{i} r(k) r^T(k) \qquad (7)$$

N is the size of the averaging window (number of samples) and i is time index.

Step 2: Remove the desired user contribution from the covariance matrix $\hat{R}_r$.

$$R_i = \hat{R}_r - A_1^2 S_1 S_1^T$$

A_1 is the desired user amplitude; S_1 is the desired user signature sequence.

Step 3: Find the eigen vector v_{max} of the interference covariance matrix that takes on average most of the interference energy.

Step 4: Remove the maximizer contribution from the matrix R_i .

$$R^{`}_i = R_i - \lambda_{max} v_{max} v^T_{max}$$

(The eigenvector of Rr that corresponds to the maximum eigen value (λ_{max}) is the vector that maximizes the mean energy)

Step 5: Cancel the maximizer contribution from r as:

$$r' = r-(r^T v_{max})\, v_{max}$$

Step 6: If all significant components of the interference are cancelled then the detection is performed and the last IC stage can be the one where the measured SIR is above a target value.

7. MC-CDMA With Blind MMSE Receiver

In this paper, BMMSE receiver [12] is used as a reference for performance evaluation. For the case where the receiver only has the knowledge of the desired user's signature waveform and timing, the blind multiuser detection schemes need to be used. The MMSE criterion for the detection of MC-CDMA signals shows the immunity to the near-far problem or the interference floor in performance exhibited by the conventional matched filter reception. However, the computation of the MMSE filter weights starts with the calculation of the inverse of the input autocorrelation matrix. An approximation of the optimal MMSE detector is equivalent to BMMSE receiver which is given by

$$\hat{c} = \hat{R}_r^{-1} s_1$$

where $\hat{R}_r$ is the sample covariance matrix of the received vector r.

8. Simulation Results

We consider an MC-CDMA system using randomly generated signature sequences (Gold codes) with processing gain M = 31. We assume that first user is the desired user and its amplitude is known exactly in the results presented here. The performance of the conventional matched filter (MF) the centralized MMSE receiver and the Single-user lower bound (SULB) are used as benchmarks for the evaluation of the BIC-MME receiver. The SULB is identical to the case where no MAI is present. The following simulation shows how the MAI is effectively cancelled using the BIC-MME technique.

The Spectrum of the rayleigh fading process is obtained using the Jakes Power Spectral Density (PSD). A rayleigh fading channel is simulated using the typical parameters of an urban environment [9]

RMS Delay Spread	Maximum Doppler Frequency	50% Coherence Bandwidth
1.37 microsecond	40 Hz	146 KHz

Table 1, Fading Channel Parameters

The Envelope of the Fading Channel is Shown in Fig 2

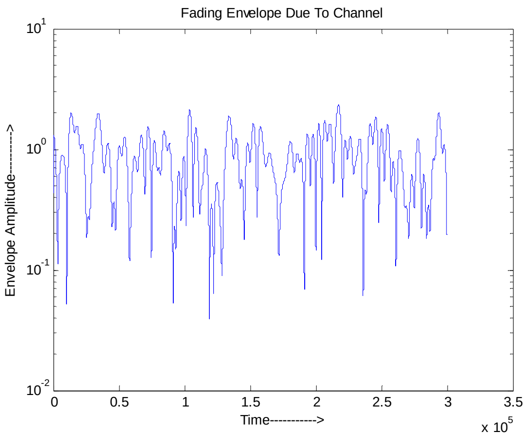

Fig.2, Envelope of the Fading Channel

For an input signal bandwidth of 775 KHz, the above channel acts as a frequency selective channel.

Fig.3 shows the BER vs. SNR performance of the MC-CDMA system using the BIC-MME scheme. The results are obtained after a total of 15 IC stages, which is where the estimated SINR reaches maximum. A noticeable change in performance is observed in comparison to MF receiver. This means that the system would be able to accommodate a greater number of users with no appreciable degradation in BER performance. By the use of Blind Successive Interference Cancellation, for same BER performance, SNR required is less than the MF receiver. Fig. 4 shows BER versus number of IC stages for SNR=10 dB and it is clear from figure that there is performance deterioration after the 15th IC stage. This is due to an excessive cancellation of the desired user in stages 16 and 17. This occurs because the interference energy is already cancelled in the first 15 stages in this example. The stopping rule (maximum estimated SINR), recognized the stage 15 as the last stage, while the results for the stage 16 and 17 are used just to illustrate the effects of excessive cancellation. Fig.5 tells us about the robustness of the BIC-MME scheme to estimation errors of the covariance matrix. We note that the performance does not improve much beyond a sample size of 1400. Even with a lower value for the sample size, the performance is appreciably good.

Fig.6 shows the BER vs. Number of users performance comparison of the MC-CDMA system using the BIC-MME and BMMSE schemes. BER performance degrades as number of simultaneous users increases, due to increase in interference. For same BER, MC-CDMA system with BIC-MME can support twice the number of users supported by BMMSE system. The performance of BIC-MME multi user detection scheme is excellent, and it can keep a good BER for a larger number of users. Fig.7 shows the BER vs. SNR performance comparison of the MC-CDMA system using the BIC-MME, SULB, MF and BMMSE schemes. By the use of Blind Successive Interference Cancellation, for same BER performance, SNR required is less than the BMMSE receiver. According to the results above, the BIC MME receiver outperforms the BMMSE receiver and MF receiver.

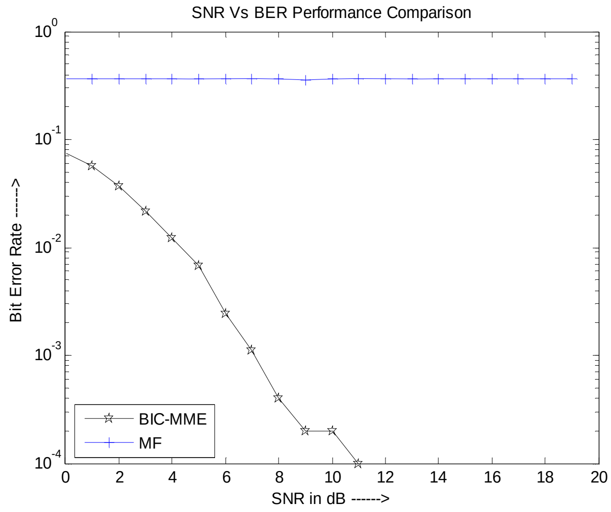

Fig.3, Performance improvement due to BIC

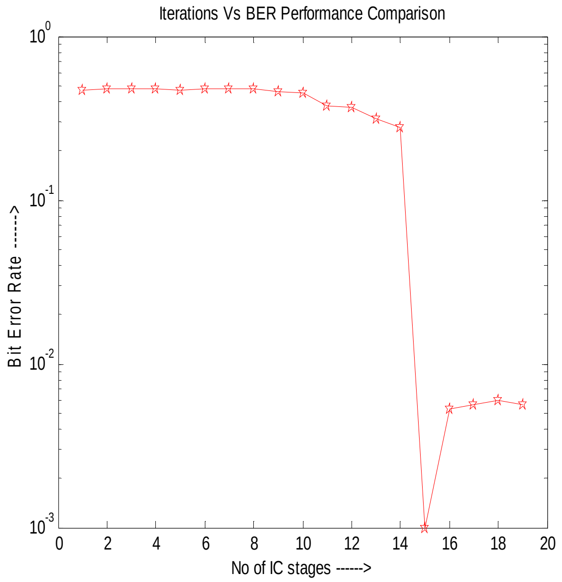

Fig.4, BER Vs No of IC Stages for SNR=10dB

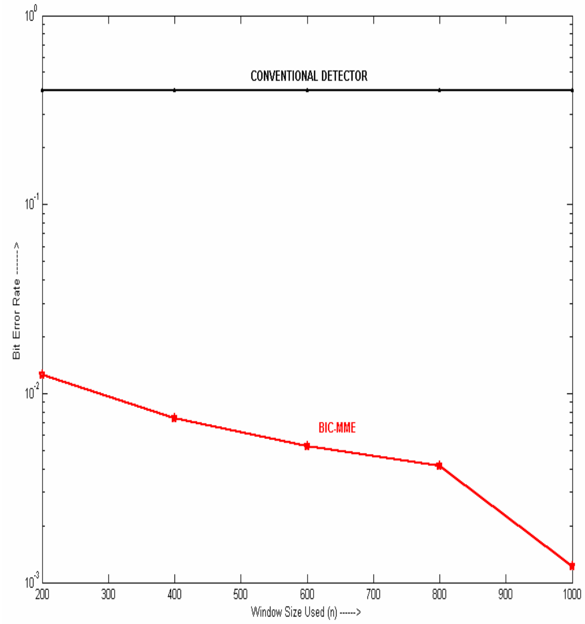

Fig.5, Performance of the BIC-MME with errors in the covariance matrix

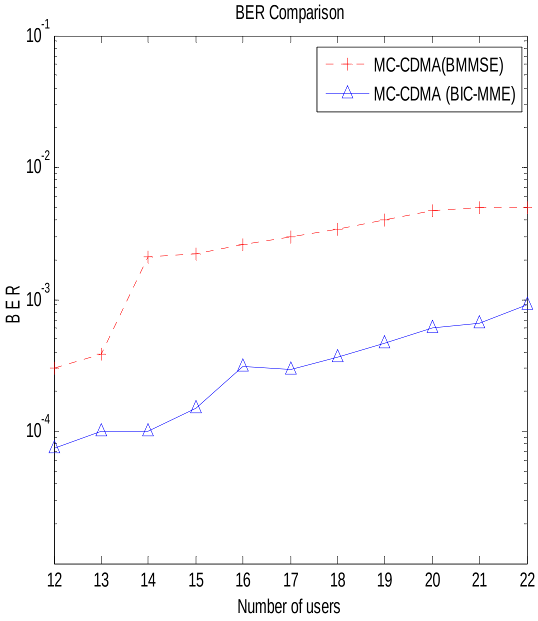

Fig.6, BER Vs Number of users

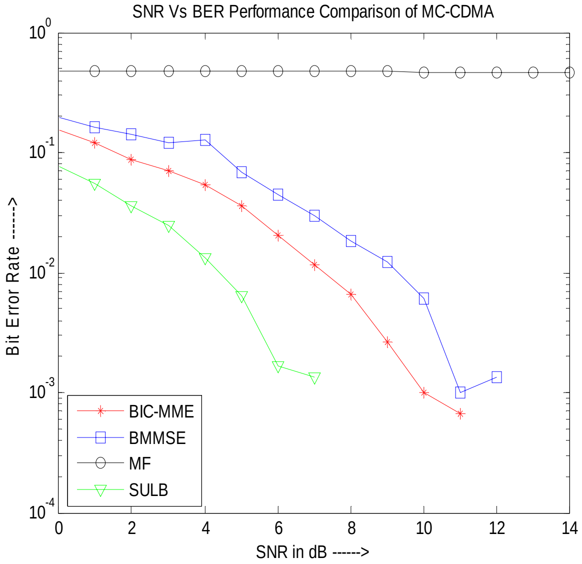

Fig.7, Performance improvements due to BIC

9. Conclusion

In this paper, a multistage Blind Interference Cancellation is chosen for countering MAI that improves the performance over a quasi-synchronous downlink channel in a frequency selective Rayleigh fading environment. We have used the MME optimization criterion to implement a blind IC receiver in a MC-CDMA system. From the simulation results we conclude that the receiver gives a good BER performance by effectively canceling out the multiple access interference (MAI). The receiver is near–far resistant. Since only the user's code and power are required for detection, this may be a very viable solution for implementation on the downlink where transmissions are usually synchronized within a cell such that intra-cell users are orthogonal and inter-cell interference may be dominant. It is found that the performance of the MC-CDMA system with the BIC-MME receiver approaches the AWGN performance for the system even in a fading multi-path channel [13]. This would mean that the number of users that the system can handle (i.e., its capacity) has been increased. In conclusion, a Multi-carrier CDMA system combined with the Blind Successive Interference Cancellation–MME receiver is an attractive candidate for the downlink of future CDMA systems.

References

[1] N.Yee, J.P.Linnartz, and G.Fettweis, Multi-Carrier CDMA in Indoor Wireless Networks, in Proc. IEEE PIMPRC '93, Yokohama, Japan, pp.468-472, Sept 9 -11, 1993

[2] S.Chatterjee,Fernando and M K Wasantha Adaptive modulation based MC-CDMA Systems for 4G Wireless Consumer Applications, IEEE Transactions on Consumer Electronics,Vol.49,No.4,November 2003

[3] Shang-Ho Tsai, Yuan-Pei Lin and Jay Kuo, MAI-Free MC-CDMA Systems Based on Hadamard-Walsh Codes, IEEE Transactions on signal Processing, Vol.54,No.8, August 2006

[4] Antonia M. Tulino, Linbo Li, and Sergio Verdú, Spectral Efficiency of Multicarrier CDMA, IEEE Transactions on Information Theory, vol. 51, no.2,pp 479,Feb.2005

[5] Richard van Nee, Ramjee Prasad, OFDM for Wireless Multimedia Communications, Artech House, 2002

[6] Simon Haykin, Digital Communications 2 nd edition, John Wiley & Sons,1998

[7] S.Verdu, Multiuser Detection, Cambridge University Press,1998

[8] I. Seskar, K. Pedersen, T. Kolding and J. Holtzman, Implementation Aspects for Successive

Interference Cancellation in DS/CDMA Systems, Wireless Networks, no. 4, pp. 447-452, 1998.

[9] H. V. Poor, Active interference suppression in CDMA overlay systems, IEEE J. Select. Areas Commun., vol. 19, no. 1, pp. 4-20, Jan. 2001.

[10] U.Madhow, Blind Adaptive Interference Suppression for DS-CDMA, in Proc. IEEE., special issueon Blind Identification and Equalization, pp. 2049-2069 ,Oct 1998

[11] D.Samardzija,N.Mandayam and I.Shekar ,Blind Successive Interference Cancellation for CDMA Systems, IEEE Transactions on Communications,2000

[12] U. Madhow and M. L. Honig, MMSE Interference Suppression for Direct-Sequence Spread-Spectrum CDMA, IEEE Transactions on Communications, vol. 42, pp. 3178-3188, December 1994.

[13] Theodore Rapport, Wireless Communications 2 nd edition,Pearson Education Inc. , 2002

G. Strang, Linear Algebra and its Applications, Harcourt Brace Jovanovich, third ed., 1988.

Gunther Auer, Stephan Sand, Armin Dammann and Stefan Kaiser. Special Issue on Multi-Carrier Spread-Spectrum Analysis of cellular interference for MC-CDMA and its impact on channel estimation, European Transactions on Telecommunications. 2004; 15:173–184.

Diakoumis Gerakoulis and Evaggelos Geraniotis, *CDMA: Access and Switching For Terrestrial and Satellite Networks* John Wiley &Sons, 2001

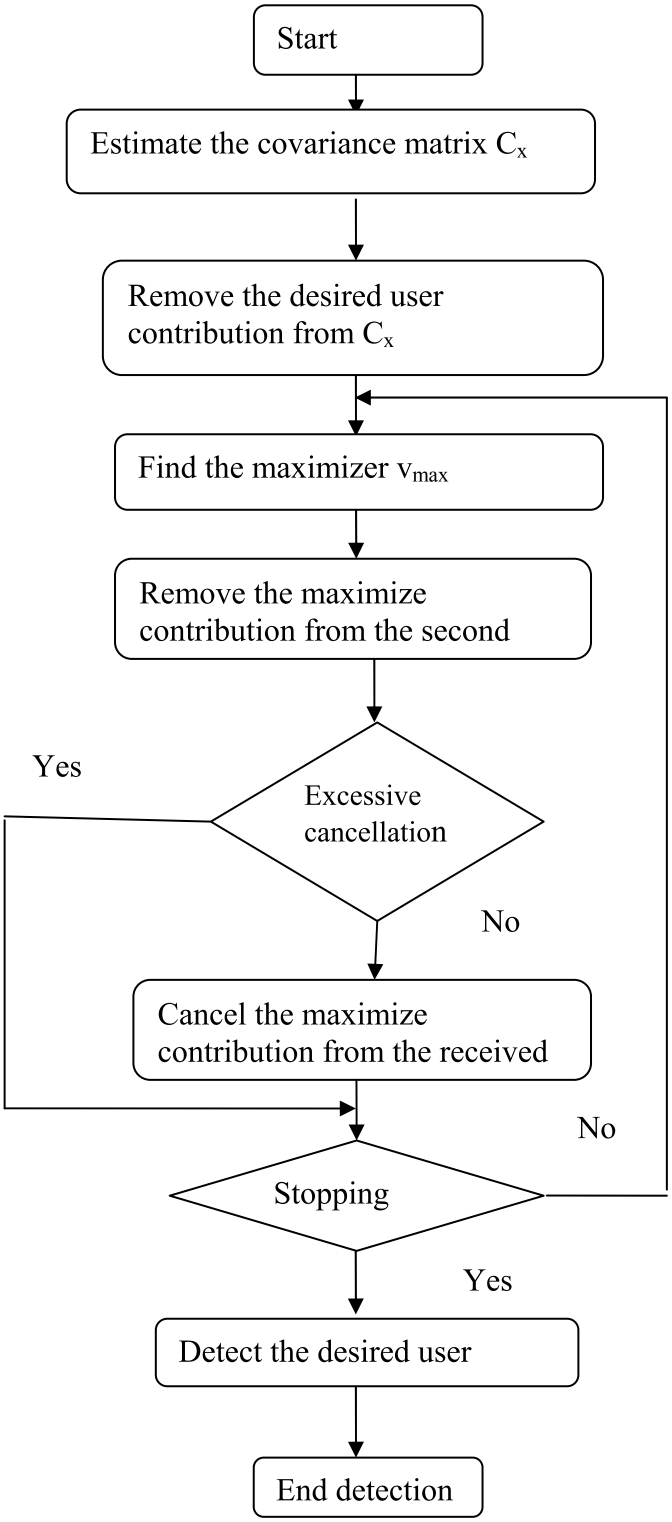

Fig.8. Flow chart illustrating the BIC-MME scheme

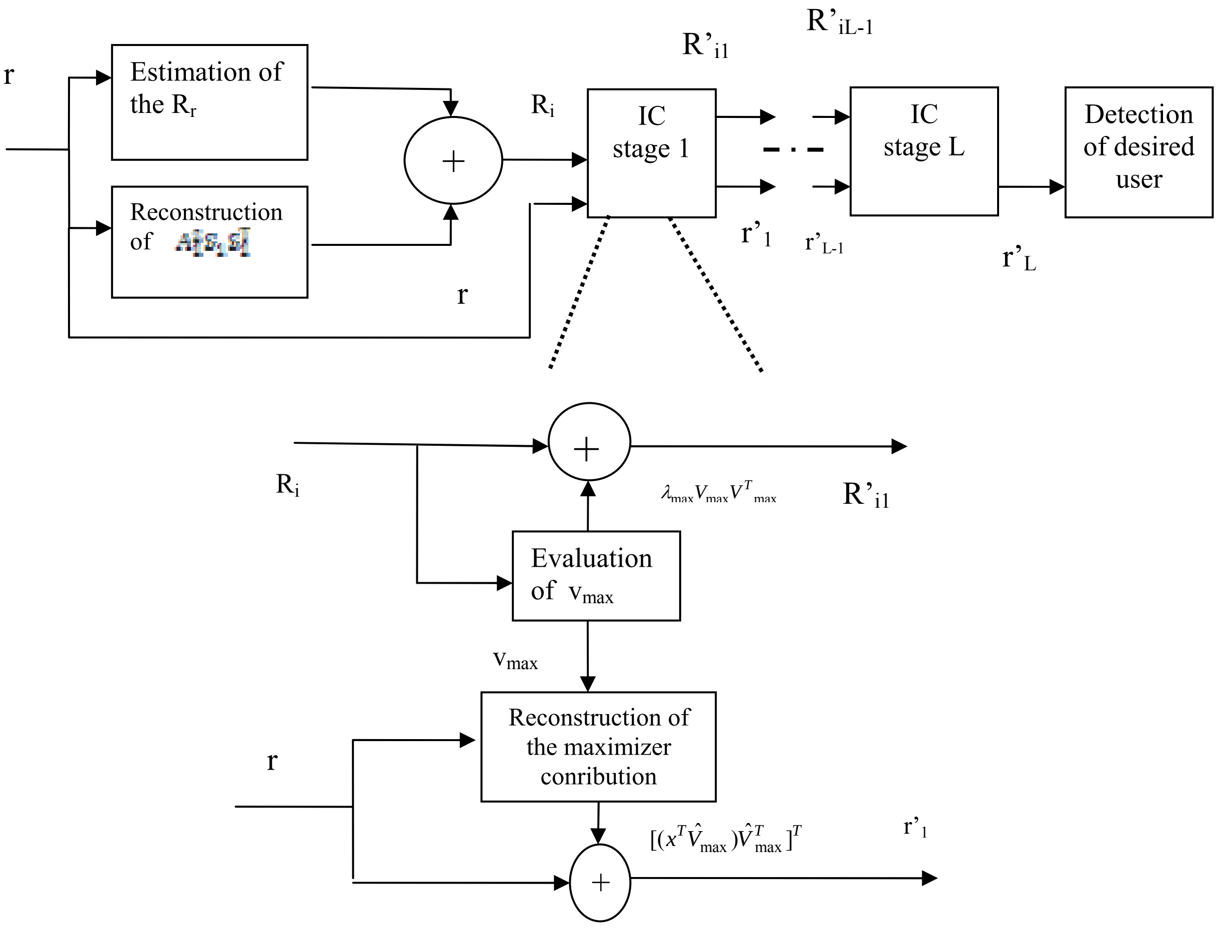

Fig.9. Block scheme of the BIC-MME Receiver

Total No. of users(L)	**Power of interferers ----------------- Power of user**	**Code Used for Spreading**	**No of Carriers**	**Type Of Channel**
16	25	Gold Code	31	FSF Channel

Table 2, MC-CDMA System Simulation Parameters.

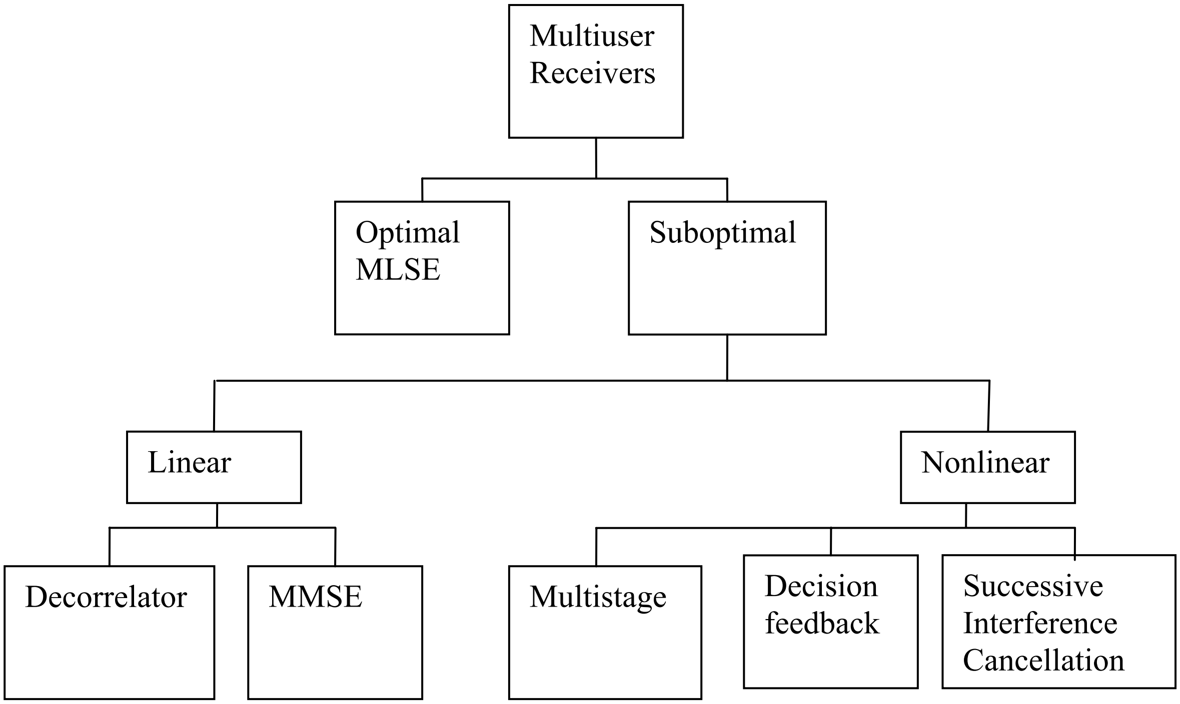

Fig. 10. Classification MUD Techniques

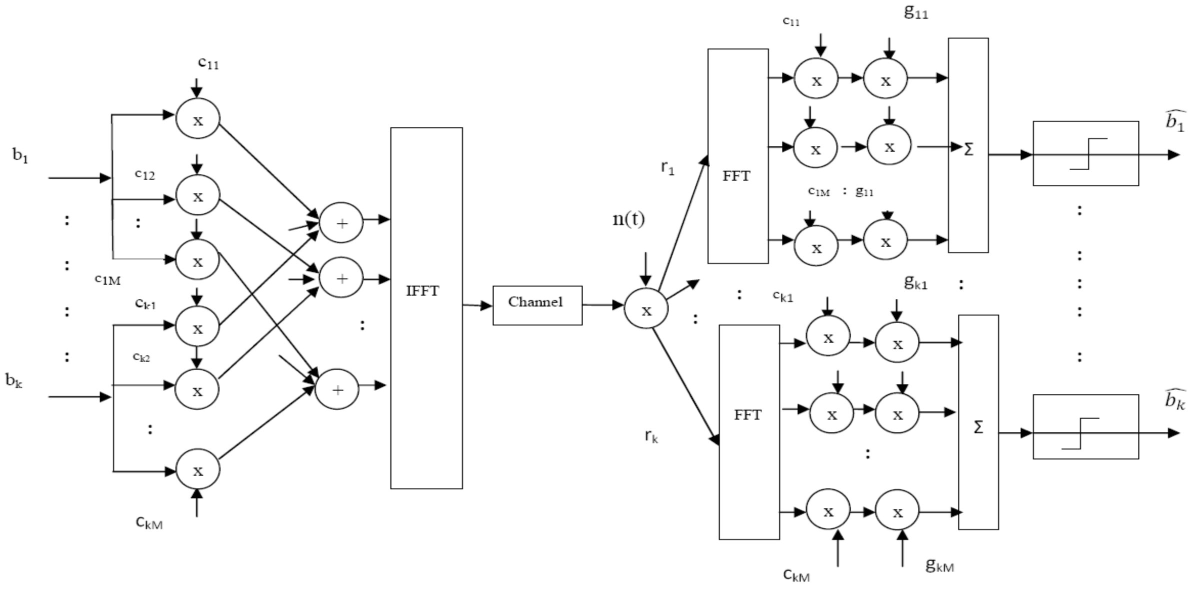

Fig. 11 Transceiver model of MC-CDMA