Performance of MIMO MC-CDMA System with Channel Estimation, Equalization and Beamforming

N. Tamilarasan[1] and L. Nithyanandan [2]

[1] Shri Krishnaa College of Engg. and Tech/Department of Electronics and communication, Pondicherry, India
Email: neithalarasu@gmail.com

[2] Pondicherry Engineering College/Department of Electronics and communication, Pondicherry, India
Email: nithi@pec.edu

Abstract— **Multipath fading and spectral crowding are the major challenges in dealing higher data rate in future broadband wireless communication system. With the increase of data rate the distortion of the received signal caused by multipath fading channel became a major problem. The multiple-input multiple-output (MIMO) assisted Multicarrier code division multiple access (MC-CDMA) systems, can tackle the problem and provide higher data rate for future wireless communication system. But inter symbol interference (ISI) caused by the frequency selectivity of the channel affect the overall performance. It is a form of signal distortion in which previous symbol interferes with subsequent symbols causing the distortion of subsequent symbols. Multipath propagation of wireless signal and band limited channels are the two factors causing ISI. It is due to mobility of transmitter, receiver and local scattering cause the signal to be spread in frequency, different arrival time and angle. So possible potential gain in spectral efficiency is challenged by the receiver's ability to accurately detect the symbol due to ISI. The use of MIMO MC-CDMA mitigates some of the problem of the transmission impairments caused by the frequency selective nature of the wireless channel. However, successful implementation requires to remove the amplitude and phase shift caused by channel. This can be done by efficient channel estimation with strong equalization along with beam forming (BF). This paper proposes MIMO MC-CDMA system with BF, Minimum mean square error (MMSE) equalization with pilot based channel estimation. The simulation result shows improved bit error rate (BER) performance when the sub carrier (SC) and antenna configuration was increased.**

Index Terms— **MIMO, MC-CDMA, ISI, MMSE Equalization, Channel Estimation, BF.**

I. Introduction

The current wireless communication system suffers performance degradation due to excessive multiple path delay. The root cause of this degradation is the ISI. The ISI caused by multipath fading of wireless channels lead to distortion of signals, causing bit errors at the receiver. As the data rate is increased the transmission time for individual pulses decreases. Therefore the transmission pulses in the time domain become narrow and the effect of channel delay spread increases. Therefore the distortion of the signal due to ISI increases with the increase in the data rate of the system. Thus the ISI has been recognized as the major obstacle for high speed data transmission over wireless channel.

These effects have strong negative impact on the BER whatever is the multiple access scheme and modulation technique. So the systems need an estimation of the frequency selective fading coefficients by channel estimation and equalization to counteract fading and interference to improve system performance and capacity. Generally, MIMO is helpful in mitigating such interference because it can spatially suppress some of the multipath. MC-CDMA, on the other hand, is also a promising technology for the next generation wireless communication systems, which is a combination of orthogonal frequency division multiplexing (OFDM) and code division multiple access (CDMA). However, the effectiveness of this suppression is very limited.

By benefiting from both techniques MIMO-MC CDMA possesses many advantages in terms of insensitivity to frequency selective channels, frequency diversity, effective utilization of bandwidth and support high data rates without change in bandwidth. However, the capacity of MIMO MC- CDMA system is limited by both user interference and ISI which causes severe degradation in BER due to multipath propagation. When MC-CDMA spreads the transmitted symbols in a non-flat fading frequency channel, the inner product of different spreading codes will be no longer zero, which leads to the destruction of orthogonality between different users and introduces interference to degrade the performance. In order to preserve the orthogonality between different users, the channel impairment should be estimated accurately and equalized efficiently.

Still to improve the link performance in terms of BER, the transmitter may be equipped with BF in which an array of antennas are directed at a desired user by adjusting the relative gain and phase of the array elements. By adjusting the relative gain and phase of the array elements, the antenna pattern, or beam, can be made such that the signal power towards the desired direction for receiving or transmitting data, or to suppress other directions in order to reduce the effect of interference. In particular, transmit BF has attracted because of its simplicity to exploit the benefits of multiple transmit antennas by using partial or full knowledge of the channel state information (CSI) at the transmitter. Using BF can improve reception quality, and increase data throughput in a MIMO communication system than single antenna without increasing bandwidth. A basic requirement for transmit BF is the use of multiple antenna elements at the transmitter, and the use of the measured wireless channel between the transmitter and receiver.

The efficient channel equalization needs channel estimation design to remove ISI. The function of channel estimation is to form an estimate of the amplitude and phase shift caused by the wireless channel then the equalization removes the effect of the wireless channel and allows subsequent symbol demodulation. But Channel estimation is a challenging problem in wireless system, because radio channels are highly dynamic. In receiver, extraction of information depends upon channel state information and efficiency of equalization, so as to minimize the error between the actual transmitted symbols and the symbols extracted from the received signal. So an accurate estimation of fading channel is always required for symbol detection. Although differential demodulation can be used without channel estimation, but this results in up to 3 dB loss in signal-to noise ratio (SNR). The CSI can be obtained through training based, blind and semi blind channel Estimation techniques. Among the various channel estimation technique pilot based channel estimation is considered to be a good solution because of its accuracy and simplicity.

The channel estimation can be classified into two groups: blind and non-blind. Blind estimation techniques need to gather a large amount of information to perform the estimation and exhibit a poor performance in mobile systems where the channel varies rapidly under the influence of Doppler's effect and multipath propagation. On the other hand, in non-blind channel estimation methods some portion of the transmitted signal (pilot symbols) or training sequences is either multiplexed with or superimposed onto the transmitted data in the time or frequency domain and is available at the receiver for the channel estimation. In this case, the estimation accuracy can be improved by increasing the pilot symbols or the training sequences

Several combining and equalization techniques for MC-CDMA signals have appeared in the literature [4-6]. As analyzing is done in the down-link of a cellular radio system and the computation is made in the mobile unit, a low complexity scheme is required. In single user communication system, conventional Equal gain combining (EGC) and maximum ratio combining (MRC) can achieve better performance. However, in a multi-access MC-CDMA system, frequency diversity reduces the orthogonality of spreading codes and results in interference and noise. Hence, the choice of equalization becomes a critical point impacting the trade-off between the residual amount of multiple access interference and the noise. In this paper, MMSE equalization is considered because of its good performance compared to other technique.

The improvement in detection techniques tries to reduce the sensitivity of the system and also reduce the noise enhancement. This improvement is however obtained at the expense of higher complexity at the receiver. The MMSE technique outperforms all the basic techniques. With this technique the detector exploits the frequency diversity introduced by the fading channel without enhancing the additive noise.

However, as indicated earlier the combining parameter of such a technique is not easily estimated at the receiver.

In [1], the author has derived the approximation of the BER for MC-CDMA with MRC, EGC and MMSE. The linear combining technique [2] such as EGC, MRC, Orthogonal Restoring Combining (ORC) and Controlled Equalizations (CE) are explored much by necessities. In MC-CDMA, It is observed that both EGC and MRC have very poor performance due to orthogonality loss between the spreading sequences. The orthogonality loss results in a high error floor making these techniques difficult for practical use; therefore the MRC is suitable only for the noise limited system. In ORC, a total cancellation of the multiuser interference is possible, but on the other hand, this method enhances the noise, because the sub channels with low SNR have higher weights and produce complicated expression for the instantaneous SNR at the ORC output posing difficulties to the performance analysis of MC-CDMA with ORC. For this reason, CE is incorporated where a threshold is introduced and the contributions of those sub-channels which are highly corrupted by the noise are cancelled. Andrea Conti and Barbara Masini [3] discussed Partial Equalization for MC-CDMA systems in which the phase distortion is partially compensated to avoid the noise.

The differential modulation technique [4] was discussed as the alternate for channel estimation, but it decrease the performance of the system and also 3 to 4 dB loss in SNR. In [5], author has derived the channel tracking method using kalman filter which results in better estimation accuracy but suffer from computational complexity and delay. Various researchers discussed the effect of phase noise during channel estimation as the phase noise affect the channel estimation process and reduce the performance of the system [6, 7]. Some authors have tried channel estimation using known training sequence and training algorithm for MIMO-OFDM system [8, 9].

The transmit BF for MIMO-OFDM with MRC receiver is discussed in [10]. Another approach is based on feedback of partial channel information [11]. In this instantaneous feedback is considered so it does not track the rapid fluctuations. There are many general feedback schemes [12] that dynamically adopt to the distribution of channel but these methods are generally too complicated to implement in practice. In [13, 14] the MIMO BF with codebook is proposed at both transmitter and receiver. These are challenges in designing the code book and BF weight vector efficiently. The performance of BF with Multiple input and single output (MISO) systems has been analyzed taking into account the errors in channel estimation and the feedback delay [15] and noise in the feedback channel. The distributed BF schemes presented in [16] assume that the transmitter, the receiver and the relay nodes all use a single antenna, as a result, these schemes do not benefit from spatial processing at the nodes. Non-iterative symbol wise BF and ICI/ISI aware BF for MIMO-OFDM is discussed in [17, 18]. In this paper, transmit BF for frequency selective fading channels with MMSE equalization and ideal channel estimation for different antenna configuration and SC is considered.

From the literature survey it is observed that the researchers had discussed either about channel estimation or equalization for the system. But the performance of the system depends on both estimation and equalization. In our previous work[19], this problem was addressed that, the idle channel estimation was incorporated along with equalization for MIMO MC CDMA system. The rest of the paper is organized as follows; system model is described in section 2, the simulation result and the discussion is in section 3 and the conclusion is in section 4.

II. SYSTEM MODEL

Fig. 1 and Fig. 2 show the simple model of MIMO-MC-CDMA transmitter and receiver respectively. The transmitter of MIMO-MC-CDMA consists of direct sequence spreader and OFDM modulator. In these schemes the pilot sequence are very important for the performance. After modulating, the data stream is multiplied by a spreading sequence. The length of this spreading code is usually identical to the number of sub carrier. The pilot signals are multiplexed to the data streams, after OFDM modulation the signals are transmitted through multiple antennas.
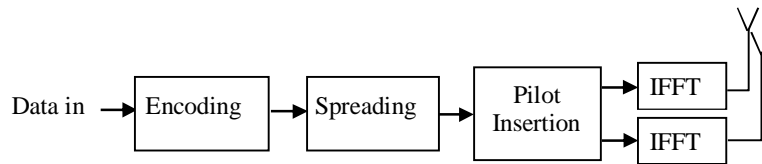

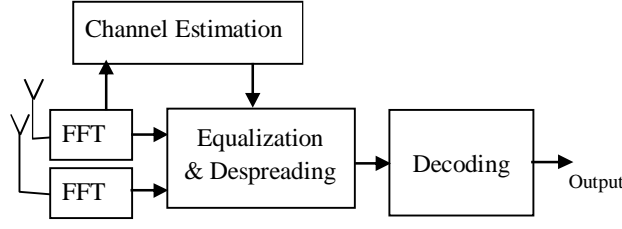Figure 1. Simple Model of MIMO MC-CDMA Transmitter

Figure 2. Simple Model of MIMO MC-CDMA Receiver

The received signal is demodulated using Fast Fourier transform (FFT). After OFDM demodulation the user data symbols and pilot symbols are recovered by despreading with corresponding spreading codes. The required transfer function for channel estimation and equalization is recovered from pilot sequence. Finally the original data stream is recovered by dividing the received signal by channel response. At the receiver end, the demodulator process the channel equalized waveform and reduces each waveform to a scalar (or) a vector that represents an estimation of the transmitted data symbol. The detector, which follows the demodulator, decides whether the transmitted bit is a 0 or 1.

Consider a MC-CDMA system having N_c subcarrier and $N_T \times N_R$ MIMO system, the transmitted signal after modulation can be expressed as

$$s(t) = \sum_{i=-\infty}^{\infty} \sqrt{\frac{2E_b}{N_c T_s}} \sum_{k=1}^{N_T} \sum_{n=1}^{N_c} b_k(i) c_n \, \mu_{T_s}(t - iT_s) \cos(\omega_n t) \tag{1}$$

where E_b and T_s are the bit energy and symbol duration respectively, $u_{Ts}(t)$ represents a rectangular waveform with amplitude 1 and pulse duration T_s, $b_k(i)$ is the ith transmitted data bit c_n is the spreading code, N_T is the transmitting antenna, $\omega_n = 2\pi f_0 + 2\pi(n-1)\Delta f$ is the radian frequency of the nth subcarrier, and the frequency spacing is $\Delta f = 1/T_s$. The received signal $r(t)$ through receiving antenna N_R is given by

$$r(t) = \eta(t) + \sum_{i=-\infty}^{\infty} \sqrt{\frac{2E_b}{N_c T_s}} \sum_{k=1}^{N_R} \sum_{n=1}^{N_c} h_n b_k(i) c_n \cdot u_{T_s}(t - iT_s) \cos(\omega_n t + \varphi_n) \tag{2}$$

Where h_n is the subcarrier flat fading gain, φ_n is the subcarrier fading phase and $\eta(t)$ is AWGN with single-sided power spectral density N_0. After phase compensation, the receiver performs amplitude correction using equalizer coefficient. The received signal after FFT is given by

$$Y(k) = X(k)H(k) + W(k), \; k = 0,1,..,N_c - 1 \tag{3}$$

The received pilot signals $Y_P(k)$ is extracted from $Y(k)$, the channel transfer function $H(k)$ can be obtained from the information carried by $H_P(k)$. With the knowledge of the channel responses $H(k)$, The transmitted data samples signal $X(k)$ can be recovered by simply dividing the received signal by channel response

$$X(k) = \frac{Y(k)}{H(k)}$$

The equalizer co-efficient is expresses as [20]

$$\alpha' = R_{yy}^{-1} R_{by} \tag{4}$$

Then the matrix $R_{b_1 y}$ is

$$R_{b_1 y} = E\left[b_1 \times \left(\sqrt{\frac{E_b T_s}{2N_c}} HC_d b + \eta \right) \right]$$

$$= \sqrt{\frac{E_b T_s}{2N_c}} E[b_1 HC_d b] \tag{5}$$

The matrix R_{yy} is

$$R_{yy} = \frac{E_b T_s}{2N_c} H C_d C_d^T H + \frac{N_0 T_S}{4} I_{N_c} \qquad (6)$$

Where I_{N_c} is an identity with $N_c \times N_c$, C_d is matrix with spreading code and H is a diagonal matrix with n^{th} diagonal element equals to h_n. Substituting equation (5) and (6) into (4), the set of equalizer coefficients for MMSE scheme for downlink as

$$\alpha = \sqrt{\frac{2N_c}{E_b T_s}} \left(H C_d C_d^T H + \frac{N_c}{2E_b/N_0} I_{N_c} \right)^{-1} . h \qquad (7)$$

Where $\alpha = [\alpha_1, \alpha_{2,} ..., \alpha_{N_C}]^T \quad h = [h_1, h_{2,} ..., h_{N_C}]^T$
Finally the received signal is equalized using expression (7).

III. SIMULATION RESULT AND DISCUSSION

The system with diversity technique for MC-CDMA is simulated using MATLAB with the parameters given in Table 1. The result shows the BER performance with respect to energy per bits to spectral noise density (E_b/N_o) for different technique such as pilot based channel estimation, equalization and BF under Rayleigh fading channel.

TABLE I. SIMULATION PARAMETERS

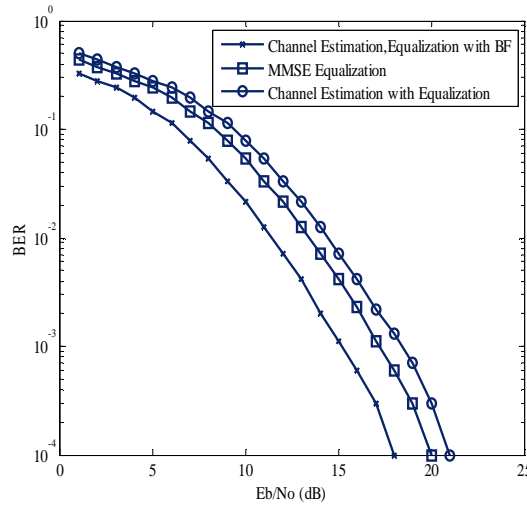| Spreading Codes	Walsh-Hadamard Code
Number of SC	16/ 64 /128
Channel	Rayleigh fading
Modulation	16 QAM
Antennas	2x2/4x4
Equalization/Estimation	MMSE/Pilot

Figure 3. BER performance of 2x2 Antenna (16 SC)
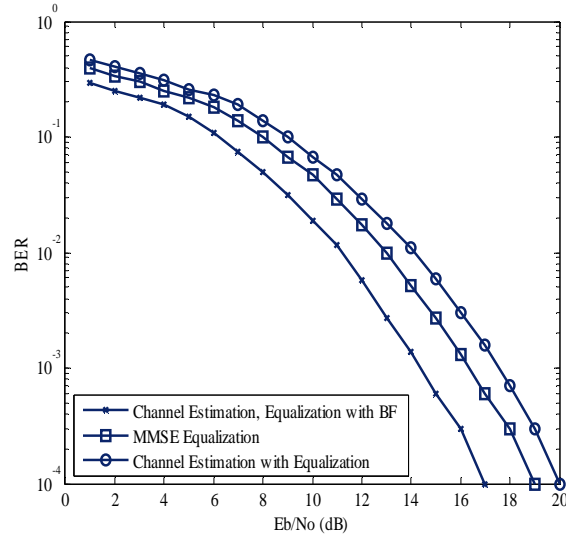
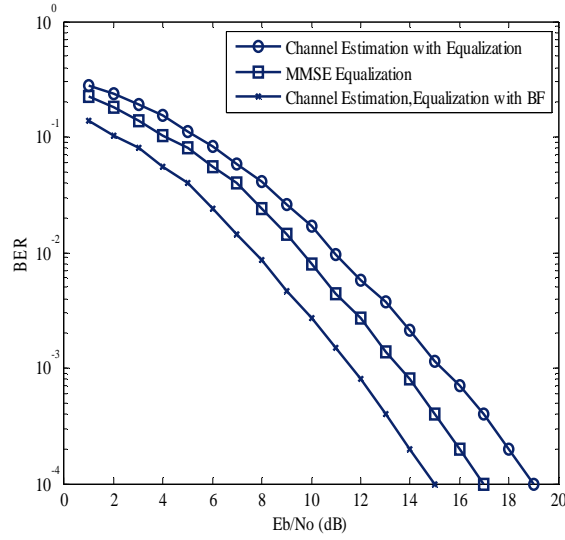Figure 4. BER performance of 2x2 Antenna (64 SC)

Figure 5. BER performance of 2x2 Antenna (128 SC)

The diversity technique uses 2 and 4 antennas for both transmitter and receiver. The result indicates that with diversity, performance of the system improves in terms of BER. Along with diversity technique the system was tested with different SC (16, 64, and 128) with 16 QAM modulation. From the result it is observed that when the number of SC is increased, the performance of the system gets increased due to reduction of ISI. Fig. 3 show the BER performance of MIMO MC-CDMA with pilot based channel estimation, MMSE Equalization and BF, for 16QAM modulation with different antenna configuration. From the graphs it is evident that the system with BF, equalization and estimation performs better than the system only with Equalization, Equalization with channel estimation due to the reduction of ISI. In the figure the channel estimation with equalization shows slightly lesser performance than the MMSE equalization. Because in MMSE equalization, the channel estimation is assumed as perfect, but it is practically not possible.
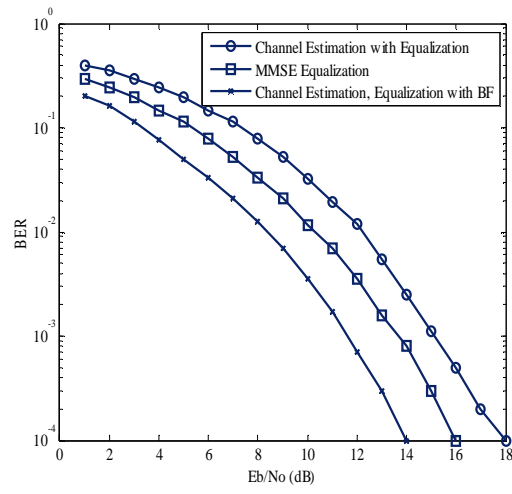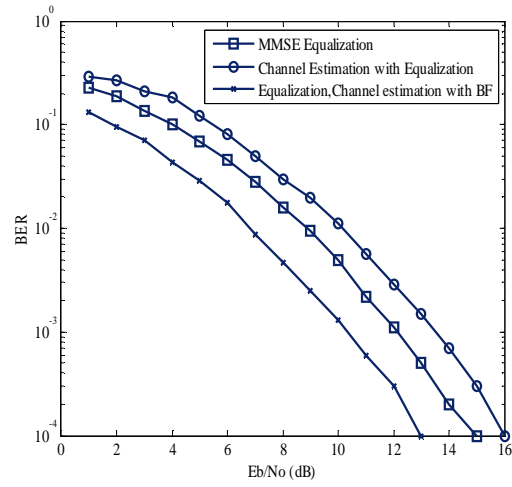
Figure 6. BER performance of 4x4 Antenna (16 SC)

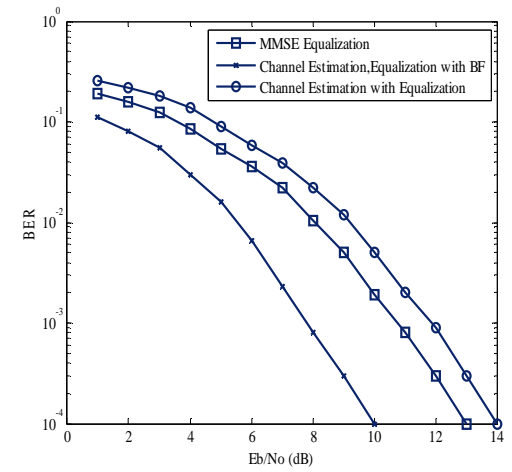Figure 7. BER performance of 4x4 Antenna (64 SC)

Figure 8. BER performance of 4x4 Antenna (128 SC)

665

The same system is tested for different SC also, which is shown in Fig. 4 and Fig.5. From Fig. 3, Fig. 4 and Fig. 5 it is observed that the performance of the system gradually increases due to the increase in number of SC i.e. as frequency diversity increases. Fig. 6, Fig. 7 and Fig. 8 show the BER performance of MIMO-MC CDMA For 4x4 antenna configuration. Comparing Fig. 3, Fig. 4 and Fig. 5 with Fig. 6, Fig. 7 and Fig. 8, the latter figures show improved performance, because when the number of antennas is increased, the performance of the system is increased due to the exploitation of space diversity. From the simulation results it is quite clear that in all the cases the system with BF, MMSE equalization with Channel estimation performs better.

IV. CONCLUSIONS

Generally, wireless channels are fading in both time and frequency, which results in ISI in the received signal. The use of MIMO MC-CDMA mitigates dispersion, but not in sufficient level. So it is necessary to improve the system performance for achieving high speed data transmission by combating the ISI. The combining technique such as EGC, MRC, ORC are suitable for single carrier communication only. If it is used in multicarrier communication, it affect the orthogonality of the user, thus increase the interference of the system. In this paper to counteract ISI, the MIMO-MC CDMA system with BF, pilot based channel estimation and MMSE equalization is discussed with different antenna configuration. From the simulation result it is inferred that the MIMO MC-CDMA system with channel estimation, equalization and BF performs better in the Rayleigh fading channel as ISI is drastically reduced.

REFERENCES

[1] Kaiser, "Analytical performance evaluation of OFDM CDMA mobile radio systems," in Proc. 1st Eur., Pers. Mobile Commun. Conf., Bologna, Italy, pp. 215-220, Nov. 1995.

[2] Flavio Zabini, Barbara M. Masini and Andrea Conti, "Adaptive TORC Detection for MC-CDMA Wireless Systems" IEEE Trans. on commun., vol. 57, no. 11, pp. 3460-3471, Nov. 2009.

[3] Flavio Zabini, Barbara M. Masini and Andrea Conti, "Partial equalization for MC-CDMA systems in non-ideally estimated correlated fading," IEEE Trans. Veh. Technol, vol. 59, no. 8, pp. 3818-3830, Oct. 2010.

[4] Mohammed El-Hajjar and Lajos Hanzo, "Dispensing with channel estimation', IEEE Trans. Veh. Technol., Magazine I, pp. 42-48, June 2010.

[5] Eric Pierre Simon, Laurent Ros, Hussein Hijazi, Jin Fang, Davy Paul Gaillot and Marion Berbineau, "Joint Carrier Frequency Offset and Fast Time-Varying Channel Estimation for MIMO-OFDM Systems," IEEE Trans. Veh. Technol., vol. 60, no.39, pp. 955-964, Mar. 2011.

[6] Roberto Corvaja and Ana García Armada, "SINR Degradation in MIMO-OFDM Systems with Channel Estimation Errors and Partial Phase Noise Compensation," IEEE Trans. on wireless commun., vol. 58, no. 8, pp. 2199-2203. Aug. 2010.

[7] S. Bittner, E. Zimmermann and G. Fettweis, "Iterative phase noise mitigation in MIMO-OFDM systems with pilot aided channel estimation," in Proc. IEEE VTC 2007 Fall, pp. 1087-1091, Sep. 2007.

[8] Benjamin R. Hamilton, Xiaoli Ma, John E. Kleider and Robert J. Baxley, "OFDM Pilot Design for Channel Estimation with Null Edge Subcarriers," IEEE Trans. on wireless commun., vol.10, no. 10, pp. 3145-3150, Oct. 2011.

[9] Francesco Montorsi and Giorgio Matteo Vitetta, "On the Performance Limits of Pilot-Based Estimation of Bandlimited Frequency-Selective Communication Channels," IEEE Trans. on Commun., vol. 59, no. 11, pp. 2964-2969, Nov. 2011.

[10] F. J. L´opez-Martinez, E. Martos-Naya, J. F. Paris, and A. J. Goldsmith, "BER analysis for MIMO-OFDM beamforming with MRC under channel prediction and interpolation errors," in Proc. 2009 IEEE GLOBECOM, pp. 1–7.

[11] S. Zhou and G. B. Giannakis, "Optimal transmitter eigen-beamforming and space-time block coding based on channel mean feedback," IEEE Trans. Signal Process., vol. 50, no. 10, pp. 2599-2613, Oct. 2002.

[12] C. Roh and B. D. Rao, "Transmit beamforming in multiple-antenna systems with finite rate feedback: a VQ-based approach," IEEE Trans. Inf. Theory, vol. 52, no. 3, pp. 1101-1112, Mar. 2006.

[13] S. Ekbatani and H. Jafarkhani, "Combining beamforming and space-time coding using quantized feedback," IEEE Trans. Wireless Commun., vol. 7, no. 3, pp. 898-908, Mar. 2008

[14] Young Gil Kim and Norman C. Beaulieu, "On MIMO Beamforming Systems Using Quantized Feedback," IEEE Trans. on Commun., vol. 58, no. 3, pp. 820 -827, Mar. 2010.

[15] Y. Isukapalli, R. Annavajjala and B. D. Rao, "Performance analysis of transmit beamforming for MISO systems with imperfect feedback," IEEE Trans. Commun., vol. 57, no. 1, pp. 222-231, Jan. 2009.

[16] Jinho Choi, "MMSE-Based Distributed Beamforming in Cooperative Relay Networks" IEEE Trans. Commun., vol. 59, no. 5, pp. 1346-1356, May 2011.

[17] Xiantao Sun, Qi Wang, Leonard J. Cimini, Larry J. Greenstein and Douglas S. Chan, "ICI/ISI-Aware Beamforming for MIMO-OFDM Wireless Systems," IEEE Trans.Wireless Commun., vol. 11, no. 1, pp. 378-385, Jan. 2012.

[18] Hyun-Ho Lee and Young-Chai Ko, "Non-Iterative Symbol-Wise Beamforming for MIMO-OFDM Systems," IEEE Trans. WirelessCommun., vol. 11, no. 10, pp. 3788-3798, Oct.2012

[19] Tamilarasan. N and Nithyanandan. L, "Performance of the MIMO-MC-CDMA System with MMSE Equalization," Int. J. on Recent Trends in Engineering and Technology, vol. 6, no. 2, pp. 223-226, Nov. 2011.

[20] Keli Zhang, Yong Liang Guan, and Qinghua Shi, "Complexity reduction for MC-CDMA with MMSEC," IEEE Trans. Veh. Technol, vol. 57, no. 3, pp. 1-4, May 2008.