# Performance of Turbo Coded MC-CDMA with Iterative Multiuser Detection and Decoding in a Nonlinear Fading Channel

C. Ghosh and R. Gangopadhyay
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur - 721 302, India
Tel:+913222-278028, Fax:+91 3222 255303
chitta, ranjan@ece.iitkgp.ernet.in

## Abstract

*Turbo decoding in combination with detection strategy for Multi Access Interference (MAI) cancellation has been shown to be very effective for MC-CDMA system in Rayleigh multi-path fading environment. This paper reports new simulation results on the efficacy of joint decoding and detection for MC-CDMA in nonlinear and fading channel.*

## 1. INTRODUCTION

Multicarrier-CDMA (MC-CDMA) [1,2] is a bandwidth efficient modulation technique highly suitable for terrestrial/satellite mobile communication systems. By using multi-carrier modulation, CDMA signal is spread over several carriers by which frequency diversity is achieved similar to path diversity in Rake receivers. The performance of MC-CDMA systems can be highly deteriorated when operated in a fading channel with/without nonlinear amplifier. The widely varying signal envelope of MC-CDMA signal makes it susceptible to distortions in systems with nonlinearity, such as the high-power amplifier in a satellite transponder, requiring the operation of a nonlinear amplifier with large input back-off, causing amplifier inefficiency as well as the other major effect of out-of-band radiation.

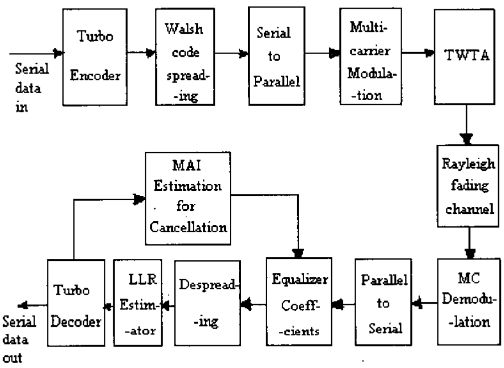
Additionally, the performance of MC-CDMA is further degraded due to MAI. Various optimal and sub-optimal multi-user detection techniques have been proposed for mitigating MAI. As CDMA systems in practice use some kind of forward error correction (FEC), recent attention has been focused on jointly optimizing multi-user detection and channel decoding. The main idea is to exchange soft reliability information between multi-user detection stage and individual channel decoder iteratively, so that better likelihood estimates can be passed on to the decoders. To exploit the multi-user information among users in detection and decoding, both multi-user detection (MUD) and channel decoders must be implemented with soft-input/soft-output (SISO) algorithms.

The purpose of the present work is mainly to evaluate the performance of Turbo coded MC-CDMA system using QPSK as sub-channel modulation in the presence of a nonlinear amplifier and the possible improvement in the bit error rate (BER) performance of MC-CDMA through the use of an iterative interference cancellation type MUD. It is based on the concept introduced by Kaiser and Hagenauer [3] for use in log-likelihood ratio (LLR) calculations and various equalization methods. Also, the Turbo code with iterative maximum a-posteriori (MAP) decoding is used for FEC in our work.

## 2. SYSTEM DESCRIPTION

Fig 1 shows the system under study and implemented through simulation considering a user transmitting an information sequence at a rate of *R* bits/s. During a frame of length *Tf* sec., a total of *(R.Tf)* bits in a block, are encoded using a rate-1/3 Turbo encoder. The coded bit sequence is then spread by Walsh-Hadamard code and passed on to the MC-CDMA modulator. The MC-CDMA modulator here consists of serial-to-parallel conversion and subsequent mapping into QPSK sub-channel modulation. The modulated MC-symbol sequence is then passed through a high-power amplifier (assumed to be Travelling Wave Tube type) and ultimately through the AWGN/fading channel.

On the receiver side, the reverse operation is carried out in order to receive the transmitted serial information sequence. The complex equivalent low-pass transmitted signal for the




[Figure 1] Block diagram of the interference cancellation system with nonlinear amplifier

j-th user is written as:

$$s^j(t) = \sum_{i=-\infty}^{\infty}\sum_{p=l}^{P}\sum_{m=0}^{K-1} a_{j,p(i)}\, d_m^j\, p(t-iTs)\, e^{j2\pi\Delta f(m+(p-1)/P)t} \quad (1)$$

where $\Delta f = 1/T_s$, $\{d_1^j, d_2^j, \ldots, d_K^j\}$ is the Walsh-Hadamard code for the j-th user (the length is K and ?f is the sub-carrier separation for $a_{j,p}(i)$). Also, the total number of sub-carriers is chosen to be P, a multiple of

K, so that P symbols (a total of $P \times K$ chips) will be transmitted during one MC-symbol.

In this paper we have made use of soft interference cancellation proposed for a convolutionally coded MC-CDMA downlink system [4]. However, the equalization coefficientsand LLR calculations are derived for the uplink transmission. Therefore, the output after performing user specific equalization and despreading can be represented as

$$y^{(j)} = \sum_{l=1}^{L} w_l^{(j)} c_l^{(j)} (r_l - I_l^{(j)}) \qquad (2)$$

where, $I^{(j)} = [\,I^{(j)}\ \ I^{(j)}\ \ \ I^{(j)}]^{T}$ denotes interference estimates from the rest of the users on the j'th user, $^{(j)}$ denotes the minimum mean square error (MMSE) and maximal ratio combining (MRC) coefficients for l'th sub-carrier for respective iterations and $c^{(i)}$ is the j-th user code sequence consisting of L chips, $c^{(j)}$=[ $^{(j)}$ $^{(j)}$ $^{(j)}$ ]T and $[\cdot]^{T}$ denotes transposition. For the first iteration (no interference cancellation (IC)), these estimates are set to zero. After decoding all users once, interference estimates for the desired user are computed from the additive contributions due to all other users. SISO channel decoders are used for decoding that provide extrinsic code bit information, $\lambda_{dec}[b^{(k)}]$ [4]. The method of estimation of interference in each sub-carrier with respect to each user is also described in [4].

# 3. IMPLEMENTATION

The MC-CDMA system was simulated using 'C' code. This section gives a brief account of the various steps used in the simulation.

**Input bits/data:** Theinput data is a train of pulses generated by a binary PN-sequence generator.

**Spreading code:** Walsh Hadamard codes are used as spreading codes for MC-CDMA system. Walsh Hadamard codes of length 32 are generated by repeatedly applying Hadamard transform.

**IFFT/FFT blocks:** The FFT and IFFT operation required for multi-channel signal generation and recovery are implemented using decimation in frequency algorithm.

**Nonlinear Channel:** The modeling of the nonlinear channel in the present study is achieved by considering a memoryless envelope model of Travelling Wave Tube Amplifier (TWTA) due to Saleh [5], the AM/AM and AM/PM conversion characteristics are given as:

$$A[\rho(t)] = A_{sat}^{2} \frac{\rho(t)}{\rho^{2}(t) + A_{sat}^{2}} \qquad (3)$$

$$\phi[\rho(t)] = \frac{\pi}{3} \frac{\rho^{2}(t)}{\rho^{2}(t) + A_{sat}^{2}} \qquad (4)$$

where $A_{sat}$ represents the amplifier input saturation voltage and $\rho(t)$ is the envelope fluctuation of the input signal to the amplifier. The output fluctuations can be avoided by operating the HPA with a large back-off in its linear region. The operating point of the amplifier is usually described by the input/output "back-off". The input back-off (IBO) and the output back-off (OBO) of the amplifier can be defined as:

$$IBO = 10log_{10} \frac{P_{O,IN}}{P_{IN}} \qquad (5)$$

$$OBO = 10log_{10} \frac{P_{O,OUT}}{P_{OUT}} \qquad (6)$$

where PIN is the mean power of the signal at the input of the HPA, $P_{OUT}$ is the mean power of the transmitted signal, $P_{O,OUT}$ is the maximum output power (saturation power), and $P_{O,IN}$ is the input power corresponding to the maximum output power. The effects of the nonlinearities can be reduced by working with high back-off which corresponds to moving the operating point of the amplifier to the linear region. Unfortunately, this leads to a loss in power efficiency of the HPA.

**Turbo Encoder and Decoder:** A rate-1/3 Turbo encoder[6] is formed by parallel concatenation of two rate-1/2 recursive sytematic convolutional encoders separated by a block interleaver. We consider N=64 and N=256 in our simulation. The number of iterations in Turbo MAP decoding is fixed to 12.

**Fading Channel:** The fading channel used in our simulation is modeled as a Rayleigh fading channel.

**Equalizer:** The set of equalization coefficients, calculated as in [4], are taken from MMSE for the first iteration ( no IC), in which the received signal is rich in interference from other users. For subsequent iterations, MRC is used.

**LLR Estimator:** LLR calculation using joint likelihood detection [4] has a large performance gain even at its first iteration compared to MMSE. After first iteration *(i)*, feedback information available from channel decoders results into a significant performance gain when iterating the MUD operation. BER drops near to single user bound after a few iterations.

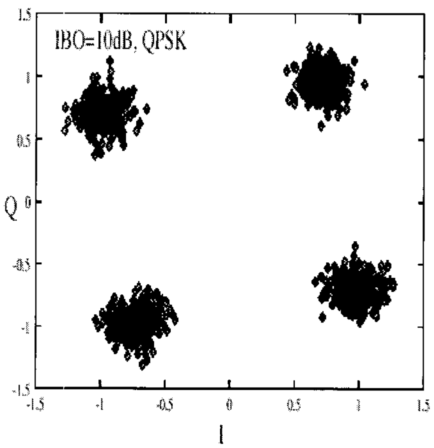
**Joint decoder and detector:** The Turbo decoder implementation is as described above. After decoding all the users once, interference estimates for the desired user are computed as in [4] from the additive contributions due to all other users.

# 4. SUMMARY OF SYSTEM PARAMETERS

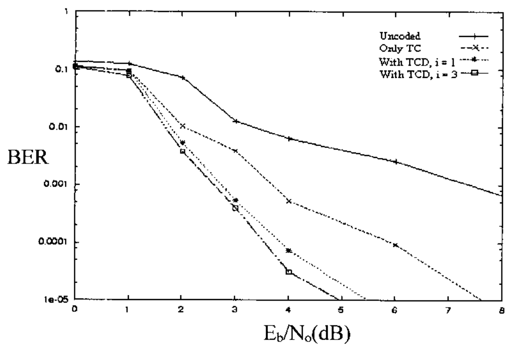
We have assumed the following parameters in the simulation for MC-CDMA system in a nonlinear channel:

| | |
|---|---|
| 1.Number of users | 4 |
| 2. Sub-channel modulation format | QPSK |
| 3. Walsh-Hadamard code length | 64 |
| 4. Data rate | 3.0 Mb/s |
| 5. Number of sub-carriers | 4096 |

6. IBO of HPA 6 dB
7. OBO of HPA 3 dB
8. Turbo coder rate 1/3
9. Interleaver size 256
10. Component coder (2,1,2)
11. MMSE equalization 1st iteration
12. MRC combining other iterations
13. Mobile speed 100 km/h
14. Carrier frequency 2 GHz
15. Maximum Doppler shift 185 Hz



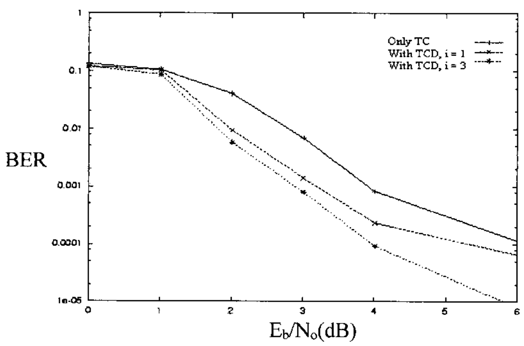

[Figure 2] Constellation at the output of the parallel-to-serial block of QPSK-CDMA in Fig 1.




[Figure 3] Comparison of BER performance with Turbo decoding (TC) and joint Turbo decoding and detection (TCD) applied to MC-CDMA, i = number of iterations.

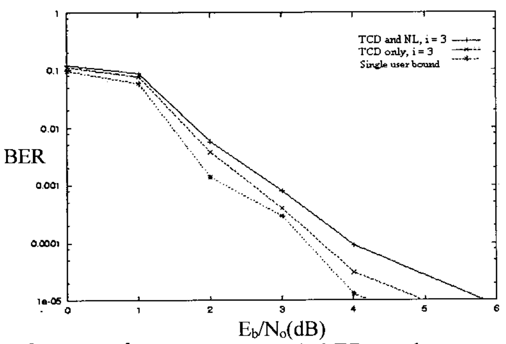
# 5. SIMULATION RESULTS

The main intent of the simulation is to investigate the deterioration suffered by MC-CDMA due to nonlinear amplifier, fading channel and the MAI and to quantify the performance improvement possible with improved FEC such as Turbo code and improved algorithms for MUD for MAI cancellation. In the first place, the severe impact of the nonlinear amplifier (TWTA) in the presence of AWGN channel on the signal constellation of QPSK-CDMA is shown in Fig 2 for a TWT amplifier OBO=3dB. For better processing of the received signal, the cloud in [Fig 2] can be removed effectively by placing a complex automatic gain control (CAGC) circuit after the parallel-to-serial block in [Fig 1] The co-efficients for compensating the rotation and attenuation of constellation can be obtained by averaging the received symbols belonging to the same decision region over a large number of symbols [7].




[Figure 4] BER performance of the proposed system in Rayleigh fading channel with nonlinear amplifier using 1/3- rate Turbo code and detection with different iterations.

[Fig 3] shows the plot of the BER versus Eb/No for MC-CDMA (QPSK) over frequency non-selective Rayleigh fading channel under different scenarios. A significant improvement in performance is exhibited when joint detection and decoding strategy is employed. Fig 4 depicts similar distinct improvement of the BER performance achievable with joint decoding and detection, with 1and 3 iterations, when used with MC-CDMA over frequency non-selective Rayleigh fading channel in the presence of nonlinearity (NL) with an amplifier OBO of 3dB. Compared to the first iteration of no IC, repeated use of soft interference cancellation in subsequent iterations improves the performance significantly. As the number of iterations is increased, the estimates of interference become more accurate contributing to the reduction of BER. Finally, the simulation results in Fig 5 indicate that MC-CDMA when used with joint decoding and detection performs better than with only Turbo decoding and can almost approach the performance limit of the single user bound [8].




[Figure 5] Comparison of BER performance of the proposed system with joint decoding and detection with 3 iterations

## 6. CONCLUSION

We have dealt with the implementation of iterative multiuser detection and decoding for MC-CDMA in Rayleigh fading channel with nonlinearity. MC-CDMA with an iterative multiuser receiver has shown an impressive gain in its performance even in a heavily loaded multiuser environment. It approaches the single user bound after few iterations even in a nonlinear fading channel.

**Acknowledgement :**

The work has been carried out under the project sponsored by CSIR, NewDelhi in place of project "ETB" sponsored by MHRD, New Delhi.

■ REFERENCE

[1] J.G. Proakis, *Digital Communications*, 2nd ed. New York: McGraw-Hill, 1989.

[2] L.J. Cimini, Jr., "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing," *IEEE Transactions on Communications*, vol. 33, no.7, July 1985.

[3] S. Kaiser, and J. Hagenauer, "Multi-carrier CDMA with iterative decoding and soft-interference cancellation," *Proc. of IEEE Global Telecomm. Conf.*, Phoenix, USA, pp. 6-10, Nov. 1997.

[4] P.D. Kafle, and A. B. Sesay, "Performance

of Turbo coded multi-carrier CDMA with iterative multiuser detection and decoding," *Proc. IEEE Canadian Conf. on Electrical and Computer Engineering,* Toronto, Canada, pp 105-110, May 2001.

[5] A.A.M. Saleh, "Frequency-independent and frequency-dependent nonlinear models of TWT amplifiers", *IEEE Trans. on Communications*, vol.29, no.11, Nov 1981.

[6] C. Berrou, A. Glavieux and P. Thatimajshima, "Near Shannon limit error correcting coding and decoding : Turbo Codes", *ICC* '93, Geneva, Switzerland, pp. 1064-1070, May 1993.

[7] G. Santella, and F. Mazzenga, "A hybrid analytical-simulation procedure for performance evaluation in M-QAM-OFDM schemes in presence of nonlinear distortions", *IEEE Trans. on Veh. Tech.*, vol. 47, no. 1, pp. 142-151, Feb 1998.

[8] C.Ghosh, R. Gangopadhyay, and R. Agrawal, "Performance evaluation of MC-CDMA in the presence of nonlinear amplifier using Turbo codes", *NCC Conference*, Chennai, India, Jan 2003.

## Biography

C. Ghosh is currently an M.S. student in the Electronics and Electrical Communication Engineer-ing Department, Indian Institute of Technology, Kharagpur, India. He received his B.Tech. degree in Electronics and Telecommunication Engineering from Kalyani University, Calcutta, India. His research interests include joint detection and decoding and power efficient algorithms in different multiple access techniques. He is a member of IEEE and recipient of the Council of Scientific and Industrial Research (CSIR), India Senior Research Fellowship.

Dr. R. Gangopadhyay is currently Professor and Head, Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology, Kharagpur, India. His current research activities include wireless communication, optical networking and lightwave transmission systems.