Multiuser detection-Fall, 2002 Project Report

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1 Abstract

Multicarrier CDMA (MC-CDMA) system with successive interference cancellation (SIC) and spatial diversity (SD) is analyzed and simulated. BER and capacity using SD shows superior performance over single antenna approach.

2 Introduction

2.1 CDMA with MUD

After the breakthrough work of verdu[1] about the increasing the capacity of CDMA systems using Multiuser Detection (MUD) at the receiver, a significant amount of work has been done. Unlike the conventional approach, the optimal MUD solution searches for the estimated bits for all users so that the mean square error between received signal and estimated received signal should be minimum. The optimal solution suffers from exponential complexity, and many suboptimal solutions are suggested and SIC is one of them.

SIC decodes current user after previous users were decoded and canceled out. It is believed that SIC has the compatibility with current commercial systems, allowing strong error correcting codes and it is robust in an asynchronous environment as well as able to be implemented with low hardware complexity. On the other hand, SIC suffers from a few problems like the latency in decoding all users, sophisticated power control in transmitter and receiver, the dependence of reliability of current user on the previous user's bit estimates [3] .

2.2 MC-CDMA

This paper studies SIC implemented on MC-CDMA system which is a combination of CDMA and OFDM. It has drawn much attention because it inherits all the advantages from OFDM such as modulation with well studied FFT device, robustness to channel frequency selectivity, good frequency utilization efficiency. But like all other multiuser systems, the interference need to be well studied and handled in order to provide reliable communication for all users.

2.3 Antenna Diversity

As one of approaches for bigger capacity without increasing frequency spectrum, spatial diversity (SD) has been studied and successfully adopted. SD is based on the observation that if two or more antenna are separated more than one half wavelength, they experience independent Rayleigh fading given isotropic transmission and reception. So the probability that all the signals in multiple antenna suffer from deep fading at the same time is very small.

Selection combining (SC) is investigated and analyzed. In this method, signal in different antenna are chosen based on decision metric. The most common metric is the signal-to-noise ratio (SNR) in one antenna. Since the SNR is difficult to estimate, most systems use signal + noise power (S+N) instead of SNR[4]. In other words, the branch with the biggest received power is chosen. In this work, SC scheme choose best signal per subcarrier and combined. Best signal may be determined after combining but it won't necessarily choose best subcarrier from multiple antenna. Combining method can be either Equal Gain Combining (EGC) or Maximum Ratio Combining (MRC). In this work, MRC is chosen for study.

3 System Model

The MC-CDMA system with SIC and the performance enhancement caused by SD is investigated. In this work, the system assumed not optimal power control for SIC, imperfect channel estimation, and BPSK modulation with independent spreading for sine and cosine.

Erroneous bit decisions from early users can potentially add interference to the later users, and this effect was not explicitly taken into account in the analytical results.

I was trying to merge powerpoint file into latex but was not successful, so Please refer to attached picture for Baseband model with single antenna with SIC.

3.1 Transmitter

The transmitted signal for user k is written as

$$s_k(t) = \sqrt{P_k} \sum_{n=-\infty}^{\infty} \sum_{m=1}^{M} b_k[n] u_T(t-nT) \Re\left\{c_{k,m}[n] e^{j(\omega_m t + \theta_{k,m})}\right\} \quad (1)$$

$$= \sqrt{P_k} \sum_{n=-\infty}^{\infty} \sum_{m=1}^{M} b_k[n] u_T(t-nT) \{c^I_{k,m}[n] \cos(\omega_m t + \theta_{k,m}) - c^Q_{k,m}[n] \sin(\omega_m t + \theta_{k,m})\} \quad (2)$$

P_k : transmit power of the user k
$b_k[n]$: the data bit of user k at time n

$u_T(t) = 1, \;\; 0 \le t \le T, \quad 0$, elsewhere
$Re\{\cdot\}$: real part of complex number
$c_{k,m} = c^I_{k,m} + jc^Q_{k,m}$: complex spreading sequence for user k on subcarrier m
$\omega_m t$: frequency for subcarrier m
$\theta_{k,m}$: phase for user k on subcarrier m, i.i.d and uniformly distributed

3.2 Channel Model

The use of cyclic prefix (CP) preserves the orthogonality of the subcarriers and eliminates the ISI between consecutive MC-CDMA symbols. Further, the channel is assumed to be slowly fading. So it is considered to be constant during one symbol. Under these assumption the system can be described as a set of parallel Gaussian channel[5] with channel coefficient on subchannel m, antenna j and user k is

$$h_{k,m,j}(t) = h^I_{k,m,j}(t) + jh^Q_{k,m,j}(t) = \beta_{k,m,j}(t)e^{j\psi_{k,m,j}(t)} \tag{3}$$

This work considered imperfect channel estimation and the estimation error is assumed to follow a lognormal distribution with a means of unity and can be written as

$$\hat{h}_{k,m,j} = h^I_{k,m,j} \cdot \lambda^I_{k,m,j} + jh^Q_{k,m,j} \cdot \lambda^Q_{k,m,j} \tag{4}$$

$$\lambda^{I,Q}_{k,m,j} = e^x/E[e^x], \;\; x \sim N(0, \sigma^2_\varepsilon) \tag{5}$$

3.3 Receiver

The receiver estimates data for one user at one time and the estimated received signal is re-constructed and subtracted from remaining received signal for next user.

The received signal on subcarrier m, antenna j can be written as

$$r_{m,j}(t) = \sum_{n=-\infty}^{\infty}\sum_{k=1}^{K}\sqrt{P_k}\beta_{k,m,j}(t)b_k[n]u_T(t-nT-\zeta_{k,j})\Re\{c_{k,m,j}[n]e^{j(\omega_m t+\phi_{k,m,j}(t))}\} + \eta_{m,j}(t) \tag{6}$$

After canceling out the accumulated re-constructed signals based on previously estimated bits

$$y_{k,m,j}(t) = r_{m,j}(t) - w_{k-1,m,j}(t) \tag{7}$$

where the accumulation of previously estimated signal $w_{k,m}$ is written as

$$w_{k,m,j}(t) = \sum_{i=1}^{k-1} z_{i,m,j}(t) \tag{8}$$

and $z_{k,m,j}$ is written as

$$z_{k,m,j} = \sqrt{P_k}\Re\left\{\hat{h}_{k,m,j}c_{k,m}\hat{b}_k e^{j(\omega_m(t-\zeta_{k,j})+\theta_{m,k,j})}\right\}. \quad (9)$$

Before combining, signal on each subcarrier and each antenna needs to go through magnitude and phase adjustment by multiplying $\hat{q}_{k,m}$. This will be explained in next chapter.

4 Analysis

4.1 Decision Matric and Combining Method for MC-CDMA

Depending on the choise of $\hat{q}_{k,m,j}$, there are two ways of combining the chips of the same data bit: Equal Gain Combining (EGC) and Maximum ratio combining (MRC). MRC is studied in this paper and EGC can be considered as a special case of MRC. For MRC $\hat{q}_{k,m,j}$ is

$$\begin{aligned} h_{k,m,j} &= \beta_{k,m,j}e^{-j\psi_{k,m,j}} && (10)\\ \Rightarrow \hat{q}_{k,m,j} &= \hat{\beta}_{k,m,j}e^{-j\hat{\psi}_{k,m,j}}, && (11)\end{aligned}$$

where $\hat{\beta}_{k,m,j} = \sqrt{(\hat{h}^I_{k,m,j})^2 + (\hat{h}^Q_{k,m,j})^2}$.

Due to the power control and the assumption for no error propagation from decision error of previous user, without losing generality first user can be considered as the representative for all k users and analized on behalf of k users

the decision statistic on subcarrier m, antenna j for the first user, $U_{1,m,j}$ can be written as[3]

$$U_{1,m,j} = D_{1,m,j} + \eta_{m,j} + I_{1,m,j} + J_{1,m,j} \quad (12)$$

where $D_{1,m,j}$ is the desired signal, $I_{1,m,j}$ is the same-carrier interference , $J_{1,m,j}$ is other-carrier interference and $\eta_{m,j}$ is noise. And they are written as

$$\begin{aligned} D_{1,m,j} &= \sqrt{P_1}b_1(0)\beta_{1,m,j}\hat{\beta}_{1,m,j}\cos(\psi_{1,m,j} - \hat{\psi}_{1,m,j}) && (13)\\ I_{1,m,j} &= \frac{1}{2T}\sum_{k=2}^{K}\sqrt{P_k}\beta_{k,m,j}\hat{\beta}_{1,m,j}[(a^I_1\zeta_{k,j} + a^I_2(T-\zeta_{k,j}))\cos(\Delta\phi_I) && (14)\\ &\quad +(a^Q_1\zeta_{k,j} + a^Q_2(T-\zeta_{k,j}))\sin(\Delta\phi_I)] \\ J_{1,m,j} &= \sum_{k=2}^{K}\sqrt{P_k}\sum_{\substack{l=1\\l\neq m}}^{M}\beta_{k,l,j}\hat{\beta}_{1,m,j}\cdot\frac{1}{2T}\{\int_0^{\zeta_{k,j}}\left[d^I_1\cos(\Omega_{k,m,l,j}(t)) + d^Q_1\sin(\Omega_{k,m,l,j}(t))\right]dt + \\ &\quad \int_{\zeta_{k,j}}^{T}\left[d^I_2\cos(\Omega_{k,m,l,j}(t)) + d^Q_2\sin(\Omega_{k,m,l,j}(t))\right]dt\} && (15)\end{aligned}$$

where

$$\Omega_{k,m,l,j}(t) = (\omega_m - \omega_l)t + \hat{\phi}_{k,l,j}(0) - \hat{\phi}_{1,m,j}(0) \tag{16}$$

assuming $\omega_{m,j}$ is idential for all antenna and index j is dropped.

4.2 Selection Combining

It is assumed that the signal whose channel gain is biggest has biggest decision matric and chosen for combining in this scheme. If the biggest channel coefficient is defined

$$\alpha_{1,m} = \max_j\{\beta_{1,m,j}\} \tag{17}$$

$$\hat{\alpha}_{1,m} = \max_j\{\hat{\beta}_{1,m,j}\} \tag{18}$$

then U_1, $E[U_1]$ and $var[U_1]$ can be written as following

$$U_1 = \sum_{m=1}^{M} \max_j\{U_{1,m,j}\} \tag{19}$$

$$E[U_1] = \sqrt{P_1}\sum_{m=1}^{M} \alpha_{1,m}\hat{\alpha}_{1,m}\cos(\psi_{1,m} - \hat{\psi}_{1,m}) \tag{20}$$

$$\begin{aligned}\mathrm{var}[U_1] &= \frac{N_0}{2T}\sum_{m=1}^{M}\alpha_{1,m}\hat{\alpha}_{1,m} + \sigma^2\sum_{k=2}^{K}P_k[\frac{1}{3}\sum_{m=1}^{M}\alpha_{1,m}\hat{\alpha}_{1,m} \\ &\quad + \frac{1}{2\pi^2}\sum_{m=1}^{M}\alpha_{1,m}\hat{\alpha}_{1,m}\sum_{\substack{l=1\\ l\neq m}}^{M}\frac{1}{(m-l)^2}]\end{aligned} \tag{21}$$

The Signal to Interference plus Noise Ratio (SINR) to be $\Gamma_k = (E[U_k])^2/\mathrm{var}[U_k]$ and assuming Gaussian modeling for the interference plus noise, the probability of error can be written as

$$P[e|\{\alpha_{1,m}\},\{\hat{\alpha}_{1,m}^{I,Q}\}] = Q\left(\frac{E[U_1]}{\sqrt{\mathrm{var}[U_1]}}\right) \tag{22}$$

where $Q(\cdot)$ is the well-known "Q function".

Since $E[U_1]$ contains random variable, Monte-Carlo integration was used to obtain the probablity error.

The simulation shows that this analysis is well representing the real system.

4.3 Power Control

Power control (PC) is a crucial in SIC system. It is shown that best average performance can be achieved if signal to interference-noise ratio for all users are same. In other words, if all users experience same performance, this gives best average performance for all users [2].

$$P_k = P_{k-1} - \frac{(1 - \varepsilon_{k-1})P_{k-1}^2}{V_{k-1} + N_k'} \tag{23}$$

where V_k is the total remaining multiple-access interference (MAI) for user k plus their own power:

$$V_k = \sum_{i=1}^{K} P_i - \sum_{i=1}^{k-1}(1 - \varepsilon_i)P_i \tag{24}$$

This power distribution equalizes the SINR at detection for all users

5 Simulation

5.1 BER

Simulation result for multiple antenna with SC method is presented,

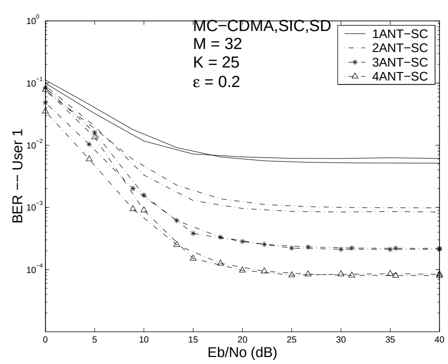

Figure 1: MC-CDMA with SIC and 4 Antenna diversity (SC): simulation and analysis

A very close result between simulation and analysis was confimed.

5.2 Capacity

The capacity, which is defined as the number of full -rate BPSK users that can be supported at a specified BER, and in a specified bandwidth and a given Eb/No, is simulated. This shows that it is important to have a good channel estimation in order to make full use of antenna diversity.

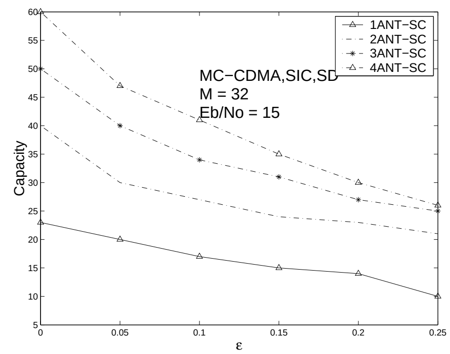

Figure 2: Capacity on Eb/No=15(db), M=32

6 Conclusion

A MC-CDMA with SIC and SD was proposed. Also optimal power control in the presence of estimation error was used. A significant performance was observed in terms of both BER and capacity on the assumption of the good channel estimate. A good channel estimation may be costly and multiple antenna system increases the complexity of channel estimation linearly so performance and complexity trade off need to be done.

References

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