Power Control for Capacity Enhancement in MCCDMA-MIMO System Using Bayesian Water Filling Game Theory

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ABSTRACT

Wireless multimedia transmissions are playing important roles in the emerging communication system, which require not only effective transmission but also resource allocation to provide Quality-of-Services (QoS) for users of various demands. MCCDMA-MIMO, a system of Multi Carrier Code Division Multiple Access (MC-CDMA) with multiple antennas at both the transmitter and the receiver (MIMO) has drawn significant interest for the future generation networks due to its ability of multiple access and spectral efficiency. The adaptive modulation is a promising concept to provide a wide variety of communication services such as voice, high speed data, and real time multimedia services. So, the implementation of adaptive modulation aspiration in MCCDMA-MIMO based system has been great interest in future wireless system in which mobile devices allocates resource in a resilient manner. However, the performances of this system are subjected to limiting factors such as Multiple-Access Interference (MAI) and Inter-Carrier Interference (ICI). The power control has been long standing open solution to mitigate interference and capacity enhancement. But the strategic choice of assigning the transmission power to individual subcarrier in the MCCDMA-MIMO system is subjected to the knowledge of Channel State Information (CSI), which usually becomes imperfect due to the time varying nature of the channels. So, in this paper Bayesian water filling game model is considered to allocate proper power to each user under imperfect knowledge of CSI.

KEYWORDS:

INTRODUCTION

The goal for the fourth generation (4G) of mobile communications system is to seamlessly integrate a wide variety of communication services such as voice, high speed data, and real time multimedia services. It also intends to meet users’ demands of higher Quality-of-Services (QoS) under the constraint of limited radio bandwidth resource. MCCDMA-MIMO system has drawn significant interest for the future generation networks due to its ability of achieving high data rate in multipath environment and high spectral efficiency due to deployment of multiple antennas at the transmitter and/or receiver[1,2]. Adaptive Modulation is a promising technique to increase the data rate that can be reliably transmitted over fading channels. The basic premise of adaptive modulation is a real-time balancing of the link budget in flat fading through adaptive variation of the transmitted power level, symbol transmission rate, constellation size[3]. For this reason, the implementation of adaptive modulation technique in the transmission scheme of MCCDMA-MIMO system inflicts significant contribution on the capacity enhancement. But the wireless channels in MCCDMA-MIMO networks are known to display significant variations across active users’ subcarriers as well as among subcarriers of the same user...
due to simultaneous spectrum utilization. So, the network performance is limited by the interference noise due to the simultaneous transmissions over all sub carriers and non identical fading conditions over all sub carriers.

The multiple input and multiple output channel is a basic channel model for MCCDMA-MIMO system that allows multiple dimension for transmission and reception and share its capacity. So, the capacity region of the MCCDMA system and its optimal resource allocation scheme has been characterized by its interference mitigation technique. In order to fully accomplish adaptive modulation based MCCDMA-MIMO system for low BER in dynamic multipath environment, it is governed by the functions of power allocation methodology. It deals with the sharing of available power over each carrier and restriction of interference noise at receiver.

The power control method [4,5] focused on balancing (equalizing) the SINRs on all radio links through centralized operations involves feedback and overhead with the increasing number of transmitters in the network and requires added infrastructure, latency, slow reconfiguration against varying environment, increased computational complexity and network vulnerability to give better response. In recent years, increased research interest has been given to the distributed algorithms that manage the power level based on the user’s SINR requirements needs the complete knowledge of Channel State Information (CSI). Since the CSI is subjected to the errors because of the imperfect channel estimation/measurement due to the time varying nature of the channels, the distributed power control algorithm is not globally optimum. Tools of game theory have been widely applied to study the resource allocation and power control problems in various types of networks such as MCCDMA, MIMO. Typically, the game-theoretic models used in these networks assume that the information/knowledge about other devices is available to all devices[6]. However, this assumption is hardly met in practice. In practical wireless communication scenarios, mobile devices can have local information but can barely access to global information on the network status.

Thus, the power allocation game in MCCDMA-MIMO system needs to be reconstructed with some realistic assumptions made on the knowledge level of channel state. Under this consideration, it is necessary to investigate scenarios in which devices have incomplete information about their channel. That is, a device is aware of its own channel state, but unaware of the channel state of other devices. In game theory, a strategic game with incomplete information is called a “Bayesian game”[7]. Bayesian game-theoretic tools have been used to design distributed resource allocation strategies in CDMA networks, multicarrier interference networks. In this paper, Bayesian water filling game has been applied to the adaptive modulation based MCCDMA-MIMO system to enhance the QoS parameters like capacity and BER.

The paper is organized in the following form: In Section II deals with the system architecture, Bayesian water filling game model for power control algorithm in MCCDMA–MIMO system. Section III describes the solution for problem and to maximize the payoff using water filling game theory. The results are depicted in section IV and the conclusions are given in section V.

![MCCDMA-MIMO Transmitter System architecture and channel model](image)

**Fig. 1:** MCCDMA-MIMO Transmitter

**System architecture and channel model:**

A. **System Architecture:**
A multi cellular MC-CDMA network constituted of \( B = \{1, 2, \ldots , N_B\} \) base stations is considered. The system bandwidth \( 'W' \) is subdivided into \( 'N_C' \) subcarriers. Bandwidth of subcarriers is selected such that they approximately exhibit flat fading channel characteristics (i.e., \( W/N_C \leq B_c \), where \( 'B_c' \) is the coherence bandwidth). The data from the user ‘u’, which is assigned to a suitable group by the user grouping algorithm is modulated using M-QAM adaptive modulation technique based on its CSI and the BER target. With an individual spreading code, the modulated data are spread into chips. The chips of all users in the same group are then summed at the input of the MCCDMA-MIMO transmitter \([8,9]\) as shown in Fig. 1. Each ‘G’ subcarriers constitute a group over which individual streams will be spread. As a result of subcarrier grouping, system bandwidth could be described in terms of a set of subcarrier groups, \( C = \{C_{(1)}, C_{(2)}, \ldots , C_{(G)}\} \), where \( N_G = N_C/G \) is the number of subcarrier groups. Each base station, \( b \in B \), is effectively supporting ‘U’ active data users.

![Fig. 2: MCCDMA-MIMO Receiver.](image)

Each base station operates under the constraint that it has at its disposal a maximum amount of power to share among all active subcarrier links. The symbol vector \( Y_u^r \) of user ‘u’ in the base station ‘b’ of an MCDMA system is

\[
Y_u^r = H^r S \sqrt{P^r} X_u^r
\]

(1)

where

- \( X_u^r \) is the active user’s symbol.
- \( S \) is the code matrix.
- \( P^r = \text{diag}\{P^r_1, P^r_2, \ldots , P^r_u\} \) is each user’s transmit power
- \( H^r = \text{diag}(H^r_1, H^r_2, \ldots , H^r_u) \) is each user’s channel gain

The sequences are then spread with respective sub carrier groups using IFFT and power allocation to each user is followed by IWFA. The sub carrier group assignment is processed by CSI. The IWFA allocate power to each user with the help of SINR value as an objective function. The MC-CDMA symbols are then transmitted through MIMO structure of ‘N,’ transmits antennas and ‘N,’ receives antennas and is illustrated in Figures.1 and 2 respectively.

**B. Channel model:**

In wireless communications, the channel may undergo slow and/or fast fading due to shadowing and Doppler effects. Essentially, matrix is not fixed and changes in time. One possible way to deal with this is by considering the channel as a random variable with a known pdf \( p(H) \) which naturally leads to the notions of ergodic capacity and outage capacity. So, a robust design which includes the uncertainty about the channel at both the transmitter and the receiver is to be considered in power allocation. There is a significant variety of channel models that can be used to model channel uncertainty. If the fading is sufficiently slow (the channel coherence time is much higher than the duration of a transmission), the system can be modeled as a compound channel, where the channel state remains unchanged during the course of a transmission and it is assumed to belong to a set of possible channel states but otherwise unknown. For fast fading, however, the compound channel is no longer appropriate and the channel state can arbitrarily change from symbol to symbol during the course of a transmission, so, the unknown channel remains unchanged over multiple transmissions and the utilization of a training sequence to estimate the channel at the receiver is particularly difficult.

In this system model all \( N \) users are simultaneously sending information to one base station. This corresponds to a fading, in which the users are the transmitters and the base station is the receiver. The signal received at the base station can be mathematically expressed as \( Y^r(1) \)

In this study, the wireless transmission is through fast fading environments, that is, the coherence time of the channel is small relative to the delay constraint of the application. When the receiver can perfectly track the channel but the transmitters have no such information, the codewords cannot be chosen as a function of the state of the channel but the decoding can make use of such information. When the fading process is assumed to be stationary and ergodic within the considered interval of signal transmission, the expected channel capacity in a fast fading channel is given by,
where \( p[H_u^+] = \rho[H^1], p[H^2], p[H^3], \ldots, p[H^u] \) power control strategy with respect to the user’s channel gain \( H_u^+ \) and \( N_0 \) is noise Spectrum with zero mean and variance \( \sigma^2 \). Here it is also assumed that each user’s channel gain \( H_u^+ \) is identically independent distribution from two discrete values, \( H^+ \) and \( H^- \) with probability \( \rho^+ \) and \( \rho^- \) respectively. Without loss of generality, we assume \( H^- < H^+ \). The considered probability set is \( q[H_u^+] = \{q(H^-), q(H^+), q(H^+), \ldots, q(H^u)\} \) where \( q(H^u) = \{\rho^-, \rho^+\} \), \( \rho^- \) is the probability value at which the channel gain is having best behavior and \( \rho^- \) is the probability value at which the channel gain is having worst behavior[7].

C. SINR Calculation:
Consider a mobile user ‘u’ of interest served by base station ‘b’. The total signal power measured at the receiver of user ‘u’ and total interference due to other users is given by

\[
[p^b_u] = \sum_{n=1}^{N_b} P^b_n [H^b_n]
\]

(3)

\[
[I^b_u] = \sum_{n=1, n \neq u}^{N_b} P^b_n [H^b_n] + [E^b_u]; b \neq b
\]

(4)

where

\( [p^b_u] \) is power of user ‘u’ in base station ‘b’

\( [I^b_u] \) is the interference to the user ‘u’ due to other users in the base station ‘b’.

\( [E^b_u] \) is inter cell interference

Then the SINR [10] of the user ‘u’ is calculated as

\[
\text{SINR}_u = \frac{\sum_{n=1}^{N_b} P^b_n [H^b_n]}{\sum_{n=1, n \neq u}^{N_b} P^b_n [H^b_n] + [E^b_u]}
\]

(5)

This SINR value is considered as an objective function for the IWFA to allocate the optimal power to each user.

I. Capacity enhancement using bayesian water filling game theory:
A. Bayesian water filling model:
The Bayesian water filling game model in the MCCDMA transmitter plays against the behavior of a wireless channel and assigns power level to the respective sub carriers. The game model also considered that the CSI errors are uncorrelated across subcarriers. The strategies of this game are the possible power level which can be assigned on the sub carriers subject to the constraint of total power at the transmitter and total sub carriers. The objective function in the strategy of the game is the SINR value received from the receiver. A mobile user ‘u’ of interest served by base station ‘b’ has the SINR value given below[10].

\[
\text{SINR}_u = \frac{\sum_{n=1}^{N_b} P^b_n [H^b_n]}{\sum_{n=1, n \neq u}^{N_b} P^b_n [H^b_n] + [E^b_u]}
\]

(6)

where

\( [P^b_n] \) is power of user ‘u’ in base station ‘b’

\[
\sum_{n=1, n \neq u}^{N_b} P^b_n [H^b_n]
\]

is the interference to the user ‘u’ due to other users in the base station ‘b’

\( [E^b_u] \) is inter cell interference

The SINR value in (6) is considered as an objective function for the power control game to allocate the optimal power to each user. The channel capacity of the individual user ‘u’ in the base station ‘b’ is considered as utility function of the game and expressed as

\[
C_u = \sum_{n=1}^{N_b} \log_2 \left( 1 + \frac{P^b_n [H^b_n]}{N_0 \sigma^2} \right) \text{bits} / \text{s} / \text{Hz}
\]

(7)
where $No$ is noise Spectrum with zero mean and variance $\sigma^2$ and $N_c$ is the total sub carriers.

The total system capacity of the base station ‘b’ that constitutes ‘U’ active users is given as

$$C_{total} = \sum_{n=0}^{U} \sum_{\nu=1}^{N} \sum_{b=1}^{N_b} \log_2 \left( 1 + \frac{P}{N_c \sigma^2} |H_n^b| \right) \text{bits/s/Hz}$$

(8)

Then the MCCDMA symbols are transmitted through MIMO system of $N_c$, $N_t$ antennas with channel matrix $H(\tau, t)$ [8,9] as shown in Fig.1 and system capacity or the utility function is modified as

$$C_{MCCDMA-MIMO} = \log_2 \left( \det \left( I_{N_c} + \frac{P}{N_c \sigma^2} \sum_{n=1}^{N_c} H(n) H^*(n) \right) \right) \text{bits/s/Hz}$$

(9)

In order to obtain the optimal power and rate adaptation for different modulation schemes, the expression for its BER in AWGN is easily inverted with respect to rate and power. But, for most non binary modulation techniques (e.g., M-QAM and M-PSK) an exact expression for BER is hard to find. The expression for the BER of M-QAM in AWGN as a function of received SINR and constellation size is given by

$$Q\left(\sqrt{\frac{b_j}{2}}\right), b_j = 1, \left(1 - \frac{1 - SE_{c_j}}{b_j}\right), b_j = 3, \left(1 - \frac{1 - SE_{c_j}}{b_j}\right)^2, b_j = 4,6,...., \left(1 - \frac{1 - SE_{c_j}}{b_j}\right)^2 \sqrt{\frac{3}{2}}, \gamma_{av}, b_j = 5,7,9,.....$$

(10)

where

$$SE_{c_n} = \frac{2b^n - 1}{2^n} Q\left(\sqrt{\frac{6n}{2^n - 1}} \gamma_{av}\right), n = 1, 2, 3, 3$$

$\gamma_{av}$ is the average SINR at the receiver from $P(\theta)$ be the required power for user $j$ to achieve the target BER with $b_j$ bits, respectively

### B. Solution for capacity maximization:

The Bayesian water filling game theory concept is modeled with selfish users and each user is interested in maximizing their own normalized effective capacity, or achievable throughput (rate), subject to an average power constraint. The capacity maximization of users in the MCCDMA-MIMO system with power constraint under Gaussian interference channel is optimized by power distribution algorithm using water filling game theory. In order to maximize the capacity of the system, the power control game must calculate all utilities and expected payoffs for each one of his possible strategies without compromising BER targets[11,12].

To minimize BER targets in the overall link, users need to be grouped optimally under the interference and capacity requirements constraint, the optimization of the problem with respect to subcarrier and power constraint is formulated as

$$\max(C^\star) = \max \left[ \sum_{n=0}^{U} \sum_{\nu=1}^{N} \log_2 \left( 1 + \frac{P_n}{N_c \sigma^2} |H_n| \right) \right]$$

Subject to $\sum_{n=0}^{U} \sum_{\nu=1}^{N} P_n \leq P_{total} ; \sum_{n=0}^{U} \sum_{\nu=1}^{N} a_n \leq U$ :

$$BER \leq BER_{target}$$

where $a_n \in [0,1]$ is the allocation index for the active user ‘u’ in group ‘i’. That is, if $a_n = 1$, then the user ‘u’ is assigned to the group ‘i’. if $a_n = 0$, then the user ‘u’ is not assigned to the group ‘i’. The solution for BER minimization problem of single-water level, multi-constraint (Power and group selection constraint) is obtained through iterative method by simple fixing the water level ‘\mu’ (power level) and adjusting it iteratively until the constraint is satisfied. The power level of user ‘u’ in the base station ‘b’ is obtained using Lagrange multipliers as given as

$$\frac{1}{U} \left( P_{total} - \sum_{n=0}^{U} \sum_{\nu=1}^{N} \sigma^2 \right) ^{-1} \left( \sum_{n=0}^{U} \sum_{\nu=1}^{N} \frac{\sigma^2}{|H_n^b|} \right)$$

(12)
Here the power level and group selection of each user are obtained simply by fixing the water level (power level) $P^*_u$, QoS requirement of individual user and then adjusting it iteratively until the constraints are satisfied as per the algorithm given below.

The expectation from Bayesian game is that each selfish and rational (rational player means a player chooses the best response given its information) players’ behaviors usually results in a Bayesian equilibrium, which represents a common solution concept for Bayesian games. In many cases, it represents a “stable” result of learning and evolution of all participants. Therefore, it is important to characterize such an equilibrium point, since it concerns the performance prediction of a distributed system.

Let $[\hat{\rho}_u(\cdot), p_u(\cdot)]$ denote the strategy profile where all players play $\rho(\cdot)$ except player $u$ who plays $\hat{\rho}_u(\cdot)$, we can then describe player $u$’s payoff as:

$$u_u(\hat{\rho}_u, p_u) = u_u(\hat{\rho}_u, p_1, \ldots, \hat{\rho}_u, \hat{\rho}_{u-1}, \ldots, p_u)$$

It has been proved that the strategy profile $\rho^*(\cdot) = [\rho^*_u(\cdot)]_{u \in K}$ is a (pure strategy) Bayesian equilibrium if for all $k \in K$, and for all $\rho_k(\cdot) \in p_k$ and $p_u(\cdot) \in p_u$

$$\pi_u(\rho^*_u, p_u) \geq \pi_u(\rho_u, p_u)$$

Where $\pi_u \in E_u[u_u]$. From this definition, it is clear that at the BE no player can benefit by changing its strategy while the other players keep theirs unchanged. It is worth to mention that the action set of each player is independent of the type set, i.e., the actions available to user ‘u’ is the same for every its type. Further it is also proved the existence and uniqueness of Bayesian Equilibrium in this game model.

RESULT AND DISCUSSION

This section evaluates the performance of the power control and grouping algorithm using IWFA solution. To show the advantage of the subcarrier grouping with power distribution using IWFA algorithms, simulations are performed in multi-path environment. The performance improvements of mean capacity and BER reduction are analyzed with the simulation of MATLAB 7.0. Simulations were conducted under a multiuser three-cell down-link scenario with Rayleigh fading. There were 48 users in an MC-CDMA-MIMO system with 256 subcarriers divided into 16 groups of 16 subcarriers. Therefore, the length of Hadamard Walsh code is 16. The possible bit loading, $b_j$ is from 1 to 8.

The power allocation scheme to enhance the capacity is optimized by IWFA in the presence of imperfect CSI. The IWFA takes 1000 iterations to allocate power to each user using 10000 Monte Carlo Channel realizations. The group assignment strategy to maximize the overall mean capacity is followed by the algorithm mentioned in section III. The capacity improvement of MCCDMA using IWFA is compared with power allocation without water filling algorithm. The algorithm is simulated for the MCCDMA system with adaptive modulation scheme of BPSK and M-QAM($M=2$ to 8). Fig. 3 shows the capacity improvement analysis of adaptive modulation based MCCDMA system using power control with IWFA and interference based sub carrier grouping. Here, the signal constellation sizes are varied from 2 to 8 and corresponding capacity improvements through theoretical formulae are obtained. The power control with IWFA in adaptive modulation based system is giving 10% of performance improvements compared with power control without IWFA.

![Fig. 3: Mean capacity of adaptive modulation based MCCDMA system](image)

Fig. 4 shows a comparison of the throughput in terms of BPS (Bits per Symbol) for adaptive modulation based MCCDMA technique and Fig. 5 shows the further improvements of MCCDMA technique with MIMO diversity scheme of $2 \times 2$, $4 \times 4$ systems.
The benefit of IWFA in power control and user grouping is significant. Regarding to performance comparison between with and without IWFA algorithms, the IWFA algorithm performs better (18% of improvements) because it avoids excess power and allocate different powers to users according to their effective channel responses. The compatible sub carrier group according to data rate demands also improves the throughput.

The power control and sub carrier group assignment strategy in the MCCDMA system improves the BER performance by eliminating transmission on poor subcarrier. Since majority of bit errors occur on severely degraded subcarriers. The BER performances of the adaptive modulation based MCCDMA system for odd and even constellation sizes are shown in Figs. 6&7 and the further reduction of the BER performances through spatial diversity of sizes 2x2, 4x4 are also shown in Figs. 8&9 and Figs.10&11 respectively.

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**Fig. 4:** Performance of bit per symbol in adaptive modulation based MCCDMA system.

**Fig. 5:** Performance of bit per symbol in adaptive modulation based MCCDMA-MIMO system.

**Fig. 6:** BER performance of adaptive modulation based MCCDMA System for odd constellation.
Fig. 7: BER performance of adaptive modulation based MCCDMA system for even constellation.

Fig. 8: BER Performance of adaptive modulation based MCCDMA system with 2×2 MIMO for odd constellation.

Fig. 9: BER Performance of adaptive modulation based MCCDMA system with 2×2 MIMO for even constellation.
Conclusions:

The capacity enhancement and BER reduction in adaptive modulation based MCDMA system is achieved by IWFA based power control and sub carrier group assignment method. The power distribution to each user using IWFA is modeled based on the SINR value as an objective function which is received from receiver in the presence of imperfect CSI. The sub carrier group assignment strategy in the MCCDMA system improves the BER performance by eliminating transmission on poor subcarrier. Since majority of bit errors occur on severely degraded subcarriers. The signal transmission of the system through MIMO also gives an additional improvement of the capacity and BER performance. The capacity in MCCDMA is enhanced nearly 10% for SISO and 32% for MIMO due to power allocation using Iterative Water Filling Game Theoretic approach.

REFERENCES