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Power Loading and Subcarrier Group Assignment for MCCDMA-MIMO System using Water Filling Game Theory

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***Abstract*— Multi-Carrier Code Division Multiple Access MC-CDMA is a promising technology for supporting high data rate in next generation wireless networks. By combining MCCDMA technology with Multiple-Input Multiple-Output (MIMO) spatial mssultiplexing, data transfer rate can be enhanced. However, the performance of MCCDMA technology is limited by the multiple-access Interference (MAI) and Inter-Carrier Interference (ICI). In this paper, the interference noise is diminished by adopting power control and subcarrier allocation methods to enhance the system performances like capacity, BER and power savings through Iterative water filling game theory. The water filling game strategy assigns power level to each subcarrier based on the SINR value received by the transmitter instead of getting full channel state information, which is time varying in nature. The subcarrier group assignment is implemented by selecting best subcarriers with maximum SINR value. The performances of mean capacity, BER and power savings of the MCCDMA-MIMO system are evaluated and compared with and without water filling algorithm.**

***Keywords*—Channel State Information, Inter Carrier Interference, IWFA, Qos- Quality of Services, Multiple-Access Interference, MCCDMA, Signal to Interference plus Noise Ratio.**

I. Introduction

MC-CDMA technique permits multiple users to access the wireless channel simultaneously by modulating and spreading their input data signals across the frequency domain using different spreading sequences [1]. It is most suitable for future 4G mobile wireless communications with high data rate because of its inheritance characteristics of both Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA) and its advantages of multiple access capability, frequency diversity and robustness against fading. Due to the simultaneous transmissions, sub-carriers interfere with each other and limit the wireless network performance. To achieve robustness and spectral efficiency in MC-CDMA system over multipath fading channels, the technology is ruled by two main functions; power allocation over the subcarriers and subcarrier group assignment.

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Power allocation is the scheme by which users share the power available at the serving base station [2]. Group assignment depicts selection of appropriate subcarriers to support information bit streams of individual users [3]. So, the distributions of users across subcarrier groups as well as their transmission power distribution has a significant effect on performance enhancement like mean capacity of the system, BER and power savings.

In this paper, the MCCDMA technology combined with MIMO system is considered as the system model, in which each user is served by all the transmitters. The transmission rate is increased without expanding the signal bandwidth[4,5]. The main contribution is focused on power allocation among all subcarriers and subcarrier group assignment to meet the system performances. The power loading algorithm in MCCDMA-MIMO system for maximizing system performance is at the expense of signaling overhead due to the sharing of Channel State Information (CSI) and it is subjected to the errors because of the imperfect channel estimation/ measurement due to the time varying nature of the channels [6]. In this paper, power control for MCCDMA-MIMO system is processed by water filling game theory with SINR as an objective function [7].

The water-filling rule in game theoretic perspective is a tool used to allocate proper power for every user in order to improve system capacity performance with global constraint (Total available power at base station) and imperfect knowledge of CSI. In this paper, the interference based subcarrier group assignment strategy with dynamic power allocation using Iterative Water Filling Game theoretic Algorithm (IWGA) is implemented for MCCDMA-MIMO system to enhance the system capacity, minimize the BER and minimize power consumption. The performance of the system are compared with different diversity (2×2, 4×4).

The organization of this paper is as follows. Section II deals with the system architecture and game model for power control algorithm in MCCDMA –MIMO and problem formation to maximize the capacity. Section III describes solution for the 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.

II. System Architecture and Game Model

A. *System Architecture*

A multi cellular MC-CDMA network constituted of B = {1, 2, . . . ,N_B} base stations is considered. The system bandwidth 'W' is sub-divided 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). 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, $C = \{C_{(1)}, C_{(2)}, \ldots, C_{(j)}, \ldots, C_{(G)}\}$, 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. Each base station operates under the constraint that it has at its disposal a maximum amount of power to share among all active sessions. The symbol of user 'u' in the base station 'b' of an MCDMA system is presented as

$$Y^u = H^u S^u \sqrt{P^u} X^u \qquad (1)$$

where

X^u is the active user's symbol.

S^u is the code matrix.

$P^u = diag\left(P^{u1}, P^{u2}, P^{u3}, \ldots, P^U\right)$ is each user's transmit power

$H^u = diag(H^{u1}, H^{u2}, H^{u3}, \ldots, H^U)$ is each user's channel fading

Y^u is MCCDMA Symbol Vector.

The time domain data stream for each user is divided into multiple parallel streams and each stream is spread using a spreading sequence as shown in Fig.1. The sequences are then spread with subcarrier group domain using IFFT and power allocation to each user is followed by IWFA. The subcarrier 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_t' transmit antennas and 'N_r' receive antennas and is illustrated in Fig. 1 and 2.

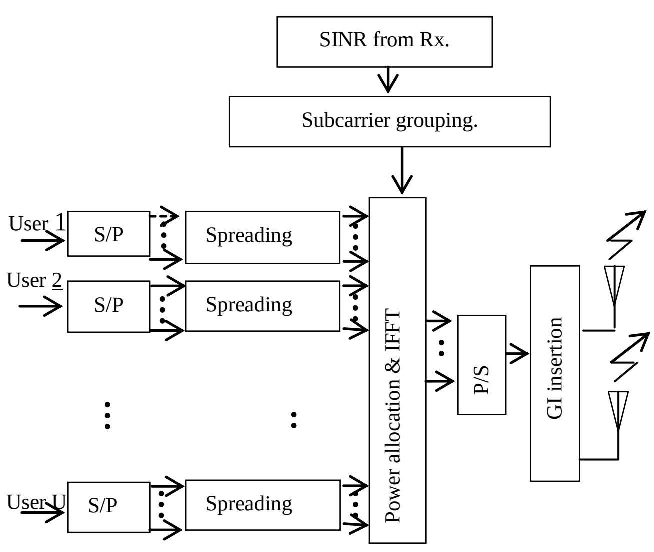

Figure 1. MCCDMA-MIMO Transmitter

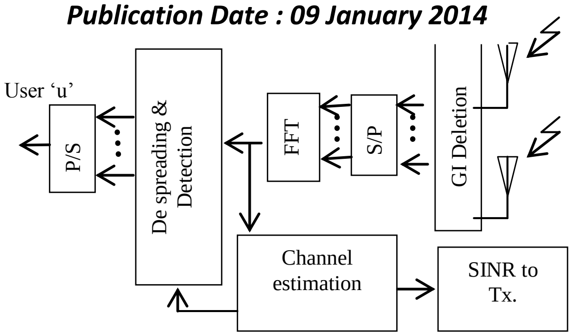

Figure 2. MCCDMA-MIMO Receiver

B. *Game Model*

The game model in the MCCDMA transmitter plays against the behavior of a wireless channel and assigns power level to the respective subcarriers. 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 subcarriers subject to the constraint of total power at the transmitter and total subcarriers. The objective function in the strategy of the game is the SINR value from the receiver. A mobile user 'u' of interest served by base station 'b' has the SINR value given below.

$$SINR_u = \frac{\sum_{n=1}^{N_c} P_n^u \left|H_n^u\right|}{\sum_{u'=1;u'\neq u}^{U} P^{u'}\left|H_n^{u'}\right| + [E_{b'}^u]} \qquad (2)$$

Where

$[p^U]_b$ is power of user 'u' in base station 'b'

$[I^u]_b$ is the interference to the user 'u' due to other users in the base station 'b'.

$[E_{b'}^u]$ is inter cell interference

This SINR value 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

$$C^u = \sum_{n=1}^{n=N_c} \log_2\left(1 + \frac{P_n^u}{N_o\sigma^2}|H_n^u|^2\right) bits/s/Hz \qquad (3)$$

The total system capacity of the base station 'b' that constitutes 'U' active users [7] is given as

$$C_{Total} = \sum_{n=1}^{n=U} C^u = \sum_{n=1}^{n=U}\sum_{n=1}^{n=N_c} \log_2\left(1 + \frac{P_n^u}{N_0\sigma^2}\left|H_n^u\right|^2\right) bits/s/Hz \qquad (4)$$

Then the MCCDMA symbols are transmitted through MIMO system of N_t, N_r antenna with channel matrix H (τ, t)

[8, 9] as shown in Fig.1 and system capacity or the utility function is modified as

$$C_{MCCDMA-MIMO} = \log_2\left(\det\left[I_{N_r} + \frac{P^u}{N_t N_r}\left\{\frac{1}{N_c}\sum_{n=0}^{n=N_c} H(n)H^{+}(n)\right\}\right]\right) bits/s/Hz \quad (5)$$

III. Water Filling Game Theoretic Solution

The water filling game theory concept in this paper 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 subcarrier group forming and 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.

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

$$\max(C^u) = \max\left[\sum_{i=1}^{G}\omega_u^i \sum_{u=1}^{U}\sum_{n=1}^{n=N_c}\log_2\left(1+\frac{P_n^u}{N_0\sigma^2}\left|H_n^u\right|^2\right)\right] \quad (6)$$

Subject to $\sum_{u=1}^{n=U}\sum_{n=1}^{n=N_c} P_n^u \le P_{Total}$; $\sum_{i=1}^{i=G}\sum_{u=1}^{u=U}\omega_u^i \le U$

where $\omega_u^i \in \{0,1\}$ is the allocation index for the active user ‘u’ in group ‘i’. That is, if ω_u^i=1, then the user ‘u’ is assigned to the group ‘i’. If ω_u^i=0, then the user ‘u’ is not assigned to the group ‘i’. The solution for capacity maximization problem of single-water level, multi-constraint (Power and group selection constraint) is obtained through iterative method by simple fixing the water level ‘µ’ (power level) and adjusting it iteratively until the constraint is satisfied [10]. The power level of user ‘u’ in the base station ‘b’ is obtained using Lagrange multipliers as given as

$$P_{A*}^{u*} = \left[\frac{1}{U}\left(P_{Total} - \sum_{n-1}^{U}\sum_{n=1}^{N_c}\frac{\sigma^2}{\left|H_n^u\right|^2}\right) - \frac{\sigma^2}{\left|H_{n*}^{u*}\right|^2}\right]^{+} \quad (7)$$

$[x]^{+} = \max\{x, 0\}$

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

Algorithm:

Step 1: Initialization
$N_c \rightarrow$ Number of subcarriers
U $\rightarrow$Total number of users
G $\rightarrow$ No of groups
P_t $\rightarrow$Total Power budget
Step 2: Get $SINR_u \rightarrow$SINRfor user ‘u’
Get QoS Requirements for user ‘u’
Step 3: Group Assignment and Power Allocation (without water filling algorithm)

Calculate λ= H_n^u → channel gain of each user groups

Compute average SINR value for all groups and arrange in order

Arrange the user priority according to the QoS requirements

Assign the groups to the user according to the order

Calculate P_{A*}^{u*} & assign the same to user ‘u’
Step 4: Power Allocation (IWFA)

Calculate λ= H_n^u →channel gain of each user groups

Compute average SINR value for all groups and arrange in order
Fix: µ= P_{A*}^{u*} & λ= H_n^u

Loop 1: Number of iterations

Fix step size(0.001)

Loop 2: Group assignment

P_A^u (i)= P_A^u (i)+step size

Check

Power Constraint : $\sum_{u=1}^{U}\sum_{k=1}^{N_c} P_k^u \le P_{Total}$

Group Constraint : $\sum_{i=1}^{i=G}\sum_{u=1}^{u=U}\omega_u^i \le U$

Capacity Constraint: C_u^i ≥Data rate

If satisfied

$P_k^u(i) = P_k^u(i) + stepsize$

Else

Assign

$P_k^u(i) = P_k^u(i)$

User ‘u’ is assigned to group ‘i’

Capacity of the user = C_u^i

End loop 2

End loop 1

Step 5 : End

IV. Results and Analysis

The performance improvements of MCCDMA are analyzed with the numerical conditions summarized in Table I

Table 1.
Simulation Parameters

Parameters	Specifications
MCCDMA system	Multi cellular structure with three cell
No of carriers (N_c)	1024
Spreading factors	1024
Multipath channel model	Rayleigh fading
Channel condition	AWGN channel
Modulation	QAM
MIMO sizes	2×2 and 4×4
Monte Carlo Channel realization	10000
Number of iterations	1000
SINR range	-10 dB to30dB
Detector	Zero forcing detector
Eb/No range	0 to 25 dB

The platform used for the simulation is MATLAB 7.0. 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.

A. *Capacity Analysis*

The group assignment strategy to maximize the overall mean capacity using IWFA is followed by the algorithm mentioned in section 3. The capacity improvement of MCCDMA in SISO using IWFA is compared with power allocation without water filling algorithm.

The further capacity enhancement of MCCDMA through MIMO multiplexing (2×2, 4×4) is also analyzed with and without IWFA. Fig.4 shows the capacity improvement analysis of MCCDMA-MIMO (SISO, 2×2, 4×4) using IWFA with interference based subcarrier grouping. The MCCDMA-MIMO system with water filling has a greater mean capacity as compared to the system without water filling. The capacity enhancement of the system is due to the proper power allocation to all users by IWFA with subcarrier group assignment strategy.

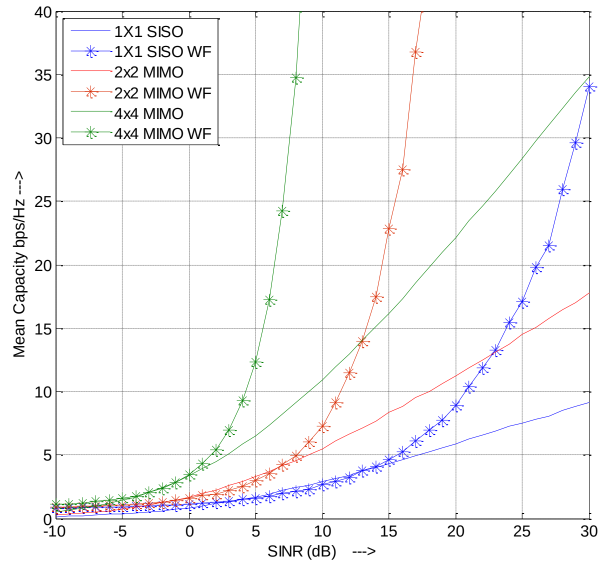

Figure 3. Mean Capacity Vs SINR of MCCDMA-MIMO with subcarrier group assignment using IWFA based power allocation .

The algorithm limits the interference noise among all users by avoiding excess power to any particular user and assigns the compatible subcarrier group according to data rate demands. The signal transmission of the system through MIMO gives an additional improvement of the system capacity.

B. *BER Analysis*

The subcarrier 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. In this paper, Quadrature Amplitude Modulation (QAM) and the ZF detection is used at the transmitting end and receiving end respectively. The downlink is assumed to be ideally orthogonal and synchronized between users within the cell, that is, no intra-cell interference is considered. Partial channel state information is assumed to be well known at BS. Fig4 Show the BER performances of MCCDMA-MIMO system using subcarrier grouping methodology.

C. *Power Savings Analysis*

Power allocation using IWFA is also used for energy reduction in MCCDMA. Saving energy will not only reduce operating cost but also improves the energy efficiency of the system.

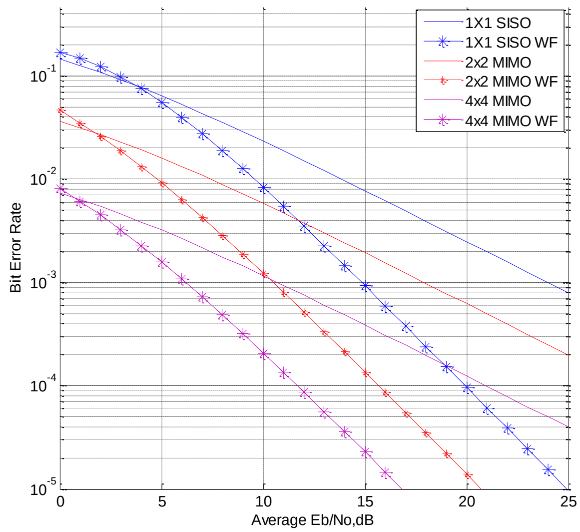

Figure 4. Mean Capacity Vs SINR of MCCDMA-MIMO with subcarrier group assignment using IWFA based power allocation.

The water filling game theory provides power minimization to grouped MC-CDMA systems depending on the channel fading conditions, SINR and bit error rate (BER) constraint. The amount of power savings per subcarrier is given below

$$P_{Savings} = \frac{P_{opt} - P_{A*}^{u*}}{P_{opt}} \times 100 \qquad (8)$$

Where

P_{opt} - optimum power level for subcarriers to maximize overall capacity of the system.

P_{A*}^{u*} - power level assigned to for subcarriers using water filling game theory.

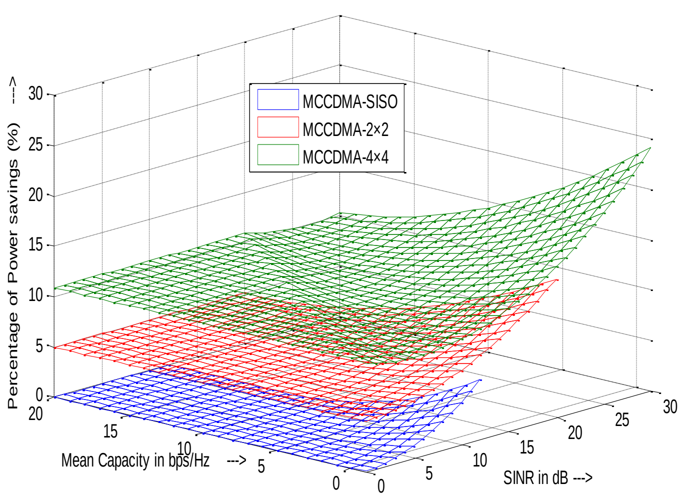

Figure 5. Percentage of power savings at various Capacity requirements and SINR ranges

The percentage of power savings at various Capacity requirements for the SINR value ranges are attained through simulations and result is depicted in Fig 5.

V. Conclusions

The distribution of users across sub$_c$arrier groups as well as their transmission powers within a given cell has a significant effect on how users and power are accordingly distributed elsewhere in the network to maximize the capacity of the system. This paper demonstrated that the interference based subcarrier group assignment strategy with power control through IWFA enhance the capacity, BER and power savings of the system by restricting interference noise. 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 further capacity improvements of MCCDMA are achieved by exploiting MIMO diversity of size 2×2 and 4×4. 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. The IWFA based power control algorithm also benefits the MCCDMA-MIMO system by minimizing the power requirement at the transmitter and improves significant power economy.

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