EFFICIENT RESOURCE ALLOCATION IN MC-CDMA CELLULAR WIRELESS NETWORKS TO SUPPORT MULTIMEDIA TRAFFIC

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ABSTRACT

The Multi Carrier Code Division Multiple Access (MC-CDMA) system with time division duplex mode, adopting unbalanced slot allocation between uplink and downlink, is a good solution for asymmetric multimedia traffic. A centralized common slot allocation to minimize inter-cell interference is not feasible as neighboring cells may carry different rates of traffic load. In this paper, we investigate and discuss the effect of asymmetric slot management strategy employing adaptive resource allocation in a MC-CDMA system, in which each cell has its own slot allocation policy according to the level of traffic load. The Bit Error Rate (BER) and Signal to Noise Ratio (SNR) of MC-CDMA considering four cases of uplink and downlink between cells is simulated separately in presence of Additive White Gaussian Noise (AWGN) and Rayleigh channel. The simulation result shows that the distance ratio and orthogonality factor are equally important parameter in BER performance, and also an SNR of around 9dB is enough to bring BER below 10^{-3}.

Keywords: *MC-CDMA, SNR, BER, Downlink, Uplink, TDD*

1. INTRODUCTION

Multi-carrier communication systems is projected as a dominant contender to the next generation wireless communication systems [1-2]. The conventional code-division multiple-access (CDMA) technique used in third generation system faces serious limitations by channel dispersion, causing inter symbol interference (ISI), and it requires advanced signal processing algorithms to contain it [3]. The MC-CDMA employing multiple stream of data channel can combat channel dispersion, hence ISI, thereby increasing system capability to accommodate a higher number of users and its data rate requirements.

The efficiency in the multiple access techniques becomes an important issue as the demand for high data rate to support Internet applications continue to grow up. Many application demands more bandwidth either in forward channel or in reverse channel, and popular applications like web browsing are bias towards downlink. Allocating equal resource in both uplink and downlink becomes bottleneck for the system as uplink remains underutilized while downlink gets strained. The MC-CDMA employing Time Division Duplexing (TDD) techniques can easily support this asymmetric traffic by dynamically varying the number of slots in uplink and downlink. Further the MC-CDMA shows higher efficiency by adopting adaptive modulation techniques like M-ary Quadrature Amplitude Modulation (M-QAM) [4-5]. By dynamically allocating subcarriers and adaptive slot management the system can meet the large dynamic resource requirements of a real-time multimedia application in Internet.

The CDMA based systems are inherently interference limited. The presence of every other user affects the SNR, and hence data supported on a particular channel. The channel state information [6-7] can be estimated periodically by with the help of a pilot carrier and based on the estimated value, the order of modulation M is decided, thus optimizing the system capacity. Based on the call arrival and traffic present in a slot, the next slot can be declared either uplink or downlink.

The block diagram of MC-CDMA system employing adaptive modulation is shown in fig.1. The channel capacity is estimated based on the SNR provided by the receiver. The requested data rate of an application is met by allocating number of subcarriers. The adaptively modulated streams are then passed through the MC-CDMA transmitter block that further modulates it. The receiver

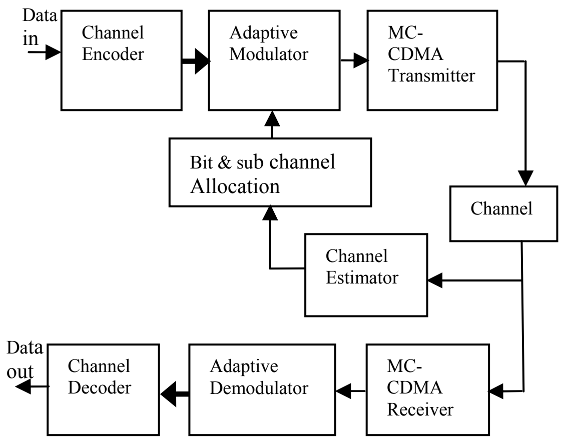

Fig.1. MC-CDMA system

performs the reverse operation to demodulate and decode the original information. The channel estimator estimates the quality of the channel from the pilot symbols transmitted periodically. The transmitter needs to inform the receiver the order of modulation to enable it to decode the signal.

In this paper the proposed algorithm tries to optimize the number of subcarrier and slot utilization for MC-CDMA employing TDD technique. Every cell can have its own slot allocation method based on the traffic load. The SNR depends mainly on the direction of traffic (uplink / downlink) in home and interfering cells. In multi-cell environment, based on prevailing conditions many cases of interference pattern may arise. The system representation could be the generalization of two cell model for multi-cell. Further, the analysis presented here includes worst case scenario to evaluate system performance. The simulation carried out is extension of the two cell model to represent MC-CDMA in time duplex mode.

The remaining part of this paper is organized as follows. In Section2, a comprehensive literature survey is presented. System model plays a vital role in defining the objective and conducting simulation. Section3 represents multi-cell as well as two cell model for SNR estimation. The development of the proposed protocol is discussed in section4. The simulated result and analysis is shown in section5. Finally this paper concludes in section6.

2. RELATED WORK

The performance of adaptive resource allocation algorithm for MC-CDMA has been studied by many researcher under different scenario [5,7,8]. Mamoun Guenach, and Heidi Steendam [3] investigate the sensitivity of downlink MC-CDMA performance considering the optimum number of carriers and guard interval. They derive SNR and try to show that the load of the MC-CDMA system only has small influence on the optimization of the parameters. U. O. Ibom [7] has proposed an adaptive MC-CDMA for next generation network. He has observed the effect of bit allocation & BER in presence of white noise, and a noise with exponential spectrum. The performance study of MC-CDMA in cross-layer resource allocation by Virginia Corvino et al.[8] demonstrates user outage rate depending on scheduling and traffic load.

In [9-10], BER performance evaluation under different channel model has been carried out. Çetin Kurnaz and Hulya Gokalp [9] have investigated the performance of the downlink in MC-CDMA systems using a channel model from in-the-field propagation measurements. They have studied the effect of transmission bandwidth, number of users and number of sub-carriers on system performance. Throughput is the focus of attention in observation made by L. Guerrero et al. [10] in Nakagami-m fading channels.

The BER Comparison of OFDM and MC-CDMA system has been carried out by [11] Muhammad Talha Ahmed et al. [11]. Their observation in Rayleigh fading channel in presence of additive white Gaussian noise shows that MC-CDMA outperforms OFDMA. S. Chatterjee et al.[4] have analyzed BER performance of adaptive modulation based MC-CDMA systems for 4G wireless systems. They have considered different modulation schemes for simulation.

Although many research papers has been presented on performance of MC-CDMA, the effect of dynamic slot management using adaptive modulation in time division duplex mode has not been studied. This paper presents an algorithm that optimally manages the resources to maximize the system performance.

3. SYSTEM MODEL

In MC-CDMA transmission, the input (M-QAM modulated) signals are spread by CDMA code and then passed it to the IFFT for further modulation (Fig.2). The output of IFFT represents N low symbol rate parallel sub-channels. A parallel to serial converter is used to pass data serially to RF module. A reverse procedure is adopted at the receiver to decode the signal.

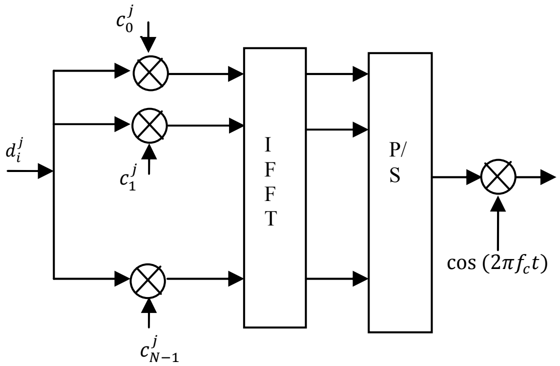

Fig.2. MC-CDMA Transmitter Structure

The signal of an ith subcarrier can be denoted as

$$S_i(t) = X_i(t)e^{j2\pi ft} \quad (1)$$

After performing transformation using N-Point IFFT, the ith subcarrier signal is given by

$$S(t) = \frac{1}{N}\sum_{i=0}^{N-1} X_i(t)\, e^{j2\pi ft} \quad (2)$$

where N is the total number of sub-carrier.

The received signal for the Kth user can be given by

$$r_{k,i} = \xi_{k,i} H_{k,i} S_{k,i} + N_i \quad (3)$$

where $\xi_{k,i}$ is channel gain, $H_{k,i}$ is channel function, $S_{k,i}$ is signal strength, and N_i is noise variance for ith sub-carrier.

The capacity of a cellular CDMA system heavily depends on interfering noise power. For M users, each cell-site receiver receives the desired signal having power P, and (M-1) interfering signals each also of power P. Hence the signal-to-noise (interference power) ratio (SNR_i) of ith sub-carrier is given by [12]

$$SNR_i = \frac{P}{(M-1)P} = \frac{1}{M-1} \quad (4)$$

In digital communication, the commonly used parameter is energy to noise density ratio (E_b / N_0), which is obtained by dividing desired signal power (P) by information bit rate (R), and noise power ((M-1)P) by the total bandwidth (W) in the SNR (4). Thus

$$E_b/N_o = \frac{P/R}{(M-1)P/W} = \frac{W/R}{M-1} \quad (5)$$

E_b / N_0 calculation in (5) ignores background noise, which results because of spurious interference and thermal noise. By incorporating background noise (5) get modified as

$$E_b/N_0 = \frac{W/R}{(M-1)+\eta/P} \quad (6)$$

In MC-CDMA because of traffic asymmetry and hence different slot allocation from cell to cell, the system suffers from both intra-cell and inter-cell interference (Fig.3). For example, mobiles in a cell may use uplink slots and at the same time the base station of an adjacent cell may use downlink slot to transmit signals. In this situation, the uplink (downlink) channel in a cell can be interfered by the downlink (uplink) of the adjacent cell and, in turn, this results in capacity degradation.

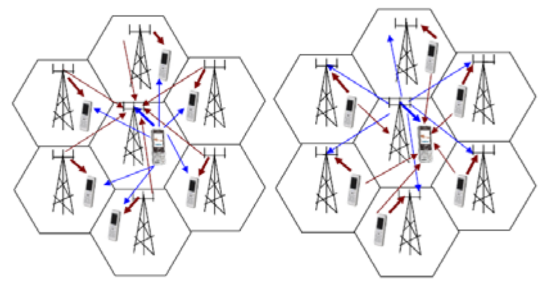
Fig.3. Interference in uplink and downlink because of cross-slot

Although a different slot allocation within a cell is also possible, but practically it is not implemented as it will cause heavy interference in both uplink and downlink. Here we assume that slot allocation within a cell is same and perfectly synchronize between base station (BS) and mobile station (MS). Cross slot allocation between two cells is the case for traffic asymmetry (Fig.4). The number of cross slot allocation can be governed by the base station controller (BSC) in a location area consisting of multiple cells. Since cross slot allocation normally causes more interference, it will be a major factor in supporting quality of service and also capacity of the system.

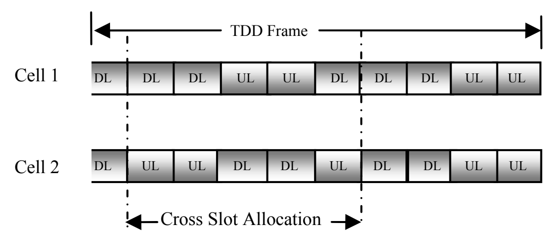

Fig.4. Different slot allocation in a adjacent cell

3.1 SNR in Multi-cell TDD Environment

In MC-CDMA with TDD, each slot will carry many user data on different channel separated / identified by Walsh-Hadamard code. Considering intra-cell and inter-cell interference separately in a multi-cell environment, the signal to noise ratio for each user's i^{th} subcarrier can be modeled as

$$SNR_i = \frac{P_r.SF}{I_{int} + I_{ext} + N_o W} \quad (7)$$

Where P_r is the received power, SF is the spreading factor, I_{int} is the internal noise within the cell, I_{ext} is external noise coming from other cells, N_o is the noise power spectral density, and W is the total transmission bandwidth.

To approximate link gain, the received power P_r at BS, can be related to the transmit power P_t of the MS as

$$Pr = \lambda \ d\text{-}v \ Pt \quad (8)$$

Where d is the distance between BS and MS and λ is a constant. In mobile communication, the loss of power in propagation is inversely proportional to the 4th power (i.e. v = 4) of the distance between transmitter and receiver [13].

In MC-CDMA a channel is represented by no. of subcarrier. The no. of subcarrier needed to support an application is dictated mainly by the bandwidth requirement. Further, the subcarrier selection is based on their current SNR.

System model for MC-CDMA in multi-cell environment can be built by generalizing the two cell model. Considering two cell approach, four cases arise: i. cell1 uplink cell2 uplink, ii. Cell1 uplink cell2 downlink, iii. Cell1 downlink cell2 uplink, and iv. Cell1 downlink cell2 downlink. Here cell1 represents a home cell for tagged mobile, and cell2 a cell in first tier interfering cells.

3.1.1 Cell1 Uplink Cell2 Downlink

Suppose m_k be the number of MS served by a channel, where k = 1,2,3,…..K. Let P^i_k denote the transmit power of i^{th} subcarrier, and H_{ki} the channel gain between i^{th} MS and its BS. The internal interference I_{int} in uplink for i^{th} subcarrier carrying part of k^{th} MS data may be given by

$$I_{int} = \sum_{k=1}^{m_k} \sum_{i=1}^{I_k} H_k^i P_k^i \quad (9)$$

The external interference I_{ext} is computed as follows. The BS present in neighboring cell j will cause interference to the uplink signal of tagged mobile. Now the I_{ext} can be represented as

$$I_{ext} = \sum_{j=1}^{J} \sum_{i}^{I_j} H_{j,k}^i P_{j,k}^i \quad (10)$$

where J is total no of interfering cells.

3.1.2 Cell1 Downlink Cell2 Uplink

Most commonly data in downlink channels (for example in W-CDMA) are transmitted with orthogonal codes. Assuming perfect time synchronization between MS and BS, and if the channel is of flat fading type, then orthogonality is preserved during downlink slot, and hence the internal noise I_{int} is absent. But the multipath propagation damages the orthogonality. An orthogonality factor (α), which is the percentage of downlink orthogonality remaining at the mobile receiver, is introduce to compute I_{int}. α is 1 for a signal without multipath, and near zero in Rayleigh fading environment.

The internal interference I_{int} arising due to non-orthogonality of the received signals is given by

$$I_{int} = \sum_{i=1}^{I} \alpha_i H_i P_i \quad (11)$$

where P_i is the transmitter power of the BS, H_i the channel gain, and α_i the corresponding orthogonality factor for the i^{th} subcarrier.

To compute external interference I_{ext} , it is assumed that same sub-carriers are used in neighboring cell. Let m_j be the number of MS served in a j^{th} cell, where j = 1,2,…..J represents J neighbor cells. Now I_{ext} may be expressed as

$$I_{ext} = \sum_{j=1}^{J} \sum_{k=1}^{m_j} \sum_{i}^{I_k} H_{j,k}^i P_{j,k}^i \quad (12)$$

where $H^i_{j,k}$ the link gain between i^{th} MS in neighbor cell and the tagged BS, and $P^i_{j,k}$ the transmit power of i^{th} MS to support its QoS requirement in its cell.

3.1.3 Cell1 Uplink Cell2 Uplink

In this case, the I_{int} is same as in section 3.1.1 given by (9). The external interference I_{ext} , is given by (12).

3.1.4 Cell1 Downlink Cell2 Downlink

Here the internal interference I_{int} and external interference I_{ext} are given by (11) and (10) respectively.

3.2 Cross slot allocation analysis (UL-DL or DL-UL)

In this section a deterministic simplified approach is presented to analyze cross slot allocation. Let N_c be the number of cross slots

(Fig.4) in each TDD frame. Assuming that channels are evenly distributed over the same type slots in every cell, let m_1 and m_2 be the number of channels assigned to cross slots in cell1 and cell2 respectively. To support multimedia traffic let the require data rate be R_u in the uplink and R_d in the downlink.

3.2.1 SNR computation for Cell1 UL Cell2 DL

Let us assume at a particular time, slot in Cell1 is for uplink and in cell2 it is for downlink. In the SNR computation, we consider noise because of presence of other user, assuming that all MS are perfectly synchronized with uplink and downlink slots in a TDD frame. Further it is assumed that a perfect power control mechanism is implemented, so that BS receives equal power from all MS in its cell. The background thermal noise N_0, can be ignored as it is very small compare to the I_{int} and I_{ext}.

Let the equal power received by BS from every MS in cell1 is P_{rms1}. The internal noise, I_{int} can be related to the number of channels in cell1 and the number of cross slot as

$$I_{int} = \{(m_1 / N_c) - 1\} P_{rms1} \tag{13}$$

The external noise I_{ext} in cell1 is the downlink signal originating from BS in cell2, and can be given by

$$I_{ext} = \lambda (2D)^{-4} (m_2 / N_c) P_{tbs2} \tag{14}$$

Where 2D is the distance (i.e. cell radius of D) between two BS, P_{tbs2} is the transmit power at BS2.

If W is the total spreading bandwidth, the spreading factor, (also called processing gain) for uplink, SF_u is given by

$$SF_u = {}^{W}/_{R_u} \tag{15}$$

Now the SNR for the uplink slot in cell1 can be given by

$$SNR = \frac{r^{-4}P_{tms1}.SF_u}{\left(\frac{m_1}{N_c}-1\right)P_{rms1}+(2D)^{-4}P_{tbs2}{}^{m_2}/_{N_c}} \tag{16}$$

where r is the distance between the tagged MS and the BS in cell1.

The received power P_{rms1} can be related to P_{tms1} by

$$P_{rms1} = \lambda\, r^{-4}\, P_{tms1} \tag{17}$$

Defining $P_{tbs2}/P_{rms1} = \rho$, and $r/D = \gamma$, (16) can be rewritten as

$$SNR_{UL} = \frac{SF_u.N_c}{(m_1 - N_c) + (\gamma/2)^4\rho} \tag{18}$$

3.2.2 SNR computation for Cell1 DL Cell2 UL

Considering MS in cell2 are uniformly distributed, and R_0 denotes the mean distance between interfering MSs in cell2 and the tagged MS in cell1. Defining $\rho_m = P_{rms2} / P_{tbs1}$ and $\gamma_m = R_0/r$, and taking advantages of (18) it can be easily shown that SNR during downlink slot in cell1 is given by

$$SNR_{DL} = \frac{SF_d.N_c}{(m_2 - N_c) + \alpha(\gamma_m/2)^4\rho_m} \tag{19}$$

where α is orthogonality factor for downlink channel.

3.3 Channel Model

There are many models available in literatures to characterize fading channel. Rayleigh channel model assumes a direct / dominant path and many reflected path. The probability density function of a Rayleigh fading channel is defined as follows [14,15].

$$f_\rho(p) = f_\rho\left(\sqrt{2\rho}\right)\left|\frac{d\rho}{dp}\right| = \frac{1}{\sigma^2} exp\left(\frac{-p}{\sigma^2}\right) \tag{20}$$

where, p is instantaneous power and is related to signal amplitude ρ as

$$p = \frac{1}{2}\rho^2 \tag{21}$$

3.4 Noise Model

We consider an Additive White Gaussian Noise (AWGN) in presence of Rayleigh channel to simulate BER given by

$$\sigma^2 = \frac{W * N_0}{N} \tag{22}$$

where W is the Total Bandwidth, N_0 is the noise spectral density, N is total subcarriers.

3.5 BER Calculation

The BER for the i^{th} Sub-Carrier corresponding to M-QAM is given by [16]

$$BER_i = \frac{1}{5} * \exp\left[\frac{(-1.5 * SNR_i)}{M - 1}\right] \tag{23}$$

Where SNR_i is the signal to noise ratio for i^{th} subcarrier, and M is the constellation points in M-QAM.

3.6 Subcarrier and Slot Allocation Algorithm

The proposed algorithm manages the subcarrier and slots to meet the quality of service requirement of an application. The selection of subcarriers is carried out based on it's current SNR to support a minimum BER. The slot management algorithm (Fig.5) decides whether an outgoing slot is to declared as uplink/downlink based on the existing capacity of the present slot.

First the SNR is calculated using the formulae shown in section3, that falls under any one of the four cases considered there. Since the CDMA based systems are inherently interference limited, the SNR is recomputed every time based on the new call arrival rate, and hence the addition of a new subcarrier in a slot. The new call includes handoff user too. The BER is computed using (23) based on the SNR and a high modulation order (M=8). If BER > 10^{-3}, then order of modulation M is reduced and BER is computed again, and this process is repeated till BER falls below 10^{-3} and the corresponding M value is retained to be used for order of modulation in M-QAM. If BER does not falls below 10^{-3} and M = 2, then the next slot is declared as same status (e.g. uplink if the current slot is uplink) and new calls are accommodated in new slots. Based on the existing SNR and application's bandwidth requirement, the no. of subcarriers are allocated to these new calls.

If the accumulated bandwidth (BW_c) i.e. no of subcarrier is just enough to meet the requirement (BW_r), the resource allocation completes for a user and the algorithm takes next call to be processed.

4. RESULTS AND DISCUSSION

Simulations were carried out for the four cases of uplink and downlink scenario of MC-CDMA system. First we simulate the BER performance of our proposed algorithm in presence of AWGN and Rayleigh channel. Different Walsh codes were used for spreading user data on each subcarrier. Fig.6 shows the traffic distribution in terms of subcarrier for different slots used in driving the simulation. The major channel parameters considered in simulation are listed in table-I.

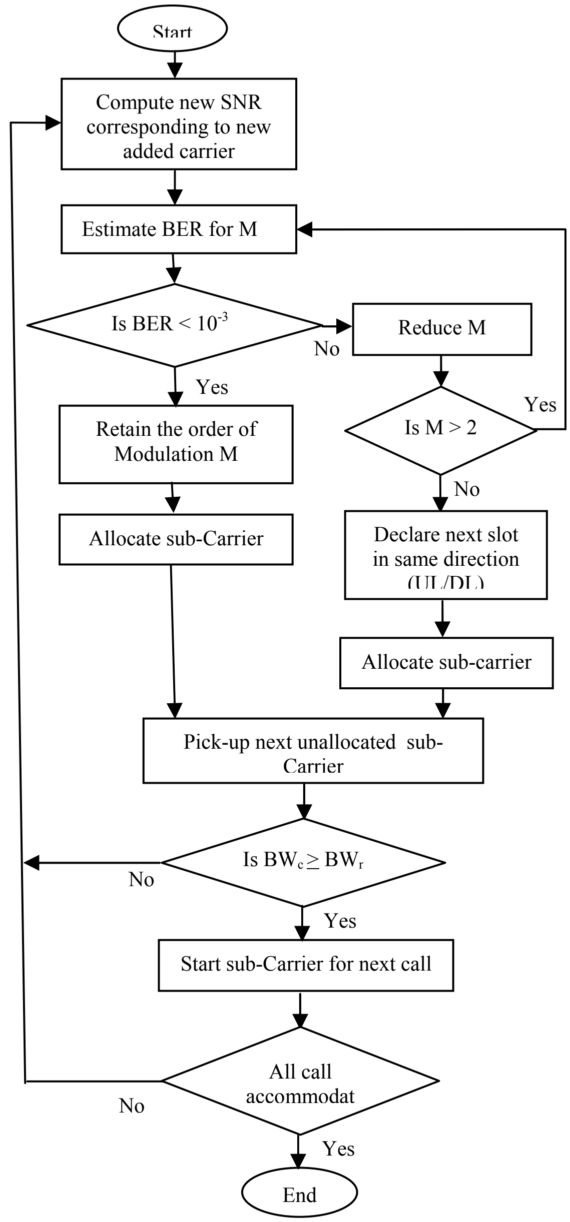

Fig.5. Flow chart of proposed algorithm

Table-I: Simulation Parameters

Bandwidth	10 MHz
Spreading Factor	128
FFT Length	1024
Modulation (M-QAM)	2 - 8
Rayleigh Channel	Ts=0.01s , Δf=10 Hz
Number of users	15-30
Length of Walsh Code	8

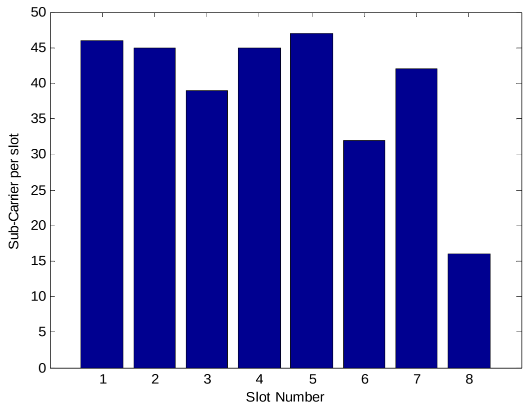

Fig.6. Input traffic distribution for simulation.

The four cases considered here represents different scenario as listed in Table-II. Each case represents a traffic direction, and the interference pattern changes accordingly. The BER in case1 as shown in Fig.7 follows a higher path as in uplink base station suffers intra cell and inter cell interference from a large no. of users.

Table-II: Simulation Scenario

Case	Cell1	Cell2
Case1	Uplink (UL)	Uplink (UL)
Case2	Uplink (UL)	Downlink (DL)
Case3	Downlink (DL)	Downlink (DL)
Case4	Downlink (DL)	Uplink (UL)

As discussed earlier, in downlink the intra cell interference is caused by orthogonality factor. Fig.8 shows the BER performance with respect to variation in orthogonality factor. In case of cross slot, i.e. case4, there could be heavy interference, as interfering mobile in neighboring cell may be near to the tagged mobile. Case3 shows a slight better performance, as interference is caused by a base station only as the neighboring cell is in downlink. A curve fitting function is used to plot BER here.

The distance ratio considered in Fig.9 represents the ratio of distance between tagged mobile to base station to the mean distance of interfering mobile in the same cell. As indicated in (8), the received power inversely varies approximately with fourth power of distance in wireless communication, a small change in distance causes large changes in interference pattern and hence SNR.

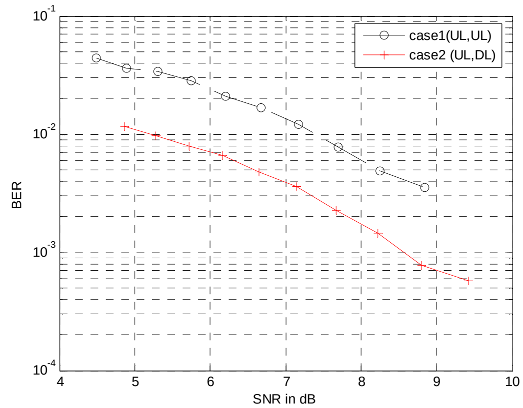

Fig.7. BER performance in case1 and case2

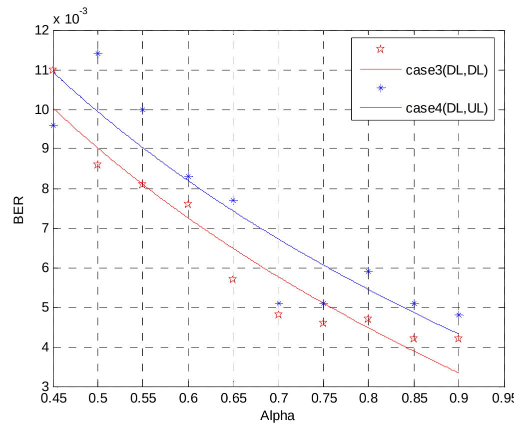

Fig.8. BER with respect to orthoganility factor in internal interference

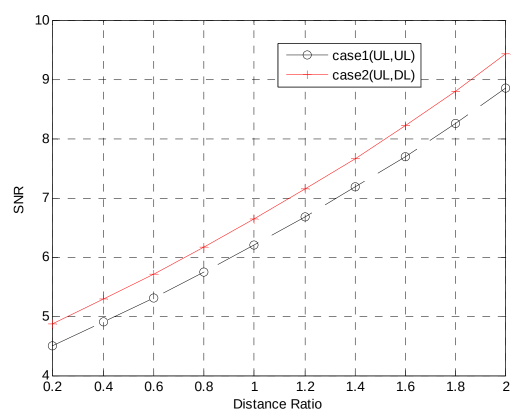

Fig.9. SNR vs distance ratio in internal interference

Fig.10 shows distance ratio plot which is applicable in all four cases as it used in computation of external interferences. Interestingly case4 performs better as the distance defined here is the ratio of mean distance from interfering MS to the tagged MS to the distance between tagged MS and it's BS.

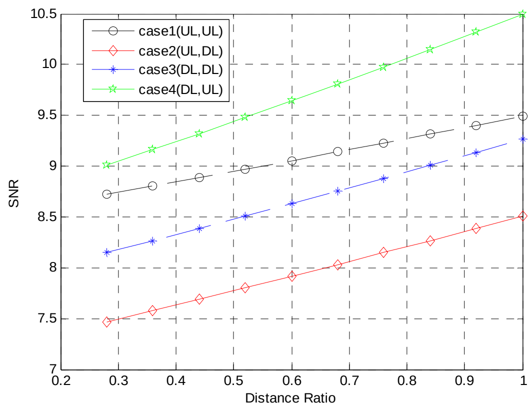

Fig.10. SNR with respect to distance ratio for external interference.

The capacity (b/s per Hz) of each subcarrier in a given slot is computed during simulation of the proposed algorithm and is plotted in Fig.11. The capacity observed here is as per slot sequence number, and not with respect to the no. of slot, hence there is no increasing/decreasing pattern present in this plot (Fig.11).

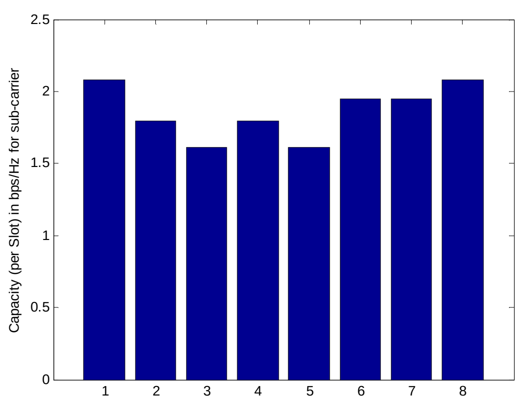

Fig.11. Capacity (b/s per Hz) per subcarrier

Table III shows the input traffic distribution and the subcarrier loading performed during simulation. Since the highest order of modulation (M) considered here is only 8, as per Shannon's theory the maximum theoretical loading could be 3 bit/s per Hz. Clearly bit loaded for all subcarrier is not linear here, as it represented the random traffic present in a particular instant. The capacity or loading pattern could be linear by considering more no of users and variety of multimedia services.

Table III : Slot wise Traffic & Subcarrier Loading

Slot No	1	2	3	4	5	6	7	8
Traffic Distribution (No of subcarriers)	46	45	38	45	47	33	43	15
Subcarrier Loading (Bit/s/Hz)	2.1	1.8	1.6	1.8	1.6	2.0	2.0	2.1

The test bed created by us need to run this simulation can provide more practical and accurate results on high performance parallel/grid computing machine. Presently we run our simulation on Intel® Pentium® 4 CPU at 3.4 GHz with 0.99 GB RAM. The no of iteration considered to simulate BER perform is 5000, which could be still higher to get more definite pattern. The randomness of our test bed could be smoothen by incorporating Monte Carlo methods representing a more predictable traffic pattern, and hence an optimized result.

5. CONCLUSION

To analyze the performance of the proposed algorithm in MC-CDMA system the interference pattern corresponding to different scenario (four cases) was presented. The multi-cell environment was modeled and simulated by generalizing two-cell model. The interference analysis has two major components: the intra cell and inter cell. The BER performance for different cases provides an overview of system analysis in presence of AWGN noise and Rayleigh channel. The capacity observed here is low mainly because of using lower order of modulation (M=8).

The system performance of MC-CDMA under TDD mode accounts for many parameters and it requires further analysis. The BER and system capacity alone were analyzed here, and other system parameters like delay and throughput need to be analyzed. Another future work could be the performance analysis of MC-CDMA based on efficient codes like, orthogonal variable spreading factor code.

Although many researchers have projected the orthogonal frequency division multiple access

(OFDMA) as a multiple access techniques for next generation mobile communication, the core advantages with MC-CDMA can't be ignored. MC-CDMA can outperform OFDMA in the case of varying resource loads. The BER performance of MC-CDMA could be better than OFDMA, when traffic load is not very high. The BER performance considered in our simulation represents medium traffic load. Finally, all CDMA based systems provides inherently added security in physical layer without costing anything. But if it comes to the capacity/efficiency, the MC-CDMA looses to it's rival OFDMA. The current research trend shows that OFDMA is the winner.

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