ADAPTIVE SLOT MANAGEMENT FOR OFDMA BASED CELLULAR WIRELESS NETWORKS IN TDD MODE

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ABSTRACT

The next generation of mobile networks is expected to support real-time multimedia applications with different classes of traffic and diverse bandwidth requirements. The Orthogonal Frequency Division Multiple Access (OFDMA) system with time division duplex mode, employing asymmetric slot allocation between uplink and downlink, is a good solution for mixed realistic traffic. In this paper, we investigate and discuss the effect of slot and subcarrier management strategy in an OFDMA system, in which each cell can adaptively control the resource allocation as per its prevailing traffic load. Considering traffic direction in home and neighbor cell, a total of four cases for interference pattern has been analyzed here. The simulation result shows that a 9dB of Signal to Noise Ratio (SNR) is enough in all four cases to bring the Bit Error Rate (BER) in acceptable limit. We also analyze the effect of change in distance ratio on BER.

Keywords: *OFDMA, SNR, BER, Downlink, Uplink, TDD*

1. INTRODUCTION

The Orthogonal Frequency Division Multiple Access (OFDMA) has attracted wide attention among researcher community as a most emerging candidate for multiple access in 4G mobile communication systems. The ever increasing growth of Internet, multimedia and broadband services demands a highly efficient multiple access techniques [1-3]. Many application demands more bandwidth either in forward channel or in reverse channel, and popular applications like Internet access 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 OFDMA applying Time Division Duplexing (TDD) techniques [4] can easily support this asymmetric traffic by dynamically varying the number of slots in uplink and downlink [5]. Further this system shows higher efficiency by adopting adaptive modulation techniques like M-ary Quadrature Amplitude Modulation (M-QAM) [6]. By dynamically allocating subcarriers and adaptive slot management the system can meet the large dynamic resource requirements of a real-time multimedia communication [7].

Compared to CDMA, OFDM offers more degrees of freedom which allow for flexible resource allocation strategies. The channel state information (CSI) [8] can be estimated periodically with the help of a pilot carrier, and based on the estimated value, the order of modulation M is decided, which helps in optimizing the system capacity. In TDD mode of communication, based on the call arrival and traffic present in current slot, the next subsequent slot can be declared either uplink or downlink.

The requested data rate of an application is met by allocating number of subcarriers representing different capacity [9]. The number of bits per subcarrier is decided based on the CSI on feedback channel (Fig.1). In other words, the order of modulation (M) is estimated dynamically. The adaptive modulated streams are further modulated by Inverse Fast Fourier Transform (IFFT). The receiver 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.

SangJun Ko et al. [10], have proposed an algorithm to optimize capacity in OFDMA-TDD cellular systems. They have compared their work with conventional algorithm and have also proposed an improved algorithm that re-distributes power in downlink. An interference aware medium access control protocol to select subcarrier dynamically has been proposed by H. Haas et al.[11]. Their aim of algorithm is to improve throughput and capacity. Hyeong-Sook Park and Youn-Ok Park [12] have studied the SNR estimation in OFDMA/TDD based wireless broadband system considering timing offset and frequency offset factor.

In this paper we have studied the effect of optimization of number of sub carrier and slot utilization on BER performance for OFDMA 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.

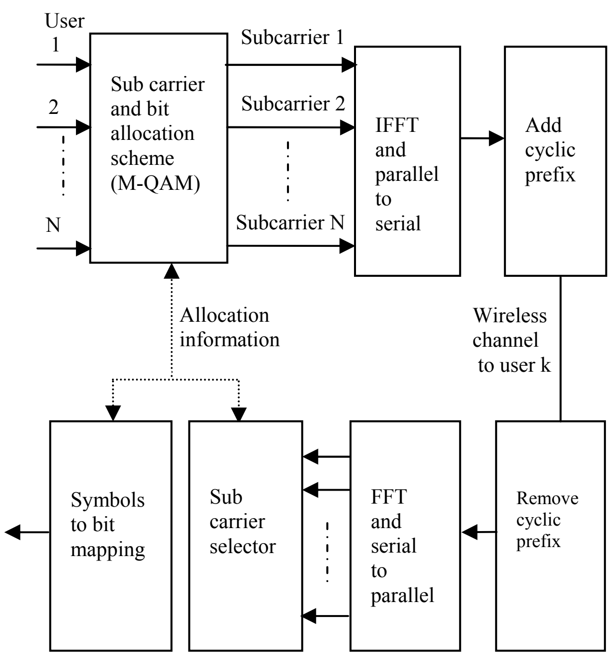

Fig.1. OFDMA system

The remaining part of this paper is organized as follows. In Section 2, system model is presented that helps in defining the objective and conducting simulation. The development of the proposed protocol is discussed in Section 3. The simulated result and analysis is shown in Section 4. Finally this paper concludes in Section 5 and includes scope for future work.

2. SYSTEM MODEL

The signal of an i^{th} 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 i^{th} 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 K^{th} user can be given by

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

where $\xi_{k,i}$, $H_{k,i}$, $S_{k,i}$, N_i are the channel gain, channel function, signal strength, and noise variance respectively for i^{th} sub-carrier.

In OFDMA systems the same sub carriers can be used in the alternate tiers of cell, but not in the same cell, thus avoiding the possibility of intra cell interference. So, the SNR in OFDMA mainly depends on inter cell interference. For example, mobile station (MS) in a cell may use uplink slots and at the same time an MS in the second tier cell may use downlink slot to receive signals. In this situation, the uplink (downlink) channel in a cell can be interfered by the downlink (uplink) of the other cell provided same subcarriers are reused and, in turn, this results in capacity degradation.

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 and normal slot allocation between two cells is shown in (Fig.2). The number of cross slot allocation can be governed by the base station controller (BSC) in a location area consisting of multiple cells.

The cross slot allocation, in particular when tagged MS uses downlink and interfering MS using same subcarriers uses uplink, can causes heavy interference. It could be the worst case scenario for system design, and hence resource allocation algorithm has to treat it as a special case for subcarrier and power allocation. The analysis carried out here assumes uniform power allocation to all subcarriers thereby it does not include any water filling mechanism.

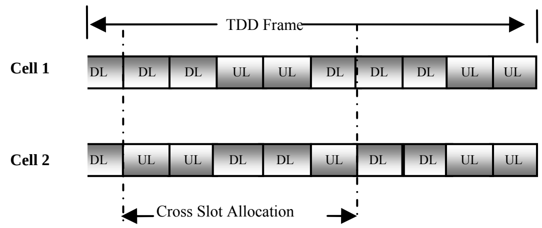

Fig.2. Different slot allocation in a adjacent cell

2.1 SNR in Multi-cell TDD Environment

In OFDMA with TDD, each slot will carry many user data on different channel. Considering the interference in a multi-cell environment, the signal to noise ratio for each user's i^{th} subcarrier can be modeled as

$$SNR_i = \frac{P_r}{I + \frac{(B * N_0)}{N}} \quad (4)$$

where $\mathbf{P_r}$ is the received power, **I** is interference power coming from other cells, **No** is the noise power spectral density, and **B** is the total transmission bandwidth. **N** is the total number of subcarriers. The second term in denominator of (4) rather represents Additive White Gaussian Noise.

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

$$P_r = d^{-v} * P_t \quad (5)$$

where **d** is the distance between BS and MS. In mobile communication, the loss of power in propagation is inversely proportional to the $\mathbf{4^{th}}$ power (i.e. **v** = 4) of the distance between transmitter and receiver [13].

In OFDMA a channel is represented by the number of subcarrier, and hence an incremental approach can be followed to meet the total data rate requirement of an MS. The number of subcarrier needed to support an application is dictated mainly by the channel condition i.e. the current SNR of a subcarrier and the bandwidth requirement.

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 second tier of interfering cells.

2.1.1 Cell1 Uplink Cell2 Downlink

Suppose **M** be the number of MS served by a channel, Let $\mathbf{P_{ti}}$ denote the transmit power of $\mathbf{i^{th}}$ subcarrier, and **d** the distance between $\mathbf{i^{th}}$ MS and its BS.

The interference **I** caused by BS in cell2 can be represented as

$$\sum_{i=1}^{N_m} P_{ti} * d^{-4} \quad (6)$$

where N_m is the same no. of subcarriers used by BS in cell2.

2.1.2 Cell1 Downlink Cell2 Uplink

Assuming same N_m subcarriers are utilized by M users in cell2. The interference I can be modeled as

$$I = \sum_{i=1}^{M} \sum_{k=1}^{N_m} P_{ti} * d^{-4} \quad (7)$$

2.1.3 Cell1 Uplink Cell2 uplink

The external interference **I** is same as in (7) but in this case it is experienced by BS.

2.1.4 Cell1 Downlink Cell2 Downlink

The BS in cell2 causes interference to the MS in cell1 and can be represented by (6).

2.2 Channel Model

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

$$f_\rho(p) = f_\rho(\sqrt{2\rho}) \left|\frac{d\rho}{dp}\right| = \frac{1}{\sigma^2} \exp\left(\frac{-p}{\sigma^2}\right) \quad (8)$$

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

$$p = \frac{1}{2}\rho^2 \quad (9)$$

2.3 Noise Model

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

$$\sigma^2 = \frac{B * N_0}{N} \quad (10)$$

where B is the total bandwidth, N_0 is the noise spectral density, N is the total subcarriers.

2.4 BER Calculation

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

$$BER_i = \frac{1}{5} * \exp\left[\frac{(-1.5*SNR_i)}{M-1}\right] \quad (11)$$

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

3. 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 its current SNR to support a minimum BER. The slot management algorithm (Fig.3) decides whether an outgoing slot is to declared as uplink/downlink based on the existing requirement in present slot.

First the SNR is calculated using the formulae shown in section2, that falls under any one of the four cases considered. The new call includes handoff user too. The BER is computed using (11) 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 corresponding sub carrier is rejected. Based on the existing SNR and application's bandwidth requirement, the no. of subcarriers is allocated to these new calls.

If the accumulated bandwidth (BW_c) i.e. the 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.

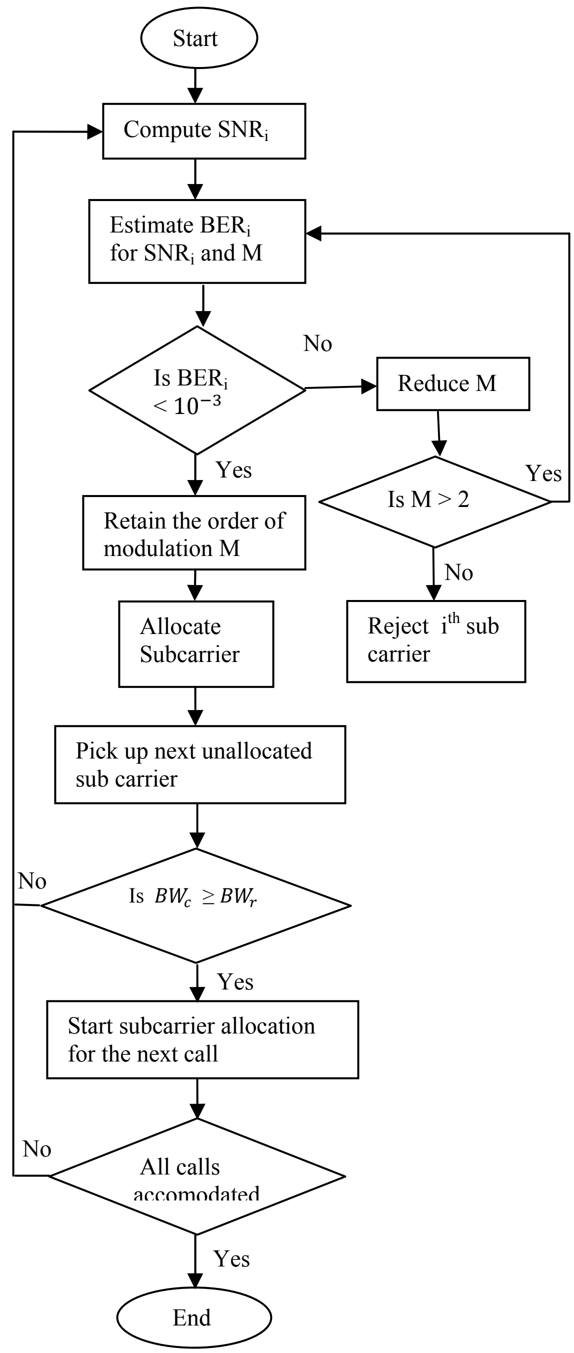

Fig.3. Flow chart of proposed algorithm

4. RESULTS AND DISCUSSION

Simulations were carried out for the four cases of uplink and downlink scenario of OFDMA system. First we simulate the BER performance of our proposed algorithm in presence of AWGN and Rayleigh channel. The major simulation parameters are listed in table-I. A test bench was created based on mathematical model presented in section2.

Table-I Simulation Parameters

Parameters	Values
Bandwidth	10 MHz
FFT Length	128
Modulation (M-QAM)	2 – 32
Rayleigh Channel	Ts=0.01 s , Δf=10 Hz
Number of users	10-20

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. Figure 4 - 7 shows the BER corresponding to different SNR pattern representing four cases. The interference in Case4 is high and Case3 is comparatively less. In the rest of the cases the interference is still less, hence affects the BER accordingly. All four plots (Fig.4-7) could not be combined into a single one as SNR estimated were not in common ranges. Lowest SNR were observed in case4. Since the test bench created here represents OFDMA system, many additional parameters need to be considered. Table III shows the additional simulation parameters. The typical power considered here is low as a user employs many subcarriers and total power is sum of power in each subcarrier. Further to represent pico cell environment, the cell size or in the other words, distance between tagged mobile and interfering mobile from neighboring cell is considered small.

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)

Table-III Other Simulation Parameters

Parameters	Values
Total number of subchannels, N	128
Total number of Pilots, N_p	128/8 = 16
Total number of data subchannels, $S = N - N_p$	112
Guard interval length, $G_I = N/4$	128/4 = 32
Pilot position interval, T_p	8
Channel length, L	16
Number of iteration in each evaluation	5000
Power ranges per subcarrier	1.2mW - 2mW
Distance range for interfering mobile	550m – 700m

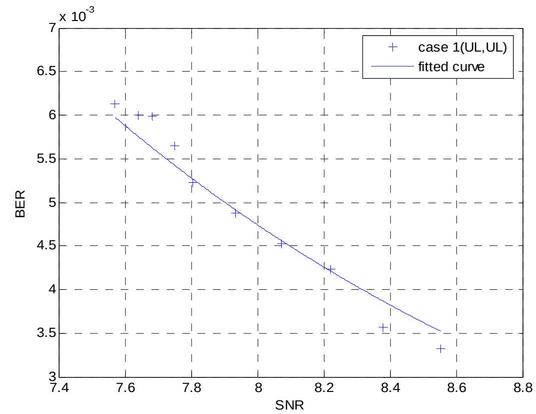

Fig. 4. BER performance in Case1

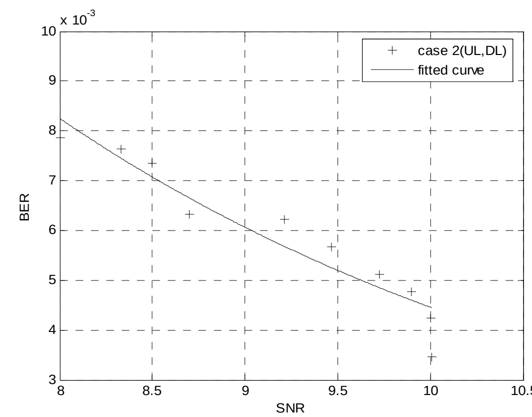

Fig.5. BER performance in Case2

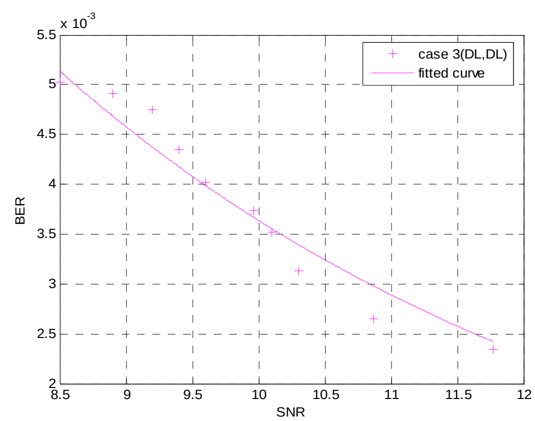

Fig. 6.BER performance in Case3

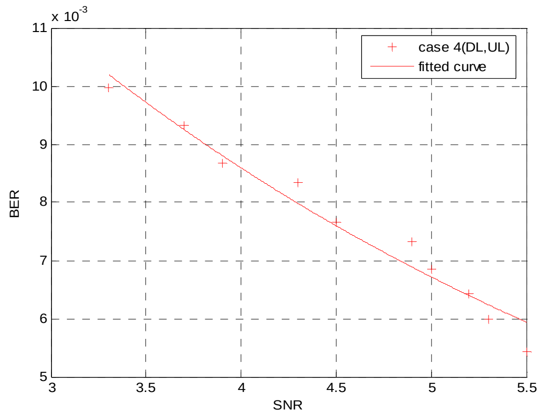

Fig. 7. BER performance in Case4

Figure8 shows the SNR of the system with respect to number of users, assuming constant distance from interfering MS/BS. Case4 (DL, UL) represents a scenario where SNR follows a lower path than the other cases considered here. Case2 (UL, DL) also follows a similar path like Case4, but for increasing no. of users, the difference between Case2 and Case4 exceeds 1.5 dB. Case3 (DL, DL) shows a higher SNR curve, but as the no. of users increases SNR comes down even lower than Case2.

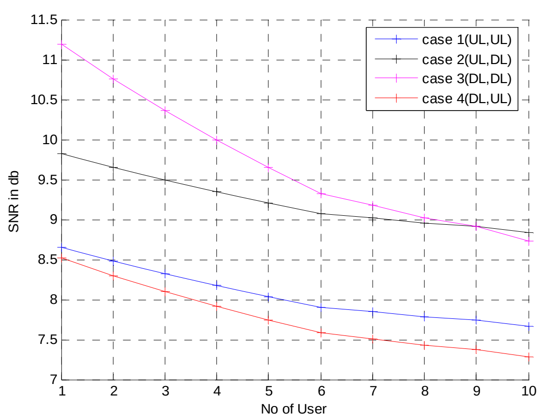

Fig. 8. SNR for all four cases

Case2 & Case4 represents a cross slot allocation, and need to be discussed separately. For example, in Case4 there could be heavy interference at tagged MS as interfering users in neighboring cell may be at shortest distance to the tagged mobile. In Case2 the interference received at BS for tagged mobile is caused by the sorrounding BS and will be constant after system deployment.

The distance ratio considered in Fig.9 and Fig.10 is defined as the ratio of distance between tagged MS and its BS to the distance between tagged MS and the interfering MS/BS. As can be seen in Fig.9, the difference in SNR in Case1 and Case2 is more than 1dB. In Case3 and Case4, the gap in SNR increases with distance ratio, and it exceed 1.5dB when the distance ration approaches unity.

Since in the mobile environment the received power varies inversely with 4th power (Refer section2.1) of the distance, a small change in distance ration can cause large variation in SNR. The maximum distance ration considered in Case3 and Case4 (Fig.10) is 1, assuming that the MS in first tier interfering neighboring cell, even at shortest distance could not be less than distance the MS and its BS.

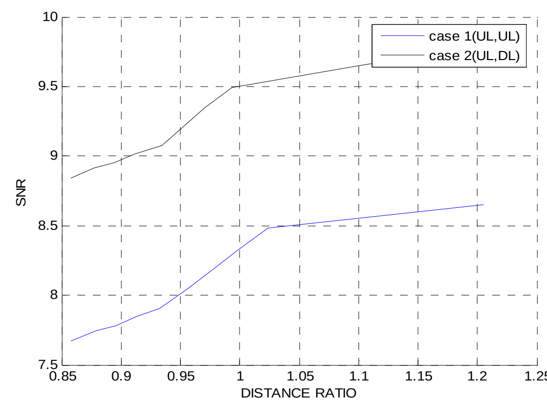

Fig. 9. SNR vs distance ratio in Case1 and Case2

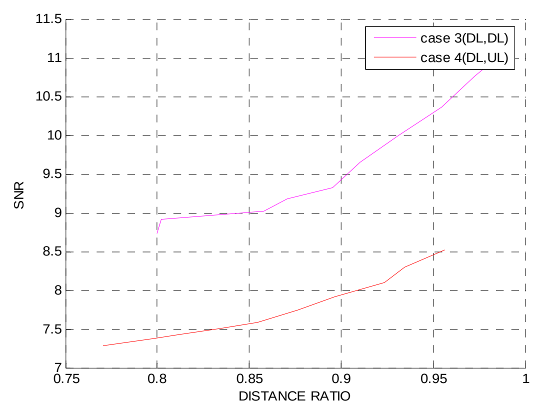

Fig. 10. SNR vs. distance ratio Case3 and Case4

5. CONCLUSION

To analyze the performance of the proposed algorithm in OFDMA system under TDD mode, 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 BER performance for different cases provides an overview of system analysis in presence of AWGN and Rayleigh channel. The BER around 10^{-3} could be acceptable by many practical systems and a suitable error correction mechanism can very well cope with it.

The system performance of OFDMA under TDD mode accounts for many parameters and it require further analysis. The BER is analyzed here, and other system parameters like delay and throughput need to be analyzed, which is our next course of action.

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