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Dynamic Fractional Frequency Reuse (DFFR) with AMC and Random Access in WiMAX System

Zohreh Mohades · Vahid Tabataba Vakili · S. Mohammad Razavizadeh · Dariush Abbasi-Moghadam

Abstract In this paper; dynamical resource allocation scheme is proposed to improve throughput and fairness in the modern broadband wireless systems such as IEEE 802.16 Worldwide Interoperability for Microwave Access. To assign the subcarriers to users, dynamic fractional frequency reuse is used. In dynamic fractional frequency reuse, each cell is partitioned into two regions, one called super region and another called regular region. Regular region is divided into 3 parts which correspond to the three sectors. In this method, a utility function is firstly used for the subcarrier allocation to the geographical regions and then opportunistic scheduling is applied for the assignment subcarriers to users in each cell. In order to increase the throughput of the system, adaptive modulation and coding techniques are used. Using dynamic fractional frequency reuse reduces fairness among users of a cell. Therefore a random access sub-band is applied to improve the fairness of the system.

Keywords Dynamic fractional frequency reuse · WiMAX · Inter cell interference · Adaptive modulation and coding · Random access

1 Introduction

WiMAX (Worldwide Interoperability for Microwave Access) is a 4th generation (4G) broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture [1]. The WiMAX air interface is based on the IEEE 802.16-2004 standard [2] and the IEEE 802.16e Mobile Amendment to the standard [3].WiMAX air interface adopts orthogonal frequency division multiple access (OFDMA) to improve multi-path performance in

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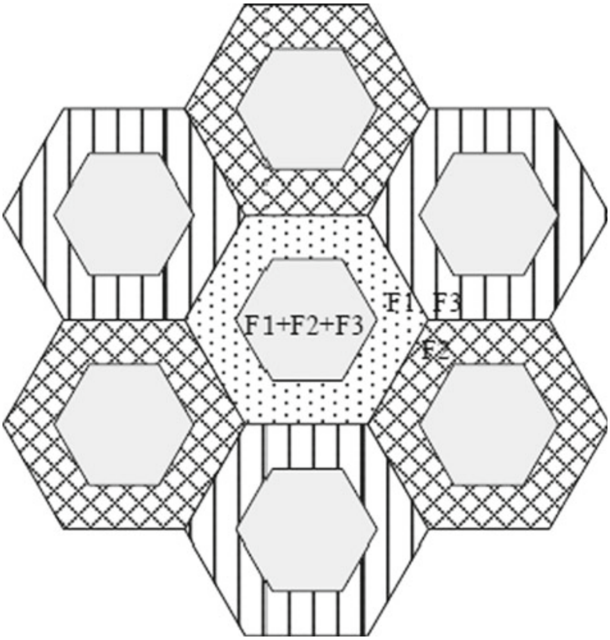

Fig. 1 Fractional frequency reuse architecture

non-line-of-sight environments. The main idea of an OFDMA scheme is to split a high rate data stream into a number of lower rate streams and transmit them by a set of orthogonal subcarriers. OFDMA inherits the immunity to inter symbol interference (ISI) in frequency selective fading channel. Therefore the inter-cell interference is a main problem in OFDMA based mobile cellular networks. One of the conventional inter cell interference (ICI) mitigation techniques is interference coordination. The inter-cell coordination techniques rely on the scheduling of the data transmission. Frequency resources (subcarriers) are distributed among the network users in a coordinated manner between the cells. In OFDMA systems, various subcarrier allocation schemes have been proposed by many researchers to increase the system throughput under some fairness or quality of service (QoS) constraints. In [4], the main interest is to increase the system capacity but the fairness issue is not considered. In order to mitigate the ICI while avoiding the demand of more extra spectrum, WiMAX forum introduced the use of fractional frequency reuse (FFR) into the mobile WiMAX system [5,6]. In FFR the cell edge users operate with only a fraction of the total bandwidth while the users near the base station (BS), operate the whole bandwidth. In FFR the cell is effectively divided into an inner and an outer region. The users in the outer region experience greater path loss but no inter cell interference. On the other hand, users in the inner region experience inter cell interference due to universal frequency reuse. This is illustrated in Fig. 1, where F1, F2 and F3 are different sets of sub-bands [7].

Mentioned method is called static FFR scheme. As mentioned before, in the FFR static scheme, subcarriers and users divide into two groups: inner and outer group. Because each user belongs to only one of these groups such partitioning reduces the trunking gain of each group. In addition, the channel states information don't consider in subcarrier partitioning. Hence, FFR static scheme is not suitable for subcarriers allocation in cellular networks. To solve this problem dynamic FFR schemes are used [8].

Furthermore in [9] a turbo encoding technique used in a CDMA multiuser system with conventional decoding and showed that it is efficient when the receiving is achieved in perfect conditions. In this case the turbo encoding compensates the effects the other users, the results obtained being close to a single user system. Also it was shown that if the cross-correlation between users is not very large, the turbo encoding is able to partially correct part of the errors.

In [10], the error probability performances of the conventional multiuser detector, the MMSE and the adaptive multiuser detector are evaluated and compared. It was shown that the linear MMSE offers slightly better performances than the conventional one. The adaptive implementation of MMSE eliminates the need for on-line computation of the impulse responses of the matched filters. The performances achieved by the adaptive MMSE are not as good as the ones obtained by the linear MMSE, but still better than the ones of the conventional receiver.

In this paper, we use a subcarrier allocation scheme in a WiMAX network. We apply adaptive modulation and coding (AMC) and random access sub-band techniques to increase the throughput and fairness of DFFR scheme, respectively.

The rest of this paper is organized as follows. The next section introduces the system model of an OFDMA-based WiMAX network. Then subcarrier assignment scheme is discussed in Sect. 3. Section 4 presents random access sub-band and AMC techniques. Section 5 discusses simulation results. The paper concludes in Sect. 6.

2 System Model

We consider the downlink of mobile WiMAX system which consists of K cells. Let M_k be the number of users in a cell k and N be the number of subcarriers available. We assume that one subcarrier cannot be simultaneously used by more than one user in a cell. Therefore, there is no intra-cell interference and the only interference is from the neighboring cells. Furthermore, subcarriers allocated to each sector are orthogonal. Channel model consists of path loss, fast fading and interference from the neighboring cells. The path loss model is a function of the distance from the serving BS (d). Path loss at a distance of d ($\mathrm{PL}\,(d)$), is given by:

$$\mathrm{PL}\,(d) = 130.2 + 37.6\log_{10} d \tag{1}$$

In this paper considers Rayleigh distributed fast fading which is modeled by the Jakes spectrum. Consequently, combining path loss and fast fading results in the following channel gain experienced by a user i on a subcarrier n from a BS k:

$$G_{i,n,k} = 10^{-\frac{\mathrm{PL}_{i,k}(d)}{10}} \times \left|H_{i,n}\right|^2 \tag{2}$$

where $|H_i, n|^2$ is fading coefficient. The signal to interference plus noise ratio (SINR) for a user i on a subcarrier n can be expressed as:

$$\mathrm{SINR}_{i,n} = \frac{G_{i,n,k} P_{i,n,k}}{N_0 \Delta f + \sum_{m \in I} G_{i,n,m} P_{i,n,m}} \tag{3}$$

where $P_{i,n,k}$ is the power for user i on subcarrier n allocated by cell k, N_0 is the power spectrum density of AWGN, Δf is the subcarrier spacing and I is the set of interferers. According to the Shannon's theorem, the data rate of a user i on a subcarrier n can be expressed as

$$R_{i,n} = \Delta f \ast \log_2 \left(1 + \frac{\mathrm{SINR}_{i,n}}{\mu}\right) \tag{4}$$

where μ called SNR gap is a constant related to the target BER, with $\mu = -\ln\,(5\mathrm{BER})\,/1.5$.

3 Dynamic Fractional Frequency Reused (DFFR)

In the dynamic FFR scheme that we use [11], the subcarriers are firstly allocated among the cells and then, within a cell, among the users. In this cellular system, each cell is partitioned into two regions: super region and regular region. The regular group is divided into three parts which correspond to the three sectors. Both regions cover the whole cell surface. Therefore, all users of a cell are virtual members of both regions. Moreover the subcarriers are divided into two groups: super group and regular group. The subcarriers assigned to the super and the sectors within the regular groups are orthogonal. Furthermore, if subcarrier n is allocated to the super or regular group in one cell, it should be reused in all the cells. The structure and frequency band allocation are illustrated in Fig. 2 [8]. In this paper, we consider 19-cell grids with 3 sectors per cell (see Fig. 2). When user i is located in sector A of cell 1, I includes all the adjacent cells in the super group and cells numbered {5, 6, 13, 14, 15, 16, 17} in the regular group setting.

Similar to [8], for distribution of the subcarriers to the geographical regions (super and regular regions) the utility functions is used. The utility of a subcarrier n for the super group is average values of achievable rates of all the users, which can be calculated from (4), on this subcarrier. But in the regular group the utility for each sector is average values of achievable rates of the present users in the correspondence sector on a subcarrier n. $R_{i,n}^{sup}$ and $R_{i,n}^{reg}$ identify the achievable data rate of subcarrier n in the super and regular group, respectively.

T_super_n and $T\_regular_{n,m}$ are utility of subcarrier n for the super group and utility of subcarrier n and sector m for the regular group, respectively. At first we assume that all the subcarriers are allocated to the super group therefore primary rate of a sector is zero. To assign a subcarrier to regular group, a new utility function is defined. This function for each sector obtains from differential utility values regular and super groups on a given subcarrier and denote with $U_{n,m}$, where $U_{n,m}$ is the utility function of sector m on subcarrier n.

In order to update the rate of a sector, denote as ϕ_m, and assignment subcarrier to regular group the following steps are performed.

1. At first rate requirements of each sector, denote as C_m, with summation data rate of the existent users in correspondence sector, are obtained.
2. In this step, the sectors that satisfied the expression $\psi_m = C_m - \phi_m$, sort into a dominant sector set. If value ψ_m for all m is negative, dominant sector set will be equaled with {1, 2, 3}.

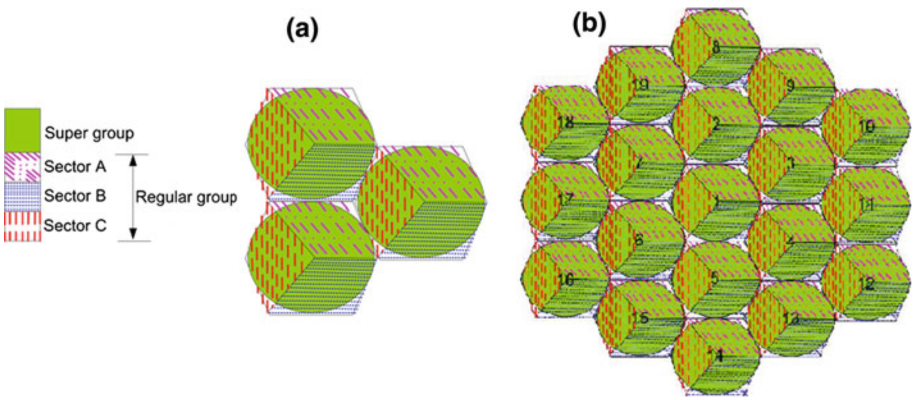

Fig. 2 **a** Dynamic fractional frequency reuse structure. **b** 19-cell grid

3. For all subcarriers and sectors belonging to the dominant sector set, $U_{n,m}$ calculate and find subcarrier sector pair $\left(n', m'\right)$ that maximize $U_{n,m}$.
4. If $U_{n',m'} < 0$, this subcarrier remains in the super group, because allocation of the subcarrier n' to the regular group lowers the system data rate. Rate of a sector can be updated as: $\phi_m = \phi_m + \lambda T\_super_{n'}$. $\lambda < 1$ is a constant value.
5. Else if $U_{n',m'} > 0$, subcarrier n' is removed from the super group and assigned to sector m' of the regular group and rate of a sector can be given by,

$$\phi_{m'} = \phi_{m'} + T\_regular_{n',m'}$$

Since the super and regular group subcarriers are orthogonal, after finding the subcarriers belonging to the regular group, with motioned method, super group's subcarriers can be uniquely determined. After subcarriers assignment to super and regular groups, we use from opportunistic scheduling for the assignment subcarriers to users in each cell. When there are many users which fade independently, at any one time there is a high probability that some of the users will have a strong channel. By allowing only those users to transmit, the shared channel resource is used in the most efficient manner and the total system throughput is maximized. Such scheduling mechanisms are called opportunistic because they take advantage of favorable channel conditions in assigning time slots to users. Assuming $R_{i,n,t}^{sup}$ and $R_{i,n,t}^{reg}$ represent instantaneous achievable rates values for user i in time slot t subcarrier n in super group and regular group, respectively. For the assignment of the super group subcarriers to the users, this algorithm scheduling finds the user i' that maximize $R_{i,n,t}^{sup}$ at every scheduling slot t. Similarly, for the assignment of the regular group subcarriers, this algorithm finds the user i' that maximize the $R_{i,n,t}^{reg}$.

4 Random Access and Adaptive Modulation/Coding

There is not fairness among users in described DFFR scheme due to the opportunistic scheduling. To improve fairness of the system a random access scheme is proposed. In this scheme, subcarriers are divided into two groups. First group is allocated dynamically to all users with mentioned method in Sect. 3. The rest of subcarriers (second group) are randomly assigned to the users in cell edge. In this paper, the users within 50 percent of the cell radius are considered belong to the cell edge. Under this scheme, the throughput of users located in cell-edge increases and therefore the fairness of the system is improved. Using random access technique reduces the total throughput of the system. This reduction is due to the some subcarriers, assignment only to the users of cell edge.

In order to improve the system throughput, AMC is used. AMC has offered a link adaptation method that promises to raise the overall system throughput. AMC provides the flexibility to match the modulation-coding scheme to the average channel conditions for each user. With AMC, the power of the transmitted signal is held constant over a frame interval, and the modulation and coding format is changed to match the current received signal quality or channel conditions. In this paper, we adopt the modulation and coding schemes for a bit error rate requirement set to 10^{-6} which is listed in Table 1 [12].

5 Simulation Results

To evaluate DFFR, the system throughput was simulated by Matlab Software. The simulation parameters are given in Table 2. The fast fading of users can be generated through the Jakes

Table 1 AMC scheme in IEEE 802.16E [12]

Modulation	Coding rate	bit/s/Hz	SNR threshold(dB)
QPSK	1/2	1	5
	3/4	1.5	8
16-QAM	1/2	2	10.5
	3/4	3	14
64-QAM	2/3	4	18
	3/4	4.5	20

Table 2 Simulation parameters

Parameter	Value
Cell layout	Hexagonal grid, 3-sector sites
Cell radius	2,000–10,000 m
Bandwidth	5 MHz
Carrier frequency	2.5 GHz
Subcarrier spacing	24 KHz
Number of subcarrier	200
Thermal noise level	−174dBm/Hz
BS transmit power	40 dBm
Number of users	15 per cell
Location of users	Uniformly distributed on cell surface
Slot duration	1 ms
Min. rate requirement	Uniformly distributed 200–250 Kbps
Fast fading	Jakes model
Number assignment subcarrier to edge cell	50

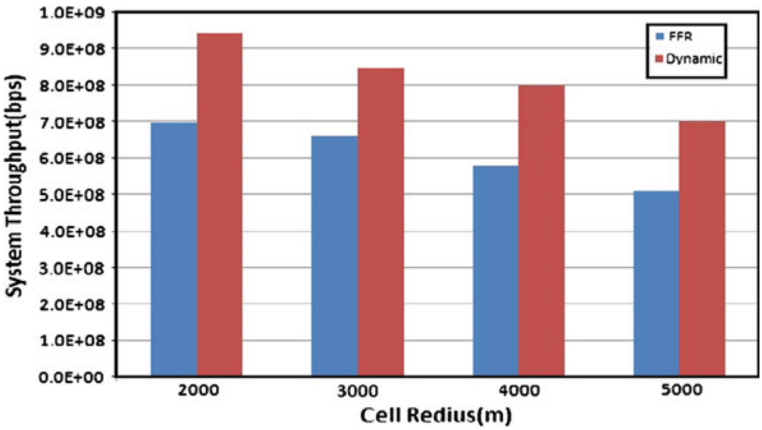

Fig. 3 Comparison of dynamic and classic FFR schemes

Model. System throughput is the aggregate throughput received by all the users in all the cells.

Figure 3 compares the achieved throughput of system by the static and dynamic FFR allocations for 19 cell grids, respectively. We assumed that all the available subcarriers were

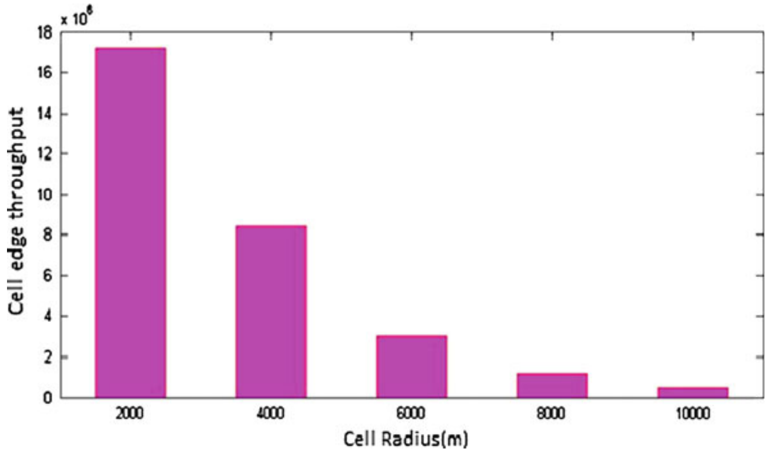

Fig. 4 Performance improvement of edge cell users

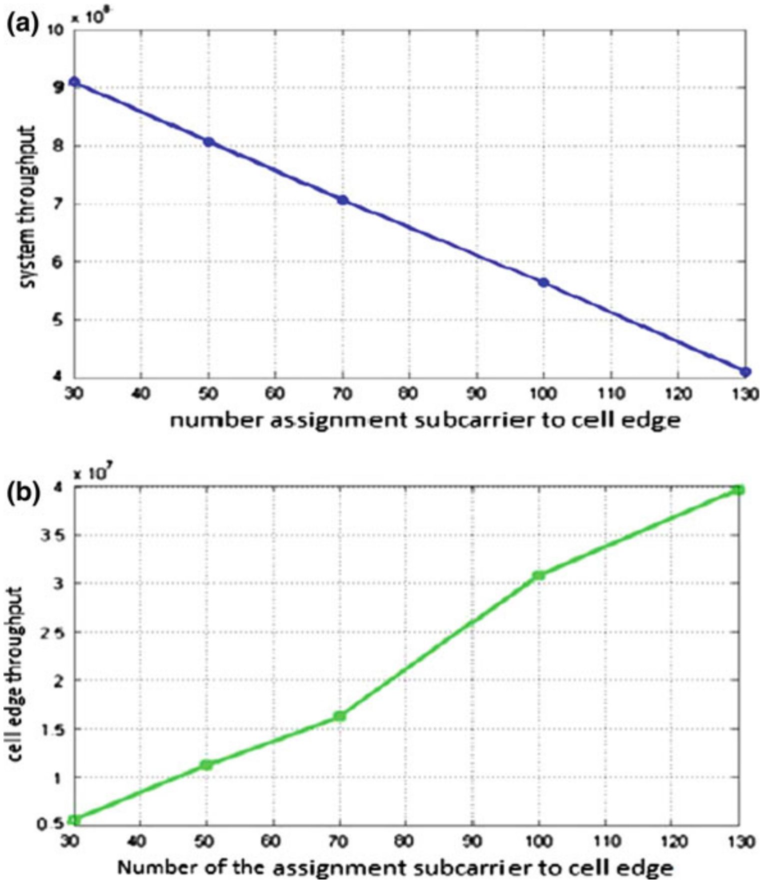

Fig. 5 Total throughput of the system versus the number of subcarriers assigned to cell edge users, **a** the total throughput of the system, **b** the cell edge throughput

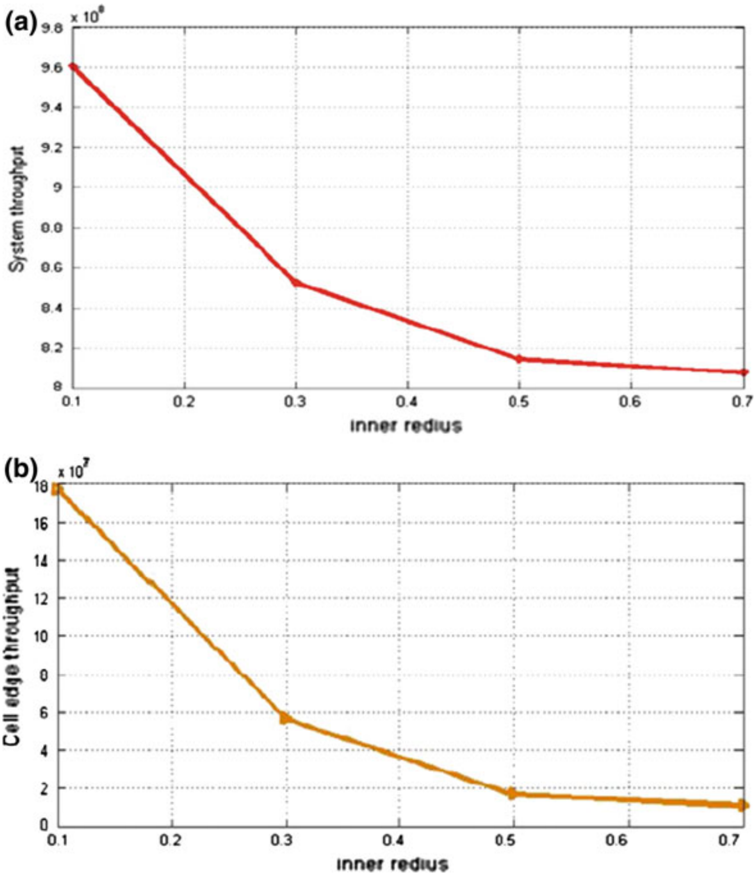

Fig. 6 Total throughput of the system and the cell edge throughput for different inner radiuses in cell radius of 2,000 m and the number of assigned subcarriers to cell edge users is 50 **a** the total throughput of the system, **b** the cell edge throughput

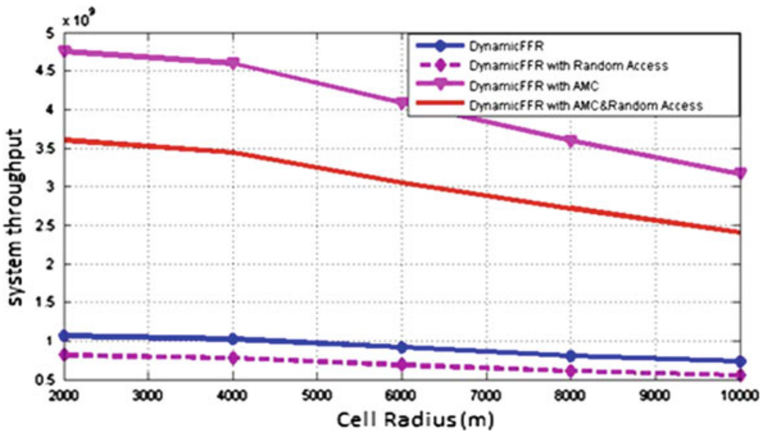

Fig. 7 Comparison of total throughput in different dynamic FFR schemes

transmitted with equivalent power. The dynamic FFR scheme performs better than the static FFR scheme. The reason for this performance improvement is that the dynamic FFR scheme intelligently and by using of information state channel, distributes subcarriers into users. As it is seen, increasing cell radius reduces the cell throughput due to the increased path loss. In DFFR scheme, the opportunistic scheduling is used for subcarriers allocation to the users. Therefore, a few subcarriers are assigned to the cell edge users that are most affected by the inter-cell interference. Figure 4 shows the performance improvement of the cell edge users with random access technique in different radiuses. As it is seen, increasing the cell radius reduces the cell edge throughput improvement due to the increased path loss.

Figure 5 shows the total throughput of the system and the cell edge throughput versus the number of the subcarriers assigned to the cell edge users in the cell radius of 2,000 m and the edge cell radius of 1,400 m. As it is seen, increasing the number of subcarriers assigned to cell edge users, the total throughput reduces due to increasing path loss and consequently reduction in SINR. As it is observed from Fig. 4b, the fairness of the system has improved.

Figure 6 displays the total throughput of the system and the cell edge throughput for different inner radiuses in cell radius of 2000 m. The number of assigned subcarriers to the cell edge users is 50. As it is seen the total throughput of the system and the cell edge throughput decreases by increasing the inner cell radius. This is because the probability of subcarrier assignment to the users with low SINR increases.

Figure 7 compares the achieved throughput of system by the DFFR, DFFR with random access, DFFR with AMC and DFFR with random access and AMC. This figure shows that using random access reduces the total system throughput. This reduction is due to the some subcarriers, assignment only to users of edge cell. To solve this problem, AMC is proposed.

6 Conclusion

Inter-cell interference is a main problem in WiMAX mobile cellular networks. One of conventional inter-cell interference mitigation techniques is interference coordination. The most commonly interference coordination technique is the frequency reuse pattern. In this paper, we evaluated DFFR with adaptive modulation/coding and random access sub-band techniques. The system architecture supports full frequency reuse. It is shown that the dynamic FFR scheme performed better than the static FFR scheme. The reason for this performance improvement is that the dynamic FFR scheme distributes subcarriers into users intelligently with using of channel information state. In DFFR scheme, subcarriers allocation to users opportunistic scheduling is used. Therefore a few subcarriers assigned to cell edge users that are most affected by inter-cell interference. To improve the cell edge throughput a random access scheme was used. Using random access scheme reduces the total system throughput. This reduction is due to the some subcarriers, assignment only to the users of cell edge. In order to increase the total system throughput, adaptation modulation and coding was used.

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