Adaptive Fractional Frequeny Reuse (AFFR) Scheme for Multi-cell IEEE 802.16e Systems

Suzan M. Shoukry
Higher Technological Institute
suzan.shukry@gmail.com

Khaled Elsayed
Cairo University
khaled@ieee.org

Ali Elmoghazy
Military Technical College

Ameen Nassar
Cairo University

ABSTRACT: In this paper we present a new Adaptive Fractional Frequency Reuse scheme (AFFR) for multi-cell OFDMA based IEEE 802.16e network. The Adaptive Fractional Frequency Reuse (AFFR) scheme is managed by the Access Service Network Gateway (ASN-GW) which coordinate a set of BSs (one cluster). To make better usage of radio resources; we assume that the cell area is virtually divided into two different zones: the fractional frequency reuse (FFR) zone which includes all users who are suffering from high Inter-Cell Interference ICI from neighbouring cells and the Full Usage (FU) zone where Inter-Cell Interference ICI can be neglected. The base station BS assigns users to each zone dynamically based on their channel state information. ASN-GW decides the set of subcarriers assigned to the FFR zone within each BS. In the FU zone; all subcarriers available in the system can be used. We provide simulation results comparing our AFFR scheme with different schemes. We examine the effect of the choice of the major system design parameters on the performance. The simulation results illustrate the superiority of the proposed scheme for multiple values of system design parameters.

KEYWORDS: ***Adaptive Fractional Frequency Reuse AFFR, Inter Cell Interference coordination, multi-cell IEEE 802.16e, radio resource management.***

I.INTRODUCTION

The IEEE 802.16e standard is an advanced system for enabling true mobile Internet services. The IEEE 802.16e specifications define three different versions of the physical layers: single carrier (SC) transmission, orthogonal frequency division multiplexing (OFDM), and orthogonal frequency division multiple access (OFDMA)[1-2]. OFDMA is one of the best schemes for use in broadband transmission system design for its capability of overcoming inter-symbol interference ISI and utilizing the given radio spectrum efficiently by dividing it into a large number of small sub-bands [3]. One of the crucial problems in OFDMA based IEEE802.16e systems is the allocation and management of radio resources. There are some few works that studied radio resource management in multi-cell OFDMA systems. In [4] the authors present a resource allocation scheme with the objective of maximizing the total system throughput. The authors define for each user in the system throughput marginal utility (TMU) which is a system throughput improvement by assigning the current subcarrier to the user within the BS being evaluated. The subcarriers assignment is progressively performed to provide the maximum improvement to the system throughput. If none of the users in the BS has a positive TMU value, then the subcarrier is not assigned to this particular BS.

To this effect, more resources are allocated to cells with users of best channel condition.

In [5] the authors present the concept of virtual cells, which is composed of three adjacent sectors belonging to three neighboring cells. The proposed algorithm have the objective of minimizing the total transmission power while satisfying users' rate requirements. The algorithm considers each user's rate requirement and confines the information exchange within the "virtual cell". As it considers frequency reuse in a virtual cell, spectral efficiency is not fully exploited. Furthermore, the computation and signaling overhead is very high.

In [6] the authors proposed a subcarrier and power allocation scheme that minimizes the total transmitted power. The allocation depends on channel statistics and rate requirements for all users. The work also covers the area of multicell OFDMA system.

In [7] the authors study the capacity of OFDMA-based IEEE802.16 and show that reuse partitioning results in improving the overall cell throughput.

In [8] the authors presented the concept of "pseudo-cell" which is composed of the major interfering sectors belonging to the neighboring cells. In order to reduce the signaling and computation overhead they adopt a distributed operation such that resource allocation is managed independently at each pseudo-cell. In this regard they provide a dynamic resource allocation that can provide load balancing among neighboring sectors while satisfying requested QoS among users.

In [9] the authors compare between the performance of MIMO-OFDMA and MIMO-MC-CDMA in multi-cell multiuser downlink scenario. They propose a simple two stage heuristic approach of resource allocation. The first stage optimizes the power and subchannel allocation to maximize the system capacity, while the second stage determines the transmission rate for every user.

In this paper we present a new Adaptive Fractional Frequency Reuse (AFFR) scheme at the ASN-GW. In our work the coverage area of each BS is virtually divided into two regions: the Full Usage (FU) zone where all subcarriers available in the system are used, and the Fractional Frequency Reuse FFR zone where subcarriers are allocated using the Adaptive Fractional Frequency Reuse AFFR method at Access Service Network Gateway ASN-GW. The ASN-GW allocates subcarriers to BSs with the objective of minimizing the effect of inter-cell interference ICI, improving usage of radio resources, and at the same time making fair radio resource allocation to BSs. The ASN-GW performs radio resource allocation periodically each Inter-cell Interference Coordination (ICIC) period.

The paper is organized as follow: section II describes the system model. In section III a description of Adaptive Fractional Frequency Reuse AFFR scheme at the ASN-GW is presented. The simulation and results are shown in section IV. Finally the conclusions are provided in section V.

II.THE SYSTEM MODEL

We consider a multi-cell OFDMA based IEEE 802.16e where each cell uses omni directional antenna. We assume the ASN-GW coordinates a cluster of M cells. Each cell m has a number of users i_m. The users are uniformly distributed throughout the cells and moving with velocity v_i in a random direction which is constant during all the simulation time. Fig.1 shows the system model used in our work. The area of each cell is virtually divided into two regions: The first is called “the Fractional Frequency Reuse FFR zone” where inter-cell interference ICI has significant effect, and the second is the Full Usage zone.

For the simplicity and for focusing on the problem at hand we assume constant transmission power for all of the BSs and the power is equally allocated to subcarriers in each cell. We consider IEEE 802.16e Time Division Duplex (TDD) frame structure as given in [10]

In IEEE 802.16e subcarriers are grouped into subchannels. Our system is based on diversity permutation, in which the subcarriers are grouped in a pseudo-random way; which is called Partial usage of subchannels (PUSC) [10]. PUSC permutation is recommended for mobile users. Let N be the number of OFDM subcarriers available to the overall system where these subcarriers are grouped into K subchannels.

Within the framework of IEEE 802.16e, the receiver calculates the SINR and quantizes it from -16 dB to 47.5 dB in units of 0.5dB. This value is then feedback to the base station in 7 bits using the UL Channel Quality Indicator Channel “CQICH” every frame.

In our system the scheduler is implemented at the BS to enable fast response to variations in traffic requirements and channel conditions. The scheduler at the BS decides the subchannels allocation to active users in the system.

After the assignments of subchannels, adaptive modulation and coding are performed, namely the proper modulation and code rate as shown in Table I [10] are selected. Finally IFFT is done to transform users’ symbols into time domain to be transmitted through the channel.

For the channel model we model the multipath channels using tap-delay lines [11]. For the path loss model that is relevant to NLOS WIMAX deployment we follow the COST-231 HATA model. The WIMAX Forum recommends the usage of the COST-231 Hata model for system simulations and network planning of macro cellular systems in both urban and suburban areas for mobility applications [11].

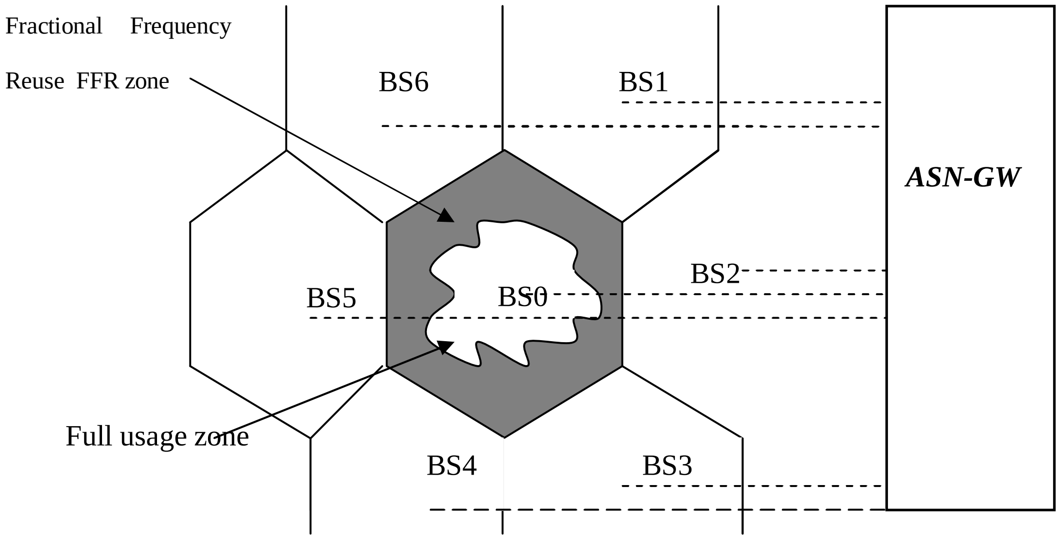

Fig. 1. System Model

TABLE I. ADAPTIVE MODULATION AND CODING IN IEEE 802.16E

Modulation	*Code rate*	*SINR Threshold*
BPSK	½	*13.9*
QPSK	½	*16.9*
QPSK	¾	*18.65*
16QAM	½	*23.7*
16QAM	¾	*25.45*
64QAM	½	*29.7*
64QAM	¾	*31.45*

III.THE PROPOSED ADAPTIVE FRACTIONAL FREQUENCY REUSE SCHEME AT ASN-GW

The Adaptive Fractional Frequency Reuse (AFFR) scheme at the ASN-GW is applied to the users included in the Fractional Frequency Reuse FFR zone. Outside the Fractional Frequency Reuse FFR zone scheduling at the BS is the main radio resource allocation algorithm applied and users are allowed to use the set of all subcarriers available in the system. To reduce the system overhead, AFFR at ASN-GW is executed periodically every Inter-Cell Interference Coordination ICIC period. (ICIC_PERIOD) .The ICIC_PERIOD is an integer number of system frame time.

Let P_m be the transmitted power from BS *m* to user *i* on subcarrier *n* (power is not dependant on the user in addition to that in our work we assume the power is equally allocated to all subcarriers so we don't put suffix *i* nor *n* in defining the power).

Let $h_{m,n,i}$ be the channel gain on subcarrier *n* between BS *m* and user *i*.

In our model, it is assumed that users receive the pilot signal from all of the BSs. Let $P_m\ h_{m,n,i}$ be the pilot signal strength received by the user *i* from BS *m* at subcarrier *n*, The SINR for user *i* in cell *m* on subcarrier *n* is given by:

$$SINR_{m,n,i} = \frac{P_m h_{m,n,i}}{\sum_{j\neq m}^{M} p_j h_{j,n,i} + N_o} \qquad (1)$$

Let d_{mn} be the dominant interfering BS to BS *m* on subcarrier *n*, where

$$d_{mn} = \arg\max_{j\neq m} P_j h_{j,n,i} \qquad (2)$$

We can define *SINR_without*$_{m,n,i}$ as the SINR without taking into consideration the dominant interference component[4] (i.e. as if the dominant interfering BS is not assigned this subcarrier so its interference effect is cancelled).

$$SINR\_without_{m,n,i} = \frac{P_m h_{m,n,j}}{\sum_{j\neq m,\, j\neq d_{mn}}^{M} P_j h_{j,n,i} + N_o} \qquad (3)$$

At the beginning of each ICIC_PERIOD the ASN-GW triggers each BS to apply the following initialization procedure which can be described as follows

A. BS initialization procedure

Step 1: Determine the users inside the Fractional Frequency Reuse FFR zone and those outside the Fractional Frequency Reuse FFR zone

In this step the BS distinguishes between users who are considered outside the Fractional Frequency Reuse FFR zone and those who are considered inside the Fractional Frequency Reuse FFR zone. the ASN-GW defines a SINR threshold value for Fractional Frequency Reuse FFR zone (*SINR_TH*). Each BS *m* calculates the average SINR value for each user in the cell i_m ($SINR\_FFR\_AV_{i_m}$).

$$SINR\_FFR\_AV_{i_m} = \frac{\sum_{n=0}^{N-1} SINR_{m,n,i}}{N} \qquad (4)$$

Any user having

$$SINR\_FFR\_AV_{i_M} \leq SINR\_TH$$

is considered inside the Fractional Frequency Reuse FFR zone; otherwise the user is considered outside the Fractional Frequency Reuse FFR zone.

Step 2: Subcarriers channel state information processing

In this step each BS in the system makes processing of the subcarriers channel state information for each user in its coverage area and provides the results of this analysis to the ASN-GW to use them in the AFFR algorithm.

Let us define for each subcarrier *n* in each BS *m* the following:

SINR_max$_{m,n}$ is the max value of SINR (between all users in BS *m*) of subcarrier n for BS *m*, taking into consideration the dominant interference component.

$$SINR\_max_{m,n} = SINR_{u\max} \qquad (5)$$

where $u_{max} = \arg\max_{i} SINR_{m,n,i}$

SINR_min$_{m,n}$ is the min value of SINR (between all users in BS *m*) of subcarrier *n* for BS *m*, taking into consideration the dominant interference component.

$$SINR\_min_{m,n} = SINR_{u\min} \qquad (6)$$

where $u_{min} = \arg\min_{i} SINR_{m,n,i}$

SINR_min_without$_{m,n}$ is the min value of *SINR_without* (between all users in BS *m*) of subcarrier *n* for BS *m*, without taking into consideration the dominant interference component.

$$SINR\_AV_{m,n} = \frac{\sum_{i=0}^{I_m-1} SINR_{m,n,i}}{I_m} \qquad (7)$$

Where I_m is the total number of users served by BS *m*

$$SINR\_DIFF_{m,n} = SINR\_max_{m,n} - SINR\_AV_{m}, \qquad (8)$$

Arrange the subcarriers in each BS in descending order according to their *SINR_DIFF* and put the results in an array called “*subcarriers_pref$_m$*”. At the end of the BS initialization procedure, the ASN-GW begins its procedure.

B ASN-GW procedure

The ASN-GW uses the information it received from the entire BSs and begins its algorithm which can be described as

Step 1: Subcarriers allocations to BSs

In this step, the ASN-GW determines the number of subcarriers to be assigned to each BS *m*. We denote the number of subcarriers to be assigned to each BS *m* as N_m. During the ICIC_PERIOD each BS uses only N_m subcarriers from the set of the total number of subcarriers available in the system *N*. For each BS *m*, the ASN-GW calculates the preset ratio Γ_m given by

$$\Gamma_m = \frac{\sum_{i_m=0}^{I_M-1} \overline{Q}_{i_m}}{\sum_{j=0}^{M-1} \sum_{i_j=0}^{I_j-1} \overline{Q}_{i_j}} \qquad (9)$$

Where $\overline{Q}_{i_m}$ is the average queue length of user i_m at BS *m*.

The preset ratio ,which is always less than 1, defines the fraction of the total number of available subcarriers (*N)* to be assigned to each BS The choice of the value of N_m changes dynamically each ICIC_PERIOD based on the queues distribution in each BS *m* and can be calculated as follows

$$N_m = \lfloor \Gamma_m * N \rfloor \qquad (10)$$

Step 2: Subcarriers assignment to BSs

In this step the ASN-GW attempts to assign a set of subcarriers to each BS to make the best usage of the radio resources. For each BS (beginning from the one having the highest preset ratio and ending with the one having the lowest preset ratio) assign each BS the best subcarriers based on the order defined in the *subcarrie_pref$_m$* array. The assignment can be applied by defining x_{mn} as a constant with x_{mn} =1 meaning subcarrier *n* is assigned to BS *m*, otherwise $x_{mn} = 0$.

Step 3: Take the advantage of adaptive modulation and coding AMC to make better usage of radio resources

In this step the ASN-GW attempts to improve the usage of radio resources taking into consideration the adaptive modulation and coding applied in the system. This can be achieved as follow: if the effect of the interference of the dominant interfering BS causes reduction in SINR such that the modulation level is decreased (as given in Table I) then the dominant interfering BS is not allowed to use this subcarrier. Otherwise the dominant interfering BS is allowed to use this subcarrier.

For example, if the *SINR_min$_{m,n}$* is 15 dB, and *SINR_min_without$_{m,n}$* is 16 dB then according to Table I both of these values lead to the same modulation level which is QPSK ½ so thus the dominant interferer BS can use the same subcarrier n as the interference here have no effect on the modulation level. If the *SINR_min$_{m,n}$* is 12 dB, and *SINR_min_without$_{m,n}$* is 16 dB then according to Table I these values lead to different modulation level which is BPSK if considering SINR_withm,n,i and QPSK ½ if considering SINR_withoutm,n,i . In this case, the dominant interfering BS d_{mn} cannot use the same subcarrier *n* as the interference here reduces the modulation level.

IV. SIMULATION AND RESULTS

We build our simulation using C++ programming with the aid of the IT++ library [12]. IT++ is a C++ library of mathematical, signal processing, speech processing, and communications classes and functions. This library has been developed by researchers in these areas. The ITbase library which is the core of IT++ contains classes and functions for mathematics with scalars, vectors, and matrices. These functions are similar to Matlab functions.

In our simulations we consider a multi-cell IEEE 802.16e system with 1 Km cell radius where each ASN-GW coordinate a cluster of 7 cells, hence M=7. Users are assumed to be uniformly distributed across the cell.

The traffic model used in the simulation is RT traffic streaming service that periodically generates packets of variable sizes. The characteristics of RT traffic are shown in Table II which is derived from the model given in [13].

In our simulation we assume the maximum allowed delay for all traffic is 250 ms, and the accepted PDR is 0.01.

We run the simulation for 10 minutes. This is equivalent to 120000 TDD frames each of 5 ms. We follow the system parameters as given in Table III.

TABLE II. CHARACTERISTICS OF RT TRAFFIC

Characteristic	*Distribution*	*Parameter*
Inter-arrival time between frames	Deterministic	10 ms
Number of packets/frame	Deterministic	8
Packet size	Truncated Pareto (mean:50; max:125 bytes)	c =20 bytes, a =1.2

Packet inter-arrival time	Truncated Pareto (mean: 0.6, max:1.25) ms)	c =2.5 ms a =1.2

In this section we study the performance of the proposed AFFR scheme at ASN-GW. For better assessment of our proposed scheme we compare our scheme with that given in [4]. In the scheme given in [4] the ASN-GW must update all users' Channel State Information (CSI) from all BSs periodically, and the decision made by ASN-GW includes the specific set of subcarriers assigned to each BS and the recommended subchannels assignments to users. If the recommended user by the ASN-GW has traffic to send, the BS agrees with ASN-GW's recommendation, otherwise the BS makes its own decision based on user's traffic conditions and channel state of each user.

We refer to the ASN-GW scheme given in [4] as the LL scheme (where LL are the initials of the authors Li and Liu). We also try to investigate the effect of the choice of the scheduler at BS on the overall system performance. We consider two different schedulers the first is the Channel State Dependent Scheduler CSDS [4], and the second is the utility based scheduler [14].

TABLE III. SUMMERY OF SYSTEM PARAMETERS USED IN THE SIMULATION

System channel bandwidth (MHZ)	*5*
FFTsize	*512*
Sub-carrier frequency spacing (KHz)	*10.94*
Carrier freq (GHz)	*2.3*
Frame length (ms)	*5*
DL/UL ratio	*3:1*
OFDMA symbol time (^{m} *s)*	*100.84*
Number of OFDMA symbols per frame	*49*
TTG (^{m} *s)*	*29.41*
RTG (^{m} *s)*	*29.41*
Number of OFDMA symbols per frame (DL)	*36*
Number of OFDMA symbols per frame (UL)	*12*

The CSDS scheduler assigns subchannels to users based on their channel state information without any consideration of any users' QoS requirements. The utility based scheduler decides which subchannel is assigned to which user based on a cross-layer approach. cross-layer approach provides better quality of service for real time users in terms of reducing Head-of-Line (HOL) packet delays, at the same time makes better usage of radio resources. In utility based scheduler a new utility function is used that accounts for users' requested QoS, users' channel state, and the users' backlogged queues. (For detailed description return to our previous work in [14]).

Thus we have four combined schemes that are as follows:

- The first scheme is the LL scheme at ASN-GW as given in [4], and the CSDS scheduling at BS which is referred to as "LL-CSDS".
- The second is the proposed AFFR scheme at ASN-GW as described in sections 3, and utility based scheduling at BS which is referred to as "Proposed-Util".
- The third is the combination resulting from applying the LL scheme at ASN-GW, and utility-based scheduling at the BS which is referred to as "LL-Util".
- The fourth is the combination resulting from proposed AFFR scheme at ASN-GW], and the CSDS scheduling at BS which is referred to as "Proposed-CSDS".

When comparing performance we study the effect of the choice of some of the major system design parameters which are the choice of the ICIC Period "ICIC_PERIOD", and also the choice of the threshold value of SINR for Fractional Frequency Reuse FFR zone "SINR_TH".

A Effect of the Choice of SINR Threshold SINR_TH for Fractional Frequency Reuse FFR Zone

In this section we study how the performance is affected by the choice of the threshold value of the SINR which distinguish users inside the Fractional Frequency Reuse FFR zone from those outside the Fractional Frequency Reuse FFR zone.

As shown in Fig.2 and 3, for all schemes there is improvement in performance (increasing system capacity and reducing average delay) with the SINR_TH. This is due to interference reduction of AFFR algorithm at ASN-GW. On the other hand this improvement is followed by degradation with any increase in SINR_TH. This is due to reduction of resources (subcarriers) available for users who are not suffering from high interference from neighbouring cells.

From Fig. 2 It is clear that the proposed AFFR scheme at ASN-GW improves the system capacity compared to the LL ASN-GW scheme when either combined with utility-based or CSDS.

From Fig. 3 we also see that applying the proposed AFFR scheme at ASN-GW improves the performance for both CSDS and utility-based scheduling.

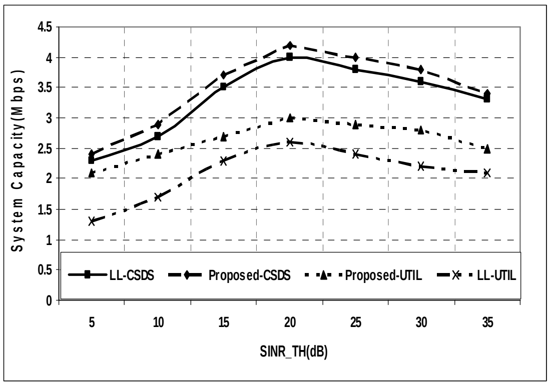

Fig. 2. System Capacity versus SINR_TH

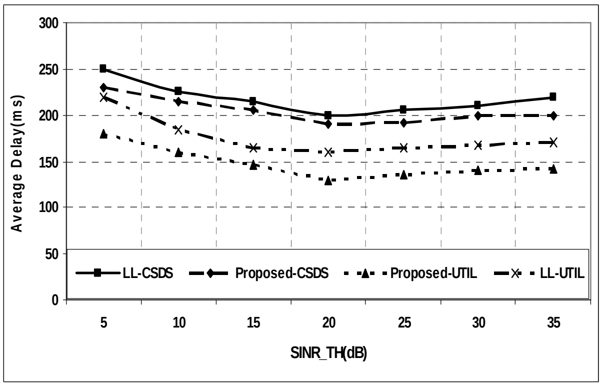

Fig. 3. Average Delay versus SINR_TH

B Effect of Inter-Cell Interference Coordination Period (ICIC_PERIOD)

In this section we provide another view of our study. That is we try to investigate the effect of the choice of ICIC_PERIOD on the overall system performance. The choice of ICIC_PERIOD represents the periodicity of ASN-GW subcarriers re-assignments to BSs. Increasing ICIC_PERIOD reduces the overall system overhead, so studying the effect of the choice of the ICIC_PERIOD on the overall system performance is a crucial problem.

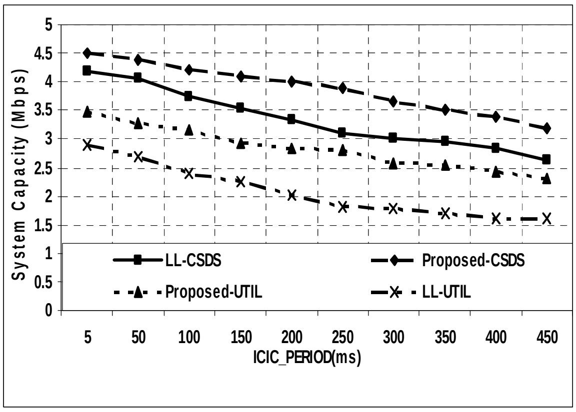

Fig. 4. System Capacity versus ICIC_PERIOD Duration

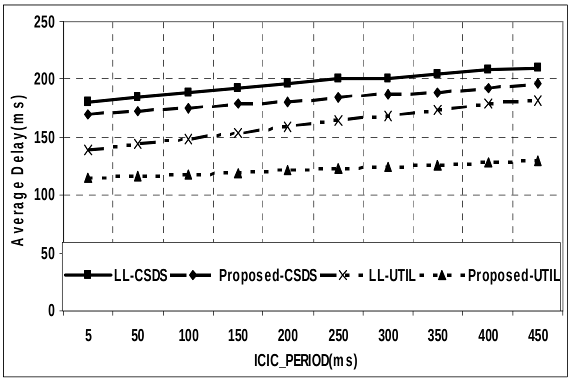

Fig. 5. Average Delay versus ICIC_PERIOD Duration

In Figs. 4, 5 we study system capacity and average delay with ICIC_PERIOD respectively. As can be seen from Fig. 4 for any scheme as the duration of the ICIC_PERIOD increases system capacity decreases. Similarly, Fig. 5 shows that as the duration of ICIC_PERIOD increases the average delay increases.

This degradation in performance can be explained as follow: as all users in the system are mobile users then their channel state is time-varying, so as the duration of ICIC_PERIOD decreases the ASN-GW captures more accurate channel state information and hence makes better decision regarding the subcarriers assignments to BSs.

So there is degradation in performance with the increase in the duration of ICIC_PERIOD but at the same time increasing the duration of ICIC_PERIOD causes a reduction in system overhead so the best scheme is the one having the least degradation in the performance with the increase of the duration of ICIC_PERIOD. That is what we present in Figs. 6, 7.

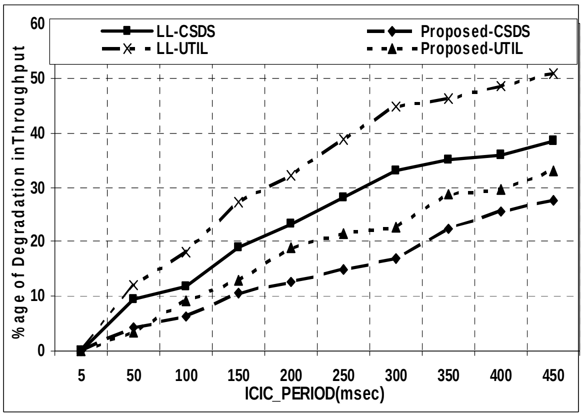

Fig. 6. Percentage of Degradation in Throughput versus ICIC_PERIOD Duration

Fig. 6 shows the degradation in the throughput with the increase of duration of ICIC_PERIOD where the reference comparison with the value of throughput at smallest duration of ICIC_PERIOD which is 5 ms. Similarly, Fig. 7 shows the degradation in average delay.

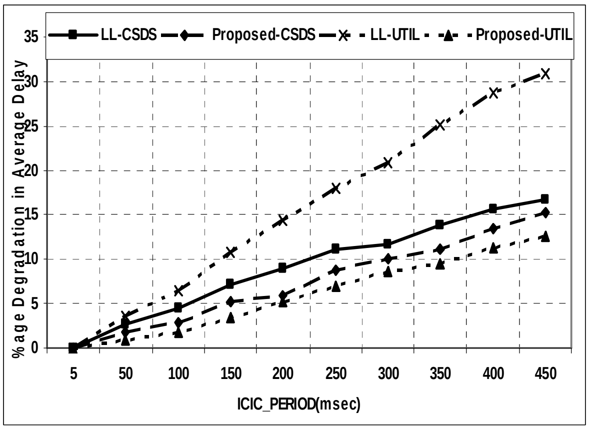

Fig. 7. Percentage of Degradation in Average Delay versus ICIC_PERIOD Duration

It is evident from Figs. 6, 7 that for all the schemes smaller duration of ICIC_PERIOD results in better system performance. At the same time we note that applying the proposed AFFR scheme at ASN-GW reduces the degradation in performance with duration of ICIC_PERIOD. This is because in our ASN-GW AFFR algorithm we assign to each BS the best subcarriers for it based on statistics on overall subcarriers channel state information for all of its users.

Hence when assigning a subcarrierl to a BS this means that the channel response for this subcarrier is good for almost most of the users in the cell and not good for only one user in the cell which may occur if the LL scheme at ASN-GW is chosen. Also the proposed ASN-GW AFFR algorithm takes the advantage of AMC which makes better usage of radio resources.

V.. CONCLUSIONS

In this paper we developed a new Adaptive Fractional Frequency Reuse (AFFR) scheme for multicell IEEE 802.16e system. The AFFR at ASN-GW decides the assignments of subcarriers to BSs based on interference cancellation criteria. Our scheme is adaptive and makes efficient usage of the available radio resources. We also study the effect of the choice of major system design parameters such as the predefined SINR threshold for Fractional Frequency Reuse FFR zone, and ICIC_PERIOD on the overall system performance. We also study the effect of the choice of the scheduling algorithm at BS on the overall system performance. Simulation results show that the choice of AFFR algorithm at ASN-GW and the scheduling algorithm at BS both have deep effects on system performance. From the simulation and comparing our scheme with other schemes it is evident that our scheme improves the performance for different system design parameters.

REFERENCES

[1] Tarhini, C., and Chahed, T., “AMC-aware QoS Proposal for OFDMA–based IEEE 802.16e WIMAX System”, in Proc. of IEEE GLOBCOM 2007.

[2] Kwon, T., Lee, H., Choi, S., Kim, J. and Cho, D., “Design and Implementation of a Simulator Based on a Cross-layer Protocol between MAC and PHY Layers in WIBRO Compatible IEEE 802.16e OFDMA System”, IEEE Comm. Magazine, Dec. 2006, pp. 135-146.

[3] Lee, W., Lee, B., Bok, K., and Bahk, S., “An OFDMA-based Next Generation Wireless Downlink System Design with Hybrid Multiple Access and Frequency Grouping Techniques”, Journal of Communication and Network, Vol. 7, No. 2, June 2005.

[4] Li, G., and Liu, H., “Downlink Radio resource allocation for multi-cell OFDMA system”, IEEE Trans. on Wireless Communication, Dec. 2006, pp. 3451-3459.

[5] Li, J., Kim, H., Lee, Y., and Kim, Y., “A Novel Broadband Wireless OFDMA Scheme for Downlink in Cellular Communication”, in Proc. of IEEE WCNC 2003, New Orleans, Mar. 2003.

[6] Gault, S., Hachem, W., and Giblat, P., “Performance Analysis of an OFDMA Transmission System in a Multicell Environment,” IEEE Trans. on Communications, Vol. 55(4), pp.740 – 751, April 2007.

[7] Tarhini, C., and Chahed, T., “On Capacity of OFDMA-based IEEE 802.16 WIMAX Including Adaptive Modulation and Coding (AMC) and Inter-cell ”, in Proc. of IEEE LANMAN 2007 Princeton, USA.

[8] Kwon, M., Lee, W., and Lee, B., G., “Low-overhead Resource Allocation for Load Balancing in Multi-cell OFDMA System”, in Proc. of IEEE VTC 2005, pp. 3063-3067, June 2005.

[9] Chan, P., W., Lo, E., S., V., Lau, K., Cheng, R., S., Letaief, K., B., Murch, R., D., and Mow, W., H., “Performance Comparison of Downlink Multiuser MIMO-OFDMA and MIMO-MC-CDMA with Transmit Side Information Multi-Cell Analysis,” IEEE Trans. on Wireless Communications, Vol. 6, No. 6, pp. 2193-2203, June 2007.

[10] IEEE WirelessMAN 802.16 Group, “Draft IEEE Standard for Local and Metropolitan Area Networks. Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems,” IEEE P802.16e/D12, Oct. 2005.

[11] Andrews, J., G., Ghosh, A., and Muhamed, R., “Fundamentals of WIMAX: Understanding Broadband Wireless Networking”, First Edition, Prentice Hall, Feb. 2007.

[12] IT++ online documentation: http://itpp.sourcefroge.net/.

[13] Ryu, S., Ryu, B., Seo, H., and Shin, M., “Urgency and Efficiency Based Packet Scheduling Algorithm for OFDMA Wireless Systems”, Proc. of IEEE ICC, Vol. 4, pp. 2779-2785, May 2005.

[14] Shoukry, S., M., Elsayed, K., Elmoghazy, A., and Nassar, A., “Utility Based Channel Aware MIMO Downlink Scheduling in IEEE 802.16e Broadband Wireless System”, in Proc. of the 6th ICEENG, May 2008.