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A NEW STATIC RESOURCE AND BANDWIDTH UTILIZATION APPROACH USING WIMAX 802.16E FRACTIONAL FREQUENCY REUSE BASE STATION

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ABSTRACT

This paper proposed a new Static Resource Assignment (SRA) approach to enhance resource and bandwidth utilization in traditional Fractional Frequency Reuse (FFR) WiMAX Base Station (BS) which widely used in cellular network deployment to overcome the inter-cell interference. The new SRA FFR efficiently tackled the wastage of resources and bandwidth in traditional FFR. The work aimed to enhance the resource exploitation in the downlink subframe of WiMAX BS by using Partial Usage of Sub-channel (PUSC) mode and Orthogonal Frequency Division Multiple Access (OFDMA). Four cases were designed modeled as a trade-off study to specify the best way of exploiting BS resources in traditional FFR technique. Quantitative measurements (Case 1 and Case 3) illustrated that the SRA FFR model had an advantage over traditional FFR technique in various metrics, where the study concluded with two optimal solutions: The number of served users and slots utilization are reached to 87.77% and 85.89% respectively of the full DL subframe capacity when Case 3 is considered. In contrast, the data rate (8.611 Mbps), subcarrier efficiency (3.210 b/subcarrier/burst), and spectral efficiency (1.395 bps) were improved more when Case 1 was applied. The spectral efficiency increased more than twice in SRA FFR that due to exploitation all the available BW in DL subframe. The new SRA FFR succeeded in solving the problems related to user's rejection as a result of a lack of resources and inefficient use of the bandwidth in cellular network. Therefore it can be considered a strong candidate in cellular networks deployment.

Keywords: *Bandwidth Utilization, FFR, Resource Utilization, Static Resource Assignment (SRA), WiMAX*

1. INTRODUCTION

High speed internet connection is required to satisfy users' demand for modern E-applications of these days. WiMAX and LTE are two kinds of high speed broadband wireless communications. WiMAX emerged with fixed (802.16-2004) [1] and mobile (802.16e-2005) [2] versions. Both versions of WiMAX use Orthogonal Frequency Division Multiplexing (OFDM) as a basic technique for modulation whereas mobile version uses OFDMA scheme. OFDMA is a multiple access scheme, where users' data (slots) can be managed in time domain (OFDM symbols) and frequency domain (sub-channels) [3]. A slot is the minimum data allocation unit that accommodates user data. The slot may span 1 subchannel in frequency domain and 1 or more OFDM symbols in time domain [3]. Group of slots sharing the same channel condition called burst, each burst defined by profile or so called burst profile [4]. The burst profile contains information such as modulation and coding type [4]. However, OFDMA assists in managing users' data in the DL subframe in a flexible manner to enable WiMAX base station to support mobile users. 802.16e uses sub channelization as a channel access method where the subcarriers are divided into a number of sub-channels [3]. The number of subcarriers in each subchannel depends on the subcarrier permutation type. There are two types of subcarrier permutations, distributed and adjacent [5]. In adjacent permutation, the subcarriers are allocated in sequence order in the sub-channels, whilst in distributed permutation the subcarriers are randomly allocated in the sub-channels. Adjacent Mapping of Sub-Carriers (AMC) or band-AMC is a type of adjacent subcarrier permutation, while Partial Usage of Sub-Channels (PUSC) and Full Usage of Sub-Channels (FUSC) are types of distributed subcarriers permutation [5]. However,

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the definition of slots varies depending on the type of permutation. In PUSC, the slot occupies one sub channel in frequency domain and 2 OFDM symbols in time domain [2].

WiMAX base station can be deployed in cellular network to increase the cell coverage area and capacity. The inter cell interference (ICI) is a major problem in cellular network. ICI occurs as a result of using the same frequency band by the neighbouring base stations, which affects the signal quality of cell edge users [4]. Network designers found many solutions to overcome the ICI problem, some of these are: frequency planning, sectoring, and Fractional Frequency Reuse (FRF) [6].

Frequency planning means dividing the available Bandwidth (BW) by the number of cells in the grid, where the division of bandwidth called Frequency Reuse factor (FR) [7]. If FR equal to 1, then all the available BW is reused in every cell in the grid as in Figure 1(a).

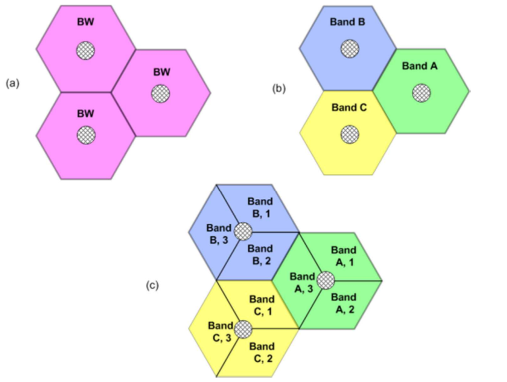

Figure 1: Frequency planning schemes, (a) FR of 1, (b), FR of 3, (c) Sectoring

In FR of 1, high throughput can achieved but cell edge users suffer from high ICI which leads to shrink the cell coverage area [7]. Another solution is to divide the BW by 3 such as in Figure 1 (b). When FR equal to 3, the impact of ICI will be less since the effect of same channel BW is far away which leads to improve the signal strength of cell edge users, but at the cost of losses 2/3 of the BW in each cell [7]. However, if sectoring is used as in Figure (1c), then the impact of ICI will be much less but again the BW is divided by three in each cell [8]. Though, in sectoring the signal-to-interference plus noise ratio (SINR) is increased, which enables the BS to use high modulation order and that would increase the cell throughput. Increase the cell throughput compensate for the loss in BW.

FFR is another technique used to control ICI in cellular network. FFR is approved by WiMAX forum to be used instead of frequency planning [9]. In FFR the cell coverage area is divided into two regions, cell centre region and cell edge region as shown in Figure 2 (a), and the DL subframe is partitioned into two parts called R1 and R3 zones as shown in Figure 2 (b) [9]. R1 zone used to transmit cell centre users' data, whilst R3 zone is used to transmit cell edge user data. The size of R1 and R3 depends on the number of OFDM symbols specified for each zone, it depends on the design issues. PUSC mode should be used in R3 zone to segment this zone into three segments named as A, B, and C [4]. Each segment occupies 1/3 of sub-channels to serve cell edge users.

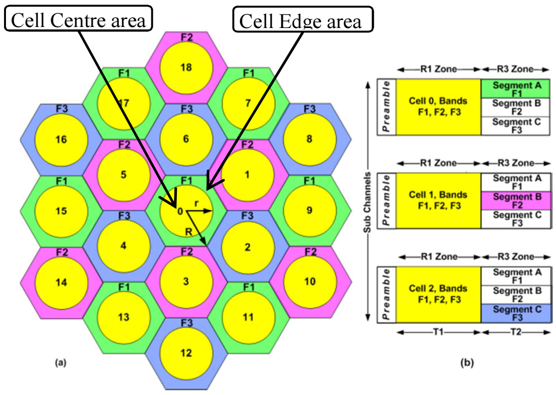

Figure 2: FFR deployment example, (a) frequency distribution, (b) DL subframe structure

The FR factor is equal to 1 in R1 zone, where all the available BW (sub-channels) is used in this zone, while FR factor is equal to 3 in R3 zone, where 1/3 of the BW (sub-channels) is used [9]. However, using 1/3 of the BW in each cell edge reduces the ICI effect since different frequency band is used in the edges of adjacent cells. In spite of losing 2/3 of the BW in each cell edge, FFR enhance signal strength of cell edge users which enable the base station to increase the cell capacity that by serving far-away users. FFR technique combines two types of frequency planning, FR of 1 and 3 as explained in Figure 1 (a) and (b), therefore there is no need for frequency planning when FFR is applied.

Many researchers have been considered FFR technique in their research, most of these researches was focusing on solving the problem of resource assignment in OFDMA system such as: improving base station data rate, cell coverage area, Quality of service (QoS), take accurate decision to serve users either in R1 or R3 zones by specifying suitable threshold value to distinguish between inner and outer users, and so on.

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The target of the study presented by [10] is to find an optimal frequency planning scheme. Three models are implemented: FR of 1, FR of 3, and FFR, these models are applied using two different modes namely: same permutation base and different permutation base. In the study, different ratios of the cell centre area have been examined to find the optimal ratio (i.e. optimal inner area radius) that gives the highest data rate in FFR model. At this ratio, the performance of the FFR is compared with the other two models in terms of outage probability and network throughput. The outcomes of the study show that the outage probability of FR of 1 becomes unfeasible for both permutation modes, whereas only the same permutation mode is feasible for FR of 3. Meanwhile, the highest system throughput is achieved by FFR technique. Therefore the study confirms that FFR is an important tool can be used in cellular network, since it controls the ICI effect. However, another study [11] considers the radius of the inner area, this study specifies the best radius for the cell centre area to guarantee best performance of FFR. The results showed that when the radius of the inner zone is reduced it will increase the number of data bits that can be carried by the subcarriers which leads to enhance the performance of FFR compared to FR of 1.

The problem of resource assignment presented by [12, 13], where SINR as a metric is used to decide which zone will assign resources to a user. The studies considered three schemes: FR of 1, FR of 3 (sectoring), and FFR technique. In [13] the highest throughput is achieved by FR of 1 compared to FFR and FR of 3, but the coverage area is better enhanced in FFR than that in FR of 1, while it achieved almost same coverage area of FR of 3. However, the authors in [12] considered R3 zone size to increase the cell coverage area where several zone sizes were examined. The results showed that the FFR improves throughput and coverage area, whilst it achieves almost same coverage area compared FR of 3.

Distance threshold is used instead of SINR to distinguish between users of cell centre and cell edge [14]. The optimal distance threshold was found by [15], in conjunction with two types of scheduler namely Round Robin (RR) and maximum SINR (MSINR). The throughput in the proposed FFR with optimal distance is better enhanced than that in traditional FFR (fixed threshold). Moreover, the results prove that when the number of served users is increased it will increase the throughput while the optimal distance threshold is decreased (cell centre radius). Away from SINR and distance thresholds, a new approach called load balance is proposed by [16], where two metrics are used to allocate resources which they are: channel condition and the available free slots (resources) in the target zone. Three schemes are applied in this work known as: distance based, SINR based, and load balance based. However, in order to evaluate the performance of these three schemes, several types of frequency reuse factors are examined, which requires changing the zones size. The resource allocation in SINR and distance schemes show poor performance compared to the load balance model, where the former two schemes could not efficiently assign resources when the zones size are changed. The results demonstrate that the load balance superior the SINR and distance schemes in terms of blocking probability and achievable bit rate, hence the system in load balance tries efficiently to utilize the available resource. Similarly improvement presented by [17], where the three former schemes are considered (distance, SINR, and load balance). The channel status is measured based on ray-tracing propagation model which make the channel estimation close to reality. The load balance improves the performance of WiMAX BS in terms of blocking ratio and offered bit rate.

Most of the works done in the previous survey are focused on improving the resource utilization in FFR technique by considering the existing resource in R1 and R3 zones. However, the resource wastage in R3 zone did not considered in their work. FFR technique uses one segment in R3 zone to ensure different frequency band in each cell edge. There are three segments in R3 zone named as A, B, and C (see figure 2 b). FFR uses 1/3 of the available sub-channels (segment A) in every base station, which result in losing 2/3 of the available sub-channels (segments B and C) in R3 zone in each DL subframe. This drawback in FFR leads to a decline in performance such as: reduces the number of served users, wastage in resources, decreases data rate, and spectral efficiency. In this work, segments B and C are considered in order to tackle this drawback, where new FFR technique is designed and model named as Static Resource Assignment (SRA) FFR. The new SRA FFR aims to increase the number of served users, resource utilization, data rate, and spectral efficiency.

2. NEW SRA FFR TECHNIQUE

In this section the proposed network design and system parameters are presented first and then SRA FFR model is explained.

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This work intended to utilize resources in segment B and C (segments BC). To use these segments, firstly, the SINR values of users belong to cell centre and cell edge need to be analysed, and secondly determine when and where these segments should be used. Follow the same notation presented in [18, 19], the SINR against distance is shown in Figure 3. Figure 3 shows four SINR lines, which are: existing FFR technique named as traditional FFR (Trd. FFR), proposed SRA FFR (Pro. FFR), segments BC (Seg. BC), and frequency reuse of 1 (FR of 1). It assumed that the output of SINR per model in Figure 3 is as result of user interaction with his base station when he moves on the X-axis from the BS toward the cell border. However, in Pro. FFR all the sub-channels in R3 zone are used, in Seg. BC only sub-channels of segments BC are used, and in Trd. FFR, only sub-channels of segment A are used. This difference in the use of sub-channels affects the interference calculation. Generally speaking, the signal strength of a user moving away from the BS decreases with distance as result of path loss effect [20]. This why the four SINR lines in Figure 3 go down when the distance increases. The SINR value of FR of 1 reaches to 0 dB after 800m, because the interference from other base stations who using the same frequency band are greatly noticeable in the cell border. In contrast, the SINR values of Trd. FFR and Pro. FFR are increased after 635m. The 635m corresponding to 5 dB, where it represents a SINR threshold used to distinguish between cell centre users and cell edge users. Importantly, the SINR value of segments BC shows slightly higher response than that in Trd. FFR and Pro. FFR. The reason is, users who use sub-channels of segments BC are under interference effect as result of using sub-channels of segments BC by other users in the neighbouring cells at the same time, but these users are not interfered with users belong to segment A, since the sub-channels of segment A are orthogonal to the sub-channels of segment BC. Therefor segments BC shows highest level of SINR compared to other models. The SINR response of segments BC show good response till 635m, where at 635m the SINR value equals to 5.3 dB. If a threshold of 5 dB is used to serve users in segments BC, then segments BC can be used to serve users in the cell centre area, since these users have enough SINR levels, which enable the BS to serve them. According to the selected threshold (5 dB), the service area of the cell centre (R1 zone and segments BC) is from 36m to 635m, whilst the service area of cell border (R3 zone) is from 653m to 1000m. The 36m is the minimum allowable distance to serve users near the BS [21]. Consequently, segments BC can be used to serve users located at cell centre area during time slots (OFDM symbols) of R3 zone. In addition, the response of traditional FFR and proposed FFR in Figure 3 are identical in the area between 36m and 365m. The reason is using segments BC to serve users in the cell centre area will not affect the normal operation of traditional FFR, since these users are served in time slot of R3 zone which is different from that in R1 zone.

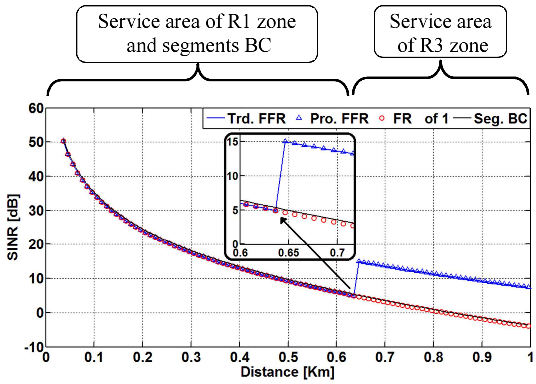

Figure 3: SINR against distance from BS (for FFR 5 dB Threshold is used)

The work considers 19 cells distributed adjacent to each other to form the proposed network, each cell contain one BS and all BSs in the network use FFR technique as shown in Figure 2 (a). The proposed system parameters are listed in Table 1, and most of these parameters are defined in [21]. It assumed all BSs use PUSC mode to enable partitioning R3 zone into three segments A, B, and C. As well as, it assumed that all the base stations are perfectly synchronized to avoid inter-zone interference between base stations.

In order to run the proposed SRA FFR model, a scenario of resource allocation per user is suggested. First, the zones size is specified and then user data load is defined. The number of OFDM symbols in WiMAX frame is 48 symbols. One of these OFDM symbols is used as a gap between the DL and UL subframes. The rest 47 symbols are used by the DL and UL frame parts. In PUSC the slot occupies two OFDM symbols in the DL direction, whilst it spans three OFDM symbols in the UL direction. Therefore, the 47 symbols should be divided as a multiple of two in the DL subframe and as a multiple of three in the UL subframe. Consequently, the number of OFDM symbols is assumed to be 29 in the DL and 18 in the UL. It should be pointed that the first three OFDM

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symbols in the DL subframe are used for frame control issues (overhead). The first OFDM symbol is used by Frame Control Header (FCH) to carry frame control messages such as frames synchronization. However, the next two symbols are used by the DL-MAP and UP-MAP. These two MAPs are used to inform DL users and UL users about their data locations in DL and UL subframes, respectively. The rest 26 symbols in the DL subframe are used by R1 and R3 zones. If 10 of these are used in R3 zone then R1 zone will use 16 OFDM symbols. The proposed DL subframe is shown in Figure 4.

Table 1: Proposed System Parameters

Item Descreation	Value
Number of cells per cluster	19
Operating Frequency	2500 MHz
Bandwidth (BW)	10 MHz
Permutation Mode	PUSC
FFT Size	1024 subcarriers
Subcarrier Frequency Spacing	10.94 kHz
Useful Symbol Time	91.4 μs
Guard Time	11.43 μs
G, is the ratio of cyclic prefix	1/8, for 10MHz BW
OFDMA Symbol Duration	102.9 μs
Number of OFDM Symbols	48 (in frame of 5ms)
Sampling Factor	28/25, for 10MHz BW
Frame Duration	5 ms
Number of slots per two successive OFDM symbols	30
Number of Subcarriers per Slot	48
Cell Centre Radius (r)	635m
Cell Border Radius (R)	1000m
Traffic Ratio (DL/UL)	29/18
Users Distribution	Random per Drop
Duplexing Mode	TDD
Adaptive Modulation and Coding	Enable
DL Power Control	Switched off

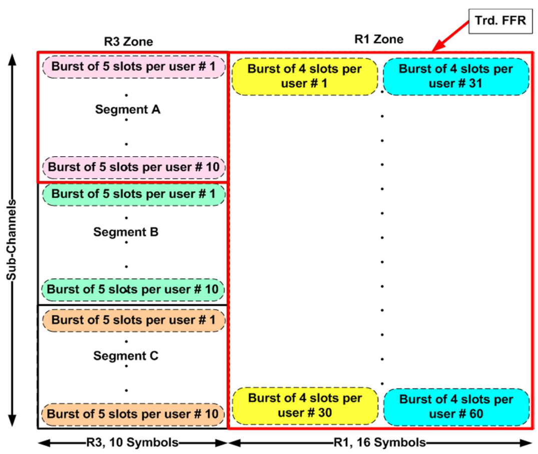

Figure 4: Proposed DL subframe structure without overhead

In 10 MHz system bandwidth using PUSC mode, the number of sub-channels is 30, 10 of these are used in R3 zone (segment A) whereas all the 30 sub-channels are used in R1 zone. However, knowing the slot dimensions (1 subchannel X 2 OFDM) and the zone dimensions (sub-channels X OFDM symbols) then the number of slots per R3 and R1 zones can be calculated. In reference to the proposed DL subframe in Figure 4, each row of each segment in R3 zone represents 5 slots and each row in R1 zone represents 8 slots. Then, the number of slots in R1 zone equals 240, in R3 (segment A) equals 50, and in segments BC equals 100. Theoretically, traditional FFR can provide 290 slots whereas this number of slots can be increased to 390, when segments BC are considered. However, If the burst occupies 5 slots in R3 zone and occupies 4 slots in R1 zone, and the burst can serve one user, then segment (A) can serve 10 users and segments BC can serve 20 users, with data load of 5 slots per user, while R1 zone can serve 60 users with data load of 4 slots per user. Theoretically, traditional FFR (indicated by a red bold line in Figure 4) is able to serve 70 users, and the proposed SRA FFR is able to 90 users.

The SRA FFR model intended to utilize untapped resources in traditional FFR (segments BC), in order to take maximum advantage of these segments, four cases are considered. The cell center area is divided into four coverage areas named as Case 1, Case 2, Case 3, and Case 4, where each case represent segments BC with different coverage area. The Interest that can be obtained from dividing the cell center area into four cases is to identify the case that maximizes the performance of SRA FFR. The proposed cell layout is plotted in Figure 5.

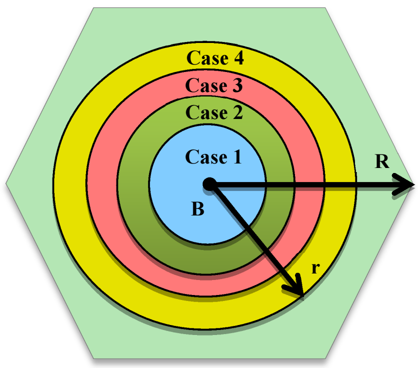

Figure 5: The proposed SRA FFR Cell layout

The cell center radius (r) is equal to 653m, and the cell radius is equal to 1000m. The cell center area is divided into 4 coverage areas (cases)

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and the radius of each case depends on the selected SINR threshold value. The resource assignment rules are defined in Table 2, where each case has been defined by two SINR thresholds, which enable each case to use two types of Burst Profiles (BP). A threshold of 5 dB is used to distinction between cell centre users and cell edge users.

Table 2: Resource Assignment Rules per Case

Case No.	Segment B		
	Minimum SINR [dB]	Burst Profile Type (MCS)	
Case 1	19.9	BP#8	46-QAM, (5/6)
Case 2	16.9	BP#6	46-QAM, (2/3)
Case 3	12.7	BP#4	16-QAM, (3/4)
Case 4	6.3	BP#2	QPSK, (3/4)
	Segment C		
Case 1	18	BP#7	46-QAM, (3/4)
Case 2	13.8	BP#5	46-QAM, (1/2)
Case 3	8.6	BP#3	16-QAM, (1/2)
Case 4	5	BP#1	QPSK, (1/2)

The BPs in Table 2 contains the type of Modulation and Coding Scheme (MCS) that used according to specific channel condition. The MCSs types are selected based on the modulations and SINR thresholds used by [17], These SINR thresholds forms 8 types of BPs (or MCSs) as listed in Table 3. The SINR thresholds in Table 3 ensures that the bit-error rate less than 10^{-6} when Convolutional Turbo Coding (CTC) is used.

Table 3: SINR Threshold for Different MCS Types

Profile No.	MCS Type		Bits per Sub-carrier	Minimum SINR Threshold [dB]
BP 1	QPSK	1/2	1	2.9
BP 2		3/4	1.5	6.3
BP 3	16-QAM	1/2	2	8.6
BP 4		3/4	3	12.7
BP 5	64-QAM	1/2	3	13.8
BP 6		2/3	4	16.9
BP 7		3/4	4.5	18
BP 8		5/6	5	19.9

The test period is set to 100 attempts, where users are randomly distributed in the Cartesian coordinate system (X-axis and Y-axis) in each attempt. The users' locations are random variables that follow the uniform distribution, and the random distribution of users gives the sense of mobility.

The SRA FFR model requests users to send their SINR through the REP-REQ control message, and users are respond by sending REP-RSP control message carrying the required information [3]. Based on the reported SINR the resources are assigned either by R3 zone or R1 zone. If the reported SINR < 5 dB, then user location is in the cell edge and the resources are assigned to this user by R3 zone as long as there are enough slots to serve new user. In return, if the reported SINR ≥ 5 dB, then user location is in the cell centre and the resources are assigned to this user by R1 zone as long as there are enough slots to serve new user. However, segments BC are used when there are extra users in the cell centre area, and these users need services. If the reported SINR ≥ 5 dB and R1 zone fully filled with users, then the new user will be served in segments BC. In other words, when the number of users in the cell centre area exceeds the capacity of R1 zone, then the extra users are served by segments BC. Going like this, the benefit of using these segments can be observed easily, since it increases the number of served users and the benefits that ensue.

3. SIMULATION RESULTS AND DISCUSSION

In this section, firstly, the performance of the four cases is evaluated and upon the evaluation a suitable case is chosen. The results discussion of the four cases is to make decision to choose the case that greatly improves the performance of the WiMAX BS. Secondly, the performance of SRA FFR is compared with traditional FFR in order to show the improvement caused by the proposed SRA FFR.

3.1 Performance Analysis per Cases

The performance of the four cases is different according to the characteristics of each case. The case characteristics are defined as: number of served users (active users) in each case, the used MCS in each case, and the achievable data rate. The response of these three metrics is different according to the characteristics of each case. The performances of these cases are evaluated as follow:

3.1.1 Based on Active Users

Users are randomly distributed in the cell coverage area, and the number of users located in each case depends on the case coverage area. The SINR thresholds mentioned in Table 2 are used to host users into particular case, and these thresholds

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lead to different areas of coverage. Therefore the number of active users in each case is different as shown in Figure 6. According to the proposed design of SRA FFR, segments BC can serve a maximum of 20 users. Case 3 and 4 can serve more number of users than Case 2 and 1. It is clearly that the population density in coverage area of the former cases is higher than that in latter cases. However, all the cases lose some users since they fall outside their coverage area. The number of users located outside the coverage area of Case 2 is more than the other cases while this number is less in Case 1.

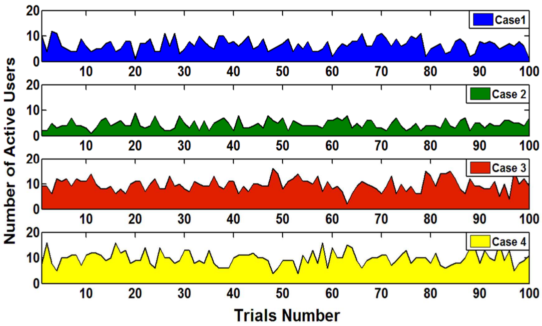

Figure 6: Number of active users per case

3.1.2 Based on Subcarrier Efficiency

Subcarrier efficiency represents the aggregate number of data bits carried by the subcarriers in each burst normalized by the total number of bursts in the intended zone or segment [22]. The normalized subcarrier efficiency (Kr_E) can be obtained as follows.

$$Kr_E\,(M) = \frac{1}{\alpha\omega} \sum_{u=1}^{\alpha(M)} \sum_{j=1}^{\omega(M)} Cr_{u,j}\,(M)\, B_{u,j}\,(M) \quad (1)$$

$$where\ M \in \{R1, R3_A, R3_{BC}\}$$

where, α is the number of active users in the target zone or segment (M), Cr denotes the code rate type, and B is the number of data bits carried by a subcarrier, which corresponds to a particular modulation type. ω is the number of subcarriers reserved for a specific user load, and equals (β* Kr_{slot}), where β is the number of slots per user, and Kr_{slot} is the number of subcarriers per slot. Note that the burst has been defined as serving one user with a specific load (ω= β*Kr_{slot}) as mentioned in Section 2. Therefore, (αω) represents the number of allocated (used) bursts in the target zone or segment, and the units of Equation (1) can attribute to per burst. M indicates the frame part type in the DL sub-frame, and may equal to R1, R3 (segment A), or segments BC.

The MCS used in each case depends on the SINR threshold. Case near the BS such as Case 1 uses the highest MCS whereas Case far away from the BS such as Case 4 uses the lowest MCS. Figure 7 depicts the subcarrier efficiency of segments BC in the four cases. Case 1 uses 64-QAM with 5/6 coding rate, and 64-QAM with 3/4 coding rate, as result of small path loss. Therefore, the subcarriers in Case 1 can carry more data bits than the other cases (maximum 5 bits and minimum 4.5 bits per subcarrier). This interpretation can be repeated for the remaining cases. For example, the SINR thresholds of Case 3 allow the use of modulation order of 16-QAM with 3/4 coding rate, and 16-QAM with 1/2 coding rate. Thus, it holds less number of data bits within its subcarriers compared to Case 1 (maximum 3 bits and minimum 2 bits per subcarrier) as revealed in Figure 7. Consequently, it makes sense that the case which carrying more data bits can produce highest data rate as shown in the following section.

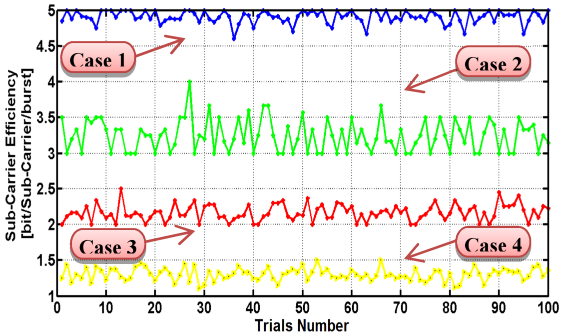

Figure 7: Subcarrier efficiency per case

3.1.3 Based on Data Rate

The WiMAX DL subframe data rate can be represented in two ways; Physical (PHY) data rate and MAC data rate [5]. The PHY and MAC data rate of the DL subframe can be obtained by using the following equations [23, 24]:

$$Dr_{PHY} = \frac{Kr_{OFDM} * B}{T_S} \quad (2)$$

$$Dr_{MAC} = \frac{Kr_{slot} * \gamma * N_b * \left(N_{OFDM}^{DL} - N_{OFDM}^{OH}\right)/2}{T_f} \quad (3)$$

herein, Kr_{OFDM} and Kr_{slot} are the number of data subcarriers per OFDM symbol and slot, respectively. γ represents the number of slots in two successive OFDM symbols (required for PUSC mode). N_{OFDM}^{DL} indicates the number of OFDM symbols in the DL sub-frame, and N_{OFDM}^{OH} indicates the number of OFDM symbols allocated for control messages (overhead). T_f is the WiMAX frame duration time which equals ($T_S * S_{frame}$), where Ts

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is the frame duration time, and S_{frame} is the number of OFDM symbols in the WiMAX frame. Finally, the number of data bits per subcarrier N_b, can be obtained by using Equation (4) [23].

$$N_b = Cr \log_2(Q) \qquad \text{bits/subcarrier} \qquad (4)$$

here, Q is the number of points in the constellation for a particular modulation, and Cr is the code rate.

Equation (3) can't be used to calculate the MAC data rate in FFR technique for the following reasons: in FFR the DL subframe is partitioned into two parts R1 and R3 zones, hence FFR serves users based on their location in the cell coverage area, and for each user location (or user signal strength), the BS use specific MCS type. Therefore, Equation (3) needs to be modified to match the FFR requirements as in Equation (5):

$$Dr_{MAC}(M) = \begin{cases} \dfrac{1}{Tf}\displaystyle\sum_{u=1}^{\alpha}\sum\nolimits_{i=1}^{\beta} N_b(u)\, P(u)\, Kr_{slot}(i) \\ for \quad P_{SINR}^{min}(M) \le SINR(u) \le P_{SINR}^{max}(M) \end{cases} \qquad (5)$$
$$where\ M \in \{R1, R3_A, R3_{BC}\}$$

where the parameters α, M, and β are same as in Equation (1), whereas Kr_{slot} and Tf are same as in Equation (3). However, N_b represents the number of data bits per subcarrier obtained based on the MCS type, and the MCS is selected according to the user channel condition $(SINR(u))$. The condition P (u) equals 1, if the active user SINR is within the zone or segment coverage area $(P_{SINR}^{min}\ and\ P_{SINR}^{max})$, otherwise it equals zero. The zone or segment boundaries are determined by defining suitable SINR thresholds as mansion in Table (3).

The average data rate per case is shown in Figure 8 when M equal to $R3_{BC}$ in Equation (5). Case that can carry more data bits in its subcarriers can produce the highest data rate as revealed by Case 1 in Figure 8.

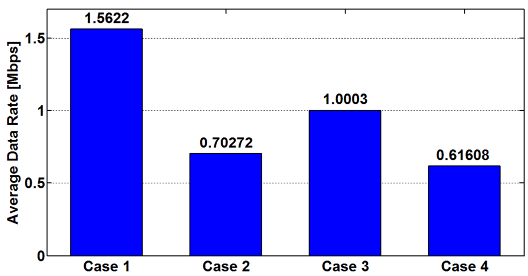

Figure 8: The Average data rate per case

Though Case 1 serves less number of users compared with Case 3 and 4 (see Figure 6), but it produces the highest data rate. The reason is Case 1 can carry more data bits in its subcarriers than that in other cases (see Figure 7). Despite of Case 4 serves more users than Case 2 and 1, and almost same number of users in Case 3, but it shows the lowest data rate among the four cases. This is because the subcarriers of Case 4 carry less number of data bits among all cases. However, the response of Case 2 and 3 are controversial. Case 2 holds more data bits than Case 3 but it shows less data rate than Case 3. The reason is Case 2 serves much less number of users than Case 3, so the number of active users can be considered as compensation factor lead to increase the data rate in a case.

The performance evaluation of the four cases can be summarized as follow: Case 1 records the highest data rate since it can carry more data bits in its subcarriers. On the other hand, Case 3 serves the highest number of users compared to other cases, and it records the second level of data rate. However, the achieved data rate in Case 2 and 4 do not help them much to excel on Case 1 and 3. Hence, the performance of Case 1 and 3 is better than Case 2 and 4. Consequently, in the rest of this work SRA FFR is presented through two models named as: SRA-Case1, where the outcomes of Case 1 are considered in the calculation, and SRA-Case3, where the outcomes of Case 3 are considered in the calculation.

3.2 Performance Comparison of Traditional FFR Versus SRA FFR

In this section, the performance of traditional FFR is compared with SRA-Case1 and SRA-Case3 models in terms of variety of metrics as follows:

3.2.1 Comparison Based on Frame Capacity

Frame capacity represents the amount of utilized resources (slots) and the number of served users in each model. The average number of active users and utilized slots per traditional FFR, SRA-Case1, and SRA-Case3 are shown in Figure 9.

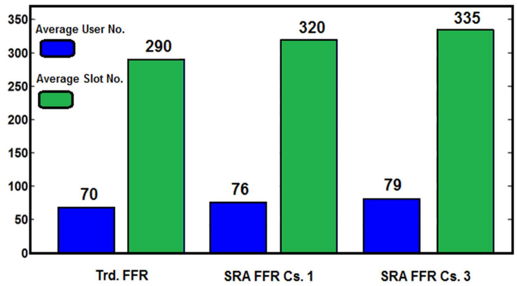

Figure 9: Average number of users and slots per traditional FFR, SRA-Case1, and SRA-Case3

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As explained in section 2, traditional FFR model can serve maximum of 70 users, where 10 users are served in R3 zone and 60 users are served in R1 zone. Traditional FFR works properly, where it able to serve the maximum number of users (70 users). The reason is related to the politics used to employ BC segments. Segments BC and R1 zone serve the same area (cell centre area) and segments BC starts to serve users when R1 zone fully exploited (filled with users). Besides, it seems that there are always a large number of users in the cell border. Therefore traditional FFR serve the maximum number of users since R1 and R3 zones are fully utilized. However, it makes sense that the system who can serve maximum number of users can exploit the maximum resources, where 290 slots are exploited in traditional FFR. In contrast, the number of active users is increased to 76 in SRA-Case1, since segments BC can serve 6 users as average value in this model. In contrast, the number of active users is increased to 79 when SRA-Case3 is applied. The different number of served users in Case 1 and 3 is related to the availability of users in each case.

The number of utilized slots is significantly increased when SRA FFR is considered. The load per user is proposed to be 5 slots in each segment in R3 zone and 4 slots in R1 zone. The resource utilization is increased [(320-270)/270 *100%] by about 18.51% in SRA-Case1, whilst it increased [(335-270/270)*100%] by about 24.07 % in SRA-Case3. These findings reveal the importance of using these segments in network deployment.

3.2.2 Comparison Based on Subcarrier Efficiency

The subcarrier efficiency of each part of the DL subframe is plotted in Figure 10.

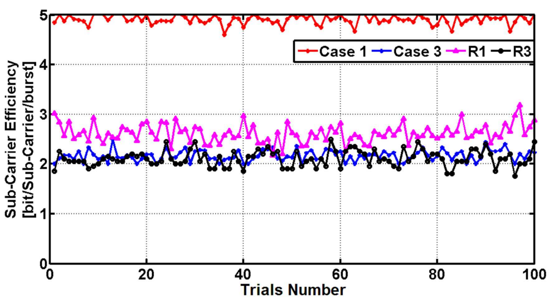

Figure 10: Subcarrier efficiency per DL subframe parts

R1 zone can serve 60 users in the cell centre area, and these users use 8 types of BPs or so called 8 types of MCSs, from high to low MCS. Thus, the subcarriers of R1 zone can carry more data bits than that in R3 zone and Case 3. R3 zone serves users far away from the BS (cell edge), and because of the path loss phenomenon these users use low MCS which result in less subcarrier efficiency. The same pervious interpretation can be repeated to analyse the response of Case 3, since it also serve users far away from the BS. The response of segments BC through Case 1 and Case 3 are the same as explained in Figure 7.

In order to simplify the analysis of Figure 10, the average subcarrier efficiency is presented in Figure 11, by averaging the output of Equation (1) by the number of trials. From an analytical point of view, it is necessary to compare the achieved subcarrier efficiency with the number of reserved slots per segments BC and R1 zone. However, R1 zone uses the largest amount of resources (240 slots) in the DL subframe whereas segments BC uses 100 slots as maximum capacity, and it represents (100/240= 0.416) 41.6% of the number of slots reserved for R1 zone. The subcarrier efficiency of segments BC in Case 3 represents (2.162/2.620=0.8251) 82.51% and in Case 1 represents (4.905/2.620=1.8721) 187.21%, of the subcarrier efficiency in R1 zone. These values of subcarrier efficiency show the effectiveness of using segment BC in the proposed design.

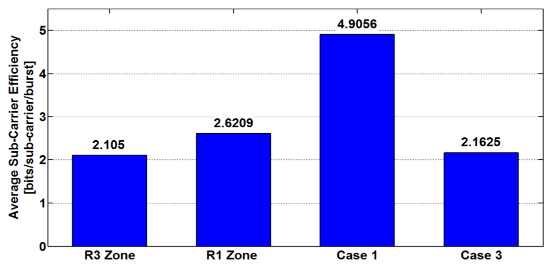

Figure 11: Average subcarrier efficiency per DL subframe parts

3.2.3 Comparison Based on Data Rate

Data rate response of traditional FFR, SRA-Case1, and SRA-Case3 are illustrated in Figure (12), as a result of collecting the outputs of Equation (5) for R1, R3, and segments BC. The two models of SRA FFR show higher data rate compared to traditional FFR, this due to the utilization of segments BC in the DL subframe. In Figure (12), SRA-Case1 achieves more data rate than that in SRA-Case3. The reason is SRA-Case1 serves users near the base station through segments BC, which enables this model to use high modulation order as result of low path loss. In contrast, SRA-Case3 serves users far away from the

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BS through segments BC, which force SRA-Case3 to use low modulation order as result of large path loss.

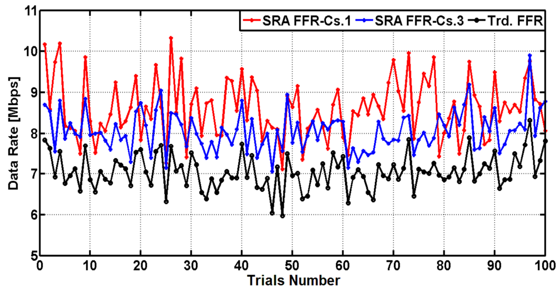

Figure 12: Data Rate Response per traditional FFR, SRA-Case1, and SRA-Case3

In order to highlight the interest of using SRA FFR, the average data rates for the previous models are shown in Figure 13, as a result of averaging the aggregate output of Equation (5) by the number of trials. The SRA FFR increases the data rate by about [(8.611-7.049)/ 7.049*100%] 22.15 % when Case 1 is considered and about [(8.049-7.049)/7.049*100%] 14.18 % when Case 3 is considered. These results reveal the importance of exploiting segments BC when using traditional FFR technique in WiMAX network deployment.

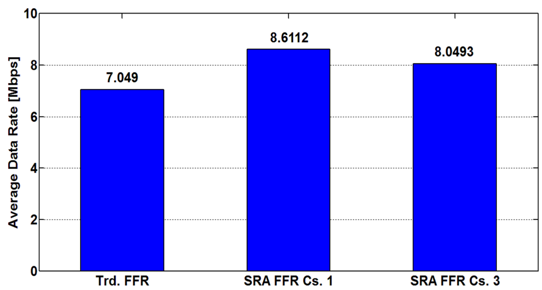

Figure 13: Average Data Rate per traditional FFR, SRA-Case1, and SRA-Case3

3.2.4 Comparison Based on Spectral Efficiency

The spectral efficiency indicates the efficiency of bandwidth utilization. If the aggregate data rate of DL users is divided by the Effective BW (EBW), then the DL spectral efficiency can be calculated such as in Equation [25] (6).

$$DL_{SE} = \frac{\sum_{i=1}^{U_{DL}} d_{DL}(i)}{EBW} \qquad (6)$$

Here, U_{DL} represents the number of active users that successfully served in the intended DL subframe, and d_{DL} is the achieved user data rate. The EBW denoted the share of BW that used by the DL subframe. Figure 14 shows the output of Equation (6) for traditional FFR, SRA-Case1, and SRA-Case3.

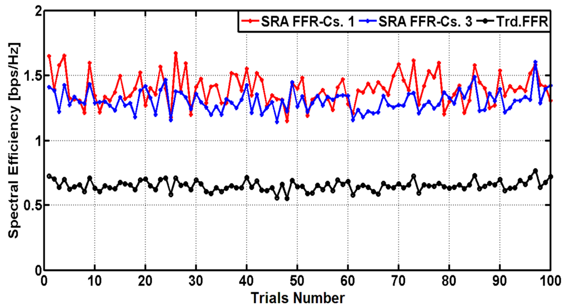

Figure 14: Spectral efficiency per traditional FFR, SRA-Case1, and SRA-Case3

The results of the three models in Figure 14 are directly proportional to the achieved data rate and the share of used BW. SRA-FFR uses all available sub-channels in R3 zone, unlike traditional FFR where only 1/3 of the sub-channels are used. Therefore, SRA-Case1 and SRA-Case3 increases the spectral efficiency more than twice than that in traditional FFR as revealed in Figure 15, where the average spectral efficiency is shown. SRA-Case1 achieves more spectral efficiency than that in SRA-Case3, since the former can achieve higher data rate than the latter. This improvement in BW utilization is important, since the available bandwidth in the markets is scarce.

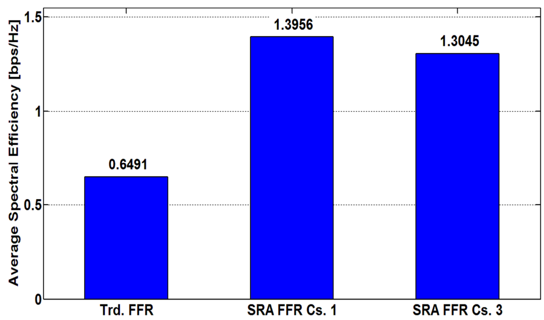

Figure 15: Average Spectral efficiency per traditional FFR, SRA-Case1, and SRA-Case3

As a conclusion, Table 4 shows the response of the three network deployment models traditional FFR, SRA-Case1, and SRA-Case3. It can be concluded from Table 4 that SRA-Case1 and SRA-Case3 enhance the performance of traditional

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FFR in terms of five metrics as result of using segments BC.

Table 4: Performance evaluation summary of Traditional FFR, SRA-Case1, and SRA-Case3

Metric type \ Model type	Trd. FFR	SRA-Case1	SRA-Case3
Users %	77.7	84.44	87.77
Slots %	74.35	82.05	85.89
Data Rate [Mbps]	7.049	8.611	8.049
Mean Sub-Car. Effici. [bits/Sub-Car./burst]	2.362	3.210	2.296
Average S. E. [bps/Hz]	0.649	1.395	1.304

Analysing the results in Table 4, SRA-Case1 records the highest data rate, sub-carrier efficiency, and spectral efficiency, since this model able to serve users near the base station through segments BC and these users have high SINR value which leads to increase the values of the previous three metrics. On the other hand, SRA-Case3 increases the number of served users and utilized slots, since segments BC in this model can serve more users and utilizes more resources than that in SRA-Case1. The calculation of the first two columns in table 4 is based on the full DL subframe capacity which they are 390 slots and 90 users. Nevertheless, the arithmetic mean of subcarrier efficiency in SRA-Case3 is little bit lower than that in traditional FFR. The reason is SRA-Case3 serves users far away from the BS in Case 3. According to the resource assignment rules mentioned in Table 2, Case 3 uses low modulation order and coding rate. It should be noted that the traditional FFR (R1 and R3 zones) work properly in the proposed SRA FFR, the utilization of segments BC did not affect the normal operation of traditional FFR, instead of it enhance the performance of traditional FFR.

4. CONCLUSIONS

Cellular network is used to increase the communication coverage area. However, the inter-cell interference between adjacent cells considered as a major problem occurs as result of using the same frequency band in neighbour cells. Network designers found different solutions to overcome the interference problem such as frequency planning and FFR techniques. Using the entire available frequency bandwidth in every cell enhances the utilization of bandwidth but at the expense of bad signal quality in the cell edge. Therefor FFR is used to enhance the signal quality of cell edge users. One of the drawbacks of FFR is the untapped resources in R3 zone, where only 1/3 of the available sub-channels are used to ensure frequency diversity in each cell border. This defect in FFR has been handled in this work, where the rest 2/3 sub-channels (segments BC) are exploited under new FFR model named SRA FFR. Four cases have been designed and modelled to use these sub-channels in segments BC. In addition, adaptive modulation and coding is used to select suitable burst profile according to user's channel condition. The simulation results demonstrate that Case 1 and Case 3 can be used to enhance the performance of traditional FFR. The outcomes of this work can be summarized as follow:

1) The proposed (SRA FFR) solves the problem of wastage in resource and BW in traditional FFR efficiently, where all the available resources and BW are used.
2) The proposed four cases enhance the performance of traditional FFR in different aspects, of these, Case 1 and Case 3 have the greater effect in improving the performance of traditional FFR, and therefore they are selected as they represent the desired solutions.
3) The new SRA FFR produces two optimal solutions:
   - If the target of the enhancement is to serve more users and utilize more resources, then Case 3 is the preferred choice.
   - If the target of enhancement is to increase the data rate and spectral efficiency, then Case 1 is the preferred choice.
4) Link adaptation was considered in the proposed design, where the interference power and noise are measured and used to assign resources in the DL subframe parts, as well as to select a suitable burst profile type.

The bandwidth and resources are always precious in cellular networks. The proposed approach contributes to the solutions of problems faced by cellular networks such as resource shortage and inefficient bandwidth utilization. Therefore, considering the proposed design in cellular networks enhance the performance of these networks.

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