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Enhanced Fractional Frequency Reuse (EFFR) Technique in WiMAX Cellular Network

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Abstract

WiMAX is a broad band high speed wireless communication system which use cellular network topology to deploy services to different subscribers. One of the major problems of deploying WiMAX base stations is the signal interference caused by neighboring cells which causes redaction in cell coverage area and capacity. The standard of WiMAX allows several methods to overcome the interference problems such as frequency planning and Fractional Frequency Reuse (FFR) technique. In this paper we propose new design for FFR in urban area to mitigate inter-cell interference and efficiently use the available network resources. The new FFR with coordination of two types of subcarriers permutation (PUCS and band-AMC) is presented to enhance system performance. The frequency diversity and user diversity are considered as tradeoff between the user's behavior and available resources, the resources are dynamically assigned to users to ensure best utilization of the available network resource.

Keywords: *WIMAX, network deployment, fractional frequency reuse, permutation technique.*

1. Introduction

The high demand for mobile applications and serves push the network designers to develop the wireless network i.e. more resources and transmission speed were used to satisfy the users demined. Worldwide Interoperability for Microwave Access (WiMAX), is the promises for such network, it is broadband wireless communication considered as alternative to Digital Subscriber Line (DSL).
IEEE issues many standards for past years, 802.16 families was one of these standards, two types of these mainly describe WiMAX which they are 802.16-2004 and 802.16e-2005 also known as fixed and mobile respectively.
WiMAX uses Orthogonal Frequency Division Multiplexing (OFDM) as a basic technique with development Orthogonal Frequency Division Multiple Access OFDMA introduced as new method give more flexibility in assigning resources to users especially mobile users with vehicle speed [1].
The concept used to transmit data is to fire multi orthogonal carriers carrying user's data with fixed space between them, the number of carriers depend on the used bandwidth. WiMAX can serve users in Line of Site LOS and Non Line of Site non-LOS condition which enables the base station to interact with different types of users like fixed, nomadic, and mobile. The 802.16e frame is divided in two parts DL-subframe and UL-subframe, figure (1) shows these two parts [2].

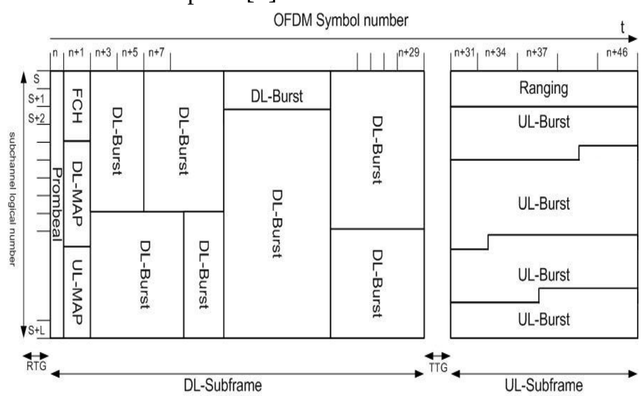

Fig. 1 WiMAX frame structure.

In WiMAX the frame can be mixed by two techniques, Frequency Division Duplexing FDD and Time Division Duplexing TDD, by using TTD the ratio between the DL to UL can be chosen more easily. The sub- channelization as channel access method used to specify user's recourses in frequency and time. The recourse allocated to users into two dimensions, frequencies which based on channel condition, and time which is decides the slot location in the frame. The number of slots is flexible to change according to the permutation mode used. There are two types of permutation modes that can be used: distributed and contiguous. The distributed mode enables the base station to allocate subcarriers per subchannel in random way, thus to take care of different users' channel condition, it suitable for mobile users, whilst contiguous locates subcarriers per subchannel in sequence order it almost used for fixed or nomadic users who their channel specifications are not change fast with time. Partial Usage of SubChannels (PUSC) and Full Usage of SubChannels (FUSC) are types of distributed subcarrier permutation; and Adjacent Mapping of Sub-Carriers (AMC) or band-AMC is a type of contiguous subcarrier permutation [3].

Adaptive Modulation and Coding (AMC) is one of WiMAX features used to enhance spectral efficiency, this feature evaluate each user channel condition and based on this evaluation a suitable modulation and code rate will be selected to transmit user's data. In practical, the Signal to Interference plus Noise Ratio (SINR) is measured at the user station and send it back to the base station through the Channel State Information (CSI) message, the base station then will use higher modulation and code rate order for high SINR such as 64 QAM 5/6, and will uses low modulation and code rate order for low SINR such as QPSK 1/2, in this way the number of error packets can be reduced and the spectral efficiency of particular user can be increased[1].

Cellular network suffering from inter cell interference ICI caused by using the same frequency band in the neighbor cells. One of the key aspects used by network designers are frequency planning and Fractional Frequency Reuse (FFR), the available bandwidth distribute through the neighbor cells to reduce the ICI. The ICI leads to decrease the cell coverage area, number of users per cell, and network throughput especially at the cell edge. Therefore, the aim at the proposed algorithm is to reallocate network resources according to the network users' type such as fixed or mobile users, also this algorithm maximize the usage of the available network resources.
The objectives of this paper are:

1- To improve the cell coverage area by reducing the inter-cell interference (ICI), this leads to increase the coverage area and cell capacity as well as network throughput.
2- To maximize the utilization of the available recourse at the base station.
3- To maximize the system throughput by utilizing channel fluctuation.

Inter-cell interference mainly affects the performance of users at the cell edge, with high level of interference the packet loss will be increased, which requires retransmission technique. The redundancy of retransmission of the lost packets causes reduction in network performance. The main contributions of the proposed work are as follows:

1- Driven an algorithm to use Fractional Frequency Reuse (FFR) which minimizes the inter-cell interference (ICI).
2- Modify the proposed algorithm to reallocate network resources based on user mobility.
3- Modify the proposed algorithm to increase user throughput based on link adaption.

The rest of this paper is organized as follows: section II briefly describes frequency planning and alternative fractional frequency reuse followed by related work in section III, network architecture and newly proposed frame structure are presented in section IV and V respectively, finally conclusions are discussed in section VI.

2. WiMAX Base Station Deployment

The growth of base stations deployment in wireless communication need more care to achieve good performance, many parameters effect the wireless environment such as inter sample interference (ISI), multi path, inter cell interference (ICI), noise, the height and power of antenna, and so on. Frequency planning and Fractional Frequency Reuse FFR are methods used to come over the ICI problem.
Frequency planning means the ability of using different frequencies bands in neighboring cells that by using different Frequency Reuse Factor (FRF), if the FRF equals to one as in figure (2a), all the available bandwidth will be used per one cell but users at the cell edge suffering from high interference. When FRF equals to three as in figure (2b), the users at the boundaries surfers less ICI due to the fact that different frequency band used in each cell which will reduce the throughput compared to case in figure (2a). The case in figure (2c) uses sectoring, it enhances the ICI match batter but again with fewer throughputs than the case in figure (2b), when the ICI reduced by sectoring, the SINR can be increased, this will end-up by using high modulation order and this will compensate for the loss in bandwidth [2].

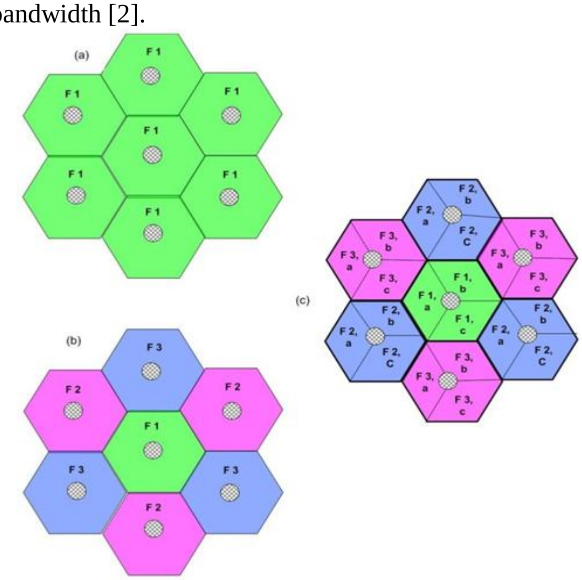

Fig. 2 Frequency planning pattern.

Fractional Frequency Reuse (FFR) also used to minimize the impact of ICI, the cell area is divided by two, inner area and outer area, and this can be implemented by dividing the DL frame into two zones. Zone implementation is supported by 802.16 families. In FFR the first zone (Z1) should use PUSC mode because this mode allows for partitioning the zone to three main parts or segments, each segment used in one of three cell edge as illustrated in figure (3). The idea behind segmentation is that each cell will use different frequency band in the cell edge, therefore this zone will serve users at the boundary. The second zone (Z2) used to serve users in the inner area only, these users can use all available bandwidth as long as they are far away from the cell edge, in this arrangement FFR can mitigated the ICI between adjutant cells[2].

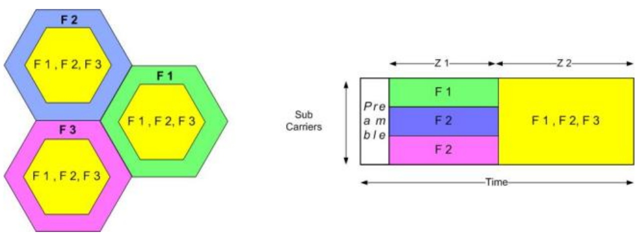

Fig. 3 Fractional frequency reuse pattern.

3. Related work

Cellular network deployment is related to several parameters such as: BS cost, coverage area, frequency distribution, cell edge interference, capacity and throughput. These parameters have been investigated by researchers in different ways, in [4] FFR impact was studied in WiMAX network, it found that when FFR equals to 3, it will reduces the ICI at the cell edge with respect to pure-reuse equals to 1, which leads to increase the coverage area and enhances the throughput according to alternative sectors method with pure-reuse equals to 3. Authors in [5] address two different networks topology (cellular topology and transmission topology), in terms of FFR and FRF of (1 and 3) respectively, the result shows that cellular topology is suitable to deploy WiMAX network in urban environment, on the other hand the transmission topology is better to deployed in sub-urban and rural area where the users density is low.
The FFR performance was investigated by [6] in terms of users zones allocation, three mechanisms of zone assignment were discussed, distance-base, SINR-base, and load balance technique. The new approach is to merge the SINR with load-balance, the user assignment was considered in per-load available and SINR; the merge of these two types enhanced the performance better than consider the distance or SINR individually. The system shows better bits rate when resources are balanced between zones. The Quality of Service (QoS) takes in account in zone allocation problem as in [7]. The service flow type and channel condition were measured in order to specify user zone location; zone switch algorithm was proposed to efficiently exploitation the resource available in DL-frame. It shows that the resources utilization is maximized while meeting the QoS demands. Others in [8] use sectoring technique and frequency reuse as new method to enhance 802.16j relay system. The relay function is to forward the base station signals farther than its coverage area. They exploit unused space in the frame that is caused by traditional relay implementation. The results show that the method introduces a significant increase in terms of spectrum efficiently and throughput at the base station.
Insufficient coverage area and high throughput requirements were solved by installing Femtocells as a relay to provide good indoor coverage area as in [9]. Femtocells installed within WiMAX base station coverage range, it enhances the indoor signal quality and capacity by meaning of high data rate per unit area.
Rural environment with low population density was presented by [10]. The FFR was used to divide the cell area into two regions to avoid interference; the outer cell region uses partial of the spectrum, while the inner area uses the full spectrum. In the inner area, the users are experience with different modulation order according to their distance from the base station and channel condition; high ordered modulation can be used near the base station. This arrangement shows better system throughput in both regions than the classical frequency reuse.

In the previous review, researchers were Interested in network deployment in term of FRF, FFR, sectoring, zone allocation, relays, and QoS as solutions to improve the cell coverage area and capacity. However zone selection per carrier permutation type upon user's behaviors in overlapped area did not discuss in their researches. In this paper we address this problem in the downlink sub-frame of WiMAX network, and furthermore zone resizing technique upon user's behaviors and available resource per zone are considered.

4. Network Architecture

WiMAX frame structure is divided into two parts UL sub-frame and DL sub-frame as shown in figure (1), separated by gap called Transmit Transition Gap (TTG) and two successive frames are separated from each other by gap called Receive Transition Gap (RTG). For example if the system parameters are 10 MHz bandwidth, 1024 FFTs size, 102.9µs OFDMA symbol, and 5ms frame length, then the total DL frame symbols number are 48, the DL to UL frame ratio assumed to be 29:18. PUSC mode can be used in the UL and DL sub-frame, it is mandatory to use in the first two symbols in the beginning of the each frame after the preamble, it also used to holds the FCH, DL-MAP and UL-MAP. In this mode 30 sub-channels are available; each sub-channel contains two slots with 48 data subcarriers and 8 pilots. These sub-channels are segmented into 6 groups; each two groups can be assigned to different sectors to avoid interference. PUSC distributes the carriers in random way in the sub-channel which allows using different subcarriers in adjacent sectors or cells, this leads to limit the chance to interfere with same slot time subcarrier at the neighbor sector or cell. Because the distribution of the subcarriers in the sub-channels is randomized, PUSC is a good choice for channel specifications that change fast with time such as mobile environment [11].

By using the same parameters, Adjacent Mapping of Sub-Carriers (band-AMC) mode can be used in UL and DL sub-frame which using bin with 8 data sub-carriers and one middle pilot, each six bins form a slot, the slot may occupy 1, 2, 3 or 6 symbols, in all cases the number of data subcarriers per sub-channel are 48. The maximum number of sub-channels can be formed in this mode is 96 within the available BW. This large numbers of sub-channels allows the base station to choose the best sub-channel to the users according to their channel condition. The subcarriers are allocated in sequence order in the sub-channels, in this context band-AMC requires stable channel condition, and hence it is better to be used with fixed or low speed (nomadic) users [1]-[11].

In both PUSC and band-AMC the sub-channel occupies 48 data subcarriers, the only difference between them are number of pilots, and symbol depth. The system may achieve higher throughput due to a trade-off with other available features that may imply the requirement of a higher SNIR [2].

5. Newly Proposed Frame Structure

Two important elements in WiMAX cellular network are affected due to interference caused by adjacent cells, which they are coverage area and capacity. The FFR and permutation mode as a combination can be considered as essentially player to enhance coverage area and capacity as well as spectrum efficiency. WiMAX standards allow for perform zones and segmentations, the DL sub-frame can be further subdivided into zones and segments, zone should have the same permutation type, while segment is a part of zone occupy several sub-channels.

5.1 Proposed Frame Structure

WiMAX cellular network serves two types of users: mobile users and fixed (or nomadic) users. The proposed work environment assumed to be in urban area, in this scenario and practically in crowded city the number of mobile users and the number of fixed users may change continually. In such environment the changes in user's behavior need to be studied in order to efficiently use the available resource at the base station when dealing with these two types of users.

In the suggested work all WiMAX network functions, parameters, and air environments (multipath, fading, pathloss, and shadowing) should be considered to run the proposed work. Cellular network with 19 cells wraparound arranged where each three adjacent cells use FFR factor equals to 3 at the cell edge, zones are constructed according to permutation type. In this work we propose three zones in the DL sub-frame: zone 1 is to execute FFR technique, zone 2 is used by PUSC mode, and zone 3 is used by band-AMC mode, figure (4) illustrates the idea.

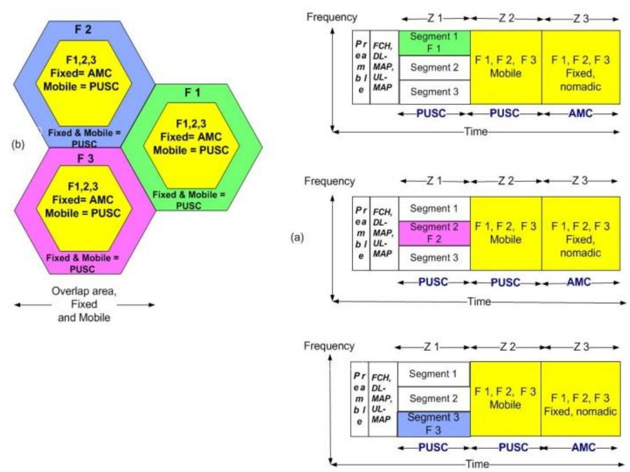

Fig. 4 Proposed frames and cell model layout.

In figure (4a), the frames structure of the proposed model are placed, the FFR Z1 is preceded by preamble and control messages, it used to reduce cell edge interfering, where F1, F2, and F3 represent three different frequencies bands that are used in the edge of the three adjacent cells. These three frequencies bands are placed in three separate segments in Z1, each base station uses one of these segments at the cell edge.

Initially and almost the number of OFDMA symbols in the DL sub-frame is equally divided between the three zones. In the proposed work the mobile users are forced to be served by Z2 in order to take advantage of the distributed permutation as frequency diversity, while fixed or nomadic users are forced to be served by Z3 in order to take advantage of the adjacent permutation as user diversity. The idea is to utilize the frequency diversity and user diversity in common area in a dynamic manner.

Figure (4b) shows the effect of frame structure design on the ground. It can see that there are two serving areas, inner area near the base station and outer area at the cell edge. The users in zone 2 and zone 3 are served by the inner area nearby the base station, the diameter of this area should be carefully specified to ensure sufficient number of users in the inner area, and in the same time consider the interference that is caused by the neighboring cells which using the same frequency. The outer area diameter also should be carefully specified to ensure adequate interference avoiding with neighboring cells and satisfy the maximum allowable pathloss. Z1 serves mobile and fixed users in the cell edge, as well as Z2 and Z3 serve the same type of users in the nearby cell center, which means the overall cell area is available to serve mobile and fixed users. The separation between Z2 and Z3 is virtual, both have the same area space and same share of resources in the DL subframe as initial start or as required. Z2 and Z3 are separated based on user's behavior. This separation doesn't appear on the ground; instead users in the inner area are served by two different permutation techniques.
Additionally, to ensure best use of available resources in the proposed work, the zone size in (Z2 and Z3) are automatically resizable, i.e. to exploit the available resource per zone, the zone size changes automatically according to the number of population at that zone in each cell, compared with its available resources per zone. In this way the benefit of using different permutation technique doesn't waste resources when the behavior (type) of user is changed, from our knowledge this new FFR design used for the first time.

5.2 Proposed Algorithm and flowchart

The proposed algorithm is divided into two parts: the first part allocates users in appropriate zones or segments, and the second part reallocates resources in Z2 and Z3. The algorithm symbols describe in table (1), as follow.

Table 1: Description of each symbol used in the proposed algorithm.

Symbols Name	***Symbols Discretion***
Rin	The inner area diameter (Z 2 and Z 3).
Rout	The outer area diameter (Z 1).
Dss	The distance between the subscriber (SS) and the base station.
RS_ss(j)	Received signal strength indicator.
Mob	The number of mobile users in Z 2.
Fix	The number of fixed users in Z 3.
Mob_th	Threshold value represents the maximum numbers of Mobil users in Z2.
Fix_th	Threshold value represents the maximum numbers of Fixed users in Z3.
As2	Free available number of slots in Z2
As3	Free available number of slots in Z3

The first part of the algorithm can be written as follows:

/# allocates users in appropriate zones and segments #/
Step 1: Read Rin
Step 2: Read Rout
Step 3: Read Mob_th
Step 4: Read Fix_th
Step 5: Read Dss
Step 6: IF (Dss <= Rin) ; Else Goto 18
Step 7: Read RS_SS (j)
Step 8: wait for specific time period (T)
Step 9: Read RS_SS (jj)
Step 10: IF (RS_SS(jj) ≠ RS_SS(j)) then X=X+1; Else Goto 14
Step 11: IF X != 10 Go To step 7
Step 12: Mob= Mob+1
Step 13: IF the (Mob <= Mob_th); SS served by zone 2; Go to 20; Else drop this SS and goto 5
Step 14: Y=Y+1
Step 15: IF Y != 10; Go To step 7
Step 16: Fix= Fix+1
Step 17: IF (Fix <= Fix_th) SS served by zone 3; Goto 20; Else drop this SS and goto 5
Step 18: IF (Dss > Rout); drop this SS; got to 5
Step 19: Assign SS to segment 1 in zone 1
Step 20: Sent to PHY layer

In the first part of the algorithm, the two diameters *Rin* and *Rout* are specified at the design time, depending on these diameters the subscribers will allocate to appropriate zones. If the subscriber distance *Dss* below or equals to *Rin* then the user location is specified in the inner area (Z2 and Z3), and if the subscriber distance *Dss* less than or equals to *Rout* and more than *Rin* then the user location is specified in the outer area (Z1). The algorithm checks the value of *RS_ss(j)* and compares it with another *RS_ss(jj)* value for the same subscriber sequentially every period of time. This period of time should be enough to notice the changes in the received signal strength, if these values continuously change, then the subscriber considered as a mobile station and served by Z2, however if these values are close to each other, then the subscriber considered as a fixed (or nomadic) station and served by Z3. The received *RS_ss(jj)* value may change not only based on user's mobility but also due to communication channel effects, therefore the threshold value must be used with acceptable margin when making decision in the above algorithm. The number of check times (equal to 10) can be changed according to simulation results in order to get more accuracy. Figure (5) shows the flowchart for the proposed algorithm.
The second part of the algorithm given below, addresses the case when the number of users in Z2 is less than the number of users in Z3 or vice versa. The algorithm measures the unused space (slots) in Z2 and Z3, which in turn reflect the number of slots that can be used in either zone and based on need.

/# resources re-allocation #/
Step 1: Read As2 from zone 2
Step 2: Read As3 from z one 3
Step 3: IF Dss < Rin and (As2 - As3) > 25% of the maximum available slots in zone 2
Step 4: Assign 25% of slots from zone 2 to zone 3 Go To 7
Step 5: IF Dss < Rin and (As3 - As2) > 25% of the maximum available slots in zone 3
Step 6: Assign 25% of slots from zone 3 to zone 2
Step 7: End

In the second algorithm, and for instance if the available slots in Z2 more than that at Z3, and Z2 free slots equals to more than 25% of its total slots space, then the granting process will apply, otherwise nothing will occur. The repetition of resources re-allocation process should be done in reasonable manner because zone switching may result in increases the overhead on the involved base station. The zone resizing process happens due to the changes in users' type in the inner area.

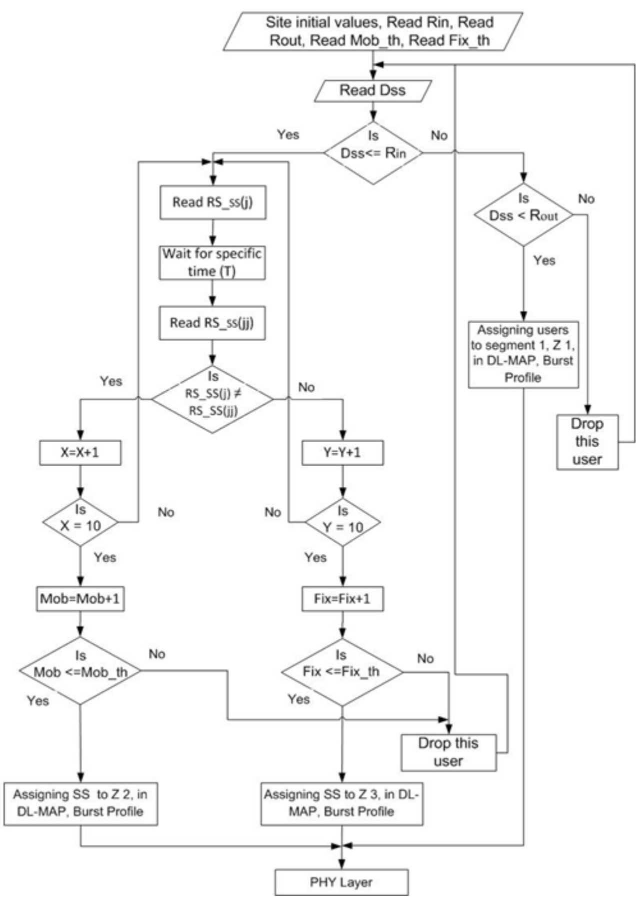

Fig. 5 Proposed flowchart.

The first step in the flowchart measures the distance from the SS to the base station, based on threshold value SSs with far distance equals to the area under the cell edge are assigned to Z1 but SSs with less distance equals to the area nearby the base station are assigned to inner area.
Z1 zone will serve users at the cell edge i.e., only part of the available sub-channels will be used. The location of these sub-channels should be broadcasted through the DL MAP to the border users, whilst the users at the inner area will be served by the Z2 and Z3, and their location should be also broadcasted by DL MAP. The next step is to distinguish between fixed and mobile SSs in the inner area, thus to allocate SSs into appropriate zone, and depending on certain criteria such as the number of variation in the received RSSI, users will be assigned to the appropriate zone based on threshold value.
The next step reads the received signal strength RS_ss(j) for a specific SS and keeps it as a reference value, then after period of time (T) the algorithm will read another value RS_ss(jj) for the same SS, the period of time (T) plays an important rule to successfully allocate SSs to the appropriate zone, for instance if (T) equals to 1sec, 5ms frame duration, and mobile user speed equal to 60 Km/h, then the RSSI will be measured every 200 frames after the mobile user moves 16.6m/sec in straight line. This value of (T) may give good opportunity to notice the changes in the received RSSI. Actually, based on simulation result, the (T) value can be specified more accurately. Moreover if the measured distance value is not equal to the inner or outer cell diameters, then the algorithm ends the process and assumes that the user location is out of the coverage area.
Subscribers with stable channel condition are considered as fixed (or nomadic) users and they are assigned to Z3, while users with continues varying channel condition are considered as mobile users and they are assigned to Z2.
In addition, spectrum efficiency take in consideration to enhance the overall cells throughputs, that by using adaptive modulation and coding AMC. The signal-to-interference-plus-noise ratio (SINR) for each user can be requested by the base station through the REP-RSP message; these values are compared with predefined SINR as they are defined in [11]. Based on the threshold values of SINR listed in table (2), the SS will be able to use a suitable modulation and coding scheme. Using adaptive modulation and coding can enhance the system throughput.

Table 2: SINR threshold values driven in AWGN channel with Reed-Solomon coding.

Modulation	*Coding rate*	*Receiver SNR (dB)*
BPSK	1/2	3.0
QPSK	1/2	6.0
	3/4	8.5
16-QAM	1/2	11.5
	3/4	15.0
64-QAM	2/3	19.0
	3/4	21.0

Zone assignment requires analyzing parameters such as RSSI, SINR, SNR, pathloss. In order to maximize the system performance these parameters should be evaluated based on trade-off to address worst situation. However, in the proposed work we rely on three criteria: first the distance between the subscriber and the base station, second the received signal strength RSSI measured at the subscriber, and third the SINR used in link adaption. The first criteria used to allocate SSs in the inner area or outer area, the second criteria used to distinguish between mobile SSs and fixed (or nomadic) SSs.

As in [1] the base station request the subscriber to send its RSSI, then the reported RSSI is sent via Channel Quality Indicator feedback (CQI), when the BS request the SS to measures the instantaneous RSSI. A series of measured instantaneous RSSI values are used to derive the mean and standard deviation of the RSSI. The mean $\mu_{RSSI}[k]$ and standard deviation $\sigma_{RSSI}[k]$ of the RSSI during the *kth* measurement report are given by Eq. (1):

$$\mu_{RSSI}[K] = (1-\alpha)\,\mu_{RSSI}[k-1] + \alpha\,\mathrm{RSSI}[k]$$
$$\chi^2_{RSSI}[K] = (1-\alpha)\,\chi^2_{RSSI}[k] + \alpha\,|\,\mathrm{RSSI}[k]\,|^2 \qquad (1)$$
$$\sigma_{RSSI}[K] = \sqrt{\chi^2_{RSSI}[K] - \mu^2_{RSSI}[k]}$$

Where $\chi^2_{RSSI}[K]$ is the instantaneous value, RSSI[k] is the *kth* measured values of RSSI, and α is an averaging parameter whose value is chosen by the BS, which its depending on the coherence time of the channel. All these values are expressed in the linear scale. In the same contrast, the SINR measurement is like RSSI, the mean and the standard deviation of the SINR during the *kth* measurement can be obtained by Eq. (2).

$$\mu_{RSSI}[K] = (1-\alpha)\,\mu_{RSSI}[k-1] + \alpha\,\mathrm{RSSI}[k]$$
$$\chi^2_{RSSI}[K] = (1-\alpha)\,\chi^2_{RSSI}[k] + \alpha\,|\,\mathrm{RSSI}[k]\,|^2 \qquad (2)$$
$$\sigma_{RSSI}[K] = \sqrt{\chi^2_{RSSI}[K] - \mu^2_{RSSI}[k]}$$

The mean and the standard deviation of the RSSI and SINR should be converted to the dB scale before they are reported to the base station.

6. Conclusions

The inter-cell interference in cellular network is a major problem causing reduction in cell coverage area and capacity. The number of mobile and fixed users may change constantly in crowded urban environment, in such environment these changes in user's behavior needs to be addressed in order to efficiently use the network resources. We believe that using this new FFR proposed design maximize the utilization of the available network resources, also this design can mitigate the inter-cell interference as traditional FFR which enhance cell coverage area and capacity.

WiMAX supports user diversity and frequency diversity as a technique to increase system performance. These techniques are suggested in the proposed design to serve two types of users: mobile and fixed. These techniques increases user's signal against unwanted signals and that enables the system to use higher order modulation with less robust coding,

The suggested design addresses two cases in order to efficiently use the available resources and enhance the throughput: first case, when the number of users in Z2 is less than the number of users in Z3 or vice versa, the algorithm measures the unused space in Z2 and Z3 which gives the available space that can be exploited by either zone and based on need. Second case, using adaptive modulation and coding can influentially increase system throughput. The AMC takes the advantage of frequency diversity and user diversity to assign suitable modulation and coding to a particular user. However, this design requires continues feedback from the users, especially the mobile users because their channel specifications continually changed, that may result in more overhead at the base station.

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