Reduction of Inter-Cell Interference (ICI) by Fractional Frequency Reuse (FFR) in Orthogonal Frequency Division Multiple Access (OFDMA)

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***Abstract*—Interference coordination technique using Fractional Frequency Reuse (FFR) is compatible to Orthogonal Frequency Division Multiple Access (OFDMA) based wireless networks which expected to be orthogonal to each other, as well inter-cell interference (ICI) is the main source of interference that restrictive for users near the boundary cells. This work focus on reduction of interference in inter-cell at the same time reduces the Power in (Watt), Capacity and Base Station Power in (Watt) thus improves the performance of system. The implementation system models of Fractional Frequency Reuse (FFR), clarifies that interference problem in inter-cell can be resolve through MATLAB simulation via formulating the optimization problem. At the end of stage, simulation results demonstrate that the proposed scheme FFR outperforms conventional Reuse-1 and Reuse-1/2 schemes by develop 12.98% in terms of Bit Error Rate (BER) and Signal to Interference Ratio (SINR).**

Index Terms*— Fractional Frequency Reuse (FFR), Orthogonal Frequency Division Multiple Access (OFDMA), inter-cell interference (ICI), Bit Error Rate (BER) and Signal to Interference Ratio (SINR).

INTRODUCTION

Interference has been demonstrated as the most important problem of wireless communication systems throughout many years. ICI is schemes in order to expand the performance of the network where each cell allocates its resources at the same time minimize the interference in the system, simultaneously increasing the spatial reuse. ICI technique in OFDMA based wireless networks presented FFR as mentioned in [1]. The main idea of FFR is to shares the cells bandwidth in objectives to improves cell-edge users of adjacent cells by decrease interferences; in and out of cell-interior users and more efficiently expending available spectrum compare to conventional frequency reuse by referring to [2]. ICI limited to downlink throughput performance in cellular systems hence to reduce interference using Co-Channel Interference (CCI) mitigation schemes, specifically for users at the cell edge, it is require to compromise throughput system due to the resource partitioning. Hence, FFR has been proposed to balance the cell-edge throughput and overall throughput of system. The reuse partitioning system is combination of low and high Frequency Reuse Factors (FRF) by sharing the cell in two zones, center and edge as in [3].

The main problems in quality of service among users are the effect of interference in multi-cellular. The major use of OFDMA, are in the intra-cell users that assumed to be orthogonal to each other and the most important source of interference is ICIC. In addition, ICIC strategy increases the performance of the network by having each cell allocate resources to minimize the interference in the system [4]. ICIC technique in OFDMA based wireless networks, has been proposed FFR to solve the interference problem [5]. In [6], the basic idea of FFR in cellular networks idea is to natural tradeoffs between increases of rate, as well as coverage for cell-edge users and overall network throughput. FFR is a technique that develops reasonable tradeoff in the middle of overall spectral efficiency and the cell-edge user throughput as in [7]. FFR successfully enlarges the cell-edge user throughput and the overall system throughput; relative to the systems by apply full frequency reuse and standard cluster-based resource partitioning schemes. Interference in wireless systems is not a major issue in the recent years as the number of users is small compared to the available frequencies. Nevertheless, in excess of the last decades, the number of user has affectedly greater; as a result a simple reuse of the spectrum is required to overcome this problem [8].

METHODOLOGY AND FLOW OF SIMULATION

Figure 1 show the flow chart of overall process involve in reduction of ICI by implemented FFR. The research starts by choosing an issue happens in cellular network thus further research will be conducted in order to investigate the specific problem, in this case we focus in reduction of interference. In order to avoid ICI, OFDMA networks are flexible in radio resource management techniques; supporting different frequency reuse schemes (FRSs) which decrease ICI thus increase network performance. Alternatively, the goal is to propose FFR scheme to reduce the interference hence increases the cell edge user throughput and the overall system throughput. MATLAB simulation applies and proposed methods will be analyzed. A troubleshoot will take place in the system and remodeling process until objective successfully achieved. Finally, the result of overall comparison between the system with and without FFR will be discussed after all the results were analyzed.

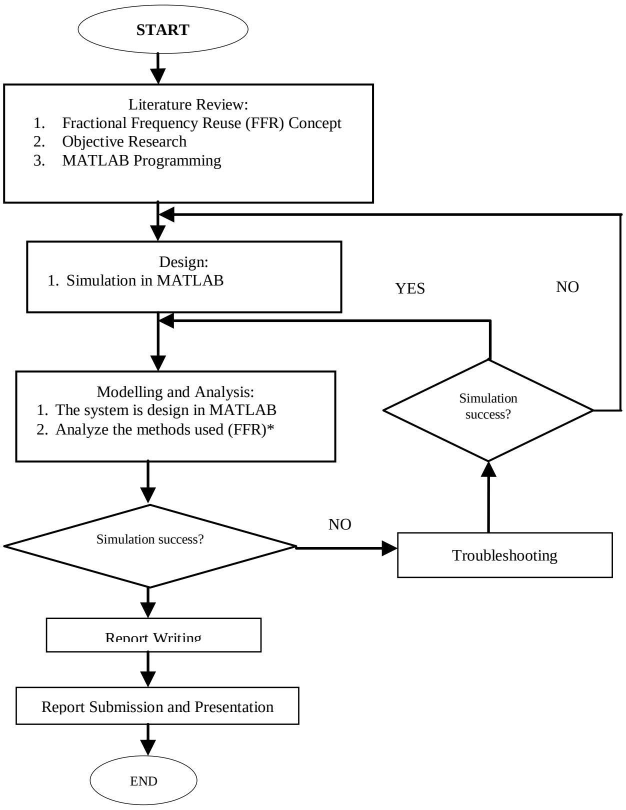

Figure 1. Methodology Flow Chart

SYSTEM MODEL OF FFR

With the purpose of implement OFDMA systems in cellular network, OFDMA mechanism are orthogonalize numbers of users within a cell at the same time concern in avoiding out-of-cell interference. FFR presenting in this study will explore the main idea of frequency reuse in cellular network. To more understanding the idea, algorithm for FFR is explained later. At the end, we analyze the performance of the scheme using MATLAB simulations; include the comparison using a toy model and the resulting analysis of FFR. Firstly, we study the configuration between the frequency Reuse-1 and Reuse-1/2 by consider two neighboring cells [15].

(a) Reuse-1 (b) Reuse-1/2

Figure 2. Network deployment for the FFR model

Reuse-1/2 scheme is a simple scheme that divides total bandwidth between two cells to avoid ICI as in Figure 2(b). In addition, users have no experience in ICI thus minimize cost of bandwidth. Differ from Reuse-1 (Universal Reuse) as in Figure 2(a); deals with interference from out-of-cell user. For additional understanding into the tradeoff between bandwidth, power and interference, a toy example provides as in Figure 3.

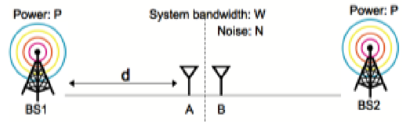

Figure 3. Network deployment for the FFR model

In this case, we consider two cells with base stations (BSs) distance l apart, each constrained with a total power constraint P and system bandwidth 2W. The system capacities achieved per user by the Reuse-1 and Reuse-1/2 schemes are (with path loss model $pl(d) = 133.6 + 35 \cdot \log(d)$):

Reuse-1

$$2W \cdot \log\left(1+\frac{\frac{P}{2} \cdot pl(d)}{WN+\frac{P}{2} \cdot pl(l-d)}\right) \tag{1}$$

Reuse-1/2

$$W \cdot \log\left(1+\frac{P.pl(d)}{WN}\right) \tag{2}$$

Within a CDR framework in analyze FFR, maximum system capacity have no sense is consider. Each user capabilities are independent Rayleigh fading on each subcarrier. All the parameters are tabulating in TABLE I:

TABLE I: PARAMETER CONSIDER IN FFR

Required rate	R
Max Tx power from BS to one user	Pmax
Thermal noise	N
Bandwidth per subcarrier	W
Max possible SNR	SNRmax=Pmax/N
Number of users in each cell	*ncell*
Number of subcarriers in system	*ns*
Fade from BS-k to Bob on subcarrier j	*hij*

Each user i, $0 \leqslant i \leqslant ncell$ can be assigned to only one subcarrier, though this analysis could be extended to a situation where each user is allowed to transmit on multiple subcarriers. We consider the outage of user in cell 1 and assume users in all neighboring cells have already been allocated subcarriers. Consider the case when $ncell < ns/2$ so that there are many subcarriers for users to choose between. Given a particular user let A, B, C denotes the following sets of subcarriers:

$A = \{j \mid 0 \leqslant j \leqslant ns$, subcarrier j is assigned to a user in cell 1

(3)

$B = \{j \mid 0 \leqslant j \leqslant ns$, power $> Pmax$ would be required to get rate R in subcarrier j}

(4)

$C = A \cup B$

(5)

A. FFR

Let us now consider P ($j \in A$) and P ($j \in B$). With *ns* large enough, other users in cell 1 can be considered to be uniformly distributed among subcarriers. Hence,

$$P\ (j \in \mathbf{A}) = \frac{ncell-1}{ns} \tag{6}$$

There are two cases to be considered to understand B;

$$P(j \in \mathbf{B}) = \mathrm{P}\left(\frac{||h1j||^2}{N+\sum_K ||hkj||^2.\ Pmax} < \frac{2^{\frac{R}{W}}-1}{Pmax}\right) \quad (7)$$

$$=\left(\frac{||h1j||^2}{N+\sum_K ||hkj||^2.\ Pmax} < \frac{2^{\frac{R}{W}}-1}{Pmax} | N > \sum_K ||hkj||^2 . Pmax\right) . P(N > \sum_K ||hkj||^2 . Pmax \mathrm{P})$$

$$+\mathrm{P}\left(\frac{||h1j||^2}{N+\sum_K ||hkj||^2.\ Pmax} < \frac{2^{\frac{R}{W}}-1}{Pmax} | N \leq \sum_K ||hkj||^2 . Pmax\right) . P(N \leq \sum_K ||hkj||^2 . Pmax)$$

(8)

The analysis considering interference from multiple surrounding cells becomes very complicated and we cannot get explicit expressions for the probabilities. Hence, we consider the case with only one interfering cell, say cell 2.

$$P\ (j \in \mathbf{B}) = \frac{2^{\frac{R}{W}}-1}{SNR\ max^2} + \frac{(2^{\frac{R}{W}}-1)^2}{(2^{\frac{R}{W}}-1)^2+1}\left(1 - \frac{1}{SNR\ max}\right)$$

(9)

Using this, we can now calculate the outage probability as:

$P\ (j \in \mathbf{C}) = P\ (j \in \mathbf{A}) + P\ (j \in \mathbf{B}) – P\ (j \in \mathbf{A})P(j \in$ I (10)

P (User in outage) $=\prod_{j=1}^{ns} P(j\ \in\ \mathbf{C})$ (11)

To understand the nature of the probability we consider a case study with *ncell/ns* ≈ 1/4 and high *SNRmax*. In this case:

$$\mathrm{P(outage)} \approx \left(\frac{1}{4} + \frac{3}{4}\Pr(j \in \mathbf{B})\right)^{\mathrm{ns}} \quad (12)$$

$$=\left(\frac{1}{4} + \frac{3}{4}\left(\frac{2^{\frac{R}{W}}-1}{SNR\ max^2} + \frac{(2^{\frac{R}{W}}-1)^2}{(2^{\frac{R}{W}}-1)^2+1}\left(1 - \frac{1}{SNR\ max}\right)\right)\right)^{\mathrm{ns}} \quad (13)$$

B. Reuse-1/2

$$P\ (\ j \in \mathbf{A}) = \frac{\mathrm{ncell}-1}{\frac{ns}{2}} \quad (14)$$

$$P\ (\ j \in \mathbf{B}) = \frac{2^{\frac{R}{W}}-1}{SNR\ max} \quad (15)$$

$$P\ (j \in \mathbf{C}) = Pr(j \in \mathbf{A}) + Pr(j \in \mathbf{B}) - Pr(j \in \mathbf{A})Pr(j \in \mathbf{B}) \quad (16)$$

P (User in outage) $=\prod_{j=1}^{n\frac{ns}{2}} Pr(j\ \in\ \mathbf{C})$ (17)

Note the difference between equations (2) and (6). In the Reuse-1/2 case, a given user can only choose from half as many subcarriers. To understand equation (9) we note that in a Reuse-1/2 scheme users in cell 1 experience no interference from users in cell 2 and vice versa. Subcarrier j can only end up in B because of a bad fade with probability. Consider again the case where *ncell*/ns ≈ 1/4 and high *SNRmax*. In this case:

$$\mathrm{Pr(User\ i\ in\ outage)} \approx \left(\frac{1}{2} + \frac{1}{2}\Pr(j \in \mathbf{B})\right)^{\mathrm{ns/2}} \quad (18)$$

$$\approx\left(\frac{1}{2} + \frac{1}{2}\left(\frac{(2^{\frac{R}{W}}-1)^2}{SNR\ max}\right)\right)^{\mathrm{ns/2}} \quad (19)$$

(19)

FRACTIONAL FREQUENCY REUSE (FFR)

Release 8 has been involved FFR in fourth generation (4G) wireless standards with WiMAX 2 (802.16m) and 3GPP-LTE as in [9]. In Figure 3, F1, F2, and F3 show arrangements of different sub channel with same frequency ınnel. Based on configuration, full load frequency Reuse- ; applied for center users to maximize spectral efficiency and to guarantee edge-user connection quality and throughput. All cells and sectors therefore, can operate on the same frequency channel without need for frequency planning [10]. While Figure 4 shows the network deployment for FFR model in [11]. In FFR, each cell in the network allocated entire spectrum for outer cell, total spectrum is shared by three segments, namely f1, f2 and f3, and each sector in outer cell allocated to only one of the segments.

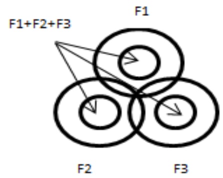

Figure 3. Arrangement of F1, F2, and F3

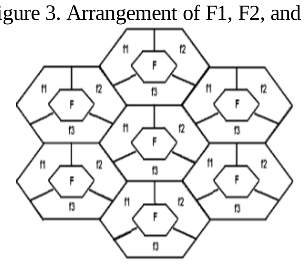

Figure 4. Network deployment for the FFR model

FFR exploits spectral efficiency for users at the inner :ell and improves signal quality and throughput for users at a cell edge. OFDMA systems of FFR framework has nainly been discussed in cellular network standardization orum such as Third Generation Partnership Project (3GPP) 12] and Third Generation Partnership Project 3 (3GPP2) 13]. In [14], the cell is separated into two regions as inner :ell and outer cell then allocates subcarriers to different ectors and the entire spectrum band divided into three egments, namely f1, f2 and f3 with each sector in the outer :ell is allocate to the same segment, for the inner cell the full frequency band used. An illustration of the FFR [14] used in outer cell users face little out of interference while the adjacent sectors use different frequency segments can be demonstrate in Figure 5. By using dynamical assigning of subcarriers in order to minimize power usage, FFR as well adjust the tranmit powers of different subbands to maximize the overall network utility.

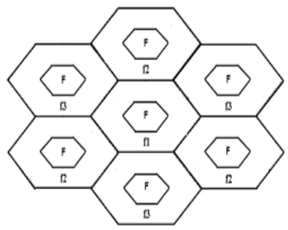

Figure 5. Illustration of FFR

SIMULATION RESULTS AND DISCUSSIONS

In this section, we will observe a system with only two neighboring cells using MATLAB software that works as a complete set of algorithms and graphical tools for image processing, analysis and algorithm development.

a) Analysis of Comparison Reuse-1 and Reuse-1/2 based on capacities in cell toy

By using Reuse-1/2 scheme, it shares the total bandwidth between the 2 cells in order to avoid ICI thus users have no ICI thus the cost of bandwidth reduced. While, Reuse-1 is a scheme where users in each cell have access to overall bandwidth but have to deal with interference from out-of-cell users. A test toy example provides additional understanding into the tradeoff between bandwidth, power and interference for 2 cells, 3 cells and 7 seven cells. The capacities per user vary with *d* by referring to equation (1) and (2) are shown in Figure 6. The green and blue color represents the capacity reached under Reuse-1 and Reuse-1/2 correspondingly. As per distance of each user from its own BS decreases, the total power available to each BS drops, thus decreases the CCI.

Reuse-1 starts outperforming Reuse-1/2 demonstrate that implementing any one fixed strategy in ignorance of user geography would be suboptimal in many systems. The FFR scheme improves system for user geography during resource allocation. However cell interior users challenge little out-of-cell interference appreciate Reuse-1; cell edge users mitigate out-of-cell interference by using a Reuse-1/2 strategy besides this method will solve problem of user capacity. Such as number of cell in toy example use decreases, the CCI decreases because more cells use in the system, more bandwidth desires and complex the network hence more interference and handover will occur. In this example, two numbers of cells is the best result at the same time avoids CCI between cells.

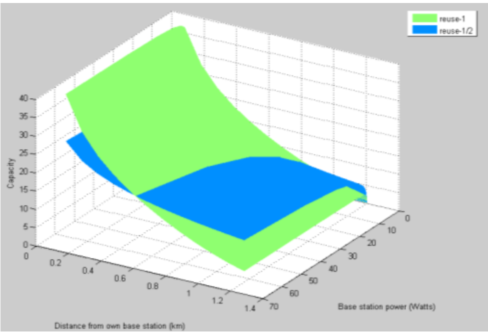

Figure 6. Comparison Reuse-1 and Reuse-$\frac{1}{2}$ based on capacities in 2 cells toy

b) Bit error rate (BER) vs Power for Reuse-1 and Reuse-1/2

To prove the results for the comparison of Reuse-1 and Reuse-1/2 by varying number of cells, a graph of BER vs power using Reuse-1 and Reuse-1/2 is shows as in Figure 7. It shows that Reuse-1/2 is the best frequency reuse compare to Reuse-1 as the bit error rate is nearest to value 0, hence minimize the power in watt at the base station.

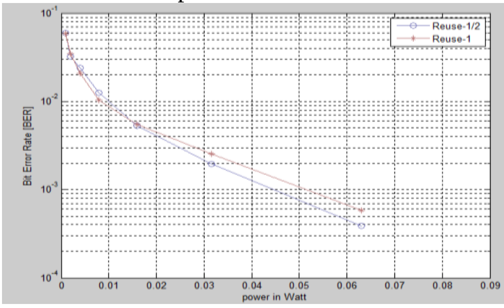

Figure 7. Bit error rate (BER) vs Power for Reuse-1 and Reuse-1/2 using 2 cells

c) Performance of Power Minimization Algorithm for cell, sub band and user

The resource allocation mechanism shows in resulting figures, by varying the total power constraint on the base station and the distance of the two users from their BS. In this case we are considering the parallel of a slice 3D as shown in Figure 8. The performance of power minimization algorithm for 2 cells, 3 cells and 7 cells are investigated. Universal reuse (green region) shows when *d* is small and both users are close to their base stations; the equation in (1) is verified. While *d* is large, and both users are on the cell-edge, that implements Reuse-1/2 as expected (blue region). A set of power-distance pairs wherever the CDR can be measured either universal reuse or Reuse-1/2 and the differences in power desires are not significant represent by the orange region. Lastly, the red region is pointed to BS power constraint achieved and the CDR is not reached.

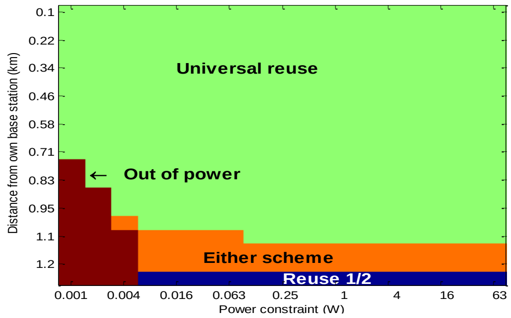

Figure 8. Performance of power minimization algorithm for 2 cells, 2 subbands, 2 users

The region out of power increases as number of cell increases, thus to minimizes the CCI, the small number of cell is required to completed the objectives. For the results number of users supported, following assumptions are prepared as TABLE II:

TABLE II: NUMBER OF USERS SUPPORTED AND FOLLOWING ASSUMPTIONS

Parameter Types	Value
Path loss model	133.6 + 35 log (d)
Two cells with inter-site distance	2.5 km
Total bandwidth	1.25 GHz
Number of subcarriers and carrier per sub band	48 subcarriers; 1 subcarrier per sub band

Subcarrier per user	Each person may only use one subcarrier
Users desire a constant data rate	9.6 kbps
Fades	Rayleigh with parameter 1 and are independent across subcarriers
Types of fading	Slow fading

d) Effect on location and power constraint on supportable number of user under FFR and Reuse-1/2

The blue region is represent Reuse-1/2 while the red region is represent FFR. Figure 9 conclude that as numbers of users supported increases, base station power is increases thus more interference occur in the system.

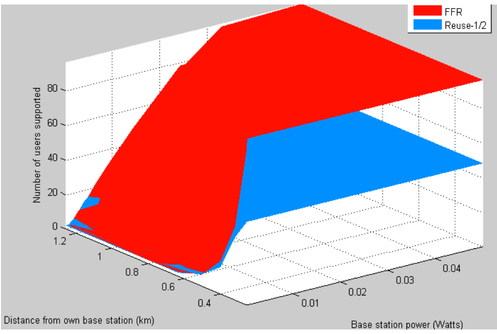

Figure 9. Effect on location and power constraint on supportable number of user under FFR and Reuse-1/2

e) FFR with varying power and distance from BS

Next figure analyze the results of FFR with varying power and distance from BS to show the effect on numbers of user location by varying the distance from the base station. From Figure 10 (a), it shows that 'Inner'(cell interior) which refers to the case where number of users exactly 0.5 km from the base stations while in the case 'Outer'(cell edge) refers to number of users are at 1.25 km. When half number of users are at 0.5 km and half are at 1.25 km it is called case 'Inner and outer' which represent the combination of two situations. Lastly, 'Uniform' or 1 km refer to number of user located randomly between their base station and the cell edge. From all value of distance tested, it shows that when distance increases, base station power will maximize, this will cause high interference.

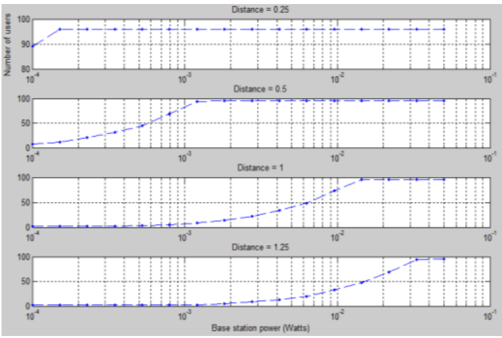

Figure10. (a) Effect number of users and base station power(watts)

To more understand the Figure 10(a), the following Figure 10(b) will explain detailed on the Effect of user distribution within the cell and total power constraint on number of users the system can support. In this case, we are focus in 'Inner' (green line) which have maximum base station power and large number of users compare to 'Outer' (red line) that have minimum base station power and small number of users. The 'Uniform' is represent by blue line while combination of 'Inner and Outer' is represent by yellow line.

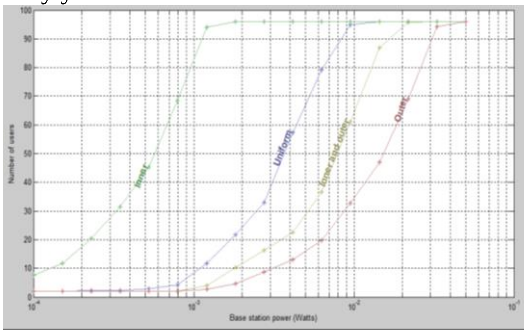

Figure 10. (b) Effectof user distribution within the cell and total power constraint on number of users the system can support

f) Effects of subbands on the number of users the system can support

Figure 11 focus on the significance effect of subbands on the supportable number of users by varying number of sub carrier for FFR. By using 1 subcarrier per subband (red line), the noise is organized where each of user can control the interferences occur in the system. Compare to case where there are 48 subcarriers per subband (blue line), the noise is disorganized and increase interference. As number of subcarrier per sub band increase, noise and interferences will increase thus effect the performance of system.

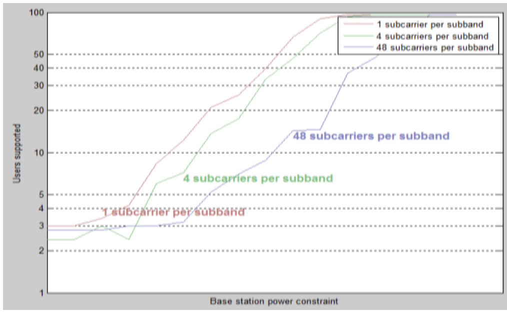

Figure 11. Effects of subbands on the number of users the system can support

g) Bit error rate (BER) vs power for FFR and Reuse-1/2

Figure 12 shows result by compare BER vs power for FFR and Reuse-1/2. In this figure, it shows that the new proposed FFR is the best frequency reuse compare to Reuse-1/2 as the bit error rate is nearest to value 0, hence minimize the power in watt at the base station and at the end the objectives of the experiment succeeded thus prove equation (13) for FFR and (19) for Reuse-1/2.

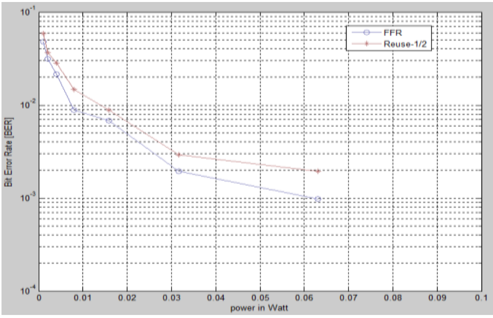

Figure 12. Bit error rate (BER) vs power for FFR and Reuse-1/2

h) Bit error rate (BER) vs Signal to Interference Ratio(SINR) for FFR and without FFR

Figure 13 shows results by compare BER vs SINR for FFR and without FFR. FFR is the best frequency reuse compare to system without FFR as the bit error rate nearest to value 0 and SINR increase, thus reduce the power in watt at the base station and achieve the objectives of the work.

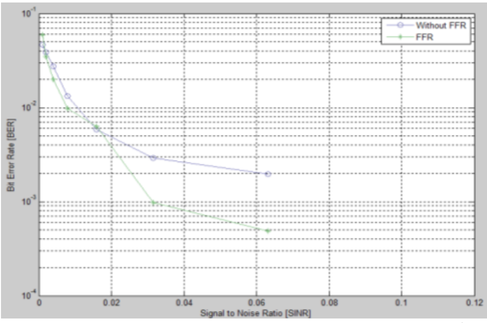

Figure 13. Bit error rate (BER) vs Signal to Noise Ratio(SINR) for FFR and without FFR using 2 cells

The summarizations for all analysis in reduction of ICI by comparing all Frequency Reuse Scheme are being tabulated in term of BER and SINR as in TABLE III:

TABLE III. COMPARISON FOR ALL FREQUENCY REUSE SCHEME

SINR		BER	
FFR	Without FFR	FFR	Without FFR
0	0	0.052	0.063
0.02	0.02	0.0027	0.0026
0.04	0.04	0.0032	0.00281
0.05	0.05	0.00034	0.00283
0.06	0.06	0.00036	0.0029

TABLE III shows the comparison for all frequency reuse for overall performance between system using FFR and without FFR which is previously conducted in MATLAB simulation. By using FFR it shows that as SINR decrease and BER increase it is prove using simulation by develop 12.98% in BER compare to system without FFR.

CONCLUSIONS

In this paper, we have use simulation in MATLAB and results of the work have analyzed the system level performance of frequency reuse patterns and FFR algorithm that are described in introduction part. This work has presented a new systematic framework to evaluate coverage probability and average rate in FFR systems. In term of power control and total power consumption, proposes work would be expectedly having a significant impact on the results and gives insight into the performance of FFR strategies. Additionally, the simple expressions derived for FFR and Reuse-1/2 for the evaluation of ICI strategies implement FFR as dynamically resource allocation strategies to adapt different channel conditions and user traffic loads in each cell. From overall result, FFR shows that as SINR decrease, BER increase and it is prove using simulation by develop 12.98% in BER compare to system without FFR. Finally, proposed FFR thus exploits in reduction of ICI in OFDMA system more efficiently than conventional Reuse-1 and Reuse-1/2 schemes, in terms of BER, SINR, Power in (Watt), Capacity and Base Station Power in (Watt) thus improving the efficiency with which the limited amount of available bandwidth is employed.

FUTURE RECOMMENDATION

In future, to reduce the interference in inter-cell network, other research will develop a consistent framework that allow insight into dynamics and significances of FFR with other important cellular network research including handoffs, base station cooperation and FFR in combination with other cells. We have focus on inter-cell interference in this work; future work enhanced ICI will be analyzed. Finally, more study on fundamental limits on the performance capacity and power from FFR, to benchmark the performance of the proposed algorithms, is a great interest.

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