Efficient Frequency Reuse Method for LTE Femtocell Network

Anita B. Jadhav

Research Student of RAIT, Faculty of UMIT, SNDTWU, Mumbai, India

Y. Srinivasa Rao

Sardar Patel Institute of Technology, Mumbai, India

ABSTRACT

Frequency reuse is the basic concept of commercial wireless communications. Frequency reuse is performed by partitioning of radio frequency (RF) area into cells. Each cell is designed to use radio frequencies within its boundaries. Hence the same frequencies can be reused in other cells which are not far away from each other without interference. These cells are known as co-channel cells. In the Long Term Evolution (LTE) integrated with femtocell (FC), deployment density faces the problem of intercell interference and resource allocation during handover. It results in the degradation of throughput of users, increase in delay and the reduction of Quality of Service (QoS). To overcome these issues we proposed a novel method as Efficient Frequency Reuse (EFR) procedure. Efficient Frequency Reuse (EFR) is based on graph-coloring concept. We proposed algorithms as EFR( ) and NEWFRE() for frequency allocation. In our method we considered the dynamic approach instead of fixed one for reusing the frequencies. The proposed scheme enhances the conventional Dynamic Fractional Frequency Reuse (D-FFR) by efficiently allocating the spectrum to cell and cell users. Such allocation can significantly handle traffic load in different cells in practical environment. Hence our proposed EFR method has shown the remarkable improvement for interference mitigation during handover.

KEYWORDS

Long Term Evolution; 3rd Generation Partnership Project(3GPP); Dynamic Fractional Frequency Reuse(D-FFR); Handover; Interference; Efficient Frequency Reuse (EFR); macrocell; femtocell.

INTRODUCTION

The increasing demand for higher data rate and coverage area have motivated the femtocell utilization. In the LTE integrated with femtocells (FC) network, high deployment of femtocells faces the problem of intercell interference and resource allocation during handover. The Intercell Interference Coordination (ICIC) is a strategy to control the downlink Intercell Interference (ICI) in OFDM networks. ICIC manages the coordination among the neighboring cells to allocate orthogonal resources to the highly overlapping interfered areas [1].

While in the LTE network integrated with femtocells (FC), deployment density faces the problem of intercell interference and resource allocation during handover. It results in poor performance in terms of throughput of users, delay and the Quality of Service (QoS).

To overcome these issues we proposed novel method as Efficient Frequency Reuse (EFR) procedure. EFR is a promising resource allocation technique which effectively mitigate inter-cell interference (ICI) in LTE networks. Our proposed EFR scheme enhances the conventional Dynamic Fractional Frequency Reuse (D-FFR)[1] scheme by efficiently allocating the spectrum to cell with load balancing. Such allocation has significantly handles traffic load in different cells in practical environment. The cell load can be asymmetric and time-varying. The Efficient Frequency Reuse method is accomplished using a graph approach[2][3] where the resource allocation problem is converted to a graph coloring problem. The performance improvement enabled by the proposed EFR scheme is demonstrated by computer simulation in NS3.

Since the radio spectrum is most scarce resource, the Radio Resource Management (RRM) schemes can bust the network capacity and minimize the deployment cost. The increasing demand for higher data rate and coverage area have motivated the femtocell utilization. Femtocells are the access points specifically for short-range and low-cost, consumer-deployed devices [4]. It acts as the communication interface for service providers network and broadband. Femtocell extends the service to indoor or cell edge users, specifically where access of network would be unavailable [5]. Currently femtocell supports 2 to 6 active user equipments in a residential setting [6], and 8 to 16 active user equipments in enterprise settings. Femtocells are auto-configurable and supports an essentially plug-and-play operation. Hence femtocells are considered as a self-organizing network (SON) [7][8]. The transmit power output of femtocells is 10 to 100 Milli-watts, which is lower than many Wi-Fi access points.

Femtocells are characterized for short range of communication, for high throughput, it can seamlessly configure with the traditional cellular networks. Femtocells are performing various tasks like handoffs, interference management, authentication, and billing [9]. To mitigate the interference and spectral efficiency problem, three (FFR) scheme was mentioned in [1]. Different variations of FFR were compared and all of them support fixed configuration so that the spectrum allocation is predetermined and not suitable for variations in cell-load. Hence dynamic fractional frequency reuse (D-FFR) method was implemented in [1]. It enhances the conventional FFR by enabling adaptive spectral sharing according to cell-load conditions. While in the LTE, frequency reuse 1 and reuse 3 methods are proposed for distribution of frequencies among the users to avoid interference. The other case is non reuse 1, where some nodes are suspended from service [1]. From these observations, it is noted that there should be efficient dynamic frequency reuse scheme to mitigate the above mentioned problems. Hence we proposed and develop the modified interference mitigation scheme as Efficient Frequency Reuse (EFR) using the graph coloring algorithm. The algorithms EFR and NEWFRE are used for efficient dynamic allocation of frequencies. The Efficient Frequency Reuse method can allocate the different subchannels to neighboring femtocells to reduce the interference. As a result it increases the coverage area and capacity to service more number of users [10].

FREQUENCY ALLOCATION TECHNIQUES IN LTE NETWORKS

In the LTE technology, in case of downlink the modulated OFDM symbols are transmitted in the form of physical resource blocks (RB) [7]. The information transmitted by one resource block is Transmission Time Interval (TTI) in the time domain and fixed number of adjacent OFDM symbols in frequency domain [10]. The different frequency allocation schemes [1] are shown in the following figure 1. The relation of our proposed method EFR with the these frequency reuse methods is shown in figure 1.

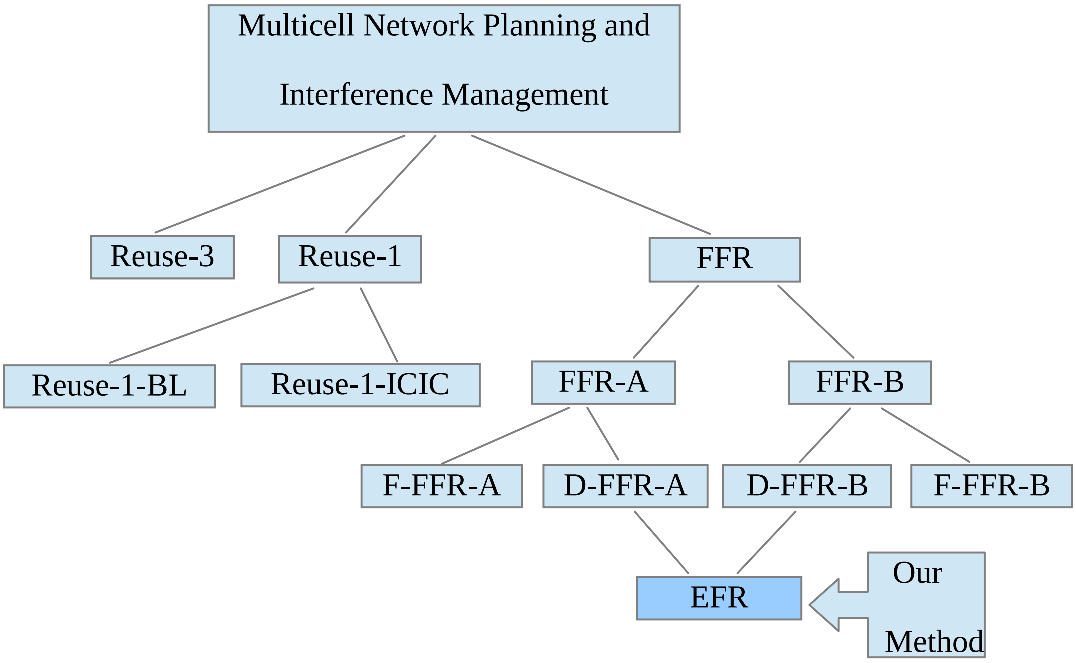

Fig 1: Different frequency allocation schemes and our EFR method

In the frequency Reuse-1 scheme, whole system bandwidth is used in the cell. The resource blocks of the system bandwidth are allocated to each cell. In frequency Reuse-1, edge users suffer more Intercell Interference (ICI) [10]. While in frequency Reuse-3, whole system bandwidth is divided into 3 sub-bands of same size as shown in figure 2. Here each adjacent cells uses one-third of the total bandwidth. It has considered the dynamic approach instead of fixed one for reusing the frequencies. Hence it is the modification of the conventional methods D-FFR-A and D-FFR-B [13][14]. The Reuse-1-BL is the blind reuse-1 scheme and it do not consider the Intercell Interference (ICI) mechanism. The Reuse-1-ICIC is the reuse-1 scheme including Intercell Interference Coordination mechanism.

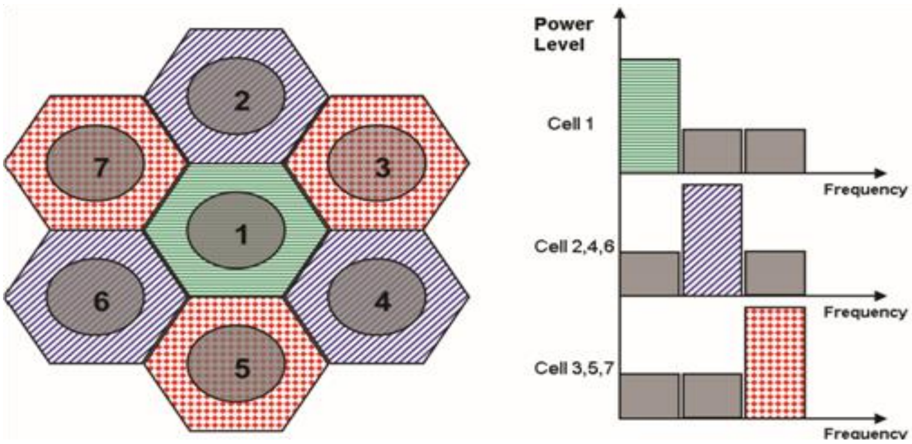

Fig 2: distribution of frequencies by Re-use 3

THEORETICAL METHODS IN LTE NETWORKS

We consider the theoretical concept for calculating different parameters used in our proposed EFR method. These parameters are Signal to Interference Noise Ratio (SINR), total cell throughput and system delay. Then, we introduced our novel EFR method with algorithms for allocating the subchannels to users in LTE integrated with femtocell networks.

CALCULATION OF METRICS [11]

We assume that the system network contained N adjacent cells. Every cell contains number of users either Macrocell Users (MUs) or Femtocell Users (FUs) sharing a group of subcarriers. The macrocell BSs are located at the center of each cell. Femtocell BSs are uniformly distributed in the topology. We have considered that the Macrocell Users are outdoor users and the Femtocell Uerss are indoor users. The scenario contains suburban path loss model in which the path loss between outdoor MU and a macrocell Base Station PL_m is calculated by following equation (1):

$$PL_m = 15.3 + 37.6\log_{10}(d) + S \qquad (1)$$

Where *d* represents the distance between the transmitter and the receiver. The variable *S* represents the outdoor shadowing and characterized as Gaussian distribution with standard deviation and zero mean.

Similarly, the path loss between an indoor Femtocell User and a femtocell Base Station PL_f is given by following equation (2):

$$PL_f = 38.46 + 20\log_{10}(d) + 0.7d + 18.3\, n^{((n+2)/(n+1) - 0.46)} \qquad (2)$$

Where *n* shows the number of penetrated floors. In case of single-floor house, the last term is considered as zero. The term *0.7d* shows the penetration loss due to walls inside a house with *d* representing the distance in the house. Hence the channel gain ***G*** can be defined as formula (3) using path loss model:

$$G = 10^{-PL/10} \qquad (3)$$

The SINR of downlink received by a user is computed using the interference of the cells which include the user within their range. In case of MU *m* on subcarrier *n*, the impact of the adjacent macrocells and overlaid femtocells are taken into consideration. So the SINR for this case is defined as :

$$SINR_{m,n} = \frac{G_{M,m,n} \cdot P_{M,n}}{\sigma^2 + \Sigma_{M'} G_{m,M',n} \cdot P_{M',n} + \Sigma_F G_{m,F,n} \cdot P_{F,n}} \qquad (4)$$

Where $P_{M,n}$ is the transmit power of the serving BS *M* on subcarrier *n* . The term $G_{M,m,n}$ refers to the channel gain between user *m* and the serving cell *M*. It is calculated from (1) for the MU. The term $G_{m,M',n}$ shows the channel gain between user *m* and the neighboring cell *M'*. The term $P_{M',n}$ is the transmit power of the neighboring base station *M'* on subcarrier *n*. Similarly $G_{m,F,n}$ refers to the channel gain between user *m* and the femtocell *F* and is calculated from (2). The term $P_{F,n}$ is the transmit power of the femtocell *F* on subcarrier *n*. The term σ^2 is considered as the power of the Additive White Gaussian Noise (AWGN).

The SINR of a FU is formulated as equation (5). It includes the interference created by macrocells *M* and neighboring femtocells *F'* that use the same frequency bands:

$$SINR_{f,n} = \frac{G_{F,f,n} \cdot P_{F,n}}{\sigma^2 + \Sigma_{F'} G_{f,F',n} \cdot P_{F',n} + \Sigma_M G_{f,M,n} \cdot P_{M,n}} \quad (5)$$

Where $P_{F,n}$ is the transmit power of the serving BS F on subcarrier n. The term $G_{F,f,n}$ is the channel gain between user f and the serving cell F. The term $G_{f,F',n}$ represents the channel gain between user f and the neighboring femtocell F'. The term $P_{F',n}$ is the transmit power of the neighboring base station F' on subcarrier n. Similarly $G_{f,M,n}$ refers to the channel gain between femtocell user f and the macrocell M. The term $P_{M,n}$ is the transmit power of the macrocell M on subcarrier n. The term σ^2 is power of Additive White Gaussian Noise (AWGN).

After the SINR estimation, we can calculate the user throughput. The capacity of user i on subcarrier n is computed using following equation (6):

$$C_{i,n} = \Delta f \cdot \log_2 (1 + a .SINR_{i,n}) \quad (6)$$

Where, Δf represents the spacing between subcarriers. The constant term a is computed using target bit error rate (BER) as $a = -1.5/\ln(5BER)$. Hence the overall throughput of the serving macrocell is formulated as equation (7):

$$T_M = \Sigma_m \Sigma_n B_{m,n} \cdot C_{m,n} \quad (7)$$

Where, $B_{m,n}$ shows the subcarrier assignment to MU m. When $B_{m,n} = 1$, the subcarrier n is assigned to MU m. Otherwise, $B_{m,n} = 0$. The term $C_{m,n}$ is capacity of user m on subcarrier n. Similar expression can be derived for the femtocell users as equation (8).

$$T_F = \Sigma_f \Sigma_n B_{f,n} \cdot C_{f,n} \quad (8)$$

where, $B_{f,n}$ represents the subcarrier assignment to femtocell user f. When $B_{f,n} = 1$, the subcarrier n is assigned to femtocell user f. Otherwise, $B_{m,n} = 0$. The $C_{f,n}$ is capacity of user f on subcarrier n.

PROPOSED EFFICIENT FREQUENCY REUSE (EFR) METHOD

The femtocell (FC) deployment density faces the problem of intercell interference and resource allocation during handover. It results in the degradation of throughput of users, increase in delay and the reduction of Quality of Service (QoS). To overcome these issues we proposed new method Efficient Frequency Reuse (EFR), which is based on graph-coloring concept. Our Efficient Frequency Reuse method is using algorithms as EFR( ) and NEWFRE() for frequency allocation. In LTE, frequency reuse [1] is a technique of reusing frequencies and channels within a communication technology to increase capacity and improve the spectral efficiency. Frequency reuse is the basic concept of commercial wireless communications and involve the partitioning of radio frequency (RF) into cells areas. As every cell is configured to use radio frequencies within its boundaries only, these frequencies can be reassigned in other cells with less distance away from each other avoiding the interference. Such cells are considered as co-channel cells [8].

Our proposed novel method is a Efficient Frequency Reuse (EFR) procedure. It has considered the dynamic approach for reusing the frequencies. It has also included the proportional fair distribution of resources to users. The method has included the load on the neighboring cells while allocating resources to the users during handover. At user level it considers the optimal bandwidth distribution for all running applications. Hence our proposed EFR method is a improved method for interference mitigation and the handover.

The proposed method is applied for the heterogeneous network as macrocell-femtocell network. The proposed Efficient Frequency Reuse (EFR) method is using the concept of graph coloring. To apply the graph coloring criteria for frequency reuse method, the network should be considered as a graph. The network can easily transformed into a graph and the graph can be colored such that no two adjacent nodes have the same color. Hence this graph coloring approach becomes much more suitable for allocating the frequencies to adjacent femtocell to reduce the interference [1][2][5][10][11]. Let m be a given positive integer which is assigned as the number of channels available to service users. The m is called as chromatic number of graph which finds the minimum number of channels required to serve the users in the entire network. In the graph coloring the nodes of graph can be colored in such a way that no two adjacent nodes have the same color yet only m colors are used. This is termed as the m-colorability decision problem, which is NP-hard. Similarly in our EFR, users are allocated with the predetermine number of limited subchannels so that no adjacent users have same subchannel (color). And hence the channel assignment problem is also the NP-hard problem.

Since the number of subchannels are limited but the size of the network is variable. Hence the network may be heavily loaded or it may be underloaded. When the network is heavily loaded the number of subchannels are under provided. In these situation all the users can not be assigned by the subchannels. Whereas when the network is less loaded, the available subchannels are over provided. The unnecessary subchannels collision should be avoided in the under provided situation. We can formulate these conditions with the Efficient Frequency Reuse method.

The concept of planar graph is applied to construct the graph from the LTE network. The graph construction algorithm is given in detailed in procedure named "**Graph-Construct**". It constructs a graph G = (V, E) from the LTE network. Where V is the set of vertices and represents the users while E is the set of edges to represent the interfering neighbor users of the graph G. Edge is represented by two nodes (i, j) adjacent to each other. Edge is indicated by undirected edge and represented by a boolean number to show the relation between users (nodes). If two users i and j

are adjacent to each other then i and j are connected by an edge and represented as (i, j) which belongs to set E. Suppose we represent a graph by its adjacency matrix GRAPH(1:u, 1:u), where u is number of users and GRAPH(i, j) = true if (i, j) is an edge of G and otherwise GRAPH(i, j) = false. The adjacency matrix is represented by Boolean values since the algorithm is only interested in whether or not an edge exists.

Algorithm ***Graph-Construct***

// This algorithm is applicable to all Base-Stations and all users belonging to them.

// The term adjacent means connect the nodes by an edge.

// The graph is considered as bidirectional graph.

1. If Base-Stations *Bk* and *Bj* are near then consider them as adjacent to each other.
2. If the user *uk* belonging to base-station *Bk* and is cell center user of Bk
   then *uk* is adjacent to *Bk.*
3. If the user *uj* belonging to *Bj*, $j \neq k$ and *uj* is cell center of *Bj* then *uj* and *Bj* are adjacent and *uj* and *Bk* are not adjacent.
4. If *uk* is cell edge user of *Bk*, *uj* is cell edge user of *Bj* then consider *uk* and *uj* are adjacent to each other with the condition that *Bk* and *Bj* are adjacent.

The graph constructed using algorithm Graph-Construct gives the idea of the user's geographic location as well as the adjacent user relation from the diversity set and site deployment available from Radio Network Controller (RNC). Following table 1 shows the diversity set of the users, each user is associated with the femtocell (anchor point) and has more neighbor femtocells.

For the graph G, number of users are $| V | = u$.

The set of subchannels is $C = \{1, 2, ..., m\}$.

The objective function is f which assigns the suitable subchannel to the particular user by the following constraints:

C1: $\forall i, |f(i)| = 1$, each user should assigned only one subchannel.

C2: $\forall (i, j) \in E$, $f(i) \cap f(j) = 0$, no two adjacent users have the same subchannel assignment.

C3: if constraints C1 and C2 are true, minimize $| \{i \mid f(i) = 0\} |$, number of users which are not served should be minimum.

In our proposed EFR method, solution is given by the vector (X(1), ..., X(u)) where X(i) is the assigned subchannel to the user i. Applying the recursive backtracking formulation to the above constraints C1 and C2, the Efficient Frequency Reuse (EFR) algorithm is constructed to allocate subchannels to users. To execute the algorithm EFR, the network (or graph) is represented by an adjacency matrix u x u. The solution vector X is initialized to zero. The Efficient Frequency Reuse (EFR) method is invoked by the call to procedure EFR(1) that is for user 1. The procedure EFR() calls another procedure NEWFRE(), which identifies the suitable subchannel for k^{th} user. The channel is selected in such a way that it is different than the neighbor nodes. Hence the identified subchannel avoids the interference to the neighboring users. The algorithm works in sequence for X(1) through X(k − 1), to assigned subchannels in order to avoid interference. The main loop of EFR( ) repeatedly picks the next subchannel from the set of available subchannels and assigns it to X(k), and then calls EFR( ) recursively for k + 1.

Table 1. The diversity set of users in scenario for EFR and 3GPP

Users	Anchor FC set	Neighbor FC set
IMSI-1	FC- { 1 }	FC- { 2, 3 }
IMSI-2	FC- { 2 }	FC- { 1, 3 }
IMSI-3	FC- { 3 }	FC- { 1, 2 }
IMSI-4	FC- { 1 }	FC- { 2, 3 }
IMSI-5	FC- { 2 }	FC- { 1, 3 }
IMSI-6	FC- { 3 }	FC- { 1, 2 }

IMPLEMENTATION

The implementation of EFR and 3GPP schemes are done on the scenario having parameters as shown in table 2. The scenario is represented as a graph and the nodes of this graph are considered as users associated with anchor point as femtocells. The subchannels are allocated by Efficient Frequency Reuse method EFR with NEWFRE algorithm. The EFR method allocates the subchannels to the users such that no two adjacent users have the same channel. Due to this concept the neighboring users do not have the near subchannels and it can reduce the interference among users. Due to reuse of frequencies more number of users are served within the limited band of frequency with less Intercell Interference. The Efficient Frequency Reuse method with efficient-bandwidth distribution method also distributes the bandwidth according to the priority of running applications on the mobile station optimally. Hence the proposed method perform well for obtaining good system throughput and reduce intercell interference as well as system delay.

Our proposed method is using two algorithms to allocate the subchannels to the users. The first algorithm-1 is EFR( ), which is invoked from the first user. It calls the other algorithm-2 NEWFRE() to assigned the suitable subchannel to the current user. This NEWFRE() procedure verifies that the adjacent users (nodes) should not have the same subchannel. It compares the subchannel being allocated to the neighboring users with the current users subchannel to ensure that neighbor user have different channel assignment. The detailed steps of these algorithms are given in algorithm EFR and NEWFRE. The Efficient Frequency Reuse method reduces the intercell interference and provide good Quality of Service to users. The frequency reuse algorithm of the 3GPP method is also implemented for the same scenario as shown in table 2 to compare the methods.

Table 2. Simulation Parameters for implementation of EFR

Parameter	**Value**
Simtime	3.0 sec
No of HeNB	3
Cell Radius	250 m
Inter cellsite distance	1000 m
System Bandwidth	5 MHz
No of Resource blocks	25
Subcarrier Bandwidth	180 Khz
Subcarrier spacing	15 KHz
Power Noise Spectral Density	-120 dbm/Hz
Channel Model	Typical Urban
Carrier Frequency	300 MHz
No of macrocells	1
No of femtocells	3
No of users per cell	2
No. of resource block in edge subband	6
Macrocell Transmit Power	40 W
Macrocell Antinna Gain	15 dB
Femtocell Transmit Power	20 mW
Femtocell Antinna Gain	0 dB
Speed of user	500 cm/sec
DataRate	100 Gb/sec
Maximum Transmission Units	1500
Delay	0.010 sec
Path loss	Suburban deployment

Algorithm-1 : EFR(k)

// variable u represents the number of users in

//the network to be serve with subchannels.

//variable m represents the maximum number of subchannels

// use in the network to serve users.

//array x[ ] is a global array to store subchannel

// numbers allocated to users.

1. define the adjacency matrix for network

   of size u by u .

2. define array x[ ] for storing the subchannels

   assigned to users in the network,

   default value of x is 0 for all users.

3. Call procedure NEWFRE(k), k is the user

   which is to allocate the subchannel.

4. If x[k] = 0 that is no subchannel available

   for the k^{th} user then exit endif.

5. If all u users are allocated with subchannels

6. then serve users with these subchannels.

7. Else call procedure EFR(k + 1) that is recursive

   call for next user to allocate the subchannel.

8. Endif

9. repeat from step 3

10. end EFR

Algorithm-2 : NEWFRE(k)

1. Calculate the new subchannel number using

   $x(k) = (x(k) + 1) \bmod (m + 1)$

// m is the maximum number of subchannels use

// to serve the users in the network.

2. if x(k) = 0 that is no subchannel found

   then return endif

3. for all users j ← 1 to u

4. if user k and user j are adjacent

   to each other and x(k) = x(j) that is k and j

   have same subchannel

5. then exit endif

6. repeat for next user that is step 3

7. if all users are assigned subchannels and there are

   no more users to serve.

8. then return endif

9. repeat from step 1

10. end NEWFRE

RESULTS

The analysis of our proposed algorithms EFR is done using the parameters as:

1. System throughput and
2. System delay.

The throughput calculation is done from the receive bytes of the trace file and the system delay using the delay parameter of trace file.

1. Average System Throughput (T) in kbps is given by following formula (9):

$$T = \sum_{i=1}^{u} (R_x bi)/u \quad (9)$$

where $R_x bi$ is receive bytes of user i and u is total number of users. The table 3 shows the comparison of the proposed EFR and the 3GPP method for the user throughput. The figure 3 shows the graphical throughput comparison of EFR and 3GPP method. The system throughput of proposed EFR algorithm is 580.2984 kbps while 3gpp system throughput is 522.2536 kbps.

2. Average System Delay (D) is calculated from the users delay using the following formula (10):

$$D = \sum_{i=1}^{u} (D_{ui})/u \quad (10)$$

where D_{ui} is the delay of user i and u is total number of users. The table 4 shows the numerical value comparison of the users delay for algorithm EFR and 3GPP method. While the figure 4 represents the graphical comparison of EFR and 3GPP method. The analysis gives average system delay of EFR algorithm as 0.00623563 sec. While the average system delay of 3GPP is 0.01203277 sec.

Table 3. Throughput comparison between EFR and 3GPP

IMSI	EFR thruput (kbps)	3GPP thruput (kbps)
1	147.2048	109.4339
2	127.5136	99.51136
3	138.49136	156.732
4	76.28016	47.4128
5	30.84768	27.31456
6	59.9608	81.84896

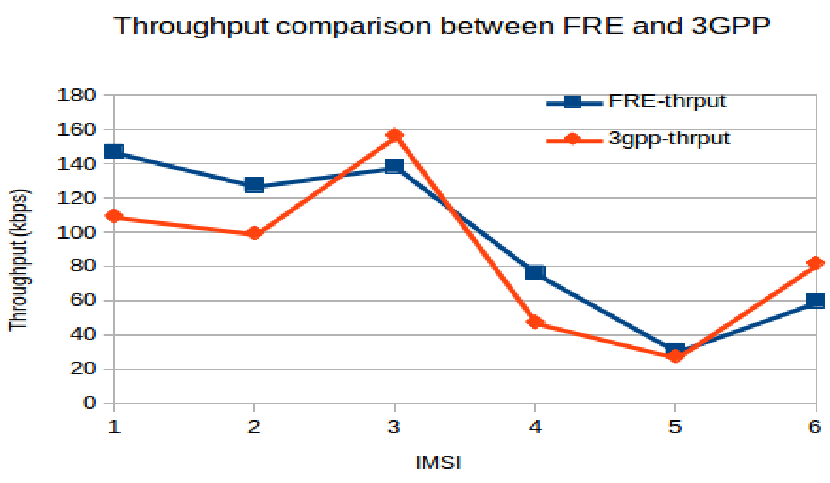

Fig 3: Throughput comparison between EFR and 3GPP

Table 4. Delay comparison between EFR and 3GPP

IMSI	EFR delay (sec)	3GPP delay (sec)
1	0.0063967	0.00733125
2	0.00591205	0.00989333
3	0.00977668	0.00996552
4	0.00344765	0.0173177
5	0.00338782	0.0176154
6	0.00849285	0.0100734

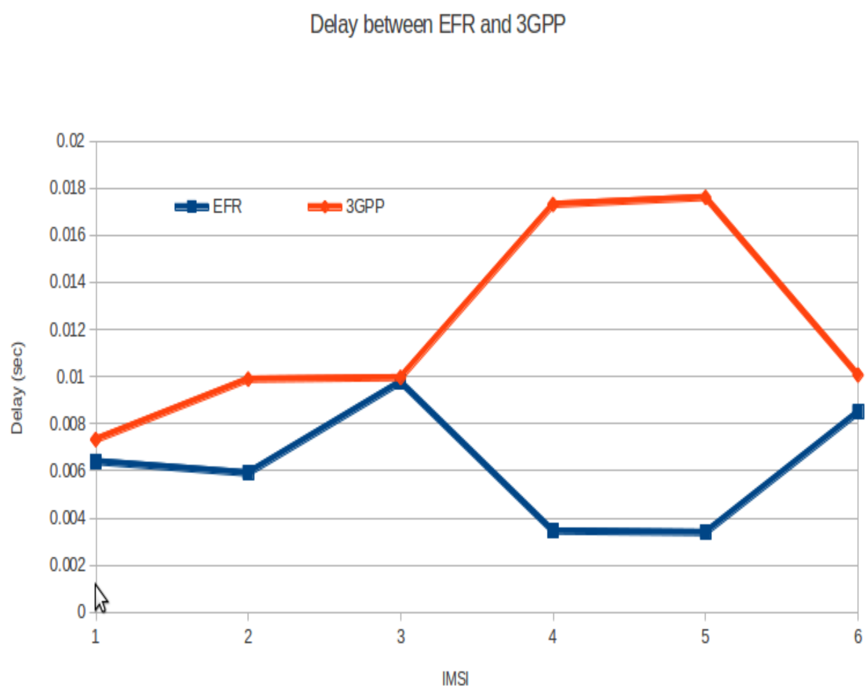

Fig 4: Delay comparison between EFR and 3GPP

CONCLUSION

In order to improve the performance of LTE network integrated with femtocells we introduced various algorithms. Our proposed algorithm is Efficient Frequency Reuse (EFR) algorithm. These algorithms are implemented for resource allocation in LTE technology with different parameters.

to do handover. The EFR considers interference and handover together. The implementation results of these algorithms are compared with the standard 3GPP method. Our results show that the bandwidth is shared efficiently and improves the user satisfaction rate as well as QoS as compare to the 3GPP method. These methods reduces interference with improved throughput and delay. Therefore our proposed algorithms outperforms in terms of throughput, user satisfaction rate, bandwidth utilization, energy consumption and delay than the standard 3GPP methods.

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