Performance of LTE-A Heterogeneous Network using NHFR Method

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***Abstract*—To overcome the interference problem in LTE/ LTE-A networks and in cellular networks in general, the frequency reuse technique is adopted. Interference is a common and big problem in cellular networks, especially in LTE-A due to the use of heterogeneous networks. Different frequency reuse methods such as soft frequency reuse, fractional frequency reuse and Reuse 3 are examples of the frequency reuse technique. In this paper, the NHFR (New Hybrid Frequency Reuse) method is used to mitigate interference in heterogeneous networks and furthermore the performance of such networks is investigated. Analytical solutions are obtained and different performance metrics are calculated. Also, simulations are performed by using the Vienna simulator and comparison with other methods is done. Both analytical and simulation results show that the NHFR method outperforms all the other methods.**

Keywords—LTE-A; heterogeneous network; frequency reuse; interference mitigation; NHFR

I. Introduction

Interference is a major problem in LTE homogeneous and LTE-A heterogeneous networks [1]. The homogenous network is defined as the network that consists of macrocells only [2]. The heterogeneous network is defined as the network of endoeBs of different transmission powers, i.e, it is the network of macrocells and low power nodes such as picocells and femtocells [3-5]. In homogenous networks, the interference occurs between the neighbouring macrocells because of the reuse of the same frequency in the different cells. In heterogeneous networks, the interference is divided into co-tier and cross-tier interference [3-5]. The co-tier interference is the interference that occurs between enodeBs of the same type (among macrocells OR among low power nodes). The cross-tier interference is the interference between macrocells and low power nodes. The frequency reuse technique is the most commonly technique used in interference mitigation in homogeneous and heterogeneous networks [6, 7].

Reuse 1, Reuse 3, soft frequency reuse (SFR) and fractional frequency reuse (FFR) are the most famous methods of the frequency reuse technique [6-8]. In order to differentiate between the different methods, an analytical model is obtained in [9]. In this model, a general expression of signal to interference and noise ratio (SINR) is derived and is applied to the different interference mitigation methods in homogenous and heterogeneous networks. In this paper, the heterogeneous network of macro and femto cells is considered, because the interference is a critical issue in heterogeneous network due to reusing the same frequency bands by the macro and femto cells. The NHFR method is implemented in [10] to mitigate the interference in homogenous networks. But, in this paper, NHFR is modified to include the interference in heterogeneous network by re-distribution of the frequency band between macro and femto cells. NHFR is compared to previously mentioned methods such as FFR and SFR, then results are obtained using analysis and simulation.

Different performance metrics that compromise between SINR values and the number of resources allocated for users, will be introduced in this paper to measure user performance. The average throughput per user is one of the most important metrics that is used to combine between SINR and user bandwidth [11]. The spectral efficiency is an important metric because a good value indicates a good user throughput. Finally, the fairness index metric is introduced to measure the fairness among different users with respect to the resource sharing for the different frequency reuse methods. This is because a high fairness index value indicates that all users have approximately the same throughput. These mentioned metrics will be calculated analytically and by simulation.

The Vienna simulator is used to measure the performance metrics in heterogeneous and homogeneous networks. NHFR was previously investigated in terms of measuring the amount of packet loss using RIVERBED simulator [10]. In this work, NHFR is investigated again in homogenous networks to study its performance regardless the used applications and the used simulator.

The paper is organized as follows. Section II describes the implementation of NHFR in heterogeneous network and the proposed system. Section III describes the different performance metrics. Section IV shows the analytical solution for the different methods. Section V shows the setup of Vienna simulator and the simulation results. Finally, section VI concludes the paper.

II. Implementation of NHFR in Heterogeneous Networks

SFR and FFR are the most commonly used methods for both homogeneous and heterogeneous networks [8]. In the SFR method, the total system bandwidth is used per each cell with different power allocation between the inner and outer regions, so it improves spectral efficiency and throughput. However, using the total system bandwidth causes interference between the neighboring cells and consequently causes performance degradation [12]. At the expense of the spectral efficiency and throughput, FFR was implemented to reduce the interference. In FFR, the total system bandwidth is not used in the cell, but it is divided into two parts. The first part is reused by all the cells in their inner regions. The second part is divided into three different parts as shown in Fig. 1 [13, 14] and reused by reuse factor 3 on the outer regions of the neighboring cells. NHFR method is implemented to combine the advantages of SFR and FFR. In NHFR, the cell bandwidth will be different from the system bandwidth, where each enodeB will use a different centre frequency to allow a guard band between the different cells. This guard band provides each enodeB with part of the new sub-carries that are not used by the neighboring one which leads to decreasing the interference between the neighboring cells. As mentioned before, the interference in heterogeneous networks is divided into two types: Firstly the interference between low power nodes or between macrocells (co-tier interference). Secondly, the interference between macrocells and low power nodes (cross-tier interference). In this paper, the low power nodes are considered to be femtocells which is commonly used [15]. Fig. 2 (a and b) describes the implementation of the NHFR method for a one tier heterogeneous network. The method depends on using different centre frequencies; it uses three different frequencies for the seven enodeBs by using reuse factor 3. The bandwidth around each centre frequency is divided into four different frequency bands (for example, the band around f2 is divided into Z1, Z21, Z22 and Z3); then these bands are distributed among macro and femto cells in the inner and outer regions. The distribution is optimized such that there is no co-tier interference between the macrocells and between femtocells in the same macrocell. Also, it mitigates the cross-tier interference between femtocells and macrocell inside the same cell and in the different cells. A little interference exists between outer regions of macrocells and the femtocells located in the centre regions of the neighbouring macrocells due to the limited resources. However, this interference is only for the macrocells that use f2 as a centre frequency, but the other macrocells that use the centre frequencies f1 or f3, do not suffer from this interference. NHFR method is compared with previously described methods and different performance metrics will be obtained using analysis and simulation.

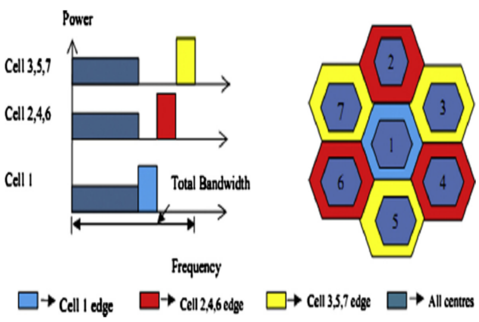

Fig. 1. FFR Implementation

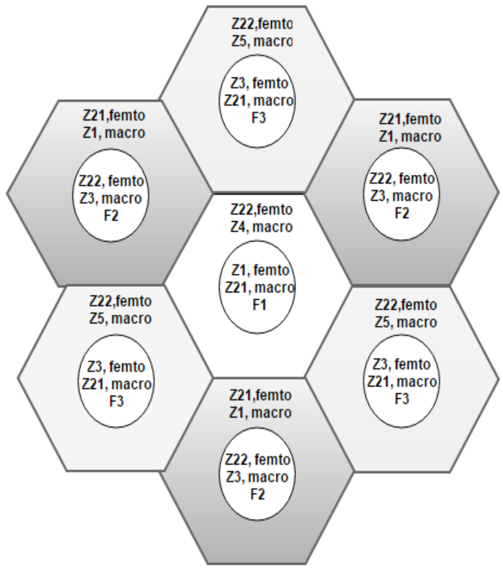

Fig. 2.a. NHFR Implementation

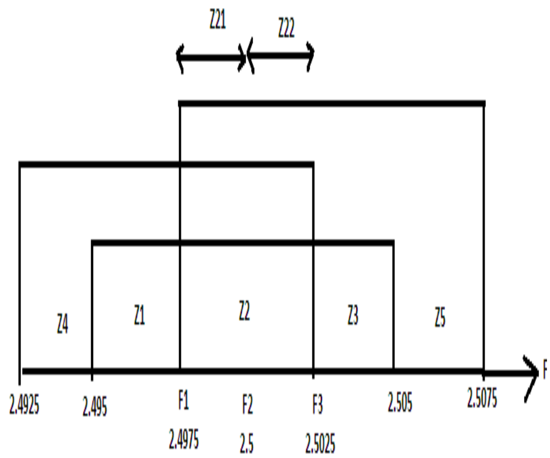

Fig. 2.b. NHFR Implementation

III. PERFORMANCE METRICS

In [9], NHFR method is modeled by deriving an expression for signal to interference and noise ratio (SINR). The SINR expression given below is generalized to include the other different methods in both homogeneous and heterogeneous networks as shown in the following equation.

$$SINR_i = \frac{P_{r,i}}{\sum_{m\neq i}^{M} I_m + \mu \sum_{m\neq i}^{M} \sum_{Lp} \sum_{z=1}^{Z} P_{r,z,m} + N_o} \quad (1)$$

where $P_{r,i}$ is the received power by the desired enodeB i, M is the number of interfering macrocells, I_m is the interference from the macrocell m, μ is a factor that equals one in case of heterogeneous networks and zero otherwise. L_p represents the number of types of low power nodes, Z is the number of low power nodes, $P_{r,z,m}$ is the received power of the low power node and N_o is the thermal noise power.

Although, the SINR is an important parameter when measuring user performance especially at the cell edge, it is not sufficient to measure the network quality [2]. This is because a high SINR value is observed when using different frequency allocation between the neighboring cells. This means that the frequency allocated is divided into small portions to be distributed among different cells in the same tier which negatively affects the number of resource blocks allocated for each user and consequently the amount of transmitted data. Therefore, other metrics that compromise between good SINR values and suitable number of resources for users, must be introduced to measure user performance. The average throughput per user is one of the most important metrics that is used to combine between SINR and user bandwidth as shown in the following equation.

$$T_i = B_i log_2(1 + SINR_i/\gamma) \quad (2)$$

where T_i is the average throughput per the desired user i, B_i is the bandwidth allocated per the desired user i, γ equals $-2/3(ln(5BER))$ and BER is the bit error rate threshold.

Also, the spectral efficiency is an important metric because a good value indicates a good user throughput. It is defined as the average throughput per users that can be transmitted over the allocated bandwidth as shown in (3). Finally, the fairness index is introduced to measure the fairness among different users with respect to the resource sharing for the different frequency reuse methods. This is because high fairness index values indicate that all users have approximately the same throughput. The fairness is defined in (4) according to Jains's formula [2].

$$\eta = \sum_{i=1}^{N} T_i \Big/ Total\ BW\ (Hz) \quad (3)$$

$$Fairness\ Index = \frac{(\sum_{i=1}^{N} T_i)^2}{N \sum_{i=1}^{N} T_i^2} \quad (4)$$

where N is the total number of users.

These metrics are obtained and the average throughput will be the main concern because it compromises between the number of resources allocated per user and the SINR.

IV. Analytical Results

The analytical computations are performed in order to make use of the application of the general SINR expression in comparing between the different interference mitigation schemes. All the mentioned performance metrics are function in SINR obtained in (1); therefore, the analytical results will be obtained by solving the SINR expression, then substituting in the equations of the different metrics. Solving equations is done by using the MATLAB tool and as shown in (1), the SINR expression is a function of the different parameters such as transmit power, antenna gain, number of cells and inter-centre distances between cells. Solving equations requires defined values for these parameters. Table I shows the network parameters (it will be used for simulation); only the fading channel gain is assumed to be unity (flat fading channel) and this is for simplicity in solving the mathematical equations [12].

A. NHFR Analytical Results in Heterogeneous Networks

SFR method is used for comparison with NHFR in this analysis. The SINR expression in (1) is obtained for macro and femto users and also for centre and edge users. Therefore, there are four varieties in calculating the performance; it can be calculated for macro-edge users, macro-centre users, femto-edge users and femto-centre users. In this paper, the analytical solution is obtained for macro-edge users. Edge user is chosen rather than centre user, because it suffers from high degradation in performance due its large distance from the serving enodeB. Also, macro user is chosen rather than femto user, because femtocells are located within macrocells in order to mitigate the coverage in bad areas (dead zones) and offload traffic from the macrocells and consequently improve overall performance of the macrocells [15]. Therefore, the objective is to measure macro-user performance in the presence of femtocells. The average throughput per macro-edge user is obtained using the mathematical expression in (2). Table II shows the average throughput and the fairness index per macro-edge user using NHFR and SFR methods. The values in the table show that the NHFR method outperforms the SFR method.

B. NHFR Analytical Results in Homogeneous Networks

The NHFR method was investigated before in [10] using the RIVERBED simulator; however, it is investigated again in this paper to show its performance regardless of the used application and the used metric. Previous results in [10] show that NHFR outperforms SFR in term of traffic management in intelligent transportation system applications. The analytical results are obtained by solving the previous mathematical equations using MATLAB tool and comparing between NHFR and SFR. Table III shows the different performance metrics for the NHFR and SFR methods and the values in the table show that the NHFR method is better than the SFR method. Also, Fig. 3 shows the performance of NHFR with respect to the average throughput versus the different frequency reuse methods used in homogeneous networks. The figure shows that the NHFR method not only outperforms the SFR method, but it outperforms the other methods such as Reuse 1 and FFR.

TABLE I. NETWORK PARAMETERS

Parameter	Value
number of macrocells	7, each with 3 sectors
enodeB transmit power	10 W
enodeB antenna gain	15 dBi
inter-enodeB distance	500 m
bandwidth	10 MHz
operating frequency	2.5 GHz
scheduler	round robin
femtocell transmit power	20 mW

TABLE II. ANALYTICAL RESULTS OF NHFR METHOD IN HETEROGENEOUS NETWORKS

Method	Average Throughput (Mb/s)	Fairness Index
E-NHFR	1.1613	0.6487
SFR	0.966	0.5847

TABLE III. ANALYTICAL RESULTS OF NHFR METHOD IN HOMOGENEOUS NETWORKS

Method	Average Throughput (Mb/s)	Spectral efficiency (Mb/s/Hz)	Fairness Index
NHFR	2.6926	2.9618	0.5601
SFR	2.44	2.9	0.5285

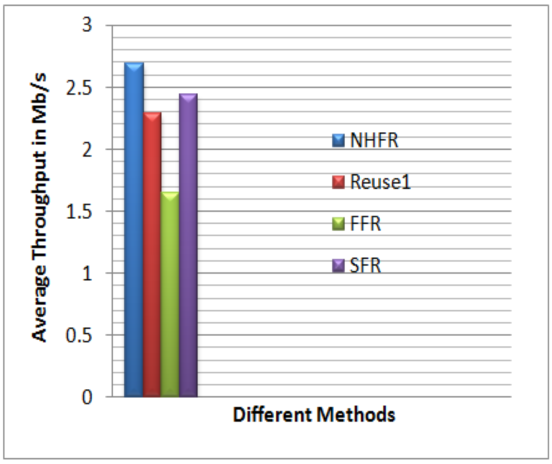

Fig. 3. Analytical Results of NHFR

V. SIMULATION RESULTS

The Vienna simulator is used as the simulation tool; it is a MATLAB-based LTE downlink system level simulator developed by Vienna University of Technology [16]. This simulator tool supports only the FFR and Reuse 1 methods and considers homogeneous power allocation. Therefore, the NHFR method and the other frequency reuse methods such as SFR and Reuse 3 are implemented with the existing FFR and Reuse 1 methods (by changing the frequency distribution between the cells according to each method). The simulator is first tested to guarantee its accuracy. Testing is done by using the simulator to obtain results and comparing them to similar results in the literature. Testing proved that the simulator produces the same results as in the literature. The simulations done in this paper do not depend on a certain application or a certain load traffic, but they are general simulations.

A. *Network Parameters*

A One tier heterogeneous network is considered in this work. The tier consist of seven macrocells; each one with three sectors and each sector contains a number of randomly distributed femtocells. Fig. 4 shows the used network layout on the Vienna simulator, where the red circles represent the macrocells and the red squares represent the femtocells. Each circle contains three sectors and these sectors are numbered from 1 to 21. The plus sign represents the user location. The simulations are done by using the parameters in Table I [2].

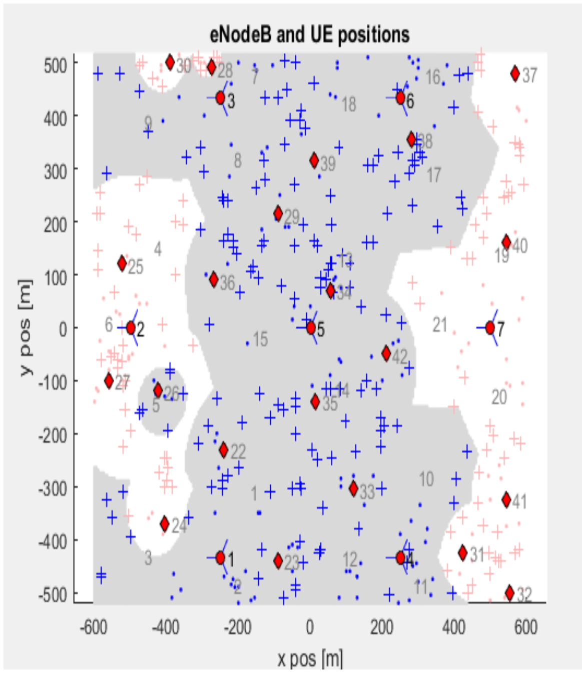

Fig. 4. Network Layout

B. NHFR Simulation Results in Heterogeneous Networks

The NHFR method for the heterogeneous network is implemented on the simulator by changing resource allocations between macro and femto cells in the inner and outer regions. As shown in Fig. 4, the simulated scenario consists of 7 macrocells (the inter-centre distance between any two macrocells is 500 m as shown in the figure); each macrocell consists of 3 sectors and each sector serves 10 users. Inside each sector, a femtocell with 10 users is randomly located. The simulator is run many times using a simulation time of 10 msec (the time of one frame, where the frame consists of 10 sub-frames, each one consists of 1 msec). Table IV shows the average throughput of any user inside the cell for the NHFR, FFR and SFR methods. The values in the table indicate that the NHFR method outperforms the SFR method by about 36.8% and outperforms the FFR method by about 74.8%. This is because the NHFR method provides each cell with new resources more than SFR due to the use of different centre frequencies. This allows the interference to be reduced and SINR to be increased and consequently the throughput is increased. The values in the table follow the same trend of the analytical results, but with a little difference between the simulated and the analytical values (analytical results are higher than the simulated ones). This is because flat fading channel with unity gain was assumed in the analytical solution, while Vienna simulator considers a practical scenario with multipath fading channel.

C. NHFR Simulation Results in Homogneous Network

As mentioned before, the NHFR method was investigated in [10] using the RIVERBED simulator in terms of amount of packet loss in the context of an intelligent transportation system application. In this paper, NHFR performance in homogenous network is investigated using the Vienna simulator regardless of the application. The network layout in Fig. 4 is used, but without femtocells (homogeneous network). Table V shows the mentioned performance metrics for the NHFR and SFR methods. The values in the table show that the NHFR method outperforms the SFR method for the different metrics. For example, the average throughput of the NHFR method outperforms the average throughput of the SFR method by about 37.1%. Therefore, the NHFR method is better than the SFR method in general and not for a specific application or a specific performance metric.

Finally, it is shown from all the previous analytical and simulations results for both homogeneous and heterogeneous networks that NHFR method outperforms the other methods such as FFR and SFR. The reason behind that is the large number of unused sub-carriers that are provided by NHFR due to using a different centre frequency per each cell as shown in Fig. 2 (a and b). These unused sub-carriers reduce the interference between the neighboring cells, increase the SINR value and consequently increase the average throughput and the overall system performance.

TABLE IV. SIMULATION RESULTS OF NHFR IN HETEROGENEOUS NETWORK

Method	Average Throughput (Mb/s)
E-NHFR	0.9781
SFR	0.715
FFR	0.5594

TABLE V. SIMULATION RESULTS OF NHFR IN HOMOGENOUS NETWORK

Method	Average Throughput (Mb/s)	Spectral efficiency (Mb/s/Hz)	Fairness Index
NHFR	1.0052	2.97	0.65
SFR	0.733	2.19	0.53

VI. CONCLUSION

Interference, limited resources and resource sharing, dead zones and other problems are considered as main aspects in any mobile network. In terms of LTE and LTE-A networks, interference is the main problem due to reusing the same frequency band among neighboring cells because of using OFDMA as a multiple access technique. Therefore, the interference problem is the main concern in this paper. Many interference mitigation techniques are used to solve or to reduce the interference problem. The frequency reuse technique is the most commonly used one in both LTE homogenous networks and LTE-A heterogeneous networks. Fractional frequency reuse and soft frequency reuse are the most famous methods of frequency reuse technique.

In this paper, the NHFR method is investigated using the Vienna simulator in terms of different performance metrics and regardless of the application. Results show that the NHFR method outperforms the SFR method irrespective of the used application and the used metric. Also, the NHFR method is applied to mitigate the interference in LTE-A heterogeneous networks. The heterogeneous network in this paper is assumed to consist of macro and femto cells. The frequency distribution in NHFR is optimized in order to mitigate the co-tier interference among the same type of cells and cross-tier interference among the different types of cells. Analytical solutions are obtained for both homogenous and heterogeneous networks using SINR expression and different performance metrics are obtained. Simulation results are obtained by using the Vienna simulator and results showed that the NHFR method improves edge user performance more than the other methods. Also, the analytical and the simulation results have the same trend.

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