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ORIGINAL RESEARCH

# An Approach to Reduce Interference Using FFR in Heterogeneous Network

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**Abstract**
As the world is progressing towards 5G technology, its primary requirement is high throughput, low latency, high spectrum and energy efficiency and guaranteed QoS. High throughput is achievable when the user (UE) and the base station/Macro eNodeB (MeNB) are close to each other. This is achieved by using femtocell or Home eNodeB (HeNB). It is a kind of small cell. The femtocell needs to exist along with macrocell. Hence, they will share the resource along with the macrocell. There arises serious inter-channel and intra-channel interference (ICIC). To mitigate the interference, various solution methodologies, e.g. power control, co-operative communication and absolute blank sub-frame, can be used. In this research work, fractional frequency reuse method is discussed where the cell is segregated into centred and edge regions. All the centred, i.e. inner, regions can be assigned with the same frequency sub-band. Edge regions, i.e. outer region, can be assigned with different frequency sub-band with reuse factor of three. In this technique, ICIC can be reduced significantly. Hence, QoS can be improved and throughput of the system can also be enhanced. The outage probability can be reduced since cell-edge users are assigned with different sub-bands with high power.

**Keywords** FFR · Interference · Femtocell · Heterogeneous network · Outage probability

## Introduction

Present-day communication systems are designed by keeping human users in mind. Design of communication system needs to consider device-to-device communication with real-time constraints for example driverless cars with machine learning and artificial intelligence, enhanced mobile broadband services (eMBB), traffic control monitoring and optimization on real-time basis, emergency and disaster response, energy efficient smart grid, remote surgery, i.e. e-health, efficient industrial communication, unmanned air vehicle (UAV), IOT and cloud computing. This leads to ultra-high user density. All these features are going to be feasible in 5G. The 5G technology includes tactile internet, Gigabit wireless, super real time and reliability, machine type communication. This requires smaller cell size, high spectral efficiency, high energy efficiency, ultra-high data rate, low latency and negligible inter-channel and intra-channel interference (ICIC). Multi-tier heterogeneous cellular network (HetNet) is already in use in LTE and LTE-A. The rate of densification of the network leads to higher interference and hence degradation of quality of service. Co-operative communication, power control and ABS are some of the methods used to minimize the interference. In this research work, fractional frequency reuse concept is adopted. The MeNB coverage area (cell) is segregated into two regions: i.e. centre and edge regions. The centre part of the cell can have frequency reuse (FR) of one and the edge part can have different frequency as compared to the centre part.

Commonly two different fractional frequency reuse (FFR) techniques are there:

Strict fractional frequency reuse (strict FFR) and soft frequency reuse (SFR) [1, 2].

(1) Strict FFR: Strict FFR is different from the frequency reuse used extensively in outer MeNB cell, i.e. hexagonal

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grid deployments. Figure 1(i) explains strict FFR for a hexagonal grid modelled structure with a cell-edge reuse factor of $\alpha = 3$. The cell is divided into two regions: inner region, i.e. centre area, and outer region, i.e. edge area. UEs in each inner cell area (centred) are assigned a common sub-band of frequencies where cell-edge UEs' bandwidth is partitioned across cells based on a reuse factor of $\alpha$. In total, strict FFR needs a sum of $\alpha + 1$ sub-bands. Centre UEs do not use any frequency spectrum (sub-carrier) with edge UEs; hence, it decreases interference for twain cell-centre and cell-edge UEs.

(2) Soft frequency reuse (SFR): Fig. 1(ii) explains a SFR implementation with a reuse factor of $\alpha = 3$ on the cell edge. SFR uses the similar cell-edge spectrum bandwidth separating method as strict FFR, but the centre UEs are granted to share frequency sub-carriers with edge UEs in different cells. Because cell-centre users share the frequency channel with neighbouring cells, centre UEs convey at lower power margin in comparison with the cell-edge UEs [1, 3]. SFR has higher spectrum efficiency than strict FFR, but it creates larger interference to both cell-centre and edge UEs.

The organization of the research paper is as follows: Section 1.1 presents overview of small cell from heterogeneous cellular network (HCN) perspective, Sect. 2 system model, Sect. 3 estimation of outage probability, Sect. 4 results and discussion, and in Sect. 5 conclusion and future scope is given.

## Overview of Small Cell Network

As wireless technology revolution happens in every 5 years, now the world has enters towards convergence. It means device-to-device communication, connecting the devices to the cloud server and remotely monitoring the behaviour of the devices are taking place. If there is any abnormality, then necessary action has to be taken immediately and can be notified on real-time basis to the user. This is only possible with high-speed internet service, lower latency and higher security of the data.

We are moving towards 5G technology which promises higher spectral efficiency, high peak and average data rate, ultra-low end-to-end latency (around 1 ms), ultra-dense device connection density (nearly $10^6$ times), high energy efficiency in comparison with the existing wireless cellular network, decrease in cost and assured quality of experience (consistent) [4, 5]. The upcoming ten enabling technologies for 5G network are identified as:

i. Heterogeneous cellular network (HetNet), ii. device-to-device (D2D) communication, iii. massive multiple-input multiple-output (MIMO), iv. millimetre wave (mmWave), v. full-duplex communication, vi. energy-aware communication, vii. energy harvesting, viii. cloud-based radio access network(C-RAN), ix. Internet of Things (IOT) and x. virtualisation of network functionalities/resources (VNF).

High-bandwidth-consuming applications, e.g. downloading of data, streaming application, online gaming and chatting and video call service, are mainly done by fixed users inside the home. These kinds of users can be separated from outside mobile users and can be shifted to indoor solutions, e.g. Home eNB or small cell.

*Small cell* gain popularity because of its very low energy consumption and can provide broadband coverage capacity. The HetNet integrates macro-, micro-, pico- and femtocells. The different types of cells can be differentiated by their transmission power ($P_t$), coverage capacity and user association. The usage of small cells has a large benefit to enhance the spatial reuse of radio resources and also to increase the transmit power efficiency and in turn, the network energy efficiency (EE). This can be achieved by offloading UEs from congested MeNB to under-loaded nearby small cells.

Hence deploying femtocell can reduce the outage probability and in turn enhance indoor coverage probability for cellular networks. The cognitive femtocells reuse the macrocell spectrum, and co-channel interference between femtocell and macrocell should be taken into consideration. To eliminate the two-tier interference/inter-channel interference, the downlink inter-cell interference coordination (ICIC) methodology can be categorized into two types:

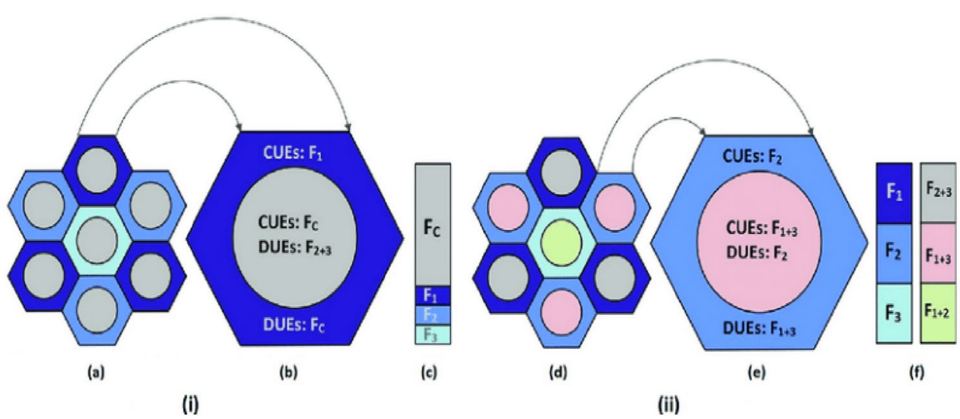


Fig. 1 (i) Strict FFR and (ii) soft FFR deployments with $\alpha = 3$ reuse factor for cell-edge user in a hexagonal grid cellular network

i. frequency reuse and ii. power control technique. But, it is cumbersome to use power control technique in practical scenario, because of multiple constraints such as flexible power control mechanism using resource elements (RE) and UE-definite specific variables. Therefore, using frequency reuse scheme is more dynamic and adaptive to reduce inter- and intra-tier interference between the two tiers [6–11].

## System Model

Consider the network with $M$ cells and each cell having 'K' users and sharing '$N_{\text{sub}}$' no. of sub-carriers. Users are distributed in a uniform random manner inside the cell. The simulation is done by using homogenous spatial Poisson point process (PPP) in MATLAB. The transmitted power using sub-carrier '$m$' by the cell '$n$' is given by, $P_{m,n}$. '$P_n^{\max}$' is the maximum radiated transmission power of cell '$n$'. 'B' is the total bandwidth. It has to be shared with '$M_{\text{sub}}$' sub-carrier. Each sub-carrier bandwidth '$B_{\text{sub}}$' can be calculated as $B_{\text{sub}} = \frac{B}{M_{\text{sub}}}$

The analytical expression for downlink signal-to-interference-and-noise ratio (SINR) of a user '$u_n$' in a sub-carrier '$m$' in cell '$n$' in the downlink direction is given by

$$\text{SINR}_{u_n,m,n} = \frac{P_{m,n} G_{u_n,m,n}}{I_{m,u_n} + \sigma^2_{m,u_n}} \tag{1}$$

where '$\sigma^2_{m,u_n}$' is the AWGN noise power over sub-carrier '$m$'. $I_{m,u_n}$ is the interference on sub-carrier '$m$' measured at the receiver of the user '$u_n$'. The interference can be given by

$$I_{m,U_n} = \sum_{j\neq n, j=0}^{N} \left( \sum_{u_j=1}^{U_j} \alpha_{u_j,m,j} \right) .P_{m,j} G_{u_n,m,j} \tag{2}$$

In Eq. (2), $u_j$ is the no. of users served by the cell '$j$'. $\alpha_{u_j,m,j}$ is the binary variable to represent allocation of the sub-carrier. '$\alpha_{u_j,m,j} = 1$' if the subcarrier '$m$' is allocated to the '$u_j^{th}$' user in cell '$j$'. '$\alpha_{u_j,m,j} = 0$' otherwise.

In each cell, an LTE resource block (RB), along with the sub-carrier in that RB, can be assigned to a single user at a given TTI. In each cell '$j$', the following condition can be confirmed

$$\sum_{u_j=1}^{U_j} \alpha_{u_j,m,j} \leq 1 \tag{3}$$

The expression '$j=0$' in Eq. (2) expresses the interference from the MeNB, whereas the summation from $j = 1$ to $j = n$ represents the interference from the femtocells.

After the SINR measurement, the throughput of the UE can be calculated. The spectral efficiency (SE) in bps/Hz of UE '$u_n$' on sub-carrier '$m$'in the nth cell, $\text{SE}_{U_m,n}$ can be estimated by the Shannon's equation as follows:

$$R_{U_n} = \sum_{m \in j_{\text{sub},U_n}} B_{\text{sub}} * \log_2(1 + \text{SINR}_{U_n,m,n}) \tag{4}$$

$$\text{SE}_{U_n,m} = \log_2(1 + \text{SINR}_{U_n,m,n}) \tag{5}$$

The most significant factor in FFR system is how to separate the UEs as centre and edge UEs since the SINR of the user depends on the gain of the UE and in fact it depends on the distance of the UE from the location of the base station and the path loss coefficient.

Hence, a threshold of the SINR needs to be set and if the $\text{SINR}_{\text{Measured}} > \text{SINR}_{\text{Threshold}}$, then the UE is in the centre region.

If $\text{SINR}_{\text{Measured}} < \text{SINR}_{\text{Threshold}}$, then the UE is in the edge region.

## Estimation of Outage Probability

This section presents explanation for outage probability. Outage is a significant parameter to take into account since it has huge impact on cell-edge UE quality of service (QoS). The outage probability can be computed as the probability that a UE's measured SINR is less than the predefined threshold.

$$O(T) = P(\text{SINR}_{\text{Measured}} < \text{Threshold}) \tag{6}$$

In this research work, analysis of FFR technique is presented. If FFR is not used, the UE tries to attach to its nearest BS and it is in coverage of that BS. When FFR is used, the UE calculates its SINR to the nearest BS, and if it is less than the threshold, then the BS chooses to transmit in a separate FFR channel arbitrarily selected from $\alpha$ sub-channels reserved for the FFR UEs. If this type of scenario happens, the user can be called as cell-edge UE. Note that the coverage (for cell-edge UEs) is determined upon both SINR measures: first the SINR on the common sub-channel to determine the status (cell-edge or not) and second the actual SINR on the newly assigned sub-channel. Both the measures of SINR are considered since the interference is produced by the similar set of BSs, and this is the reason the investigation is highly demanded.

Hence, a predetermined threshold of the SINR needs to set, and if the $\text{SINR}_{\text{Measured}} > \text{SINR}_{\text{Threshold}}$, the UE is in

### Algorithm I (for strict FFR)

**Step 1**. Measure the SINR, i.e. $\text{SINR}_{\text{Measured}}$

If $SINR_{Measured} > SINR_{Threshold}$: Yes, then the UE is centred user (same sub-channel shared by all cells)

If **No**, the UE is an **edge** user (new sub-channel assigned to them from the $\alpha$ i.e. available sub-channels allotted for the edge UEs)

*Step II*. For edge user, now measurement needs to be done with respect to the new sub-channel, the interference power and the UE's fading measures have exchanged, but the position of the UE with respect to the base stations has not changed; hence, the effective path loss remains equal.

*Step III*. For the centred UEs in the case of strict FFR. The outage probability of the inner UE does not rely on $\alpha$ since the UE is assigned a sub-channel commonly shared by all the base stations.

### Soft FFR (SFR)

The main difference between SFR and strict FFR is the power control, rather than frequency reuse for the edge UEs. The base stations can reuse all the sub-channels, but the design parameter ($\beta$) can be applied exclusively to one of the $\alpha$ sub-channels.

## Results and Discussion

The research work describes two layer heterogeneous cellular network including macro cell and femtocell. Here, three scenarios are considered. i. Rural Macro, ii. Urban Macro, iii. Urban Micro. The different scenarios can be simulated by varying The base station (BS) density $\lambda_{BS}$ and user density $\lambda_{UE}$. In urban areas, the density of the BS and user are high in comparison with rural scenario.

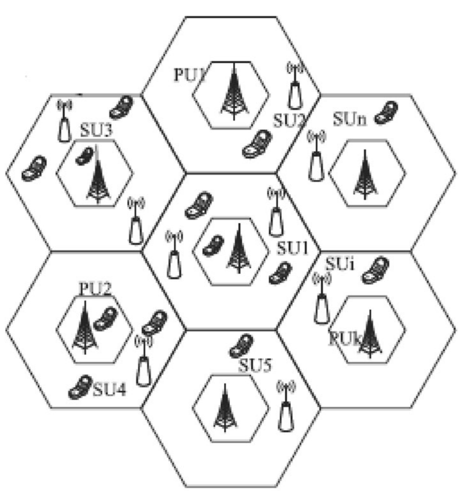


**Fig. 2** Heterogeneous cellular network. *PU* primary user attached to the macro base station (MBS). *SU* the secondary user attached to the femto base station (FBS)

In this research work, interference between the neighbouring cells can be mitigated and spectrum resources can be used efficiently. As the inter- and intra-channel interference decreases the quality of the service increases, total throughput of the cell increases. The sum total of throughput for all the users is calculated and represented in Fig. 2. As the number of femtocells increases, the total throughput decreases due to inter- and intra-channel interference. The UEs will enter in outage and QoS, i.e. total throughput reduces. The maximum achievable throughput is 1.75 Mbps as per Fig. 3.

Table 1 presents various simulation parameters of the heterogeneous cellular network. Table 2 shows comparison of throughput of centre users for without FFR, strict FFR and soft FFR. It is observed that strict FFR and soft FFR provide better throughput (more than twice) in comparison with 'without FFR'. As interference reduces, throughput enhances. Table 3 shows throughput for edge users, and Table 4 shows overall throughput of all UEs.

Figure 4 shows total throughput of all UEs for strict FFR, soft FFR and without FFR. It is clearly shown that strict FFR and soft FFR has comparable results and reduced throughput for without FFR because of interference. Hence, interference can be significantly reduced using the FFR scheme. Without

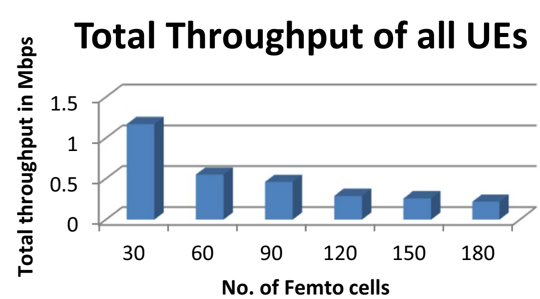


**Fig. 3** Total throughput of all UEs

**Table 1** Simulation parameters of the heterogeneous network

| Parameters | Value |
|---|---|
| Total number of macro base stations | 19 |
| Total number of users in a macro cell | 100 |
| Transmitting power of MeNB | 46 dBm |
| Transmitting power of HeNB | 20 dBm |
| System bandwidth | 10 MHz |
| Sub-carrier bandwidth | 180 kHz |
| Cell radius | 250 m |
| Carrier frequency | 2 GHz |
| Noise power spectral density | − 174 dBm/Hz |
| Noise figure | 7 |
| Power factor | 0.4 |

**Table 2** Throughput of centre users (in Mbps)

| No. of femto-cells | Without FFR | Strict FFR | Soft FFR |
|---|---|---|---|
| 30 | 2.883 | 6.8935 | 7.0158 |
| 60 | 1.123 | 2.096 | 2.2078 |
| 90 | 0.8154 | 1.2068 | 1.2955 |
| 120 | 0.5956 | 1.0404 | 1.1047 |
| 150 | 0.417 | 0.866 | 0.9098 |
| 180 | 0.4096 | 0.7625 | 0.7926 |

**Table 3** Throughput of edge users (in Mbps)

| No. of femto-cells | Without FFR | Strict FFR | Soft FFR |
|---|---|---|---|
| 30 | 0.0201 | 0.041 | 0.1633 |
| 60 | 0.0111 | 0.0375 | 0.1494 |
| 90 | 0.0072 | 0.0297 | 0.1184 |
| 120 | 0.0058 | 0.0216 | 0.0859 |
| 150 | 0.0045 | 0.0147 | 0.0584 |
| 180 | 0.0038 | 0.0101 | 0.0402 |

**Table 4** Overall throughput (in Mbps)

| No. of femto-cells | Without FFR | Strict FFR | Soft FFR |
|---|---|---|---|
| 30 | 2.6755 | 3.7111 | 3.914 |
| 60 | 1.1471 | 1.5915 | 1.6981 |
| 90 | 0.6606 | 0.9606 | 1.0641 |
| 120 | 0.5735 | 0.7885 | 0.8491 |
| 150 | 0.5155 | 0.7449 | 0.7845 |
| 180 | 0.3668 | 0.6236 | 0.6565 |

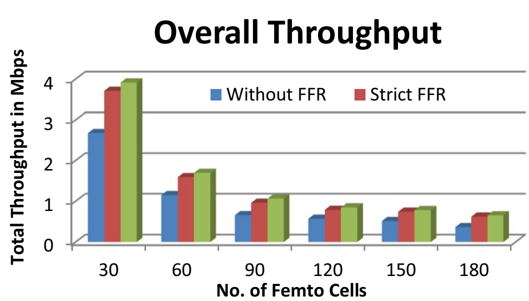


**Fig. 4** Comparison of sum total throughputs of strict FFR, soft FFR and without FFR

FFR, maximum obtainable throughput is 3Mbps, whereas with FFR throughput significantly increased to 7Mbps, which is more than double the throughput of without FFR

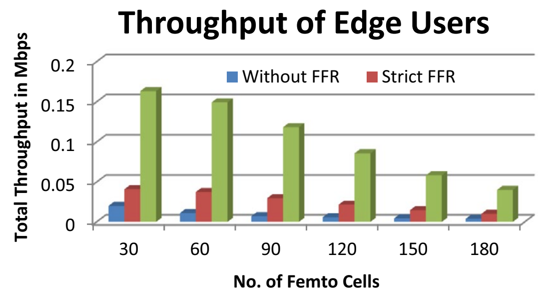


**Fig. 5** Comparison of sum total throughputs of edge users for strict FFR, soft FFR and without FFR

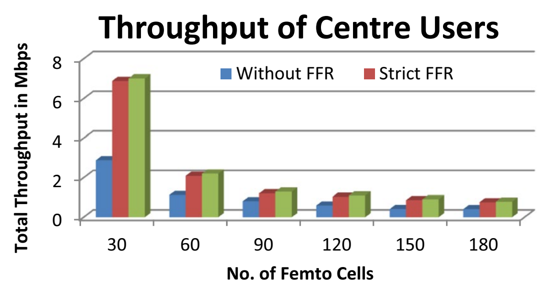


**Fig. 6** Comparison of total throughput of centre users for without FFR, strict FFR and soft FFR

Figure 5 shows total throughput of all the UEs at the edge of the cell. It's clearly shown that the soft FFR and strict FFR have better throughput than without FFR. The total throughput of edge UEs is about 0.165 Mbps and 0.04Mbps for soft FFR and 0.02Mbps for without FFR.

Figure 6 shows total throughput of centre UEs for strict FFR, soft FFR and without FFR. It is observed nearly equal throughput for strict FFR and soft FFR of about 7 Mbps and for without FFR throughput is of 3 Mbps because of interference.

Figure 7 shows graphical representation of outage probability of cell-edge UEs as a function of SINR threshold in dB for strict FFR, soft FFR and without FFR as a function of SINR. Outage probability in without FFR scenario is 20% more compared to strict and soft FFR as interference level is more.

Figure 8 shows probability of outage as a function of SINR threshold in dB of cell-centre UEs for strict FFR, soft FFR and without FFR

## Conclusions and Future Scope

Hence, it can be concluded that by segregating the centre UEs from edge UEs of a cell, assigning different Frequency channels for both centre and edge UEs the interference level can be reduced significantly. Hence, total throughput of the

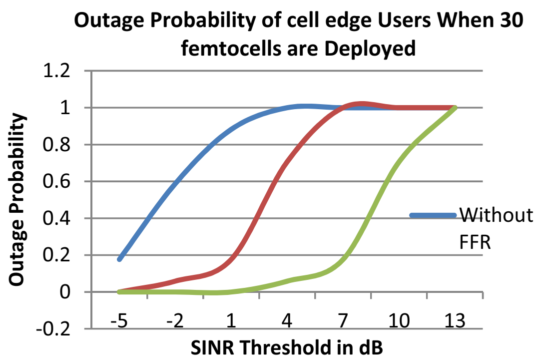


**Fig. 7** Probability of outage of cell-edge UEs for strict FFR, soft FFR and without FFR

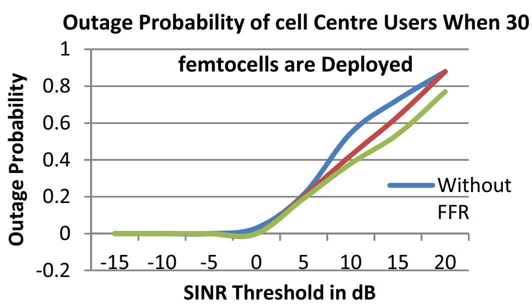


**Fig. 8** Probability of Outage of cell-centre UEs for strict FFR, soft FFR and without FFR

cell can be increased by 100% and the outage probability can be reduced by 20%. The simulation shows that performance of the heterogeneous cellular network located at FFR scenario will be surely improved.

As we are migrating towards 5G technology, ultra-densification of the network will be the real scenario. As the UE gets close to the base station, signal strength received by the UE from the attached BS will be large. But simultaneously the UE can get signals from nearby multiple BSs. These signals can be termed as interference which can degrade the SINR ratio. Hence, necessary steps need to be considered to reduce the interference which in fact increases the capacity, data rate and spectral efficiency.

This work can be further extended for mobile users with user's fairness as a constraint and adaptability of centre region radius and resource allocation can be dynamically controlled as per user's movement.

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