



PERFORMANCE OF HYBRID NETWORK IN FRACTIONAL FREQUENCY REUSE AND FEMTOCELL POWER CONTROL SCHEMES

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ABSTRACT

The Fractional Frequency Reuse (FFR) scheme combines the benefits of universal Frequency Reuse and Frequency Reuse Factor (FRF) 3. Universal Frequency Reuse scheme has high spectral efficiency while FRF=3 scheme is normally used to mitigate Inter-cell Interference (ICI) in a cellular system. Nevertheless, the advancement of the wireless technology does not stop here. The trend of Long Term Evolution-Advanced (LTE-A) is still looking forward to further penetration in better coverage, higher capacity and higher spectrum efficiency. Femtocell is a promising option in terms of cost-effectiveness, coverage and capacity improvement in hybrid network. Furthermore, the physical size of Femtocell allows it to be deployed at "Died zone" and improve the cell-edge user performance. This paper evaluates the performance of hybrid network with three different networks, universal FRF, FFR scheme and FFR with Femtocell power control scheme. The performance is evaluated base on SINR experienced by Macrocell users and Femtocell users. The ultimate goal of the research is to analyze the performance of hybrid network and further reduce the impact of the interference generated by Femtocells. The result shows that both FFR and power control schemes improve the SINR of cell edge Macrocell user.

Keywords: fractional frequency reuse, long term evolution-advanced, femtocell.

INTRODUCTION

The Fractional Frequency Reuse (FFR) scheme combines the benefits of universal Frequency Reuse and Frequency Reuse Factor (FRF) 3. Universal Frequency Reuse scheme has high spectral efficiency while FRF=3 scheme is normally used to mitigate Inter-cell Interference (ICI) in a cellular system. Nevertheless, the advancement of the wireless technology does not stop here. The trend of Long Term Evolution-Advanced (LTE-A) is still looking forward to further penetration in better coverage, higher capacity and higher spectrum efficiency. Femtocell is a promising option in terms of cost-effectiveness, coverage and capacity improvement in hybrid network. Furthermore, the physical size of Femtocell allows it to be deployed at "Died zone" and improve the cell-edge user performance. This paper evaluates the performance of FFR in hybrid network structured by Femtocells. The performance is evaluated base on SINR experienced by Macrocell users and Femtocell users.

RELATED WORKS

(Kinoshita *et al.*, 1989) is the first who suggested reusing the frequency by playing the second layer network in Macrocell network. The "Frequency Double Reuse" (DR) technique encourages the reuse of frequency bands in urban area for indoor cordless telephone. This concept provides a solid platform for the development of Macrocell and Microcell concept. (Kinoshita *et al.*, 1994, 1997) reuse the frequency channel in the adjacent cell within the service area of Macrocell and considered as high density space division multiple access (SDMA). In this Hybrid network formed, apart from ICI that has already taken care in FFR, here comes interference channel interference (CCI). If spectrum management is not

done well, this will be one of the significant interference contributed to SINR. (3GPP TR 36.921 V10.0.0) has analyzed different kinds of interference will affect Femtocell hybrid network while it is deployed in OFDMA environment based LTE network. On the other hand, Femtocell is widely used in Worldwide Interoperability for Microwave Access (WiMAX), in which (D. Lopez-Perez *et al.*, 2008) has proposed to use Dynamic Frequency Planning (DFP) to combat with interference occur while deploying Femtocell in WiMAX. In his design, spectrum allocation is dynamically assigned base on user demand only. This greatly reduces interference and improves in capacity. A power control method is introduced by (H. Claussen, 2007) to work in spectrum efficient universal frequency scheme. Three different types of power controls are introduced in LTE network. (Bouras, C., *et al.*, 2012) has suggested evaluated the performance of randomly deployed Femtocells in FFR Macrocell network. The above studies provide a solid groundwork for this research.

In the following section, Fractional Frequency Reuse will be introduced, followed by Femtocell network. The modeling and pseudo-code used in this research describes how the simulation is done. In the result analysis section, the performance of the two schemes will be highlighted. The paper ends with Conclusion at last.

FRACTIONAL FREQUENCY REUSE

The occurrence of ICI encourages the development of frequency planning technique. It is a network design planning to partition the entire bandwidth into spectrums to be shared among the cells or sectors. Frequency Reuse Factor (FRF) 1 make use of the whole spectrum. It has high spectral efficiency but requires



power control to mitigate ICI for the cell edge user who suffers from high interference due to cochannel neighboring cells. Frequency partitioning with FRF 3 has low ICI problem. However, it uses 1/3 of the bandwidth which causes the limitation of inefficient in reusing the spectrum. The price of losing 2/3 of the entire bandwidth for the low ICI is considered luxury from network planning point of view.

The FFR combines the benefits of both universal FRF and FRF=3 and thus results a network with low ICI and high spectrum gain. It divides the cell into virtual inner and outer regions. Inner region employs FRF=1 scheme in which whole spectrum in zone R1 is used.

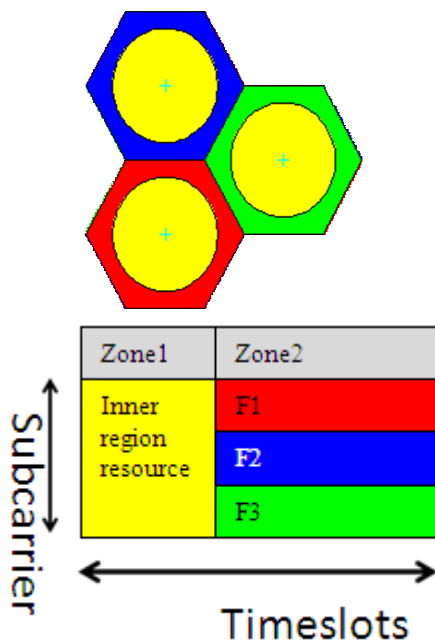


Figure-1. FFR resource allocation.

Referring to Figure-1, FFR does not sacrifice 2/3 of the entire bandwidth compared to FRF=3 network design all the time, FFR fills up the inner region of the cell with zone R1 resource. Outer region uses FRF=3 scheme and occupies 1/3 of zone R2. Zone R2 is built up of three sub-bands, F1, F2, F3 and they are used by cell edge users adjacent to each others. At cell edge (outer region), the three partitions in zone R2 is critical to ensure ICI reduction (Forum 2006a). However, this means that the FFR has high spectral efficiency at inner region, but sacrifices 2/3 of the spectrum at outer region. In other words, if all sub-bands in zone R2 can be fully utilized with no wastage, then this indirectly hints that the FFR network can achieve FRF=1 or efficiently using the whole spectrum.

FFR with higher efficiency

Since 2/3 of the spectrum in zone R2 cannot be used in the outer region of the cell, they can be reused in the inner region where the wanted signal level is high enough to overcome ICI. Consequently, the novelty of this research is to determine the furthest distance that the inner

region can occupy while maintaining user signal quality base on the measurement of SINR. The equation of SINR can be shown as below:

$$SINR = \frac{\text{Wanted signal power}}{\sum \text{Interference power} + N_0} \quad (1)$$

The numerator of SINR is the power received by the user from the serving cell. The denominator consists of interference power from co channel cells and thermal noise power (N_0).

FFR in hybrid network

The frequency fragmentation in Hybrid network needs to plan in advance in order to minimize the impact of co channel interference. Figure-2a and b is the duplicate of Figure-1 but they show how the spectrum is partitioned for the use of Macrocell and Femtocell in this research. Spectrum orthogonality is the ultimate goal of this frequency planning. For example while Macrocell network is deploying one of the sub-bands from Zone2 to serve cell edge users, this particular sub-band will be used by Femtocell to serve cell center users. The same applies to the 2/3 sub-band in Zone2, Femtocell deploys these sub-bands to cell edge users while Macrocell assigns them to cell center. Macrocell and Femtocell are sharing the Zone1 resource at Macrocell center since at this region, they are able to coexist in harmony with the application of Femtocell Power Control Scheme.

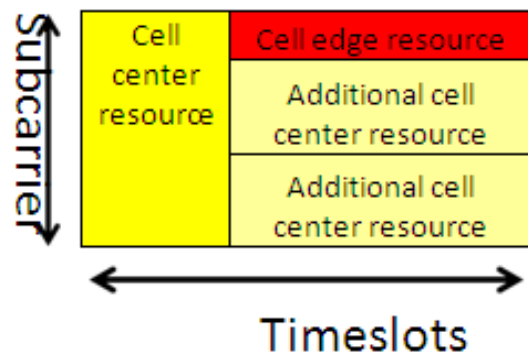


Figure-2a. FFR resource allocation for Macrocell network.

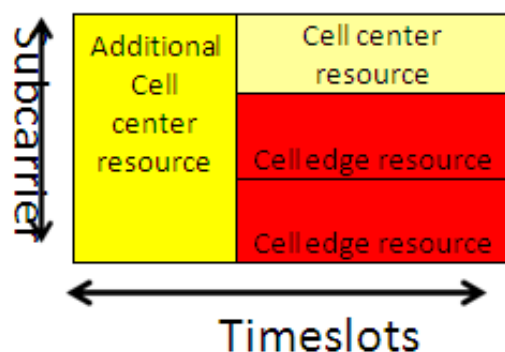


Figure-2b. FFR resource allocation for Femtocell network.



The analysis is done by considering a two tier cellular system. The whole environment consists of 19 hexagonal cells as shown in Figure-3. In other words, the inner region of the target cell experiences interference from 18 others adjacent cells that are surrounding it, while the outer region of the target cell experiences interference from 6 other co channel cells. In the scenario of utilizing sub-band F2 and F3 in the inner region of the cell, the users who are assigned to use these spectrums will experience interference from 12 other co channel cells.

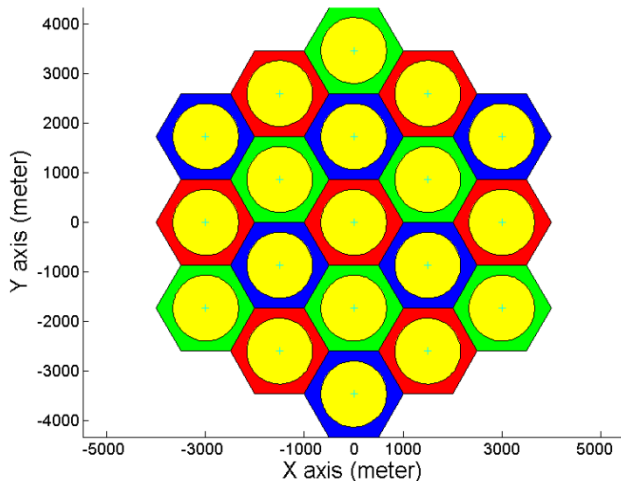


Figure-3. Two-tier network made of 19 hexagonal cells.

FEMTOCELL

Due to coexistence of Femtocell within Macrocell network, Femtocell users experience interference from Macrocell and Femtocell base stations. Figure-4 shows the possible downlink interference in a Hybrid network. The solid blue or red arrows indicate the serving base station. The dotted lines are the interference from the adjacent cells. This research will look into Femtocell interference towards Macrocell users and Macrocell interference towards Femtocell users.

Femtocell applies three access policies, Closed, Open and Hybrid mode access. A Closed access mode services the subscribed home or office users only. Thus, when Macrocell user is located at cell edge, the user can only receive weak signal from Macrocell but yet receive strong interference from Femtocell due to no access given. Femtocells with Open access are for any Macrocell or Femtocell users (Chandrasekhar, V., 2008).

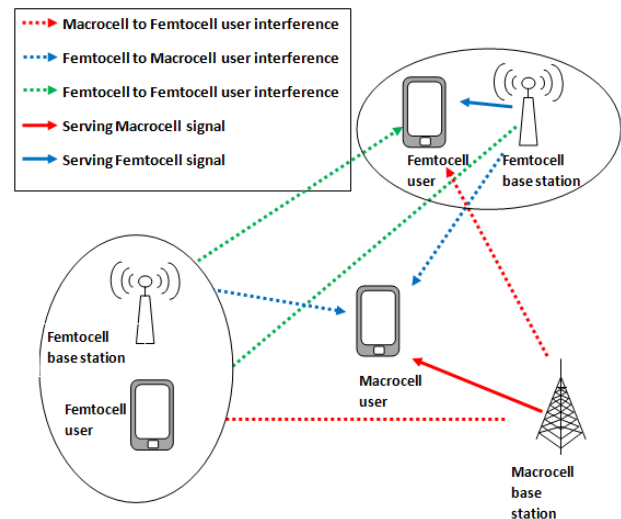


Figure-4. Downlink interference in hybrid network.

Thus, open access reduces the load of Macrocell and enhanced the coverage area. Hybrid access mode services all users but will prioritize the subscribed Femtocell users. This paper is going to focus on closed access mode in which the Macrocell user is going to receive high cross tier interference from Femtocell.

MODELLING

Table-1 shows the configuration parameters used in the simulation. The network as in shown in Figure-3 is simulated. The performance of the red color Macrocell at the center of the network is evaluated as it experiences interference from two tier-networks (from 18 Macrocells). The environment of typical urban is setup with the operating base stations at 2 GHz (Band 1). Cost 231 Hata Model which has the highest path loss in urban area is used (Shabbir, Noman *et al.*, 2011) (Sauders *et al.*, 2000). Macrocells are configured to have 1000 meter as radius and base station which is located at the center of the cell transmit power at 20 Watt. Femtocells which are dropped within the Macrocell area are configured to have radius 40 meter. The base station of Femtocell has the ability to transmit maximum power at 0.1259 Watt and minimum power at 0.001 Watt. While Femtocell power control scheme is not deployed, Femtocell base station transmits power at 0.0631 Watt. While Femtocell power control scheme is implemented, transmit power of the base station fluctuates depending between its maximum and minimum to achieve target SINR = 5dB at its radius. SINR 5dB is selected to maintain user signal quality (Boddu *et al.*, 2013).

**Table-1.** Simulation configurations.

Parameter	Units	Value
Number Macrocells simulated		19
Carrier frequency	MHz	2000
Channel model		3GPP Typical urban
User's speed	km/h	3, Pedestrian A
Path loss	dB	Cost 231 Hata Model
Macrocell radius	meter	1000
Macrocell base station output power	Watt	20
Femtocell base station output power (fix)	Watt	0.0631
Femtocell base station maximum output power	Watt	0.1259
Femtocell base station minimum output power	Watt	0.001
Femtocell target SINR	dB	5
Femtocell radius	meter	40

Modelling SINR based power control scheme

The ultimate goal of Femtocell base station power adjustment to ensure intended SINR (stated in Table-1) is achieved by Femtocell user within a specific area. The algorithm can be summarized in equation (2). In any scenario, the Femto base station output power is bounded by its maximum transmit power.

$$P(k+1) = \frac{SINR_t}{SINR_c} P(k) \quad (2)$$

where, $P(k+1)$ = Femto base station next iteration's output power

$P(k)$ = Femto base station at kth iteration

$SINR_t$ = Target SINR

$SINR_c$ = Current SINR

ALGORITHM

The whole process of scanning the Macrocell user's SINR across Macrocell area is summarized in Figure-5. The algorithm starts with scanning the the Macrocell from center of the cell to cell border. To determine inner and outer radius of the Macrocell, SINR of Macrocell user is measured by considering universal frequency network planning (interference are coming from 18 adjacent Macrocells). The purple color highlighted code is used for FFR deployment. SINR = 5dB is used to maintain determine Macrocell inner region in FFR scheme. Femtocell positions are scanned through from Macrocell center to border then. If the Macrocell network is operating in FFR scheme, interference from Femtocell only adjoins the interference measurement while the Macrocell user is locating at cell center.

```

Loop for from center of Macrocell to border
{
    Measure SINR (in FRF=1)
    if (FFR is deployed)
    {
        if (SINR < 5)
        {
            Outer region interference is calculated
        }
        else
        {
            Inner region interference is calculated
        }
    }
    else
    {
        interference for FRF=1 scheme is calculated
    }
    Loop for Femtocell positions
    {
        if (FFR is deployed)
        {
            if (SINR >= 5)
            {
                Interference from Femtocell is calculated
            }
        }
        else
        {
            Interference from Femtocell is calculated
        }
    }
    Measure SINR of Femtocell user
    Adjust Femtocell power base on SINR at Femtocell

```

Figure-5. Pseudo-code.



This is owing to Femtocell is assigned to deploy other band which is orthogonal to the spectrum used by Macrocell user in FFR scheme. In the scenario of Femtocell power control scheme is applied, Femtocell base station output power is adjusted according to Equation-2. SINR of Macrocell user is determined eventually.

RESULT ANALYSIS

The analysis is done in two parts, where the cross tier interference of Macrocell users and Femtocell users are considered. In the simulation, a Femtocell is placed a distance away from Macrocell, while the SINR of the Macrocell users at 36, 136, 236, 336, 436, 536, 636, 736, 836, 936 meters along X-axis are evaluated. Figure-6 shows SINR plot of different distance for Macrocell user away from Macrocell in FRF=1 scheme, while moving Femtocell from Macrocell center towards Macrocell radius along X-axis. The SINR of Macrocell user decreases when moving away from the Macrocell due to the propagation loss with longer distance. Macrocell user experiences a drastic SINR drop when Femtocell closes to the user and achieves the minimum when Femtocell is 1 meter away from the Macrocell user location. This is due to the Femtocell simulated is operating in Closed access mode. Macrocell user is not allowed to access Femtocell resources. User experiences large value of cross tier and co channel interference and thus it is explainable using Equation (1) where the denominator (interference) increases, SINR decreases. The SINR of Macrocell user picks up immediately once the user can get rid from Femtocell region.

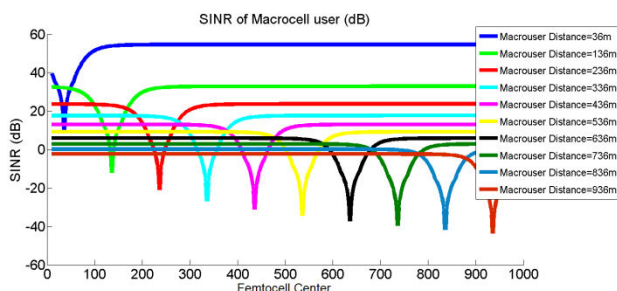


Figure-6. SINR versus Femtocell distance at different locations within Macrocell FRF=1 network.

The analysis of SINR performance is then focuses on FFR network. Similar to Figure-6, Figure-7 shows the plot of SINR but in FFR network. The Macrocell user graphs from 36 meter to 636 meter are identical to Figure-6. This is due to cell inner radius is configured to approximately 665 meter (experimentally, Macrocell user at X-axis receives SINR=5dB at 665 meter). Macrocell user located in cell inner radius (Macrocell user distance < 665 meter) is within the universal frequency reuse scheme. Thus, it experiences interference from 18 Macrocells and the Femtocell which is moving close and moving away from the Macrocell user. Consequently, these graphs are the unchanged compared to Figure-6. When Macrocell user is located

more than 665 meter away from Macrocell center (735, 836, 936 meter), the graph is observed constant across all Femtocell distances. Macrocell user at cell edge is operating in FRF=3 scheme. Hence, the resource used by Macrocell user at this region is orthogonal to the operating frequency of Femtocell. SINR of the Macrocell user is therefore constant across the Femtocell distance plot.

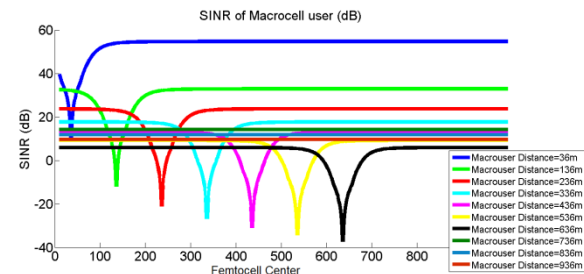


Figure-7. SINR versus Femtocell distance at different locations within Macrocell FFR network

To further protect the Macrocell user from interference, Femtocell power control base on SINR is used. Figure-8 shows again the same Macrocell user plots. SINR drops can still be observed at each Macrocell user locations. However, the drops are getting narrower. In order words, the drops occur when Macrocell user is located at a closer distance to Femtocell. Femtocell SINR based power control scheme involves Femtocell base station power adjustment to ensure intended SINR (5dB) achieved by Femtocell user within a specific area (Femtocell radius=40meter). In the scenario when power more than the maximum power or less than minimum power can be supported by Femtocell, Femtocell power will be saturated. Thus, Macrocell user SINR plot in Figure-8 has narrower drip to achieve SINR = 5dB at a distance 40 meter away from Femtocell. Nevertheless, there is still some case where Macrocell user is unable to achieve 5dB at 40 meter away from Femtocell (especially that Macrocell user located near to the border of cell inner radius). This is owing to weak serving Macrocell signal (due to propagation loss) and Femtocell power control scheme saturates the Femtocell base station transmit power to the minimum.

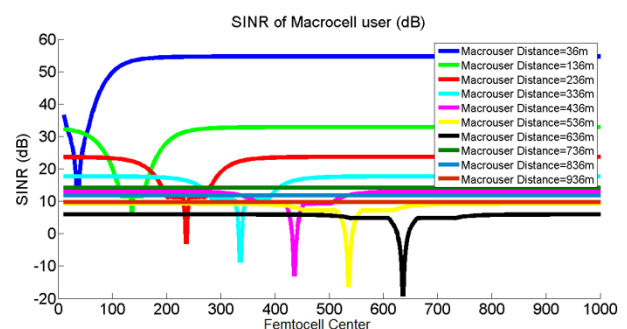


Figure-8. SINR versus Femtocell distance at different locations within Macrocell FFR network and Femtocell power control scheme is applied.



To further understand the SINR performance of Macrocell user in both schemes, Table-2 summarizes the SINR difference between FFR only scheme and FFR with Femtocell power control scheme. The measurement point takes place at 40 meter away from Femtocell (This is where the power control scheme tries to achieve SINR balance between Femtocell and Macrocell). At a distance near to Macrocell (for example 36 meter away from Macrocell), SINR of Macrocell user is reduced from 46 dB to 43 dB while applying Femtocell power control scheme. This is owing to Femtocell power is increased by power control scheme to protect the Femtocell user from

being interfered by strong nearby Macrocell base station power. At a point far away from Macrocell center (but not entering the cell edge region, Macrocell user received weak signal from Macrocell base station. Femtocell power control scheme tunes the Femtocell base station transmit power to the minimum in order not to interfere with adjacent Macrocell user. As a result of this, SINR of Macrocell user with Femtocell power control scheme is higher. At a distance further than 665 meter, SINR of Macrocell user is found constant due to it is using zone R2 resource which is orthogonal to Femtocell spectrum.

Table-2. SINR at 40 meter away from Femtocell for FFR only network and FFR with Femtocell power control scheme.

Macrocell user distance (meter)	SINR of Macrocell user at 40 meter away from Femtocell (with FFR Only) (dB)	SINR of Macrocell user at 40 meter away from Femtocell (with FFR and Femtocell power control scheme) (dB)
36	46.08	43.39
136	24.37	21.68
236	15.34	11.84
336	9.536	10.57
436	5.225	9.173
536	3.174	7.147
636	-1.118	4.758
736	14.21	14.21
836	11.84	11.84
936	9.654	9.654

CONCLUSIONS

A thorough scan of the SINR based evaluation has been done across Femtocell and Macrocell territories. The SINR based evaluations are done in three different network schemes, universal FRF, FFR scheme and FFR with Femtocell power control. Femtocell no doubt is a promising option to double enhance network coverage. However, the cross tier interference generated by closed access mode Femtocell cannot be disregarded. The implementation of FFR scheme and Femtocell power control scheme has successfully strengthen the SINR of the cell edge Macrocell users. FFR scheme explores the use of orthogonal spectrum and protect the cell edge Macrocell user from being interfered by neighbor Femtocell. The simulation result shows that Femtocell power control scheme improves the SINR of Macrocell user at 636 meter away from Macrocell center (a distance near to Macrocell inner region) and 40 meter away from Femtocell (radius of Femtocell) by approximately 5.9 dB. This paper has done a foundation research for future projects. The potential research can be done later is to explore the performance of the network made up of randomly distributed Femtocells and Macrocell users.

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