# Performance Comparison Between Fractional Frequency Reuse Schemes Employing Beamforming


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## Abstract

In this paper, the performances of using Fractional Frequency Reuse (FFR) schemes together with beamforming technique are presented. The key performances in terms of Signal-to-Interference plus Noise Ratio (SINR) and channel capacity are compared. The beamforming antenna array have been both simulated and measured. The results show that the beamforming technique improves the channel capacity and SINR. The best performance is obtained when the system employs a soft FFR with three sectors and beamforming technique.



**Keywords :** Beamforming, LTE, Array Antennas, Intercell interference, Frequency reuse


## 1. Introduction

LTE systems are a preliminary mobile communication standard, formally submitted ITU-T in late 2009 as a candidate for the 4$^{th}$ Generation of mobile communication (4G) systems and expected to be finalized in 2011[1]. The main goal of LTE system is to provide high data transfer-rate, low latency, increased flexible and effective bandwidth, and improve quality of service to reduce delay. However, LTE technology cannot provide full benefits due to the problem of interference signal from neighbor cells, so called ICI problem. This is occurred when users move from cell center to cell edge resulting the signal transmitted from the cell center is reduced while interference signals from neighbor cells is increased. From literatures, the techniques to mitigate the ICI problem can be classified as several types [2]. One of the interesting techniques is a Fractional Frequency Reuse (FFR). The FFR technique divides a whole frequency band into several sub-bands and wisely allocates to a specific area in order to improve the signal quality at cell edge. However, the mentioned technique cannot completely mitigate the ICI problem. Therefore, a smart antenna technology [3] in cooperating with FFR technique is envisaged to be the best solution to enhance the system quality. From literatures, the work presented in [4] has revealed that beamforming is one technique to improve the cell edge performance. Also the authors in [5] have shown the advantage of beamforming in 4G mobile networks in term of number of collided mobile terminals in one beam. However, the true benefit of beamforming for beamforming-LTE systems in term of signal quality as well as channel capacity is still needed to be exposed. Therefore, this paper investigates into the LTE system performance when employing FFR schemes including FFR or soft FFR, three sectors per one cell or without sector and beamforming.

## 2. Inter-Cell Interference

An Inter-Cell Interference (ICI) occurs when users are moving away from cell center toward cell edge. According to this, the SINR at a mobile terminal is reduced due to two reasons as follows. Firstly, the signal transmitted from base station to mobile terminals is dropped because of an increase in path loss. Secondly, ICI from neighbour cells becomes more pronounced when users

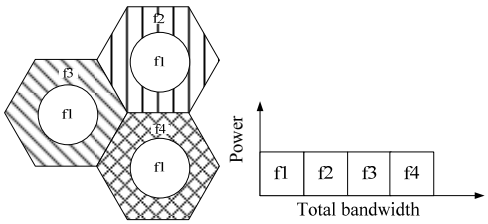



Figure 1: Fractional frequency reuse.

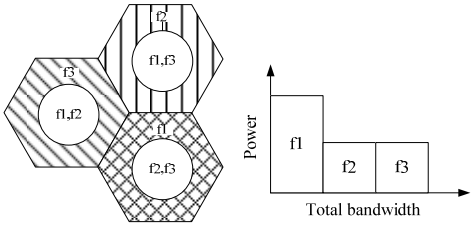
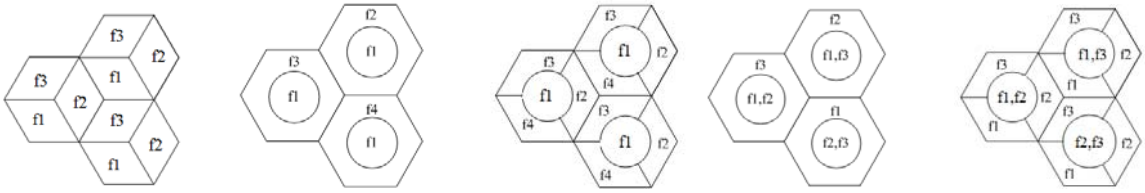
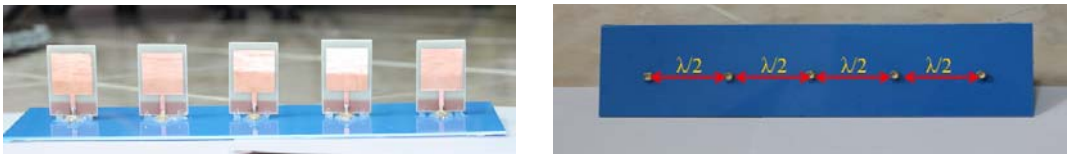



Figure 2: Soft fractional frequency reuse.



(a) (b) (c) (d) (e)

Figure 3: Configuration of FFR schemes. (a) Sector no FFR (b) FFR (c) FFR sector (d) Soft FFR (e) Soft FFR sector




(a) (b)

Figure 4: Linear array antennas

are close to the cell edge. The SINR of the system can be expressed by (1). Please note that all base stations in the system transmit the same level of power. In a severely interference limited scenario, the background noise can be ignored.

$$\rho = \left(\frac{2R}{r} - 1\right)^{\alpha} \tag{1}$$

where α is the path-loss exponent, $R$ is the cell-radius, r is the distance between user and base station.

## 3. Fractional Frequency Reuse Technique

The FFR technique offers separation of frequency spectrum resources into sector. The reused frequency spectrum resource is shown in Figure 1. This method also provides maximum utilization of frequency spectrum. Lately, soft FFR technique has been proposed for better utilization of frequency spectrum as shown in Figure 2. For the soft FFR technique, the transmitted power at some sub-frequencies is higher to cover the area of cell edge. This technique provides power allocation arrangement to improve cell-edge SINR while degrading SINR for users towards the other cells. In this paper, the simulation situations of FFR schemes is presented in Figure 3 (a) sector no FFR (b) FFR (c) FFR sector (d) soft FFR and (e) soft FFR sector. Both FFR and soft FFR have been introduced in order to relieve the effect of ICI problem, especially at the region of cell edge. However, the beamforming technique is envisaged to boost up the system performance without expansion of frequency spectrum. Next section shows the design of practical beamforming for LTE system.

## 4. Beamforming

The authors had investigated the optimum number of beamforming which is suitable for three sectors per cell (120 degree/sector) in LTE system. The optimum solution is 3 beams per sector. Hence, the beamwidth of each beamforming is $40^{o}$. Then the authors found that the 5×1 linear array antennas provide the beamwidth of $37.9^{o}$ which is appropriate for our desired solution. Therefore in this paper, the beamforming has been designed by 5×1 linear array antennas. For

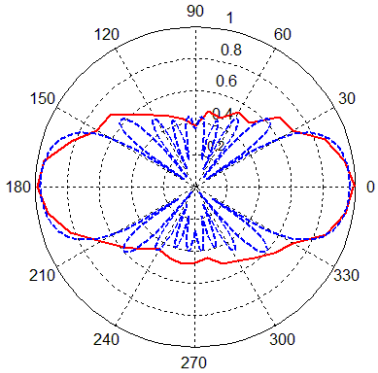



Figure 5: Comparison of radiation pattern between a simulated result (blue-dash line) and a measured result (red-solid line).

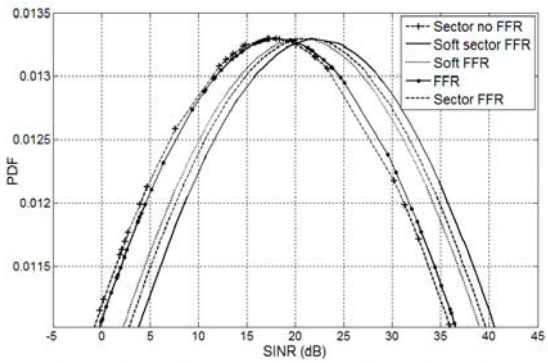



Figure 6: PDF of SINR for systems with beamforming.

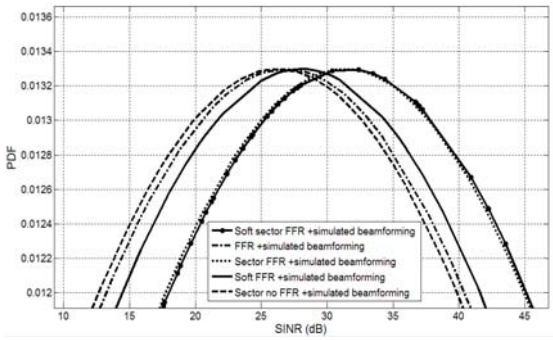



Figure 7: PDF of SINR for systems with simulated beamforming.

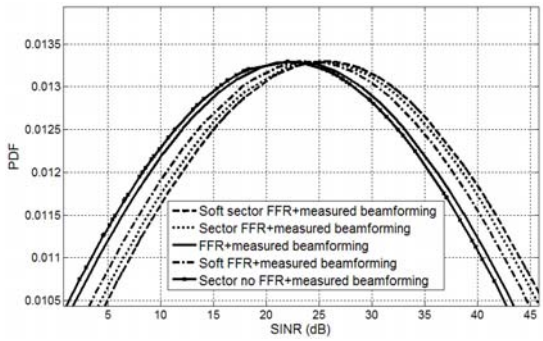



Figure 8: PDF of SINR for systems with measured beamforming.

antenna type, this paper uses a printed monopole because it is simple and can support the wideband operation for LTE system. In this paper, five printed monopoles are linearly placed with an inter element spacing of λ/2. The manufactured array antenna is shown in Figure 4 (a) and (b). The measured radiation pattern shown in Figure 5 is also similar to the simulated result from MATLAB programming.

Table 1: Simulation Parameters

| | |
|---|---|
| Number of base station | 19 |
| Inter-base station distance | 1000m |
| Pathloss model | 3GPP Macro cell [4] |
| Number of antenna elements | 5 |
| Inter-element spacing | d=λ/2 |
| Number of users random | 100 |

Table 2: Simulated Channel Capacity

| | Channel capacity [b/s/Hz] | | |
|---|---|---|---|
| Type | No beamforming | Simulated beamforming | Measured beamforming |
| Sector no FFR | 1.4655 | 2.0127 | 1.9878 |
| FFR | 2.4513 | 2.9962 | 2.8539 |
| FFR sector | 2.8987 | 3.2491 | 3.1989 |
| Soft FFR | 2.9769 | 3.3697 | 3.2445 |
| Soft FFR sector | 3.0176 | 3.8531 | 3.7543 |

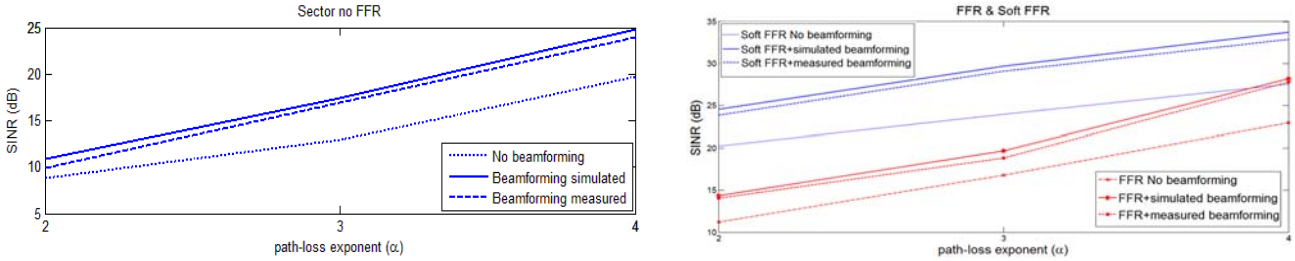



Figure 9: SINR versus path-loss exponent

## 5. Results and discussion

In simulation, the total number of adjacent base stations is 19 cells. Every base station has the equal power and serves equal mobile users. The scenarios of simulations are based on schemes shown in Figure 3. For measured cases, the measured radiation pattern shown in Figure 5 is imported to the program while evaluating the performance. More parameters utilized in simulations are shown in Table 1. Please note that random distribution for 100 users is given. Figures 6, 7 and 8 show the Probability Density Function (PDF) of SINR for 15 cases: scenarios shown in Figure 3 with and without beamforming, and also those scenarios when including measured radiation pattern. For sector cases, three sectors are considered as depicted in Figure 3. As expected, we obtain the worst performance from the case of conventional system without FFR technique. However, this can be improved by including beamforming technology to the base station. Among all cases, the best performance can be obtained when soft FFR sector is used in cooperating with beamforming. The results also confirm that the use of FFR, sector and beamforming can improve the system performance. In addition, Table 2 shows the obtained channel capacity for 15 cases in simulation. It reveals that utilizing soft FFR technique including beamforming provides the highest channel capacity for LTE systems. Lastly, Figure 9 shows the performance of SINR versus path-loss exponent.

## 6. Conclusion

This paper has investigated into the performance of LTE systems when FFR technique in cooperating with beamforming techniques. The key parameters to show the system performance are SINR and channel capacity. The results obtained from computer simulation have shown that both FFR and beamforming techniques can improve the system performance. Soft FFR sector with beamforming is the best choice for LTE systems.

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