COMPARATIVE EVALUATION OF FRACTIONAL FREQUENCY REUSE (FFR) AND TRADITIONAL FREQUENCY REUSE IN 3GPP-LTE DOWNLINK

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ABSTRACT

3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) is focusing towards aggressive frequency reuse i.e. reuse of 1 so that we can get maximum number (all available spectrum) within a cell. Now, the major hindrance is co-channel interference which increases dramatically due to nearby adjacent co-channel cell and most especially for cell edge users. Traditional frequency reuse concept for interference management doesn't provide satisfactory coverage and rate. In this paper, FFR is purposed as a candidate for interference management and its comparative evaluation over Traditional frequency reuse on the basis of two parameter metrics viz. probability of coverage and probability of acceptance rate is done. We observe that FFR has relatively better performance in 3GPP-LTE downlink.

KEYWORDS

LTE, Frequency reuse, co-channel interference, downlink

1. INTRODUCTION

LTE is accepted worldwide as the Long Term Evolution perspective for today's 2G and 3G networks based on WCDMA/HSPA, GSM/EDGE, TD-SCDMA and CDMA 2000 technology. The 4th Generation (4G) of wireless mobile systems is characterized by Long Term Evolution (LTE) [1] and WiMAX [2] technology which evolved with higher data rates and improved quality of service even for cell edge users. It is expected that LTE will be deployed in a reuse one configuration, in which all frequency resources are available to use in each cell. LTE has adopted Orthogonal Frequency Division Multiple Access (OFDMA) multiple access technique for Downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for Uplink, other detail specification can be found in reference [3]. Release 7 on December 2007 by 3rd Generation Partnership Project (3GPP) contained first work on LTE [3]. Then afterward lots of works have been added in LTE and it is consider as recent hot research topic.

Now considering LTE cellular network, when a frequency reuse of 1 is supported, i.e. all cells will operate on same frequency channels to maximize the spectral efficiency (number of channels per cell is increased), the inter-cell interference is major concern. There will be less effect to the users near to Base station but cell edge users may suffer degradation in connection. This can be address by using reuse ratio of 3 (classical frequency planning) i.e. dividing total spectrum band

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into 3 sub bands and allocate only one sub band to a given cell, so that adjacent cells use different frequency bands. Meanwhile co-channel interference is reduced but at expense of decrease in efficiency in terms of coverage and capacity.

Analysing above scenario a mix frequency reuse 1 and 3 schemes can be used to avoid interference at cell edges. Here, the total frequency band is divided into two sub bands: a frequency reuse 1 sub band is allocated to users at cell centres of all cells, and a frequency reuse of 3 sub bands is allocated to cell edge users [4]. This decreased the interference but also decreases the data rates as full frequency band is not used by this method. For implementation if this new idea there are two different methods: A static approach where a user is assigned a bandwidth depending on its position (path loss), and another is dynamic approach where the frequency assignment is done on the basis of position as well as cell loads. This above present concept is of FFR technique and our paper focus on static approach.

There are various frequency allocation schemes like OFDMA, SC-FDMA, Partial isolation, classical frequency planning, Fractional frequency planning [5], here we basically focus on two of them which are as follows:

1.1. Traditional Frequency Reuse

This is simplest scheme to allocate frequencies in a cellular network by using reuse factor of 1 (Figure 1) which leads to high peak data rates. However, in this case, higher interference is observed on cell edges. The classical interference management is done by using reuse ratio 3 (Figure 2), by using this interference is low but large capacity loss because only one third of resources are used in each cell.

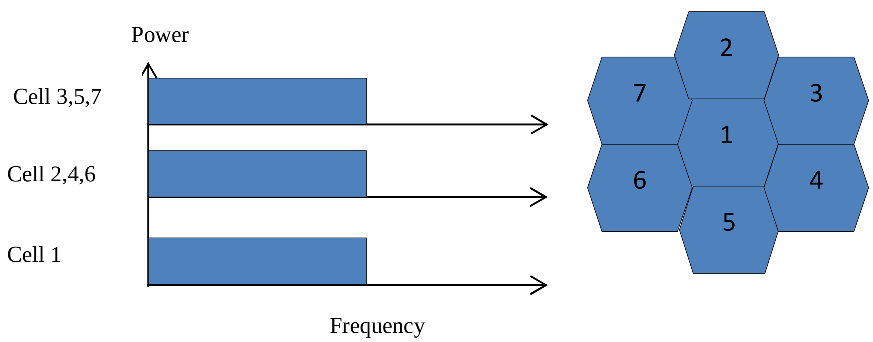

Figure 1. Traditional Frequencies Reuse with reuse ratio 1.

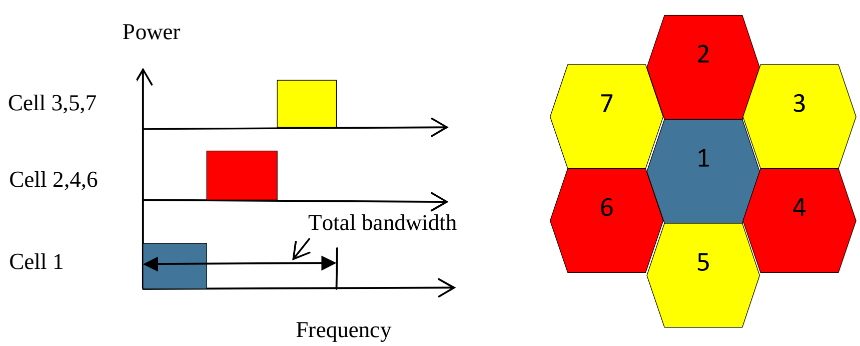

Figure 2. Traditional Frequency Reuse with reuse ratio 3.

1.2. Fractional Frequency Planning

The basic idea of FFR is to partition the cell's bandwidth so that (i) cell-edge users of adjacent cells do not interfere with each other and (ii) interference received by (and created by) cell-interior users is reduced, while (iii) using more total spectrum than classical frequency reuse [6]. The use of FFR in cellular network is tradeoffs between improvement in rate and coverage for cell edge users and sum network throughput and spectral efficiency.

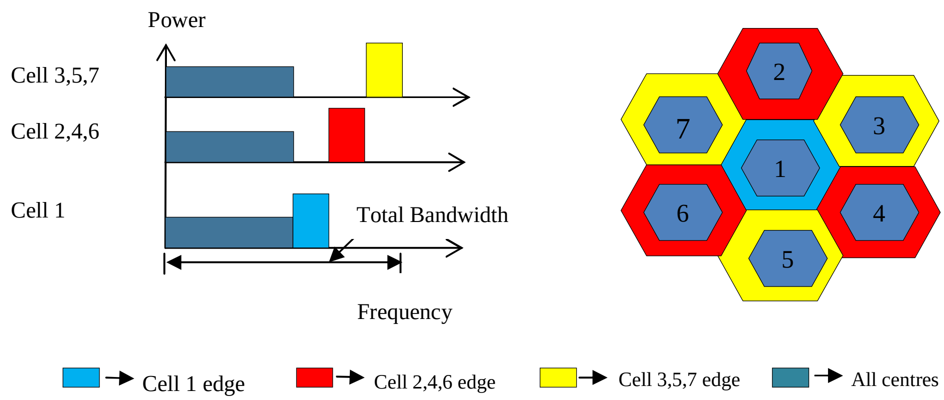

Figure 3. FFR in LTE, Frequency Reuse factor for cell edge users is 3.

Among 3 major frequency reuse patterns, FFR is compromised between hard and soft frequency reuse. In Hard frequency reuse splits the system bandwidth into a number of distinct sub bands according to chosen reuse factor and it let neighbor cell transmit on different sub bands. FFR splits the given bandwidth into an inner and outer part. It allocates the inner part to the near users located near to BS in terms of path loss with reduced power applying frequency reuse factor of one i.e. the inner part is completely reused by all eNBs (illustrated in Figure 3). The far users over cell edge, a fraction of the outer part of bandwidth are dedicated with the frequency reuse factor greater than one [7]. With soft frequency the overall bandwidth is shared by all base stations (i.e. reuse factor of one is applied) but for the transmission on each sub-carrier, the eNBs are restricted to a certain power bound [8].

There are two common FFR models: strict FFR and Soft Frequency Reuse (SFR) [6]. Strict FFR is modification of the traditional frequency reuse used extensively in multi-cellular networks (Figure 3 is example of strict FFR for reuse 3 at cell edge users) and they don't share the exterior sub bands to the inner frequency bands. Soft Frequency Reuse (SFR) employs the same cell-edge bandwidth partitioning strategy as Strict FFR, but the interior users are allowed to share sub-bands with edge users in other cells. Thus, the shared sub bands by the interior users will be transmitted at lower power levels than the cell edge users [6]. SFR is more bandwidth efficient than strict FFR, it results more interference to both cell-interior and edge users [9]. Here in our paper we focus basically on Strict FFR type.

2. SYSTEM MODEL

Here the system model is simple implementing Hexagon geometry. Each cell has given systematically integer label to indicate which frequencies are to be used in a frequency reuse scheme. The distribution of mobile are randomly scattered across the cell and stationary over the plane. Their intensity is λ, and distributed as per random distribution. Each mobile is communicating with nearest base-station. We assume that respective base station and respective user experience only Rayleigh fading with mean 1 and constant transmit power of 1/μ. Now, the received power at a typical node at a distance r from its base station is $hr^{-\alpha}$ where random variable *h* has exponential distribution with mean 1/μ and h ~ exp(μ). From above mentioned model, the SINR of the mobile user at a random distance of r from its associated base station is:

$$SINR=\frac{hr^{-\alpha}}{\sigma^2+I_r} \quad (1)$$

Here interference power which is sum of received power from all other base station other than the home base station treated as noise is:

$$I_r=\sum_{i\in\phi/b_o}(g_i R_i^{-\alpha}) \quad (2)$$

Where,

‘g’ is statistical distribution and is fading value or value for fading, shadowing and any other desired random effect with mean (1/μ). When g is also exponential then simpler expression will result.

‘h’ is exponential random variable(h~ exp(μ)).

‘r’ is distance from mobile to its base station.

‘R’ is distance from the mobile to other stations on same reuse assignment.

‘ α ’ is path loss coefficient.

‘ σ^2 ’ is noise power.

And ‘i’ represents each of the mobiles which are interfering with the mobile whose SINR is being calculated. All above results are for single transmit and single receive antenna and similarly we consider that there is no same cell interference due to orthogonal multiple access (OFDMA) within a cell. The noise power is assumed to be additive and constant with value of σ^2 but no specific distribution is assumed [10].

The detail formulation of these equations is given in reference [10]. The coverage probability is the probability that a typical mobile user is able to achieve some threshold SINR, i.e. it is the complementary cumulative distribution function (CCDF).
Mathematically, coverage probability is:

$$p_c(T,\lambda,\alpha)\cong P[SINR>T] \quad (3)$$

Where, T is target threshold SINR value.

The CDF gives P [SINR≤ T] so CCDF of SINR over the entire network is probability of coverage too. The achievable rate [10] shows $\tau\rightarrow\ln(1+SINR)$, i.e. Shannon bound. τ has unit nats/Hz (since log is base e and 1 bit =ln(2)=0.693nats).

The term Traditional Frequency reuse and Conventional Frequency reuse is used in same sense thus, somewhere it is mentioned as conventional frequency reuse which means the same. The system is simulated in MATLAB and mathematical expression basis is reference [10]. The environment assumed is static, plane terrain, urban area with Hexagonal geometry with symmetric alignment of eNBs. This makes the simulation a bit simpler. Here in this paper we are doing comparative analysis thus, this assumption also makes good sense for analysis though we are not assuming real time scenario.

3. RESULTS AND ANALYSIS

Parameters used:

User Equipment's intensity, $\lambda = 5$
Path loss exponent, $\alpha = 4$ (Urban Area)
Avg. SNR (to calculate noise) = 10Db

Total tiers considered are 15 and users are distributed randomly within first 10 tiers from centre cell. SINR threshold to distinguish cell edge users and cell centre users is 15dB. Cell radius of 1KM is taken during observation. The environment considered is totally static and flat terrain. Simulation is carried out for number of times to calculate SINR and rate for user equipment and its mean value is taken during final plot so that best result is obtained.

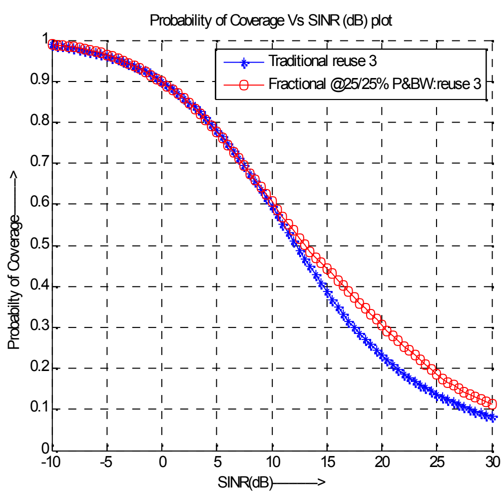

Figure 4. Probability of Coverage over SINR Thresholds for Traditional reuse 3 and FFR 25/25 (P/BW) reuse 3.

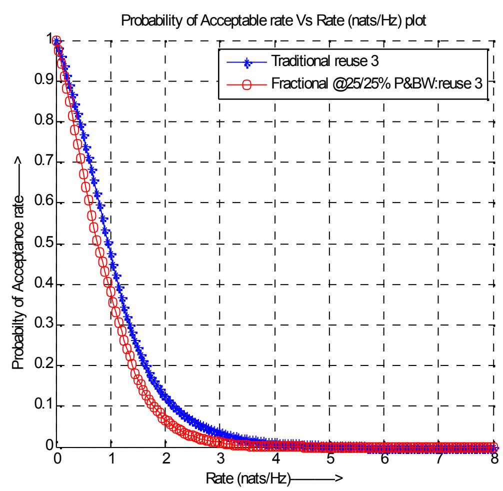

Figure 5. Probability of Rate over Rate Thresholds for Traditional reuse 3 and FFR 25/25 (P/BW) reuse 3.

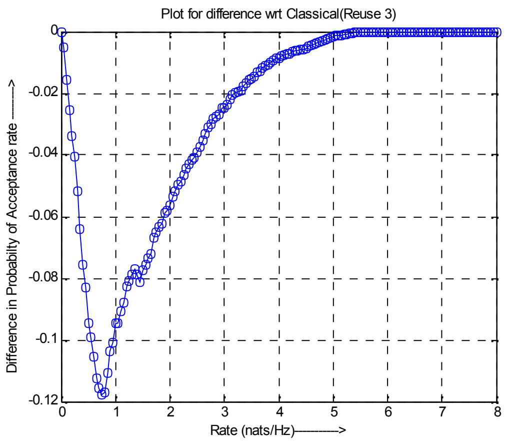

Figure 6. Plot for difference between FFR reuse 3 w.r.t. Traditional frequency reuse 3 at various rate thresholds.

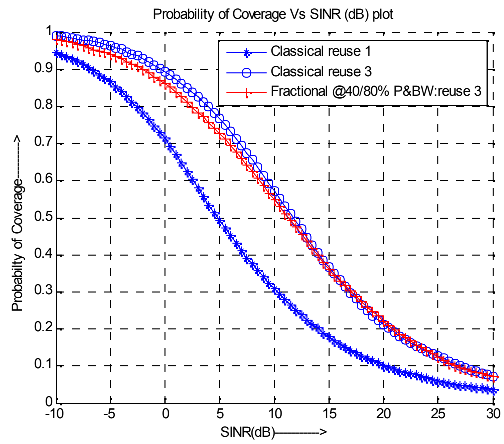

Figure 7. Probability of Coverage over SINR Thresholds for Traditional reuse 3, reuse 1 and FFR 40/80 (P/BW) reuse 3.

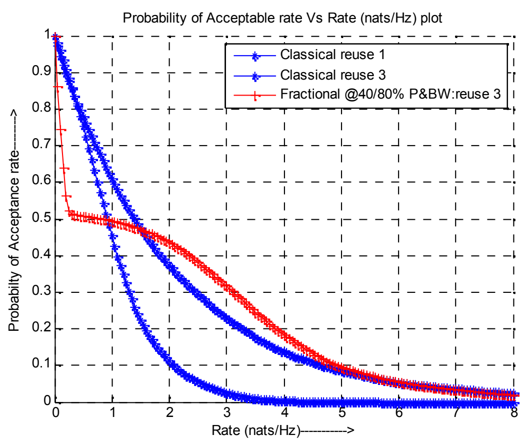

Figure 8. Probability of Rate over Rate Thresholds for Traditional reuse 3, reuse 1 and FFR 40/80 (P/BW) reuse 3.

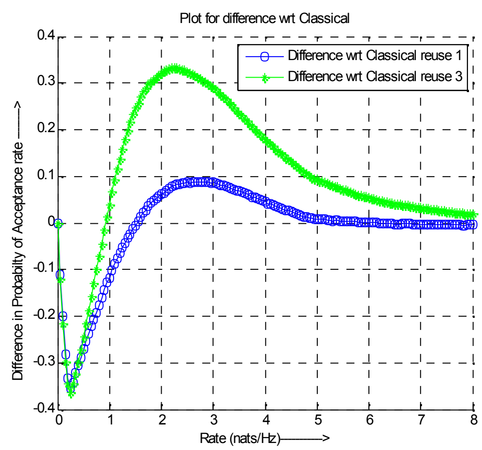

Figure 9. Plot for difference between FFR reuse 3 w.r.t. Traditional frequency reuse 3 and reuse 1 at various rate thresholds.

Table 1. Percentage gain in Probability of Acceptance rate (PAR) calculation for FFR reuse 3 with respect to Traditional Reuse 1 and Reuse3.

S.N.	Rate (nats/Hz)	PAR1 Traditional Reuse1	PAR2 Traditional Reuse3	PAR3 FFR Reuse3	% gain w.r.t PAR1	% gain w.r.t PAR2
1	0	1	1	1	0	0
2	0.5	0.7785	0.753	0.5077	-34.78	-32.57
3	1	0.6104	0.4556	0.4934	-19.17	8.29
4	1.5	0.4757	0.2239	0.4705	-1.09	110.14
5	2	0.3734	0.1131	0.4345	16.36	284.17
6	2.5	0.2942	0.0565~0	0.3809	29.47	38.09
7	3	0.2291	0.0257~0	0.3162	38.02	31.62
8	3.5	0.1777	0.0108~0	0.2456	38.21	24.56
9	4	0.1375	0	0.1827	32.87	18.27
10	4.5	0.1085	0	0.1338	23.32	13.38
11	5	0.0865	0	0.0947	9.48	9.47
12	5.5	0.0689	0	0.0725	5.22	7.25
13	6	0.0536	0	0.0548	2.24	5.48

Higher reuse for FFR is not done indeed as this make cell rich of channels which is our main motive. Thus, FFR cell edge reuse should be limited to 3 only. We compare Traditional reuse 3 and FFR 25% power and 25% bandwidth for centre users. Similarly, Traditional reuse 3 and reuse 1 is compared with FFR 40% power and 80% bandwidth for centre users. By doing variation in FFR for different power and bandwidth allocation for cell centre user gives better performance for FFR. It is observed that 40/80 allocation as power and bandwidth respectively allocation to centre users gives best performance than other combination.

We are always in seek of Frequency reuse scheme which has SINR performance that match with Traditional reuse 3 and Rate that match with Traditional reuse 1. Now, observing Figure 4, FFR has SINR as Traditional reuse 3 but Figure 5 shows it has lower acceptance rate.

In Figure 6, we can see difference of -0.12 in probability of acceptance rate at ~1 nats/Hz rate threshold. Now for FFR 40/80 (P/BW), we obtain superior performance in coverage and rate than Traditional frequency reuse. Performance that we were seeking can be easily figure out in FFR 40/80 (P/BW).

From Figure 7, it is clear that FFR has similar in performance in SINR as of Traditional reuse 3 and Figure 8 shows initial degradation but better performance after 0.5 nats/Hz in rate. It is clear from Figure 9 that the differences are both in upward i.e. significant improvement. There is at most of difference of ~0.3 w.r.t Traditional reuse 3 and ~0.1 in probability of acceptance rate for rate threshold values ranging from 2 to 3 respectively.

Table 1 is tabulation of Figure 8. This shows that for FFR we obtain 110% (value is more than doubled) and 284% (value is nearly tripled) at 1.5 and 2 nats/Hz rate threshold values respectively relative to Traditional reuse 3. Similarly, gain of 38% is there for 3-3.5 nats/Hz rate thresholds relative to Traditional reuse 1 for FFR. These observations clearly show that FFR has better performance than Traditional frequency reuse.

4. CONCLUSIONS

This paper presents overall comparative evaluation of FFR and Traditional Frequency reuse in 3GPP-LTE downlink homogenous condition. Results shows that FFR provided better probability of coverage and probability of acceptance rate than Traditional frequency reuse 1 and reuse 3. In fact, FFR balances the requirements of interference reduction and resources utilization efficiently.

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