Soft Frequency Reuse for Inter-Cell Interference Co-ordination in LTE Based Cellular Network

ISSN 2047-3338

Rajesh Kumar Paudyal
Department of Electronics and Computer Engineering, Himalaya College of Engineering, Tribhuvan University, Kathmandu, Nepal
rajesh@hcoe.edu.np

***Abstract*– In third generation partnership project (3GPP) Long Term Evolution (LTE), the frequency planning with reuse of one is aim to provide high bandwidth service to the user but such a frequency planning strategy can lead to unacceptable inter-cell interference levels experienced especially by users located at the cell edge area. In this paper two methods, Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR) are proposed as interference management scheme in order to enhance overall per user Quality of Service (QoS) and throughput as per basis on Signal to Interference Plus Noise Ratio (SINR) metrics. Both of them are analyzed on the basis of probability of coverage and acceptance rate by considering the average SINR experienced by the user. Along with individual analysis, comparative analysis, it was found that FFR and SFR have relative better performance in terms of per user acceptance rate and coverage probability. Among them Soft frequency reuse improves the cell capacity with seven percent in coverage and thirty five percentage in rate than FFR but it still suffers from more interference than FFR.**

***Index Terms*– Soft Frequency Reuse (SFR), Fractional Frequency Reuse (FFR), Traditional Frequency Reuse, Inter-cell Interference Coordination (ICIC) Technique and SINR**

I. INTRODUCTION

LONG Term Evolution (LTE) is a standard for wireless data communications technology, which was evolved to meet the needs of future broadband cellular communications. The goal of LTE was to increase the capacity and speed (data rate) of wireless data networks using new digital signal processing (DSP) techniques and modulations that were developed around the turn of the millennium. Unlike previous generation, LTE uses orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) as the baseline for modulation and multiple access scheme respectively, which increases the channel capacity and system performance [1].

The target requirement of LTE includes the increase in peak downlink data rates as high as 100Mbps, increase in coverage with full performance up to 5 km and increase in control plane capacity for 200 users per cell. But radio resource management attracts great attention while utilizing available resources to provide users with enhanced system throughput. Radio resources management includes transmission power management, mobility management, and scheduling of radio resources. An intelligent radio resource management is at the heart of LTE to make it robust technology to meet the broadband mobility needs of upcoming years. This will schedule the available resource in a best way and provide to the users with the enough transmission capability to achieve the decided quality of service (QoS) even while they move freely and also will make sure that these assigned resources would not interfere with already assigned resources. This will also be of interest that the transmitted signal will reach the receiver in a good health while utilizing the power efficiently available at the transmitter [2], [3].

A. Classical Frequency Planning

Classical or Traditional Frequency planning scheme allocate the frequencies in a cellular network by using reuse factor of one i.e., same frequency spectrum is used in the all cells, which leads to high peak data rates. By adopting reuse of one scheme higher interference is observed on cell edge area. To mitigate the classical interference reuse ratio of three is used. In this, interference is low but there is large capacity loss because only one third of resources are used in each cell.

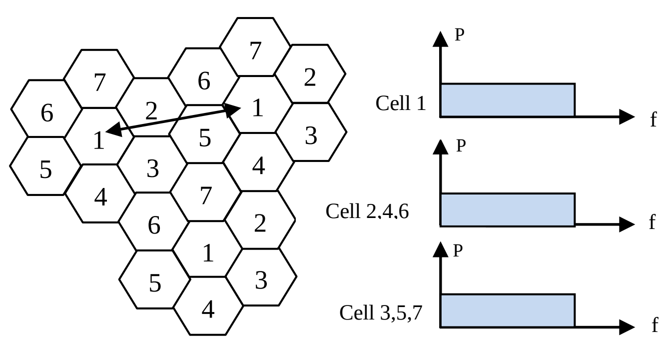

Fig. 1. 7-cell Frequency Reuse in GSM and power distribution

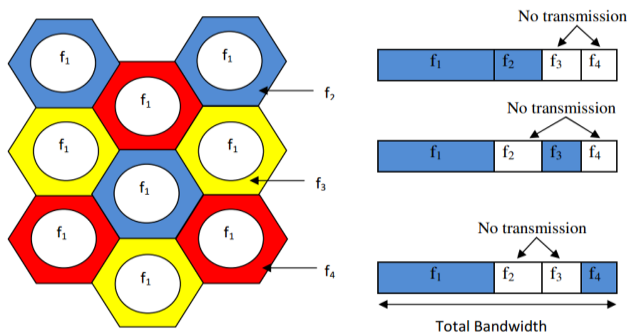

Fig. 2. Fractional Frequency Reuse

B. Fractional frequency Reuse (FFR)

FFR is a subcarrier reuse scheme where only a part of the total bandwidth, that is, a subset of subcarrier is allocated. The whole bandwidth is divided into sub-bands, some of which are allocated to a different location in the cell. In FFR, cell area is separated into two different geographical regions with different reuse partitioning: the inner cell area close to the base station and outer cell area near to the cell edge. In reuse partitioning, lower reuse factors are assigned to the users with high signal quality while users with low SINR use a higher reuse factor.

As mentioned above reuse of one provides the best throughput for users in the cell-center experiencing higher SINR while reuse of three provides the highest throughput for the cell-edge users experiencing low SINR. So FFR generally uses universal reuse scheme (reuse one) for cell center users while reuse three for the edge users in order to improve overall throughput and system capacity as shown in Fig.2. The total frequency resource is divided into four segments namely (f_1, f_2, f_3, f_4). The frequency resource (f_1) is used in all the cells to serve users experiencing good SINR. A frequency reuse of three is implemented on the remaining three resource segments(f_2, f_3, f_4) [16].

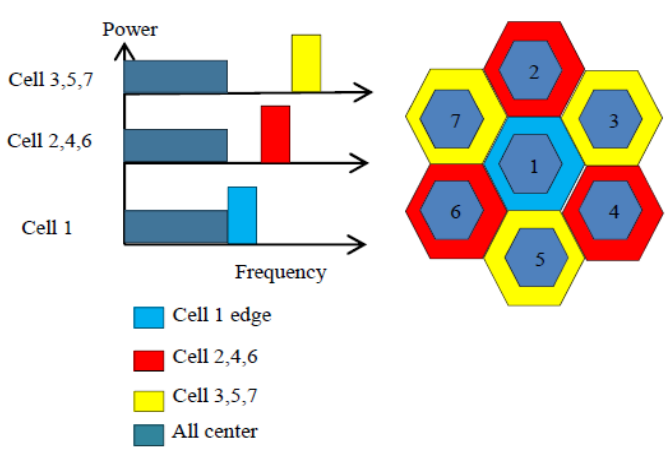

Fig. 3. FFR in LTE, Frequency Reuse factor at edge is 3

C. Soft Frequency Reuse (SFR)

The basic idea of SFR is to apply a frequency reuse of one at the cell center area and a higher frequency reuse factor at the cell edge area. In SFR, the available spectrum is divided into two reserved parts: a cell-edge band and a cell-center band. Users within each cell are also divided into two groups, cell-center users and cell-edge users, based on their distance to the base station or other differentiating factors. Cell-edge users are restricted to the reserved cell-edge band while cell-center users have exclusive access to the cell-center band and can have access to the cell-edge band but with lower priority. A frequency planning of SFR applied in a seven-cell hexagonal system layout as shown in Fig.4, where the cell-center users can use the entire frequency band but the cell-edge user only uses the partial frequency band non-overlapping with adjacent cells. The cell-edge users must transmit on a higher power level in order to improve their data rates, whereas the cell-center users can transmit with a reduced power level. Fig.4 shows the power distribution of SFR [1].

II. METHODOLOGY

Here the work has been done on downlink capacity and coverage by considering full network interference. Hexagonal geometry has been implemented with each cell notation to indicate which frequencies are to be used in a reuse scheme.

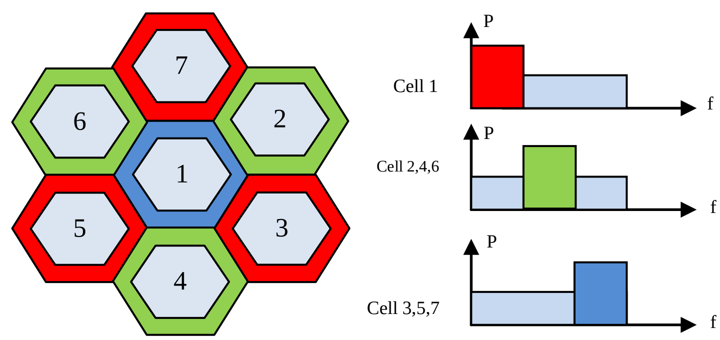

Fig. 4. The frequency planning and power allocation for the SFR scheme

Two parameters coverage probability and probability of rate acceptance are calculated. The coverage probability is the probability that a typical mobile user is able to achieve some threshold SINR, i.e., it is complementary cumulative distribution function (CCDF). The coverage is derived from a number of special cases, namely combinations of (i) exponentially distributed interference power, i.e. Rayleigh fading, (ii) path loss exponent of 4, and (iii) interference-limited network, where thermal noise is ignored. These assumptions make simple formula for coverage probability that only depends on threshold SINR. The probability of rate acceptance is CCDF of rate such that each user achieve Shannon bound for their instantaneous SINR i.e., log(1+SINR).

As far as random channel effects such as fading, shadowing, it is assumed that the tagged base station and tagged user only experience Rayleigh fading with mean one, and employ a constant transmit power of $^1/_\mu$ [18]. Now the received power by the user at a distance r from the base station is $hr^{-\alpha}$ where random variable *h* has exponential distribution with mean $\frac{1}{\mu}$ and $h \sim exp(\mu)$.

A. Signal to Interference Plus Noise Ratio (SINR)

The SINR of the mobile user at a random distance of r from its associated base station is:

$$SINR=\frac{hr^{-\alpha}}{\sigma^2+I_r} \text{ ……………………. [1]}$$

Here, interference power that is sum of received power from all other base station except home base station is treated as noise is given as:

$$I_r=\sum_{i\epsilon \frac{\Phi}{b_0}}(g_i R_i^{-\alpha}) \text{ …………………. [2]}$$

Where,

g = statistical distribution and is fading value, shadowing and any other desired random effect with mean ($1/\mu$).

h = exponential random variable as mentioned,

r = distance from user to its base station,

R_i = distance from the user to other base stations on the same reuse assignment,

α = path-loss coefficient and

σ^2 = constant noise power.

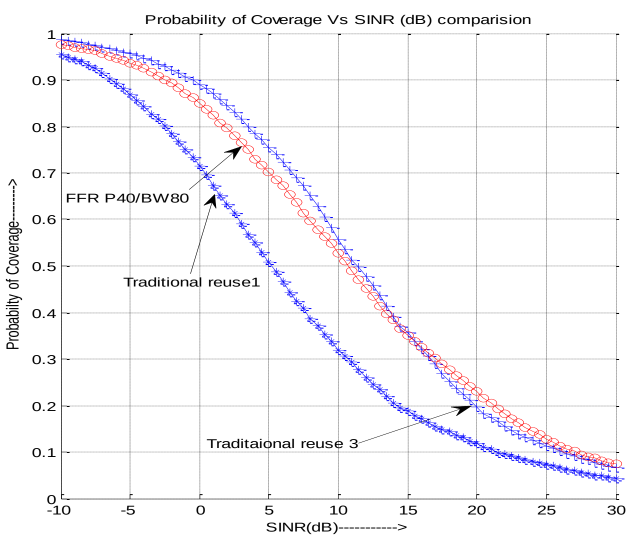

Fig. 5. SINR vs. Probability of coverage for Traditional and FFR

B. Coverage probability and Rate

Coverage probability is probability that a particular mobile user can achieve some threshold SINR or the probability that a randomly chosen user can achieve a target SINR *T*, and defined as:

$$p_c(T, \alpha)\triangleq P[SINR>T] \text{ ………………………..….. [3]}$$

The probability of coverage is also the CCDF of SINR over the entire network, since the CDF gives:

$$P[SINR<T] \text{ ………………………………..…….. [4]}$$

Where, the mobile user under consideration is assumed to be located at the origin. A user is in coverage when its SINR from its nearest BS is larger than some threshold *T* and dropped if it below *T*.

The achievable rate is given by:

$$\tau = \log_2(1+SINR) \text{ Bits/sec/Hz …………………. [5]}$$

III. SIMULATION RESULT

The parameters considered during simulation:

No. of Rings (total tiers considered) = 10

Inner Rings (No of tiers) = 6

Lambda (Mobile equipment density) λ= 5

Alpha (path loss component) α =4 (Urban Area)

SNR =10; Threshold SINR = 15dB

No of data observed (SINR/Rate) for individual mobile = 10

All these data are assumed for cellular network environment in urban area. The variation in these parameters cannot change the performance of overall system abruptly in comparative analysis but small amount of variation can be observed with change in the factor of mobile distribution (λ) and noise level.

A. Comparative analysis in Coverage and Rate analysis of Traditional reuse versus FFR

While comparing FFR with relative to traditional reuse one and reuse three, reuse one has maximum improvement in coverage by 96% at 20dB; minimum improvement of 2.4% at -10dB (SINR) and overall probability of coverage is improved for FFR relative to Reuse one. The maximum improvement of rate by 34% at 5bps/Hz and degraded by 30.7% at 1bps/Hz.

While comparing FFR with traditional reuse three, It was observed that 7% of maximum degradation of coverage at 5dB and remain same at -10 and 15dB and improved by 18% at 20dB. The acceptance rate, after 2bps/Hz it got 391% improvement i.e. about 4 fold at 3bps/Hz, degradation of 21.2% at 1bps/Hz at 1bps/Hz and improved rate afterward. It suffered from degradation in rate before 2bps/Hz.

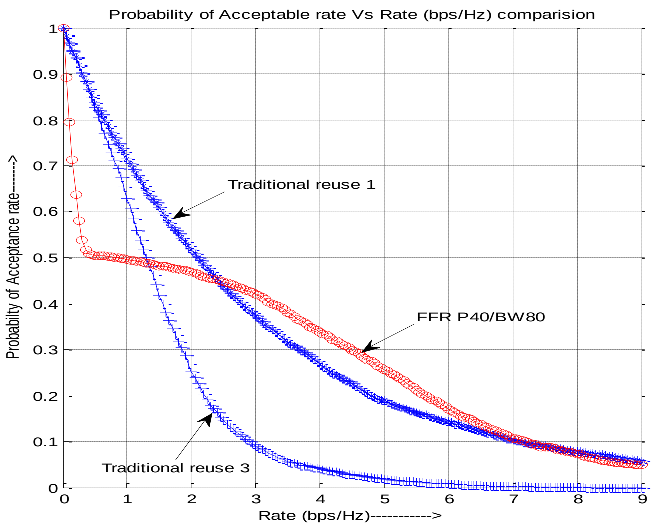

Fig. 6. Rate vs. Probability of acceptance rate for Traditional and FFR

From Fig. 5, it is clear that FFR has better probability of coverage than traditional reuse one and three. The probability of coverage for FFR is near about traditional reuse three and has worst rate initially but improved after 2bps/Hz. Theoretically it has more number of channels (bandwidth) available in any cell than Traditional reuse three so, it has better probability of acceptance rate.

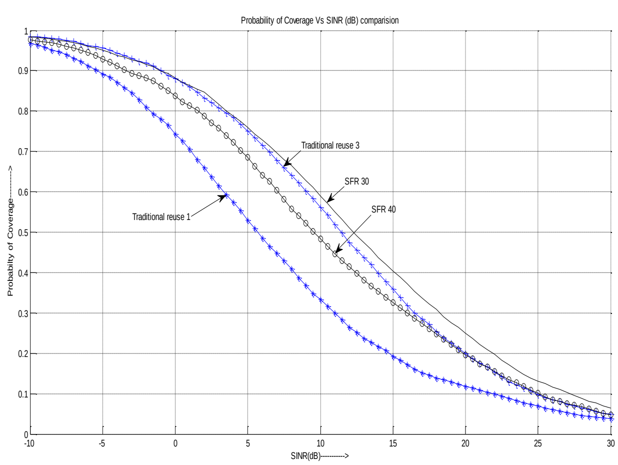

Fig. 7. SINR vs. Probability of coverage for Traditional and SFR

B. Comparative analysis in Coverage and Rate analysis of Traditional reuse versus SFR

While considering SFR, percentage allocation of power and bandwidth for the central users takes the major role in analysis for its best results. When there is variation in bandwidth allocation for center then choice of power allocation changes accordingly. From Figure 8, Power 30 combination i.e., 30% power allocation to center user has better probability of acceptance rate.

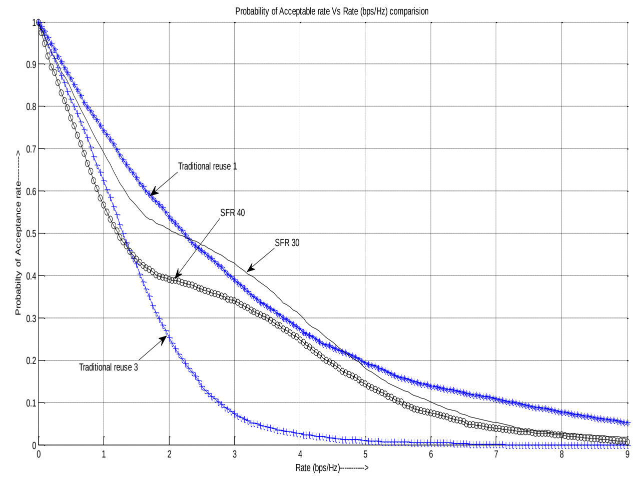

Fig. 8. Rate vs. Probability of acceptance rate for Traditional and SFR

C. Comparative analysis of Traditional Reuse, FFR, and SFR combined conclusive analysis

Here the percentage improvement in different parameter among Traditional reuse one & three, FFR and SFR were compared.

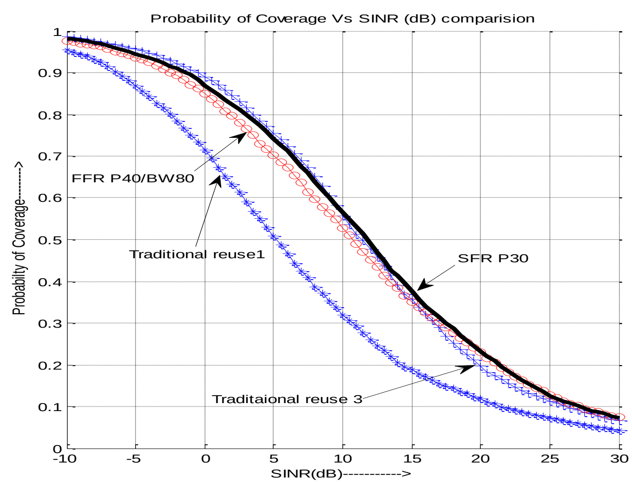

Fig. 9. Comparison of Probability of coverage of Traditional, FFR and SFR

TABLE 1. COMPARATIVE ANALYSIS IF IMPROVEMENT PERCENTAGES OF PROBABILITY OF COVERAGE FOR TRADITIONAL REUSE ONE (TR1) AND THREE (TR3), FFR AND SFR

	Probability of coverage				% Improvement of FFR		% Improvement of SFR		% Improvement of SFR
SINR (dB)	TR1	TR3	FFR	SFR	Over TR1	Over TR3	Over TR1	Over TR3	Over FFR
-10	0.953	0.986	0.977	0.983	2.476	-0.903	3.116	-0.284	0.625
-5	0.868	0.956	0.937	0.945	7.94	-2.06	8.838	-1.244	0.833
0	0.716	0.889	0.85	0.869	18.73	-4.475	21.43	-2.294	2.283
5	0.508	0.754	0.701	0.743	38.07	-7.016	46.31	-1.459	5.976
10	0.32	0.557	0.527	0.565	64.87	-5.351	76.60	1.3827	7.114
15	0.188	0.356	0.358	0.375	90.18	0.477	98.99	5.1347	4.636
20	0.118	0.196	0.232	0.232	96.44	18.19	96.44	18.186	0
25	0.073	0.112	0.126	0.126	73.1	11.85	73.10	11.854	0

It was found that FFR has better probability of coverage near about performance as of reuse three while SFR has better rate near about performance as of reuse one. From comparison, it observed that SFR has approximately 8% improvement in coverage than FFR but SFR has gradual degradation in rate performance after 2bps/Hz where maximum of 35% improvement was achieved at 1bps/Hz. From overall analysis, it was found that both FFR and SFR schemes improve the performance of user at cell edge area but we have to choose best suitable model. The criteria to choose better scheme depends on the power and bandwidth allocation for the cell center and cell edge users.

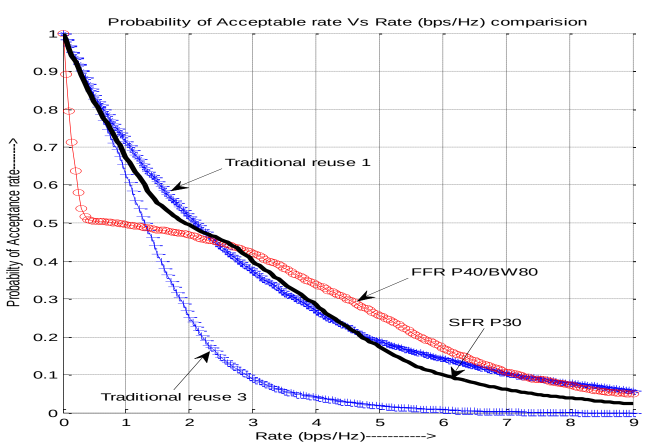

Fig. 10. Comparison of acceptance rate for Traditional, FFR and SFR

TABLE 2. COMPARATIVE ANALYSIS OF IMPROVEMENT PERCENTAGE IN PROBABILITY OF ACCEPTANCE RATE FOR TRADITIONAL REUSE ONE AND THREE, FFR AND SFR

	Probability of acceptance rate				% Improvement of FFR		% Improvement of SFR		% Improvement of SFR
Rate (bps/Hz)	TR1	TR3	FFR	SFR	Rate (bps/Hz)	TR1	TR3	FFR	SFR
0	1	1	1	1	0	1	1	1	1
1	0.716	0.629	0.495	0.673	1	0.716	0.629	0.495	0.673
2	0.518	0.252	0.468	0.495	2	0.518	0.252	0.468	0.495
3	0.373	0.1	0.42	0.4	3	0.373	0.1	0.42	0.4
4	0.268	0	0.338	0.285	4	0.268	0	0.338	0.285
5	0.19	0	0.256	0.173	5	0.19	0	0.256	0.173
6	0.143	0	0.17	0.1	6	0.143	0	0.17	0.1
7	0.105	0	0.107	0.061	7	0.105	0	0.107	0.061

IV. CONCLUSION

In this paper, interference management techniques FFR and SFR are considered as major techniques and their significance was analyzed for interference management. Traditional cellular concept reduces the interference with other cells by adopting different reuse ratio hence increase the SINR but it has certain drawbacks. In FFR, user at cell center and user at cell edge has different reuse factor so that overall throughput as well as SINR is balanced properly but in Soft frequency reuse, it uses all available bandwidth within a cell (N=1) and manage interference by simply varying power and bandwidth for central and edge users. While comparing these three schemes, SFR has seven percentage improvements in probability of coverage and thirty-five percentage improvements in probability of acceptance rate over others. Generally, FFR improves the performance of users at cell edge, that results in improvement of overall system performance while SFR improves cell capacity but suffers from interference. For increasing the capacity of system with acceptable rate SFR is better than the FFR.

V. ACKNOWLEDGEMENT

This research is supported by Department of Electronics and Computer Engineering, Pulchowk Campus, Tribhuvan University, Nepal. I would like to thank Asst. Professor Dr. Sanjeeb Prasad Pandey, Department of Electronics and Computer, Pulchowk Campus, Institute of Engineering, Kathmandu, Nepal and Er. Chandra Thapa, PhD scholar, University of Newcastle, Australia for the valuable suggestion and guidance during this research work.

REFERENCES

[1] Yiwei Yu, Eryk Dutkiewicz, Xiaojing Huang, Markus Mueck and Gengfa Fang, "Performance Analysis of Soft Frequency Reuse for Inter-cell Interference Coordination in LTE Networks", *International Symposium on Communications and Information Technologies*, 26-29 October 2010.

[2] Ericsson. (2012, May), *Long Term Evolution (LTE): an introduction* , White paper,13 Dec2008, [online], Available: http://www.ericsson.com/technology/ whitepapers/lte_overview.pdf

[3] K. Doppler, C. Wijting, K. Valkealahti, " Interference Aware Scheduling for Soft Frequency Reuse", *Radio Technology Laboratory*, Nokia Research Center, VTC spring 2009,pp 1-5. April 2009

[4] G´abor Fodor, Chrysostomos Koutsimanis, "Inter-cell Interference Coordination in OFDMA Networks and in the 3GPP Long Term Evolution System", *Journal of communications*, vol. 4, No. 7, pp 445-453, August 2009.

[5] C. He, F. Liu, H. Yang, C. Chen, J. Zhang, "Co-channel Interference Mitigation in MIMO-OFDM System", *Wireless Communications, Networking and Mobile Computing, 2007 IEEE*, pp. 204-208,.

[6] (2012, May),*UTRA-UTRAN Long Term Evolution (LTE) and 3GPP System Architecture Evolution(SAE)*, 3GPP LTE paper, [online], Available: ftp://ftp.3gpp.org/Inbox/2008_web_files/LTA Paper.pdf

[7] T. D. Novlan, R. K. Ganti, A. Ghosh, and J. G. Andrews, "Analytical Evaluation of Fractional Frequency Reuse for OFDMA Cellular Networks", *IEEE Transaction on Wireless Communications*, vol. 10, no. 12, December 2011.

[8] J. G. Andrews, F. Baccelli and R. K. Ganti, "A Tractable Approach to Coverage and Rate in Cellular Networks", *IEEE Transactions on Communications*, vol. 59, no. 11, pp. 3122-3134, November 2011.

[9] Racz A., Reider N., Fodor G., "On the impact of inter-cell interference in LTE", Globecom 2008, New Orleans, USA, pp. 1-6, November 2008.

[10] T.S. Rappaport, "*Wireless Communications",* Prentice Hall, Upper Saddle River, NJ, 2002, ch. 2, pp. 37-42.

[11] H. Holma and A.Toskala,*" LTE for UMTS –OFDMA and SC-FDMA Based Radio Access,"* 1st edition, John Wiley and Sons, 2009.

[12] D. Martin-Sacristan, J.F.Monserrat, J.Cabrejas-Penuelas, D.Calabuig, S. Garrigas, and N. Cardona, "On the way towards Fourth-Generation Mobile:3GPP LTE and LTE-Advanced", *EURASIP Journal on Wireless Communications and Networking*, Volume 2009, Article ID 354089, 10 pages.

[13] Alcatel Lucent Strategic white paper, "The LTE Network Architecture: A comprehensive tutorial"

[14] S.E. Elayoubi, O. Ben Haddada, and B. Fouresti'e, "Performance Evaluation of Frequency Planning Schemes in OFDMA-based Networks", *IEEE Transaction on Wireless Communications*, vol. 7, no. 5, May 2008.

[15] C. Gerlach *et al*., "ICIC in DL and UL with Network Distributed and Self Organized Resource Assignment Algorithms in LTE," *Bell Labs Tech*. J., vol. 15, no. 3, Fall 2010.

[16] F. Khan," *LTE for 4G Mobile Broadband: Air Interface Technologies and Performance"*, 1st edition, Cambridge University Press, 2009.

[17] Mustafa M.M, El. Tantawy, Mohamed A Dahab, H. El-Badawy, "Performance Evaluation of Frequency Reuse Schemes in LTE Based Network",*18th Telecommunications forum TELFOR*, 2010.

[18] Y. S. Cho, J. Kim, W.Y. Yang and C.G. Kang, "MIMO-OFDM Wireless Communications with MATLAB" *John Wiley &* Sons (Asia) Pte Ltd, 2010.