Assessment of LTE Uplink Power Control with Different Frequency Reuses Schemes

Mohamed M. El-Ghawaby
Electronics and Communications
AAST
Cairo, Egypt
ghawaby25@gmail.com

Hesham El-Badawy
Network Planning Department
National Telecom Institute
Cairo, Egypt
heshamelbadawy@IEEE.com

Hazem H. Ali
Electronics and Communications
AAST
Cairo, Egypt
hazemhali@gmail.com

***Abstract*— Single Carrier Frequency Division Multiple Access (SC-FDMA) is the access scheme chosen by 3GPP for uplink UTRAN Long Term Evolution project (LTE). As SC-FDMA provides intra-cell orthogonality, one of the main reasons for performance degradation is the Inter-Cell Interference (ICI). This degradation is accentuated by the frequency reuse of 1 deployed in the system, Since the Frequency Reuse (FR) and Power Control (PC) functionalities is a strong tool for co-channel interference mitigation, using them critical issues in cellular Orthogonal Frequency Division Multiple Access (OFDMA)/LTE networks. In this paper, we compare between the Open Loop Power Control (OLPC) and Closed Loop Power Control (CLPC) performance using different frequency reuse schemes. Simulation results show that large differences exist between the performance of different (FR) schemes and the optimal case in the overall cell throughput, as well as the cell-edge user performance. Also the closed loop power control has shown more cell and edge throughput gain over OLPC.**

Keywords*— Open Loop Power Control; Closed Loop Power Control; Hard Frequency Reuse; Fractional Frequency Reuse; Soft Frequency Reuse.

I. INTRODUCTION

LTE introduces a number of innovations that, in aggregate, continue to push ever closer to the theoretical maximum data rates defined by Shannon's Law [4]. Advances in multi-antenna techniques, OFDMA methods, wider bandwidth, interference mitigation, and protocol efficiencies are fundamental to deliver the promise of 4G Mass Market Wireless Broadband. The amazingly high data rates and sector throughputs (capacity) per cell are fundamental to supplying the ever increasing demand for wireless broadband.

Effective reuse of resources in a cellular system can highly enhance the system capacity. With a smaller Frequency Reuse Factor (FRF), more available bandwidth can be obtained by each cell. So, in this sense the classical FRF of 1 is desirable see Fig. 2a. However, with the usage of FRF-1, the most User Equipments (UEs) are seriously afflicted with heavy ICI, especially near the cell edge. And that causes severe connect outages and consequently low system capacity. The conventional method to figure out this problem is through increasing the cluster-order, which can mitigate the ICI efficiently, nonetheless at the cost of a decrease on available bandwidth for each cell. This leads to restricted data transmissions and lower system spectrum efficiency. To take aim at improving cell-edge performance while retaining system spectrum efficiency of reuse-1.

There are many techniques which can be used to mitigate interference in E-UTRA uplink. The basic approaches are classified into different type such as Power Control, Inter-cell-interference randomization, Coordination/avoidance, and Frequency domain spreading.

Recent researches are focused at OLPC and CLPC performance evaluation. This is due to its capability of interference mitigation as well as increasing the system throughput. Many investigations for the performance and configurations of the OLPC and CLPC [4][7]. Results show that the different configuration is directly effect on both cell edge users and cell center users.

Also, many recent researches are focused at FR techniques such as Hard Frequency Reuse HFR, Fractional Frequency Reuse FFR, Soft Frequency Reuse SFR and performance evaluation and developing [5][6], Results show great performance, especially for the cell edge throughput due to interference mitigation.

The current paper investigates about the ICI as a result of uplink PC and FR. In addition, it will combine between each PC techniques and the three FR schemes to achieve better performance.

The paper is organized as follows; Section II describes the general interference mitigation concepts for E-UTRA followed by detail description of OLPC, CLPC and the most famous frequency reuse schemes which will be used with both OLPC & CLPC. Section III is discussing proposed system model. Section IV illustrates results and its analysis. Finally, the conclusion is presented in Section V.

II. INTERFERENCE MITIGATION

PC and FR schemes are representing the main building blocks of the proposed system model.

A. Open Loop Power Control:

PC refers to set output power levels of transmitters, Base Stations (BSs) in the downlink and UEs in the uplink. A PC formula has been already agreed in a 3GPP meeting for the Physical Uplink Shared Channel (PUSCH) [2]. Fig. 1 is based on an OLPC algorithm and CLPC adjustments can also be applied.

The 3GPP specifications [3] defines the setting of the UE transmit power P for PUSCH by the following equation

$$P = \min\{P_{\max}, P_0 + 10 * \log_{10} M + \alpha * PL + \delta_{msc} + f(\Delta_i)\} \quad (1)$$

where $P_{\max}$ is the maximum UE transmit power, P_0 is a parameter that has a cell specific and nominal part. It is measured in dBm/Hz, expressing the power to be contained in one Physical Resource Block (PRB), M *is* the number of assigned PRBs to a certain user, α is the cell-specific path-loss compensation factor that can be set to 0.0 and from 0.4 to 1.0 in steps of 0.1, PL is the downlink path-loss measured in the UE, δ_{msc} is a UE-specific parameter (optionally cell-specific), and $f(\Delta_i)$ is a UE-specific close-loop correction value with a relative or absolute increase.

The scope of PC is to define the transmitting power in one PRB according to (1), letting the UE scale it to the assigned transmission bandwidth (BW). This implies that ultimately it will transmit with a constant power in each assigned PRB, For this reason, the term $10 \cdot \log_{10} M$ can be extracted from (1). Finally, removing the closed loop term, the Power Spectral Density (PSD) formula results in (2), which is referred to as the Fractional Power Control (FPC) formula.

$$PSD = P_0 + \alpha * PL \qquad \text{“dBm/Hz”} \quad (2)$$

It is preferred to work with the path gain information which is the linear inverse of the path loss. Then, (2) is re-written as (3) in dBm

$$PSD = P_0 - \alpha * PG \qquad \text{“dBm/Hz”} \quad (3)$$

where PG is the path gain of the user to the serving BS.

If α =0, a case referred to as **no compensation**. All UEs will transmit at full power which results in high interference level and poor cell edge performance. With α =1, a case referred to as **full compensation**. The equation reduces to traditional slow power control scheme where all UEs are received at the same power resulting in poor spectral efficiency. By letting 0< α <1, one can achieve both good edge performance and high spectral efficiency by letting UEs with good channel condition transmit at relatively low power level to reduce the interference. At the same time, UEs with bad channel condition are transmitting at relatively high power level to achieve high spectral efficiency.

Regarding to one of the references [4], we will use α =.8 and $P_0 = -81$ dBm/PRB which achieve both good edge and cell throughput.

- Impact on the CINR Distribution

  The Carrier to Interference plus Noise Ratio (CINR) is one of the factors that determine the user throughput. Therefore, a discussion of the impact of the OLPC parameters on each UE experienced CINR would be very helpful for the operator. Let's define the experienced CINR per user

$$isd_j = \sum_{k=s(j)} E[psd_k] * pg_{k,j} \quad \text{“mW/Hz”} \quad (4)$$

where, isd_j is the average interference spectral density perceived by a given BS, *s(j)* denotes the users not served by BS j and allocated to transmit on the observed PRB, psd_k is the power spectral density for user k which is not serving by the given BS, $pg_{k,j}$ is the path gain between user k and the given BS.

$$\mathrm{CINR}_i = E\left[\frac{psd_i * pg_{i,s(i)}}{isd_{s(i)} + n}\right] \quad (5)$$

where n is the thermal noise.

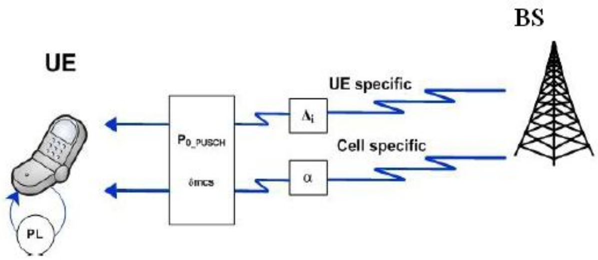

Figure 1. PUSCH power control parameters broadcasted by BS towards the UEs

- Impact on the Cell and Edge throughput

  In EUTRAN LTE UL, the Modulation and Coding Scheme MSC is chosen according to the state of CINR, higher orders are used when this is higher. Equation (6) shows how the user throughput is calculated for a given user from its experienced CINR and allocated bandwidth. [4]

$$C_i = BW_{eff} * v * M * BW_{PRB} * \log_2\left(1 + \frac{CINR_i}{S_{eff}}\right) \text{"bps"} \quad (6)$$

where BW_{eff} is the bandwidth efficiency Set to 0.72, v is a correction factor set to 0.68, M is the number of allocated PRBs, BW_{PRB} is the bandwidth of one PRB Equal to 180 KHz, S_{eff} is the CINR efficiency at system level Set to 0.2 dB. By taking one PRB to be compatible with the fractional frequency reuse which will be discussed later, so there will be difference between our edge throughput and the reference edge throughput [4].

Equation (7) is to calculate the cell throughput.

*T=E[C]**total number of PRBs at the system "bps" (7)

where *T* is the cell throughput, *E[C]* is the average UEs throughput.
Edge throughput is the lowest 5 % of Cumulative Distribution Function (CDF) of the total cell throughput.

B. Closed Loop Power Control:

There are different techniques are used in CLPC because it does not have standardization. But the main idea of the closed loop is to start with OLPC then the UEs also sends feedback to the BS, which is then used to correct the user Transmitted T_X power.

There are two main techniques used for CLPC, Generalized Interference Based Power Control GI-PC, which take in the consideration the path loss to the serving BS, and the generated interference from the UEs to the neighbour BS.

The second technique is Cell Interference Based Power Control C-IPC, which proposed for each UE to have not less the minimum reference CINR.

In our work, we will use the GI-PC as the second PC reference.

The power spectral density can be obtained from (8)

$$PSD_i = I_0 - PG_s * \beta - PG_i * \gamma \text{ "dBm/Hz"} \quad (8)$$

where I_0 is interference power spectral density limit, it work as p_0 in OLPC but the main difference is that I_0 is the power spectral density per hertz but p_0 is the total power contained in one PRB, PG_s is the path gain to the serving BS, PG_I is the path gain to the nearest interfered BS from the UE_i, β is a parameter that affects the impact of PG_s on the T_X PSD, γ is a parameter that affects the impact of PG_i on the T_X PSD.

- Impact on the CINR Distribution

  The CINR can be easily obtained same as OLPC but the main difference will be only in the PSD term.

$$S_i = \frac{I_0 * PG_s^{1-\beta}}{PG_I^{\gamma} * [I + N]} \quad (9)$$

where I is the average interference spectral density perceived by a given BS and N is the thermal noise.

For the cell and edge UEs throughput will be the same as OLPC, other assumption will be at the Table 3.

C. Frequency Reuses Schemes:

There are three major techniques used

- Hard Frequency Reuse (HFR), hard frequency reuse splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub bands see Fig. 2b.
- Fractional Frequency Reuse (FFR), Fractional frequency reuse [5] splits the given bandwidth into an inner and an outer part. The inner part is completely reused by all BSs, the outer part is divided among the BSs with a frequency reuse factor greater, as one seen in Fig. 2c.

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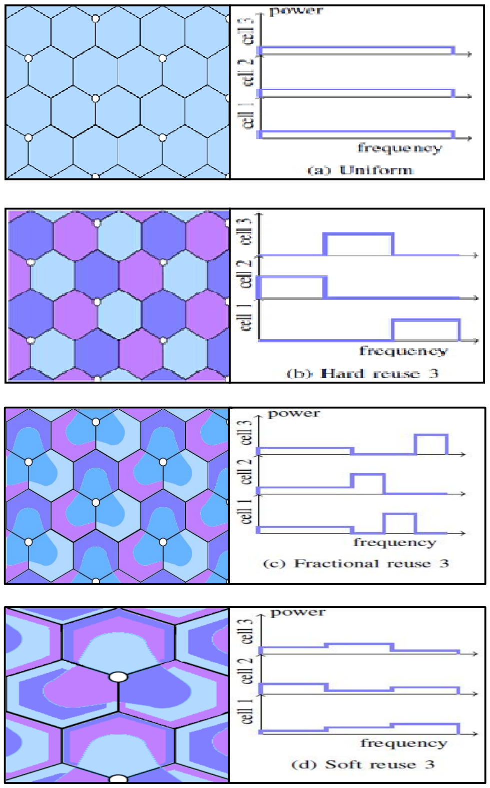

Figure 2. Different frequency reuses techniques

- Soft Frequency Reuse (SFR), soft frequency reuse [6][8][9], the overall bandwidth is shared by all base stations (reuse factor of one is applied), but for the transmission on each sub-carrier the BSs are restricted to a certain power bound see Fig. 2d.

III. PROPOSED SYSTEM MODEL

In this section, the system model is discussed; details are shown in tables 1, 2.

Following the 3GPP guidelines [1], the cell simulation layout consist of a wrap around Macro-cell scenario reference case 1; see Fig. 3. Composed by a grid of 19 sites with 3 sectors each (19 BS with 3 sectors, total cells are 19*3=57cells), each cell has 100 user, the inter site distance is 500 meters and each sector is modeled by a hexagon

The operating bandwidth is divided in 50 PRBs (48 PRB for users and 2 for signaling) with a bandwidth of 180 KHz each. There is a Maximal Ratio Combining (MRC) in the specifications, used to constructively combine the multiple received signals in the antennas. It is modeled here as a constant gain of 3 dB in the received signal.

The total path loss between an UE and a BS is modeled as in (10).

TABLE 1 SYSTEM MODEL DETAIL

Simulation case	**ISD meters**	**BW MHz**	**PLoss dB**	**Speed Km/h**
1	500	10	20	3

TABLE 2 SYSTEM MODEL DETAIL

Parameter	**Assumptions**
Cellular Layout	Hexagonal grid, 19 cell sites, 3 sectors per site (wrap around)
Distance-dependent path loss	L=128.1 + 37.6*log10(R) R in kilometers
Penetration Loss	20 dB
Antenna pattern(horizontal) (For 3-sector cell sites with fixed antenna patterns)	$A(\theta) = -\min\left(12 * \left(\frac{\theta}{70}\right)^2, 20\right)$
Shadowing modeled as a log-normal distribution (SF)	Mean =0, standard deviation= 8dB
Total path loss	*L+A(θ)+SF*
Max UE Tx power	24 dBm
Number of users in system	100*3*19=5700 user

$$PL=L+A(\theta)+SF \quad \text{“dB”} \qquad (10)$$

where L is the path loss between BS and UE, $A(\theta)$ is the modeled antenna gain and SF is the shadowing

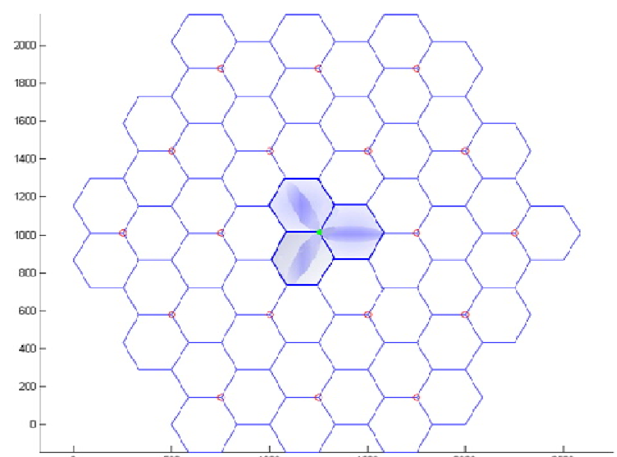

Figure 3. Wrap around Macro cell model

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TABLE 3 PC PARAMETERS

Parameter	Value	Unit
Bandwidth efficiency	.72	bps/Hz
PRB bandwidth	180	KHz
Max UE power	250	mW
Number of PRBs per user	1	-
Outage	5	%
Thermal noise level	-174	dBm/Hz
Total number of PRBs	48+2 for signalling	-
Number of users per cell	100	user
MRC gain	3	dB
α	.8	-
P_0	-81	dBm/Hz
I_0	-157	dBm/Hz
β	.7	-
γ	.3	-

For the PC parameter we will take the same assumption as [4], except the PRB for each user will be one PRB, all parameters are shown in Table 3.

For the frequency reuse

- For HFR, we will divide the total used PRBs for the 3 sectors which will give 16 PRBs for each sector.
- For FFR, we will divide the total PRBs to two groups each group is 24 PRBs, 24PRBs for the centre UEs (Ues, which have path loss less than 120dB), and 24 PRBs is distributed to the three sectors (8PRBs for each sector for the UEs which have path loss more than 120dB).
- For SFR, we divide the total PRBs to three [9] groups, the first group include the UEs which have path loss less than 110dB, the second group include the UEs, which have a path loss between 110dB and 120dB and the last group include the UEs, which have a path loss more than 120dB.

IV. RESULTS AND ANALYSIS

The implementation and simulations are carried out using a multi-cell radio network dynamic simulator implemented in MATLAB to evaluate the PC with different FR schemes.

The results show that all techniques start from the lowest cell throughput and edge throughput and both of them increase to a certain point, peak edge throughput observed when the first user reaches the maximum UE power limitation. Sudden decreasing appears in edge throughput due to interference increasing regarding to the many UEs reach the maximum power limitation which leads to average PSD increasing, which is responsible of edge throughput decreasing.

We will divide the results to three main parts, validation results, OLPC with different FR schemes and CLPC with different FR schemes

A. *Validation results*

Fig. 4 shows a comparison between the obtained results and that had been presented in [4] in the same operational conditions. It is shown that the obtained results get more gains and have the same behaviour of [4] taking in the consideration that in [4] there are 6 PRB for each user ,but in our case there are only 1 PRB for each user to be compatible with each FR scheme.

B. *OLPC with different FR schemes*

Fig. 5 illustrates different schemes of FR. It is shown that by decreasing the interference level by using different FR there will be an increasing in the CINR. The obtained results may be categorized into two main sections. The first one is the edge throughput and the other one is cell throughput.

1. Impact on edge throughput

All FR schemes obtained edge throughput gain over the ordinary OLPC.

OL-HFR has become the highest obtained edge throughput, on the other hand OL-SFR is acting as the lowest edge throughput.

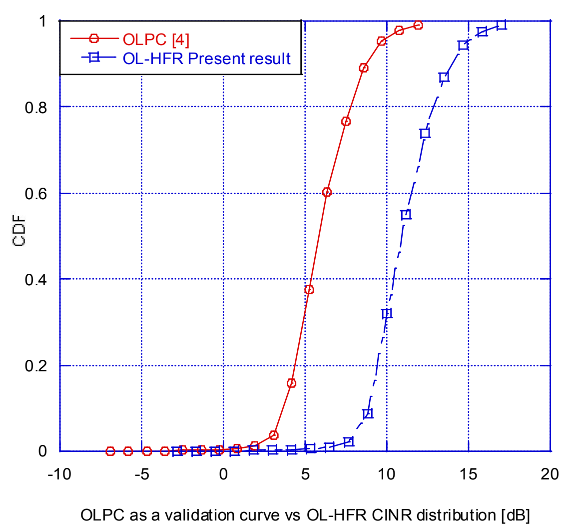

Figure 4. Shows there are CINR shift towards increasing with HF reuse scheme

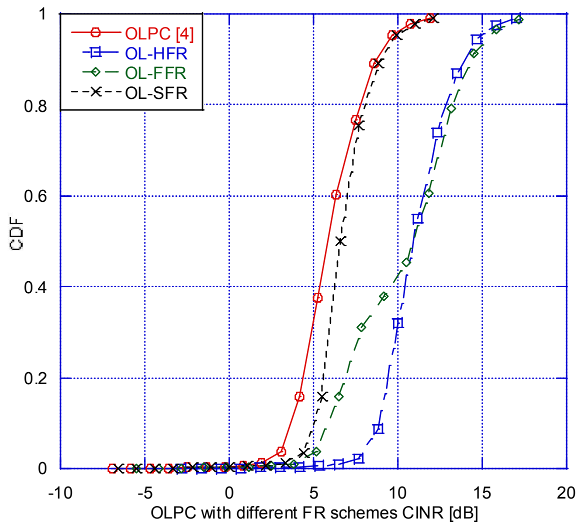

Figure 5. CINR distribution of OLPC with $\alpha = .8$, $P_0 = -81$ dBm /Hz with different FR schemes, there are an increasing in CINR for all FR

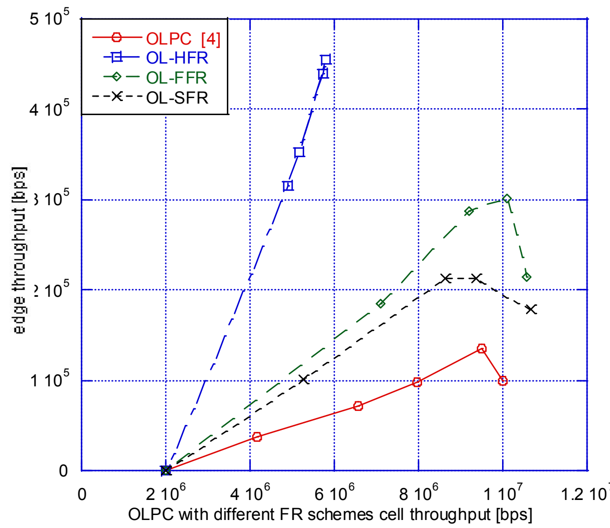

Figure 6. Edge throughput vs. Cell throughput of OLPC with $\alpha = .8$, $P_0 = -81$ dBm/Hz and with all FR schemes, there are edge throughput increasing for all FR over OLPC

The results may be explained as follows;

- OL-HFR: As a result of taking sixteen PRBs only for each cell, The interference level is decreased by 1/3 compared with ordinary OLPC; see Fig. 6.
- OL-FFR: Has a moderate edge throughput due to degradation of interference level by 1/3; see Fig. 6.
- OL-SFR: Has the lowest edge throughput due to the increasing of the interference level when it is compared to the other FR schemes; see Fig. 6.

2. Impact on cell throughput

Both OL-FFR and OL-SFR obtained cell throughput gain over ordinary OLPC on the other hand CL-HFR has lower cell throughput than ordinary OLPC.
The result may be explained as follows;

- OL-HFR: Has the lowest cell throughput as the total number of PRBs is decreased to 16 PRBs only; see Fig. 6.
- OL-FFR: Has a good cell throughput regarding to decreasing the amount of interference which is generated from the edge UEs; see Fig. 6.
- OL-SFR has the highest cell throughput because of decreasing the total amount of interference for the cell; see Fig. 6.

C. CLPC with different FR schemes

Fig. 7 illustrates different schemes of FR. It is shown that by decreasing the interference level by using different FR there will be an increasing in the CINR. The obtained results may be categorized into two main sections. The first one is the edge throughput and the other one is cell throughput.

1. Impact on edge throughput

All FR schemes obtained edge throughput gain over the ordinary CLPC.

CL-HFR has become the highest obtained edge throughput, on the other hand CL-SFR is acting as the lowest edge throughput.
The results may be explained as follows;

- CL-HFR: The interference level is decreased by 1/3 compared with ordinary CLPC; see Fig. 8.
- CL-FFR: Has a moderate edge throughput due to degradation of interference level by 1/3; see Fig. 8.
- CL-SFR: Has the lowest edge throughput due to interference level is higher than the other two FR schemes; see Fig. 8.

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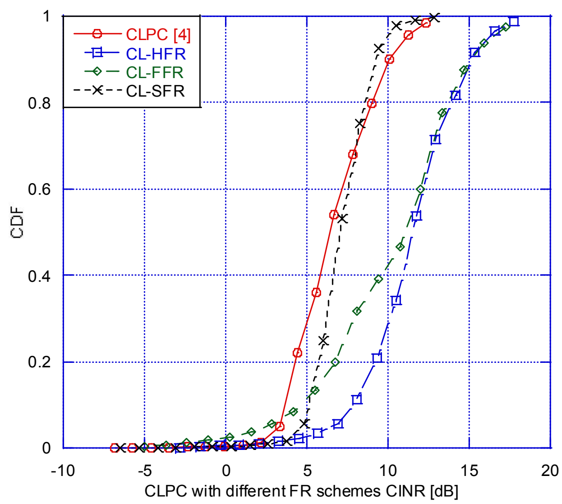

Figure 7. CINR distribution of CLPC with $\beta = .7$, $\gamma = .3$, $I_0 = -157$ dBm/Hz with different FR schemes, there are an increasing in CINR for all FR

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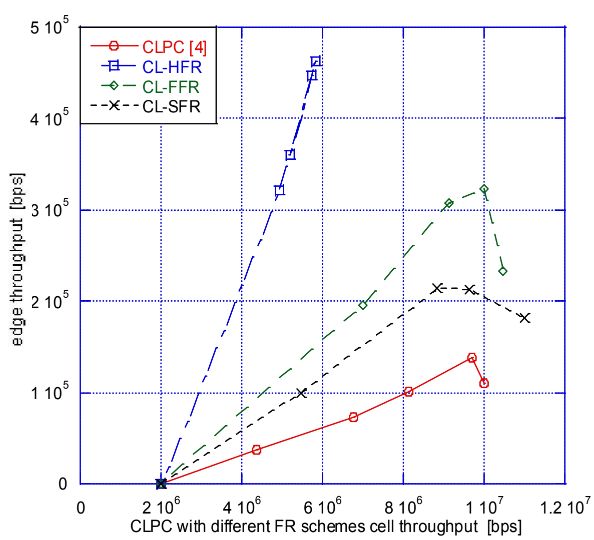

Figure 8. Edge throughput vs. Cell throughput of CLPC with $\beta = .7$, $\gamma = .3$, $I_0 = -157$ dBm/Hz and with all FR schemes, there are an increasing in all edge throughput

- CL-FFR: Has a good cell throughput regarding to decreasing the amount of interference which is generated from the edge UEs; see Fig. 8.
- CL-SFR has the highest cell throughput because of decreasing the total amount of interference for the cell; see Fig. 8.

V. CONCLUSION AND FUTURE WORK

As the FR and PC functionalities is a strong tool for co-channel interference mitigation, using them critical issues in cellular (OFDMA)/LTE networks**.**

Both of OLPC & CLPC techniques had been investigated.

The novelty of the current work is presented via considering both of FR schemes as well as the PC techniques.The obtained results shows gain in CINR for all FR schemes.

The closed loop power control has shown more cell and edge throughput and system gain.

During this work PC techniques with different FR schemes were analyzed by the means of a fixed bandwidth, balanced load and specific boundries of PL for FR schemes.

Future work could investigate the impact of variable bandwidth and unbalanced load. An important contribution would be to find a mechanism to automatically set the optimum boundries of PL for FR schemes and the ability to switch between different FR schemes to obtain the best performance

REFERENCES

[1] 3GPP TR 25.814, Physical layer aspects for evolved universal terrestrial radio access (UTRA) (release 7), Tech. report, v7.1.0, 2006.
[2] R1-073224, Way forward on power control of PUSCH, 3GPP TSG-RAN WG1 49-bis, 2007.
[3] 3GPP TS 36.213 V8.2.0, E-UTRA Physical layer procedures, 2008.
[4] Nestor J. Quintero, Advanced Power Control for UTRAN LTE Uplink, October 2008.
[5] Yong Soo Cho, Jaekwon Kim, Won Young Yang, and Chung G. Kang, MIMO-OFDM wireless communication with matlab, 2010.
[6] R1-050507, 'Soft Frequency Reuse Scheme for UTRAN LTE', Huawei.3GPP TSG RAN WG1 Meeting #41, Athens, Greece, May 2005.
[7] Carlos Ubeda Castellanos, Dimas Lopez Villa, C Rosa, Klaus I Pedersen, F D Calabrese, Per-Henrik Michaelsen, Jurgen Michel, Performance of Uplink Fractional Power Control in UTRAN LTE, VTC Spring 2008 IEEE Vehicular Technology Conference (2008) Publisher: Ieee, Pages: 2517-2521.
[8] Ashley Mills, David Lister, and Marina De Vos, Understanding Static Inter-Cell Interference Coordination Mechanisms in LTE, Journal of communications, vol. 6, no. 4, July 2011.
[9] Mathias Bohge, James Grossy, and Adam Wolisz, Optimal Power Masking in Soft Frequency Reuse based OFDMA Networks, in Proc. of the European wireless conference 2009 (EW '09), Aalborg, Denmark, May 2009.