Interference Based Power Control Performance in LTE Uplink

Malek Boussif [#], Nestor Quintero [*], Francesco D. Calabrese [*1], Claudio Rosa [#], and Jeroen Wigard [#]

[#] *Nokia Siemens Networks*
Niels Jernes Vej 10, 9220 Aalborg East, Denmark
[1] firstname.lastname@nsn.com

[*] *Aalborg University, Radio Access Technology*
Niels Jernes Vej 12, 9220 Aalborg East, Denmark
[1] fdc@es.aau.dk

Abstract— **In LTE Uplink, the slow varying pathgain and shadowing are compensated by the standardized open loop power control (OLPC). Further optimization of the system performance can be done via closed loop power control commands. In this contribution, it is shown that using such commands to control the interference caused by users to the system, it is possible to achieve a gain in the order of 20% on the average cell throughput while maintaining the same outage cell throughput compared to the performance of the OLPC. Furthermore, gain on both average and outage cell throughput can be achieved by tuning the parameters of the proposed scheme.**

I. Introduction

LTE E-UTRA is currently being standardized in 3GPP Release 8 with the aim of achieving a 2 to 4 times higher spectral efficiency gain over HSPA UTRA [1]. The main features include reduced latency in user data transmission, the possibility of having scalable bandwidth up to 20MHz and support for packet-switched domain only.

In the uplink, SC-FDMA has been chosen as the multiple access technique since it benefits from a lower Peak to Average Power Ratio (PAPR), which is beneficial from the User Equipments' (UEs) power consumption point of view, enabling better uplink coverage. Furthermore, it theoretically avoids intra-cell interference thanks to the orthogonality of the multiple carriers. This leaves the intercell interference as the main cause of performance degradation, especially when a reuse factor of 1 is used (which is highly desirable in order to reach the target spectral efficiency gain). This makes the control of the users' transmission power for the physical uplink shared channel (PUSCH) [2] [3] a critical issue since it allows the control of the interference caused by UEs to neighboring cells, while ensuring that the required SINR is met.

3GPP has already specified an OLPC scheme known as Fractional Power Control (FPC) that allows for full or partial compensation of pathgain and shadowing. Though not finalized yet, the specified FPC scheme is expected to remain unchanged in the final version of the specifications due mid-2008.

The performance of FPC has been investigated in [4] where a gain was exhibited tough with a high dependency on the propagation scenario and *IoT* (*Interference (I) over Thermal noise (N) = (I+N)/N)* operation point. In [5] the authors propose to use the difference between the pathgain to the serving sector and that to the 2nd strongest as main criteria for adjusting the transmission power to limit the caused interference. However, the proposed algorithm was based on open loop power control and relied on the possibility for the UEs to estimate the path gain to the 2nd strongest sector.

The present paper will focus on the possibility given by the closed loop power control (CLPC) to further adjust the users' transmission power with the aim of improving the system performance both from the average and outage cell throughput performance point of view. The algorithm proposed in this contribution is based on the interference caused to the entire system (and not only to the sector with the second strongest pathgain) and its performance will be studied in details.

The remainder of the article is organized as follows: Section II introduces details about the power control concept in LTE UL, Section III presents the interference based power control, Section IV gathers details about the simulator platform and simulations assumptions, Section V contains the analysis of the results, and finally, section VI concludes the article.

II. Power Control in LTE UL

The power control in LTE UL has an open loop and a closed loop component as explained in [3]. The open loop component is meant to compensate the slow variations of the received signal, that is, pathgain plus shadowing.

The closed loop component is meant to further adjust the user's transmission power so as to optimize the system performance. The setting of the UE Transmit power P_{PUSCH} for the PUSCH transmission in a given subframe is defined in equation (1), in dB scale.

$$P_{PUSCH}=\min\{P_{MAX}, 10.\log(M)+P0+\alpha.PL+\Delta_{MCS}+f(\Delta_{PUSCH})\} \quad (1)$$

where P_{MAX} is the maximum UE transmission power, M is the number of assigned Physical Resource Blocks (PRB), P_0 is a UE specific parameter, α is the cell-specific pathloss compensation factor, PL is the downlink pathloss measured at the UE based on the transmit power of the reference symbols

[6], Δ_{MCS} is a UE-specific parameter depending on the chosen MCS, $f(\Delta_{PUSCH})$ is a UE-specific correction value also referred as TPC, and $\Delta_{PUSCH} = [-1;0;1;3]$ in the case of cumulate power control commands. The 3GPP specifications allow 2 types of CLPC commands:

- absolute: the user applies the offset given in the PC command using the latest OLPC command as reference;
- cumulative: the user applies the offset given in the PC command using the latest transmission power value as reference.

In this contribution, the cumulative commands are considered since they allow a wider dynamic range for the transmission power.

The FPC algorithm aims at decreasing the perceived pathgain of the users located at the cell edge more than those located close to the cell centre. As can be seen in Figure 1, reducing the fraction of compensated pathgain plus shadowing (i.e. moving from the orange to the green curve) results in decreasing the transmission power for users with a low total pathgain whereas the opposite effect can be observed for users with a high pathgain. The value of P_0 is tuned so as to obtain approximately the same average *IoT* for the 4 depicted cases.

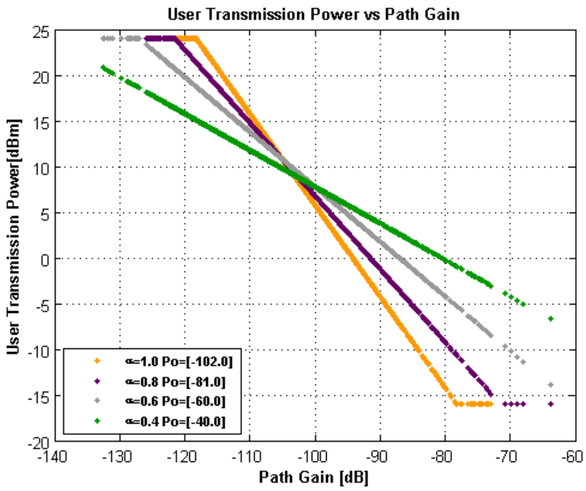

Fig. 1. Transmission power versus pathgain for FPC reference cases. Macro 1 scenario

The FPC relies on the assumption that the interference generated towards other cells is mostly due to users at the cell edge. However, when one looks at the interference caused to the system for a given pathgain value, as shown in Figure 2, it becomes clear that the generated interference follows a different trend than the expected one and that the interference samples are spread over a range of up to 20dB for the same path gain. This shows that the assumption that the users with lowest pathgain generate most of the interference is not always true, especially in a three-sectorized cell layout with correlated shadow fading. This suggests that the transmission power should be adjusted so as to compensate for the generated interference to the system rather than the pathgain, with the goal of having each user producing the same amount of interference. This is going to be the basis for the proposed contribution.

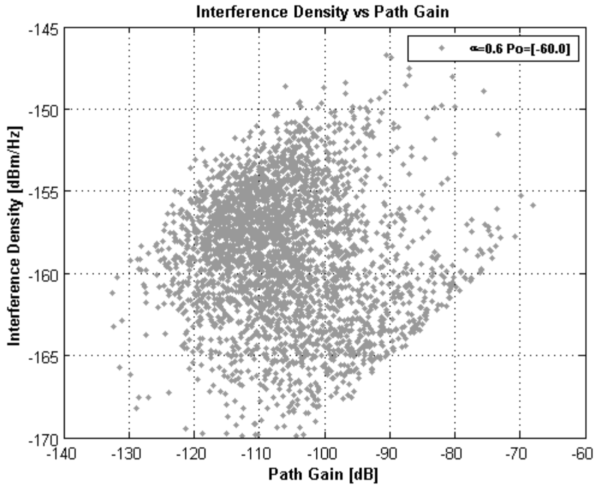

Fig. 2. Interference Density versus Pathgain to serving sector

III. Interference Based Power Control

A. Basic Concept

The implementation proposed in this paper is based on the level of interference generated by a user to the entire network. The idea is to specify a level of interference density users need to comply to. The interference density caused to the system by a certain user can be calculated using the user's power spectral density *psd* and the path gains PG_i between the considered user and all the sectors (except the serving one). Let's call I_0 the wanted upper limit for the generated interference spectral density, the corresponding upper limit for the psd can be obtained as shown in equation (2), expressed in linear scale.

$$psd \le \frac{I_0}{\sum_{i \ne own\ sector} PG_i} \tag{2}$$

While introducing the interference dimension, this approach does not exploit the fact that some users may generate the same interference to the system but have a more favourable path gain to their own sector.

B. Generalized Concept

The extended concept weights the previous expression of the caused interference density by the path gain to own sector as shown in equation (3) (in linear scale), where $PG_{oth} = \sum_{i \ne own\ sector} PG_i$. This constitutes the expression of the proposed Interference Based Power Control (IBPC).

$$psd \le \frac{I_0}{PG_{own}^{\beta}\left(\sum_{i \ne own\ sector} PG_i\right)^{\gamma}} = \frac{I_0}{PG_{own}^{\beta} PG_{oth}^{\gamma}} \tag{3}$$

It is worth pointing out that the proposed scheme actually includes the FPC scheme which can be obtained by setting $\gamma=0$.

C. Implementation aspects

The CLPC commands are sent after the OLPC has applied the desired α and P_0 settings potentially as suggested in [4].

The study assumes that cumulative commands are used, since they allow a wider range in the PC. The possible values transmitted by the CLPC are $\Delta_{PUSCH} = [-1;0;1;3]$ and therefore the applied correction depends on the ideal correction shown in equation (4), in linear scale.

$$Correction = \frac{I_0}{PG_{own}^{\beta} PG_{oth}^{\gamma}} \cdot \frac{1}{psd} \tag{4}$$

The applied correction is thereafter calculated as follows:

- If Correction [dB] < 0 then -1 is sent,
- Else If Correction [dB] < 1 then 0 is sent,
- Else If Correction [dB] < 3 then 1 is sent,
- Else If Correction [dB] > 3 then 3 is sent.

For example, assuming that the required correction is equal to 10dB, the IBPC would transmit the following commands: 3, 3, 3, and 1.

In order for the algorithm to be feasible, the knowledge of PG_{own}, PG_{oth} and psd is needed at the eNodeB. While information on the average path gain to the serving as well as to neighbor sectors can be obtained through RSRP measurements [7], information on the user psd can be made available at the eNodeB via power headroom reports [8] (or alternatively by using information on PG_{own} since the other OLPC parameters are known). Note that the correction is calculated every 1ms and can be applied almost without delay.

IV. Simulations Assumptions

A. Simulator description

The performance analysis is conducted using a quasi-dynamic multi cell system level simulator which follows the guidelines in [5].

The system bandwidth is fixed to 10 MHz with settings according to the LTE working assumptions. The full buffer traffic model proposed for LTE benchmarking evaluation in [9] is assumed. The cell layout is a regular grid comprising 57 sectors and includes the wrap-around technique [10]. The link to system level mapping is based on the actual value interface (AVI) method [11]. It is assumed that distance-dependent path loss and shadowing are maintained constant for each UE. On the other hand, fast fading is updated every TTI based on the ITU Typical Urban power delay profile and depending on the UE speed. Further, shadowing is fully correlated between cells of the same site, while the correlation is 0.5 between sites. The system model includes synchronous adaptive HARQ with Chase Combining.

Proportional fair scheduling in frequency domain is used, and although LTE allows dynamic bandwidth allocation, this study assumes a fixed allocated bandwidth for all the users in order to isolate the effect of the studied algorithm.

The link adaptation is based on fast AMC with outer loop link adaptation (OLLA), see [12] for more details.

The used simulation parameters are shown in Table I.

TABLE I
Simulation Parameters

General Parameters	
Simulation Time	10s/run - 2s/run warm-up - 5 runs
Layout	19 sites - 3 sectors/site - wrap-around [10]
Propagation scenario	Macro 1 [ISD 500m]
Thermal noise per PRB	-116 dBm
Penetration loss	20dB
System bandwidth	10MHz [50 PRBs]
Number of users per sector	10
User's bandwidth	1080KHz [6 PRBs]
eNodeB's receiver	2-Rx MRC
Max user's transmission power	250mW [~24dBm]
TD – FD scheduling	Round Robin – Proportional Fair
HARQ	Synchronous Non-adaptive
Traffic model	Full Buffer [13] with balanced load (i.e. constant number of users per sector)
BLER target	30%
Link adaptation	OLPC & Fast AMC
Available MCS	QPSK [*R=1/10, 1/6, 1/4, 1/3, 1/2, 2/3, 3/4*] 16QAM [*R=1/2, 2/3, 3/4, 5/6*]
Shadowing correlation	Intra-site is 1.0 - Inter-site is 0.5
Shadowing statistics	$\mu= 0dB$ and $\sigma= 8dB$
CSI resolution	2 PRBs
CSI error statistics	$\mu= 0dB$ and $\sigma= 1dB$
Fractional Power Control Parameters	
α	0, 0.4, 0.6, 0.8, 1
P_0	24, -24.2, -48.4, -72.5, -95.6 [dBm]
Δ_{MCS}	0 for all available MCSs
IBPC Parameters	
β	0,…,0.9,1
γ	0,…,0.9,1
I_0	Depends on β and γ [dBm/Hz]

V. Simulation Results

The value of I_0 that optimizes the 5%-ile user throughput has been obtained for each (β, γ). Then simulations have been run for those specific combinations in order to investigate the performance of each (β, γ, I_0).

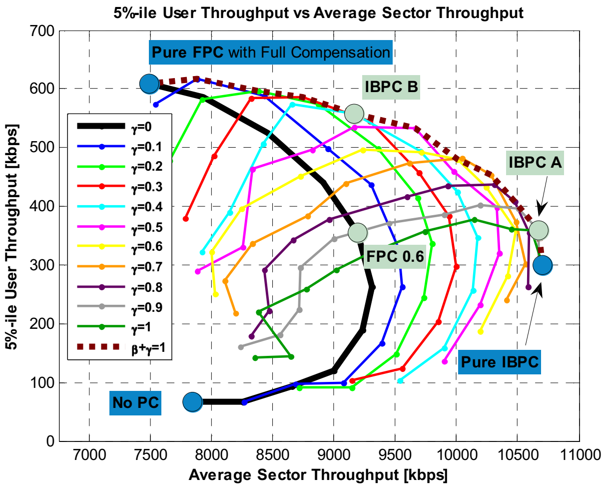

Fig. 3. User 5%-tile throughput vs average sector throughput for IBPC and FPC

Figure 3 reveals the throughput performance by showing the 5%-tile user throughput versus the sector average throughput. Each IBPC curve is obtained varying β for a specific value of γ. A pattern can be seen that reveals the impact of the (β, γ) parameters. For a fixed γ *(e.g.* $\gamma=0.5$*)*, decreasing β results in improved performance for both average and outage throughput. This is true until a certain value for β that causes the coverage throughput performance to drop significantly while the sector throughput losses are more moderate. The optimal case for each value of γ is obtained for $\beta+\gamma=1$. The curve of $\beta+\gamma=1$ defines the best trade-off between pure interference based power control ($\gamma=1$ *and* $\beta=0$) and the pure fractional power control ($\gamma=0$).

Looking at the chosen FPC reference case ($\alpha=0.6$), the performance gain can be calculated and it can be seen with case IBPC A (capacity optimized) compared to FPC 0.6 that the average cell throughput can be increased by 16% while keeping the same cell outage performance. Similarly, case IBPC B (coverage optimized) exhibits an impressive 57% gain on outage cell performance while keeping the same average cell throughput as shown in Table II.

TABLE II
GAIN OF IBPC OVER FPC

	Average cell throughput [kbps]	**Gain**	**5%-tile cell throughput [kbps]**	**Gain**
FPC 0.6/ IBPC A	9196 / 10670	16%	355 / 360	1%
FPC 0.6 / IBPC B	9196 / 9166	~0%	355 / 557	57%

The two best IBPC cases are extracted and compared more in details with the FPC reference case ($\gamma=0$ and $\beta=0.6$ in the legend below).

The effect of the IBPC algorithm on the transmission power for a given pathgain is illustrated in Figure 1. It can indeed be seen that the transmission power is no longer a linear function of the pathgain (as in FPC) but rather a cloud of points. Its spreading increases as we put more emphasis on the interference generated to the system with the parameter γ and its slope decreases with β.

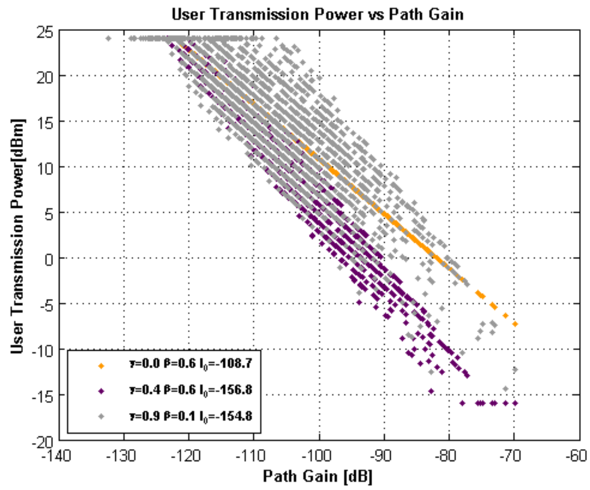

Fig. 4. User Transmission Power vs PathGain

Figure 5 shows that the IBPC cases have a more controlled *IoT* level, as the slope of the curves attests. This is indeed an important result since it leads to a more reliable estimation of the uplink channel quality, and therefore to a more accurate selection of the most appropriate MCS. Note that having as low varying interference in the uplink as possible is an important target since there is a clear benefit resulting from its close control. Moreover, the IBPC B case ($\gamma=0.4$ *and* $\beta=0.6$) shows a significantly lower *IoT*.

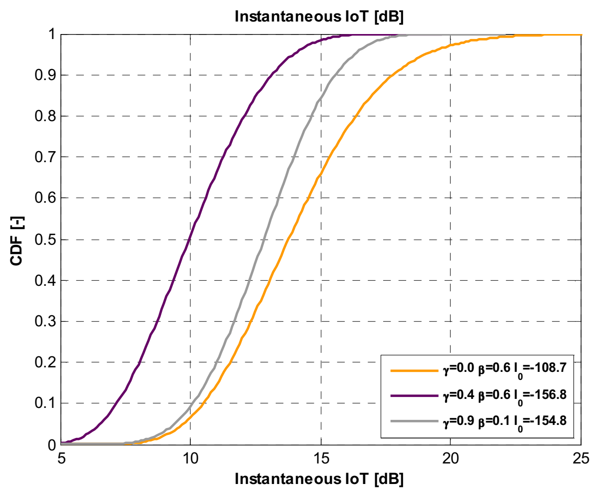

Fig. 5. IoT distribution for the best cases

The impact on the users' transmission power can be observed in Figure 6. Comparing the IBPC B case to the reference FPC case reveals that there is significant decrease in the users' transmission power. This is highly beneficial from a

UE power consumption point of view. Note that this case still exhibits a cell throughput outage gain. On the other hand, the IBPC A case shows a higher transmission power outage but the same median value. Still, the average cell throughput performance is improved.

The CSI (channel state information) error is defined as the difference between the estimated CSI (input to the MCS selection algorithm) and the SINR experienced on the corresponding frequency band when the UE is scheduled for transmission. The error on the estimated SINR can be seen in Figure 7 where the distribution of the CSI error is narrower for the IBPC cases and shows an improvement of about 1dB.

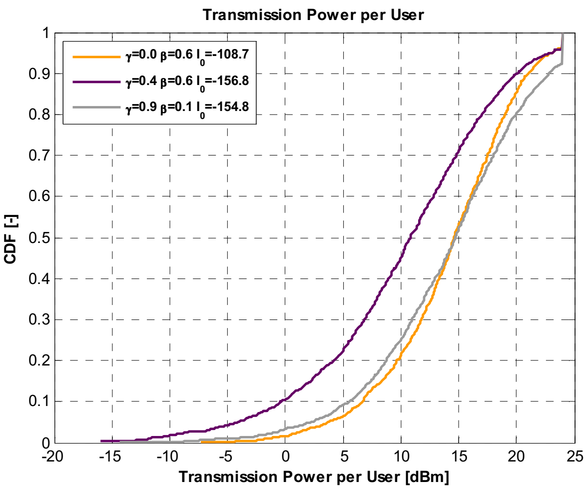

Fig. 6. Average Transmission Power per User

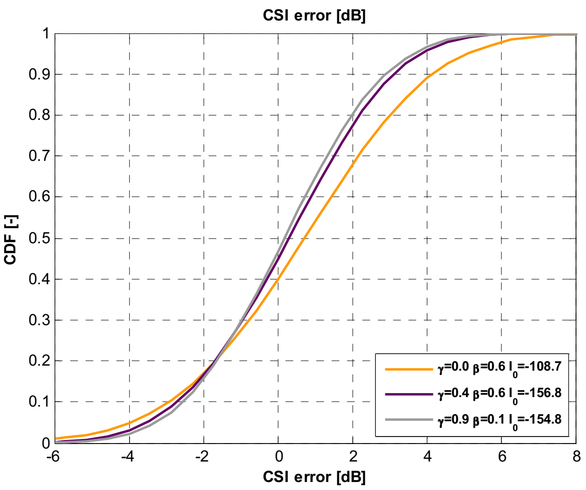

Fig. 7. CSI error

To conclude on the results analysis, Figure 8 compares the average SINR vs. spectral efficiency curves for FPC and IBPC. The improvement is visible especially in the higher range of the SINR curve. IBPC can achieve the same spectral efficiency as FPB for an approximately 0.6dB lower SINR.

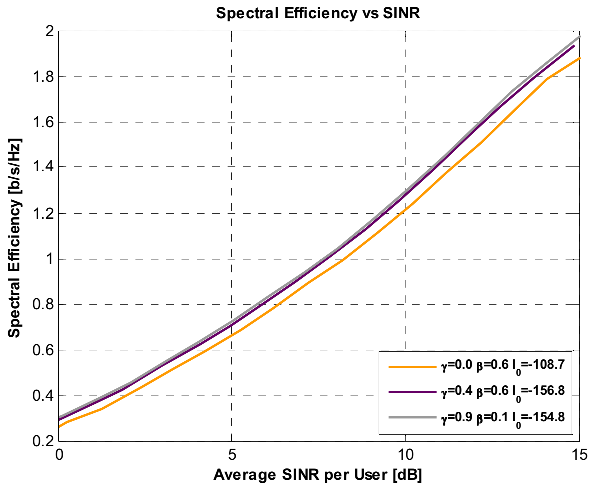

Fig. 8. Spectral Efficiency versus average user SINR

VI. Conclusion

In this contribution, a novel scheme for the LTE Uplink CLPC has been proposed which adjusts the transmission power of the user so as to control the generated interference to the system. Through tuning of its parameters, the IBPC scheme can provide up to 16% average cell throughput gain while maintaining the same cell outage throughput and 57% gain in cell outage throughput while maintaining the same average cell throughput.

Future work includes impact of dynamic bandwidth allocation and RSRP measurement errors.

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