Load Adaptive Power Control in LTE Uplink

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***Abstract*— In LTE Uplink, the slow varying pathgain and shadowing are compensated by the standardized open loop power control (OLPC) which is based on a power density offset and a compensating factor for the pathloss experienced by the users. The optimization of those parameters reveals a dependency on the allocated bandwidth. A Load Adaptive Power Control (LAPC) algorithm is proposed to handle the bandwidth variations and ensure optimal system performance. In this contribution it is shown that using closed loop power control commands to adapt the transmission power density to the used bandwidth, it is possible to achieve coverage gains up to 60% while maintaining a cell throughput comparable to the reference case.**

LTE; Uplink; Power Control; Load Adaptive

I. Introduction

The standardization of Release 8 of LTE E-UTRA has been completed with the aim of achieving a 2 to 4 times higher spectral efficiency gain over HSPA UTRA [15]. 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. 3GPP has already specified an OLPC scheme known as Fractional Power Control (FPC) that allows for full or partial compensation of pathloss and shadowing. The performance of FPC has been investigated in [1].

The present paper will focus on the impact of the Adaptive Transmission Bandwidth (ATB) algorithm (described in [15] and in which UEs are not allocated more bandwidth than their power capabilities allow) on the optimal power control settings. The algorithm proposed in this contribution is based on the observed dependency of the optimal settings on the allocated bandwidth. The closed loop power control (CLPC) will be considered to optimize transmission power according to allocated bandwidth.

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 load adaptive power control algorithm, 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 [6]. The open loop component is meant to compensate the slow variations of the received signal due to the pathloss (including shadowing). The closed loop component is meant to further adjust the user's transmission power so as to compensate for errors and rapid variations as well as potentially optimize the system performance. The way to do such corrections and optimizations is left up to the equipment manufacturer.

The setting of the UE Transmit power PPUSCH for the PUSCH transmission in a given subframe is defined in equation (1), in dB scale.

$$P_{PUSCH}=min\{P_{MAX}\ ,\ 10.log_{10}(M)+P_0+\alpha.PL+\Delta_{MCS}+f(\Delta_{PUSCH}\ )\} \qquad (1)$$

where P_{MAX} is the maximum UE transmission power, M is the number of assigned Resource Blocks (RB), P_0 has both a UE specific component and a broadcast one, α is the cell-specific pathloss compensation factor, PL is the downlink pathloss estimated by the UE based on the transmit power of the reference symbols [4], Δ_{MCS} is a UE-specific parameter depending on the chosen Modulation and Coding Scheme (MCS), $f(\Delta_{PUSCH})$ is a UE-specific correction value also referred as TPC, and Δ_{PUSCH} $=[-1;0;1;3]$ dB in the case of cumulative closed loop 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 trans-mission power.

The FPC algorithm aims at partially compensating the pathloss of users in such a way that it will impact users located at the cell edge more than those located close to the cell center. The coverage (defined as the 5th percentile user throughput averaged over the session time) versus capacity (defined as the average cell throughput) mapping is shown in Figure 1 for different values of *α*. The dots on each curve are obtained by increasing the value of P_0 with steps of *2 dB* only. The coverage performance tops before that of the capacity and are obtained from different values of P_0 *([-108, -84, -64, -36]* dBm) depending on *α ([1, 0.8, 0.6, 0.4])*. These results are obtained in Macro1 using a fixed trans-mission bandwidth of 6 RBs with 10 UEs per cell.

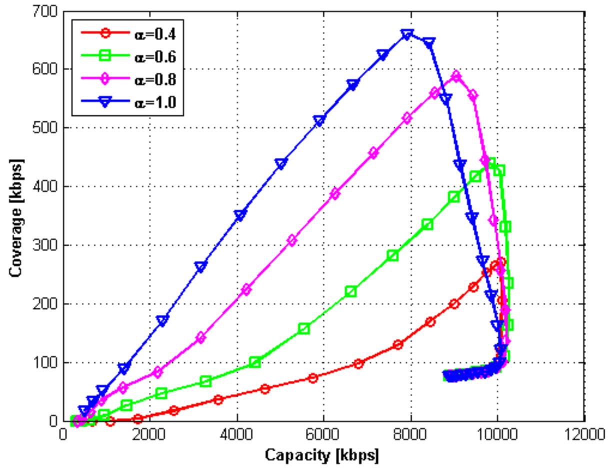

Figure 1 Coverage versus Capacity for FPC. Macro 1 scenario.

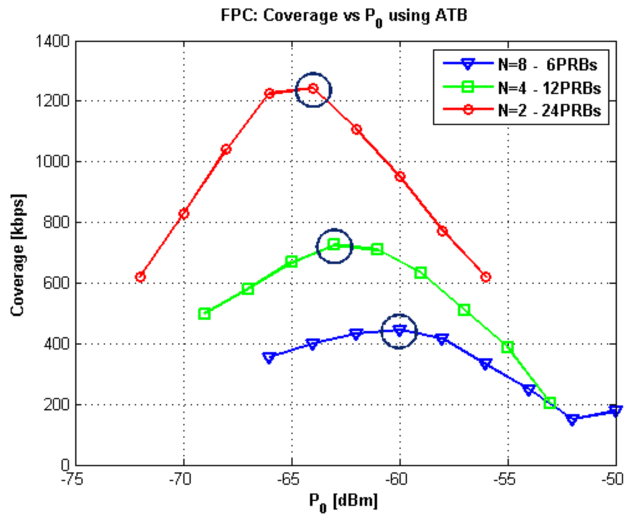

Figure 2 Impact of allocated bandwidth on coverage

This constitutes our reference performance case and illustrates that the throughput performance is highly dependent on the value of P_0. Indeed, small variations of *2 dB* have a significant impact on the throughput performance.

III. Load Adaptive Power Control

This section introduces the need for Load Adaptive Power Control (LAPC) based on performance investigations in bandwidth varying conditions.

A. Load Dependency

The results shown in section 2 assume that a Fixed Transmission Bandwidth (FTB) scheme is used. This means that all users are allocated the same amount of bandwidth in terms of number of RBs. But what if the allocated bandwidth was no longer constant but instead varied? In order to answer that question, let us have a look at the impact of different values of the allocated bandwidth on the location of the optimal P_0. The graph in Figure 2 shows the coverage performance as a function of P_0 for $\alpha=0.6$ and 3 different values of the average allocated bandwidth: 6, 12 and 24 RBs. Such values have been obtained by fixing the number of users per cell and let the ATB algorithm allocate the appropriate amount of RBs. This means that the 48 RBs available for scheduling in the 10 MHz bandwidth are distributed between 2, 4 or 8 users hence yielding average bandwidth of respectively 24, 12, and 6 RBs.

The values of P_0 providing the best coverage are circled in black. As can be seen, the optimal P_0 is changing with the average allocated bandwidth per user. This means that it is not possible to set a specific value of P_0 and expect it to operate the system optimally as the number of users per cell is naturally bound to change in real systems hence implying a change in the average allocated bandwidth. Despite the change in bandwidth, the underlying power distribution is almost identical for all optimal cases as shown in Figure 3. This aspect is going to act as a reference criteria in the algorithm proposed in next section.

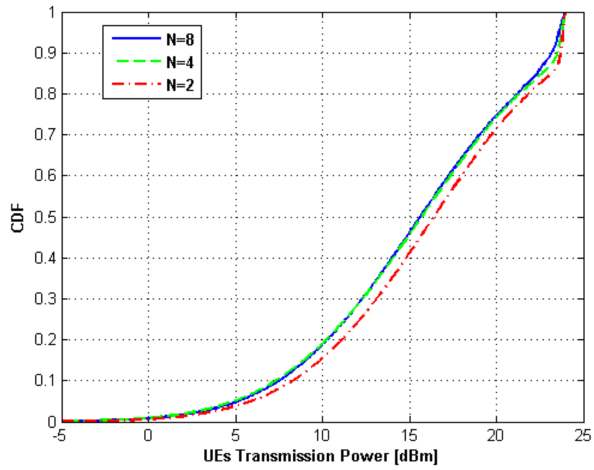

Figure 3 Power distribution for the 3 optimal cases

B. Load Adaptive Power Control Concept

The concept behind LAPC is to update the value of the total transmission power density so as to compensate for the variation in the allocated bandwidth by maintaining the transmission power constant. If one assumes that the optimal value for a specific allocated bandwidth is known, then the transmission power for the PUSCH can be calculated as shown in equation (1). Here it is assumed that the user is not power limited.

$$P = P_0 + M_{dB} + \alpha \cdot PL \tag{1}$$

Then if the bandwidth M varies, the value of *P* will change, too. This needs to be avoided since the transmission power *P* has to remain constant for all users. Any change in the bandwidth has to be accounted for in the total transmission power. Since it is assumed that the pathloss does not change, then either the value of P_0 has to change or the total transmission power density has to be changed using closed loop power commands. Let us take 2 consecutive time instants where the bandwidth has changed as shown in equation (2).

$$\begin{cases} P(t_1) = P_0 + M_{dB}(t_1) + \alpha \cdot PL \\ P(t_2) = P_0 + M_{dB}(t_2) + \alpha \cdot PL \end{cases} \quad (2)$$

Equaling the powers at the two time instants means that a correction or the difference in bandwidth in *dB* has to be applied to either the total transmission power or P_0.

$$\begin{cases} P(t_2) = P(t_1) = P_0 + M_{dB}(t_2) + \alpha \cdot PL + \Delta M_{dB} \\ where\, \Delta M_{dB} = M_{dB}(t_2) - M_{dB}(t_1) \end{cases} \quad (3)$$

The difference to be applied has to be evaluated periodically by the system. This can be done in various ways and here we propose one which is based on the estimate of the average number of users per cell *N*. Using a memory factor a for the filtering provides the expression of the estimate of the allocated bandwidth in equation (4).

$$\begin{cases} \hat{M}(t_{n+1}) = a \cdot \hat{M}(t_n) + (1-a) \cdot M(t_n) \\ where \\ \hat{M}(t_n) = \max\left(\dfrac{BW}{\hat{N}(t_n)}, \dfrac{BW}{N_{\max}} \right) and \\ \hat{N}(t_{n+1}) = a \cdot \hat{N}(t_n) + (1-a) \cdot N(t_n) \end{cases} \quad (4)$$

The underlying assumption is that the bandwidth is equally distributed among the users in a given cell. Therefore, the average bandwidth per user can be estimated as the ratio of the total allocable bandwidth to the number of users per cell. Note that the minimum allocable bandwidth is defined by the limit set by FD-PS as for how many users can be scheduled at one given time instant.

Since the present study does not consider different traffic types, both methods are equally good.

C. Implementation Aspects

The required correction can either be implemented through a direct update of P_0 or CLPC commands. Using P_0 is a rather direct method but because of the limitations in terms of frequency update it may not be the preferred choice. On the other hand, the method based on using CLPC fits perfectly since it can be applied every TTI if needed.

In order for the algorithm to be practically feasible, the knowledge of average number of users per cell is needed for each cell. This knowledge is readily available. Should one choose the other method based on a direct evaluation of the allocated bandwidth, then the same consideration applies and the required knowledge is readily available at the eNodeB. Note that in the present investigation, the correction is calculated every 1ms and applied without delay.

IV. Simulation Assumptions

The performance analysis is conducted using a quasi-dynamic multi cell system level simulator which follows the guidelines in [2].

The system bandwidth is fixed to 10 MHz with settings according to the LTE working assumptions. The finite buffer traffic model proposed for LTE benchmarking evaluation in [8] is assumed. The cell layout is a regular grid comprising 57 sectors and includes the wrap-around technique [9]. The link to system level mapping is based on the actual value interface (AVI) method [10]. Users are distributed randomly in the system. It is assumed that distance-dependent pathloss 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.

Round robin scheduling is used in the time domain whereas proportional fair scheduling is used in frequency domain. The bandwidth allocation is dynamic and users get a bandwidth allocation respecting their available power headroom.

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 1**.

Table 1 Simulation Parameters

General Parameters	
Simulation Time	60s - 10s warm-up
Layout	19 sites - 3 sectors/site - wrap-around [9]
Propagation Scenario	Macro 1 [ISD 500 m]
Thermal Noise Density	-174 dBm/Hz
Penetration Loss	20 dB
System Bandwidth	10 MHz [50 RBs]
Users per Sector	Varying: 2, 4, 6, 8 and 10
UE Bandwidth	1080 kHz [6 RBs]
eNodeB-B Receiver	2-Rx MRC
Max UE Tx Power	250 mW [~24 dBm]
TD - FD Scheduling	Round Robin – Proportional Fair
HARQ	Synchronous Non-adaptive
Traffic Model	Finite Buffer [7] with unbalanced load (i.e. varying number of users per sector but constant for the system)
BLER Target	30%
Link Adaptation	OLPC & Fast AMC
Available MCSs	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	$\mu = 0\ dB$ and $\sigma = 8\ dB$
CSI Resolution	2 RBs

CSI Error Statistics	$\mu = 0\ dB$ and $\sigma = 1\ dB$
FPC Parameters	
α	1
P_0	Variable range [dBm]
Δ_{MCS}	0 for all available MCSs
LAPC Parameters	
Update period	0,…,0.9,1

The point with the simulations being to compare the throughput performance of the LAPC scheme to the reference case with fixed P_0, it is only natural that the number of users per cell varies throughout a simulation. In order to cover different load conditions, the following average number of users per cell has been chosen: 2, 4, 6, 8, and 10. The total number of users remains constant throughout a given simulation but not the one per cell. Each time a user has emptied its data buffer, it will end its session and a new user will be generated and located in the network based on a random process. This results in the user distributions shown in Figure 4 where it can clearly be seen that targeting an average number of users per cell of 10 still provides variations in the actual number of users. This is an absolutely necessary condition to test the robustness of the proposed algorithm.

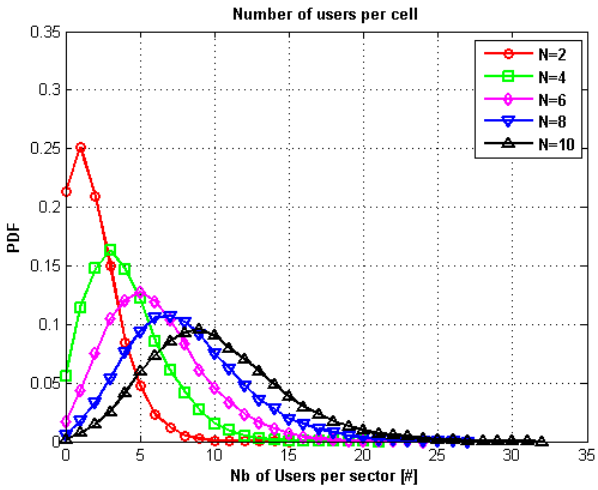

Figure 4 Distribution of the number of users per cell.

V. SIMULATION RESULTS

In this section, comparisons are going to be made between the traditional FPC scheme where the value of P_0 is fixed beforehand and the proposed LAPC scheme where the value of transmission power density is dynamically updated as the allocated bandwidth changes. Keep in mind that the bandwidth is changing with time since the number of users per cells is changing with time and that those two KPIs are related by the 2nd formula in equation (4).

For each one of the selected load cases (respectively 2, 4, 6, 8, and 10 users per cell on average) a simulation has been run per value of P_0 (ranging from *-115 dBm* to *-100 dBm* for $\alpha=1$) for FPC. This provided the 5 curves displayed in **Figure 5**. Then 1 simulation per load value has been run using the LAPC algorithm. Their coverage performance is depicted with the 5 circled dots in **Figure 5**. Let us analyze this figure in details by focusing on one of the cases and let us take *N=4* for example. There, the fixed P_0 technique reveals that an optimal state is reached when P_0 is around *-107 dBm* topping the coverage at just below 700 kbps. Looking at the corresponding case for LAPC (represented by a single dot since the power density offset is constantly corrected using the bandwidth variation as input) reveals that not only the observed average P_0 is lower (at around *-111 dBm*) than that of the FPC case but that the obtained coverage is even significantly higher (around 800 kbps).

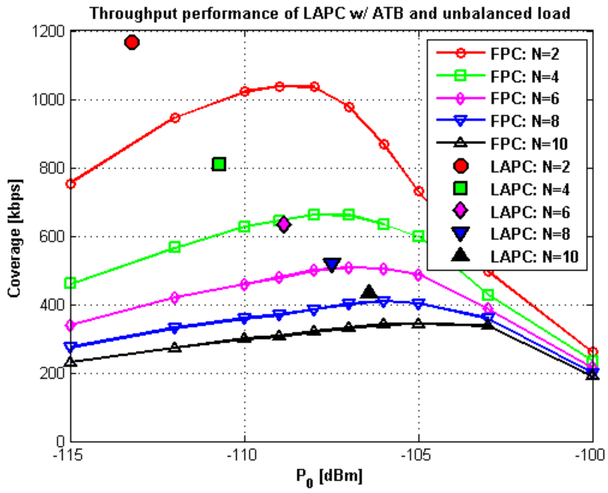

Figure 5 User 5%-tile throughput vs. P0 for different load conditions

How to explain this difference? To start with, looking at **Figure 6** shows how variable P_0 actually is for any given value of the load. For example, having N=4 means that P_0 is going to experience variations in a *12 dB* range. Remember now that in section III.A it was shown that the optimal P_0 was varying with changes in the load. This is precisely the reason why no single value of P_0 can be optimal and hence the FPC case is not necessarily attaining the optimal case. The LAPC algorithm is able to follow the variations of the load and responds by always selecting the optimal value of *P0*. That is the reason why the coverage performance is overall better.

Figure 7 shows the throughput performance in the coverage / capacity plane where both the FPC and the LAPC cases are put side to side. Of course the LAPC case will only include one single point where the FPC will have as many points as there are values of *P0*. On a general note one can observe that the LTE UL throughput performance is clearly defined as a trade-off between coverage and capacity. Coming back to the performance comparison, it appears clearly that the gain in coverage is made at the expense of capacity which the LAPC causes to shrink; moderately though as losses no greater than 10% are observed.

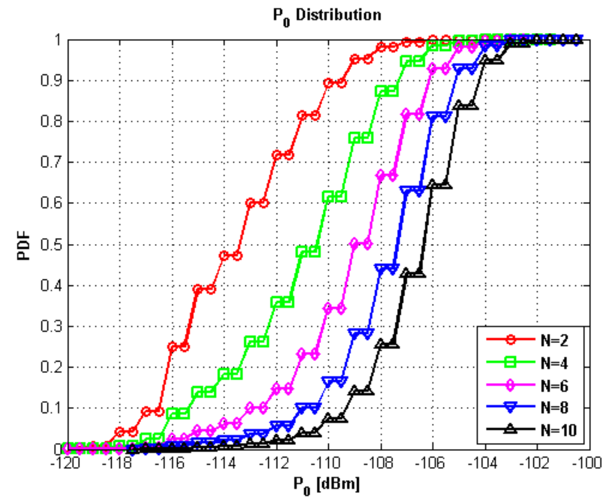

Figure 6 Distribution of the adjusted power density for the different load cases

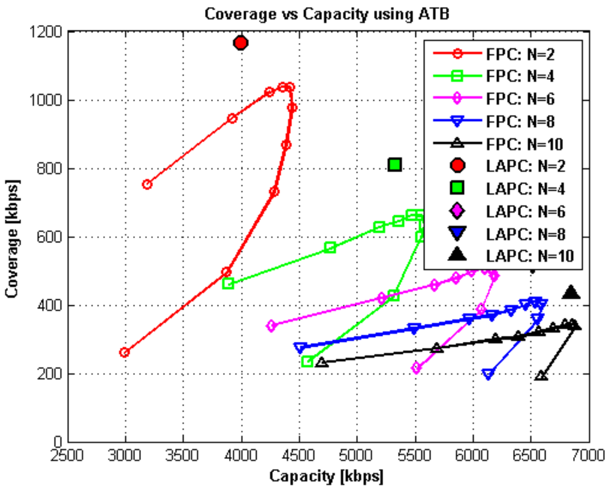

Figure 7 Throughput performance

It is now relevant to have a closer look at the obtained gains for all the possible load combinations. This aspect can be analyzed thanks to Figure 8. The coverage values shown in Figure 5 are used to form the graphs: one assumes that an operator would want to plan its network based on an expected load. Once the load is chosen, it is possible to derive what value of P_0 would give the optimal performance as was also pointed out in III.A. For example, during roll-out phase the load is expected to be low and therefore the optimal value of P0 will be close to *-109 dBm*. Whereas when the LTE penetration rate has grown to lead the network to commercial maturity, a more appropriate value for P_0 is *-105 dBm*. The coverage gain of LAPC under those assumptions is shown by respectively the red and the black curves. The red case is naturally optimal for low load values as shown by the low gain provided by LAPC. But as the load increases, the mismatch in P_0 setting increase and therefore the LAPC algorithm is able to provide significant gains growing here up to 40%. Similarly, choosing the black curve (i.e. the conservative settings) will provide lowest gains for the high load, though still being significant (40%) and top as the load decreases (with gains close to 60%). The same tendencies can be observed for other values of α.

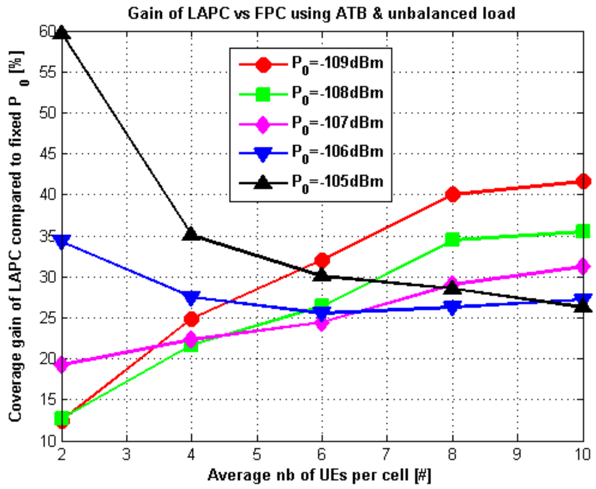

Figure 8 Coverage gain with α=1.0

VI. Conclusions

In this contribution, a novel scheme for the LTE Uplink CLPC has been proposed that adjusts the transmission power of the user so as to adapt to the variations in the allocated bandwidth. Depending on the reference configuration, the LAPC scheme can provide up to 60% coverage gain while maintaining a comparable average cell throughput.

Future work includes impact of non homogeneous network grid.

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