

# LTE Uplink Power Control and its Impact on System Performance

Elena-Roxana Cîrstea, Silviu Ciochină  
Electrical Engineering and Telecommunications  
'Politehnica' University of Bucharest  
Bucharest, Romania  
rcirstea@elcom.pub.ro, silviu@comm.pub.ro

**Abstract**—Long Term Evolution (LTE) is the new standard of the 3GPP (3<sup>rd</sup> Generation Partnership Project) and it was designed to increase capacity and improve service performance. Since SC-FDMA (Single Carrier-Frequency Division Multiple Access) is the multiple access scheme being used, compared with WCDMA (Wideband Code Division Multiple Access) multiple access scheme implemented in UMTS or HSPA, there are no intra-cell interferences. The problem of inter-cell interference is still present. One of the fundamental algorithms that was developed to control inter-cell interferences is the uplink fractional power control mechanism. This paper evaluates possible ways to tune this adaptive algorithm in order to maximize system performance. Simulation results are presented in order to identify the best option for algorithm parameter setting.

**Keywords** - power control; adaptive algorithm; throughput; load; SINR (Signal to Interference Plus Noise Ratio)

## I. INTRODUCTION

Over the last few years, the requirements concerning service performance have become very tight. To be able to deliver the strict performance requirements requested by applications and services, new standards for innovative technologies are under development. For many operators in many countries, this year is going to be the starting point for launching LTE (Long Term Evolution) networks. The main objectives for this new system are: improvement of spectral efficiency, increase of uplink and downlink transfer rates, support for scalable bandwidth and all IP network, reduced delay.

The uplink multi access scheme is SC-FDMA (Single Carrier FDMA). By using this access scheme, a unique frequency can be allocated to users at the same time. This way, intra-cell interference is eliminated. Also, carriers are not combined in random phases so there is no large variation of the instantaneous power for the modulated signal. This translates into a lower PAPR (Peak to Average Power Ratio). The power amplifier in the terminal has an increased efficiency and power consumption is reduced.

One of the key elements that is in charge to improve service performance is the Uplink Fractional Power Control (FPC) [1]. As it is known, interference, even if it is intra-cell or inter-cell, it is an important factor that introduces severe service performance degradation and users dissatisfaction. The FPC algorithm was designed to improve cell throughput or cell edge throughput and to improve battery life time [2],[3].

This paper investigates the way FPC mechanism works and evaluates possible tuning of this algorithm and its impact on service performance both on user experience and on system functionality.

The paper is structured in four parts. The first part is dedicated to a short introduction and the second part describes the fractional power control algorithm as it is specified in the standard. The last two parts are the main parts of the paper that contain simulated scenarios and relevant results. Finally, after analyzing simulation results, recommendations concerning parameter setting are provided.

## II. FRACTIONAL POWER CONTROL ALGORITHM

In LTE system, the power control algorithm for uplink is different, compared to that used for UMTS and HSPA. The differences come from specific characteristics of the LTE system like:

- The multiple access scheme for LTE uplink is SC-FDMA (WCDMA for UMTS) so there are no intra-cell interferences thanks to user orthogonality assured by the multiplexing scheme;

- The LTE flat architecture where base stations communicate one to another to control inter-cell interferences (RNC –Radio Network Controller- the superior entity in UMTS and HSPA that controls interactions between base stations is eliminated in LTE and eNodeB (enhanced NodeB) takes part of its responsibilities);

- The uplink scheduler is located at basestation level and power control should synchronize with link adaptation to be able to adapt to multiple QoS requirements of applications.

Uplink power control mechanism is part of link adaptation mechanisms [5]. Its purpose is to compensate channel variations. Based on different channel variations, two power control categories have been defined:

- a) *Slow Power Control*: compensates for slow channel variations (pathloss, shadow fading) ;

- b) *Fast power control*: compensates for fast channel variations, like fast fading;

Another classification for power control algorithms is based on the characteristics of the information sent by the mobile terminal to establish its level of transmit power:

- a) *Open Loop Power Control*: power level is determined by the terminal using parameters and measurements obtained from the signals sent by eNodeB; no feedback related to the power being used by the user equipment is sent to the eNodeB;

b) *Closed Loop Power Control*: the mobile terminal sends its feedback to the eNodeB which is used afterwards for power corrections.

A Closed Loop Power Control scheme is going to introduce important overhead but at the same time, it will be able to do a better compensation for channel variations. Open Loop Power Control schemes are easy to implement and signalization overhead is much lower compared to the anterior scheme. The limitation is that power compensation for channel variations cannot be done at terminal level.

Full compensation power control schemes implemented for UMTS and HSPA uplink assume that all users are received with the same SINR. In a real network, users have different SINR requirements. For example, users located at cell edge have a higher path loss and instead of using full compensation which increases interference of the neighboring cells, fractional power control scheme is being used. This way, cell edge users could operate at lower SINR and interferences at neighboring cells are diminished.

The standardized formula for uplink fractional power control [1] is described in the next equation:

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

$P_{MAX}$  is the maximum transmit power of the terminal and it depends on terminal power class,  $M$  is the number of PRBs (Physical Resources Blocks) being allocated by the uplink scheduler on PUSCH (Physical Uplink Shared Channel),  $P_0$  is a specific cell parameter that represents the power allocated to one PRB,  $\alpha$  is also a cell parameter,  $PL$  is the downlink pathloss measured by the mobile terminal,  $\delta_{MCS}$  is an offset specific to a user equipment and it is in a strict connection with the modulation and coding scheme and the last parameter,  $f(\Delta_i)$  is a function that allows relative, cumulative and absolute corrections and it is also user specific.

The eNodeB broadcasts parameters  $P_0$  and  $\alpha$ . The destination of this broadcast is represented by the user equipment. Using these two parameters plus the measured pathloss, a mobile terminal is able to establish the power level used during the first phase. This is the Open Loop Power Control. After this stage, mobile terminals send feedback to the eNodeB.  $\delta_{MCS}$  and  $\Delta_i$  are being sent by the eNodeB. These last two terms represent the Closed Loop Power Control.

When  $\alpha=0$ , no power control mechanism is implemented and all mobile terminals use the same transmit power. The case when  $\alpha=1$ , corresponds to full power compensation. For  $\alpha$  in the interval 0 and 1, a compromise is being done in between full compensation and no power control mechanism. In this case, a fractional compensation of pathloss is used.

As it was specified, parameter  $\alpha$  can take values in the set  $\{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$  although values in between 0 and 0.4 have no practical use.

While the value for parameter  $\alpha$  determines a compromise between cell edge users and cell center users,  $P_0$  equally impacts all the users in the cell. As  $\alpha$  decreases, cell edge throughput decreases and cell average throughput

increases [2], [3], [4]. Each possible combination of the parameters  $\alpha$  and  $P_0$  defines an operation point for the Fractional Power Control algorithm and also a certain performance.

For this study, Closed Loop Power Control is not taken into account and only Open Loop Power Control is analyzed. This mechanism is based on the principle that target SINR is calculated using pathloss. Actually, SINR is a linear function of pathloss. Therefore, it is possible to have a higher SINR target at cell center in order to increase throughput while having a lower SINR target at cell edge. The low SINR target at cell edge it is an important factor destined to decrease the level of inter-cell interference.

The Fractional Power Control algorithm allows a tradeoff between cell center users and cell edge users. When  $\alpha$  is less than 1, the SINR target decreases with pathloss. As pathloss decreases, a smooth increase in SINR target was observed.

The combination of Open Loop and Closed Loop Power control is in charge to correct the open loop errors.

### III. SIMULATED SCENARIOS

To be able to evaluate and provide recommendation in such a way that system performance is maximized, several scenarios have been run.

For each run, the mobiles are placed on the geographical area and rejected or admitted according to specified radio conditions. After this stage, the performance per mobile station is calculated. At the beginning of a new simulation, there are mobiles present in the system and also new mobiles arrive in the network. After identifying the best server for each mobile terminal, the admission control is performed.

Here are the inputs for the system-level simulator:

- Frequency band: 2.6GHz
- Bandwidth: 10MHz
- Environment: Suburban
- Traffic: FTP (File Transfer Protocol)
- Slow power control: compensate for slow channel variations (pathloss, shadow fading)
- Path Loss model: Hata suburban, eNodeB antenna height 30m, mobile terminal height 1.5m
- Shadow fading:  $\sigma=6\text{dB}$ ,  $\delta=0.95$
- Maximum transmit power for the terminal: 23dBm
- Fading channel profile: 3km/h, Extended Pedestrian
- The nominal pathloss related to the reference target SINR: 60dB
- No mobility

The number of Physical Resource Blocks (PRB) allocated to a user depends on the service type. For FTP traffic the user requests a minimum guaranteed rate and it has no delay constraints. The number of PRBs allocated is determined by the value of the minimum guaranteed rate.

The uplink power control mechanism is adjusted for each modulation scheme and coding rate. Power adjustment is done while maintaining a target BLER. The first step is to calculate the SINR achieved with maximum transmit power, then the modulation scheme corresponding to the predetermined SINR is decided. The last step is to calculate

the lowest power that can be used to obtain the modulation and the coding scheme previously determined.

Admission control is based on radio conditions and the number of available PRBs. A mobile could be rejected based on uplink or downlink coverage or the unavailability of free PRBs. For uplink admission, each mobile has to reach a C/I threshold to meet the QoS requirements. When the required power to meet this threshold is higher than the maximum transmit power of the terminal, the user is rejected due to bad uplink coverage. Then, the number of PRBs is verified. If the number of unallocated PRBs is lower than the required number to offer the required QoS, the user is blocked and it is taken into account for blocking statistics.

For each simulation, the parameters related to the Fractional Power Control algorithm that can be modified are:

- Parameter  $\alpha$
- Target SINR value at cell edge, Min\_SINR
- Target SINR value at cell center, Max\_SINR
- Arrival rate of users in the system

In order to evaluate the impact of the Fractional power control parameter setting on system performance, the following scenarios have been considered for the suburban case. The table below contains the proposed scenarios:

TABLE I. SIMULATED SCENARIOS

| Scenario number | $\alpha$ | Min_SINR | Max_SINR | Arrival rate | Traffic |
|-----------------|----------|----------|----------|--------------|---------|
| 1               | 0.8      | -1dB     | 12dB     | 80           | UL+DL   |
| 2               | 0.5      | -1dB     | 12dB     | 80           | UL+DL   |
| 3               | 0.8      | 2dB      | 12dB     | 80           | UL+DL   |
| 4               | 0        | -1dB     | 12dB     | 80           | UL+DL   |
| 5               | 0.8      | 2dB      | 12dB     | 200          | UL+DL   |
| 6               | 0        | -1dB     | 12dB     | 200          | UL+DL   |
| 7               | 0.8      | 5dB      | 12dB     | 80           | UL+DL   |
| 8               | 0.7      | -1dB     | 12dB     | 80           | UL+DL   |
| 9               | 0.8      | -5dB     | 12dB     | 80           | UL+DL   |
| 10              | 0        | -1dB     | 12dB     | 120          | UL+DL   |
| 11              | 0.7      | 0dB      | 12dB     | 80           | UL+DL   |
| 12              | 0.8      | 2dB      | 12dB     | 120          | UL+DL   |
| 13              | 0.7      | -1dB     | 12dB     | 120          | UL+DL   |
| 14              | 0.8      | 5dB      | 12dB     | 120          | UL+DL   |
| 15              | 0.7      | -5dB     | 12dB     | 80           | UL+DL   |
| 16              | 0        | 8dB      | 8dB      | 80           | UL      |
| 17              | 0        | -1dB     | 12dB     | 120          | UL      |
| 18              | 0.8      | 2dB      | 12dB     | 80           | UL      |
| 19              | 0.7      | 0dB      | 12dB     | 80           | UL      |

The case when  $\alpha$  is 0 means that the Fractional Power Control mechanism is deactivated. Because of the low admission probability due to downlink limitations (not enough resources to accommodate all downlink users), downlink traffic is set to 0 for the last four scenarios.

To study the functionality of the Fractional Power Control algorithm, a number of four parameters in the simulation output will be analyzed and compared between all defined scenarios:

a) *Admission probability*: The probability for a user to be admitted in the network. It is defined as the percentage of admitted users from the total number of generated users.

b) *Average uplink load*: The ratio between the average number of PRBs allocated for uplink traffic and the number of total available PRBs at eNodeB level.

c) *Average uplink throughput at cell level, R*:

$$R = \frac{N_{PRB}}{\text{Simulation time}} N_{PRB}^{allocated} (1 - \text{BLER}) \quad (2)$$

where  $N_{PRB}$  is the total number of available PRBs on uplink, at eNodeB level,  $N_{PRB}^{allocated}_i$  is the number of PRBs allocated to user  $i$  during one simulation run and BLER is the Block Error rate, also an input for the simulation.

d) *Average number of users in the cell*: Average number of FTP users during a simulation run.

#### IV. SIMULATION RESULTS

The next stage after deciding the scenarios to be run, is to collect and interpret the obtained results. Figure 1, illustrated on the next page, contains the four parameters after running the proposed scenarios. Comparing different scenarios, the functionality of the fractional power control is analyzed.

Because mobility is not considered, pathloss is constant for each user during one run.

Varying only Min\_SINR (scenarios 1, 3, 7, 9, 18) and for  $\alpha=0.8$ , when Min\_SINR increases, both, the admission probability and the number of user in the cell also increases, uplink load decreases (higher modulation and coding scheme, better spectral efficiency) and the throughput is higher. Comparing scenario 3 and scenario 18 with uplink traffic only (avoid being limited by downlink), the output parameters maintain the same tendency.

For a decreasing  $\alpha$  (scenario 1, scenario 8, scenario 2, scenario 4), pathloss compensation is lower so the mobile transmits with less power and SINR decreases. In this case, cell edge throughput decreases and average throughput increases. Also admission probability is lower. To make a compromise between cell edge throughput and average cell throughput, the possible values for  $\alpha$  are 0.7 and 0.8, depending on operator deployment strategy.

By analyzing simulation number 16 and comparing it with scenario 4, users are closer to cell center and throughput, admission probability, average number of users are all higher.

Increasing arrival rate while maintaining other parameters at constant values (scenarios 3, 5, 12), admission probability decreases and uplink load increases. This is the case when the Fractional Power Control algorithm is activated. For the case when this algorithm is turned off (scenarios 4, 6, 10), although admission probability and average number of users in the cell is comparable with the case when power control is turned on (simulation output in figure 1 for scenarios 3 and 4, 5 and 6, 10 and 12), uplink load is lower in this case.

When increasing arrival rate, the admission probability has a very small increase for FPC activated (the difference between admission probabilities is increasing by 0.2 for scenario 3 compared to scenario 4, 0.4 for scenario 10 and S12, 0.5 for scenario 5 compared to scenario 6).

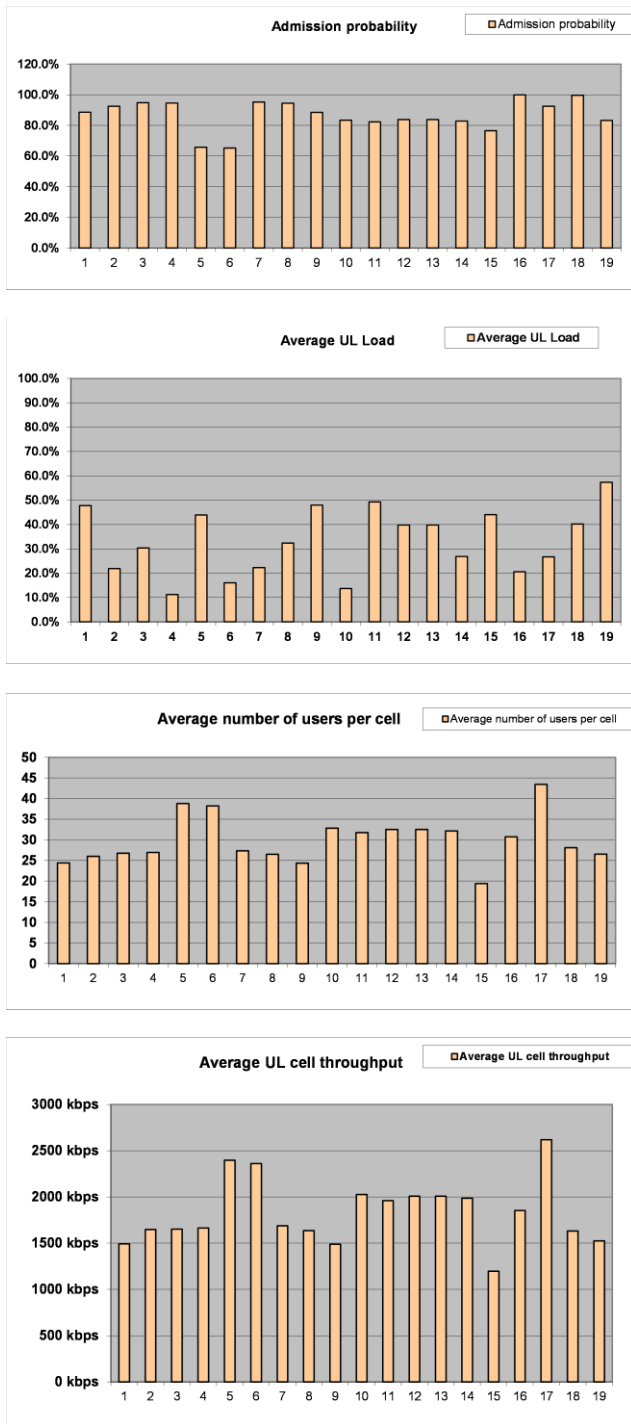


Figure 1. Simulation results: Admission probability, Average uplink load, Average uplink throughput at cell level; Average number of users in the cell

Comparing scenario 3 and scenario 8 ( $\alpha$  is 0.8 and 0.7) and arrival rate 80 and scenario 12 and scenario 13 (same settings for  $\alpha$ ) with arrival rate 120, the average throughput per Cell, uplink load and admission probability are higher for

the case when  $\alpha$  is 0.8 and arrival rate is 80. Increasing arrival rate, almost the same results are obtained for both  $\alpha$  0.7 and 0.8, the difference in between the two  $\alpha$  values translates into a higher cell average throughput.

Another interesting comparison to be done is scenario 9 ( $\alpha=0.8$ ) and scenario 15 ( $\alpha=0.7$ ). Both scenarios have the same Min\_SINR, -5dB. Although three of the output parameters are comparable (load is only 4% higher for scenario 9), the average throughput for scenario 9 is 1489kbps while for scenario 15 it is only 1196kbps. Analogous, an analysis for scenario 1 ( $\alpha=0.8$ ) and scenario 8 ( $\alpha=0.7$ ) but this time Min\_SINR is -1dB. The average throughput for simulation 1 is 1493kbps and 1635kbps for simulation 8. Average throughput for the first comparison is approximately 300kbps higher for  $\alpha=0.7$  and only 142kbps higher also for  $\alpha=0.7$  but for higher Min\_SINR.

A parallel between scenario 4 (no FPC) and scenario 8 ( $\alpha=0.7$ ) both with Min\_SINR=-1dB shows that throughput is comparable. Because users start to be limited by power, the effect of the Fractional Power Control mechanism is less evident. Conversely, evaluating output from scenario 14 (FPC on, arrival rate 120 and Min\_SINR 5dB) and scenario 16 (FPC off, arrival rate 80 and Min\_SINR 8dB) throughput is higher when FPC is active. This is the case when user located close to cell center can benefit more from a power increase compared with cell edge users.

Taking into consideration the implemented simulations, the recommendation for parameter  $\alpha$  is 0.7. Using this value, it gives an opportunity for the network operator to make a compromise between full pathloss compensation where fairness is taken into account and fractional pathloss compensation where users close to cell center can better benefit from good radio conditions. At the same time, an equilibrium between cell edge and cell center average throughput is maintained.

To better highlight the advantages of the Fractional Power Control, a future study for dense urban should be done.

### CONCLUSION

This paper has assessed the functionality of the adaptive fractional power control algorithm for uplink LTE. First, some relevant scenarios have been run and the output parameters have been analyzed.

It can be stated that the uplink power control mechanism has a key role in optimizing uplink system capacity. Uplink power control together with uplink scheduling strategies can enhance cell edge performance by realizing interference coordination. Another way to increase uplink system performance is to implement the Closed Loop Power Control adaptive mechanism to correct errors generated by the Open Loop Power Control algorithm.

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