Open-Loop and Closed-Loop Uplink Power Control for LTE System

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2013/06/22

Abstract-Uplink power control in Long Term Evolution consists of an open-loop scheme handled by the User Equipment and closed-loop power corrections determined and signaled by the network.Open-loop fractional power control for the user located in the vicinity of the serving eNodeB show high throughput, however,steep performance degradation has been observed when the user is moving towards the cell edge. The user throughput at the cell border can be increased by the closed-loop component. The benefit of closed-loop power control is the higher homogeneity in terms of throughput across the entire network area and the ability to automatically stabilize the network performance under different conditions like cell load and traffic distribution. Simulation results indicate that the LTE power control mechanism is advantageous compared to reference mechanisms using full path loss compensation and SINR balancing. The fractional pathloss compensation can improve the cell-edge bitrate and/or the capacity with up to 20% while at the same time battery life time is improved.

Keywords-LTE, uplink, open-loop, closed-loop, power control.

1 INTRODUCTION

Uplink transmitter power control is a key radio resource management feature in cellular communication systems. It is usually used to provide an adequate transmit power to the desired signals to achieve the necessary quality, minimizing interference to other users in the system and maximizing the battery life of the mobile terminal. In order to achieve these goals, uplink power control has to adapt to the radio propagation channel conditions, including path loss, shadowing and fast fading fluctuations, while limiting the interference effects from other users, within the cell and from neighboring cells. The paper is structured as follows.Section 2 describes the goal of power control. The simulation model designed for performance evaluation is introduced in Section 3. Detailed simulation results are presented and discussed in Section 4. Finally the conclusions are given in Section 5.

2 Goal of Power Control

In order to maximize the spectral efficiency, 3GPP LTE is designed for frequency reuse both for downlink and uplink, which means that all cells in the network use the same frequency bands. Thus with frequency reuse, both data and control channels are sensitive to inter-cell interference. The cell edge performance and the capacity of a cell site can be limited by the inter-cell interference. Since the LTE use a Orthogonal Frequency Division Multiplexing(OFDM) technology for downlink, the interference in a single cell is so low that hardly has a necessity to consider mainly. Therefore the role of power control becomes decisive to provide the required SINR to maintain an acceptable level of communication between the eNB and the UE while at the same time controlling interference caused to neighboring cells.

Battery power is a scarce resource for portable devices such as notebooks, ultra-portables, gaming devices and video cameras. In the coming years these devices will operate over mobile broadband technology such as LTE. Therefore to minimize consumption of battery power and use the available power efficiently, power control can be helpful. The 3GPP specifications defines the setting of the UE transmit power for PUSCH by the following equation

$$P = \min\{P_{max} ,10 \times \log_{10}M + P_0 + \alpha \times PL + \delta_{MCS} + \triangle i\}. \ (1)$$

where,
-P_{max} is the maximum allowed transmit power.
-M is the number of physical resource blocks (PRB).
-P_0 is cell/UE specific parameter. It is used to control SNR target and is signaled by the radio resource control (RRC). In this paper, it is assumed that P0 is cell-specific.
-α is the path loss compensation factor. It is a 3-bit cell specific parameter in the range [0-1] signaled by RRC. - PL is the downlink path loss estimate. It is calculated in the UE based on the reference symbol received power (RSRP).
-δ_{MCS} is cell/UE specific modulation and coding scheme defined in the 3GPP specifications for LTE.
-$\triangle$i is a closed loop correction value and f is a function that permits to use accumulate or absolute correction value.
The parameter P_0 is calculated as

$$P_0 = \alpha \times (SNR_0 + P_n) + (1 - \alpha)(P_{max} - 10 \times \log_{10}M_0) \text{ [dBm] } (2)$$

where,
SNR_0 is the open loop target SNR (signal-to-noise ratio)
P_n is the noise power per PRB.
M_0 defines the number of PRBs for which the SNR target is reached with full power. It is set to 1 for simplicity.
The LTE closed loop power control mechanism operates around open loop point of operation. The UE adjusts its uplink transmission power based on the TPC commands it receives from the eNB when the uplink power setting is performed at the UE using open loop power control.
Therefore, eq. (1) can be rewritten as

$$P_{PUSCH} = \min\{P_{max}, P_{OL} + \delta i\} \text{ [dBm] } (3)$$

Where POL is the uplink transmit power set by the open loop point of operation and is given by

$$P_{OL} = \min\{P_{max},10 \times \log_{10}M + P_0 + \alpha \times P_L\} \text{ [dBm] } (4)$$

It is worthwhile to note that, if PPUSCH is set using the closed loop power control then power limitation is neglected in eq. (4) and is applied by eq.(3).

3 SIMULATION MODEL

A set of simple basic uplink power control models are studied. They represent different usage and parameter settings of the LTE power control mechanism.
1) No Power Control (No PC)

Fixed transmission power, the UE power is set to $P = P_{max}$, where P_{max} is the maximum UE power. Used as a reference case. This can be applied in LTE by setting α=0 and $P_0 = P_{max}$.
2) Open Loop Power Control, α=1

Open loop with a fixed received SNR target. α=1 and $P_0 = SNR_{target} + P_{noise}$, where P_{noise} is the noise power level, SNR_{target} is a targeted received power level relative to the noise floor. Note that the desired SNR_{target} with this algorithm must include a margin for expected interference. Values of SNR_{target} between 0 and 30dB have been simulated.
3) Open Loop Power Control, α=0.7

Open loop with fractional path loss compensation. $\alpha = 0.7$ and $P_0 = SNR_{target} + P_{noise}$. All the compensation factors α in the LTE standard (0.4, 0.5, 0.6, 0.7, 0.8, 0.9) have been simulated in combination with SNR_{target} between 0 and 30dB. α=0.7 was found to give a good trade-off between cell-edge bitrate and capacity, as will be shown in the results.

4) Closed Loop Power Control

Fast SINR balancing closed loop. This is based on algorithm 2, but with individual UE specific compensation factors targeting a desired effective SNR; SNR_{target}. The open loop component is set as algorithm 2, α=1 and P0 = $SNR_{target} + P_{noise}$, where P_0 defines the initial power only. Effective SNR (after antenna combination) including interference is measured for each UE and compared with the desired SNR_{target}. The difference is adjusted by sending TPC to the UE. An ideal closed loop is simulated resulting in an upper bound for this type of algorithm. In line with this assumption perfect interference knowledge and an ideal update rate are assumed. The closed loop compensation is repeated until power levels converge.

Static snapshot simulations have been used. In each iteration of the simulation, terminals are randomly positioned in the system area, and the radio channel between each base station and terminal antenna pair is calculated according to the propagation and fading models. To study different system load levels, terminals are randomly selected to be transmitting with an activity factor f ranging from 20 to 100%. In active cells transmitting users are selected independently of channel quality. Based on the channel realizations and the active interferers, a signal-to-interference and noise ratio (SINR) is calculated for each link and receive antenna. Then, using a receiver model, an effective SNR (after antenna combining) is calculated per resource block. Following this, using the mutual information model of [5], the effective SNR values are mapped to active radio link bitrates Ru, for each active user u. Note that Ru is the bitrate that user u gets when scheduled. Active base stations and users differ between iterations, and statistics are collected over a large number of iterations. For each activity factor, the served traffic per cell T(f) is calculated as the sum of the active radio link bitrates for the active users:

$$T(f) = \Sigma_{u=1}{}^{U(f)} R_u / N_{cell} \quad (5)$$

where, U(f) is the total number of active users for activity factor f, and Ncell=57, the number of cells in the system. This assumes that user are scheduled an equal amount of time. The mean and the 5th percentile of the active radio link bitrate are used as measures of average and cell-edge user quality respectively. Note that as the activity factor increases, individual user bitrates decrease because of increased interference and thereby decreased SINR. The served traffic however increases as the number of active users increase.

4 SIMULATION RESULTS

The simulation results mainly come form reference [2] and reference [4].

As seen in Fig. 2, the two open loop algorithms improve the cell edge bitrate almost equally. This improvement comes at the cost of average bitrate reduction. The fractional compensation open loop performs in general best with the same cell edge performance as with full compensation but around 20% higher average bitrate. This is also seen in Fig.1 where the fractional open loop performs equal to or better than the fully compensating open loop.

Utilizing mobiles in good radio conditions and link adaptation improves the served traffic and the mean bitrate. To further investigate this power control targets have been scanned to find the parameter setting giving highest mean bitrate as a function of served traffic at high load, $f \geq 60\%$. The results are shown in Fig. 5. The best setting was found to be:

SNR_{target} =20dB for open loop with $\alpha = 1$,
SNR_{target} = 15dB for open loop with $\alpha = 0.7$,
Effective $SINR_{target}$ = 13dB for closed loop.

The higher open loop targets are due to that interference margin must be included. This optimization is almost the same as maximizing served traffic at full utilization (f=100%), as seen in Fig. 1, for open loop the later results in some dB:s higher targets. The open loop algorithms can achieve around 20% higher capacity than the closed loop.

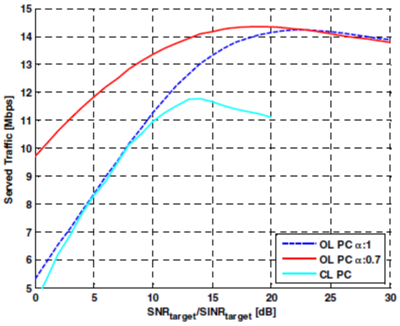

Figure 1: **Served traffic per cell for different SNR and SINR targets.**[2]

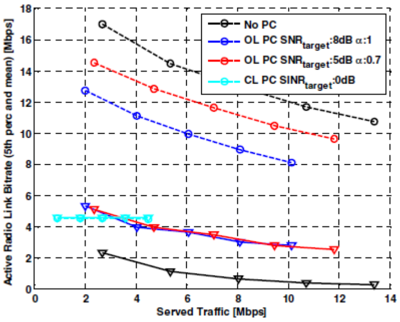

Figure 2: **Mean (circles) and cell-edge (triangles) bitrate vs served traffic, scheduled optimized for cell-edge bitrate.**[2]

In Fig. 3 it is seen that with this parameter setting all three algorithms improve both average bitrate and cell edge bitrate at the same time compared to the reference with constant power. This is since the inter cell interference is reduced. Both average and cell edge bitrate are improved by reduction of interference and using a more efficient link quality range where link adaptation is active. The closed loop performs best at low load since it adapts to interference. However, at higher load the open loop algorithms perform better for cell edge users. One reason for this is that SINR balancing costs radio network capacity, as seen in Fig. 1, moving the closed loop to the left in Fig. 3. This results in that even though the mean bitrate at 100% utilization is higher than with the open loop it is lower for the same served traffic.

The open loop algorithms perform equally regarding average bitrate and capacity. However, the fractional compensating open loop shows 20% better cell edge bitrate, see Fig. 3. The reason for this is that the fractional compensation has a lower SNR target resulting in lower average transmission power. Lower transmission power decreases the interference which the cell edge users gain from and enables a lower SNR target for the same average bitrate. This is also another reason why the closed loop performs worse at higher load. Higher power is used when compensating for interference variations. The fully compensating open loop is between the closed loop and the fractional compensating open loop.

The transmission power per Resource Block(RB) shown in Fig. 3a defines the maximum number of RBs assigned to the UE due to UL power limitation and ideal ATB. This is demonstrated in Fig. 3c. Due to the high power requirements per RB the number of assigned RBs has to be reduced in the scenario for full PL compensation with P_0 = -52 dBm already immediately after leaving the initial position. For this high P_0 setting only one RB is assigned to the UE in most parts of the cell area. Even close to the eNodeB the user cannot profit from a high number of vacant cell resources due to UL power constraint. Contrasting behavior has been observed for P_0 = -100 dBm. The transmission power per RB is sufficiently low to maintain the number of allocated RB during large areas of the cell. A homogenization of the cell resources among the served UEs occurs provoking a fair distribution almost independent of the users position. For P_0 = -76 dBm lack of transmission power occurs in large parts of the cell resulting in a restriction of the assigned resources to a single RB for a distance higher than 100 m. Nevertheless the UE in the vicinity of the eNodeB profits from vacant cell resources with an initial allocation of 40 RBs. FPC with P0 = -52 dBm and α =

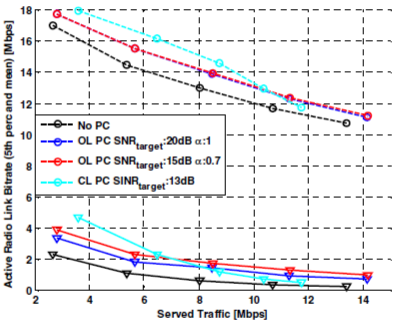

Figure 3: **Mean (circles) and cell-edge (triangles) bitrate vs served traffic. scheduled optimized for mean bitrate.**[2]

0.7 shows similar resource assignment behavior as full PL compensation with P_0 = -76 dBm. Differences have been observed with respect to the number of RBs assigned at the start of the users motion and to the cell area in which more than one RB is assigned to the UE. The effect of higher number of RBs allocated when approaching again the eNodeB compared to initial assignment is related to the lower number of users registered in the serving cell sharing the resources at the same time.

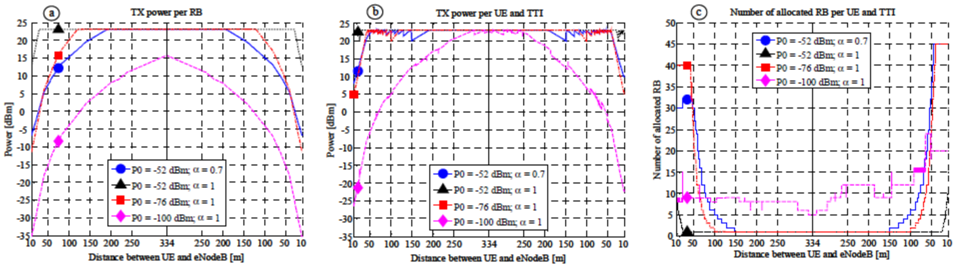

Figure 4: **(a) Transmission power per resource block, (b) total uplink transmission power, and (c) number of assigned resource blocks over distance for OLPC using fractional vs. full PL compensation.**[3]

5 CONCLUSIONS

The performance difference between open-loop schemes based on fractional and full path-loss compensation as well as between open-loop and closed-loop power control at full system load has been thoroughly analyzed by means of tracing an individual test user moving from the serving eNodeB to the cell border and back again. Fractional Power Control, e.g. with P_0 = -52 dBm and $\alpha = 0.7$, is an efficient way to achieve high user throughput in large areas of the cell. At high path-loss, however, the transmission power is considerably lower than that set by the full path-loss compensation scheme, which leads to a lower number of assigned resource blocks by Adaptive Transmission Bandwidth and consequently to lower throughput for users at the cell border. For full path-loss compensation setting P_0 to -100 dBm provides homogeneous performance throughout the whole cell range.

The closed-loop component counteracts the drawback of steep throughput decrease at the cell border provided by Fractional Power Control by adjusting the transmission power to keep the desired quality and level. High cell border performance is achieved in case of low closed-loop power control target necessary to keep the interference level in the network low. Yet in the vicinity of the eNodeB the user throughput is far below that achieved for high closed-loop power control targets or pure open-loop power control. The benefit of closed-loop power control is the higher homogeneity and the opportunity to maintain a specific performance target throughout the whole cell range. Closed-loop power control aims to maintain these targets for all connections and under different conditions like cell environment, traffic load, or possibly not optimized P_0 values and stabilizes automatically the system performance. Finally the combination of open-loop and closed-loop power control leads to good results especially referring to the flexibility and configurability of the 3GPP standardized Long Term Evolution power control options.

ACKNOWLEDGMENT

The author thank Professor Xinbing Wang and Dr. Xiaohua Tian give the chance to take part in the LTE project with Huawei.ltd. Although, it is pity that our efforts of the research can not meet the Huawei engineer's requirements, I have learned lots of knowledge about LTE system in the discussions with Dr. Xiaohua Tian and Dr Chuan Ma.

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