A Downlink Power Control Heuristic Algorithm for LTE Networks

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A Downlink Power Control Heuristic Algorithm for LTE Networks

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Abstract—The recent development of mobile terminals, the proliferation of mobile applications and the increasing need for mobile data have led to a dense deployment of mobile networks. In this context, the Long Term Evolution (LTE) standard is adopted by a large number of mobile network operators. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) technique on the downlink of the radio interface along with frequency reuse-1 model. However, Inter-Cell Interference (ICI) and system power consumption will cause limitations in terms of mean user throughput and system performance. Indeed, several recent works focus on the minimization of ICI and power consumption in multi-user OFDMA networks. In this paper, we propose a distributed heuristic power control algorithm that aims at minimizing the total downlink power of an LTE system. We also study the impact of the power control algorithm on ICI and system performance. Simulation results show that the proposed algorithm largely reduces the downlink power consumption without degrading system performance. In addition, it increases the mean throughput for cell-edge users that are mainly affected by ICI problems.

Index Terms—Long Term Evolution, OFDMA, power control, resource block, Inter-Cell Interference, CQI.

I. INTRODUCTION

Power control mechanism in Long Term Evolution (LTE) [1] adjusts the transmission power on the different frequency resources to improve system performance. Power allocation varies from cell to cell. It can also be device specific, and it has an impact on data throughput, which affects user experience. In fact, downlink transmission power is an important issue in distributed networks with dense frequency reuse schemes. The excessive use of downlink power causes interference problems to the neighboring cells. Thus, it degrades system performance, and lowers spectrum profitability. Several works have proposed power control algorithms in multiuser Orthogonal Frequency Division Multiple Access (OFDMA) [2] systems such as LTE. For instance, authors in [3] investigate a power control mechanism that tries to minimize the requested power under user rate constraints in a non-collaborative system. In addition, [4] introduces a hybrid algorithm that combines adaptive modulation along with power control (*i.e.*, power is increased when the order of the modulation scheme is reduced and vice versa).

The transmission power allocated for frequency resources on the downlink affects mobile users in the neighboring cells. In fact, the 3GPP LTE [1] is introduced to provide higher bitrates for the mobile users and to improve the quality of service for both Downlink and Uplink traffic. It is characterized by the full frequency bandwidth reuse in all the system cells (frequency reuse factor = 1). Therefore, Inter-Cell Interference (ICI) problem arises due to the usage of the same frequency resources during the same time interval in adjacent cells. ICI decreases the SINR of the users and consequently the total system bit rate. Each cell is divided into two zones: cell-center zone (containing users that are close to the base station) and cell-edge zone (containing users that are close to the edge of the cell). Cell-edge users are more affected by ICI than cell-center users (*i.e.*, they have lower SINR) due to propagation loss and due to their proximity to the neighboring interfering cells. For example, authors in [5] noticed that high transmission power for cell-center users in 4G systems degrades the performance of cell-edge users in the neighboring cells. Therefore, an Adaptive Power Control (APC) is proposed to reduce ICI.

A distributed power control is used in [6] to reduce ICI especially when there is a lack of cooperation between base stations. Power control mechanisms were already proposed in [7] and [8] where they lead to dynamic Soft Frequency Reuse schemes. In addition, authors in [9, 10] have proposed dynamic subcarrier, bit and power allocation for multiuser OFDM systems. In fact, frequency resources, modulation order and transmission power are dynamically assigned depending on channel conditions. This flexibility allows to reduce the transmission power while guaranteeing the required bitrates and bit error rate for all the users. Therefore, it is more advantageous than static access schemes such as time division multiple access and frequency division multiple access.

ICI mitigation is also the objective in [11], where the authors use a proportional fair scheduler along with an open loop power control to reduce ICI on the uplink of multi-user OFDMA system. Their objective is to reduce SINR variation in order to increase average user throughput and cell-edge user throughput on the uplink. Power is allocated to each user depending on the number of used Resource Blocks (RB), on cell-specific characteristics and on path loss parameters. Authors in [12] introduce a cooperation between base stations of the OFDMA cellular systems in order to couple the resources allocated by the source and relay base stations for a mobile user. They also propose a distributed power control mechanism that operates independently of the information received from neighboring cells. The influence of cooperation and power control is tested over four different schedulers.

In LTE, interference mainly affects cell-edge users that receive high interfering signals due to their proximity to the neighboring cells. In this context, we propose a distributed heuristic power control algorithm that operates

along with the scheduler deployed at the base station of an LTE network. The objective of this algorithm is to avoid power wastage especially for cell-center users (that are close to the base stations) or users having good radio conditions. In fact, resources are allocated to mobile users on a timescale of one Transmit Time Interval (TTI = 1ms). Numerous scheduling techniques can be used together with our power control algorithm such as Proportional Fair, Round Robin, Maximum SNR and many others. Particularly, we introduce a heuristic power control algorithm that computes power allocation to the different resource blocks once they are allocated to the users.

We tackle the power allocation problem as a method to reduce ICI in multi-user OFDMA systems such as LTE. In fact, LTE system is based on the reuse-1 model where all the available frequency resources are used in the adjacent cells during the same time interval. Power control does not only reduce the power levels of interfering signals (signals usually belonging to cell-center users), but it can also increase the power levels on resource blocks that suffer of bad radio conditions (usually RB allocated for cell-edge users). Therefore, it is considered as a method for Inter-Cell Interference Coordination (ICIC) [13].

The rest of the paper is organized as follows: the downlink power control in LTE is described in section (II). We explain the proposed power control heuristic algorithm in section (III). Simulation environment is described in section (IV), and simulation results are reported in section (V). Conclusion is given in section (VI).

II. DOWNLINK POWER CONTROL IN LTE

In LTE, downlink Reference Signal (RS) exists only in the physical layer. There are two types of RS: cell specific and user specific. The former is transmitted every sub-frame, and it spans the operating bandwidth. However, the latter is only transmitted within the resource blocks allocated to a specific UE. RSs are inserted every 6 sub-carriers in the frequency domain [14]. Each RB contains 2 RSs in the first and the fifth OFDM symbols.

The power level for the RS is signaled within system information to the device. It is cell-specific [15], and it ranges between $-60dBm$ and $+50dBm$ per $15kHz$. It is a requirement that the LTE base station transmits all reference signals with constant power over the entire bandwidth. RS is an important element for downlink power allocation, which can be done on a $1ms$ basis. In fact, it delivers the reference point for the downlink power.

Traditionally, downlink power control for LTE femto-cells is performed according to distance-based algorithms. The femtocell pilot power is configured such that it is received on average with equal strength as the pilot power received from the strongest macrocell at a defined target cell radius, subject to its maximum downlink power [16]. LTE femtocell transmission power is estimated using path-loss models. In measurement-based techniques, the received power is measured using the built-in measurement capability of the femtocell. Then, the downlink pilot power is calculated.

Authors in [17] propose a downlink power control algorithm based on Channel Quality Indication (CQI). Users with different types of service are studied. The

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Algorithm 1 Downlink power control

1: Each user sends CQI feedback about all available RBs to the serving base station
2: **for each** $RB \in RB\_pool$ **do**
3:    **if** $((CQI < CQI_{threshold})$ **and** $(P_{t-TTI} < P_{max\,per\,RB}))$ **then**
4:      $P_t \leftarrow P_{t-TTI} + Power\_Control\_Step$
5:    **else if** $((CQI > CQI_{threshold})$ **and** $(P_{t-TTI} > P_{min\,per\,RB}))$ **then**
6:      $P_t \leftarrow P_{t-TTI} - Power\_Control\_Step$
7:    **end if**
8: **end for**

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downlink power allocated for all the RBs is initialized with the minimum transmission power. For voice-over-IP and data users, transmission power is increased until their data requirements are met. However, an additional offset throughput is set upon the minimum data rate requirement for web users. The base station stops increasing the transmission power when the additional throughput is achieved.

III. HEURISTIC POWER CONTROL ALGORITHM

We propose a distributed heuristic power control algorithm that aims at reducing power wastage especially for cell-center users that usually have good radio conditions. Moreover, this algorithm increases downlink transmission power on the RB allocated for cell-edge users that suffer the most from interference and path loss problems. The downlink channel dependant scheduling in LTE requires specific information to be sent by the terminals to the network. Such information is transmitted through Channel State Reports that contain CQI feedback. CQI represents the highest modulation and coding scheme that guarantee a block error rate less than 10% for physical downlink shared channel transmissions [18]. There are two types of channel state reports in LTE: either periodic configured by the network to be delivered with a certain periodicity or aperiodic delivered when explicitly requested by the network. Moreover, several reporting modes are supported. For example, wideband CQI feedbacks reflect the average channel quality across the entire cell bandwidth while configured reports require the transmission of one CQI per configured sub-band.

We use the CQI feedbacks as an entry to solve the downlink power allocation problem. In this context, we propose a distributed heuristic downlink power control algorithm that computes downlink power allocation on the different resources according to CQI values received from the users. The heuristic power control algorithm is compared with the scenario where no power control is applied $i.e.$, the scheduler allocates permanently the maximum downlink transmission power for each RB.

In the proposed algorithm, the scheduler of each base station ($e.g.$ Proportional Fair, Round Robin or Best CQI) performs both RB and power allocation each TTI, independantly of the other base stations in the network. The idea behind this algorithm is to minimize downlink transmission power without degrading the performance of cell-center users. In addition, transmission power allocated for RBs having low SINR values is increased

in order to guarantee a better usage of the available spectrum. If the received CQI feedback is higher than a predefined $CQI_{threshold}$, downlink transmission power is decremented as long as it is higher than a predefined minimum power P_{min}. However, if CQI feedback is lower than $CQI_{threshold}$, downlink transmission power is incremented as long as it is lower than the maximum allowed transmission power P_{max}, where:

$$P_{max} = \frac{Sector\ Maximum\ Downlink\ Power}{Number\ of\ Available\ RB} \quad (1)$$

The minimum transmission power P_{min} is a predefined parameter that guarantees an acceptable bitrate over the considered RB. $CQI_{threshold}$ can take one of fifteen possible integer values since $1 \leq CQI \leq 15$. When $CQI_{threshold} = 15$ the power control algorithm allocates the maximum downlink transmission power for each RB. Moreover, P_{max} (given in (1)) guarantees that the maximum transmission power allocated for all the RB is always less than or equals the maximum transmission power of the cell.

Algorithm 1 describes how downlink transmission power attributed for each RB is adjusted by the scheduler according to the last received CQI feedback. The objective of this algorithm is to avoid power wastage especially for cell-center users (that are close to the base stations) or users having good radio conditions (high CQI values). In addition, this power decrease will reduce the ICI that mainly affects the cell-edge users of the neighboring cells. We also improve the throughput of cell-edge users by increasing their downlink transmission power.

IV. SIMULATION ENVIRONMENT

In order to study the performance of our power control algorithm, several LTE system level simulations are performed. Comparison parameters are: downlink transmission power and mean user throughput. We simulate our proposed algorithm using a MATLAB LTE system level simulator [19], and we compare its performance with other power control strategies.

We adapted the chosen LTE system level simulator before performing the required simulations. In fact, SINR calculations were made assuming the maximum downlink transmission power is attributed permanently for all the RB. In addition, no downlink power control mechanism was implemented. Therefore, we implemented the MATLAB open-source code of the simulator to ensure that the effective power levels on each RB are taken into account when calculating SINR levels. We choose the proportional fair scheduler to implement the proposed power control algorithm. Note that this algorithm can also be integrated within other schedulers such as round robin or best CQI. Simulation parameters for the simulated LTE system and the power control algorithm are summarized in Table I.

V. SIMULATION RESULTS

A. Downlink transmission power

First, we simulated a basic scenario where an LTE system contains one cell-center user and one cell-edge user in two adjacent cells. The objective of the simulation is

TABLE I
SIMULATION PARAMETERS

Parameter	Value	Description
Cell geometry	$Hexagonal$	A cell is served by an eNodeB
Inter-eNodeB distance	$500m$	Urban area
Operating bandwidth	$5MHz$	——
Number of RB	25	In the $5MHz$ bandwidth
Transmission frequency	$2GHz$	——
Subcarrier frequency	$15kHz$	1 RB = 12 sub-carriers
TTI	$1ms$	Transmit Time Interval
Pathloss model	$TS25.814$	Same as in HSDPA
Thermal noise density	$-174dBm/Hz$	——
Feedback delay	$3ms$	3TTI
Scheduler	$Proportional Fair$	——
Traffic model	$Fullbuffer$	——
eNodeB max. power	$10W$	——
Max. power per RB	$0.4W$	$\frac{eNodeB\ max.\ power}{Number\ of\ RB}$
Power control step	$0.04W$	$\frac{Max.\ power\ per\ RB}{10}$
Min. power per RB	0.16	$4 * Power\_Control\_Step$
$CQI_{threshold}$	7	$1 \leq CQI \leq 15$

to show the impact of our proposed heuristic algorithm on the downlink transmission power for cell-center and cell-edge users. The simulated LTE system bandwidth is $5MHz$; therefore, we have 25 RBs available in each cell. Simulation time equals 500 TTI which is equivalent to $500ms$, and CQI feedback reception at the base station is delayed by 3 TTI. The proportional fair scheduler is used, and it allocates the RBs based on the full buffer model. We report the variation of the total downlink transmission power allocated for each user along with time. These variations are illustrated in Fig. 1.
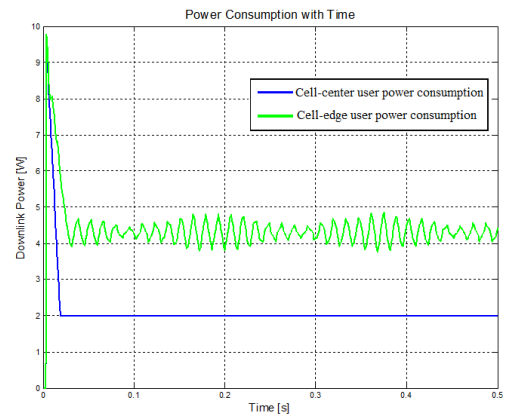

Fig. 1. Downlink transmission power variation with time

According to Fig. 1, we notice that the downlink transmission power allocated for the cell-center user is reduced

after receiving the CQI feedback at the serving base station. In fact, the power control algorithm implemented at the scheduler will decrease the downlink power attributed for the RBs allocated to this user since the received CQI is higher than the predefined $CQI_{threshold}$. Downlink power is decreased as long as the CQI received is higher than the predefined threshold until it reaches the minimum downlink transmission power. However, when the received CQI value is lower than the $CQI_{threshold}$, downlink transmission power allocated for the corresponding RB is increased. The oscillations observed for the downlink transmission power of the cell-edge user are due to successive increase and decrease in the downlink transmission power. Indeed, when the received CQI becomes higher than the threshold, the downlink transmission power is decreased. Consequently, this power reduction will affect the current CQI value that will also decrease. Thus, downlink power value along with time is subject to oscillations that are ruled by the received CQI feedback values. To reduce these oscillations, we may define a CQI interval around $CQI_{threshold}$ where we tolerate CQI variations (*i.e.*, we do not modify the allocated downlink power).

B. System performance

We simulate an LTE system having 7 hexagonal adjacent cells and 10 mobile users in each cell. Therefore, the simulated LTE system contains 70 mobile stations. The scheduler used at each base station is Proportional Fair, and it allocates resources for the users with a period of one TTI. The heuristic power control algorithm adjusts downlink transmission power according to the CQI feedback received from the mobiles. This simulation is repeated 100 times. Downlink parameters of our simulated system, such as mean throughput per user and power consumption, are averaged over the 100 simulations. Path loss and radio conditions are randomly generated. Users in the central cell of the system are cell-edge users; however, all other users are cell-center users. Simulation results are reported in Fig. 2 to 5.
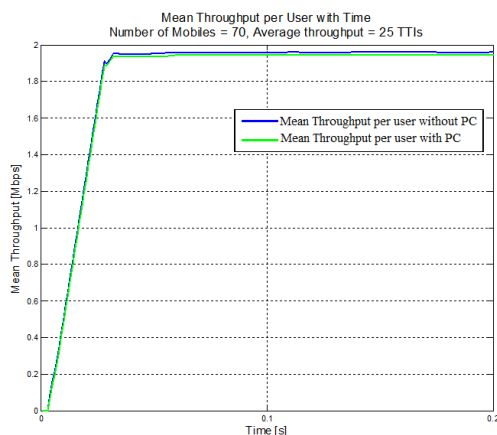

Fig. 2.   Mean throughput per user with time

In Fig. 2, we report the mean throughput per user with and without the power control heuristic algorithm. It shows that the system performance remains approximately the same when using our proposed algorithm. In fact, downlink transmission power for resource blocks having good
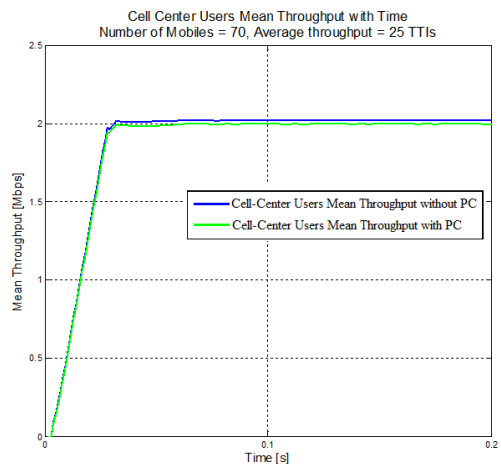

Fig. 3.   Cell-center users mean throughput with time

radio conditions (CQI relatively high) is decreased; however, the transmission power allocated to RB characterized by low CQI feedback values is increased to compensate throughput loss that might occur due to propagation loss and ICI problems. Globally, the mean throughput per user remains approximately the same for the entire system. Fig. 3 shows the impact of downlink transmission power adjustments on cell-center users. Such mobile users are geographically close to the base station. Thus, they are characterized by a lower path loss. In addition, cell-center users are less affected by inter-cell interference since the interfering signals will experience important degradation before reaching the mobile. For these reasons, resources allocated for cell-center users show relatively high CQI feedback values. Hence, downlink power allocated for these resources is decreased, and the mean throughput per cell-center user is slightly reduced.
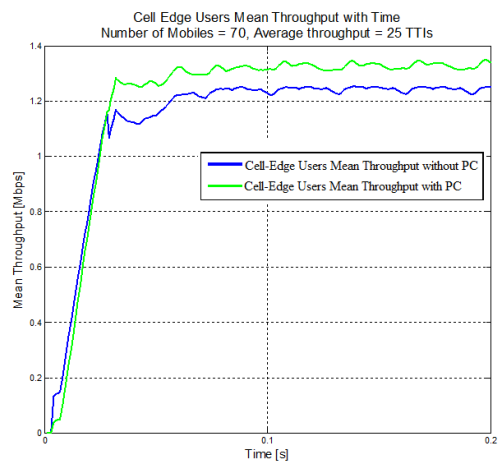

Fig. 4.   Cell-edge users mean throughput with time

Simulation results reported in Fig. 4 show the average throughput per cell-edge user with and without the power control heuristic. We notice that the mean throughput is increased for cell-edge users when applying the proposed algorithm. In fact, these users suffer the most from inter-cell interference problems for two reasons: first, their signal path loss is important; second, they are highly affected by interfering signals transmitted by the neighboring cells.

Since resource blocks allocated for cell-edge users are characterized by low CQI values (due to propagation loss and inter-cell interference), the power allocated for these RB is incremented. Thus, the signal loss caused by free space propagation is reduced. Furthermore, resource blocks used by cell-center users in the neighboring cells have higher CQI values. According to our power control algorithm, the downlink power allocated to these RB is decreased. Hence, we reduce the amount of inter-cell interference that mainly affects cell-edge users. These power adjustments will improve the channel quality for edge users allowing them to get higher throughputs and better performance.
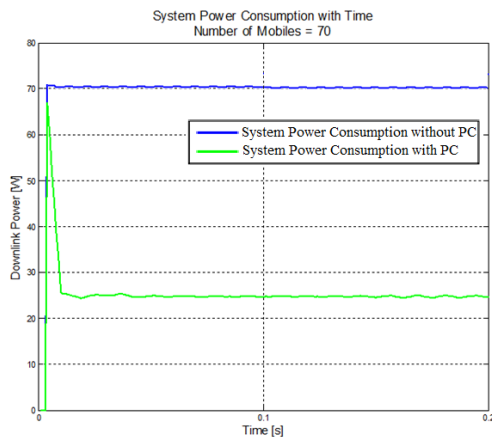

Fig. 5. System power consumption with time

Curves in Fig. 5 show that the power control heuristic largely reduces the total downlink transmission power. Indeed, the LTE system consumes only $25W$ instead of $70W$ (which is the maximum power consumption for an LTE system having 7 cells transmitting at $10W$ each). Thus, the total downlink transmission power is reduced by 64%. Joining these results along with the results obtained in Fig. 2 (system performance is approximately the same) allows us to exhibit the main advantage of our algorithm: we avoid power wastage without degrading system performance. Moreover, cell-edge users mean throughput is improved when using the power control algorithm.

Note that in the special case where all the users are located at the edge of the cells, downlink transmission power is increased (as long as the received CQI feedback is lower than the predefined CQI threshold) until we reach the maximum transmission power. Thus, user position has an important impact on power consumption.

VI. CONCLUSION

Multiuser OFDMA systems, such as LTE, are becoming widely deployed to fulfill the increasing demand for mobile data. However, inter-cell interference problem arises due to the dense reuse of frequency resources. Cell-edge users are mainly affected by ICI due to their proximity to the neighboring cells. Thus, we proposed a distributed power control heuristic algorithm that can be implemented within several schedulers such as proportional fair, round robin or best CQI.

The proposed algorithm adjusts the downlink power allocated for each RB according to the received CQI feed-back. Simulation results show that the main advantage of the algorithm is reducing power wastage without degrading system performance. It also improves the performance of cell-edge users by decreasing the transmission power on resource blocks allocated to cell-center users since they are the main source of interference between neighboring cells.

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