Role Game Theory Approach for LTE Uplink Power Control

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Abstract – **In this paper the application of Role Game Theory to Uplink Power Control (UPC) for Long Term Evolution (LTE) is considered. The authors propose an approach based on defining different roles of the subscribers within a cell of the LTE network. The main idea is to apply different methods and algorithms for UPC depending on the classified by role subscriber. Such an approach will give the possibility for flexible application and utilization of the different UPC methods to obtain better performance.**

Keywords – **LTE, Uplink Power Control, Game Theory.**

I. Introduction

In mobile communication systems it is necessary to balance between the need for sufficient transmitted energy per bit to achieve the required service quality (in respect of higher throughput and lower bit error rate performance), against the needs to minimize interference to other users of the system and to maximize the battery life of the mobile terminal. To achieve this, Uplink Power Control (UPC) methods are applied in order to adapt the transmission to the characteristics of the radio propagation channel, including path loss, shadowing and fast fading, as well as overcoming interference from other users - both within the same cell and in neighboring cells [1].

Currently, two major approaches for the realization of Power Control (PC) for the Long Term Evolution (LTE) uplink are under consideration. They are based on open and closed-loop schemes to control energy per resource element applied for an uplink transmission. With the *Open Loop Power Control* (OLPC) the devices set their power depending on their own measures and the ones obtained from the Evolved NodeB (eNB). For the *Closed Loop Power Control* (CLPC) User Equipments (UEs) also send feedback to the eNB, so they can receive more accurate information to set their transmission power [2].

LTE PC algorithms work in terms of Power Spectral Density (PSD) rather than total power. In traditional systems as 3G the used spectrum was fixed so total power was the usual term. Contrarily, LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in which the available spectrum depends on the Physical Resource Blocks (PRBs) assigned, so the PC is only capable to fix the power in each resource [3, 4].

Another important feature of PC, which must be taken under consideration when choosing and PC method for practical implementation, is the speed of the control algorithm. *Slow* PC aims to correct for shadow fading or path loss changes and *fast* PC is meant for fast channel variations like fast fading.

The implementation of an effective LTE Uplink Power Control method is of key importance for achieving steady service quality of User Equipment, regardless of their location in relation to eNB and other UE in the neighboring service area. The application of game-theoretic tools for finding an effective solution to this problem dates back to more than 10 years ago and in most cases they are based on the rule game principles. There the mobile users play non-cooperative or cooperative games, aiming at maximizing their utility functions, which from PC point is increasing their signal-to-interference-and-noise-ratio (SINR) and decreasing in the power level.

Most of these approaches are based on setting management rules depending on the distance between the UE and the cell; defining areas where service quality oriented algorithms for power management are applied; analysis and formation of user coalitions for which specific functions of power management could be applied. All this proves the lasting implementation of the game theory in this subject area.

In this paper the proposed approach is not rule based, it applies a role game theoretical methodology. The mobile users are classified by roles, where each role corresponds to predefined parameters, such as distance, traffic type, service quality, user satisfaction, etc. In this case to each role a specific UPC method could be assigned, to achieve such utility functions which are closest to the required uplink transmission quality of the mobile users.

The paper is organized as follows. In section II the basic LTE Uplink Power Control methods are reviewed. A short comparison of the rule and role game theoretic approaches to power control is done in section III. A role game method for LTE uplink power control is proposed in section IV.

II. Basic LTE Uplink Power Control Methods

A. Fractional Power Control (FPC)

In this method each User Equipment (UE) sets its transmission power as follows [5]:

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$$P_{tx} = 10\log_{10}(M) + P_{0,PUSCH} + \alpha PL\ , \quad (1)$$

where M is the number of scheduled Physical Resource Blocks (PRBs), which are 180 kHz wide. Usually the assumption is that only one PRB is scheduled to a particular UE. $P_{0,\,PUSCH}$ is a parameter broadcasted by the eNB (BS). The term PL is the result of the long-term Path Loss (PL) measurement by the UE, and 0 ≤ α ≤ 1 is a compensation factor broadcasted by the BS. It is obvious that if the calculated value of P_{tx} is greater than the maximum power of the UE it will transmit with its maximum power. Using Eq. 1 it is seen that UE can set its transmission power only by using the control parameters broadcasted by BS. This method is used to set the transmission power on the Physical Uplink Shared Channel (PUSCH). Using Eq. 1 each UE can calculate its transmission power (P_{tx}) without having to give any feedback to the serving BS. This is why the method is called Open Loop Power Control (OLPC). This method requires signaling between the eNB over the X2 interface.

The role of α is to act as a compensating factor for the attenuation experienced by each UE. The parameter α can take values between 0 to 1, and in particular α = [0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1]. Values between 0.1 and 0.3 are not used in practice. Assigning zero to α means that the power control mechanism is turned off. Changing the value of α determines how much an UE will be compensated for its poor channel conditions. Higher values of α ensure more compensation. Full compensation is achieved when α = 1. Analyzing the performance of this method, it could be seen that when α increases from zero to one the overall throughput of the cell decreases while the outage throughput increases considerably. Thus, implementing this type of power control gives advantage of the UEs in the outage area of the cells on the expense of the overall cell throughput [5].

B. Interference Based Power Control (IBPC)

In the case of FPC, UEs in the outage area which are suffering from weak channel conditions significantly increase their maximum data rate when power control is applied. On the other hand UEs with low path gain, close to the serving eNB, generate most of the interference as they transmit with higher power. This is as a result of the similar values of the path gain to the serving and to the neighboring eNB used in the calculations. Let PG_s be the Path Gain (PG) to the serving eNB and PG_I the sum of the path gains to all non serving eNB [6]. The total generated interference by the UE is:

$$I_i = p_{txi} \cdot \sum_{j \neq i} PG_{ij}\ , \quad (2)$$

where p_{txi} is transmitted power from the *i-th* UE and ΣPG_{ji} is equal to PG_I.

In order to eliminate such high interference levels a method called Interference Based Power Control (IBPC) is proposed. In this method an interference limit is determined, as a result of which no eNB in the system can generate more than a given amount of interference.

It is known from Shannon’s formula that the capacity doesn’t increase linearly with the increase of the Signal to Noise Ratio (SNR). When the SNR is below a given value, a small increase of the SNR could result in a large increase of the capacity of the system, but for higher values of the SNR a relatively high increase won’t result in such a significant increase in capacity. This philosophy lies in the core of IBPC method. If an UE increases the transmission power, the increase of the SNR will lead to an increase of its capacity, but on the other hand it will generate more interference. If ΔI is the increase of the generated interference in the cell after an UE increases its transmission power, I_c is the interference before, ΔT is the increase of the user experienced throughput after a UE increases its transmission power, T_c is the throughput before, then a metric M can be defined that evaluates gain in terms of throughput, and loss in terms of generated interference:

$$M = \frac{\Delta T}{\Delta I} \cdot \frac{I_c}{T_c} \quad (3)$$

This metric is used in the algorithm of the IBPC method. The implementation of the algorithm follows the following basic rules. One UE is allowed to increase it’s transmit power p_{tx} only with fixed steps Δp at a time up to its power limitation. Each UE willing to increase its transmission power must send a request to the serving BS. The BSs that have received requests calculate the metrics M for all the UEs and the UE with the highest metric is permitted to increase its power [6, 7, 8].

III. Role vs. Rule Games in Power Control

This current treatment is an attempt to appropriate a different perspective to the application of game theory models in achieving higher efficiency of LTE Uplink Power Control. Let’s ask the question which approach - role-based or rule-based policy LTE Uplink Power Control - is more efficient. The currently known methods could be successfully listed in the rule-based game theory field because UE are based on rules which result from the main target function to provide the highest possible service quality (higher speed, lower bit error rates, continuity and congruity of quality) by measuring the distance between the user and the eNB, the incidence in view of the eNB system and the active UEs in the neighboring service area. This approach suggests that each UE is “obliged” to benefit from the maximum speed, to be by all means active in using the services.

In the rule-based methods the user’s profile is not taken into account, the policies are applied to all users, no matter what type their end terminal devices are and no matter what average upstream they are generating at the moment or is statistically measured for a certain past time slot. Thus the role of the user in the communication process, whose quality we are trying to manage effectively, is not reviewed or measured. For the specific application the role as a concept could be defined as follows: *the roles are collections of properties and permissions to use resources appropriate to a UE's communication needs.* This assumes that all properties and permissions needed to perform an individual role-connected communication function can be neatly encapsulated.

The primary purpose of establishing roles is to provide an easy way to manage power control rules for groups of users. In such a way the actual management of the „uplink power control” process is limited to a dynamic appropriation of roles to UEs. For each role a power control method is previously defined, which is specifically oriented towards the characteristics of the role.

The challenges of role-based LTE uplink power control will continue to be the contention between the user's satisfaction, in the sense of required throughput and service quality, and easier administration. For performance improvement to be achieved, it is better for each role to be more granular, to have multiple roles per UE, to try to allow each role to improve as much as possible its own performance. For easier administration, it is better to have fewer roles to manage. For each role, depending on its communication profile and the specific number of individual characteristics of UE, a method of LTE uplink power control will be applied which provides the effective execution of this role, i.e. the UE will receive servicing characteristic of the role that has been applied to it.

The idea of making a coalition is also pressing, though viewed from another perspective. Two types of coalitions could be defined:

- ✓ *Flat coalitions*, which are temporary associations of UEs to which one and the same role had been appropriated.
- ✓ *Subject coalitions*, consisting of different by type but compatible, collaborating UEs.

In this sense the role could be applied as a parameter for recalculating the weight function in a coalition's graph model and thus "resetting" the coalition partnership and discharging the process of uplink power control from the task of appropriating UE with roles which are not matching the current communication profile and the specific sum of individual properties of a specific UE [9].

IV. ROLE GAME APPROACH TO UPLINK POWER CONTROL

The proposed approach is a slot-by-slot power control scheme as shown in Fig. 1. The users are assigned different roles determined by their type, distance from eNB, activity, etc. The role appropriation is possible to be executed by two groups of criteria:

- ✓ *Static criteria* – they are related to the equipment limitations imposed by the UE type;
- ✓ *Dynamic criteria* – they are related to the current communication profile of the user [10].

In both cases the assigned role should aim at maximum of their *utility functions*. Utility is *the level of satisfaction that a user gets from consuming a good or undertaking an activity*. Applying this concept of utility to wireless mobile communications, the user is now the mobile subscriber and the good is the energy stored in the battery of the mobile terminal device. The subscriber consumes the battery energy to gain information throughput or respective quality of performance or service. The utility now measures how much information is delivered or what throughput is achieved by consuming a basic unit of energy. Based on this, the utility of a wireless data user is the total number of correct bits that a user can transmit per unit of its battery energy [bits/Joule] [11, 12, 13].

Coming back to Fig. 1, the different roles are selected so as to achieve the optimum level of user satisfaction defined by their utility functions. Thus the role can be modeled by:

$$Role_i(UPCA_i) = \{UET_i, UEA_i, UEPos_i, MAX[uf_i(ST_i, p_i, P_n)]\} \quad (4)$$

where UET_i is UE_i type, UEA_i is UE_i activity, $UEPos_i$ is UE_i position alteration in regard of the service eNB, uf_i is utility function derived by user i, ST_i is service type, such as voice, data, text, fax, image and video, p_i is power level chosen for UE_i and P_n is maximum power for service cell.

	Time slot 1	Time slot 2	…	Time slot K
UE_1	Role $_1$	Role $_1$	…	Role $_1$
UE_2	Role $_2$	Role $_3$	…	Role $_N$
UE_3	Role $_3$	Role $_N$	…	Role $_1$
…	…	…	…	…
UE_m	Role $_N$	Role $_2$	…	Role $_3$

Fig. 1. Slot-by-slot power control scheme based on roles

In the proposed approach the role appropriation is dynamic and the definition of the duration of the overall validity slot for each role (number of time slots from Fig. 1) is a function of the role itself as well as of the role structure of the users registered in the current eNB and the type of currently existing coalitions.

From a methodological perspective the application of the Role-play game theory in the LTE uplink power control suggests the application of the procedure from Fig. 2.

During its registration in the eNB the User Equipment (UE) - UE_i is assigned an initial role R1 with its corresponding algorithm for the LTE uplink power control - $UPCA_1$. For the duration of the first UE_i slot, role R1 shall be assigned and the eNB shall gather statistics at Key Performance Indicators, which are Utility Functions parameters allowing assessment of the quality of performance acquired by UE_i during the first time slot and within the assigned role R1. Prior to the completion of the first slot the value of the Utility Functions for UE_i shall be calculated and a decision shall be taken whether or not to change the currently acquired role – R_1. If the value of the Utility Functions lies within the frames of the confidence interval for the respective quality of performance, the role shall be preserved for the next slot; if it goes beyond the interval, a change of the role from R_1 to R_j shall be performed thus leading to the algorithm appropriate for the role R_j - $UPCA_j$.

For the effective implementation of the proposed approach it will be necessary to define the relation between the value of the Utility Functions for the current slot and the selection of an appropriate role (algorithm) for the next slot for the specific UE_i. Another issue to be considered relates to the slot duration, i.e. the time during which a role (algorithm) for the LTE uplink power control is not changing for the specific UE_i in regard of the time of calculation of Utility Functions and the dynamics of the position change or the current UE_i activity. Thus each UE_i shall be awarded an individual management profile, formed by a dynamic roles succession (algorithms for LTE uplink power control), which are acquired with the time according the UE_i type, UE_i activity and the UE_i position alteration in regard of the service eNB. In this sense LTE uplink power control turns into a process, which is in close relation to and depending on the current activity of UE_i, as the interrelation between UE_i is assessed indirectly through the actual values of the Utility Functions calculated for each time slot and each UE_i.

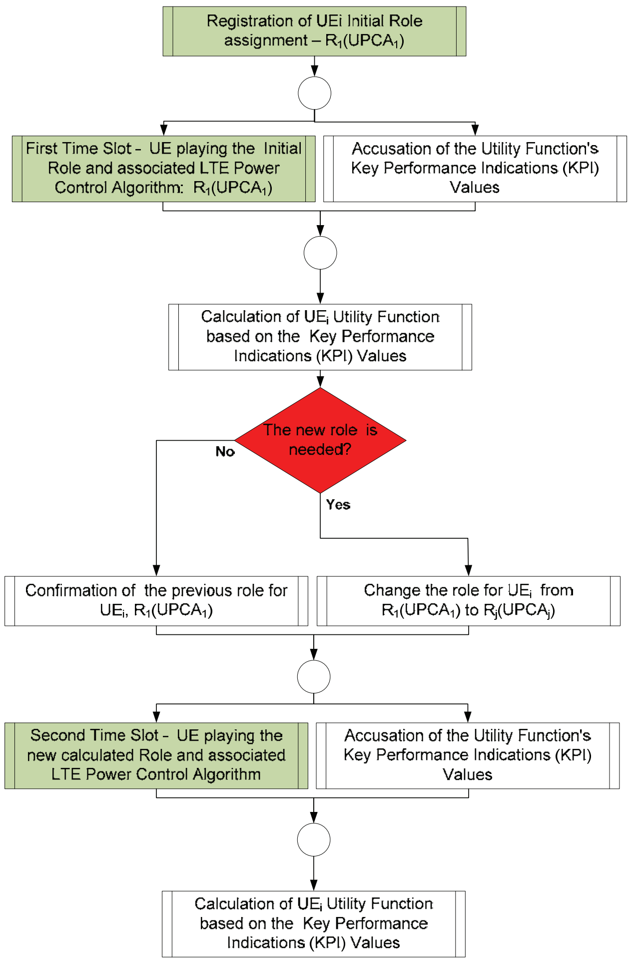

Fig. 2. Procedure for application of the Role-play game theory in the LTE uplink power control

V. CONCLUSION

In this paper an approach based on defining different roles of the subscribers within a cell of the LTE network for uplink power control is proposed. Comparison between Rule and Role Game Theory is presented. The concept of applying different methods and algorithms for uplink power control, depending on the classified by role subscriber is introduced. The role appropriation is dynamic based on a time slot-by-slot basis. The duration of the overall validity time slot for each role is a function of the role itself as well as of the role structure of the users. This gives the possibility of better utilization of the advantages and application of the existing uplink power control methods. The efficiency of this kind of a role approach is largely dependent on the effective role engineering, such as proper choice of appropriation criteria, characteristics and means of the role dependent method selected for LTE uplink power control.

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