ISSN:0975-9646

Purnachand S et al, / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 3 (2) , 2012,3683-3688

Performance Analysis of Open Loop and Closed Loop Power Control Schemes for LTE Uplink

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***Abstract*— In multi user environment number of users share the same radio resources. A consequence of the limited availability of radio channels in the network is that the same channel has to be assigned to many users. Thus a signal intended for a certain user will reach other users and introduce interference to their connection, and degrade the quality. This makes the Power Control functionality a vital issue. Power control needs to reduce inter-cell interference level at the same time achieve a required SINR level. The LTE power control mechanism constitutes of a closed loop component operating around an open loop point of operation. The open loop component compensates path loss and shadowing through fractional power control enabling a trade-off between cell edge throughput and mean cell throughput. The closed loop component allows further improvement in the performance of the system by compensating fast variations in channel. This paper presents the performance analysis of LTE power control schemes. Simulation results indicate that fractional power control is advantageous compared to the conventional open loop power control in terms of mean cell throughput.**

***Keywords*—LTE, Uplink, Power Control, Fractional Power Control.**

I. INTRODUCTION

The last few years have witnessed a phenomenal growth in wireless industry, both in terms of mobile technology and subscribers. Since its introduction, UMTS has evolved considerably, especially with high-speed packet access (HSPA) and the beginnings of a move towards all-IP architecture. Mobile broadband based on HSPA technology is already a great success. UMTS networks worldwide are upgraded to HSPA in order to increase data rate and capacity for packet data. HSPA refers to the combination of High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA). However, even with the introduction of HSPA, evolution of UMTS has not reached its end. HSPA + has brought significant enhancements in performance of HSPA based radio networks in terms of spectrum efficiency, peak data rate and latency, and exploit the full potential of WCDMA based 5 MHz operation. Important features of HSPA+ are downlink MIMO (Multiple Input Multiple Output), higher order modulation for uplink and downlink, improvements of layer 2 protocols, and continuous packet connectivity.

In order to ensure the competitiveness of UMTS for the next 10 years and beyond, concepts for UMTS Long Term Evolution (LTE) have been introduced by 3GPP with an objective of high-data-rate, low-latency and packet-optimized radio access technology. LTE is also referred to as EUTRA (Evolved UMTS Terrestrial Radio Access) or E-UTRAN (Evolved UMTS Terrestrial Radio Access Network). Implementation of LTE is based on new multiple access schemes on the air interface: OFDMA (Orthogonal Frequency Division Multiple Access) in downlink and SC-FDMA (Single Carrier Frequency Division Multiple Access) in uplink. Usage of SC-FDMA in uplink eliminates intra-cell interference. But as 3GPP LTE is designed for frequency reuse 1 the existence of inter cell interference cannot be neglected. Since both data and control channels are sensitive to inter cell interference there should be PowerControl (PC) functionality in uplink to minimize the effect of inter cell interference.

In LTE, the standardized uplink power control formula contains an open loop component and a closed loop component. In open loop power control (OLPC), the transmitting power is set at the user equipment (UE) using parameters and measures obtained from signals sent by the base station. In this case no feedback is sent to the UE regarding the power to be used for transmission. The closed loop component is considered to improve the performance of FPC by compensating fast variations in channel. In closed loop power control (CLPC) the base station sends feedback to the UE, which is then used to correct the transmitting power. Qualifying the power control technique as open loop and closed loop helps to have an anticipated idea of the implementation complexity and expected level of performance. For example, it is presumed that a closed loop power control scheme would require high signal overhead of transmission but at the same time it would provide with a fast mechanism to compensate for interference and channel conditions. On the other hand, an open loop power control would result in simpler implementation and low signaling but would be unable to compensate for channel variations for individual users.

The rest of the paper is organized as follows: Section II provides a detailed description of open loop power control component. Section III briefly describes the closed loop power control component. Section IV gives the details of simulation setup and results followed by conclusions and future work in section V.

II. OPEN LOOP POWER CONTROL

This section focuses on the open loop component of the LTE standardized power control scheme. The power control in LTE UL has an open loop and a closed loop component. The open loop component is meant to compensate the slow variations of the received signal, that is, path gain plus shadowing. The closed loop component is meant to further adjust the users' transmission power so as to optimize the system performance.

A. Power Control Scheme in LTE UL

The setting of the UE transmits power P_{tx} for the uplink transmission in a given subframe is defined in Equation (1), in dB scale.

$$P_{tx} = min\{P_{max}, P_0 + 10 \cdot log(M) + \alpha \cdot PL + \delta_{mcs} + f(\Delta_i)\} \quad (1)$$

Where:

- P_{max} : Maximum power allowed by the trasmission in for uplink. It depends on the UE.
- M: The number of allocated Physical Resource Blocks (PRBs) per user
- P_0 : The power to be contained in one PRB. It is cell specific parameter and measured in dBm/PRB
- α : Path loss compensation factor. It is a cell specific parameter in the range [0 1]
- PL : Estimated uplink path loss at the UE
- δ_{mcs} : MCS dependent offset. It is UE specific
- $f(\Delta_i)$: Closed loop correction function

The parameters P_0 and α are same for all cells and signaled from the BS to the UEs as broadcast. Path loss is measured at the UE based on the reference symbol received power (RSRP). This information enough to let the UE initially set its transmitting power and thus they are called as open loop parameters. δ_{mcs} is a UE-specific parameter depending on chosen modulation and coding scheme. However, δ_{mcs} is not included in this study. $\Delta_i$is a closed correction value and f is a function that permits to use absolute or cumulative correction value. $\Delta_i$is signaled by the BS to any UE after it sets its initial tranamit power *i.e.*,Δ_i have no contribution in the setting of initial transmit power by UE.

B. Fractional Power Control Concept

The expression, based on which a UE sets its initial transmitting power can be obtained from Equation (2) by ignoring δ_{mcs} and closed loop correction factor. While power limitation can be negelected since it corresponds to the UE to respect it.

$$P_{tx} = P_0 + 10 \cdot log(M) + \alpha \cdot PL \qquad [dBm] \qquad (2)$$

The power assignment for the transmission at the UE performed in such a way that each PRB contains equal amount of power. Thus the expression used by the UE to assign power to each PRB can be obtained by neglecting M, and is given by

$$PSD_{tx} = P_0 + \alpha \cdot PL \qquad [dBm/PRB] \qquad (3)$$

Then Equation (3) can be rewritten in terms of path gain as Equation (4) in dB and as in Equation (5) in linear.

$$PSD_{tx} = P_0 - \alpha \cdot PG \qquad [dBm/PRB] \qquad (4)$$

$$psd_{tx} = \frac{p_0}{pg^{\alpha}} \qquad [mW/PRB] \qquad (5)$$

Where, PG is the path gain of the user to the serving Base Station. To explore the open loop power control concept, first the effect of the parameters P_0 and α on PSD_{tx} is studied. Note that the PSD_{tx} is linearly depending on P_0, while α weights its dependency with the path gain. $P_0$is constant for all users while the term $\alpha \cdot PG$ varies for each UE according to its experienced path gain. Attention is drawn to this, since it is the element that will differentiate a user's performance.

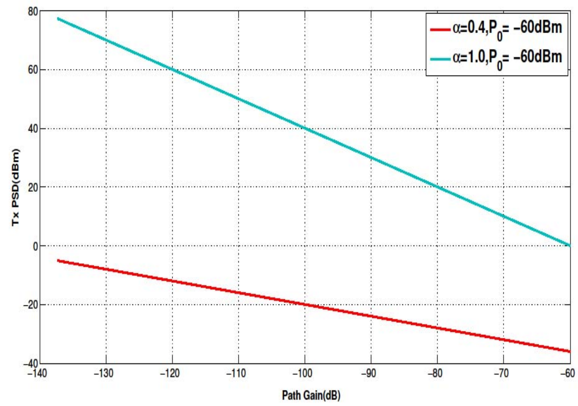

Fig.1PSD_{tx}Vs. Path gain (PG) for α = 1 and α = 0.4

Fig.1 shows the effect of α on PSD_{tx} for a wide range of PG values. The case α = 1 results in a PSD_{tx} that aims to compensate the degradation caused by the path gain. The compensation is done allowing user to transmit with more power if such path gain is lower. The second case, $\alpha = 0.4$, shows the same tendency for the result but with a less spread distribution *i.e.*, with different slope and the slope is equal to $-\alpha$ when the plot is seen in dB. For example, the difference on PSD_{tx} values for the two α values around -70dB of path gain is less than that of around -130dB of path gain. It can be noted that the user lesser path gain (*i.e.*, cell edge user) is transmitting more power with increase in α.

The case of α = 0 represents no PC, since all users transmit with the same power, while with α = 1, they transmit with a power that intends to totally compensate for their path loss, referred to as full compensation also known as **Conventional power control scheme**.

Values of α between 0 and 1 are cases to compromise between the full compensation and no PC where only a fraction of the path gain is compensated to the user. Thus, the scheme is known as **Fractional Power Control scheme**.

C. Impact ofP_0 and α on SINR Distribution

The SINR is one of the factors that determine the performance. Therefore, a discussion on the impact of the OLPC parameters P_0 and α on SINR would be very helpful for the operator. The SINR for a user i is given by

$$s_i = \frac{psd_{rx}^i}{I + n} \qquad (6)$$

Where s_i denotes the SINR of user i, psd_{rx}^i is the received psd of user i at its serving BS. I is the interference density level, while n is the thermal noise density level both received at the BS serving user i. The received power density, psd_{rx}^i can be given as

$$psd_{rx}^i = psd_{tx}^i \cdot pg_i \qquad [mW/PRB] \qquad (7)$$

Where psd_{tx}^{i}, is the transmitted power density of user i and pg_i is the total path gain from user i to its serving BS. From Equations (5) and (7) psd_{tx}^{i} is further simplified to

$$psd_{rx}^{i} = p_0 \cdot pg_i^{(1-\alpha)} \qquad [mW/PRB] \qquad (8)$$

It is important to note that in conventional PC scheme *i.e.*, when α=1 the received power density at the BS is equal toP_0, which is same for all users. For $0 < \alpha < 1$ the received power density depends on path gain of user. So psd_{rx} will be different for each user in the case of Fractional PC scheme. By replacing the received power density in Equation (6), the SINR of user *i*is given by

$$s_i = \frac{p_0 \cdot pg_i^{(1-\alpha)}}{I + n} \qquad (9)$$

Rewriting the above Equation in dB as

$$S = P_0 + 10log(M) + (1-\alpha)PG - IoT - N \; [dB] \qquad (10)$$

Where,IoT is the Interference over Thermal, is calculated as the ratio of interference plus thermal noise over thermal noise in linear domain, and *N* is the thermal noise.

Assuming a constant level of interference and noise, a higher P_0 means shifting the SINR curve to the right and hence an overall SINR increase. But in a real system, an increase in P_0 will rise the power of all users and hence the level of interference. Thus the increase in overall SINR is lesser than the expected increase in SINR. For example, as shown in Fig.2(a) an increase of 7dB in P_0 results approximately 1dB rise in SINR distribution.

Similarly, a change of α changes each user transmitting power, making it lowers for lower α values. A lower α not only decreases the SINR, but also spreads the curve which leads to a higher differentiation in terms of SINR between cell edge and cell center users. In SINR terms, P_0 controls the mean SINR and α controls the variance of SINR.

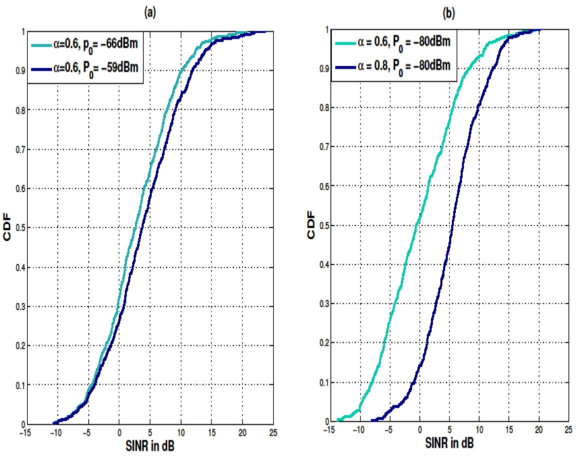

Fig.2CDF of SINR per user (a) for two different values of P_0 and a fixed α (b) for two different values of α and a fixed P_0

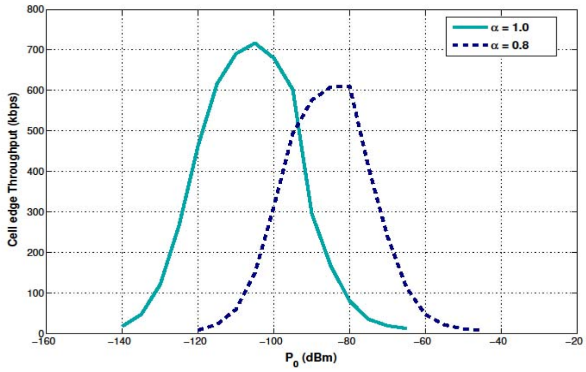

Fig.3Cell edge user throughput Vs.P_0 for $\alpha = 0.8$ and $\alpha = 1.0$

The cell edge user throughput is defined as the 5^{th} percentile point of the Cumulative Distribution Function (CDF) of user throughput. It is an indicator of the outage performance.

Fig. 3 gives the dependency of the cell edge throughput with P_0 for a given α. Both α cases show an increase of cell edge throughput up to certain P_0 , after which the cell edge throughput shows a significant drop. Since, an increase in P_0 will increase the power of users, cell edge users will reach the maximum power limit beyond certain P_0 and continue to transmit same power. Furthermore, the users with good radio conditions will boost their power as P_0 increases till the maximum limit reaches and cause more interference. This degrades the cell edge performance considerably beyond certain P_0 value. It can be observed in the Fig. 3 that peak cell edge throughput point for different α values corresponds to different P_0 values. This shows that both the OLPC parameters need be tuned to achieve the better performance.

III. Closed Loop Power Control

This section focuses on the closed loop term of the LTE standardized PC scheme to analyze the performance of conventional closed loop power scheme.

A. *Closed Loop PC Concept*

The In a closed loop power control system, the uplink receiver at the BS estimates the SINR of the received signal, and compares it with the desired SINR target value. When the received SINR is below the SINR target, a Transmit Power Control (TPC) command is transmitted to the UE to request for an increase in the transmitter power. Otherwise, the TPC command will request for a decrease in transmitter power. The 3GPP specifications allow 2 types of TPC commands:

- **Absolute**: the user applies the offset given in the PC command using the initial transmit power in OLPC as reference.
- **Cumulative**: the user applies the offset given in the PC command using the latest transmission power value as reference.

In LTE, closed loop power control operates around an open loop point of operation. The initial power is set using open loop power control. The initial power is further adjusted using closed loop correction value. Equation (11) defines the closed loop power control expression.

$$P_{tx} = min\{P_{max}, P_{OL} + f(\Delta_i)\} \qquad [dBm] \qquad (11)$$

P_{OL} is the uplink power set in the open loop point of operation and $f(\Delta_i)$ is the closed loop correction function.
$f(\Delta_i)$ is defined by the expression

$$f(\Delta_i) = f(\Delta_{i-1}) + \Delta_i \qquad [dBm] \qquad (12)$$

Δ_i is the correction value, also referred as TPC command. The TPC commands are sent after the OLPC has set the initial transmit power using desired α and P_0 values. The TPC commands are generated based on the difference between SINR target and received SINR. The possible values transmitted by TPC command are $\Delta_i = [-1,0,1,3]$.
The closed loop correction value is obtained from the SINR difference as:

- If difference[dB] $<= -1$ then -1 is sent,
- else if $-1 <$ difference[dB] $<= 1$ then 0 is sent,
- else if $1 <$ difference[dB] $<= 5$ then 1 is sent,
- else if difference[dB] > 5 then 3 is sent

B. *CLPC with Constant SINR Target*

To understand the behavior of CLPC, average received SINR is investigated for closed loop and fractional power control operations. In conventional closed loop power control the SINR target is kept same for all users. Fig. 4 gives the SINR distribution for CLPC and FPC. It can be seen in the plot, some of the users are not able reach the target SINR because of maximum power limit. Those users, who are already transmitting with maximum power cannot increase their transmitpower, and hence, the SINR.
The fractional power control allows users with good radio conditions (users close to the base station) to achieve high received SINR, resulting in high mean user throughput while keeping reasonable cell edge throughput.Whereas conventional closed loop power control steers all users to achieve equal received SINR, as a consequence of this, users with good radio conditions which can achieve high received SINR are affected, thus resulting in lower mean user throughput. CLPC allows cell edge users to reach better SINR, it provides better cell edge throughput.

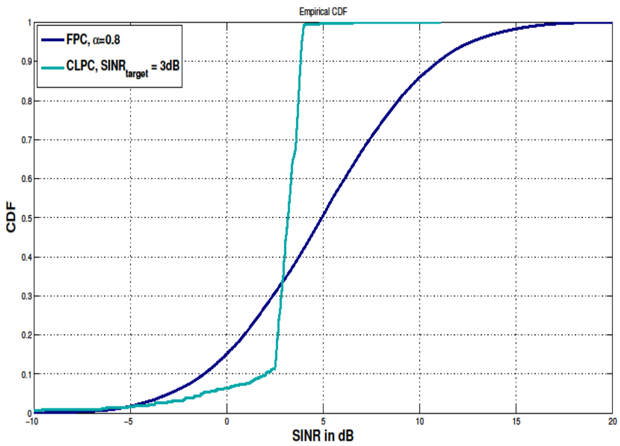

Fig.4CDF plot of received $SINR$ for FPC using $\alpha = 0.8$ and CLPC with $SINR_{target} = 3dB$

Setting a high closed loop SINR target means users need to transmit more power to achieve target SINR. Due to power constraint some users may not reach such high SINR target which results in low cell edge throughput though it provides high mean user throughput. While lower SINR target leads to low mean and high cell edge throughput. Thus, setting of the closed loop SINR target is a trade-off between the cell edge and mean throughput. It is desired to design a closed loop power control scheme that can provide a reasonable improvement in cell edge throughput and simultaneously allowing users with good radio conditions to achieve high received SINR, thus getting high mean user throughput. To achieve the above goal it is worthy to consider a closed loop power scheme with different SINR targets for different users.

IV. SIMULATION SETUP AND PERFORMANCE ANALYSIS

This section presents the simulation parameters used for analyzing uplink power control schemes in LTE uplink, performance of fractional power control at different point of operations and comparison of results of FPC with those of conventional open loop power control.

A. *Simulation Model*

To analyze the performance of uplink power control schemes in LTE a simple system model is needed. For this purpose, a simplified static simulation approach has been used which focuses mainly on power control by assuming ideal channel, path loss and interference estimations. The approach consists primarily in taking a certain instance of the system where a configuration of users transmits with a certain power, and proceeds to calculate the interference and signal distributions. In this paper, the performance analysis is done by considering uplink received SINR and transmitting power, average cell throughput and cell edge user throughput as the performance indicators. The scope of using different performance indicators is to provide with a relative measure of the gain of a specific power control scheme in terms of system as well as user performance.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Carrier frequency	2.4 GHz
Doppler Spread	7Hz
Cell layout	19 cell
No.of BSs	19
No.of Sectors per BS	3
Users per Sector	10
Number of strong interferer	8
Number of antennas at the BS	2
Number of antennas at the UE	1
Receiver structure	MRC
FFT size	1024
System Bandwidth	10 MHz
UE Bandwidth	900KHz [5 PRBs]
Scheduler	Round Robin
Thermal Noise per PRB	-116 dBm
Base station noise figure	5 dB
Maximum UE Transmitting Power	23dBm

B. *Results and Performance Analysis*

Fig.5 shows the SINR distribution performance of FPC with $\alpha = 0.8$ and conventional open loop power control. It can be observed the range of received SINR values is more with $\alpha = 0.8$ than that of with $\alpha = 1.0$. When $\alpha = 1$ (full compensation) the received power density of all the users is same because of total compensation of path loss. This reduces the variance in SINR distribution. While a lower α means the received power density is different for differnt users depending on the path loss of the user. Thus, a lower α leads to a higher differentiation in terms of experienced SINR between cell edge and cell center users.

A lower α decreases the perceived path gain of the users located at the cell edge more than those located close to the cell center. This leads increase in average cell throughput as cell center users experience a higher SINR. However, such improvement is at the cost of a decrease in power of cell edge users, and hence, cell edge throughput. Fig. 6 shows that the cell edge throughput is slightly better with $\alpha = 1.0$ than with $\alpha = 0.8$. But in case of average throughput, FPC with $\alpha = 0.8$ features better performance. Fig. 7 shows that the number of users, transmitting at maximum power is reduced with reduction in path loss compensation factor.

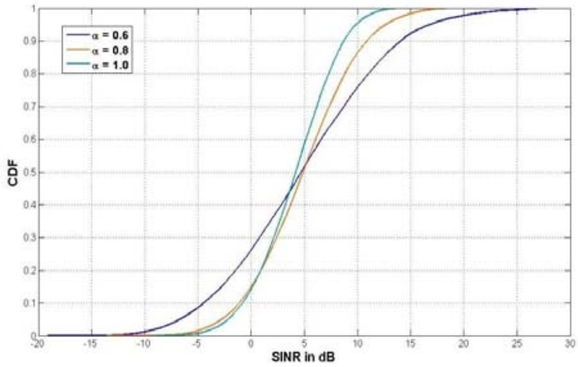

Fig.5CDF plot of received SINR for FPC with $\alpha = 0.6$, $\alpha = 0.8$ and $\alpha = 1.0$

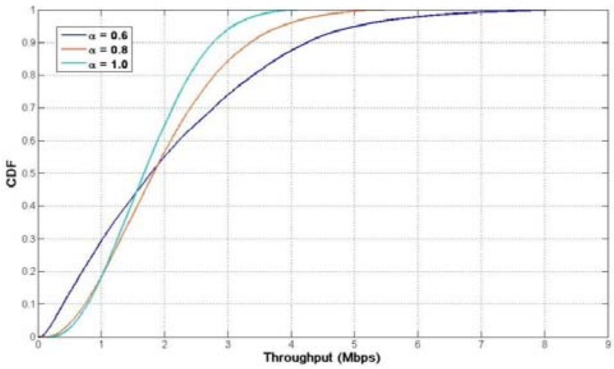

Fig.6CDF of user throughput for FPC with $\alpha = 0.6$, $\alpha = 0.8$ and $\alpha = 1.0$

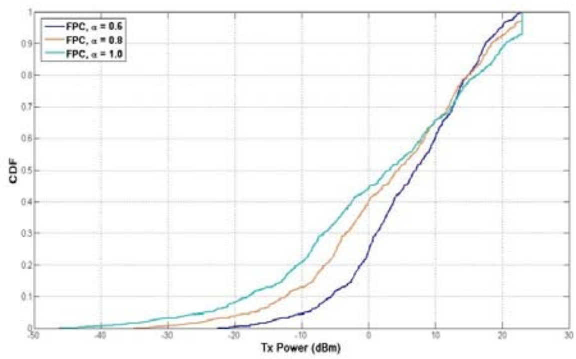

Fig.7CDF of user throughput for FPC with $\alpha = 0.6$, $\alpha = 0.8$ and $\alpha = 1.0$

TABLE II
PERFORMANCE OF FPC FOR DIFFERENT PATH LOSS COMPENSATION FACTORS

α	P_0 [dBm/PRB]	Average cell Throughput [Mbps]	Cell edge Throughput [Kbps]
0.4	-38	21.8	178
0.6	-58	21.1	421
0.8	-81	20.5	598
1.0	-102	17.3	615

Table. II gives the performance of fractional power control with different path loss compensation factors. The FPC algorithm aims at decreasing the perceived path gain of the users located at the cell edge more than those located close to the cell center. Thus, lower α means higher differentiation in SINR of cell edge and cell center users. FPC scheme allows cell center users to achieve higher SINR, and hence, higher throughput. However, such SINR improvement is at the cost of a decrease in power of cell edge users, which means lower SINR, resulting in a poorer performance. As α gets close to the value 1 the spreadness in SINR distribution decreses which leads to decrease in average cell throughput and increase in cell edge throughput.

V. CONCLUSIONS AND FUTURE WORK

A. Conclusions

No This section summarizes the main conclusions of this work and presents further practical considerations along with related future work. This paper is focused on the power control for EUTRAN LTE cellular system, corresponding to the uplink direction of the 3GPP Long Term Evolution Project. In the current standardization process, the power control is specified to function both with open loop and closed loop mechanisms. The open loop functioning is based on the Fractional Power Control technique which is designed to allow full or partial compensation for the path loss. On the other hand, the algorithms used to implement the closed loop term are vendor specific and still under research.

In this paper, a detailed study has been done in conventional open loop power control and fractional power control techniques. Both the open loop power control schemes are compared in terms of system performance based on SINR distribution, mean cell throughput and cell-edge throughput. Simulation results suggest that fractional power control scheme shows 20% increase in mean cell throughput by keeping nearly same cell-edge throughput. Also, it is found that the system performance is optimized with lower interference levels and with lower transmitting power distribution in FPC compared to the conventional method. Then, closed loop power control concept is introduced with the aid of conventional closed loop power control scheme. In conventional CLPC all the users are targeted to same SINR level. In conventional CLPC the users with good radio conditions and cell edge users are also targeted same SINR level which leads to a significant reduction mean cell throughput.

B. Future work

In this paper, a comparative analysis of open loop power control schemes has been done. The closed loop power control concept introduced by considering same SINR target for all the users. Instead of using same SINR target for all users, who are having different radio conditions, it is worthy to considering closed loop power control scheme with different SINR target for each user based on radio conditions of the users. Furthermore, the power control schemes were analyzed by assuming a fixed bandwidth allocation for each user. Most of the Radio Resource Management (RRM) functionalities are neglected to focus the study on power control. Thus, the RRM functionalities are still open aspects that could be studied. LTE offers different Modulation and Coding Schemes (MCS), and these should be included in further study.

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