Fractional Power Control in LTE Cellular Networks

by

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B.Sc., Comsats Institute of Information Technology, Islamabad, Pakistan, 2007

A Report Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF ENGINEERING

in the Department of Electrical and Computer Engineering

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Abstract

The Long Term Evolution (LTE) uplink power control in cellular networks consist of a closed loop power control component and an open loop power control component. The open loop component is also called Fractional Power Control (FPC) because it allows the User Equipment (UE) to partially compensate for the path loss. This report focuses on fractional power control which is characterized by two main parameters: a target received power and a fractional compensation factor. Results are presented which show user throughput, cell mean throughput, cell edge user throughput, and SINR are key performance indicators of fractional power control.

Table of Contents

List of Figures

List of Tables

Acknowledgments

I would not have been able to complete this project without the kind support of many individuals. I would like to express my deepest and sincere thanks to all of them. I am very thankful to my supervisor Dr. T. Aaron Gulliver for his guidance, knowledge, constant supervision, and continuous support during the project and throughout my academic journey. I would also like to thank Mr. Mohammad Hanif for his generous support during this project.

I am thankful and grateful to my wife, son, daughter, parents, siblings and the staff of the UVIC ECE department for their kind support, cooperation and motivation which helped me complete this project. My thanks and appreciation also go to my friends Atique, Manzoor, Ahsan and all the amazing people who have supported me during my stay at the University of Victoria.

Dedication

This work is dedicated to Raahim (son), Waniya (daughter) and my loved ones, who motivate and support me every step of the way.

Glossary

3GPP	Third generation partnership project
ARQ	Automatic repeat request
CDF	Cumulative distribution function
CDMA	Code division multiple access
DL	Downlink
eNodeB	Evolved NodeB
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FPC	Fractional power control
HARQ	Hybrid ARQ
LOS	Line of sight
LTE	Long term evolution
MATLAB	Matrix laboratory
MCS	Modulation and coding scheme
MIMO	Multiple input, multiple output
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
PAPR	Peak to average power ratio
PHY	Physical layer
PL	Path loss
PRB	Physical resource block
PSD	Power spectrum density
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RF	Radio frequency
RRC	Radio resource control
RRM	Radio resource management
RSRP	Reference signal received power

RTT	Round trip time
SINR	Signal to interference and noise ratio
SNR	Signal to noise ratio
TDD	Time division duplex
TDM	Time division multiplexing
TDMA	Time division multiple access
TPC	Transmit power control
TTI	Transmission time interval
UE	User equipment
UL	Uplink
UTRA	Universal terrestrial radio access
UTRAN	Universal terrestrial radio access network

List of Acronyms

Acronym	**Definition**
psd_{rx}	Received power spectrum density
psd_{tx}	Transmit power spectrum density
BW_{PRB}	Bandwidth of one PRB
BW_{eff}	Bandwidth efficiency
N_{PRB}	Number of PRBs in the working bandwidth
PSD_{tx}	UE transmit power spectrum density (dB)
P_{max}	Maximum power allowed by UE in UL (dB)
P_o	Power in one PRB (dB)
S_{eff}	SNR efficiency
UE_{cell}	Number of users in a cell
p_o	Power contained in one PRB
s	SINR
δ_{mcs}	MCS dependent offset
C	User throughput
$E(C)$	Average user throughput
I	Interference
IoT	Interference over thermal noise power
M	Number of allocated PRBs per user
N	Thermal noise power (dB)
PL	Path loss (dB)
S	SINR (dB)
T	Cell mean throughput
$f(\Delta)$	Closed loop correction function
n	Thermal noise power density
pl	Total path loss
v	Correction factor
α	Path loss compensation factor

1 Introduction

This chapter presents the fundamentals of cellular networks and the background on channel impairments in wireless communications. This chapter includes an overview of Long Term Evolution (LTE) and its Physical Layer (PHY), which are fundamental components of the power control problem in wireless communications.

1.1 Wireless Communication Systems

In wireless communications, the channel changes with time due to changes in the environment between the transmitter and receiver, and user mobility. Some key channel impairments will be discussed in this chapter.

In a wireless system, the radio signals are attenuated as they travel through the air. When a transmitted signal propagates through the air it encounters different objects, and the signal will be attenuated, delayed in time and phase shifted due to reflection, diffraction and scattering. The attenuation caused by distance is modeled as path loss. The signal variations due to diffraction are modeled as shadow fading (shadowing), whereas the effects of reflections are taken as multipath fading (multipath), as shown in Figure 1 [10].

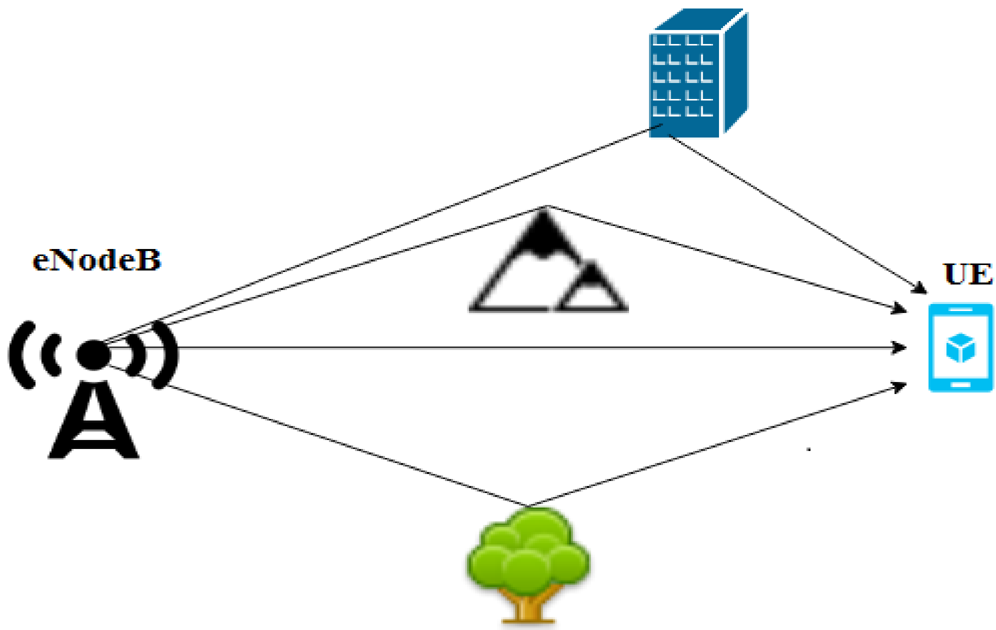

Figure 1: A wireless network showing refraction, shadowing and multipath.

A geographical area covered by a cellular network is divided into cells. Each cell has an eNodeB which is a fixed terminal which communicates with mobile terminals using transceiver antennas. Mobile users close to the eNodeB are called cell center users and on the edge of the cell coverage are called cell edge users. The eNodeB connects the user equipment (UE) to the network [7]. The communication from eNodeB to UE is called the downlink (DL) and from UE to eNodeB is known as the uplink (UL).

In a communication system, resource sharing is achieved using multiple access which divides the resources along the time, frequency or code space axes. Orthogonal Frequency Division Multiple Access (OFDMA) is a FDMA technique in which the modulated signals are orthogonal to each other in the frequency domain. A channel is divided into subcarriers, referred to as subchannels, and these are further split into physical resource blocks which are allocated to the users by a DL scheduler [7].

1.2 Long Term Evolution (LTE)

3GPP LTE is a significant development in cellular systems. LTE evolved from an earlier 3GPP system known as Universal Mobile Telecommunication System (UMTS). LTE was designed to support high speed data and voice for wireless communication systems. LTE was developed to support flexible carrier bandwidths from 1.4 MHz to 20 MHz. The LTE downlink peak rate can be as high as 300 Mbps and the uplink peak rate up to 75 Mbps in a 20 MHz channel bandwidth. LTE is compatible with Frequency Division Duplex (FDD) and Time Division Duplex (TDD) techniques for uplink and downlink transmissions. In FDD, uplink and downlink transmissions use different frequency bands whereas in TDD the uplink and downlink transmissions are separated in time but both use the same frequency band [11] [12].

The LTE Physical Layer (PHY) is different for downlink (DL) and uplink (UL) transmissions. In the downlink, Orthogonal Frequency Division Multiplexing (OFDM) is used as the modulation technique to mitigate multipath fading. A disadvantage of OFDM is that it has a high Peak to Average Power Ratio (PAPR) which requires higher transmission power to maintain the required Bit Error Rate (BER) [15]. Mobile equipment has power consumption restrictions. To address the concerns with a high peak to average power ratio, Single Carrier Frequency Division Multiple Access (SC-FDMA) was introduced for the uplink. SC-FDMA is a modified form of OFDMA which has similar throughput performance as OFDMA but with a lower PAPR [11] [12] [13].

In the LTE uplink, data are transmitted in frames. Each frame consists of 10 subframes and each subframe has two time slots of 1 ms duration. A time slot consists of 7 SC-FDMA symbols with a time duration of 0.5 ms as shown in Figure 2.

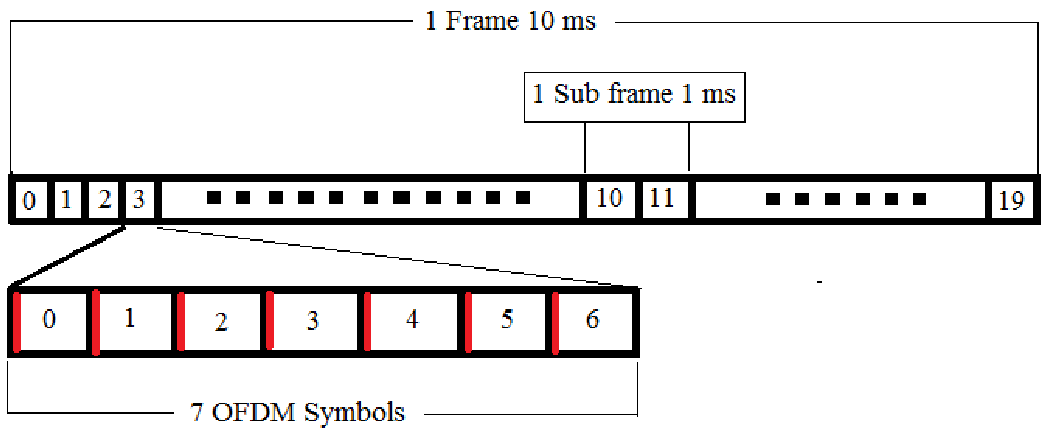

Figure 2: The LTE frame structure [7] [9].

In LTE transmission, a Physical Resource Block (PRB) is the smallest resource element allocated by the eNodeB scheduler. A PRB is defined as 180 kHz in the frequency domain and 0.5 ms (1 time slot) in the time domain. Each PRB consists of 12 subcarriers with a 15 kHz subcarrier spacing for a PRB bandwidth of 180 kHz as shown in Figure 3 [12] [13].

The Physical Uplink Shared Channel **(**PUSCH) is responsible for carrying user information. The uplink scheduler allocates resources for the PUSCH on a subframe basis. Subcarriers are assigned in multiples of 12 PRBs and hopped from subframe to subframe. The PUSCH supports QPSK, 16QAM and 64QAM modulation [13].

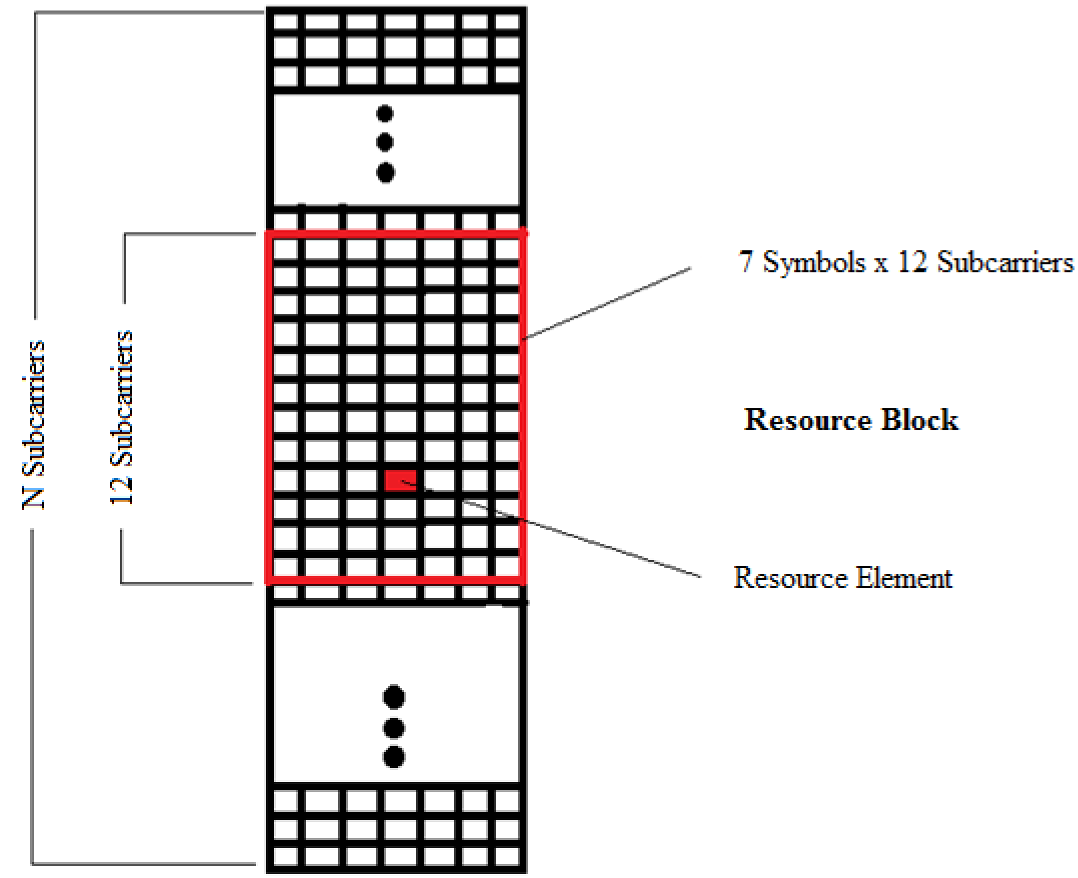

Figure 3: The LTE uplink resource grid [7] [9].

1.3 Power control

Power is an important resource for mobile devices. To minimize the UE power consumption, power control is employed in the LTE uplink. Power control plays an important role in system throughput, capacity, quality and power consumption. In a wireless multiuser environment, a number of users share the same radio resources. Frequency reuse is an important feature of a cellular system which improves the network capacity. LTE supports a frequency reuse factor of one to maximize the spectrum efficiency for the uplink and downlink transmissions. The presence of interference cannot be ignored due to this frequency reuse factor. To minimize the effect of interference, Power Control (PC) is used for the LTE uplink. It enhances system throughput performance and reduces interference to other cell users [14]. The use of SC-FDMA in the LTE uplink eliminates interference between users in a cell (intra cell interference). However, the transmissions in neighboring cells are not orthogonal which causes interference between users (inter cell interference). This has a significant effect on the system throughput [7].

1.4 Project objectives

The 3GPP standard has defined uplink power control as a combination of open loop power control and closed loop power control [6]. The open loop term is also known as Fractional Power Control (FPC) [4]. The objective of this project is to evaluate the performance of FPC based on two basic parameters, the received power P_o and the path loss compensation factor α. In order to measure the performance gain of FPC, a set of key performance indicators are employed.

1.5 Scope of investigation and methodology

The scope of this report is limited to fractional power control for the LTE uplink to mitigate inter cell interference and enhance system throughput. The users are randomly distributed to evaluate FPC behavior [8]. Simulation is done using MATLAB to determine the path loss, interference and SINR at the eNodeB to set the UE transmit power.

1.6 Project outline

Chapter 2 provides the mathematical expressions for the performance analysis of fractional power control and the influence of the two main parameters, the received power P_o and the path loss compensation factor α. Chapter 3 covers the methodology and simulation parameters involved in the implementation of FPC in MATLAB. Simulation results and a comparative analysis for different values of P_o and α are given to examine FPC performance. The SINR, cell mean throughput, and cell edge throughput are the performance indicators used to evaluate the system. Chapter 4 provides conclusions and some possible directions for future work.

2 Fractional Power Control

This chapter describes LTE uplink fractional power control and provides the mathematical equations for the model.

2.1 Uplink power control in LTE cellular networks

Power control in wireless systems sets output power levels for eNodeBs in the downlink and User Equipment (UE) in the uplink. The LTE uplink power control contains a closed loop power control term and an open loop power control term. The open loop term compensates for path loss and shadowing. The closed loop term gives further performance improvements by compensating for variations in the channel. The UE transmitted power P_{tx} for the uplink transmission is defined in dB as

$$P_{tx} = \min\{P_{max}, P_o + 10\, log(M) + \alpha PL + \delta_{mcs} + f(\Delta)\} \qquad (1)$$

where

P_{max} is the maximum power allowed by the UE in uplink transmission,

M is the number of allocated Physical Resource Blocks (PRBs) per user,

P_o is the power contained in one PRB,

α is the path loss compensation factor,

PL is the estimated uplink path loss at the UE,

δ_{mcs} is a MCS dependent offset which is UE specific, and

$f(\Delta)$ is a closed loop correction function.

The uplink power control can be broken into five parts. The first part is the amount of additional power needed based on the number (M) of PRBs. The higher the number of PRBs, the higher the power required. The second part is the received power P_o which is a cell specific parameter. The third part is the product of Path Loss (PL) and α. The fourth part is a MCS dependent offset value which is UE specific and is used to adjust the power based on the MCS assigned by the eNodeB. Last, $f(\Delta)$ is the closed loop correction value which is closed loop feedback. It is the additional power that the UE adds to the transmission based on feedback from the eNodeB [6].

The values of P_o and α are the same in the cell and are signalled from the eNodeB to the UE as broadcast information. The path loss is measured at the UE and is based on the Reference Symbol Received Power (RSRP). This information is sufficient for the UE to initially set its transmit power. δ_{mcs} is a UE specific parameter dependant on the modulation and coding employed. $f(\Delta_i)$ is a correction function that uses a correction value Δ which is signaled by the eNodeB to a user after it sets its initial transmit power [6] [14] [16].

2.2 Fractional power control and its basic parameters

When the value of α is between 0 and 1 it means only a fraction of the path loss is compensated to control the UE transmit power. Such a mechanism is called open loop power control or fractional power control. This study is focused on evaluating the performance of fractional power control. Some assumptions are used to obtain the results.

The measured path loss at the UE together with P_o and α broadcast by the eNodeB are sufficient to set the initial transmit power for open loop power control. The closed loop term has the ability to adjust the uplink transmit power with the closed loop correction value, also known as Transmit Power Control (TPC) commands. TPC commands are transmitted by the eNodeB to the UE based on the target SINR and the measured SINR. The correction function $f(\Delta)$ and modulation and coding scheme (δ_{mcs}) are not considered in this report. The UE transmitted power in the UL is then [14] [15]

$$P_{tx} = P_o + 10\,log(M) + \alpha PL \qquad \text{(dBm)} \qquad (2)$$

The UE performs the transmission in such a way that each PRB contains an equal amount of power. For a single PRB ($M = 1$), the UE assigned power spectrum density is

$$PSD_{tx} = P_o + \alpha PL \qquad \text{(dBm)} \qquad (3)$$

To explore fractional power control, first the effect of the parameters P_o and α on PSD_{tx} is studied. PSD_{tx} is linearly dependent on P_o and PL. Parameters P_o and α are constant for the users in a cell while the term αPL varies for each UE according to the path loss and so is the term which differentiates user throughput.

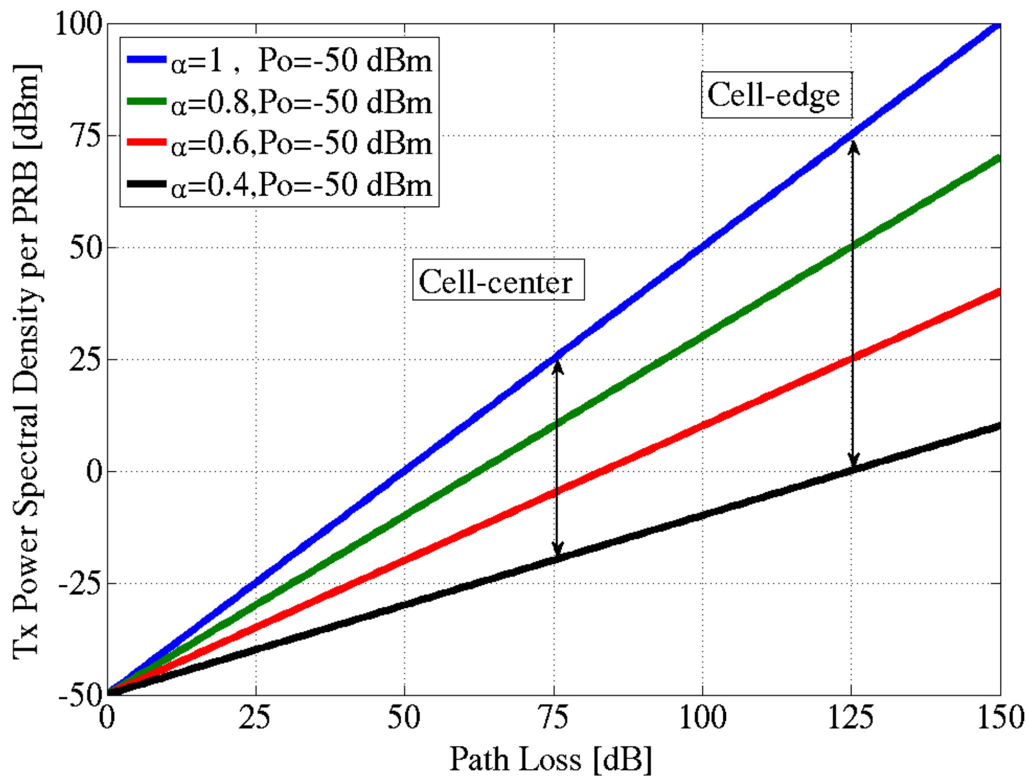

Figure 4: Transmit power PSD_{tx} and Path Loss (PL) for α = 1, 0.8, 0.6, and 0.4.

Figure 4 shows the effect of α on PSD_{tx} for a range of PL values. For α = 1, PSD_{tx} provides full compensation for the degradation caused by the path loss. For α = 0.4, 0.6, and 0.8, PSD_{tx} shows the same trend but with different slopes and different values at the cell center and cell edge. The difference in PSD_{tx} for α values at 75 dB path loss is less than that at 125 dB path loss. It is observed that the cell edge users have more path loss compared to the cell center users [8] [14].

Figure 5 shows the compensation for α from 0 to 1. A value between 0 and 1 represents fractional compensation for the path loss. There is no power control for α = 0 and all users transmit with the same power, while with α = 1 users transmit with a power that completely compensates for the path loss, which is referred to as full compensation or conventional power control.

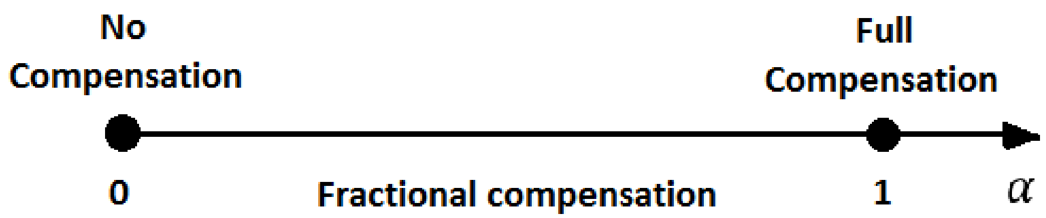

Figure 5: Power control based on the value of α [7].

2.3 The network model

Equation (3) can be expressed as

$$psd_{tx} = p_o(pl^{\alpha}) \quad \text{(mW/PRB)} \tag{4}$$

where

psd_{tx} is the UE power spectrum density,

p_o is the power contained in one PRB, and

pl is the path loss of the user to the serving eNodeB.

The SINR determines the performance with fractional power control. Therefore, an investigation of the impact of p_o and α on the signal to interference and noise ratio would be helpful to understand fractional power control. The SINR is given by [14]

$$s = psd_{rx}/(I + n) \tag{5}$$

where

psd_{rx} is the received power spectrum power density of the user at the serving eNodeB,

I is the interference power density, and

n is the thermal noise power density,

The received power spectrum density is [14]

$$psd_{rx} = psd_{tx}/pl \tag{6}$$

From (4) and (6), psd_{rx} is

$$psd_{rx} = p_o(pl^{\alpha-1}) \quad \text{(mW/PRB)} \tag{7}$$

With conventional power control, α = 1 and the received power spectrum density at the eNodeB is p_o, which is the same for all users in a cell. For 0 < α < 1, the received power spectrum density depends on the path loss of the user, so psd_{rx} will be different for each user in the case of fractional power control. By replacing the received power spectrum density in (6), the SINR is [14]

$$s = p_o(pl^{\alpha-1}) \,/(I + n) \tag{8}$$

The numerator of (8) can be written as

$$(I + n) = n(I + n)/n \tag{9}$$

$$= n(I/n + 1)$$

where $(I + n/n)$ is the interference over thermal noise which is calculated as the ratio of interference plus thermal noise over thermal noise.

Equation (9) can be written in dB as

$$10\log(I+n) = 10\log\left(n\left(\frac{I}{n}+1\right)\right) = N + IoT \qquad (10)$$

where

IoT is the interference over thermal noise (dB), and

N is the thermal noise power (dB).

Equation (8) can rewritten using (9) as

$$s = p_o(pl^{\alpha-1})\,/n(I/n+1) \qquad (11)$$

Equation (11) can be written in dB as

$$S = P_o + (\alpha+1)PL - IoT - N \qquad \text{(dB)} \qquad (12)$$

2.4 Key performance indicators

The user throughput of a cellular network is calculated for a user from its SINR and allocated bandwidth [3] [14] and is given by [15]

$$C = BW_{eff}\ v\ M\ BW_{PRB}\ log_2\left(1+\frac{SINR}{S_{eff}}\right) \qquad \text{(bps)} \qquad (13)$$

where

BW_{eff} is the bandwidth efficiency. It is the information bit rate per unit bandwidth occupied which is set to 0.72 [15],

v is a correction factor. It is a value that is applied to the estimated received signal power to account for the propagation which is set to 0.68 [15],

BW_{PRB} is the bandwidth of one PRB equal to 180 kHz [6][15], and

S_{eff} is the SNR efficiency of the system which is set to 0.2 dB [15].

The cell mean throughput is calculated by multiplying the average user throughput by the number of users allocated in a single Transmission Time Interval (TTI) [15]. The cell mean throughput is calculated as

$$T = E(C)UE_{TTI} \qquad \text{(bps)} \qquad (14)$$

where

$E(C)$ is the average user throughput, and

UE_{TTI} is the number of users allocated in a single TTI.

The number of allocated users in a single TTI is [15]

$$UE_{TTI} = \frac{UE_{cell}}{N_{PRB}} \qquad (15)$$

where

UE_{cell} is the number of users in a cell, and

N_{PRB} is the number of PRBs used in a TTI for the available bandwidth.

The cell edge throughput is defined as the lowest 5% of the Cumulative Distribution Function (CDF) of the total cell throughput. It is also known as the cell outage throughput [14].

3 Performance results

3.1 Simulation model

A path loss propagation model was employed to evaluate the performance of fractional power control. A honeycomb pattern is used with 50 uniformly distributed users per cell, where each cell has the same number of users. The target eNodeB experiences four strong inter cell interferers from neighbouring cells. MATLAB was used to calculate the path loss, interference and SINR using the Cost 231 path loss model which was designed for dense urban city areas with high user densities and traffic loads [16]. The shadowing follows a lognormal distribution. The signal attenuation measured in dB is lognormally distributed with zero mean and an 8 dB standard deviation [13]. The simulation parameters are given in Table 1. In this report, the performance is evaluated by considering uplink received SINR, user throughput, cell mean throughput and cell edge throughput. These indicators are studied to measure the gain with fractional power control. P_o is a cell specific parameter which ranges from -126 dBm to 24 dBm with lower values assigned for a low interference environment and vice versa [6] [13]. The performance gain of FPC is evaluated for low, mid and high values of P_o, which are represented by -57, -81 and -102 dBm, respectively. These values have been used in the literature to evaluate FPC performance. The received SINR, user throughput, cell mean throughput and cell edge throughput are comparable to the results in [14]. The path loss model used in the simulations is [16]

$$PL = 57.92 + 20\, log(f_c) + 37.6\, log(d) \quad (16)$$

where

f_c is the carrier frequency in Hz, and

d is the distance in meters.

SIMULATION PARAMETERS

Parameter	**Value**
Carrier frequency (f_c)	2.0 GHz
System bandwidth (BW)	10 MHz
Thermal noise per PRB (N)	-116 dBm/PRB
Maximum UE Transmit Power (P_o) [13]	23 dBm
Bandwidth efficiency (BW_{eff}) [15]	0.72
PRB bandwidth (BW_{PRB})	180 kHz
Number of PRBs per user (M)	5
Correction factor (v) [15]	0.68
SINR efficiency of the system (S_{eff}) [15]	0.2 dB
Shadowing [13][14]	Lognormal distribution
Standard deviation of the signal (σ) [13]	8 dB
Path loss model [13] [14]	Cost 231
Number of trials	2000

Table 1: Simulation parameters used in MATLAB.

3.2 Discussions and results

The results in this report show the performance of FPC and conventional power control. The SINR performance is presented for low, mid and high values of P_o. It is observed that a change in P_o shifts the SINR distribution. Figures 6 to 9 show the SINR distribution for α = 0.6 and 0.8 and different values of P_o. A higher P_o shifts the SINR distribution to the right and thus increases the overall SINR. An increase in P_o will increase the power of all users and thus the level of interference. An increase of 10 dB in P_o results in approximately a 1 dB shift in the SINR distribution. These results are similar to those in [8] [14].

Figures 10 to 12 show how a change in α changes the UE transmit power. A lower α lowers the UE transmit power and vice versa. A lower α not only decreases the SINR but also spreads the distribution which results in a greater difference in the SINR between the cell edge and cell center users. Thus, P_o controls the SINR mean and α controls the SINR variance. Figures 10 to 12 show similar performance compared to that in [8] [14].

Figures 13 to 15 show the SINR performance with α = 0.4, 0.6 and 0.8. It can be observed that the SINR distribution is wider with a lower α. For α = 1, the received power spectrum density is greater than with α = 0.4, 0.6 and 0.8 because of full compensation for the path loss. This reduces the SINR distribution variance. A lower α changes the received power spectrum density of the UE according to the path loss from the eNodeB. A lower α gives a greater SINR difference between the cell edge and cell center users. These results are similar to those in [14].

Figures 16 to 18 show that cell edge users have more path loss compared to cell center users because of the distance. A lower α when multiplied by the path loss decreases the effect of path loss on users located at the cell edge more than those located close to the cell center. Hence a lower α increases the cell mean throughput as the cell center users have a higher SINR. This improvement is at the cost of a decrease in the power of cell edge users, and thus their throughput. Figures 16 to 18 show that the cell edge throughput is slightly better with α = 1 than α = 0.8, 0.6 and 0.4, but α less than one provides better cell mean throughput. The results in Figures 16 to 18 are similar to those in [14].

Tables 2 to 4 give the throughput with fractional power control for different values of α and P_o. Fractional power control reduces the effect of path loss on cell edge users in order to improve the cell mean throughput. A value of α less than 1, when multiplied with the path loss, lowers the effect of path loss more for cell edge users than for users located close to the cell center. Hence, a lower α means a better SINR for cell center users. FPC allows the cell center users to achieve a higher SINR at the cost of a decrease in the power of the cell edge users and hence a lower interference to other cells. This SINR improvement is at the cost of a decrease in the power of the cell edge users, which results in a lower throughput at the cell edge.

Figures 19 to 21 show that as α gets close to one, the SINR difference decreases which decreases in the cell mean throughput and increases the cell edge throughput. Values of α below 0.4 have no practical use due to very low cell edge throughput. A value of α = 0.4 has a high cell mean throughput which is 15% more than with conventional power control. Further, using a value of α = 0.4 significantly decreases the cell edge throughput by 83%. A value of α = 0.8 provides a more balanced trade-off with an increase in cell mean throughput of 6% and a decrease in cell edge throughput of 37%. A value of α = 0.8 was proposed in [5] and [14]. In conclusion, there is a trade-off with FPC which can be used to tune the system performance according to the deployment scenario. A value of α lower than one reduces the inter cell interference. The results in [14] for the cell mean throughput and cell edge throughput are similar to those presented in this report.

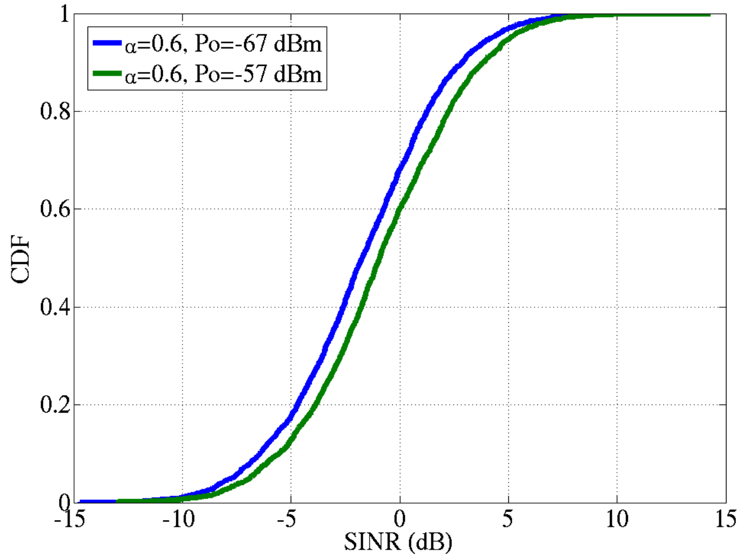

Figure 6: SINR CDF for α = 0.6 and P_o = -67 and -57 dBm.

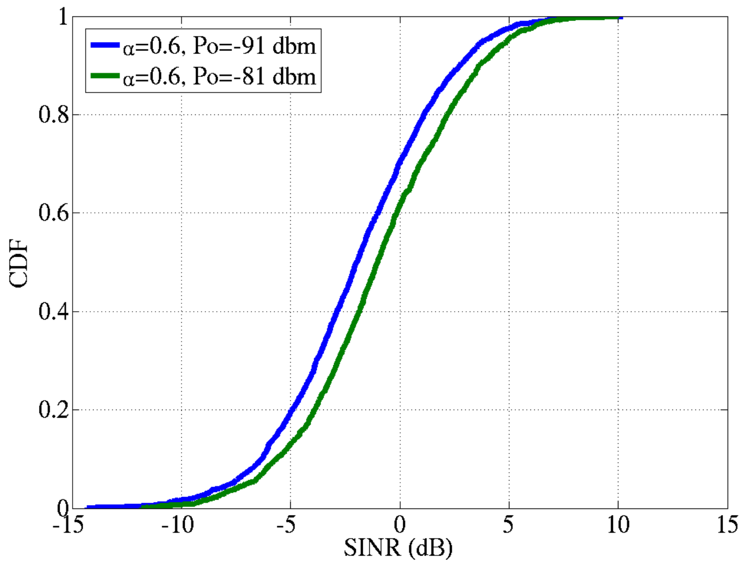

Figure 7: SINR CDF for α = 0.6 and P_o = -91 and -81 dBm.

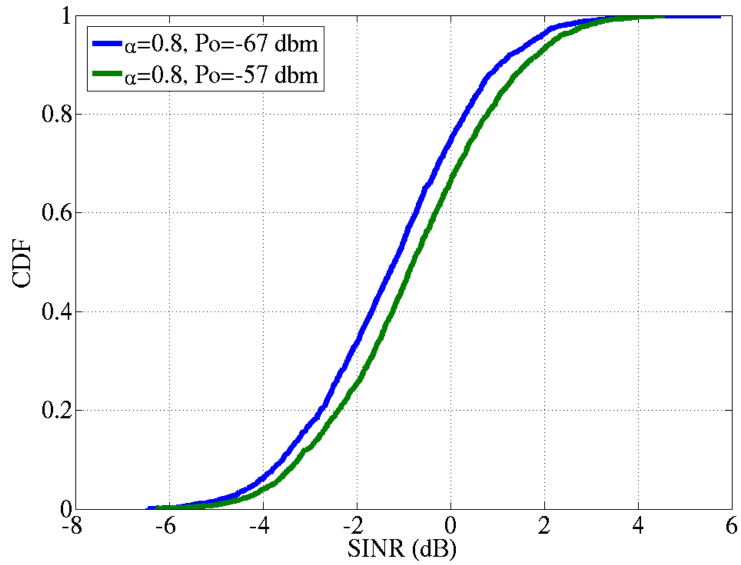

Figure 8: SINR CDF for α = 0.8 and P_o = -67 and -57 dBm.

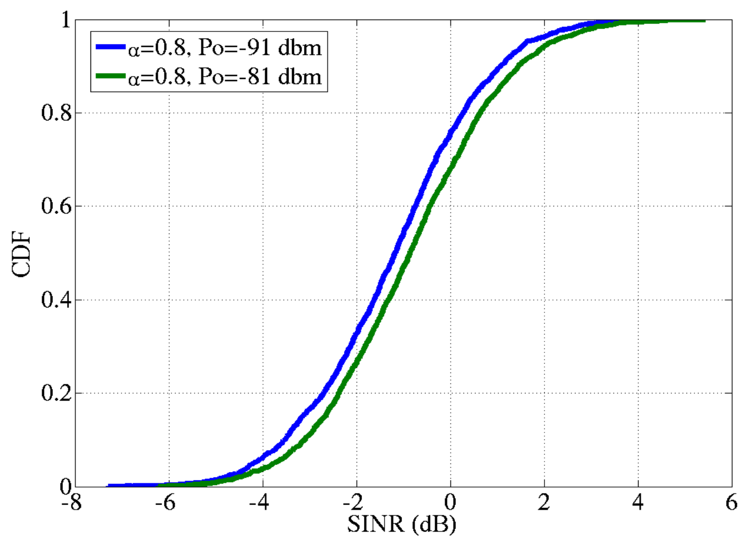

Figure 9: SINR CDF for α = 0.8 and P_o = -91 and -81 dBm.

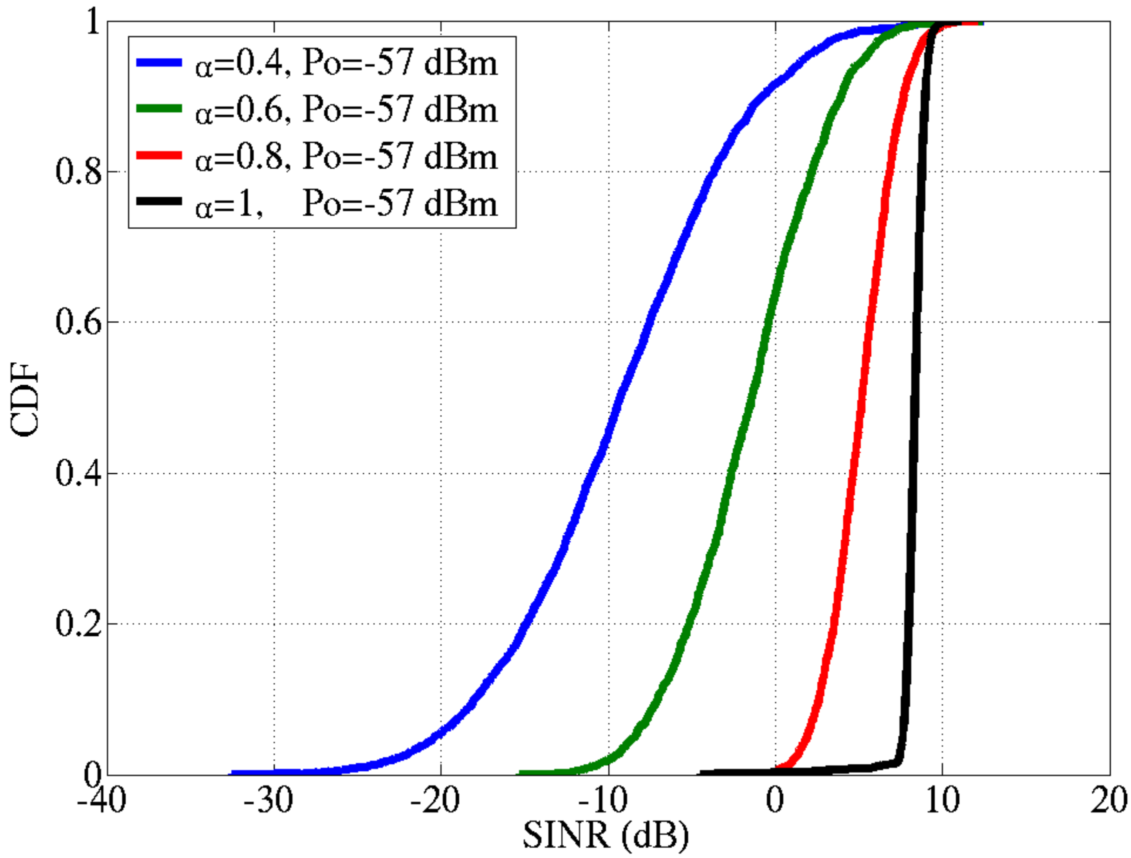

Figure 10: SINR CDF for P_o = -57 dBm with one interferer and different α values.

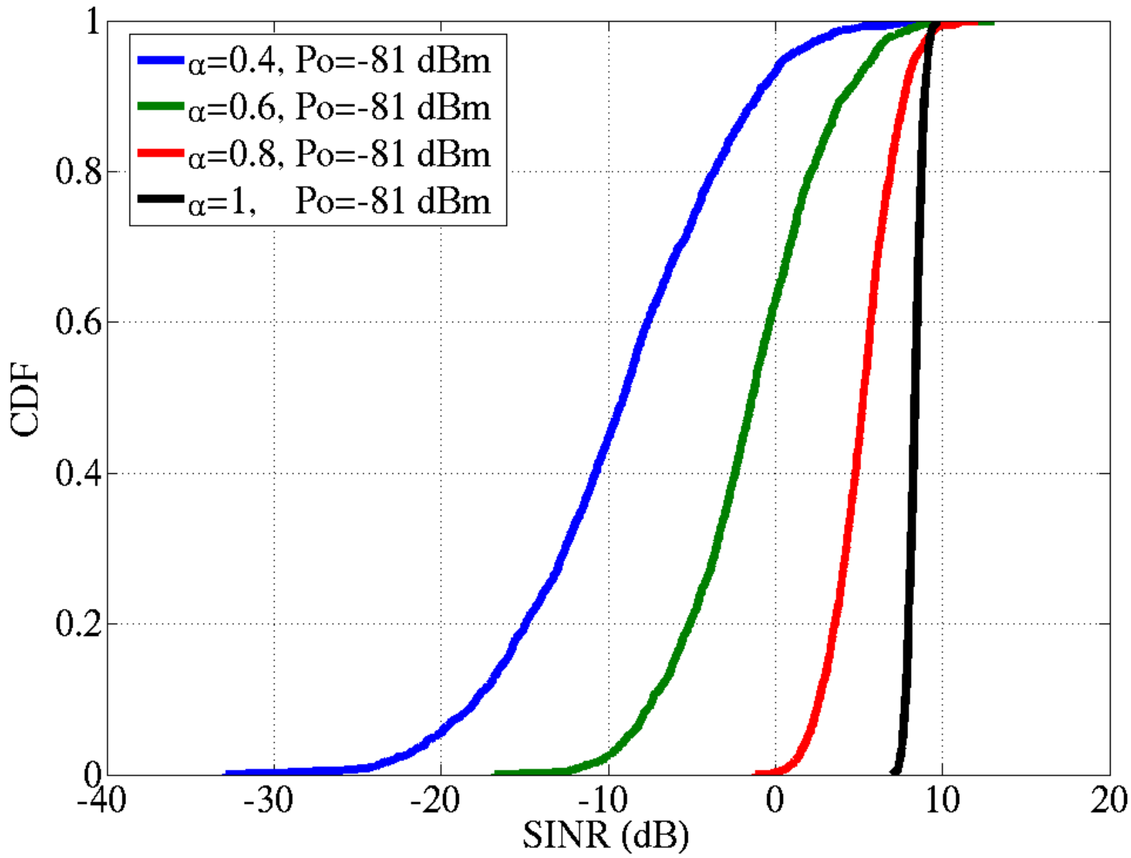

Figure 11: SINR CDF for P_o = -81 dBm with one interferer and different α values.

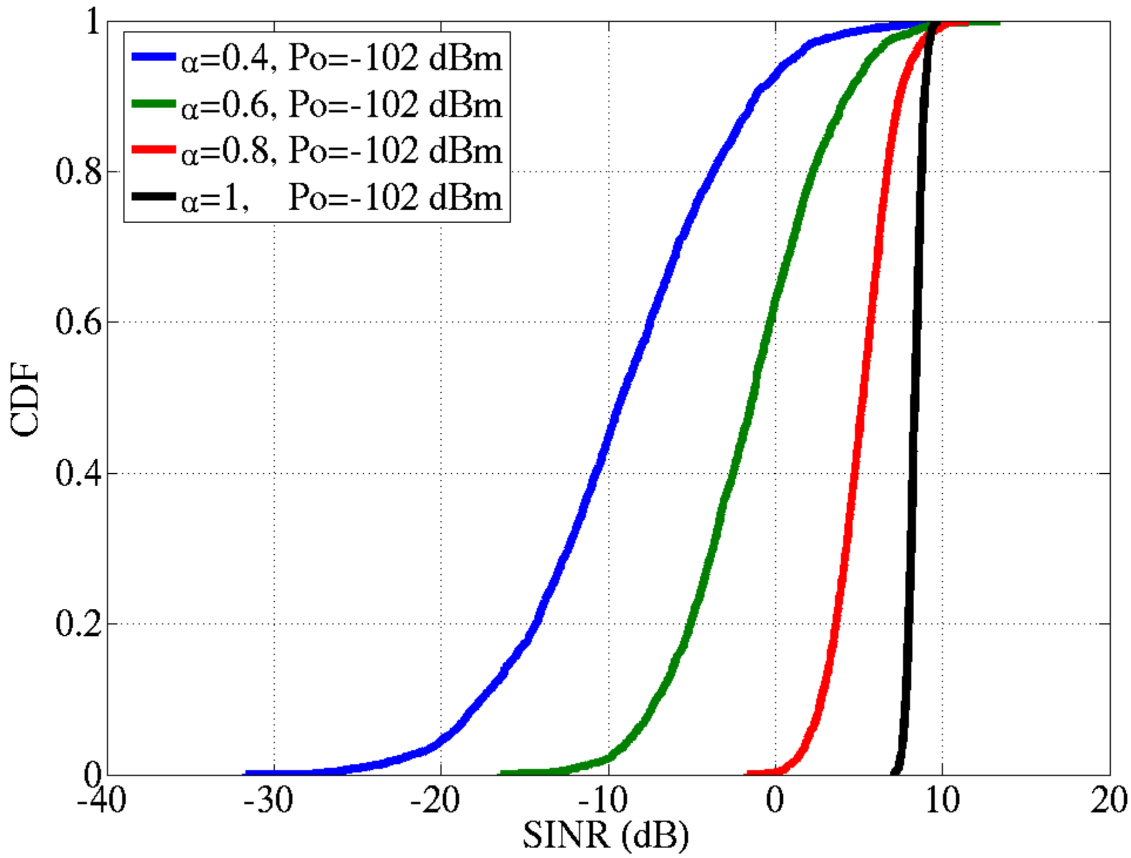

Figure 12: SINR CDF for P_o = -102 dBm with one interferer and different α values.

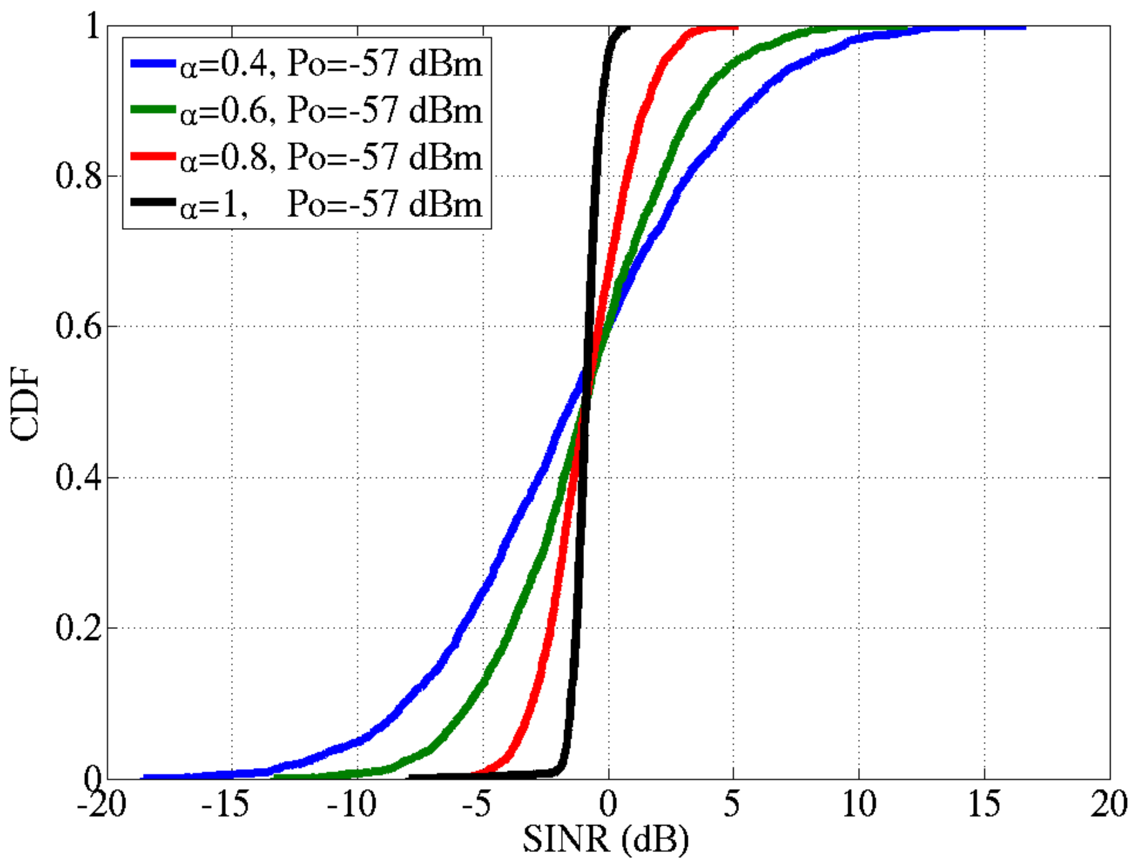

Figure 13: SINR CDF for P_o = -57 dBm with four interferers.

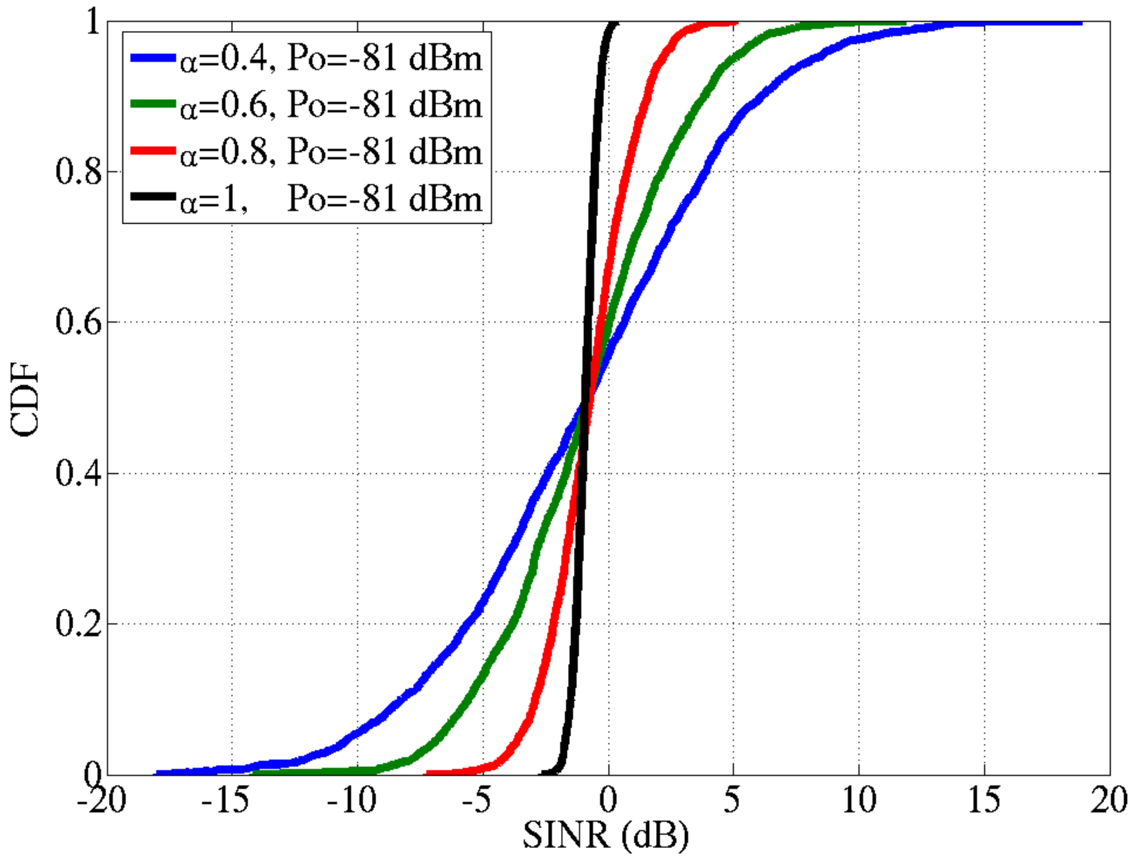

Figure 14: SINR CDF for P_o = -81 dBm with four interferers.

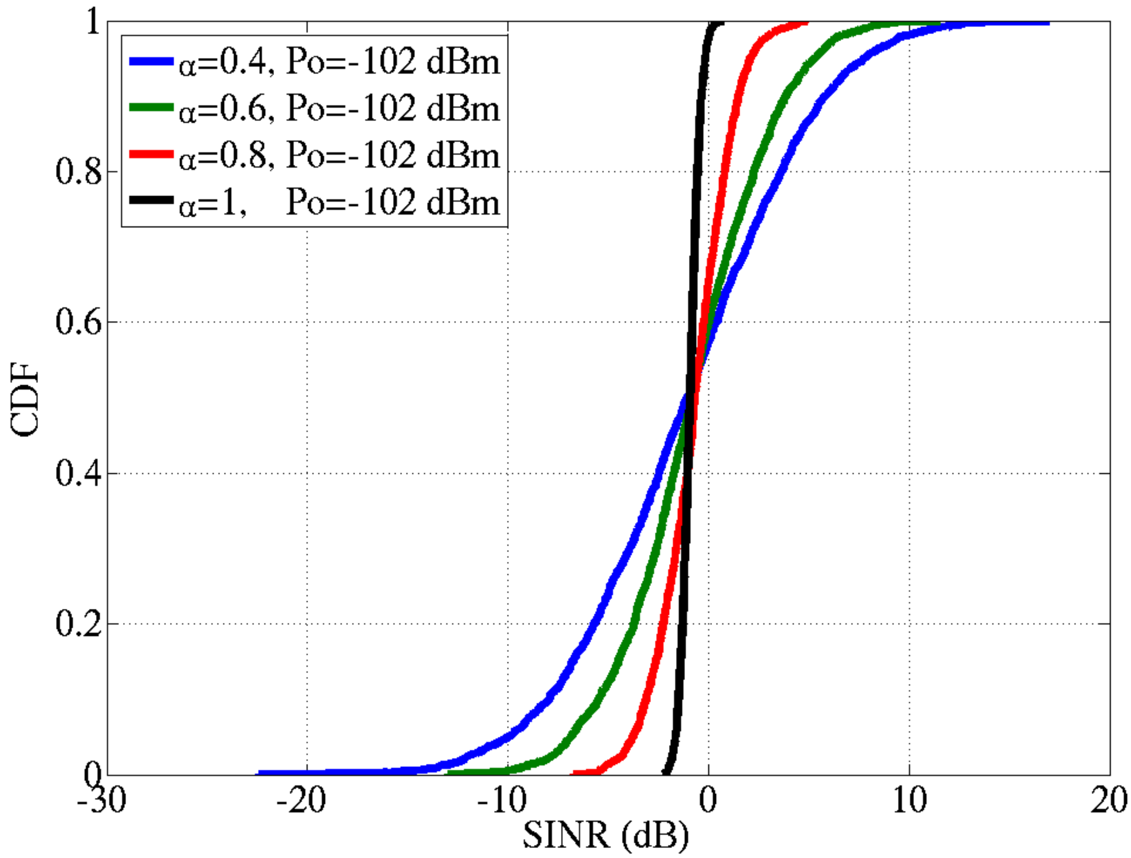

Figure 15: SINR CDF for P_o = -102 dBm with four interferers.

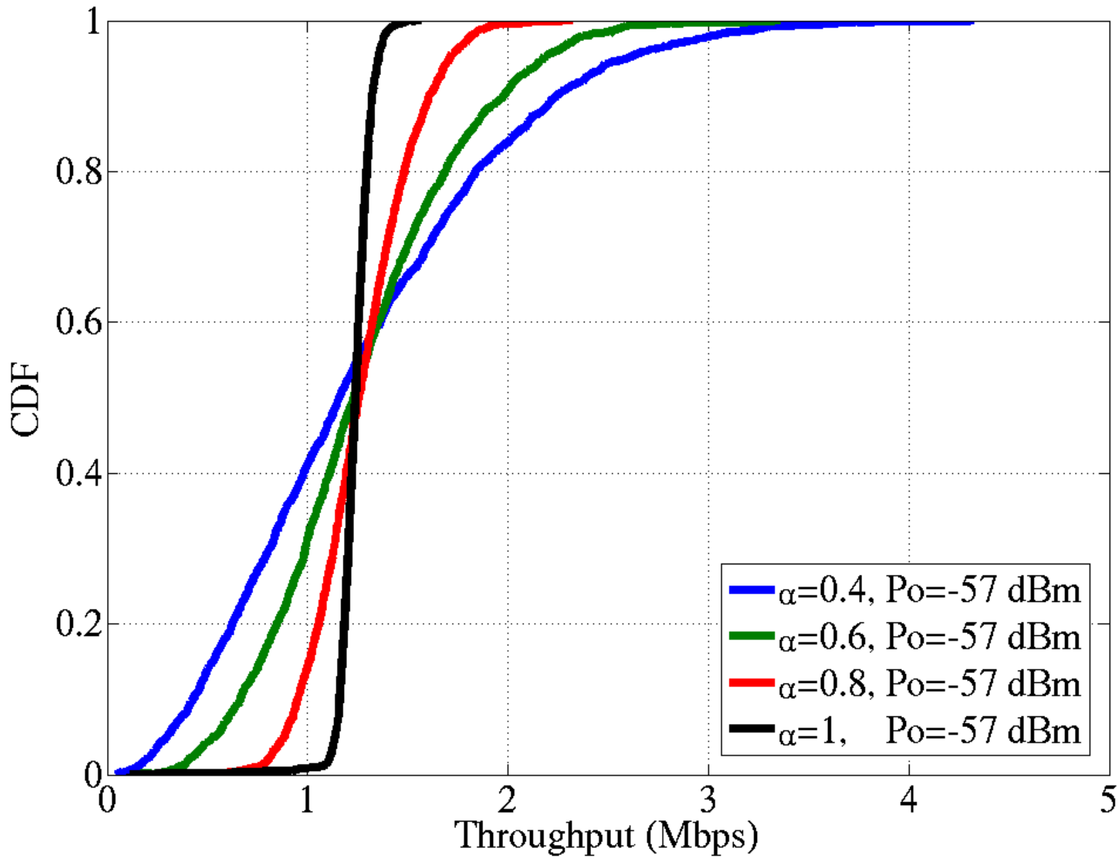

Figure 16: User throughput CDF for different values of α and P_o = -57 dBm.

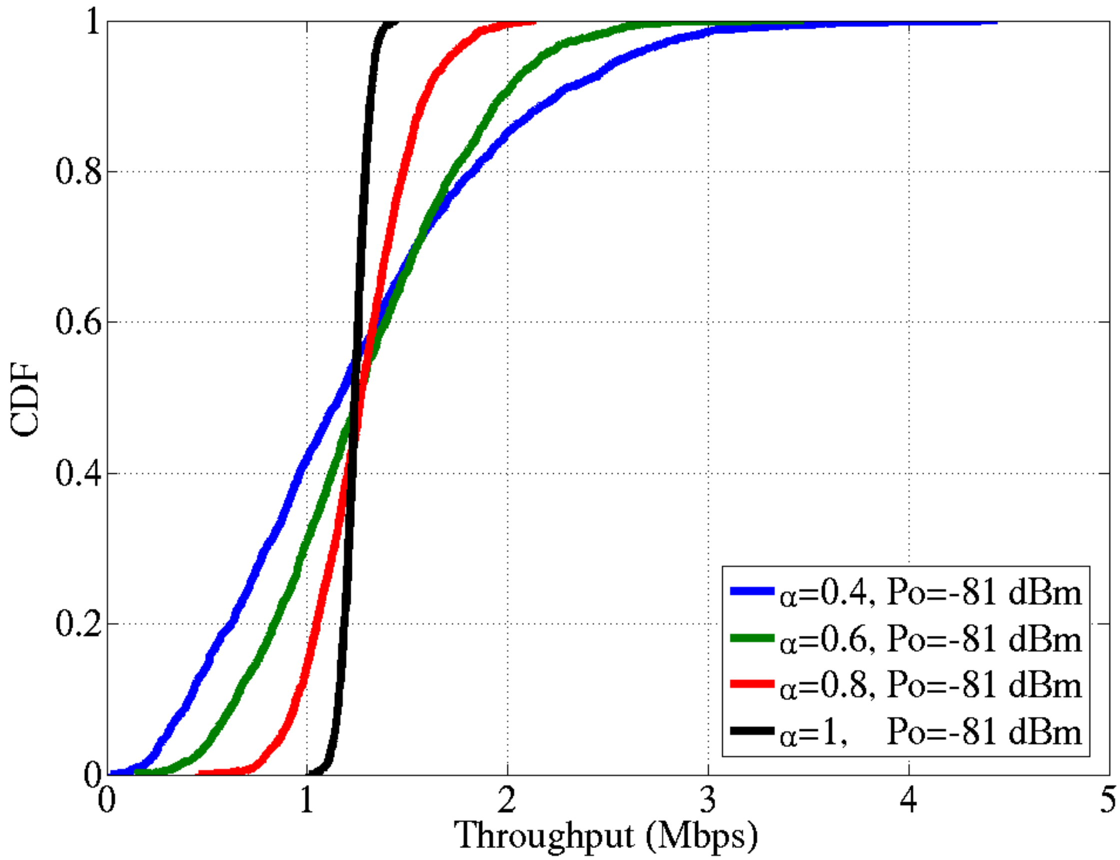

Figure 17: User throughput CDF for different values of α and P_o = -81 dBm.

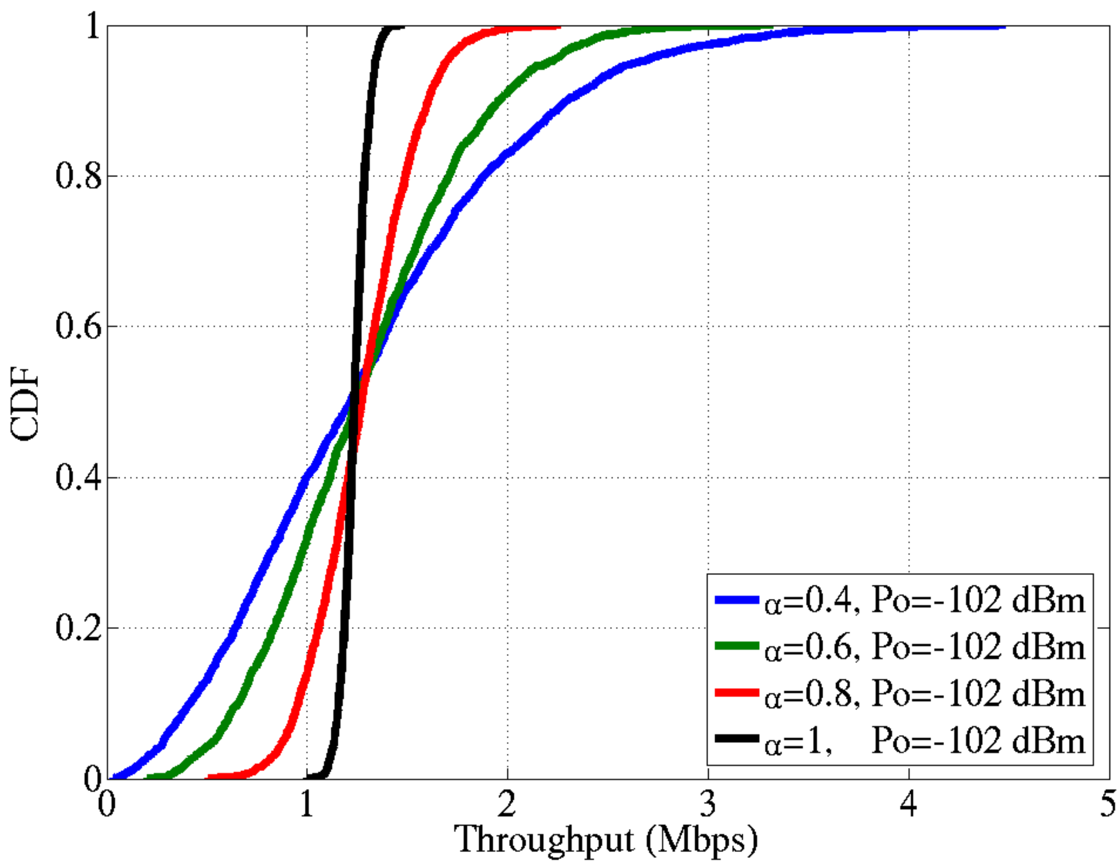

Figure 18: User throughput CDF for different values of α and P_o = -102 dBm.

α	P_o [dBm/PRB]	Cell mean throughput [Mbps]	Cell edge Throughput [kbps]
1	-57	12.5	619
0.9	-57	12.7	496
0.8	-57	13.1	391
0.7	-57	13.3	305
0.6	-57	13.4	209
0.5	-57	13.8	147
0.4	-57	13.6	106
0.3	-57	14.3	62
0.2	-57	14.8	45
0.1	-57	14.8	28
0	-57	15.1	14

Table 2: Throughput for different values of α and P_o = -57 dBm.

α	P_o [dBm/PRB]	Cell mean throughput [Mbps]	Cell edge Throughput [kbps]
1	-81	12.3	618
0.9	-81	12.8	498
0.8	-81	13.0	385
0.7	-81	13.4	286
0.6	-81	13.4	204
0.5	-81	13.9	150
0.4	-81	14.1	101
0.3	-81	14.2	59
0.2	-81	14.3	41
0.1	-81	14.5	24
0	-81	15.3	16

Table 3: Throughput for different values of α and P_o = -81 dBm.

α	P_o [dBm/PRB]	Cell mean throughput [Mbps]	Cell edge Throughput [kbps]
1	-102	12.3	618
0.9	-102	12.7	488
0.8	-102	13.1	389
0.7	-102	13.4	294
0.6	-102	13.3	210
0.5	-102	13.7	152
0.4	-102	13.8	90
0.3	-102	14.0	61
0.2	-102	14.1	41
0.1	-102	14.3	20
0	-102	15.2	17

Table 4: Throughput for different values of α and P_o = -102 dBm.

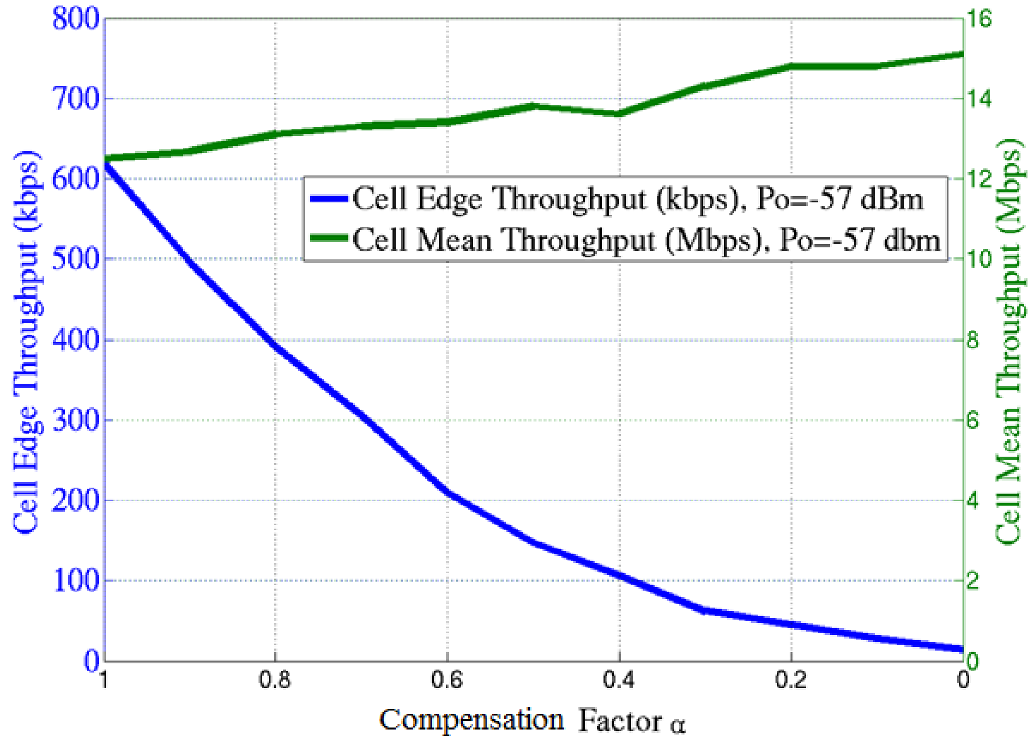

Figure 19: Throughput for different values of α and P_o = -57 dBm.

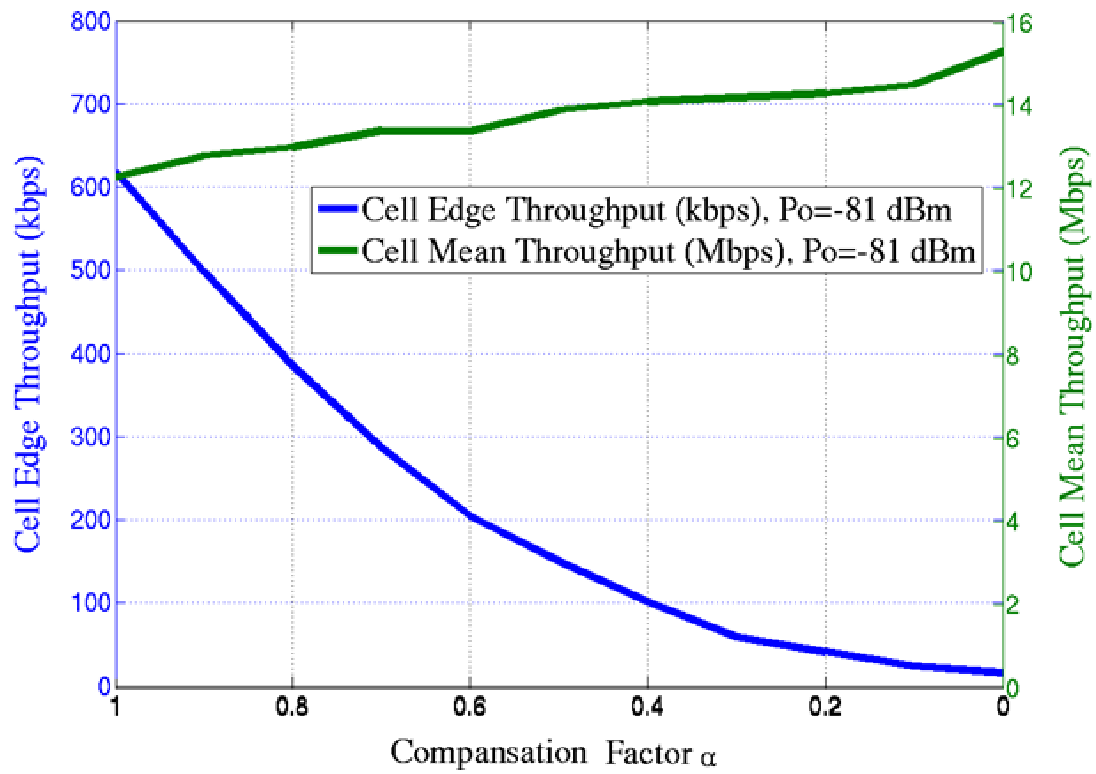

Figure 20: Throughput for different values of α and P_o = -81 dBm.

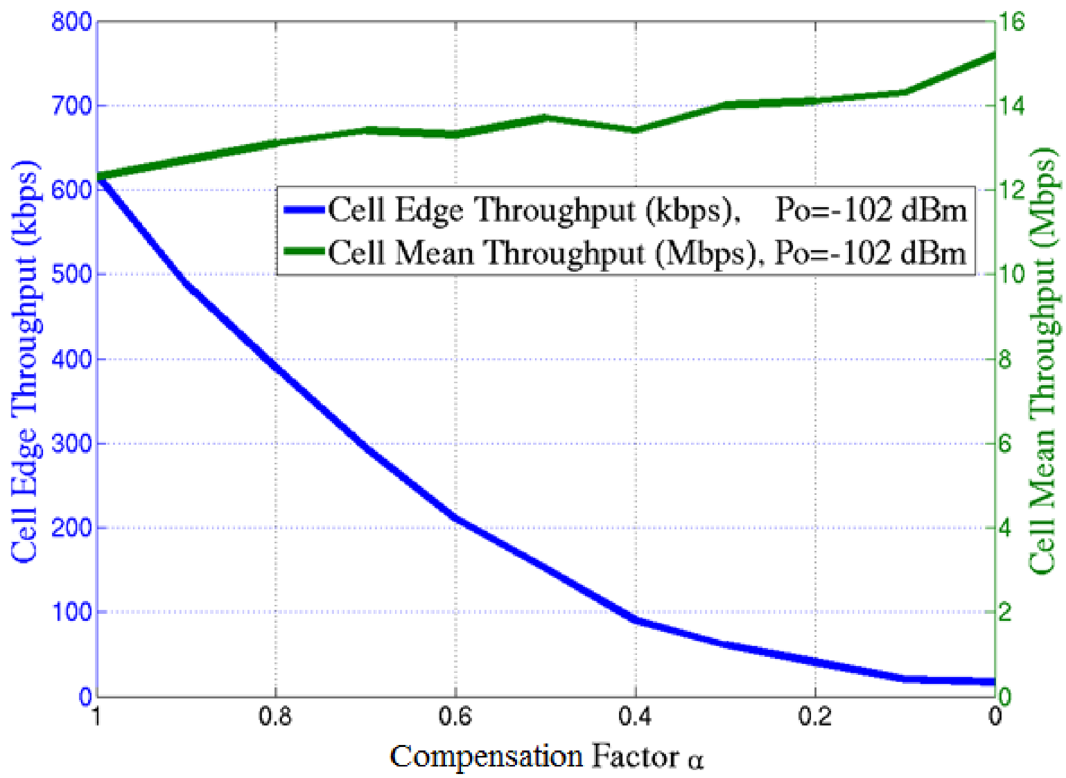

Figure 21: Throughput for different values of α and P_o = -102 dBm.

4 Conclusions and Future Work

4.1 Conclusions

The uplink power control in LTE is flexible and simple. It consists of a closed loop term and an open loop term. This report focused on the open loop term which is also known as fractional power control. The path loss compensation factor of fractional power control is used to improve cell mean throughput. Simulation results were presented which indicate that fractional power control can improve the cell mean throughput up to 15% compared to conventional power control by decreasing the transmit power of cell edge users more than cell center users. It also improved the network throughput up to 15% and reduced the power consumption at the UE. A value of $\alpha = 0.8$ was considered to provide the good performance with an increase in cell mean throughput of 6% and a decrease in the cell edge throughput of 37% compared to conventional power control. It was concluded in [5] and [14] that $\alpha = 0.6$ to 0.8 is appropriate for good| performance. In [5] it was shown that closed loop power control with FPC provides better performance than closed loop power control with conventional power control. The results in [5] [14] show that FPC is the key component for power control in the LTE uplink compared to the closed loop component. In a sparse user environment, a larger α should be employed to increase cell edge throughput whereas in a dense user environment a smaller α should be used to increase cell mean throughput. Thus, FPC supports different deployment scenarios. FPC enables a trade-off between the cell edge throughput and cell center throughput. It also decreases inter cell interference and reduces the power consumption at the UE.

4.2 Future work

Uplink power control is a combination of a closed loop term and an open loop term. The closed loop term adjusts the uplink transmit power with the closed loop correction value also known as Transmit Power Control (TPC) commands. TPC commands are transmitted by the eNodeB to the UE based on the target SINR and measured SINR. The closed loop term is cell specific and can be studied with different target SINRs. LTE has different modulation and coding techniques which could be studied with the closed loop term in conjunction with the open loop term.

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