Energy Efficiency in Cellular Wireless Networks

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ABSTRACT

Energy efficiency of Long Term Evolution (LTE) cellular communication networks has become a major concern for network operators, not only to reduce the operational costs, but also to reduce their environmental effects. Within LTE cellular networks, base stations are responsible for most of the energy consumption, consuming 70-95% or more of the network power depending on the network topology, configuration, radio technology and data rates that are used.

Power control is an important function in cellular wireless networks and refers to setting the output power levels of transmitters, termed eNodeB in the downlink and user equipment (UEs) in the uplink. LTE utilizes two different mechanisms for uplink power control: Open Loop Power Control (OLPC) and Closed Loop Power Control (CLPC). Uplink OLPC is performed by the UE following eNodeB configuration and can compensate for long term channel variation such as path loss and shadowing. The uplink CLPC mechanism attempts to improve power control performance by compensating fast channel variations due to multipath fading. In CLPC the eNodeB sends Transmit Power Control (TPC) commands to the UE to adjust the UE's transmit power.

This thesis focuses on an Open Loop Power Control (OLPC) scheme for LTE uplink by using the Okumura-Hata propagation path loss model to set the User Equipment (UE) uplink transmit power control parameters in order to reduce the UE energy consumption. In general, the UE requires more power to connect to distant base stations than closer base stations and therefore this thesis analyses the required power levels using the Okumura-Hata propagation path loss model. Estimation of path loss is very important in initial deployment of wireless network and cell planning. This thesis analyses the Okumura-Hata propagation path loss in different receiver antenna heights (h_{bs}), different path loss compensation factor (α) and different eNodeB sensitivity (P_o) in urban, suburban and rural environments. The results from this analysis can be used to optimally set the UE transmit power, but also to create improved relay sections in a hybrid

link in order to achieve optimum data rate transfer while maximizing battery lifetime of the UE. This work is one further step toward “green” cellular networks.

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Declaration

I declare that, this thesis is my own work. I also declare and certify that, to the best of my knowledge, this thesis does not infringe upon anyone's copyright nor violate any proprietary rights. It is submitted for the purpose of a PhD degree requirement to the School of Biological Sciences, the University of Reading, UK. This thesis has not been submitted before for any degree or exam of any other university or institute.

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Nomenclature

2G	Second Generation
3G	Third Generation
3GPP	The Third Generation Partnership Project
4G	Fourth Generation
ACLR	Adjacent Channel Leakage Radio
ADC	Analog to Digital Control
BB	Baseband
BS	Base Station
BTS	Base Transceiver Station
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CLPC	Close Loop Power Control
CoMP	Coordinate Multi-Point
COST	COoperative europe dans le domain de la research Scientifique et Technique
CW	Code Words
DoD	Direction of Departure
DL	Downlink
DS-CDMA	Direct Sequence-Code Division Multiple Access
DTX	Discontinuous Transmission
EARTH	Energy Aware Radio and Network Technology
ECG	Energy Consumption Gain
ECR	Energy Consumption Ratio
EE	Energy Efficiency
EEE	Energy Efficient Ethernet
EEW	Energy Efficient Wireless
eNodeB	Evolved Node B

E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Full Division Duplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FPC	Fractional Power Control
GA	Genetic Algorithm
GC	Gain Control
GSM-R	Global System for Mobile communication-Railway
HSPA	High Speed Packet Access
ICT	Information and Communications Tecnology
LOA	Low Noise Amplifier
LOS	Line Of Slight
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advance
MAC	Medium Access Control
MIMO	Multiple-Input Multiple-Output
MSE	Mean Square Error
MU	Mobile Unit
OLPC	Open Loop Power Control
PA	Power Amplifier
PARP	Peak to Average Power Ratio
PCs	Personal Communications
PEF	Power Added Efficiency
PMU	Power Management Unit
PRBs	Physical Resource Blocks
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service
RAN	Radio Access Network

RF	Radio Frequency
RRC	Radio Resource Control
RMSE	Root Mean Square Error
RX	Received power
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SINR	Signal to Interference plus Noise Ratio
SIR	Signal Interference Ratio
SM	Sleep Mode
TBS	Transport Block Size
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio mobile Access
TPC	Transmit Power Control
TTI	Transmission Time Interval
Tx	Transmit power
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Transmissions System
V-MIMO	Virtual Multiple-Input Multiple-Output
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide interoperability for Microwave Access

CHAPTER 1 INTRODUCTON

1.1 Introduction

The number of User Equipments (UEs) is increasing in wireless industry year by year, both in terms of mobile technology and subscriber. Energy reduction for wireless systems becomes more and more important due to its impact on the operation cost and global carbon footprint.

Power control plays an important role on the uplink of Long Term Evolution (LTE) cellular networks. The standard uplink power control formula contains an Open Loop Power Control (OLPC) and Close Loop Power Control (CLPC). In OLPC is performed by the User Equipment (UE) using parameters and measures obtained from signals sent by eNodeB and can compensate for long term channel variations such as path loss and shadowing. In this case, no feedback is sent to the UE regarding the power to be used for transmission. The CLPC mechanism attempts to improve power control performance by compensating fast channel variations due to multipath fading. In CLPC the eNodeB sends Transmit Power Control (TPC) commands to adjust the correct UE's transmitted power. Qualifying the power control technique as an open loop and closed loop helps to have an anticipated idea of the implementation complexity and expected level of performance. For instance, it is presumed that CLPC 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 condition. On the other hand, OLPC would result in simpler implementation and low signal but would be to compensate for channel variation for individual UEs. This thesis focuses on an OLPC scheme for LTE uplink by using the Okumura-Hata propagation path loss model to set the UE uplink transmit power control parameters in order to reduce the UE energy consumption. In general, the UE uses more power to connect to distant base stations than closer base stations and therefore this thesis analyses the required power levels using the Okumura-Hata propagation path loss model. The results from this analysis can be used to optimally set the UE transmit power, but also to create improved relay sections in a hybrid link in order to achieve optimum data rate transfer while maximizing battery lifetime of the UE. This work is one further step toward "green" cellular networks.

1.2 Research Question

Base on the discussion to reducing user equipment uplink transmission power in LTE trough Okumura-Hata propagation models. The thesis focus is the UE uplink transmission power control parameters in order to reduce the UE energy consumption and improve the UE experience. The scope limitation shown in figure 1.1. This is lead to the following research questions:

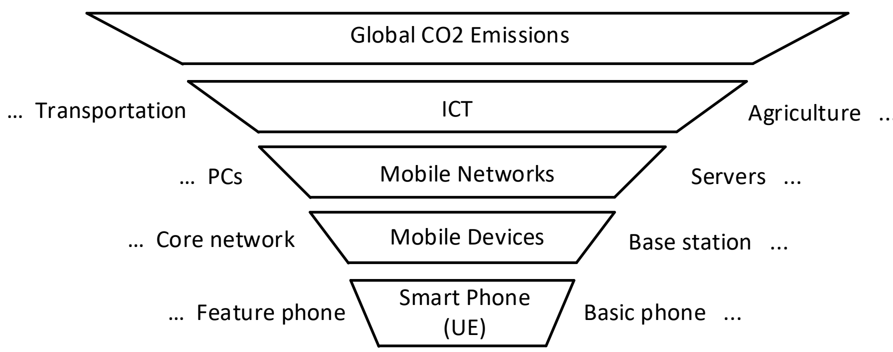


Figure 1.1: The Thesis scope

1. What is the power consumption of LTE UE components?

   To determine how to save energy in UE it is necessary to identify the most power consuming components.

2. How can the power consumption of UE can be reduced while remain performance?

Improving the battery life should not affect the quality of service and therefore it is important to maintain the performance of UE.

3. How can a future Fourth Generation (4G) be designed to significantly improve the UE battery life?

   To analyse the UE energy consumption's dependency on height of base station (h_{bs}), path loss compensation factor (α) and eNodeB sensitivity (P_o)

1.3 Thesis Outline

This thesis is organized in seven main chapters. For the sake of earlier understanding the content of the thesis, this section provides an introduction of thesis chapters. The PhD thesis is organized as follows:

Chapter One: Introduction – This chapter presents the research aims, scope and research questions, methodology and contributions in this research has also discussed in this chapter

Chapter Two: Literature review and related work – This chapter provides main literature and related work have reviewed and explained in this chapter. However, many other search works have demonstrated and explained through the study.

Chapter Three: Energy saving in LTE user equipment – This chapter explains the UE model design of the cellular communication network.

Chapter Four: Model analysis and simulation – This chapter covers the system model for UE and LTE uplink power control in mobile communication.

Chapter Five: Results – This chapter presents the novel simulation results and the main parameters for open loop LTE uplink power control.

Chapter Six: Discussion – This chapter discusses the results from the simulation and the analysis of these results is drawn.

Chapter Seven: Conclusion – This chapter provides conclusion of overall research study and possible future work.

This chapter focus on introduction of the thesis by using an OLPC scheme for LTE uplink by using Okumura-Hata propagation model to set the UE uplink transmit power. Research question of my thesis and thesis outline.

CHAPTER 2 LITERATURE REVIEW AND RELATED WORK

2.1 Introduction

In this chapter focus on how to go to green cellular network. It is important to reduce CO_2 emission caused by mobile networks and devices, and that is the starting point of the thesis. Many researchers have already studied the mobile network and power consumption.

Over the last decade global warming has become an increasingly important problem on the global political agenda. Energy consumption has important issues in the world as the carbon emissions of energy sources have great negative impact on the environment and price of energy is increasing. The European Union has acted as a leadership in energy saving over the world and targeted to have a 20% greenhouse gas reduction. Moreover, political initiatives impose requirements on manufacturers and operators to lower CO_2 emissions of communication networks. The European Commission research project EARTH (Energy Aware Radio and network TecHnologies) consolidates the energy efficiency activities from major vendors and operators in Europe such as Vodafone has set a group target to reduce its CO_2 emissions by 50% by 2020, from the 2006/2007 level [1] and Orange has set a target to reduce its greenhouse gas emissions per customer by 20% between 2006 and 2020 [2]. Therefore, carbon footprint and energy operation costs have become vital constraints in future telecommunication system designs.

Besides reducing the carbon footprint of the industry, there is a strong economic incentive for the network operators to reduce the energy consumption of their communication network systems. Currently more than 80% of the power in mobile communication is consumed in the radio access network, more specifically in Base Stations (BS) [3]. However, most of the efforts for energy saving in cellular networks still focus on reducing the transmit power of BS. Energy saving in the network can be realized by reducing the number of active BSs in the access networks when they are not necessary because traffic is low. When some cells are switched off, there is a great potential to reduce energy consumption in the cellular networks.

2.2 Green Cellular Networks and Energy Efficiency

Green communication is an innovative research area to find radio communication and network solutions that can greatly improve energy efficiency as well as resource efficiency of wireless communication without compromising the Quality of Service (QoS) of users. It not only contributes to global environment improvement but also achieves commercial benefits for telecommunication operators. To meet the challenges of increasing energy efficiency in communication networks, it is imperative to resort to paradigm shifting technologies, for example energy efficient network architectures, energy efficient wireless transmission techniques, energy efficient networks and protocols, smart grids, etc. Some resent efforts towards achieving green communication solution include [4], [5]. Moreover, in order to achieve real green wireless and cellular communications, the energy efficiency of both networks and mobile devices needs to be addressed evenly.

The energy in the telecommunication networks is consumed by three different parts. First, the access network which includes the main and auxiliary equipment (e.g. the cooling facilities). Second, the core network. Finally, the transmission network. These energy expenditures can be optimized by lowering the equipment usage and adjusting the resource allocation [6]. A taxonomy graph of our approach towards the design of green cellular networks is given in Figure 2.1. Hasan *et al* [7] identified four important aspects of a green networking defining green metrics, bringing architectural changes in BSs, network planning and efficient system design. Since BSs consume the major chunk of input energy therefore, BS equipment manufacturers have begun to offer a number of eco and cost friendly solutions to reduce power demands of BSs. A typical cellular network consists of three main elements: a core network that takes care of switching, BSs providing radio frequency interface and the mobile terminals in order to make voice or data connections. As the number of BSs increase, it becomes crucial to address their energy consumption for cellular network. Some typical system features to improve BS energy efficiency are to shut down BS during low traffic or cell zooming.

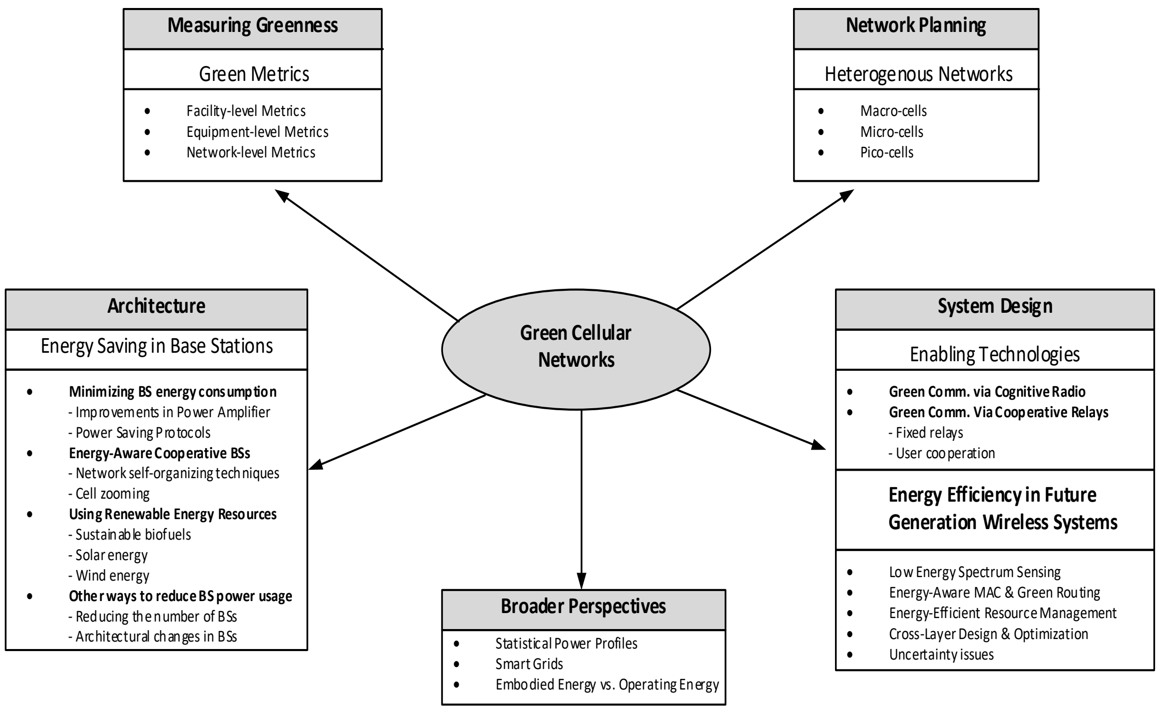


Figure 2.1. Technical roadmap for Green Cellular Networks: a taxonomy graph [7]

2.3 Green Communication from System Architecture

There are many green cellular networks techniques to reduce energy consumption due to base stations that have emerged in recent years. The mobile industry is facing a critical energy conservation challenge. By year 2020 the number of mobile devices will excess 11.6 billion worldwide and will surpass PCs as the most popular web access devices. This fact has impact on the amount of energy consumed by the supporting infrastructure equipment. Meanwhile, the network data volume is expected to increase by a factor of 10 every five years, associated with about 20% increase of energy consumption correspondingly. Therefore, the mobile industry faces a grate sustainable development problem in energy consumption.

2.3.1 Minimizing BS Energy Consumption

The energy consumption of a typical base station can be reduced by improving the BS design and by including additional software and system features to balance between energy consumption and performance. In order to improve energy consumption in BS design, it is important to address the energy efficiency of the Power Amplifier (PA). A power amplifier dominates the energy consumption of base station and its energy efficiency depend on the frequency band, modulation and operation environment.

2.3.1.1 Improvements in Power Amplifier

There are three essential parts of a BS: radio, baseband and feeder. Out of these, the radio consumes more than 80% of a base stations energy requirement, of which power amplifier consumes almost 50%. Therefore, design of flexible power amplifiers that would allow a better adaptation of amplifier to the required output power need to be addressed. Many investigate more efficient in power efficiency. As an example, Shin *et al* [8] presented iterative algorithm to solve the problem of energy efficient BS planning in a green heterogeneous network. Firstly, the positions of base-stations that maximize the energy-normalized throughput for a fixed number of base stations were found. Secondly, the optimal number of base stations which maximizes the energy-normalized throughput was established. Power consumption in office networks has become a major issue due to its running cost. In order to reduce the power consumption, several approaches have been proposed. Nguyem *et al* [9] presented a power consumption model for office networks and applied the model to evaluate performance of Energy Efficient Ethernet (EEE) and Energy Efficient Wireless (EEW) aggregation. They also explored the possibility of further conserving power by combining the exiting power saving techniques was also explored. The combining EEE and EEW can save more than 66% of the power consumed if only EEE is used and it is even more if they put link-sleep technique into the combination. Han *et al* [10] presented three case studies for improving energy efficiency in wireless base stations. Firstly, resource allocation strategies in the term resource allocation was used to describe how the base station transmitter make the decision of how and when to transmit data to different users on the downlink (base station to mobile link) within the cell it is saving. Secondly, interference management and mitigation. The impact of interference is more severe as a user moves closer to the boundary region between two cells in cellular networks leading to significant signal to interference plus noise ratio (SINR) and reducing data rate. Finally, energy efficiency routing and multihop. The use of relays to exchange information between the base station and mobile terminal may be an efficient way to improve base station energy efficiency because the transmission distance can be reduced and increase data rates.

The investigation on the impact of deployment strategies on the power consumption of mobile radio networks. Richter *et al* [3] presented the concept of area power consumption as a system performance metric and employ simulations to evaluate potential improvements of this metric through the use of micro base station and shows that the power saving from deployment of micro base stations are moderate in full load scenarios and strongly depends on the offset power consumption. Richter *et al* [11] investigated the efficiency of homogeneous and heterogeneous networks consisting of varying number of micro sites with regard to traffic load conditions. In this regard, they applied the framework develop from Salman *et al* [6] and Fehske *et al* [12] in order to obtain a relation between the two efficiency measures. Further, they extended the framework to load considerations, expressed by means of different user densities and adapted the power model of micro base stations to take load variations into account.

In wireless communications micro cells are potentially more energy efficient than conventional macro cells due to the high path loss exponent. Energy efficiency of any deployment is impacted by the power consumption of each individual network element and the dependency of transmit power and load. Arnold *et al* [13] developed a power consumption model for macro base stations which comprises of a static power consumption part only and applied this power consumption model for conventional macro base station deployments the widely used inter site distance of 1500m is most energy efficient. Efforts to increase the energy efficiency of information and communication systems in general and cellular mobile radio networks in particular has recently gained momentum. Fehske *et al* [12] provided a framework to evaluate and optimize cellular network deployments with respect to average number of micro sites per macro cell as well as the macro cell size and introduced the concept of area power consumption and quantile base area throughput. Chee *et al* [14] presented an energy consumption modelling framework to evaluate total power consumption in cellular networks. They consider different scenarios for example; different femto-cell penetration rates, different open access limits and various cell coverage, to evaluate the system from several different aspects. Using the proposed framework to investigate the power consumption and performance of cellular network equipped with femto-cell.

The energy consumption of cellular network can be reduced by decreasing the energy consumption of Base Transceiver Station (BTS) sites and also by minimizing the number of BTS sites. The energy consumption of BTS sites can be reduced by improving energy efficiency of BTS equipment, using system level features and by employing energy efficiency site solutions. Renewable energy sources can be used to generate energy in the location where the availability if electrical grid is limited [15]. Bousia *et al* [16] studied the energy consumption problem. They introduced a distance aware algorithm that achieved a significant reduction in power consumption. In particular, they proved how important is to efficiently choose the eNBs to be switch off during low traffic periods, by considering not the distance of the UEs from the eNB. Our results indicated that they can save up to 29% of power consumed to operate the network, by decreasing the number of active eNBs during low traffic periods.

Ling *et al* [17] presented evolving direction of cellular network, namely denser base station deployment, based on a 2-dimensional hexagon cellular array. They proposed a propagation model to charecterize the difference between far-field and near-field users and the difference between base above-cluster and base below-cluster scenario and show how the operating regime shifts from interference limited to noise limited as increasing the base density. Chiaraviglio *et al* [18] showed that a large amount of energy can be saved if a careful dynamic radio coverage planning is used instead of a static one. In particular they showed that it is possible to switch off some cells and Node B's in urban areas during low-traffic periods, while still guaranteeing quality of service constraints in term of blocking probability and electromagnetic exposure limits. Willikomm *et al* [19] presented a large-scale characterization of primary users in the cellular spectrum and discussed the implications on enabling cellular dynamic spectrum access approaches. Marsan and Meo [20] evaluated the energy saving that can achieved with the energy-aware cooperative management of the cellular access networks of two operators offering service over the same area. They evaluate the amount of energy that can be save by using both networks in high traffic conditions, but switching off one of the two during the periods when traffic is low that the desired quality of service can be obtained with just one network. When one of two networks is off, its customers are allowed to roam over the one that is on. Zhou *et al* [21] studied the energy consumption problem. They proposed a smart strategy in order to minimize the energy consumption in a given network, without compromising the offered quality of service and introduced a distance-aware algorithm that achieves a significant reduction in power consumption.

ICT systems are meanwhile responsible for the same amount of CO2 emissions as global air travel. If the growth of ICT systems energy consumption continuous at the present pace, it will endanger ambitious plans to reduce CO2 emissions and tackle climate change. Increasing the energy efficiency of ICT systems is thus clearly the major R&D challenge in the decades to come [22]. Davaslioglu and Ayanoglu [23] described the sources of inefficacies in such networks. First they presented results of the studies on how much carbon footprint such networks generate. They also discussed how much mobile traffic is expected to tremendously increase. Then discussed specific sources of inefficiency and potential sources of improvement at the physical layer as well as at higher layers of the communication protocol hierarchy.

Hass *et al* [24] investigated the performance of their maximum packing algorithm for cellular structures, that used the interference-adaptation dynamic channel allocation. Their also proposed a procedure based on two sets of heuristics, which allowed the estimation of the number of channels required to serve a given mobile population. Hashem and Sousa [25] proposed the capacity of the DS/CDMA cellular system employing the IS-95 standard. The users were assume to be moving slowly such that the rate of power commands is enough to track multipath fading perfectly. They investigated the effect of changing the path-loss exponent value on the system capacity and reduce the intercell interference by imposing a limit on the maximum increase in power to compensate for multipath fading and show how can this increase the capacity by more than 100%. Sang *et al* [26] suggested a limit-cell coordination scheme for cellular systems of high speed downlink shared channels, where a dilemma exists as follows: On one hand, there is no physical layer power control or MAC layer soft handoff. On the other hand, inter cell interference and asymmetric load distribution in multiple cells are hindering the global system performance, which traditionally requires dynamic power control or soft-handoff.

Qi *et al* [27] investigated a novel deployment strategy is proposed to save the overall energy consumed by a cellular system. By separating the whole network into two parts: dense traffic zone and sparse traffic zone, the cell size can be adaptively adjusted based on the spatial traffic distribution. With smaller number of base stations deployed in the sparse zone, the overall energy consumption is successfully reduced. Marsan *et al* [28] proposed the transients for the switch-off base stations in cellular access networks with different layouts, ranging from a very simple 2-cell case, to regular structures, to a real case. For all these base station layouts, they studied the switch-off transients for one cell, investigating the average amount of time necessary to implement the switch-off, while allowing terminals to handover from the BS being switched off to a new BS without overloading the signalling channels. Kang *et al* [29] considered the comprehensive performance of quality of service and energy saving metrics. A total network performance maximization problem is modelled with graph and optimization theory. It was concluded that both the energy saving and energy efficiency achieved better optimization in dynamic energy saving than that in base stations. Zhu *et al* [30] considered a joint network performance maximization problem modelled with graph and optimization theory, and a user association scheme considering both quality of service guarantee and energy saving was proposed, which can optimize the network association. The power consumption, energy efficiency and blocking probability were evaluated by simulation when user association scheme is applied to the cell zooming based cellular networks.

Carminati *et al* [31] presented a study on green cellular networks for 3GPP-LTE networks, comparing the performance of the sleep mode and cell zooming algorithms not only in terms of their energy efficiency, but also verifying whether energy savings do not cause coverage or throughput losses in the network. Then proposed a modification, called virtual cell zooming. Oh *et al* [32] focused on the problem of base station switching for energy saving in wireless cellular networks. In particular they suggested a design principle based on the newly introduced concept of network-impact. Taking into account the implementation difficulty, the computational complexity and the amount of feedback information problems, they proposed several switching-on/off based energy saving algorithms. Cho *et al* [33] evaluated and highlights the performance of three dynamic cell zooming algorithms applied in both omni-directional and sector-based networks. The performance of three different dynamic cell zooming algorithms were evaluated and highlighted in terms of power saving and ratio of outage users. It can be concluded that the dynamic cell zooming algorithms are beneficially applicable during high load traffic hours rather than low traffic period.

Yu *et al* [34] proposed a cell zooming aided dynamic base station switching scheme considering inter-cell cooperation and power control to improve the energy efficiency of cellular networks. By introducing the inter-cell cooperation mechanism, their proposed scheme provided a better coverage in contrast to traditional schemes. Benefiting from the lower downlink transmit power of central user equipment's, the power control algorithm could reduce inter-cell interference. Gong *et al* [35] focused on reducing the energy consumption of base stations by adjusting their working mode (active or sleep). Specifically, the objective was to minimize the energy consumption while satisfying quality of service requirement and at the same time, avoiding frequent mode switching to reduce signalling and delay overhead.

Chen *et al* [36] presented, based on the multiple component carrier feature specified in Long Term Evolution-Advanced (LTE-A) systems, an energy efficient coordinated scheduling mechanism to reduce the energy consumption in cellular networks by dynamically switching off component carrier and base stations according to load variations, with special attention on the switching off order and base station transmit power adjustment to maintain service continuity of downlink users. Both the energy and spectral efficiency of the system under the proposed scheduling mechanism were analysed. Gong *et al* [37] studied the joint optimization problem of BS sleeping and resource allocation in a long-term point of view with the average network traffic profile and the harvested energy profile. The proposed two-state dynamic programming algorithm was shown to achieve optimal performance in symmetric traffic distribution scenario. Gio and O'Farrell [38] proposed a novel cell expansion technique, where the coverage area of cells can expand and contract base on the traffic load. This was accomplished by switching off low load site and compensating for coverage loss by expanding the neighbouring cells though antenna beam tilting.

Soh *et al* [39] investigated the design of energy efficient cellular networks through the employment of BS sleep mode strategies. Using a stochastic geometry based model, they derived the coverage probability and energy efficiency under sleeping strategies and formulated optimization problems in the form of power consumption minimization and energy efficiency maximization. Samarakoon *et al* [40] provided a novel cluster-based approach for optimizing the energy efficiency of wireless small cell networks. A dynamic mechanism based on the spectral clustering technique was proposed to dynamically from cluster of small cell base station. Simulation results showed that the proposed approach yields significant performance gains in term of reduced energy expenditure up to 40% and reduced load up to 23% compared to conventional approaches.

2.3.1.2 Power Saving Protocols

In the current cellular network architecture based on WCDMA/HSPA, BSs and mobile terminals are required to continuously transmit pilot signals. Newer standards such as LTE, LTE-A and worldwide interoperability for microwave access (WiMAX) have evolved to cater ever growing high speed data traffic requirements. With such high data requirements, although BS and Mobile Units (MUs) employing newer hardware (for example: Multiple-Input and Multiple-Output (MIMO) antennas) increase spectral efficiency allowing to high speed data networks and they require energy conservation both in hardware circuits and protocols. A fairly intuitive way to save power is to switch off the transceivers whenever there is no need to transmit or receive data. In the future wireless standards, energy saving potential of base stations needs to be exploited by designing protocols to enable sleep modes in base stations.

The energy efficiency of cellular networks can be increased significantly by selectively switching off some of the base stations during periods of low traffic load. Han *et al* [41] proposed a scalable BS switching strategy and use cooperative communication and power control to extend network coverage to the service areas of the switch-off BSs. The outage probability and the achievable power savings of the proposed scheme are analyzed, both analytically and numerically, and a potential of up to 50% power saving is observed in numerical results. Hossain *et al* [42] investigated the improvement of cellular access network architecture inspired by the principle of ecological cooperation. Base stations are equipped with more intelligence enabling them to make decisions by cooperating with each other for reducing energy consumption and also for achieving a self-sustainable access network. Depending on the traffic situation, any BSs may switch to a low power sleep mode, whereas other BSs would take its traffic. Xiang *et al* [43] analysed the ratio between dynamic and fixed power consumption part can affect the power savings of practical energy-efficient planning and management of base stations in cellular networks. Therefore, the relationship between the optimum number of active and shunt down strategy need to be considered. Marsan *et al* [44] investigated of reducing the energy consumption of the access portion of cellular network by reducing the number of active cells during the periods in which they are under-utilized because traffic is low. When some cells are switched off, radio coverage and service provisioning take care of the cells that remain active.

Green communication over LTE networks were investigated by Yaacoub [45]. Reassignment of mobile users to different LTE BSs was performed in order to achieve energy saving by switching off lightly loaded BSs. Energy efficient small cells were deployed in order to offload the traffic from macro-cell BSs. Both the uplink and downlink directions were considered in the proposed approach in order to decide if certain BSs can be switched off or not. Energy efficiency and self-organizing network architectures are the main issues for future cellular wireless systems. Hossain *et al* [46] proposed an energy saving self-organizing access network architecture for LTE. Based on the network traffic, eNBs in E-UTRAN dynamically interact in mutual cooperation over the X2 interface for minimizing the active number of eNBs in the network and thus achieve energy savings. Abdallah *et al* [47] focused on sleep scheduling of BSs as a way to improve the energy efficiency of cellular networks. When coordinated among neighbouring base stations, the sleep scheduling can take advantage from the consequent reduction of inter-cell interference. Simulation results showed that only by coordinating the sleep schedules was is possible to significantly improve the throughput and energy efficiency.

Sleep modes are emerging as a promising technique for energy-efficient networking. Previous studies [48] [49] [50] [51] have investigated and evaluated sleep mode for wireless access networks. Rengarajan *et al* [52] characterized the maximum energy saving that can be achieved in a cellular wireless access network under a given performance constraint. By taking into account the QoS perceived by end users, their approach allowed the derivation of more realistic estimates utilizing sleep modes to save energy. Ghosh *et al* [53] focused on the performance evaluation cell sleep mode to save power. A special case of more indoor users during low load (night time) condition was also presented. It was been found that 16% to 22% of the total power can be saved over a day in the cellular network maintaining a certain user satisfaction level, if BSs either sleep mode along with either tilt or height and power optimization is allowed during low load hours. Nahas *et al* [54] interested in power efficient methods altering the transmitted power of BSs, especially sleep mode and cell zooming techniques. Nahas *et al* [54] introduced a new algorithm that should be implemented and applied on BSs to reduce their total power consumption. This algorithm considered several cases including cell zooming and combination of sleep mode and cell zooming depending on the cell loads and mobile distribution.

In alternative way, Cili *et al* [55] showed improving cell switch off schemes for further energy saving enhancements using the Coordinated Multipoint (CoMP) transmission scheme technique and proved the advantages in terms of both energy and capacity efficiency. Han and Ansari [56] discussed how to reduce the energy consumption of cellular networks via multi-cell cooperation. They focus on three multi-cell cooperation scenarios that enhance energy efficiency of cellular networks. The first one was traffic intensity aware multi-cell cooperation, in which multiple cells cooperatively estimate traffic demands and adapt the network layout base on the estimated traffic demands. Through network layout adaptation, the number of active BSs can be reduced, thus reducing the energy consumption of cellular networks. The second scenario is energy aware multi-cell cooperation, in which off grid BSs powered by green energy are enforced to serve a large area to reduce on-grid power consumption. The third one is energy efficient CoMP transmission, in which the overall energy consumption is reduced by improving the energy efficiency of BSs in serving cell edge users. Chiaraviglio *et al* [57] assessed the effectiveness of sleep mode techniques coupled with different network planning schemes. They considered three network planning strategies that minimize the number of transmitters, the power consumption or a combination of the above. The results showed that an energy saving between 8% and 44% can be achieved on a realistic scenario, depending on the adopted power profile or strategy.

Saker *et al* [49] developed a genetic framework for applying Sleep Mode (SM) to mobile networks. They considered a cell with a set of available resources and activated resources based on the cell load and specifically proposed two SM schemes: Firstly, a dynamic one where resources are activated based on the instantaneous number of users in the cell. Secondly, a semi-static one, in the sense that resources remain active for a relatively longer time interval, some tens of minutes, in order to minimize the number of activation/deactivation commands. Saker and Elayoubi [48] studied practical implementation issues for sleep mode in BSs. Based on the observation that base stations have a pre preponderant part in the overall energy consumption of the network, and focus on switching OFF resources of the cell whenever possible. They make two observations: the first was that activating a new resource (carrier) is not instantaneous, leading to call losses if a guard interval is not considered, and the second was that a ping-pong effect may appear at the frontier between two capacity regions and then define a guard interval to anticipate bursts of arrivals by switching on an additional resource and a hysteresis time before switching off to avoid ping-pong effects.

Falconetti *et al* [58] introduced two node sleep modes operating on a fast and intermediate time scale respectively, in order to exploit short and long idle periods of the nodes. Their results point out that heterogeneous deployment where additional low power nodes are introduced in an existing network can be energy efficient solution. By saving the users from a nearby pico node, energy is saved in the macro node. If micro DTX is used in all nodes (macro and pico) and if the pico nodes are put in a deep sleep mode when they are not carrying any user traffic, then a significant reduction of the network energy consumption can be achieved. Saker *et al* [50] proposed energy-aware system selection schemes that minimize energy consumption of cooperative 2G/3G networks. They assessed analytically the energy savings with and without sleep mode implemented in the base stations and found out that the low energy mode will provide large gains for periods of low to medium traffic. Then they recommended to implement sleep mode. In this mode, together with the energy aware system selection, they achieved large energy reductions.

Micallef *et al* [59] investigated the energy saving potential of exploiting cell size breathing by putting low loaded cells into sleep mode. The energy consumption and network performance of the resulting network are used to quantity the potential of the feature. An energy saving feature, which can be turned to prioritize between energy consumption and network performance was proposed and investigated. Since putting cells into sleep mode changes the configuration of the network, the effects of antenna tilting were also examined. Results showed that when enabling sleep mode on a cell level, over a period of 12 hours, a daily energy saving of 33% was possible. Ashraf *et al* [51] and Ashraf *et al* [60] introduced a class of energy-efficient sleep mode algorithms for small base stations. The proposed algorithms allow the hardware component in the base station to be astutely switched off in idle conditions, such that the energy consumption is moderated over the variations in traffic load. Three different strategies for algorithm control were discussed, relying on small cell driven, core network driven, and UE driven approaches. Based on a mix of voice and data traffic model, the algorithm was shown to offer approximately 10-60% energy savings in the network compared to no sleep modes in small cells.

Wang *et al* [61] described a time-domain approach for base station sleep modes, taking LTE system as a specific example. The idea of this design is to enable the base station to reduce Radio Frequency (RF) energy consumption in low traffic conditions, while still properly supporting active user connections. By switching off traffic during a certain time period and delivering all user information with fewer transmissions under the same rate targets, the energy consumption can be reduced since the control signalling during non-active time is gated off. Compared to non-sleep modes an energy reduction of up to 90% was obtained at low traffic loads.

2.3.2 Energy-Aware Cooperative BS Power Management

Traffic load in cellular networks have significant fluctuations in space and time due to a number of factors such as user mobility and behaviour. During the daytime, traffic load is generally higher in office areas compared to residential areas, while it is the other way around during at night. Therefore, there will always be some cells under low load, while some others may be under heavy traffic load. Hence, a static cell size deployment is not optimal with fluctuating traffic conditions. For the next generation cellular networks based on microcells, Picocells and femtocells, such fluctuation can be very serious. Limited cell size adjustment maybe made using "cell-breathing" (a cell under heavy load or interference reduces its size through power control and the mobile user is handed off to the neighbouring cells). Cell zooming is a technique through which base stations can adjust the cell size according to network or traffic situation in order to balance the traffic load while reducing the energy consumption.

Zhaohui *et al* [62] studied the capacity improvement for CDMA cellular communications systems with BS antenna arrays for both uplink and downlink. Simulation results showed that there can be a substantial increase in system capacity by incorporating antenna arrays at the BS. Pi [63] derived the necessary and sufficient condition for optimal single-stream and multi-stream transmitter beamforming with per-antenna power constraints and developed iterative algorithms to achieve the optimal single-stream and multi-stream beamforming solutions with per-antenna power constraints. Farrokhi [64] introduced the consideration of joint optimal beamforming and power control. The work provided an iterative algorithm amenable to distributed implementation which converges to the optimal beamforming and power allocations if there exists at least one solution to the joint problem. A new directional power-base admission control scheme for cell deploying beamforming antenna arrays has been proposed by Pedersen [65]. The proposed admission control algorithm was derived for the case where simple beamforming techniques are applied at the BS. The actual capacity gain from deploying antenna arrays was controlled by the new admission control algorithm in accordance with the expected spatial filtering gain by monitoring the spatial interference distribution in the cell. Thus, a higher cell throughput is typically allowed when the spatial interference is white.

Tosa [66] considered the requests of 4G technology to establish suitable links BSs and their users characterized by a very high mobility. Adaptive algorithms were more appropriate because of their real-time flexibility. Quyen and Vu [67] proposed a multibeam antenna combining OFDM for the next generation mobile communications. Analysis and simulation showed that this kind of antenna is comparable to MIMO scheme and can be applied to 4G.

Fixed beam smart antennas are simple but effective methods to boost the downlink capacity of UMTS FDD. Baumgarther and Bonek [68] compared two possible strategies. For the first method, they found the optimum number of beams to be four for low DoD spreads and two or three for large DoD spreads. For the second method, the optimum number of beams per sector was seven for small DoD spreads and down to four or five beams per sector for large DoD spreads depending on BS spacing. The results shown using for 1km inter BS distance, a capacity gain of more 160% over a conventional 3-sectored reference system by both fixed beam methods was obtained. Kitahara *et al* [69] proposed the BS adaptive antenna for high-bit rate downlink transmission in the DS-CDMA system. By supporting the signals in the target region from the error signal, the proposed adaptive antenna reveals the very low side lobe feature, and suppresses the interference strongly outside the target region.

2.3.2.1 Implementation

The framework for cell zooming can include a cell-zooming server to make decisions for cell zooming. If there is a need for a cell to zoom in or out, it will coordinate with its neighbouring cells by assistance of a cell-zooming server. Cells can zoom in or out by a variety of techniques including cell zooming [70]. Cell zooming can not only solve the problem of traffic imbalance, but also reduce the energy consumption in cellular networks. Weng *et al* [71] considered energy saving in cellular network planning stage. An evaluation method was proposed to determine whether or not to adjust deployment obtained from traditional planning in order to switch off more cells, which normally requires remaining active cells to extend their coverage to certain extent. This requirement could be achieved with cell zooming by increasing transmitter power. Even if cell zooming is insufficient, it is still possible to deploy smaller but more cells to increase energy efficiency if cell zooming ratio is reaching sufficient and low traffic time ratio is larger than certain threshold.

Two key metrics have been identified [72] that quantify energy consumption performance. Firstly, the Energy Consumption Ratio (ECR) and secondly, the Energy Consumption Gain (ECG). The energy consumption gain applies to the Radio Access Network (RAN) and measures the relative radio access network energy consumption between two deployments for the same user density and service area. Babic *et al* [72] evaluated two deployment architectures: Architecture 1 a reduced cell size architectures only and architecture 2 a reduced cell size with sleep mode architectures. In architecture 1 reducing the cell size was found to reduce the energy consumption ratio while the energy consumption gain remained constant at unity. In architecture 2 reducing the cell size and power off unused cells was found to reduce the energy consumption ratio and increase the energy consumption gain. Lee *et al* [73] analysed the satisfaction of QoS and power consumption constraints in a relay selective cooperative multicast scheme with cell zooming under a varying number of multicast group users and cell coverage of the base station. If the system configurations are given, they can find the optimal point of power consumption and predict system performance. This will help made decisions on whether the system should operate cooperative communication base on consideration of users of the multicast group and the assigned base station coverage.

The analysis of Erlange-like capacity of the network from Saker *et al* [74] composed of macro networks and study the impact of introducing a number of picocells per site. The impact of picrocells on the performance of LTE-A networks. The results of picocells represent a good network densification option in term of achieving a higher throughput at reasonable energy cost and provided that energy consumption of picocells is not too high. Saker *et al* [75] analysed the impact of small cell deployment on the capacity and power consumption of otherwise pure macro cells. Firstly, developed capacity models for macro cells, femto cells and pico cells heterogeneous network setting. Secondly, used the achievable rate to develop an Erlang-type flow level model. The results quantified the gains perceived by the user as well as the cell load decrease as femto cells are deployed within the macro network.

One concept that has been discussed by Christoffersson [76], was to turn off one MIMO antenna when allowed by the traffic situation. In case there are no MIMO users in a cell, one of the MIMO antennas and corresponding power amplifier in this cell is turned off. Furthermore, if the user distribution is such that the traffic can be handled by an Omni configuration the site is reconfigured to Omni site. If reconfiguring to Omni cell as well as turning off one MIMO antenna when permitted, the saving can be up to 40 to 50% with the same fraction of MIMO users in a low load situation. Two problems of how to appropriately sectorize the cell such that minimize the total receive power and total transmit power of all users were investigated by Saraydar and Yener [77] while giving each user acceptable quality of service in both cases. For the received power optimization problem, Elmurtada *et al* [78] showed that the optimum arrangement equalizes the number of user in each sector. The transmit power optimisation is formulated as a graph partitioning problem that is polynomial solvable. Then, provided an algorithm that found the best sectorization assignment as well as the optimum transmit powers for all users. Given the number of sectors and terminal locations and study the best way of sectorizing the cell such that all subscribers in the cell meet their quality of service requirements while using as little power as possible.

Gkonis *et al* [79] investigated an adaptive admission control strategy for wideband code division multiple access (WCDMA) cellular networks which employ antenna arrays at the BS. The antenna arrays are either used to form a fixed grid of beams or to steer beams in the directions of group of users. The adaptive admission control strategy maximizes the cell throughput in a multirate environment by grouping as many users as possible under a common berm formed by the antenna arrays. Elmurtada *et al* [78] presented a tool for the modelling, analysis and simulation of smart antenna system direction of arrival estimation and adaptive beam forming needed in the design of smart antenna arrays for wireless mobile communications. The performance of smart antenna system had been studied for some linear and planar array antenna with different numbers of elements.

Zhang *et al* [80] studied the optimization problem of adaptive cell sectoring to minimize the total transmission power in CDMA systems, which resulted in the maximized system capacity. The complexity of existing optimal solutions depends on the number of users in the cell, and hence suffers high computation time for high-density cells. Mahmoudi *et al* [81] proposed a Butler matrix fed circle array for modifying the already deployed fixed sector CDMA systems to an adaptive sectorized one. Using a simple algorithm for adaptation, it was shown that the proposed system was capable of overcoming non-uniform user distributions and effectively obtain higher capacity compared to current cellular systems. Giuliano *et al* [82] suggested a technique to improve system capacity base on adaptive sectorization. Sectors are rotated and resized adaptively in order to equalize the uplink C/I or the total downlink transmitted power in each sector. The performance of the proposed procedure is analysed for both uplink and downlink transmissions.

Nguyen *et al* [83] discussed the problem of handling non-uniform traffic in CDMA cellular systems. They studied the capacity of the system based on the estimation of SIR in the uplink. The investigation shown that the overall capacity of the system was influenced by the presence of areas of congested traffic and the capacity of sector with congested traffic can be increased with adaptive sectorisation. Qi *et a*l [84] proposed a novel energy-aware adaptive sectorisation strategy, where the BS is able to adapt itself to temporal traffic variation by switching off some sector and changing the beam-width of the remaining sectors. No dynamic BS transmission power was required.

Kelif and Coupechoux [85] established a closed form formula of the other-cell interference factor for omni-directional and sectored cellular networks, as a function of the mobile location. It allowed a spatial integration leading to closed-form formula for the global outage probability on the downlink. Samdanis *et al* [86] presented methods to perform dynamic energy aware network re-configuration in order to conserve maximum energy base on load balancing. A simulation-based study evaluated the performance of the proposed schemes considering the network service quality and energy cost. Lee *et al* [87] proposed an efficient sector power control base on distance between base station and mobile node. Also they proposed a sleep mode energy control mechanism. In sleep mode energy saving protocol, each sector monitors the number of user in sector cell. If number of mobile node falls down a given threshold in sector cell, base station shuts down power.

Hossain *et al* [88] provided a traffic-sensitive energy efficient direct sequence technique for orthogonal frequency division multiple access based multi-cells cellular networks. Results identified the potential of the scheme in substantially reducing the energy consumption. User data rates and distributions, sector switching patterns and original network configurations have shown to have a large impact on savings. An energy saving cell sectorization technique of distributed self-organizing nature for long term evolution eNBs has been proposed by Hossain *et al* [89]. Using the proposed traffic aware algorithm, each eNB, in self-organizing fashion, reconfigures itself with time-varying traffic employing minimum number of sectors resulting in reduced energy consumption.

Li *et al* [90] focused on reducing the energy consumption of super density networks by adjusting the BSs working mode (active or sleep) and proposed a dynamic base station sleeping scheme to dynamically turn some Bss into sleep mode. With their two-stage strategy, network energy consumption is greatly reduced. The number of active mode matches the variation of the traffic in time and space domain while guaranteeing a tolerable blocking probability. Athley *et al* [91], presented the performance potential of higher-order horizontal (six sectors) and vertical sectorization for LTE downlink in urban and rural macro cells under the assumption of interference-limited coditions. The results for these scenarios showed that higher-order horizontal and vertical sectorization gave similar performance for small urban macro cells, but that high-order horizontal sectorization outperforms vertical sectorization for large cells. Hevizi and Godor [92] focused on one particular technique, which switches the originally 3-sector sites into omnidirectional, 1-sector sites by connecting the antennas of 3 sectors to common radio unit via a 3-way power splitter. The experiment showed that a reasonable compromise can be worked out between the contradicting objectives, namely, saving energy during night-time operation while maintaining a guaranteed service quality.

2.4 Green Communication form the Mobile User Equipment

Studies indicate that the power drain for User Equipment (UE) per subscriber is much lower than that for the BS [93]. However, the effect of UE energy consumption cannot be ignored neither form the individual user's point of view nor from the environmental perspective. Moreover, despite the efforts in recent years, the reduction of carbon footprint from the UE usage perspective has not been adequately explored. Most of the existing work is targeted to reducing the power consumption by incorporating smart mobile applications or invoking standby mode in UEs. There are a few approaches attempting to optimize the energy efficiency of UEs from Medium Access Control (MAC) protocol aspects of the IEEE 802.11 WLAN [94], [95]. Another recent investigation on combined performance of both power saving and QoS features in IEEE 802.11e based WLANs can be found in the literature [96]. In another attempt [97], the authors analysed the impact of network discovery on the UE's power consumption through network scanning and broadcasting approaches and reported about 8-35% of energy saving for the involved UEs.

2.4.1 Uplink Power Control in LTE

In LTE uplink, power control is an important function in cellular networks. The standardization of Release 8 of LTE E-UTRA has been completed with the aim of achieve a 2 to 4 times higher spectral efficiency gain over HSPA UTRA [98]. The main features include reduced latency in user data transmission, the possibility of having scalable bandwidth up to 20 MHZ and support for packet-switched domain only. 3GPP has already specified and OLPC and Fractional Power Control (FPC) that allows for full or partial compensation of path loss and shadowing and CLPC [99]. In LTE, the standardized uplink power control formula contains an OLPC and CLPC. In OLPC the transmitting power is set by the UE using parameters and measurements obtained from signals sent by the BS. In this case no feedback is sent to the UE regarding the power to be used for transmission. CLPC is considered to improve the performance of FPC by compensating for fast variations in the channel. In CLPC, the BS sends feedback to the UE, which is then used the correct the transmit power.

There are many papers that have studied uplink power control. For example Tejaswi and Suresh [100] focused on the power control for E-UTRAN LTE cellular system. The power control is specified to function both with OLPC and CLPC. Simulation results indicated that the fractional compensation can improve the cell-edge bitrate with up to 20% for a given average bitrate, improving the average bitrate and capacity up to 20%. According to a novel scheme for LTE uplink CLPC has been proposed to adjust the transmission power of UE so as to adapt to the variation in the allocated bandwidth [101]. It is possible to achieve coverage gains up to 60% while maintaining a cell throughput comparable to the reference case. Uplink FPC in UTRAN LTE has been proposed and evaluates in detail the impact of an FPC scheme on the SINR and interference distributions in order to provide a sub-optimal configuration turned for both interference and noise limited scenarios. In an interference limited scenario, the best choice when the aim is to prioritize the capacity is to operate at around 14 dB with $\alpha = 0.6$, (α is the path loss compensation factor. It is a three-bit cell specific parameter in range [0-1] signaled by the

Radio Resource Control (RRC)) getting cell gain of about 15% with a negligible outage loss [102]. Essassi *et al* [103] showed the power control mechanism for uplink of LTE system. This mechanism is based on fractional compensation of the path loss. This approach decreased inter-cell interference. By using FPC, inter-cell interference decreases by 20 dB $(\alpha = 0.8)$.

The gap between mobile phone complexity and battery capacity is increasing year by year leading to limited and continually decreasing battery lifetime. Lauridsen *et al* [104] proposed reducing LTE uplink transmission energy by allocating Physical Resource Block (PRB). The simulation results, based on a mapping from transmission power to energy consumption show that it is more energy efficient to allocate as many PRBs as possible to a single user instead of assigning several users less PRBs. On average at least 24% energy can be saved if a user is allocated an entire 10 MHz channel (48 PRBs) instead of 8 PRBs.

Uplink power control in UTRAN LTE consists of an open loop scheme handled by the UE and closed loop power corrections determined and signal by the BS. There are many papers that study the difference in performance between pure open loop and combine open and close loop power control. For example Muller *et al* [105] focused on open loop and closed loop power control in UTRAN LTE uplink by UE trace analysis. This study demonstrated the effect of distance path loss of a test user on several physical layer performance metrics including throughput, resource allocation as well as modulation and coding scheme utilization. Simulation results showed high throughput for open loop FPC for the user located in the vicinity of the serving eNodeB, however, steep performance degradation was observed when the UE was moving toward the cell edge. The user throughput at the cell border can be increased by closed loop power control. Purnachand *et al* [106] studied the performance of open loop and close loop power control schemes for LTE uplink. Power control is needed to reduce inter-cell interference level at the same time achieve a required SINR level. Simulation results indicated that FPC scheme shows 20% increase in mean cell throughput. Also, it is found that the system performance is optimized with lower transmitting power distribution in FPC compared to conventional methods.

Uplink power control is a key radio resource management feature in the 3GPP LTE. In order to adapt to a change in the inter-cell interference, or to correct for power amplifier errors, closed loop adjustments should be applied. Muhammad and Muhammad [107] focused on the performance of closed loop power control combined with fractional path loss compensation factor and an optimal value for the path loss compensation factor. The closed loop power control with loss compensation factor was found to improve the system performance in terms of mean bit rate by 68% and utilized the battery power more effectively. Coupechoux and kelif [108] focused on the former and studied the compensation factor of the related FPC scheme to propose a first analysis approach in order to derive approximate equations for SINR at a given distance of eNodeB, the average SINR and average cell spectrum efficiency. They showed in particular that the optimum compensation factor slightly depends on the half distance between eNodeB but it is highly dependent on the path loss coefficient. Similar to work done by Bautista *et al* [109], they proposed a UE based adaptive OLPC approach where a UE selectively, and autonomously, applies predetermined offsets to the standard OLPC as relative location. The simulation results showed that the UE base adaptive OLPC approach significantly increases the center cell UE's throughput at the expense of a slight and controllable, throughput degradation of the UEs at the cell edge. Ding *et al* [110] proposed a novel OLPC scheme for LTE uplink and considered power control and resource allocation according to users channel condition. This method makes efficient use of limited radio resource and reduce interference in the system. Simulation results showed that the proposed method provides at least 18% spectral efficiency gain compare to the conventional method. While setting LTE open loop transmit power control parameter (α) and P_o (P_o is a cell/UE specific parameter signaled by radio resource) an important metric to be considered is the dynamic receive power range at receiving base station. Berger *et al* [111] derived a closed-form expression for base stations dynamic receive power range and justify an upper limit for the same and showed that the dynamic receive power limitation along with an uplink coverage limitation lead to a confined set of suitable parameters (α, P_0) called the operation range.

In order to reduce energy consumption, and thus realise the goal of green communication, Mesodiakaki *et al* [112] designed user association in cognitive heterogeneous networks. They evaluated the existing approaches, in terms of energy efficiency, and showed the potential of exploiting the available context aware algorithms for energy reduction. Naeem *et al* [113] investigated the interference aware joint secondary user problem and proposed two iterative low-complexity user selection schemes in order to maximise the sum rate capacity of a cognitive MIMO uplink communication system. The work had an interesting constraint that the interference to the primary user needs to be below a threshold level. Chen and Wei [114] studied a distributed power control scheme for uplink Virtual MIMO (V-MIMO) for cellular systems. From this work, the total transmit power for each UE was optimised to achieve a maximum of 23dBm.

2.5 Propagation Models

The Okumura-Hata model is the most widely used empirical propagation prediction model. There are many papers that have studied Okumura-Hata propagation models. For example, the objective in Cota *et al* [115] is evaluated the suitability of the Okumura-Hata propagation model for radio coverage prediction in GSM-R railway communications and to characterize the large-scale propagation in this type of environments. The Okumura-Hata model was tuned based on railway radio network measurements and the model was enhanced with water correction and diffraction additional loss. The algorithm used on model tuning was fast and precise, improving the original model accuracy. This was validated by radio measurements carried out in several railways. Beire *et al* [116] proposed the use of a Genetic Algorithm (GA) for automatic optimization of the Okumura-Hata model on railways communications in order to increase prediction accuracy. The algorithm tuning and validation were based on real networks measurements carried out on four different propagation scenarios and several performance indicators were used. It was shown that the proposed GA is able to produce significant improvement over the original model.

Network designers rely heavily on path loss models to predict outdoor radio coverage areas within a certain error using conventional propagation models designed for systems prior to 4G. Alamoud and Schutz [117] provided radio frequency engineers and regulators with a reference that presented results of tuning the Okumura-Hata model to increase its accuracy to be used for Terrestrial Trunked Radio (TETRA) mobile radio applications in Saudi Arabia. It includes correction factors based on measurement campaigns conducted in small-medium cities. Farhoud *et al* [118] studied the performance of Okumura-Hata model and presented a correction of Okumura-Hata propagation prediction model to suit the propagation conditions in Egypt. It also proposed a better categorization for different regions in Egypt, which allowed obtaining better corrections for the original Okumura-Hata model. The results are verified as well by employing the new corrected models in different regions that follow the same topography and morphology. Elfadhil *et al* [119] examined the applicability of Okumura-Hata model in Oman in GSM frequency band. This work focused on predicting the mean signal strength in different areas and with the signal variability as the mobile moves. The effects of terrain situation predicted at 900 MHz were analyzed. Results of radio signals propagation measurements for an open area in Oman were compared to those predicted based on Okumura-Hata model. The improvement was achieved by using the Mean Squared Error (MSE) between measured and predicted path loss value in order to provide sufficient MSE for radio prediction. The Okumura-Hata model has been tuned based on the field measurements carried out in the rural Australia. The least square method was used to tune parameters of this model. A more accurate definition is proposed for the transmitter antenna height. Simulation results showed the ability of the modified tuned model in the reduction of prediction error [120]. Medeisis and Kajackas [121] presented an approach of how to the universal Okumura-Hata propagation prediction model may be adapted to specific environments. The Okumura-Hata model gave significant errors in rural areas. Akhoondzadeh and Noori [120] described an approach, which allowed to introduce necessary changes to the Okumura-Hata model through statistical analysis of measurement results with application of the least square method.

Bhupuok and Dejhan [122] proposed prediction propagation of path loss for 2100 MHz 3G, the mobile in suburban Thailand. The experiment measured the signal at different distances and different direction from mobile BS. The results from the experiment were compared with their theoretical value in order to make a new empirical model that was suitable for suburban Thailand. A statistical method, Root Mean Square Error (RMSE) and Okumura model were used. Vinaye and Ramraj [123] aimed to calculate the path loss for urban and rural areas of Mauritius and compare with different empirical models. The practical measurements that were collected over different distances from the BSs were used to estimate the path loss. The measured path loss obtained for suburban areas was compared with that for the rural areas and then with four propagation models, being, Clutter, Lee, Okumura-Hata and Extended COST-231. The results showed the Okumura-Hata gave better agreement for all rural, suburban and urban regions. Singh [124] compared of Okumura, Hata and COST-231 models on the basis of path loss and signal strength. The path loss of Okumura, Hata and COST-231 models showed a decreasing trend with respect to transmitter antenna height and receiver antenna height and increasing trend with respect to transmission distance. Among the communication models Okumura model shows the least path loss and COST-231 model shows the largest path loss. The signal strength trends are opposite to that path loss as signal strength with respect to transmitter antenna height and receiver antenna height showing an increasing trend and decreasing trend with respect to transmission distance. The signal strength of Okumura model is largest in all the three cases and COST-231 model shows the least signal strength. Among the three models Hata model shows intermediate results both in case of path loss and signal strength. Akhpashev and Andreev [125] developed hardware and software that allowed to calculate the correction factors for the empirical COST-231 Hata propagation model based on LTE measurements from mobile devices.

2.5.1 Free Space Propagation Model

The major assumption in free space propagation is that there is a clear in Line Of Slight (LOS) between transmitter and receiver, the wave is not reflected or absorbed. Ideal propagation implied equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation. The receive signal power P_r and d from the transmit antenna can be given as [126]:

$$P_r = P_T \frac{G_{Tx} G_{Rx}}{(4\pi d/\lambda)^2} \tag{2.1}$$

where

P_r = Receive power at distance d from the transmitter

P_T = Transmit power

G_{Tx} = Gain of transmitting antenna

G_{Rx} = Gain of receiving antenna

λ = Wave length

d = Distance between the transmitter and receiver

The propagation loss is usually express in decibels (dB) and it is given by

$$L[dB] = 10 log \frac{P_T}{P_r} \tag{2.2}$$

Therefore,

$$L[dB] = 10\log\left[\frac{(4\pi d/\lambda)^2}{G_{Tx}G_{Rx}}\right] \quad (2.3)$$

Since

$$\lambda = \frac{c}{f} \quad (2.4)$$

where

c = Light velocity in space $(3 * 10^8\ m/sec)$

f = Operating frequency

Substituting (2.4) in (2.3)

$$L[dB] = 10log\left[\frac{\left(\frac{4\pi f d}{c}\right)^2}{G_{Tx}G_{Rx}}\right] \quad (2.5)$$

$$L[dB] = -g_{Tx} - g_{Rx} + 20\log(f) + 20\log(d) + 20\log(4\pi/c)$$

Free space path loss, which represents the attenuation of signal power, is defined as the difference (in dB) between the effective transmitted power and received power. When antenna gain are excluded, then the free space path loss (PL_{FS}) can be given as

$$PL_{FS}[dB] = 32.44 + 20\log(f) + 20\log(d) \quad (2.6)$$

Where the frequency f is in units of MHz and distance d in units of Km. If d is expressed in miles, then equation (2.6) can be written as:

$$PL_{FS}[dB] = 36.5 + 20\log(f) + 20\log(d) \tag{2.7}$$

Equation (2.6) and (2.7) are called Friis equations [127]. It is noteworthy to observe that the free space path loss increase 20 dB/decaded of either frequency or distance. In other words, free space path loss increasing by 6 dB for each doubling in either frequency or distance.

2.5.2 Okumura Propagation Model

This is the most popular propagation model that is applied to the signal prediction. The Okumura model for urban areas is radio propagation model that was built using data collected in the city of Tokyo, Japan [128]. The model is ideal for using in cities with many urban structures but not many tall blocking structures. The model served as a base for the Hata model. Okumura model was built into three modes. The ones for urban, suburban and open areas. The model for urban areas was built first and used as the base for others. This model is applicable for frequencies in the range 150–1920 MHz (although it is typically extrapolated up to 3000 MHz) and distances of 1–100 km. It can be used for BS antenna heights ranging from 30–1000 m. Okumura developed a set of curves giving the median attenuation relative to free space (A_{mu}) in an urban area over a quasi-smooth terrain with a base station effective antenna height (h_{te}) of 200 m and a mobile antenna height (h_{re}) of 3 m. These curves were developed from extensive measurements using vertical omni-directional antennas at both the base and mobile, and are plotted as a function of frequency in the range 100–1920 MHz and as a function of distance from the base station in the range 1–100 km. To determine path loss using Okumura's model, the free space path loss between the points of interest is first determined, and then the value of $A_{mu}(f,d)$ (as read from the curves) is added to it along with correction factors to account for the type of terrain.

The formula for Okumura model is express as:

$$P_{L\,(dB)} = L_f(d) + A_{mu}(f,d) - G_{(h_{te})} - G_{(h_{re})} - G_{AREA} \qquad (2.8)$$

Where:

$P_{L(dB)}$ = median path loss (dB)

$L_f(d)$ = free space propagation path loss (dB)

$A_{mu}(f,d)$ = Free space path loss (dB)

$G_{(h_{te})}$ = base station antenna height gain factor

$G_{(h_{re})}$ = mobile antenna height gain factor

G_{AREA} = gain corresponding to specific environment and parameters given in urban, suburban or open areas.

f = Frequency (MHz)

h_{te} = Transmitter antenna height (m)

h_{re} = Receiver antenna height (m)

d = distance between transmitter and receiver antenna (km)

$$G_{(h_{te})} = \begin{cases} 20log_{10}\left(\frac{h_{re}}{200}\right) & if\ 100 > h_{re} > 10 \\ 10log_{10}(\frac{h_{re}}{3}) & if\ h_{re} \leq 3 \\ 20log_{10}\left(\frac{h_{re}}{3}\right) & if\ 10 > h_{re} > 3 \end{cases} \qquad (2.9)$$

With the following conditions:

Carrier frequency: 150-1920 MHz

Effective BS antenna height 30-1000m

Effective MS antenna height 1-3m

Distance between base station and mobile station: 1-100 km

Okumura's model is considered in terms of accuracy for path loss prediction of mobile cellular and land mobile radio systems in cluttered environments. Attenuation and gain terms are given in equation (2.9).

2.5.3 Hata Propagation Model

The Hata Model is a radio propagation model for predicting the path loss of cellular transmissions in exterior environments, valid for microwave frequencies from 150 to 1500 MHz. It is an empirical formulation based on the data from the Okumura Model, and is thus also commonly referred to as the Okumura-Hata Model. The model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. Additionally, the Hata Model applies corrections for applications in suburban and rural environments with the following conditions:

Carrier frequency: 150-1500 MHz

Effective BS antenna height 30-200m

Effective MS antenna height 1-10m

Distance between base station and mobile station: 1-20 km

2.5.4 Okumura-Hata Propagation Models

An empirical formula for propagation path loss model is derived from Okumura's report in order to put his propagation prediction method to computational use. Okumura's report [128] is very practical because it carefully arranges field strength and service area. Not only is the report used as comparison data with authors' reports, but also the propagation prediction methods in the report have become standard for planning in today's land mobile system in Japan [129], [130].

The Okumura-Hata model was proposed to be used in the frequency range of 500 MHz to 2 GHz, although most relevant research studies use this path loss model up to 3 GHz. The model is typically used to estimate channel path loss because of its simplicity and availability of correction factors. It is commonly restricted to macro cells. The Okumura-Hata path loss model is created from a number of representative path loss models for the small and medium, urban, suburban and rural areas environments, expressed as [131]

$$P_L = A + B * log(d) + C \tag{2.10}$$

where A, B, and C are factors that depend on frequency and antenna height:

$$A = 69.55 + 26.16log(f_c) - 13.82log(h_{bs}) - ah_m \tag{2.11}$$

$$B = 44.9 - 6.55log(h_{bs}) \tag{2.12}$$

with:

d is the distance between the user and base station (km),

h_{bs} is the height of the base station (m),

while the function ah_m and factor C depend on the environment.

Small and medium size cities:

For a built up small city or a medium town with small buildings and houses, ah_m and C are defined as:

$$ah_m = (1.1log(f_c) - 0.7)h_{ue} - (1.56log(f_c) - 0.8) \quad (2.13)$$

$$C = 0 \quad (2.14)$$

where:

f_c is carrier frequency (MHz),

h_{ue} is height of UE.

Urban areas:

This category is for a built up city or a large town with large buildings and houses with two or more stories, or a large village with close, tall, thickly grown trees. In this case, ah_m and C are defined as:

$$ah_m = 3.2 * \left(log_{10}(11.75 * h_{ue})\right)^2 - 4.97 \quad (2.15)$$

$$C = 0 \quad (2.16)$$

Suburban areas:

This category is for a village or highway scattered with tree and houses with a few obstacles near the UE. In this case, ah_m is defined as equation (2.15) and C is defined as:

$$C = -2\left(log\left(\frac{f_c}{28}\right)\right)^2 - 5.4 \quad (2.17)$$

Rural areas:

This category is for rural areas with no tall trees or buildings in the propagation path, or a plot of land cleared for 200-400m, e.g. farmland, rice fields and open fields. In this case, ah_m is defined as equation (2.15) and C is defined as:

$$C = -4.78\left(log(f_c)\right)^2 + 18.33log(f_c) - 40.98 \quad (2.18)$$

2.5.5 COST-231 Hata Propagation Model

COST (COoperation europee dans le domaine de la research Scientifique et Technique) is a European Union Forum for cooperative scientific research which has developed a model accordingly to various experiments and research [132]. The COST-231 Hata model is also known as COST Hata model. The COST-231 Hata model is a path loss model for the case of small distances between mobile stations and base station or small height of mobile station, with the following conditions: [133].

Carrier frequency: 800-2000 MHz

Height of the BS antenna 4-50m

Height of the MS antenna 1-3m

Distance between base station and mobile station: 0.02-5km

The path loss according to COST-231 Hata is expressed as:

$$L_p(dB) = A + Blog_{10}(d) + C \tag{2.19}$$

Where:

$A = 46.3 + 33.9log_{10}(f_c) - 13.82log_{10}(h_{bs}) - ah_m$

$B = 44.9 - 6.55log_{10}(h_{bs})$

$C = 0$ for medium city and suburban areas

$C = 3$ for metropolitan areas

The function ah_m for urban area is defined as:

$$ah_m = 3.2(\log(11.75h_{ue}))^2 - 4.97 \quad (2.20)$$

and for rural and suburban areas it is as follows:

$$ah_m = (1.1\log(f_c) - 0.7) - (1.56log(f_c) - 0.8) \quad (2.21)$$

This chapter has focused on how to go green in a cellular network. There are many green cellular networks techniques to reduce energy consumption. For example, network planning, measuring greenness, architecture, broader perspective and system design. This thesis focuses on green communication from the mobile user equipment by using uplink power control in LTE. There are many propagation path loss models. For example, free space propagation model, Okumura propagation model, Hata propagation model, Okumura-Hata propagation model and COST-231 Hata propagation model. This work uses the Okumura-Hata propagation model because this model is the most popular of signal prediction propagation models. The Okumura-Hata propagation path loss model was created from a number of representative path loss for the small and medium, urban, suburban and rural areas environments. This model is very practical because it carefully arrange field strength and service areas. Therefore, the Okumura-Hata model is only one model use for prediction propagation path loss model in all three environments.

CHAPTER 3 ENERGY SAVING IN LTE USER EQUIPMENT

3.1 Introduction

This chapter focus on how to achieve green communication in cellular networks, energy saving for UEs is also considered. Energy reduction in wireless systems has become an important issue due to its impact on the operation cost and global carbon footprint. The rapid development of information and communication technologies has led to energy consumption growing at a staggering rate [134]-[136]. The exploding growth of energy consumption in wireless communications will be potentially harmful to the environment and increase operation costs. The gap between available and required energy in battery supplied in UE is increasing year by year [137]. The 3rd Generation Partnership Project Long Term Evolution (3GPP LTE) standard therefore includes energy saving methods like discontinuous reception. Unfortunately the available methods cannot fill the gap and therefore new methods are investigated to further reduce energy consumption.

3.2 UE Model Design

The UE's power consuming physical layer components are examined one by one. The purpose is to determine how the components affect the total power consumption. Figure 3.1 illustrates the LTE physical layer components and the UE model parameters. The envisioned UE model shall depend on received (Rx) and transmit (Tx) power levels, uplink (UL) and downlink (DL) data rate and RRC mode. In the following sections the parts in figure 3.1 are showed to determine if and how they depend on the aforementioned parameters.

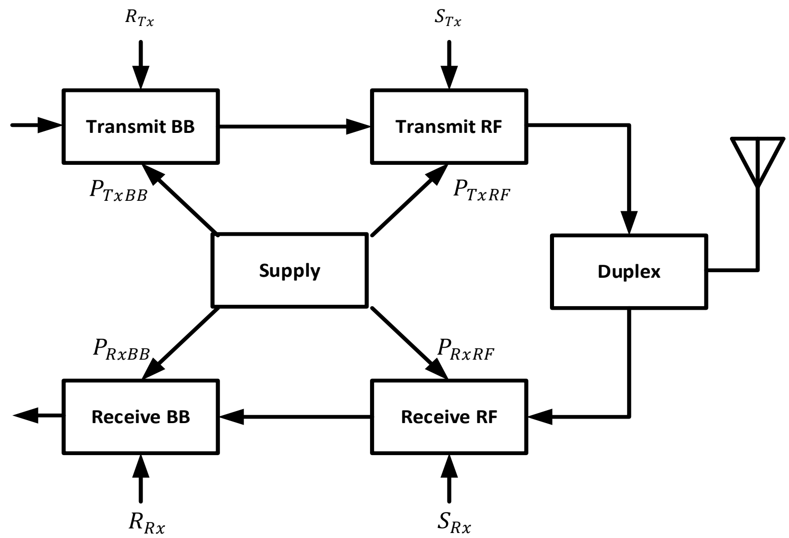


Figure 3.1 LTE UE physical layer

Transmit Baseband: In the LTE Tx baseband (BB) the main task is to turbo encode user data with Forward Error Correction codes (FEC). Turbo coding relies on conventional encoding and generates a bitstream with code rate 1/3. The turbo coding complexity scales linearly with the amount of data to encode which is set by the Transport Block Size (TBS) i.e. the UL data rate, but is independent of the UL Tx power [138]

Transmission Radio Frequency: In general the Radio Frequency (RF) will not depend on the UL data rate, but when the modulation format is changed the Peak to Average Power Ratio (PAPR) is affected. This entails the Power Amplifier (PA) will adjust its performance to comply with the Tx emission requirements [139] such as the Adjacent Channel Leakage Ratio (ACLR) and this may affect the power consumption. The Tx RF will obviously on the UL Tx power. A single PA only has one output power level where it achieves its maximum energy efficiency and therefore researchers develop methods to increase the efficiency at other output levels. These include the use of multiple PAs [140] voltage supply and bias switching [141] and the envelope tacking concept [142]. The Power Added Efficiency (PEF) is expected to be stepwise increasing with output power as each of the methods are utilized.

Receive Radio Frequency: The RX RF power consumption is expected to be independent of DL data rate, but it will depend on the DL Rx power level. The reason is that the RF contains Gain Controls (GA) and Low Noise Amplifiers (LOA), which are used to obtain a certain signal level at the Analog to Digital Converter (ADC). If the DL Rx power level is high the gain in the aforementioned circuits can be reduced and they may be powered off to reduce the power consumption [143].

Receive Baseband: The majority of the BB processing tasks are complexing, e.g. channel estimation and equalization are independent of the DL data rate. To decode the received user data the UE applies turbo coding, which is an iterative algorithm and the most computational complex task in the digital BB. To support the high data rate of LTE a highly parallelized turbo decoder architecture is required [144]. The complexity and thus the power consumption scale linearly with DL data rate [145].

UE Power Consumption Model: Base on the review of the four physical layer parts, the model is defined as follows:

$$P_{tot} = m_{idle} \cdot P_{idle} + \overline{m_{idle}} \cdot \{P_{con} + m_{Tx} \cdot m_{Rx} \cdot P_{Rx+Tx} + m_{Rx} \cdot [P_{Rx} + P_{RxRF}(S_{Rx}) + P_{RxBB}(R_{Rx}) + m_{2CW} \cdot P_{2CW}] \; m_{Tx} \cdot [P_{Tx} + P_{TxRF}(S_{Tx}) + P_{TxBB}(R_{Tx})]\} \quad [\mathrm{W}] \qquad (3.1)$$

where P is the power consumption the scrip tot defines the total consumption, $idle$ and con the consumption in RRC idle and connected mode, $rxRF$ and $txRF$ is the consumption of the RF part in the Rx and Tx chains respectively, $rxBB$ and $txBB$ is the consumption of BB parts and $2CW$ is related to increased consumption when using two code words (CW) in DL. The parameters P_{Rx}, P_{Tx} and P_{Rx+Tx} are included to model the base power the Rx and Tx chains consume when active. The logical variable m is the mode, which can be the RRC idle, transmitting, receiving and indicate the use of $2CW$. The Rx and Tx power levels are designed by S and R is the Rx and Tx data rate.

3.3 Power versus Energy

A battery is usually stated to have a certain capacity in ampere-hours at a specific voltage supply. Therefore, it contains energy

$$U \cdot I \cdot t = P \cdot t = E \qquad [J] \tag{3.2}$$

Where:

U is the battery voltage supply [V]

I is the current drawn from the battery [A]

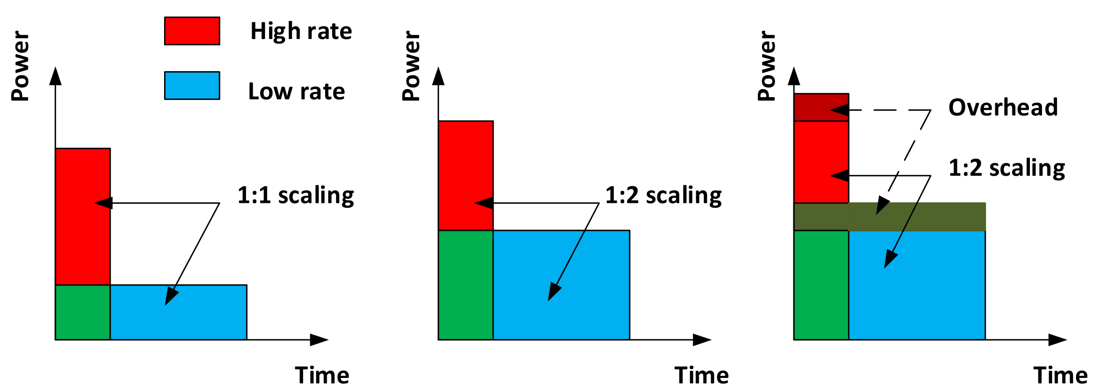
t is the time of use [s]

P is the instantaneous power drawn from the battery [W]

E is the energy drawn from the battery [J]

Given the battery's specifications, the first thing the designer will need to ensure is that the amount of current drawn by the UE does not exceed a certain limit defined by the battery's internal resistance. If the current is to high it may lead to battery voltage drop, which may cause the Power Management Unit (PMU) to power down the UE to protect it from unexpected behavior. The current draw is typically at its peak when many components are powered "ON" at once, and therefore the PMU can apply a power ON sequence [138]. Provided that this fundamental requirement is fulfilled designer can start optimizing the components to achieve longer battery life.

The power consumption is important to keep at a minimum, both to avoid the battery voltage drop and improve battery life. However it may sometimes be benefit to accept a high instantaneous power consumption if it entails the "ON" time of the UE is reduced. The increased "OFF" time may then be switched with a low power sleep mode. This will, for example, be the case if a single data transfer is scheduled. Figure 3.2a shows the case where the power consumption scale 1:1 with the data rate and the area of each block corresponds to the total energy consumption required to transfer the specific amount of data. In this case the total energy consumption and the number of bits transferred is the same whether the data rate is low and the transfer time is long or data rate is high and the transfer time is short.



(a) Data rate is scaling 1:1 with power consumption.

(b) Data rate is scaling 1:2 with power consumption.

(c) Power consumption including overhead.

Figure 3.2 Power consumption as a function of data rate scaling. Note the same of bits is transferred in each case.

However a more realistic case is illustrated in figure 3.2b, where the double data rate does not entail a doubling of the power consumption. The explanation is that there will be a certain base power consumption due to the data rate independent components being on, such as the Radio Frequency (RF) front end. Furthermore if the data transfer is related to the user browsing a web page there may be an additional overhead, which for example includes the display being “ON”. If the page is loaded faster the user will also turn “OFF” the display faster, as showed in figure 3.2c.

From the figure 3.2a, 3.2b and 3.2c it is important not only to optimize for low power consumption, but also low energy consumption, because the method to achieve the latter may be to go up the first. Otherwise the UE may have low power consumption but also low performance and therefore also short battery life due to increased “ON” time. For this chain of arguments to be avoid, the UE will obviously need to enter a very low power mode when it has finished the data transfer. One important metric, which relates the immediately power consumption to data transfer is the Energy Efficiency (EE), which is defined as:

$$EE = \frac{R}{P} = \frac{b}{P \cdot t} \qquad \left[\frac{bit}{J}\right] \tag{3.3}$$

Where:

EE is the energy efficiency	[J/bit]
R is the data rate	[bit/s]
P is the power consumption	[W]
t is the time to transfer	[s]
b is the number of bits transferred	[bit]

Comparing figure 3.2a and 3.2b it is clear that the EE is constant for 3.2c while it increases for data rate in 3.2b.

This chapter has focused on how to achieve green communication in cellular networks, with a focus on energy saving for UEs. The purpose is to determine how the components affect the total power consumption.

CHAPTER 4 MODEL ANALYSIS AND SIMULATION

4.1 Introduction

The gap between UE equipment and battery capacity is increasing year by year, leading to limited and continually decreasing battery lifetime. Power control is a crucial radio network function in wireless cellular networks. This chapter describes the LTE uplink power control for the Physical Uplink Shared Channel (PUSCH), discusses different applications of it and evaluates its performance for different parameter settings.

4.2 System model

Resource allocation in LTE uses PRBs. The PRB is the smallest unit of resource that can be allocated to a user. A PRB occupies 1 time slot of duration $T_S = 0.5$ ms [146]. PRBs occupy either 12 x 15 kHz subcarriers or 24 x 7.5 kHz subcarriers, with 12 being the most common leading to occupied bandwidth of 180 kHz. Each subcarrier has 7 Single Carrier-Frequency Division Multiple Access (SC-FDMA) symbols. In the case of 10 MHz bandwidth, 50 PRBs are provided as shown in Fig. 4.1. Depending on bandwidth needs, a UE may be allocated k PRBs. Two consecutive PRBs are assigned to the same user for a Transmission Time Interval (TTI=1ms). The LTE system requires that two co-cell users do not use the same PRB in the same TTI. In the same way co-cell users are orthogonal and therefore do not interfere with each other. Therefore, only inter-cell interference needs to be managed in the LTE system [147].

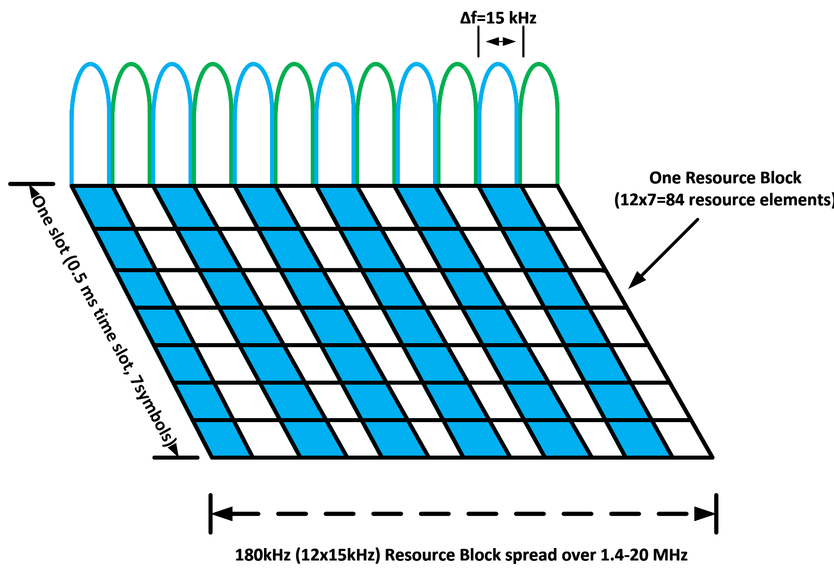


Figure 4.1 LTE uplink physical resource block

4.3 Functional power control in LTE

Power control refers to setting the UE transmitter output power to an acceptable level in order to maintain suitable reception signal power often in a fading channel. The power control objective is a multi-variable optimisation problem to configure the transmitter power level considering system capacity, coverage and quality of service, while transmitting the lowest acceptable power, thus reducing the UE power consumption. To obtain this goal, power control mechanisms typically aim at minimising the received power of desired signals, while limiting the generated interference.

4.3.1 LTE uplink power control

Uplink power control has been standardized in 3GPP for LTE networks to control the transmit power of each UE. It fractionally compensates for the path loss between the UE and its serving base station and is commonly known is the fractional path loss compensation power control scheme. Users in the LTE uplink are orthogonal, therefore at least in the ideal case, no interference is present between users in the same cell, and only interference between cells is present. The amount of interference generated to neighbour cells depends primarily on the UE position, or more specifically the path gain from UE to neighbour cells. A UE close to neighbour cells generates more interference than a UE far away. For a given interference level in neighbour cells, a UE far away from that cell may hence transmit with a higher power than UE near the cells.

The LTE uplink power control is based on both signal strength measurements done by the UE (open loop power control) as well as measurements by the eNodeB used to generate transmit power control commands that are subsequently fed back to the UE as part of downlink control signal (closed loop power control). The functional path loss compensation is done in the open loop power control.

The setting of the UE transmit power, P_{T_X}, for the uplink transmission in a subframe of the Physical Uplink Shared Channel is defined as [148]:

$$P_{T_X} = min\left(P_{max}, P_o + 10log_{10}(M) + \alpha * P_L + \delta_{mcs} + f(\Delta_i)\right) \quad \text{(dB)} \quad (4.1)$$

Where:

Open loop parameters:

P_{max} is the maximum allowed UE transmit power (class 3) of 23 dBm [148].

P_o is a cell/UE-specific parameter signalled by Radio Resource Control (RRC). However, we assume that P_o is cell specific. P_o is the eNodeB sensitivity.

M is the bandwidth of the UE uplink resource assignment, expressed in number of PRB for each TTI.

α is the path loss compensation factor. It is a three-bit cell specific parameter in the LTE standard, α belongs to the set {0, 0.4:0.1:1} signalled by the RRC.

P_L is the downlink path loss estimated and calculated in the UE which is used to compensate the received power at eNodeB in uplink power control.

Closed loop parameters:

δ_{mcs} is a cell/UE-specific Modulation and Coding Scheme (MCS) parameter defined in 3GPP specification for LTE and has been set to 0 in this work.

$f(\Delta_i)$ is a correction value provided by the Transmit Power Control (TPC) command. The TPC commands are sent from an eNodeB after the OLPC has set the initial transmit power using the desired α and P_o values to adjust the target SINR for different UEs. In CLPC, $f(\Delta_i)$ can be used to improve system performance controlled from eNodeB. Since in this paper discusses OLPC, $f(\Delta_i)$ is set to 0 in this work.

In this work, focus only on open loop power control, hence the expression of UE transmit power allocated by given user to a PRB simplifies to:

$$P_{T_X} = min(P_{max}, P_o + 10log_{10}(M) + \alpha * P_L) \qquad (4.2)$$

When α = 0 (i.e. no compensation of path loss), no power control is present and all users will use the maximum allowed transmit power. When α = 1 (full compensation of path loss), the UE power is set to $P_{T_X} = P_{max}$. With α = $(0 < \alpha < 1)$ (functional compensation of path loss) full functional power control is thus obtained. Therefore the control of α is of primary importance in this work.

This chapter has presented a model analysis to describe the LTE uplink power control for physical uplink shared channel. It has discussed different applications of power control and evaluated its performance for different parameter settings such as, height of base station (h_{bs}), path loss compensation factor (α) and eNodeB sensitivity (P_o).

CHAPTER 5 RESULTS

5.1 Introduction

In this chapter present simulation results for implementing the path loss using the Okumura-Hata models and then we present the required UE uplink transmit power under open loop power control is presented. The simulations were performed using MATLAB. To analyse the UE energy consumption's dependency on the path loss compensation factor (α) and eNodeB sensitivity (P_o) are applied. This approach consisted of 3 environments (urban, suburban and rural) and different of height of eNodeB (10m, 35m, 50m and 75m).

The simulation steps are as follows:

1. Implement the Okumura-Hata path loss model (equ. (2.10)) in the 3 cases of urban, suburban and rural areas.

2. Calculate the required P_{T_X} for a typical urban area by substituting equ. (2.15) into equ. (2.11) and then substituting equs. (2.11), (2.12) and (2.16) to equ. (2.10). Then substituting equ. (2.10) to equ. (4.2)

3. Calculate the required P_{T_X} for a typical suburban area by substituting equ. (2.15) into equ. (2.11) and then substituting equs. (2.11), (2.12) and (2.17) to equ. (2.10). Then substituting equ. (2.10) to equ. (4.2)

4. Calculate the required P_{T_X} for a typical rural area by substituting equ. (2.15) into equation (2.11) and then substituting equs. (2.11), (2.12) and (2.18) to equ. (2.10). Then substituting equ. (2.10) to equ. (4.2)

5. Vary path loss compensation factor, (α), height of base station,(h_{bs}), and base station sensitivity,(P_o).

Important simulation parameters are given in Table 5.1.

Table 5.1 System level simulation model parameters

Parameter	**Value**
Layout	Hexagonal 7 site 3 cells/site
System carrier frequency	2 GHz
System bandwidth	10 MHz
UE transmit power	-50 to +23 dBm [149]
PRBs available to users	48 (2 are used for control signal)
Base station sensitivity $(\boldsymbol{P_o})$	-60 dBm to -100dBm
User distribution	Uniform distribution
UE velocity	3 km/h
Thermal noise density	-174 dBm/Hz
Height of UE	1.5m

The Okumura-Hata propagation path loss is shown in Figure 5.1 as a function of distance from the eNodeB with different base station heights (10m, 35m, 50m and 75m) [150] for the urban, suburban and rural environments. From Figure 5.1, the antenna height is the basis of the base station coverage areas. The relationship between path loss and antenna height can be establish through the model proposed by Okumara-Hata propagation model, the impact of antenna height on coverage can clearly be seen. When the base station height is increased, the path loss is reduced and on decreasing base station height then the path loss increases. Because higher of eNodeB can cover the area of service more than lower eNodeB.

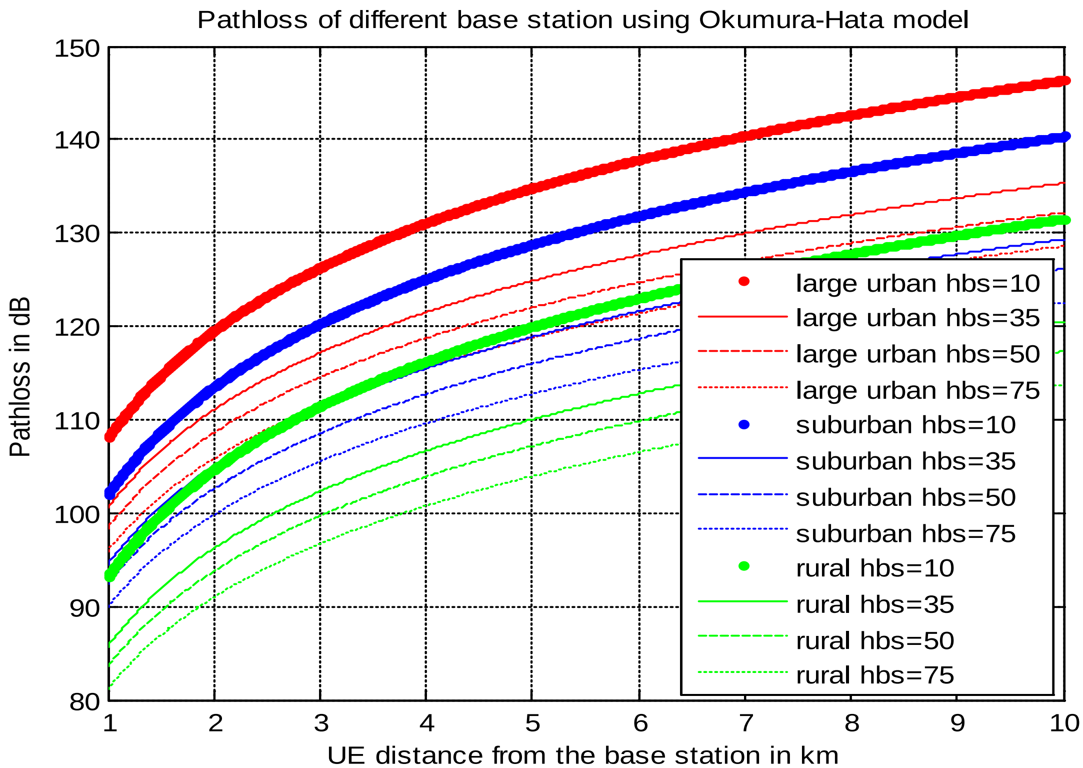


Figure 5.1 Okumura-Hata Propagation model path loss

Figure 5.2 shows the path loss Cumulative Distribution Function (CDF) plot as a function of UE transmit power. When the UE in the urban area required more transmit power then UE in the suburban and rural areas. Likewise, Figure 5.3 shows the required UE transmit power with different height of base station. The results show that the UE in the higher areas of base station can save power by requiring less transmit power than the UE in lower area of base station.

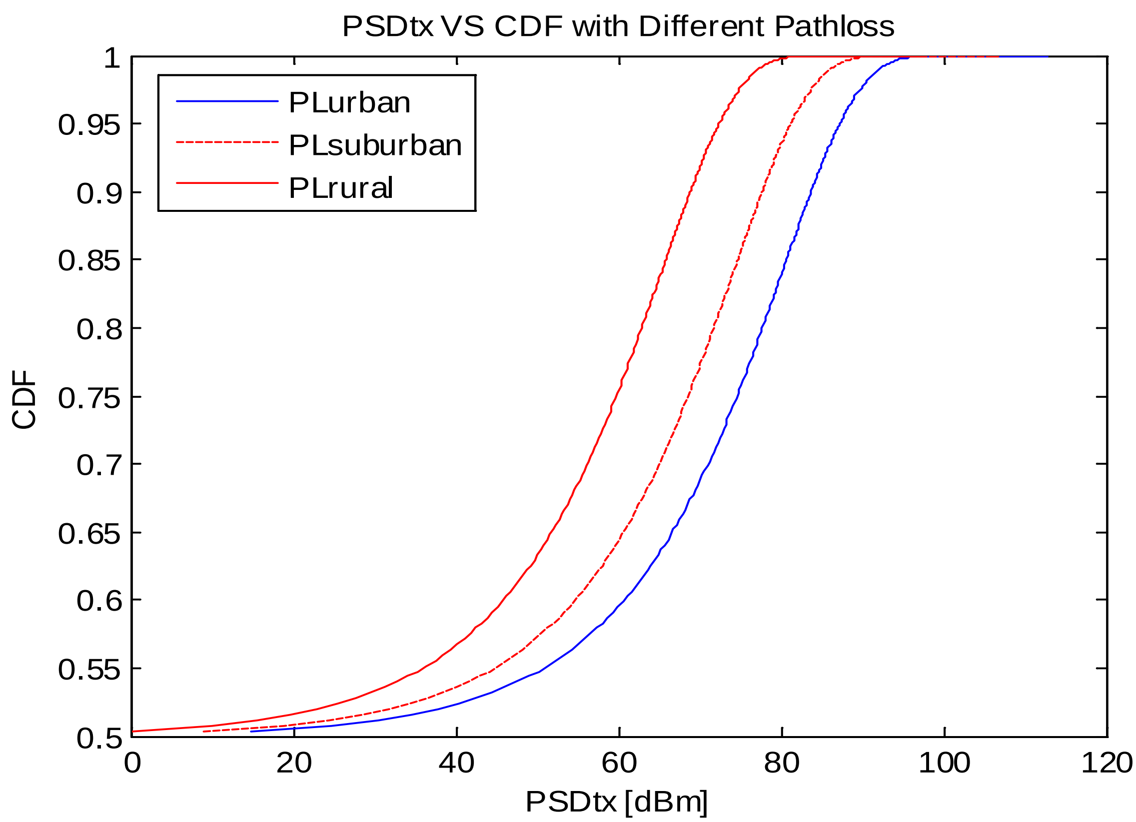


Figure 5.2 Required UE transmit power with different path losses

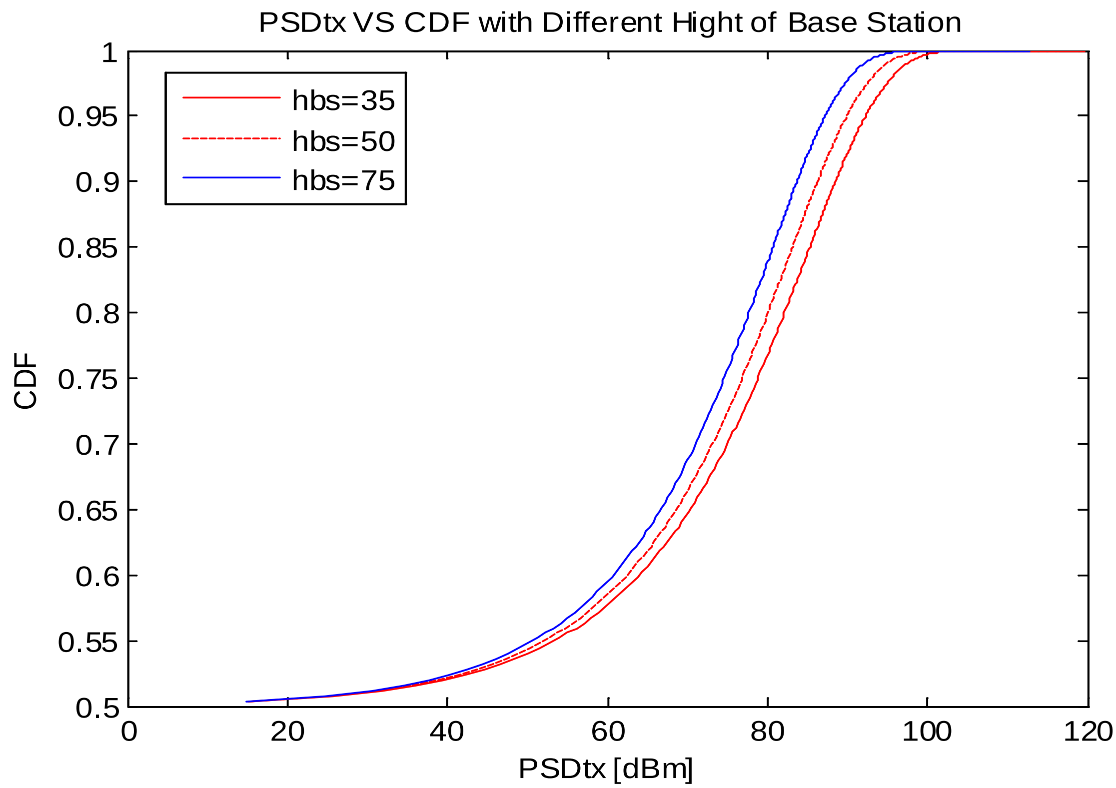


Figure 5.3 Required UE transmit power with different height of base station

Figure 5.4 shows the total path loss CDF plot as a function of UE transmit power. It can be clearly seen this figure that UE in the rural area utilizes transmit power more efficiently as UE in the urban and suburban areas. Likewise, Figure 5.5 shows the required UE transmit power as a function of distance. The results show that the UE in a rural area can save power by requiring less transmit power than the UE in an urban and suburban area.

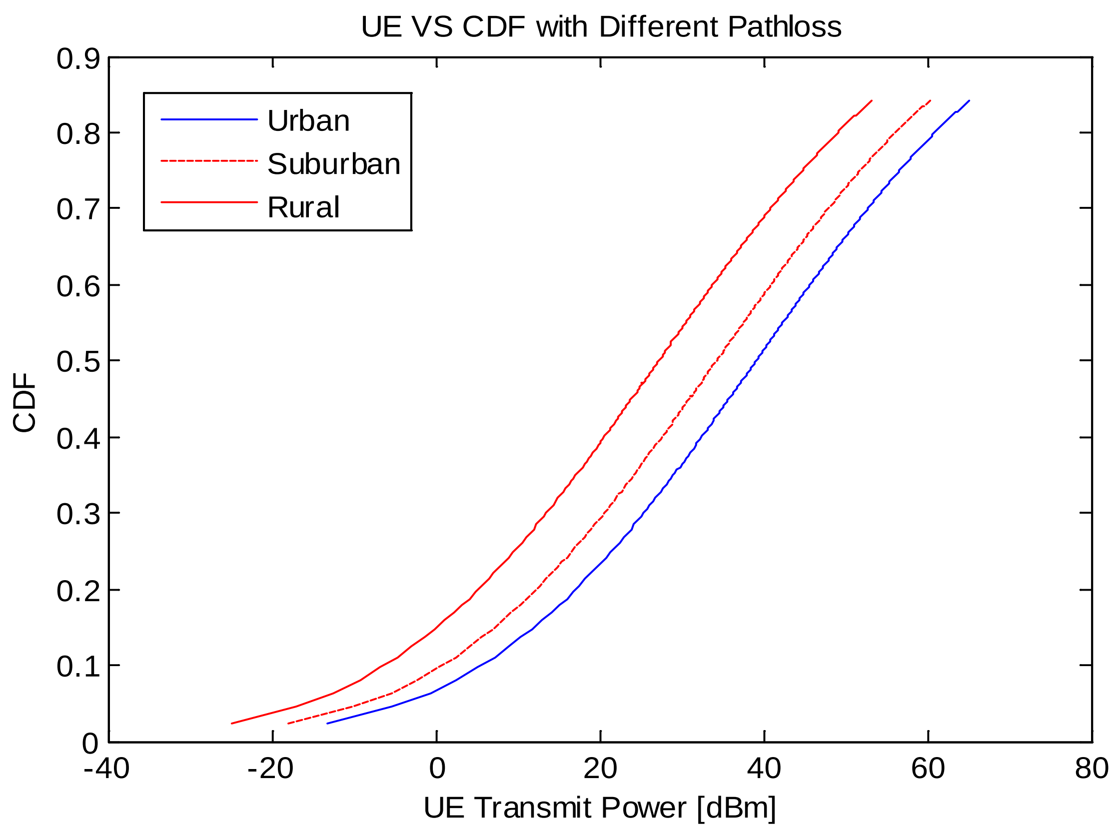


Figure 5.4 UE Transmit power with different path loss

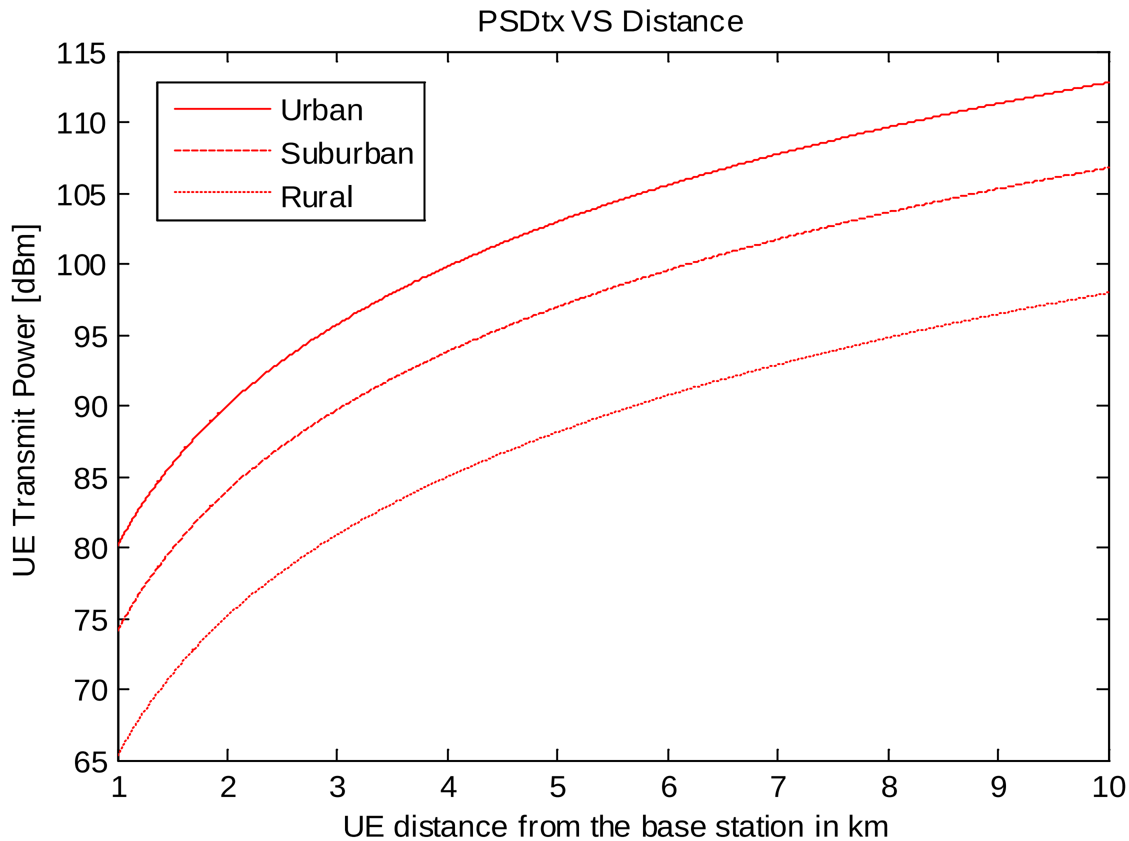


Figure 5.5 Required UE transmit power from the base station with different path loss

Figure 5.6 shows the required UE transmit power as a function of distance from the urban eNodeB using different eNodeB antenna heights (10m 35m 50m and 75m). The results show that the UE in the area of a lower eNodeB antenna height requires more transmit power than higher eNodeB antennas because the radio signals would be blocked by buildings if the antenna were near the ground.

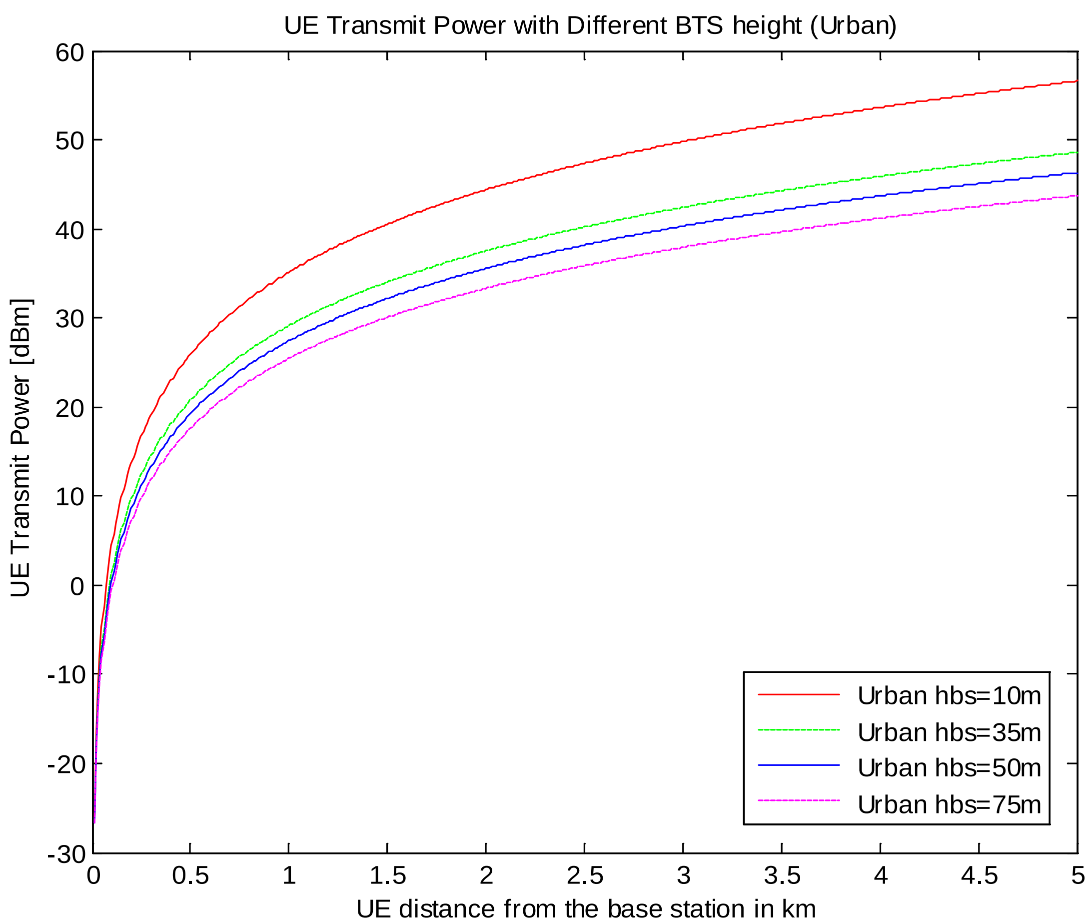


Figure 5.6 Required UE transmit power from the base station with different height of base station for urban

Figure 5.7 shows the required UE transmit power as a function of distance from the suburban eNodeB using different eNodeB antenna heights (10m 35m 50m and 75m). The results show that the UE in the area of a lower eNodeB antenna height requires more transmit power than higher eNodeB antennas because the radio signals would be blocked by buildings if the antenna were near the ground.

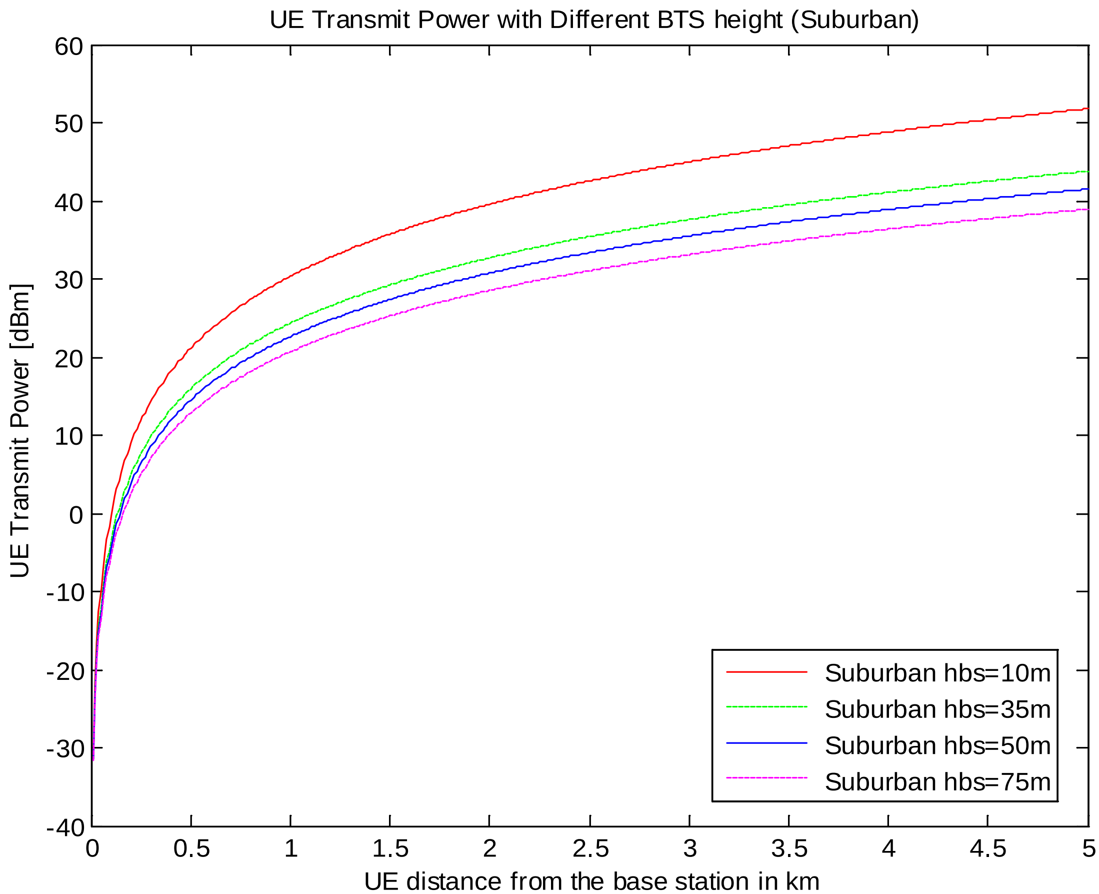


Figure 5.7 Required UE transmit power from the base station with different height of base station for suburban

Figure 5.8 shows the required UE transmit power as a function of distance from the rural eNodeB using different eNodeB antenna heights (10m 35m 50m and 75m). The results show that the UE in the area of a lower eNodeB antenna height requires more transmit power than higher eNodeB antennas because the radio signals would be blocked by buildings if the antenna were near the ground.

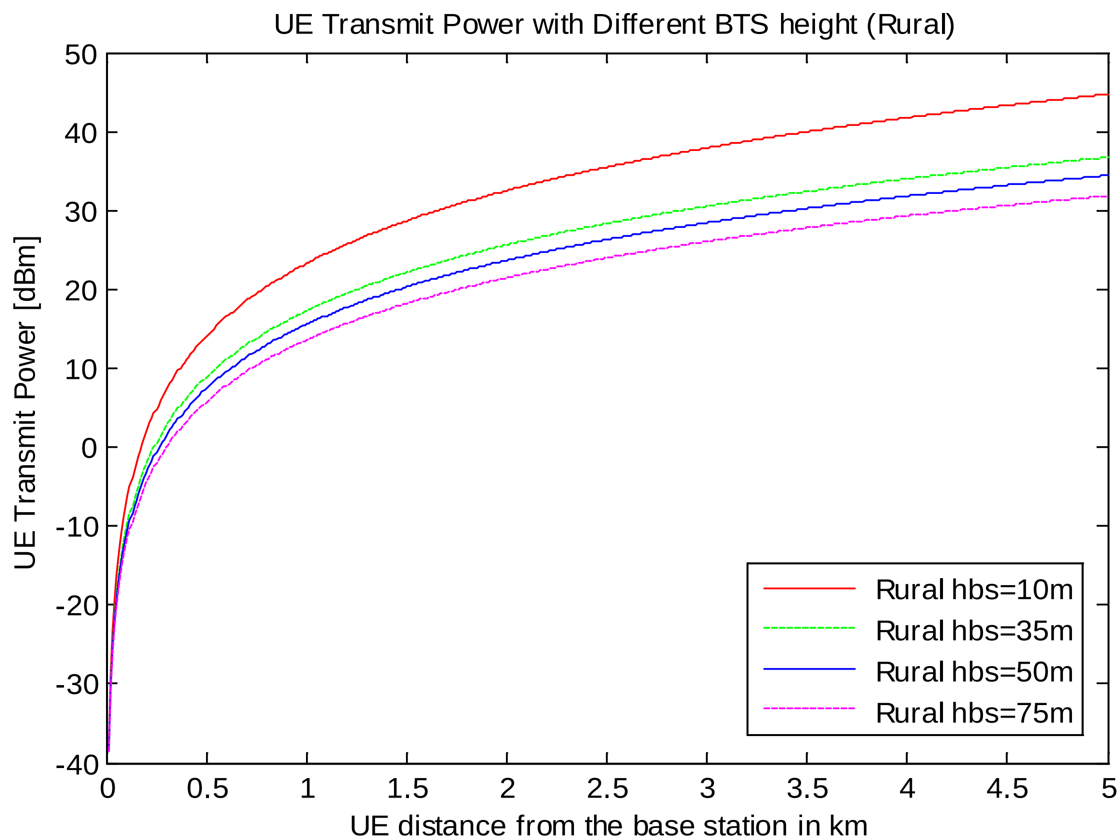


Figure 5.8 Required UE transmit power from the base station with different height of base station for rural

Figure 5.9 shows the effect of α on PSD_{tx} for a wide range of path-loss (P_L) values. The case $\alpha = 1$ results in a PSD_{tx} that aims to compensate the degradation caused by the path loss. The compensation is done allowing user to transmit with more power if such path loss is higher. The case $\alpha = 0.6$ illustrated the same tendency for result but with a less spread distribution with different slop and slope is equal to – α when the plot is seen in decibel (dB). For example, the different on PSD_{tx} value for the two α values around 50 dB of path loss is less than that around 125 dB of path loss. It can be note that the user more path loss (cell edge user) is transmitting more power with increase in α. The case of $\alpha = 0$ means no power control, since all users transmit with the same power, while with $\alpha = 1$, users 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. The case of $0 < \alpha < 1$ are cases to compromise between full compensation of path loss and no power control where only a fraction of path loss is compensated to the user. Thus, the scheme is known as fractional power control scheme.

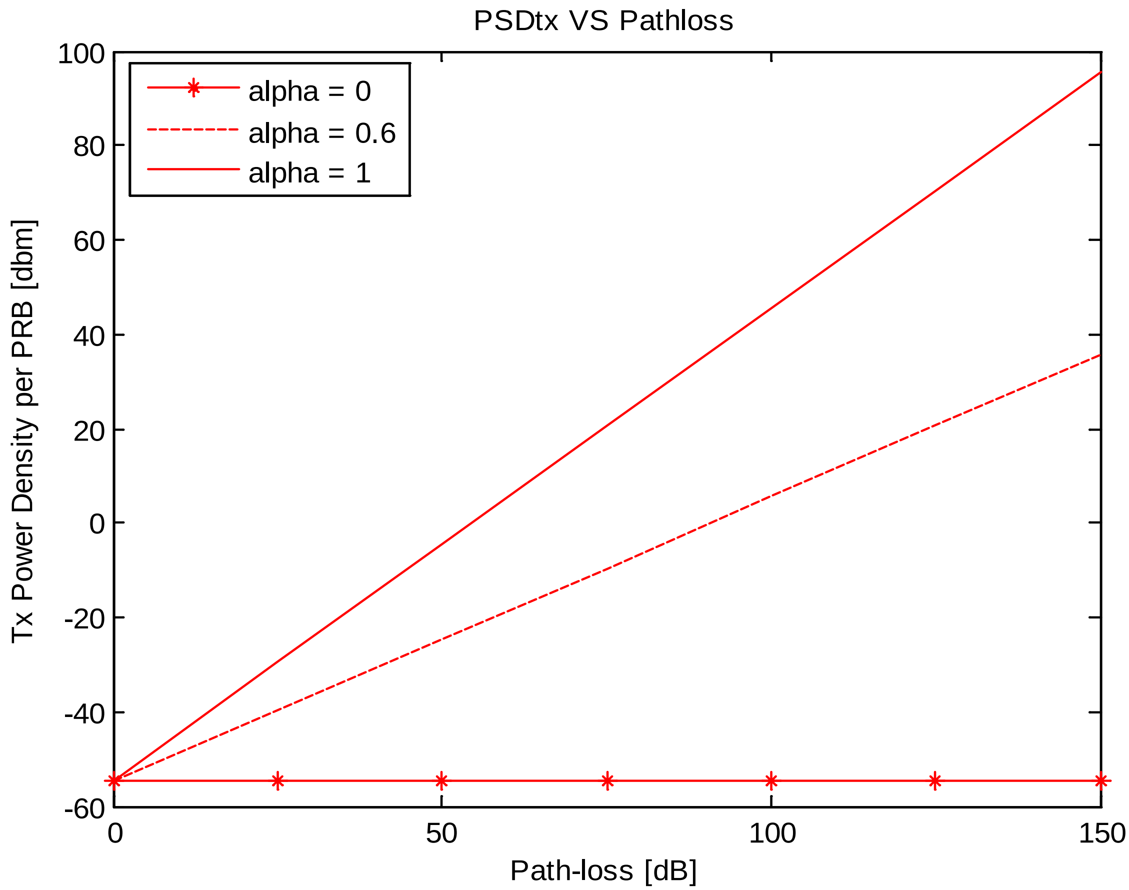


Figure 5.9 PSD_{tx} Vs Path-loss (P_L) for $\alpha = 0, 0.6$ and $\alpha = 1$

Figures 5.10 and 5.11 show the relationship between path loss and transmit power for different number of physical resource block. When $\alpha = 1$ the scheme totally compensates the path loss in order to reach the target received power P_o. All UE of the cell, whatever their location, see their signals received with the same power at eNodeB. When $0 < \alpha < 1$ in the case of a fractional power control, where path loss is partially compensated by the power control scheme. The higher is the path loss, the smaller is the received power at eNodeB. Cell edge UEs are received with a weaker signal. Thus, lower α means higher differentiation in SINR of cell edge and cell centre users. The maximum number of PRBs are in the range 2 to 48 in single user simulation. If the user only get 2 PRBs the transmission channel will look like Frequency Division Multiple Access (FDMA), where many users are active concurrently but allocated a few resources in the frequency domain. If the user is allocated up to 48 PRBs (2 are used for control signalling) the transmit channel changes towards Time Division Multiple Access (TDMA), where the users are active in short time frame and occupying a large amount of the available bandwidth.

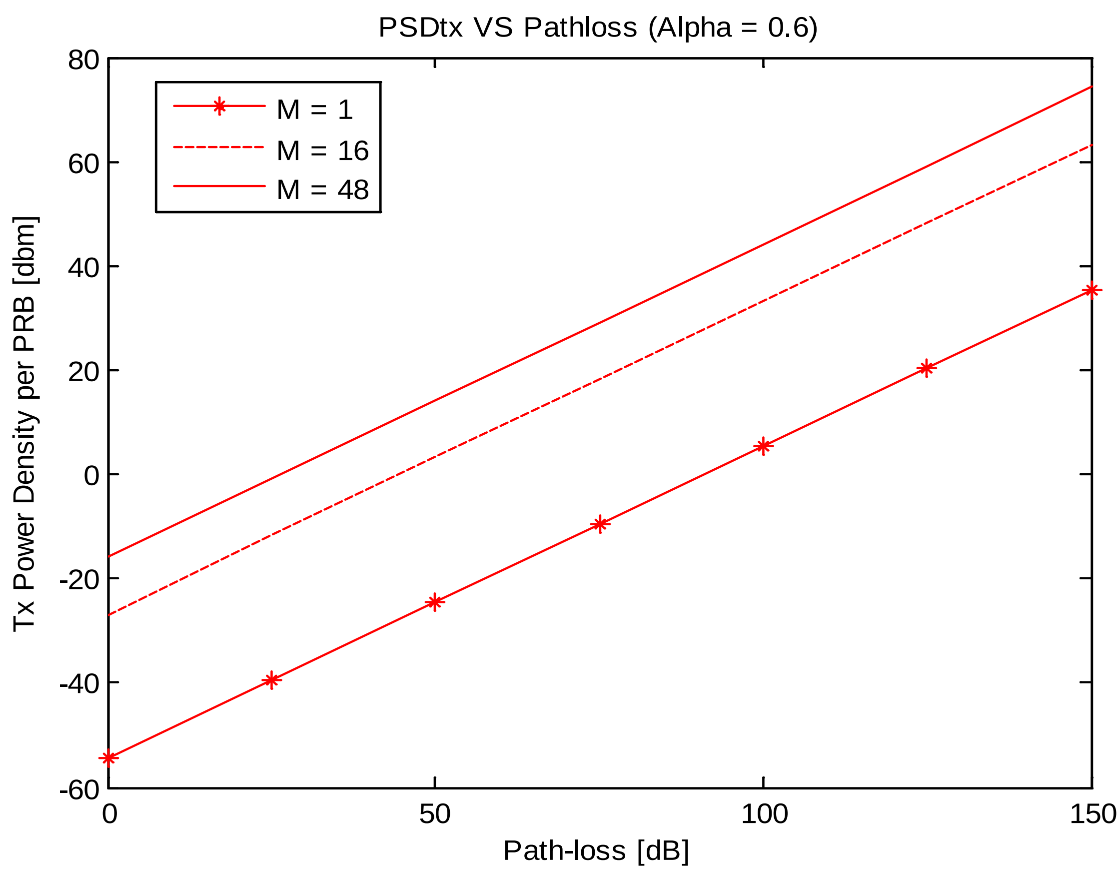


Figure 5.10 PSD_{tx} Vs Path-loss (P_L) for different physical resource block

(M = 1, 16 and 48) with $\alpha = 0.6$

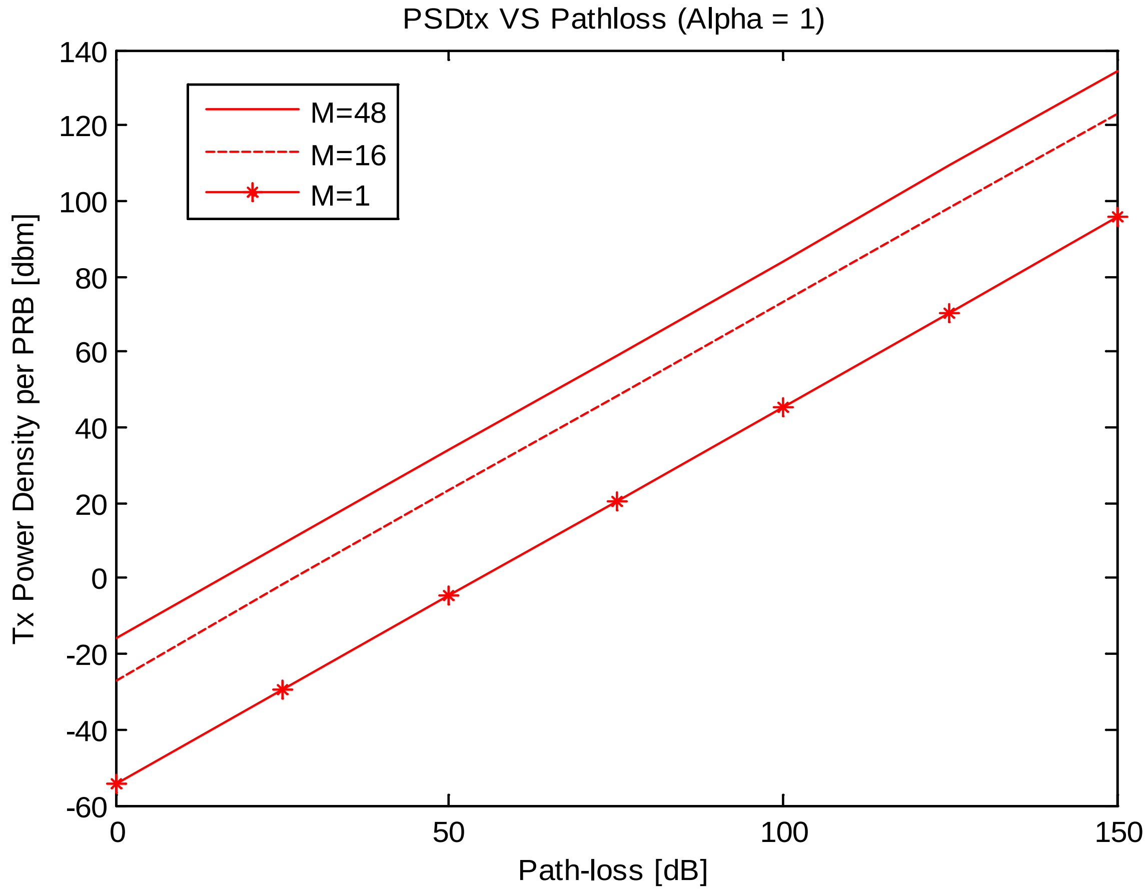


Figure 5.11 PSD_{tx} Vs Path-loss (P_L) for different number of physical resource block

(M = 1, 16 and 48) with $\alpha = 1$

Figure 5.12 shows the path loss CDF plot as a function of UE transmit power with different path loss compensation factors (α) applied. It can be clear that when using $\alpha = 0.6$ (fractional compensation) UE using utilizes transmit power more efficiently than $\alpha = 1$ (full compensation). That mean UE can be save battery power more efficiently as it provides better system performance.

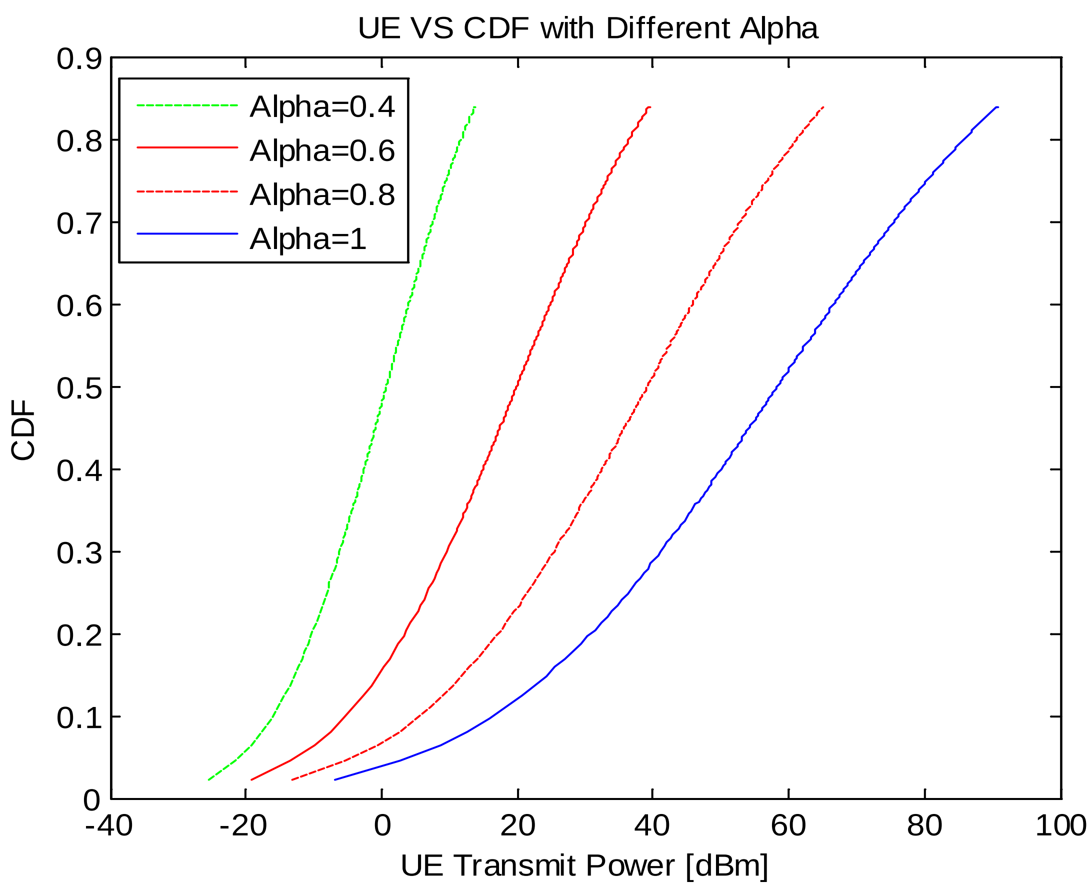


Figure 5.12 Required UE transmit power with different path loss compensation factor (α)

Figures 5.13, 5.14 and 5.15 illustrate required UE transmit power as a function of distance for the 3 environments (urban, suburban and rural). As can be seen, when $\alpha = 1$ we call full compensation of path loss, while a lower α means the received power density is different for each user depending on the path loss between each user and eNodeB. Thus, a cell edge user will need to transmit an increased power level for an increase in α (fractional compensation of path loss.)

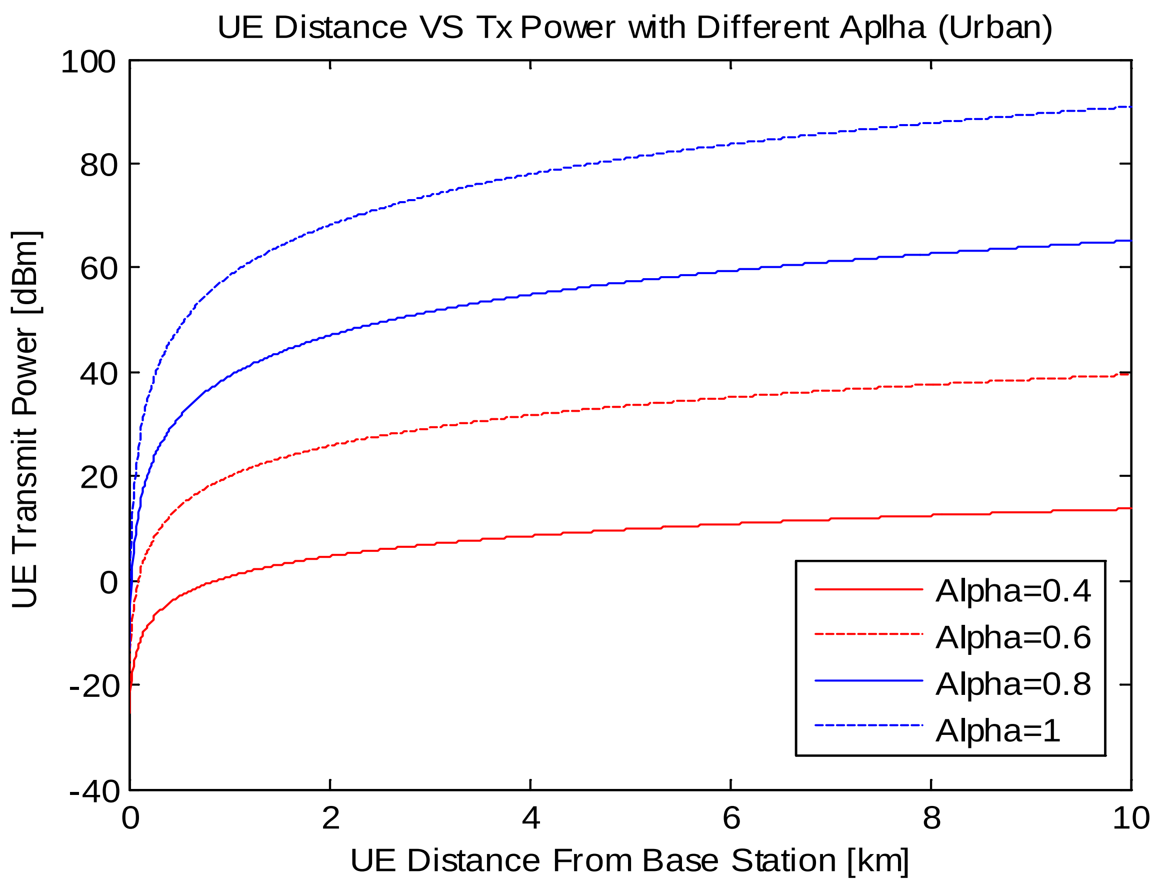


Figure 5.13 Required UE transmit power with different path loss compensation factor (α) using the Okumura-Hata urban model

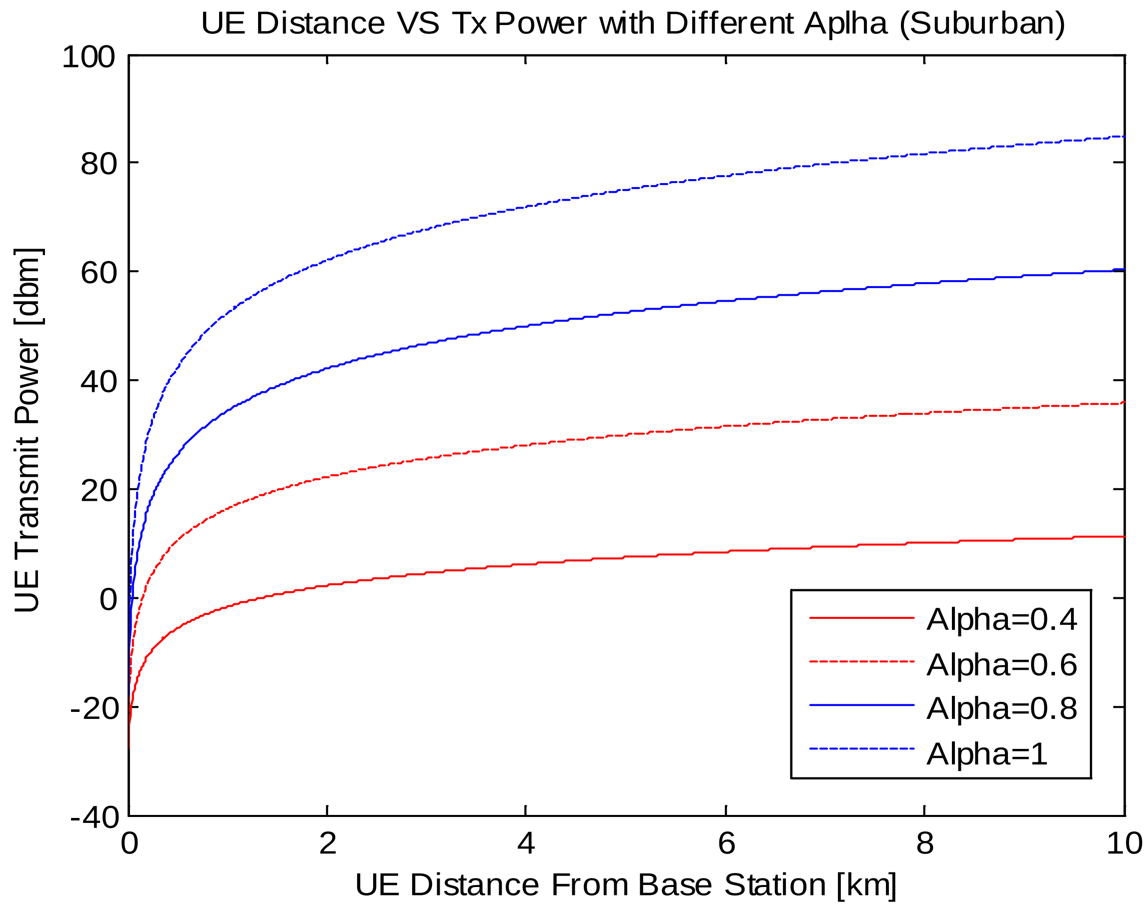


Figure 5.14 Required UE transmit power with different path loss compensation factor (α) using the Okumura-Hata suburban model

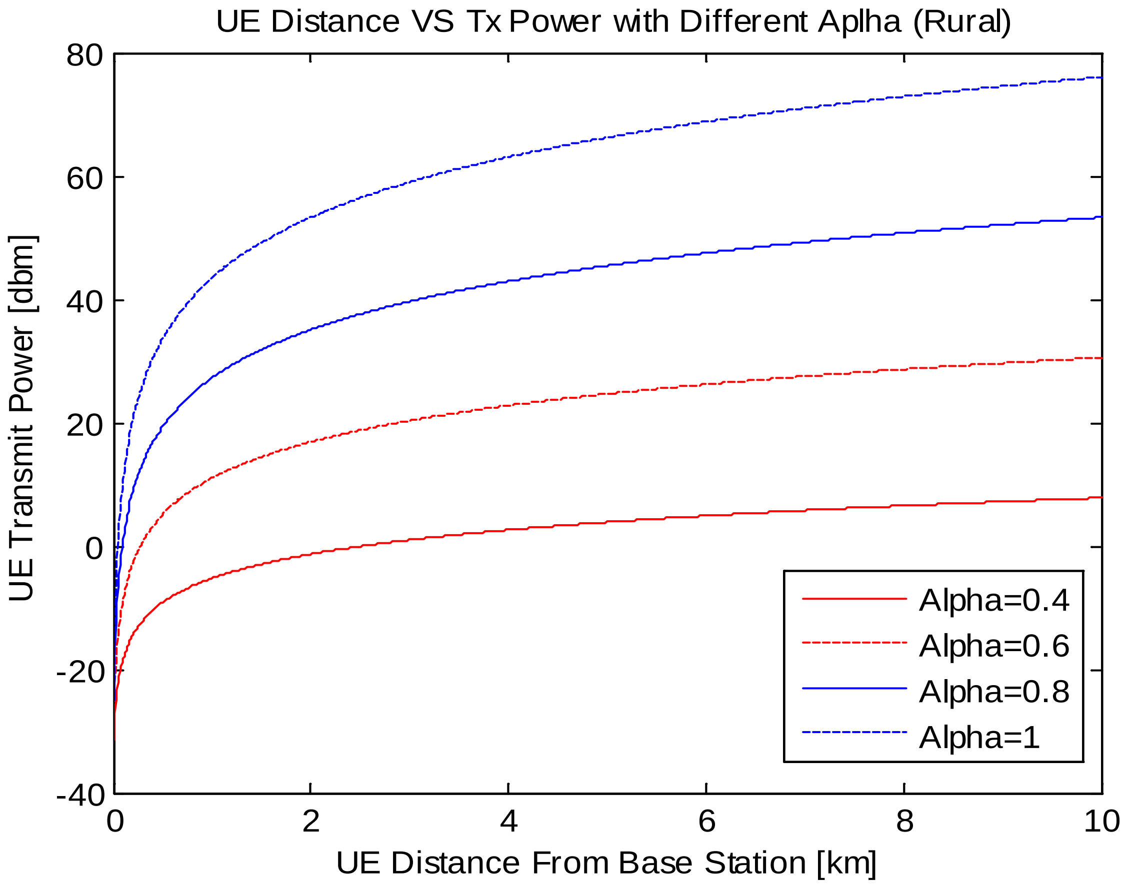


Figure 5.15 Required UE transmit power with different path loss compensation factor (α) using the Okumura-Hata rural model

Figures. 5.16, 5.17, 5.18 and 5.19 illustrate the required UE transmit power as a function of distance for urban environment using different base station sensitivities, P_o and α. When comparing $P_o = -60\ dBm$ and $P_o = -100\ dBm$ at the same UE distance from the base station a higher base station sensitivity can reduce the UE transmit power as a higher base station sensitivity can successfully receive a lower uplink power from the UE. Typical value for the current macro and micro cell base station sensitivity lies between -96.5 dBm to -106.5 dBm [22].

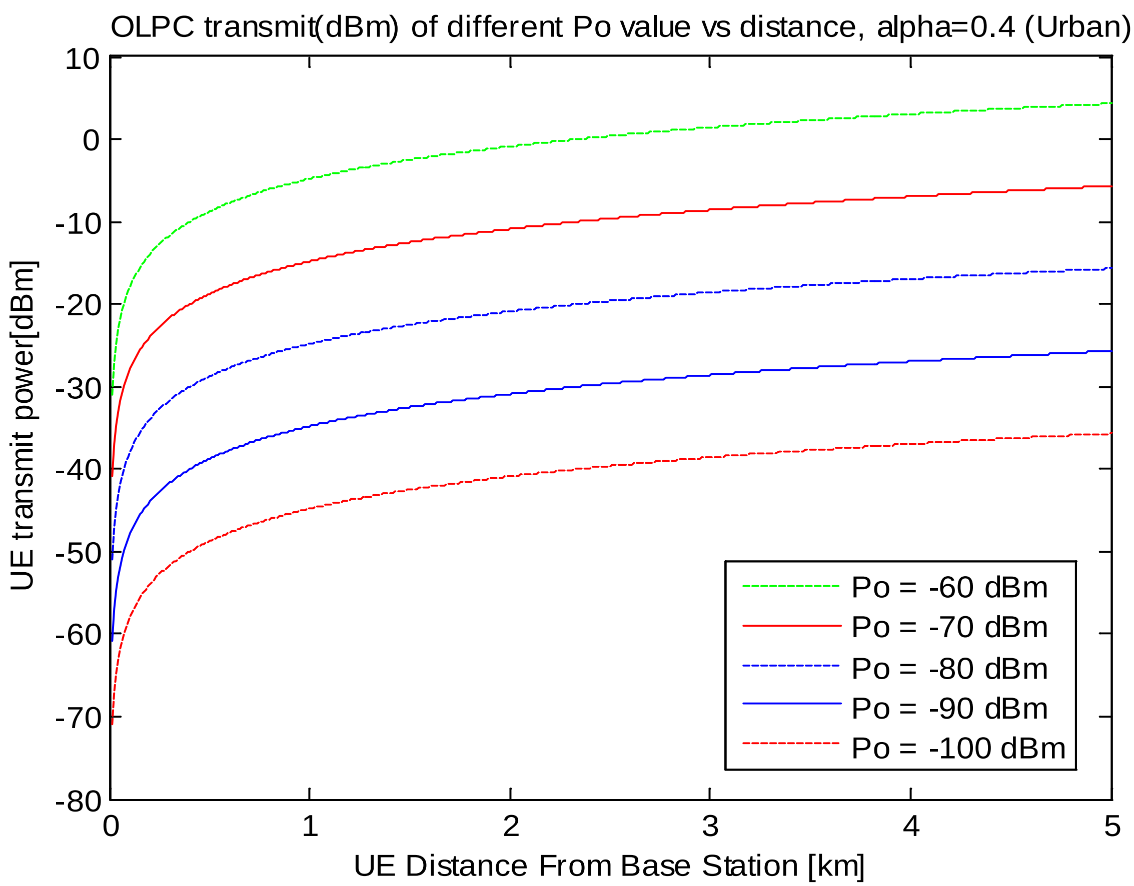


Figure 5.16 Required UE transmit with different base station sensitivity (P_o) with

$\alpha = 0.4$ using the Okumura-Hata urban model

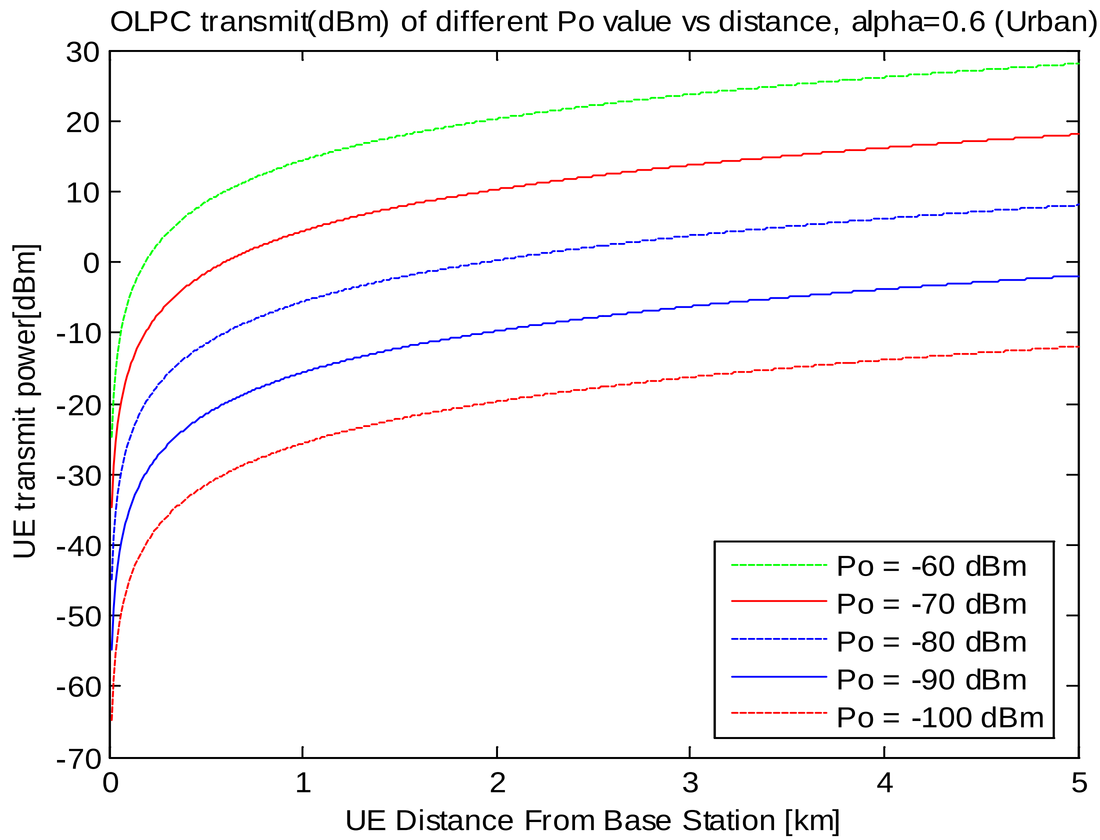


Figure 5.17 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.6$ using the Okumura-Hata urban model

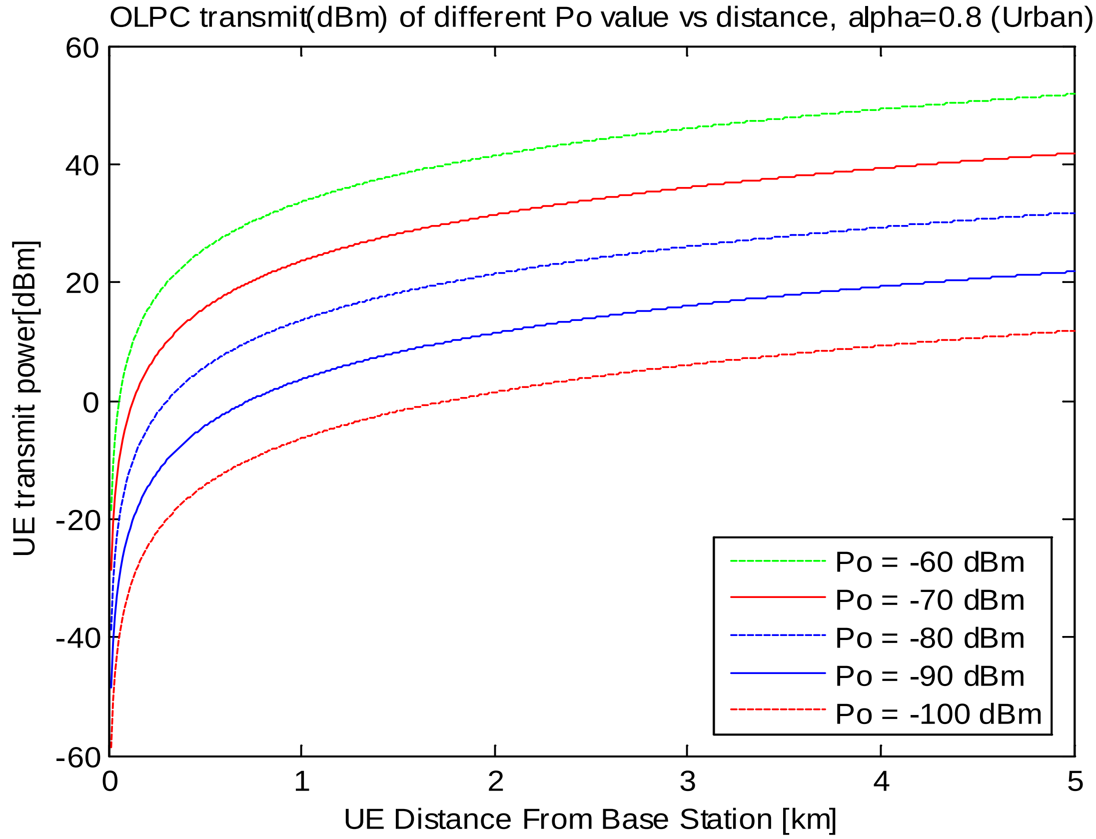


Figure 5.18 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.8$ using the Okumura-Hata urban model

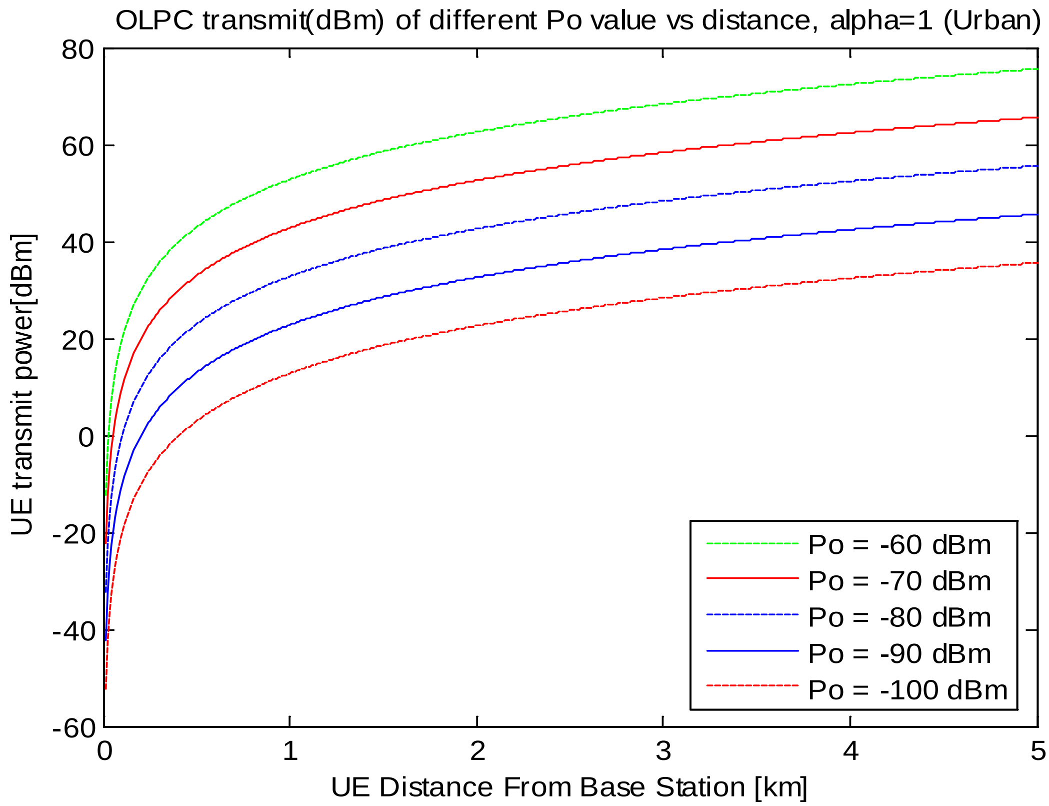


Figure 5.19 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 1$ using the Okumura-Hata urban model

Figures. 5.20, 5.21, 5.22 and 5.23 illustrate the required UE transmit power as a function of distance for suburban environment using different base station sensitivities, P_o and α. When comparing $P_o = -60\ dBm$ and $P_o = -100\ dBm$ at the same UE distance from the base station and it can be seen that a higher base station sensitivity can reduce the UE transmit power as a higher base station sensitivity can successfully receive a lower uplink power from the UE.

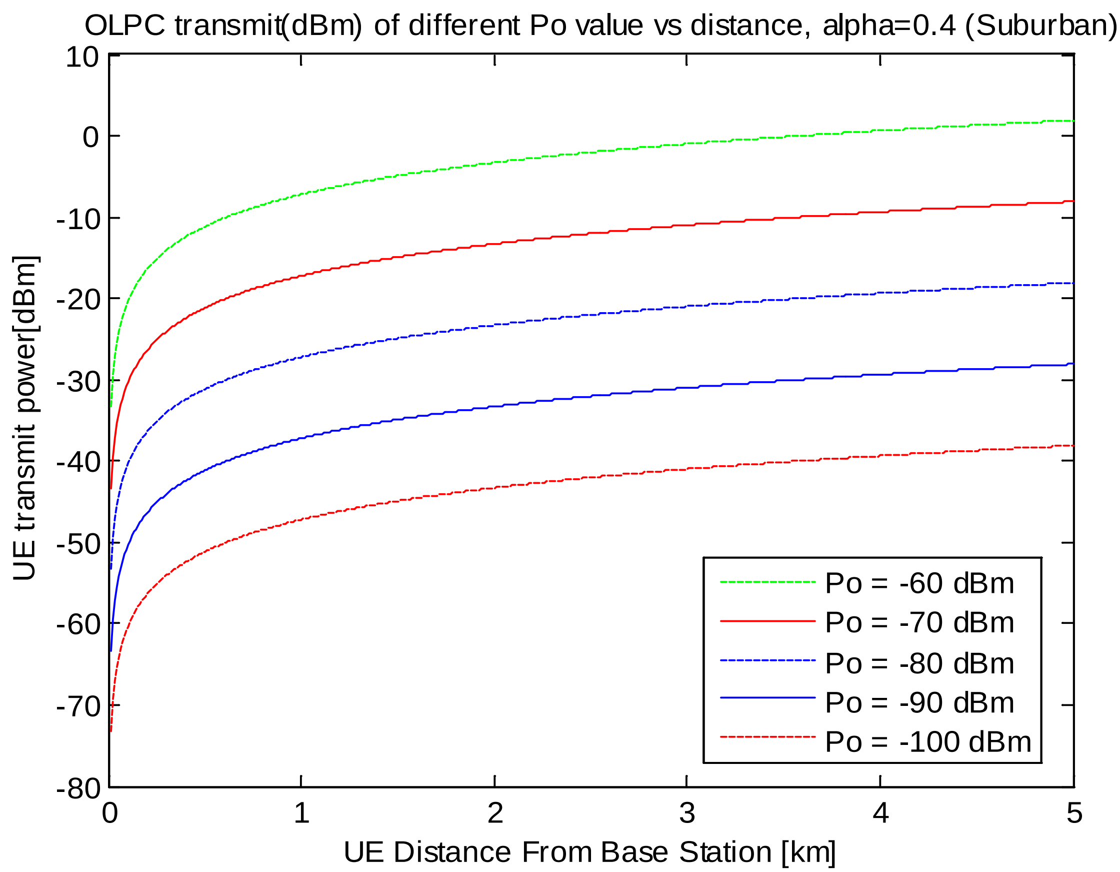


Figure 5.20 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.4$ using the Okumura-Hata suburban model

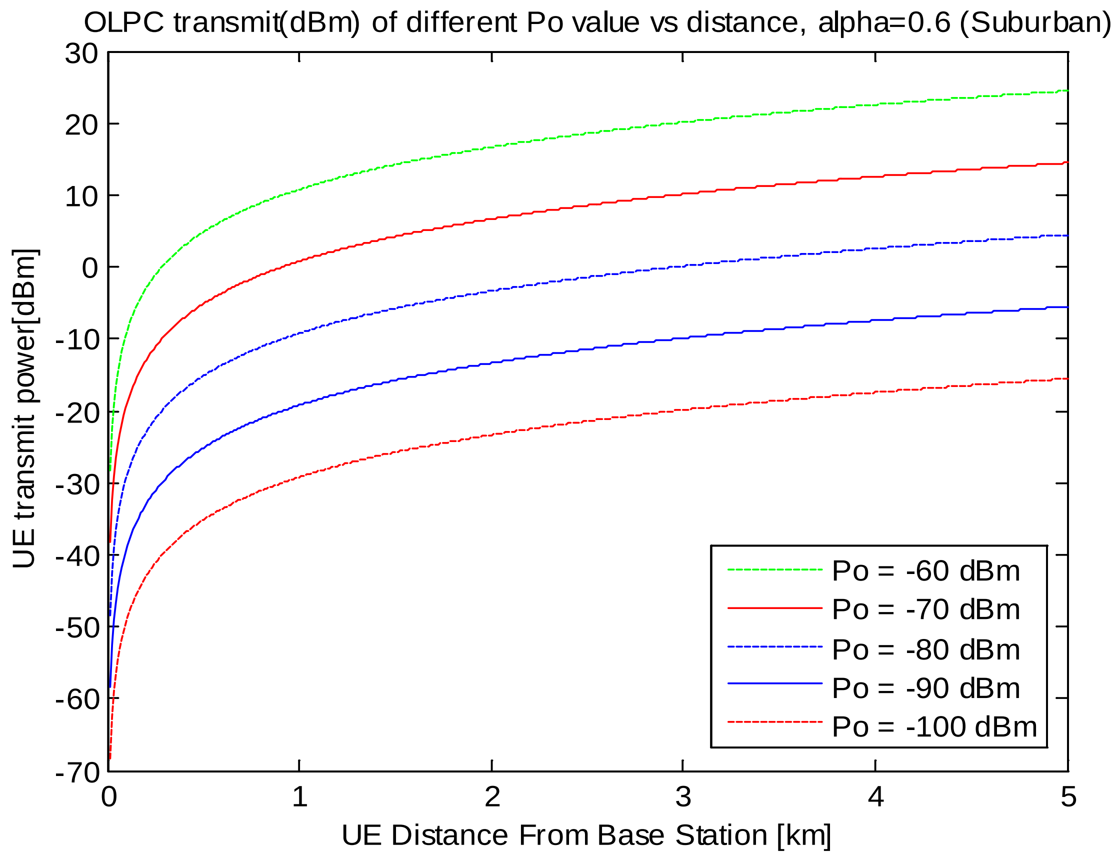


Figure 5.21 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.6$ using the Okumura-Hata suburban model

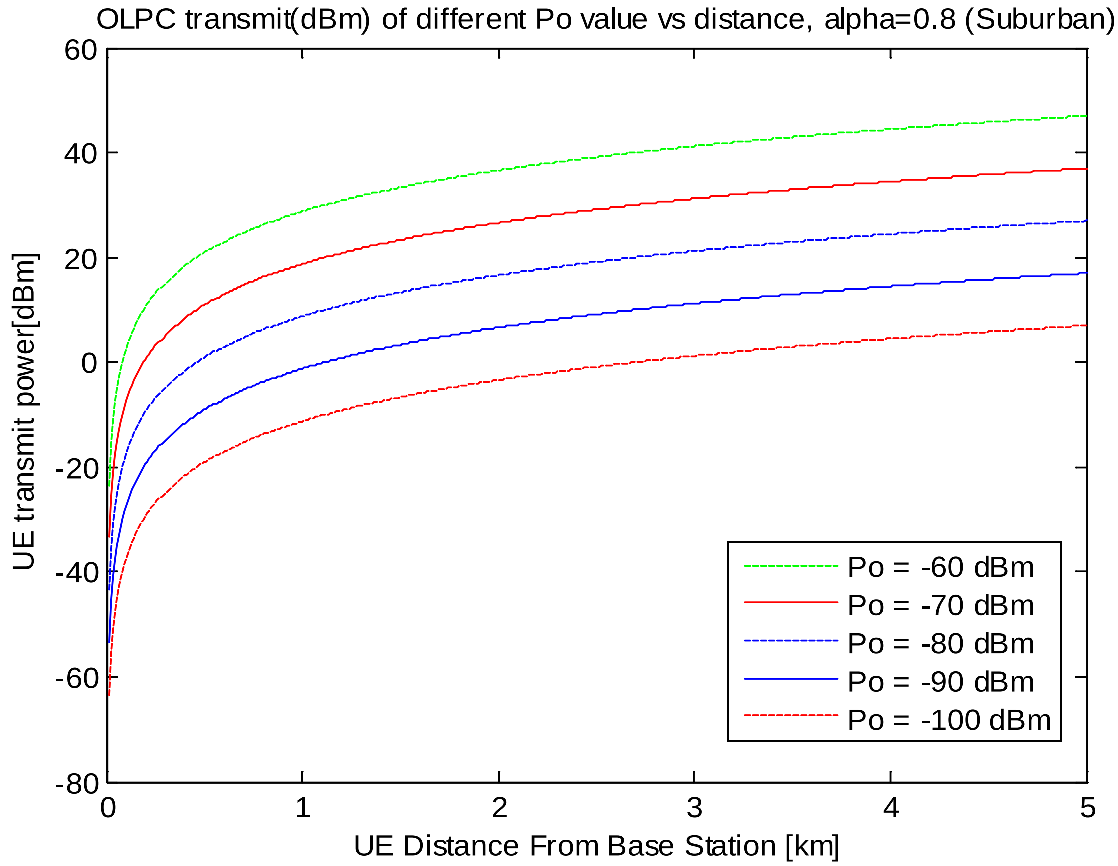


Figure 5.22 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.8$ using the Okumura-Hata suburban model

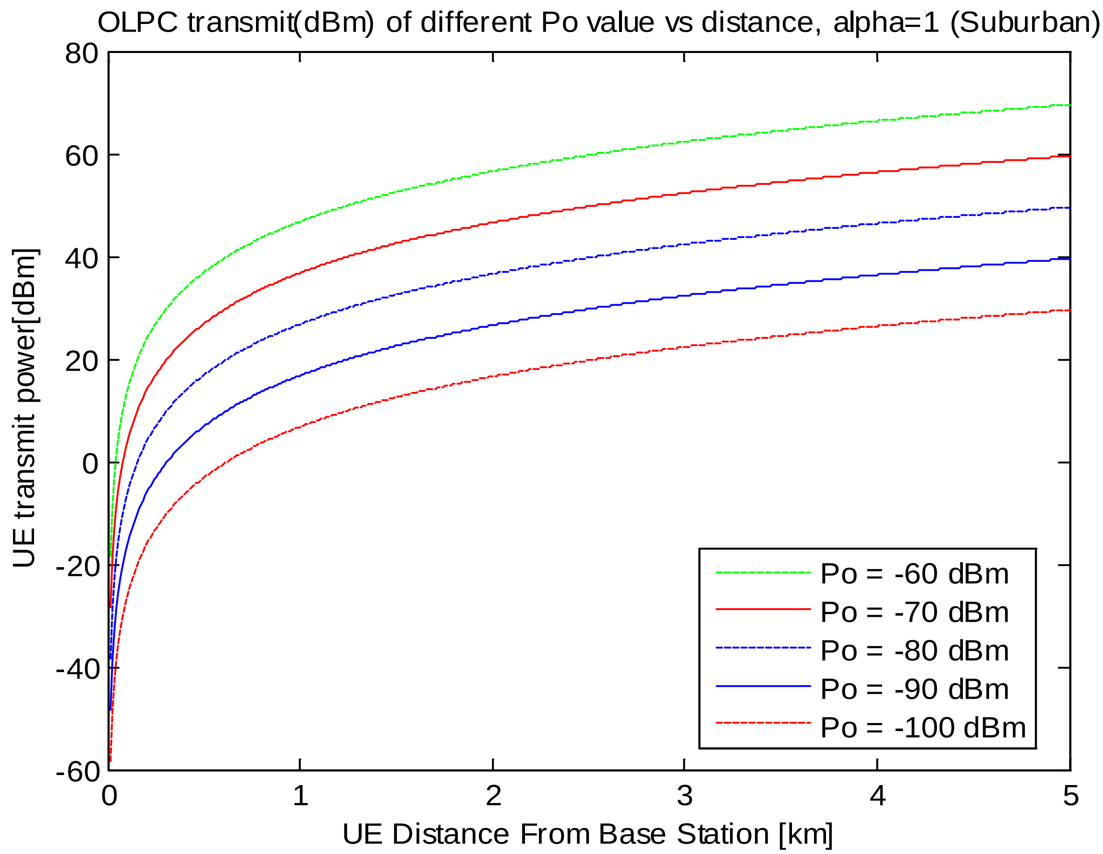


Figure 5.23 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 1$ using the Okumura-Hata suburban model

Figures 5.24, 5.25, 5.26 and 5.27 illustrate the required UE transmit power as a function of distance for rural environment using different base station sensitivities, P_o and α. When comparing $P_o = -60\ dBm$ and $P_o = -100\ dBm$ at the same UE distance from the base station it can be seen that a higher base station sensitivity can reduce the UE transmit power as a higher base station sensitivity can successfully receive a lower uplink power from the UE.

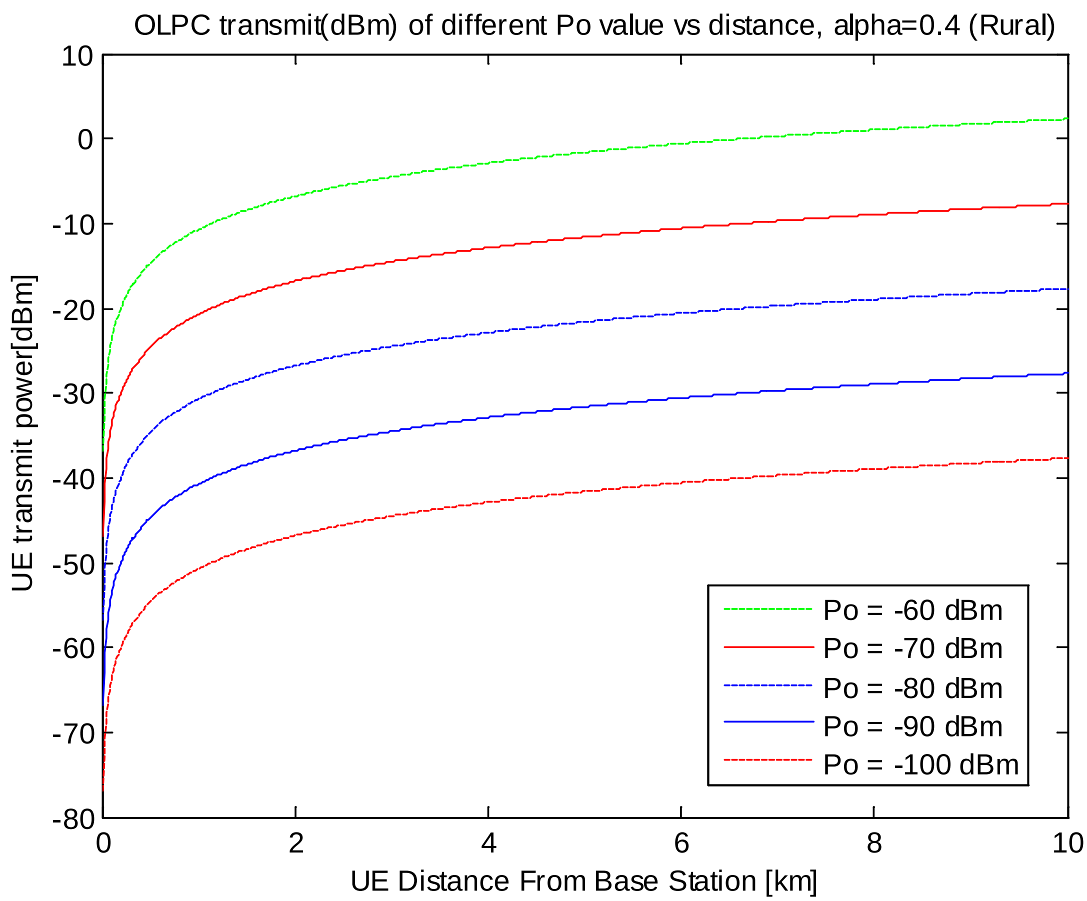


Figure 5.24 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.4$ using the Okumura-Hata rural model

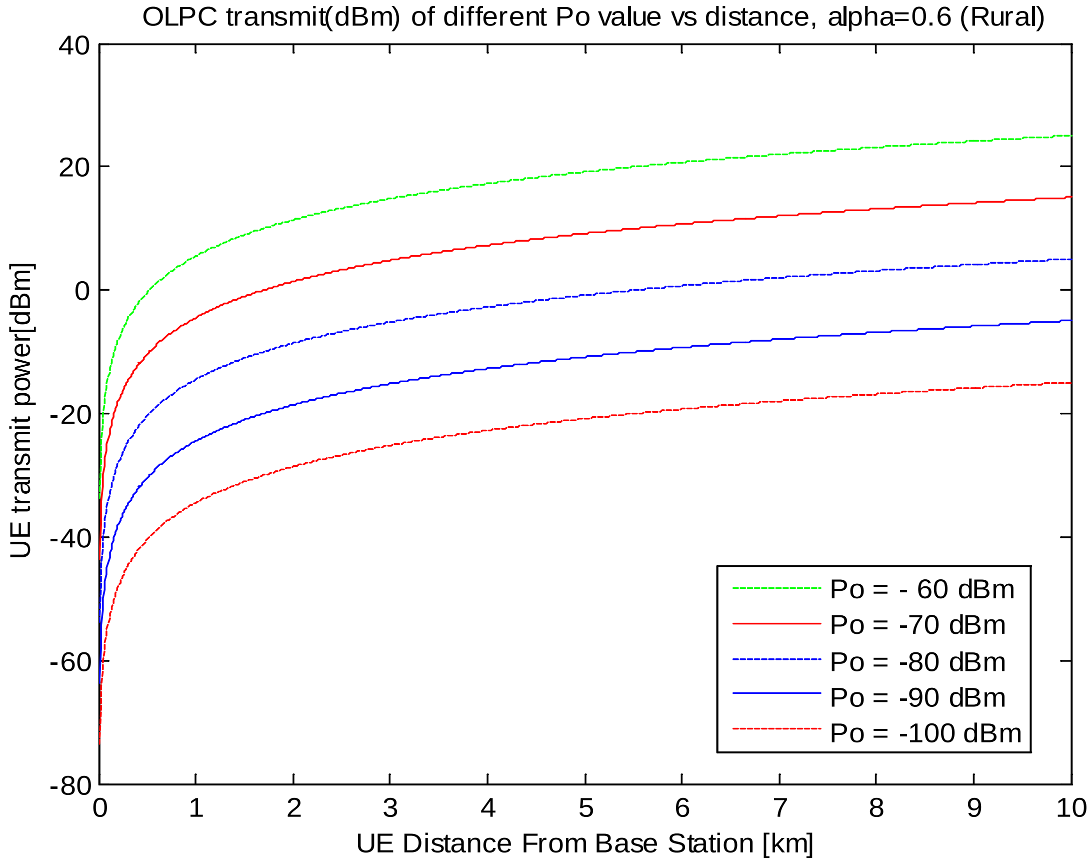


Figure 5.25 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.6$ using the Okumura-Hata rural model

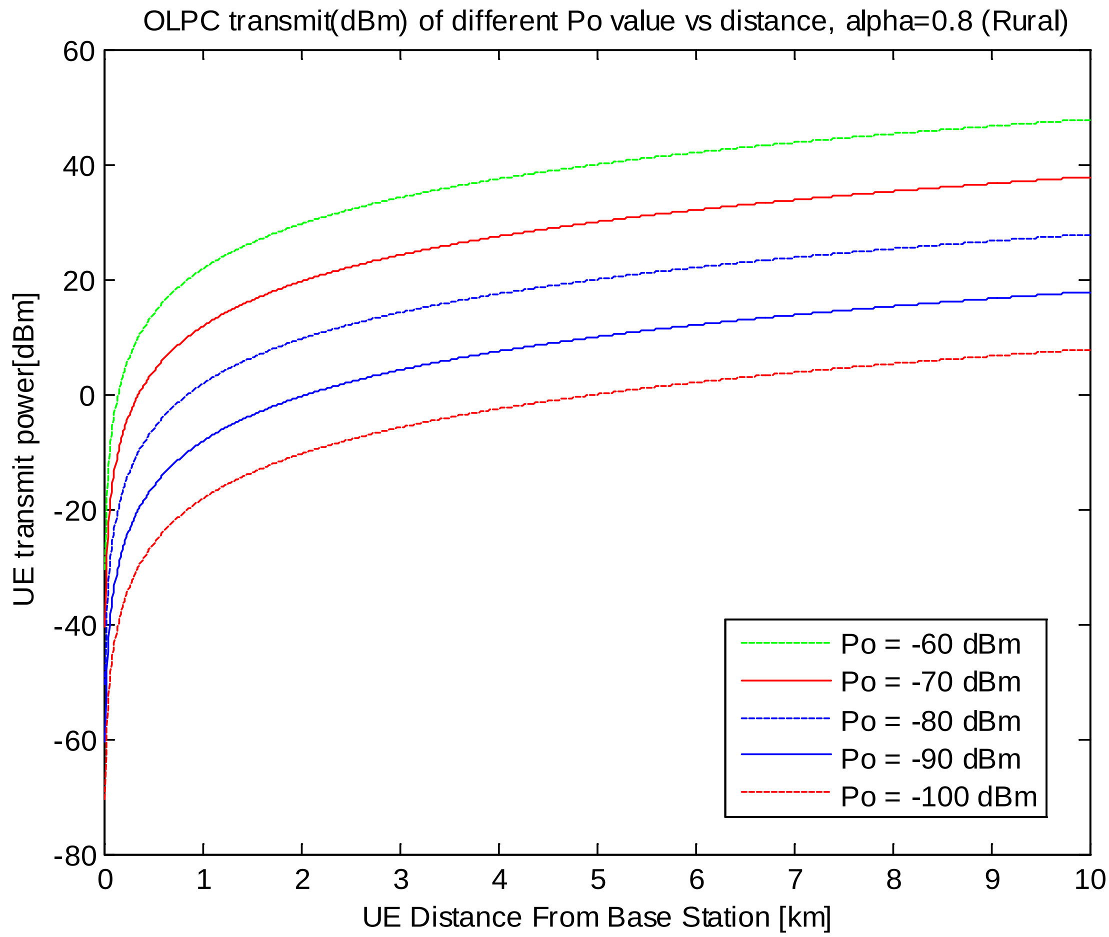


Figure 5.26 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 0.8$ using the Okumura-Hata rural model

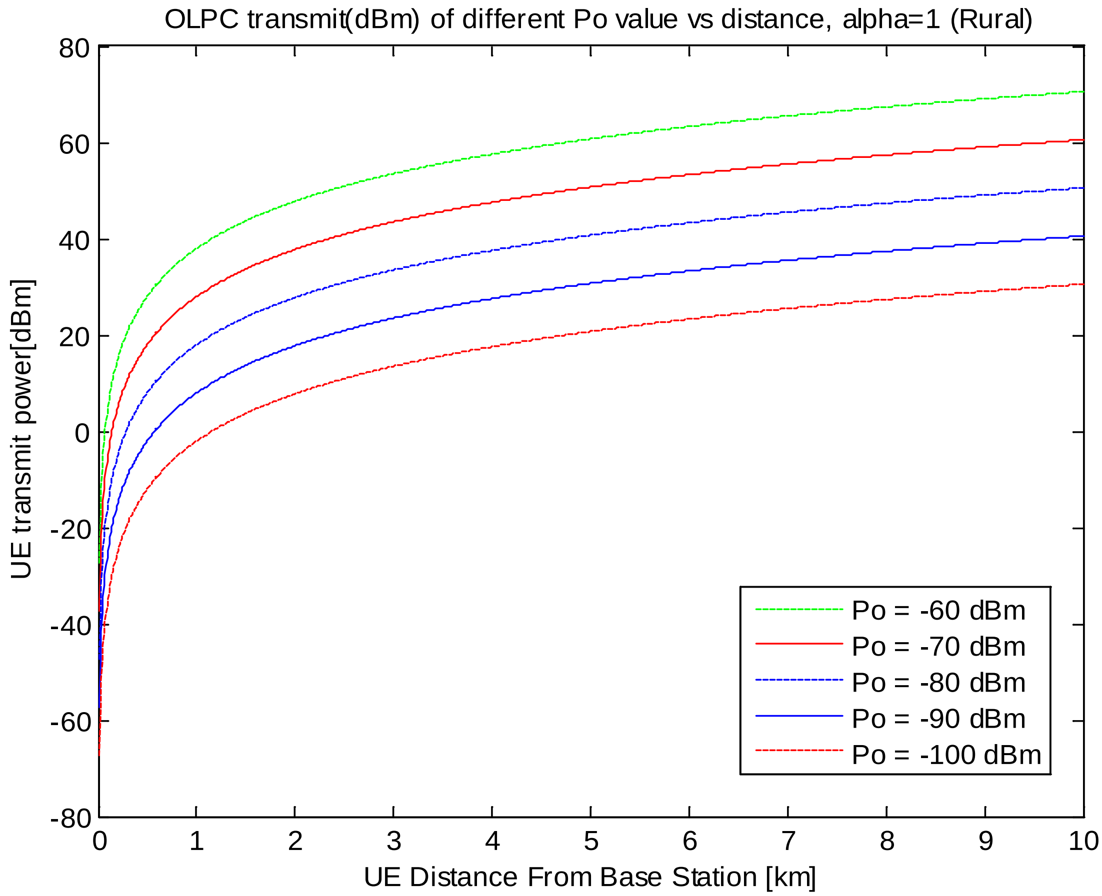


Figure 5.27 Required UE transmit with different base station sensitivity (P_o) with $\alpha = 1$ using the Okumura-Hata rural model

This chapter has presented simulation results of implementing path loss using the Okumura-Hata propagation model and system level simulation model parameters. The simulations were performed using MATLAB. To analyse the UE energy consumption's dependency on the path loss compensation factor (α) and eNodeB sensitivity (P_o) were applied. This approach consisted of 3 environments (urban, suburban and rural) and different of height of eNodeB (10m, 35m, 50m and 75m).

CHAPTER 6 DISCUSSION

The purpose of the present thesis was to focus on a novel OLPC scheme for LTE uplink by using the Okumura-Hata propagation path loss model to set the UE uplink transmit power control parameters in order to reduce the UE energy consumption. The power control is specified to function with both OLPC and CLPC mechanisms. The open loop functioning is based on a FPC technique and was designed to allow for full compensation for path loss or partial compensation of path loss. On the other hand, the algorithms used to implement CLPC are vender specific and still under research. The standardized equation for FPC allows to set the user transmitting power according to the fraction of path gain to the serving base station that the UE has to compensate for.

The Okumura-Hata path loss model was created from a number of representative path loss models for urban, suburban and rural areas environments. The parameter h_{bs}, α and P_O can be set in order to have an operating point on which cell performance and outage are accordingly compromised.

Height of base station (h_{bs})

The effect of path loss of different base station hights using Okumura-Hata propagation path loss model is show in Fig.5.1 as a function of distance from the eNodeB with different base station heights (10m, 35m, 50m and 75m). When the base station height is increased, the path loss is reduced and on decreasing base station height then the path loss increases. Because higher of eNodeB can cover the area of service more than lower eNodeB, the received signal strength increases as the antenna height and the effect of the path loss in urban environment more than rural (see Fig. 5.6, 5.7 and 5.8). Increasing the base station height will provide more probability to find the better quality signal from eNodeB. Therefore, the UE in rural areas can save power by requiring less transmit power than the UE in the urban area.

Path loss compensation factor (α)

α is selected from the set of (0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1) to decide the compensation weight of UE's path loss (see Fig. 5.9).

Fig. 13, 14 and 15 show the required UE transmit power as a function of distance for 3 environments (urban, suburban and rural). It can therefore be considered as 3 cases for the path loss compensation factor (α).

1. The case of $\alpha = 0$, the transmission power is fixed. There is no compensation and in fact no power control at all, since all users transmit with the same power. UE close to the eNodeB are received with high power while cell edge UE are received with a weak signal.

2. While $\alpha = 1$, UE's transmit with full power resulting in full path compensation, also known as the conventional power control scheme. The case of $\alpha = 1$ results in a UE transmit power that aims to compensate the degradation caused by the path loss. The compensation is done allowing the UE to transmit with more power if such path gain is lower.

3. Values of α between 0 and 1 offer a compromise between the full compensation and no path loss compensation, where only a function of path loss is compensated to UE. Thus, the scheme is known as fractional power control scheme. It is a clear trade-off between cell edge users and UEs close to the eNodeB. As α increases, the spectrum efficiency for closer UEs decreases, whereas it increases for cell edge users. Thus, a lower α leads to a higher differentiation in terms of experienced SINR between cell edge and cell center users.

eNodeB sensitivity $(\boldsymbol{P_o})$

A higher base station sensitivity (P_o) can reduce the UE transmit power as an improved base station sensitivity can successfully receive a lower uplink power from the UE. As can be seen from Fig. 5.16, 5.17, 5.18 and 5.19 for urban environment, Fig. 5.20, 5.21, 5.22 and 5.23 for suburban environment and Fig. 5.24, 5.25, 5.26 and 5.27 for rural environment. Typical value for the current macro and micro cell base station sensitivity lies between -96.5 dBm to -106.5 dBm.

The Okumura-Hata path loss model is created from a number of representative path loss models for urban, suburban and rural areas environments. The parameter height of base station (h_{bs}), path loss compensation factor (α) and eNodeB sensitivity (P_o) can be set in order to have an operating point on which cell performance and outage are accordingly compromised.

CHAPTER 7 CONCLUSION

The uplink power control in LTE is flexible, simple and robust. It consists of a closed loop component operating around a reference obtained by parameterised open loop. This thesis has focused on an Open Loop Power Control (OLPC) scheme for LTE uplink by using the Okumura-Hata propagation path loss model to configure the UE uplink transmit power control parameters in order to reduce the UE energy consumption. Controlling the transmit power of the UE and eNodeB reduces the system interference and thus can be used to reduce the cluster size if implemented properly. In practical LTE, and personal communication systems, the power levels transmitted by every subscriber unit are under constant control by the serving eNodeBs. This is done to ensure that each UE transmit the smallest power necessary to maintain a good quality link on the reverse channel. From the results obtained from this work, the parameter height of base station (h_{bs}) path loss compensation factor (α) and eNodeB sensitivity (P_o) can be set in order to have an operating point on which cell performance and outage are accordingly optimised. The implementation of function compensation of path loss enables a UE to transmit a lower power compared to full compensation of path loss. Furthermore, improving the base station sensitivity level also enables reduced UE power levels and hence UE lower power consumption. By parameterising the path loss models, further control can be gained to influence the UE battery life. Therefore, if suitable parameters are used to set up and control UE transmission power then the energy consumption in a UE can be reduced thus saving battery lifetime and reducing overall background interference.

The investigation has been completed and as shown in the result analysis, it can be concluded that coverage is highly influenced by antenna height (h_{bs}), path loss compensation factor (α) and eNodeB sensitivity (P_o). For the better performance of reducing UE uplink transmit power the network required antenna height and eNodeB sensitivity should be high (-96.5 dBm to -106.5 dBm). While path loss compensation factor should be optimum.

The Okumura-Hata path loss model is created from a number of representative path loss models for urban, suburban and rural areas environments.

For urban areas: This category is for a built up city or a large town with large buildings and houses with two or more stories, or a large village with close, tall, thickly grown trees.

For suburban areas: This category is for a village or highway scattered with tree and houses with a few obstacles near the UE.

For rural areas: This category is for rural areas with no tall trees or buildings in the propagation path, or a plot of land cleared for 200-400m, e.g. farmland, rice fields and open fields.

This three environments of Okumura-Hata propagation path loss model were built using data collected in the city of Tokyo, Japan. The current research work presented in this thesis also used the Okumura-Hata propagation model and thus the work is directly applicable to areas with similar terrain as Japan, and Thailand has a similar terrain to Japan. Therefore, the work presented in this thesis can be applied to the User Equipment (UE) uplink transmit power in Thailand. The future research derived from this thesis will focus on implementing the research in Thailand and the unforeseen differences in the terrain will be investigated.

REFERENCES

[1] http://www.vodafone.com/etc/medialib/attachments/cr_downloads, accessed 1 September 2016.

[2] http://www.orange.com/en_EN/tools/boxes/documents/att00005072/CSR_report_2007.pdf, accessed 30 June 2017.

[3] F. Richter, A.J. Fehske and G.P. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," IEEE Vehicular Technology Conference Fall, Alaska, USA, pp 1-5, 2009.

[4] H. Zhang, A. Gladisch, M. Pickavet, Z. Tao and W. Mohr (guest editors), "Special issue on energy efficiency in communications: Part II," IEEE Communications Magazine, Vol. 49, No. 6, pp. 30-82, June 2011.

[5] V. Mancuso and S. Alouf, "Reducing costs and pollution in cellular networks," IEEE Communications Magazine, Vol. 49, No. 8, pp. 63-71, August 2011.

[6] M.I. Salman, Chee Kyun Ng, N.K. Noordin, B.M. Ali and A. Sali, "Energy efficient transmission for LTE cellular system," International Conference on Computer and Communication Engineering, Kuala Lumpur, Malaysia, pp. 222-227, July 2012.

[7] Z. Hasan, H. Boostanimehr and V.K. Bhargava, "Green cellular networks: A survey, some research issue and challenges," IEEE Communications Surveys & Tutorials, Vol. 13, Issue 4, pp. 524-540, November 2011.

[8] W.-Y. Shin, Hyoseok and V. Tarokh, "Energy-efficient base-station topologies for green cellular networks," 2013 IEEE Consumer Communication and Networking Conference, Las Vegas, NV, USA, pp. 91-96, January 2013.

[9] P. L. Nguyem, T. Morohashi, H. Imaizumi and Hiroyuki Morikawa, "A performance evaluation of energy efficient schemes for green office networks," 2010 IEEE Green Technologies Conference, Grapevine, TX, pp. 1-9, April 2010.

[10] C. Han, T. Harrod, S. Armour, L. Krikidis, S. Videv, P. M. Grant, H. Hass, J. S. Thompson, I. Ku, C.-X. Wang, Heriot-Watt, Tuan Anh Le, M. R. Nakhai, J. Zhang and L. Hanzo, "Green radio: Radio techniques to enable energy-efficient wireless networks," IEEE Communication Magazine, Vol. 49, Issue 6, pp. 46-54, May 2011.

[11] F. Richter, A.J. Fehske, P. Marsch, and G.P. Fettwweis, "Traffic demand and energy efficiency in heterogeneous cellular mobile radio networks," 2010 IEEE 71st Vehicular Technology Conference, Taipei, Taiwan, pp. 1-6, May 2010.

[12] A. J. Fehske, F. Richter, and G. P. Fettwweis, "Energy efficiency improvements through micro site in cellular mobile radio networks," 2009 IEEE GLOBECOM Workshops, Honolulu, HI, pp. 1-5, December 2009.

[13] O. Arnold, F. Richter, G. Fettweis and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks," Future Network and Mobile Summit, pp. 1-8, 2010.

[14] D. Chee, M. S. Kang, H. Lee and B. C. Jung, "A study on the green cellular network with femtocells," 2011 Third International Conference on Ubiquitous and Future Networks, Dalian, China, pp. 235-240, June 2011.

[15] J. T. Louhi, "Energy efficiency of modern cellular base stations," 29th International Telecommunication Energy Conference, Rome, Italy, pp. 475-476, 30 September-4 October 2007.

[16] A. Bousia, A. Antonopoulos, L. Alonso and C. Verikoukis, "Green distance-aware base station sleeping algorithm in LTE-advanced," IEEE International Conference on Communication, Ottawa ON, pp. 1347-1351, 10-15 June 2012.

[17] Y. Ling, A. Goldsmith, G. Foschini, R. Valenzuela and D. Chizhik, "Evolution of base stations in cellular networks: denser deployment versus coordination," IEEE International Conference on. Communication, Beijing, China, May 2008.

[18] L. Chiaraviglio, D. Ciullo, M. Meo and M.A. Marsan, “Energy-aware UMTS access networks,” IEEE Workshop on Green Wireless, Lapland, Findland, pp. 1-8, September 2008.

[19] D. Willikomm, S. Machiraju, J. Bolot and A. Wolisz, “Primary user behavior in cellular networks and implications for dynamic spectrum access,” Communication Magazine, Vol. 42, pp. 88-95, March 2009.

[20] M. A. Marsan and M.Meo, “Energy efficient management of two cellular access networks,” ACM SIGMETRICS Performance Evolution Review, New York, NY, USA, Vol. 37, Issue 4, pp. 69-73, March 2010.

[21] S. Zhou, J. Gong, Z. Yang, Z. Niu and P. Yang, “Green mobile access network with dynamic base station energy saving,” ACM Mobile Communication, Vol. 9, No. 262, pp. 10-12, September 2009.

[22] G. P. Fettweis and E. Zimmermann, “ICT energy consumption trends and challenges,” IEEE International Symposium on Wireless Personal Multimedia Communications, pp.1-4, September 2008.

[23] K. Davaslioglu and E. Ayanoglu, “Quantifying potential energy efficiency gain in green cellular wireless networks,” IEEE Communication survey & tutorials, Vol. PP, Issue 99, 9 May 2014.

[24] Z. J. Hass, J. H. Winters and D. S. Johnson, “Simulation results of the capacity of cellular systems,” IEEE Transactions on Vehicular Technology, Vol. 46, No. 4, pp. 805-817, November 1997.

[25] B. Hashem and E. S. Sousa, “On the capacity of cellular DS/CDMA systems under slow rician/Rayleigh-fading channels,” IEEE Transactions on Vehicular Technology, Vol. 49 No. 5, pp. 1752-1759, September 2000.

[26] A. Sang, X. Wang, M. Madihian and R. D. Gitlin, "Coordinated load balancing, handoff/cell-site selection, and scheduling in multi-cell packet data systems," Wireless Network, Vol. 14, Issue 1, pp. 103-120, February 2008.

[27] Y. Qi, M. Imran and R. Tafazolli, "On the energy aware deployment strategy in cellular systems," IEEE International Symposium on Personal, Indoor and Mobile Radio Communications Workshops, Istanbul, pp. 363-367, 26-30 September 2010.

[28] M. A. Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, "Switch-off transients in cellular access networks with sleep modes," IEEE International Conference on Communication Workshops, Kyoto, pp. 1-6, 5-6 June 2011.

[29] T. Kang, X. Sun and T. Zhang, "Base station switching based dynamic energy saving algorithm for cellular networks," IEEE International Conference on Network Infrastructure and Digital Content, Beijing, China, pp. 66-70, 21-23 September 2012.

[30] Y. Zhu, T. Kang, T. Zhang and Z. Zeng "QoS-aware user association based on cell zooming for energy efficiency in cellular networks," International Symposium on Personal, Indoor and mobile Radio Communications: Workshop on End-to-End Green cellular Networks, London, pp. 6-10, 8-9 September 2013.

[31] B. S. Carminati, M. F. Costa and A. N. Barreto, "Virtual cell zooming and sleep mode for 3GPP-LTE green cellular networks," Symposium Brazilian Telecommunications. 01/2013.

[32] E. Oh, K. Son and B. Krishnamachari "Dynamic base station switching-on/off strategies for green cellular networks," IEEE Transactions on wireless communications, Vol. 12, No. 5, pp. 2126-2136, 29 May 2013.

[33] K. C. Tun and K. Kunavut, "Performance evolution of dynamic cell zooming algorithms in omni-directional and sector-based cells," International Joint Conference on Computer Science and Software Engineering, pp. 158-163, 2014.

[34] P. Yu, Q. Yang, F. Fu and K. S. Kwak, “Inter-cell cooperation aided dynamic base station switching for energy efficient cellular networks,” Asia-Pacific Conference on Communication, Jeju Island, pp. 159-163, 15-17 October 2012.

[35] Jie Gong, Sheng Zhou and Zhisheng Niu, “A dynamic programming approach for base station sleeping in cellular networks,” IEICE Transactions on Communications, Vol. E95-B, No.2, pp. 557-562, February 2012.

[36] H. Chen, Y. Jiang, J. Xu and H. Hu, “Energy-efficient coordinated scheduling mechanism for cellular communication systems with multiple component carriers,” IEEE Journal on selected areas in communications, Vol. 31, No. 5, pp. 959-968, 5 May 2013.

[37] J. Gong, J. S. Thompson, S. Zhou and Z. Niu, “Base station sleeping and resource allocation in renewable energy powered cellular networks,” IEEE Transactions on Communications, Vol. 62, Issue 11, pp.3801-3813, 2014.

[38] W. Gio and T. O’Farrell, “Dynamic cell expansion with self-organizing cooperation,” IEEE Journal on Selected Areas in Communications, Vol. 31, No. 5, pp. 851-860, May 2013.

[39] Y. S. Soh, T. Q. S. Quek and M. Kountouris, “Dynamic sleep mode strategies in energy efficient cellular networks,” IEEE International Conference on Communication, Budapest, pp. 3131-3136, 9-13 June 2013.

[40] S. Samarakoon, M. Bennis, W. Saad and M. Latva-aho, “Dynamic clustering and sleep mode strategies for small cell networks,” International Symposium on Wireless Communication Systems, Barcelona, Spain, pp. 934-938, 26-29 August 2014.

[41] F. Han, Z. Safan, W.S. Lin, Y. Chen and K. J. R. Liu, “Energy-efficient cellular network operation via base station cooperation,” IEEE International Conference on Communication , Ottawa, ON, pp. 4374-4378, June 2012.

[42] M. F. Hossain, K. S. Munasinghe and A. Jamalipour, “A protocooperation-based sleep-wake architecture for next generation green cellular access networks,” International

Conference on Signal Processing and Communication System, Gold Coast, GLD, Australia, pp. 1-8, December 2010.

[43] L. Xiang, F. Pantisano, R. Verdone, X. Ge and M. Chen, “Adaptive traffic load-balancing for green cellular networks,” IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Toronto, ON, Canada, pp. 41-45, September 2011.

[44] M. A. Marsan, L. Chiaraviglio, D. Ciullo and M. Meo, “Optimal energy savings in cellular access networks,” IEEE International Conference on Communications workshop, pp. 1-5, June 2009.

[45] E. Yaacoub, “Green communications in LTE networks with environmentally friendly small cell base stations,” 2012 IEEE Online Conference on Green Communications (GreenCom), Piscataway, NJ, USA, pp. 110-115, September 2012.

[46] M. F. Hossain, K. S. Munasinghe and A. Jamalipour, “On the energy efficiency of self-organizing LTE cellular access networks,” IEEE Global Communications Conference, Anaheim, CA, pp. 5314-5319, December 2012.

[47] K. Abdallah, I. Cerutti and P. Castoldi, “Energy-efficient coordinated sleep of LTE cells,” IEEE International Conference on Communications, Ottawa, ON, pp. 5238-5242, June 2012.

[48] L. Saker and S. E. Elayoubi, “Sleep mode implementation issues in green base stations,” IEEE 21st International Symposium on Personal Indoor and Mobile Radio Communication , Istanbul, pp. 1683-1688, September 2010.

[49] L. Saker, S. E. Elayoubi and T. Chahed, “Minimizing energy consumption via sleep mode in green base station,” IEEE Wireless Communications and Networking Conference, Sydney, NSW, pp. 1-6, April 2010.

[50] L. Saker, S. E. Elayoubi and H. O. Scheck, “System selection and sleep mode for energy saving in cooperative 2G/3G networks,” IEEE 70th Vehicular Technology Conference Fall, Anchorage, AK, USA, pp. 1-5, September 2009.

[51] I. Ashraf, F. Boccardi, and L. Ho, “SLEEP mode techniques for small cell deployments,” IEEE Communication Magazine, Vol. 49, Issue 8, pp. 72-79, August 2011.

[52] B. Rengarajan, G. Rizzo and M.A. Marsam, “Bounds on QoS-constrained energy savings in cellular access networks with sleep modes,” International Teletraffic Congress, San Francisco, CA, USA, pp. 47-54, 2011.

[53] P. Ghosh, S. S. Das, S. Naravaran and P. Chanhar, “Energy saving in OFDMA cellular systems using base-station sleep mode: 3GPP-LTE a case study,” National Conference on Communications, Kharagpur, pp. 1-5, February 2012.

[54] M. Nahas, S. Abdul-Nabi, L. Bouchnak and F. Sabeh, “Reducing energy consumption in cellular networks by adjusting transmitted power of base stations,” Symposium on Broadband Networks and Fast Internet, Baabda, Lebanon, pp. 39-44, May 2012.

[55] G. Cili, H. Yanikomeroglu and F. R. Yu, “Cell switch off technique combine with coordinated Multi-Point (CoMP) transmission for energy efficiency in beyond-LTE cellular networks,” IEEE Conference on Communications, Ottawa, ON, Canada, pp. 5931-5935, June 2012.

[56] T. Han and N. Ansari, “On green cellular networks via multicell cooperation,” IEEE Wireless Communications, Vol. 20, Issue 1, pp. 82-89, February 2013.

[57] L. Chiaraviglio, D. Ciullo, G. Koutitas, M. Meo and L. Tassiulas, “Energy-efficient planning and management of cellular networks,” Annual Conference on Wireless On-demand Network Systems and Services, Courmayeur, pp. 159-166, January 2012.

[58] L. Falconetti, P. Frenger, H. Kallin and T. Rimhagen, “Energy efficiency in heterogeneous networks,” IEEE Online Conference on Green Communication , Piscataway, NJ, UAS, pp. 98-103, September 2012.

[59] G. Micallef, P. Mogensen and H.-O. Scheck, “Cell size breathing and possibilities to introduce cell sleep mode,” European Wireless Conference, Lucca, pp. 111-115, April 2010.

[60] I. Ashraf, F. Boccardi, and L. Ho, “Power savings in small cell deployments via sleep mode techniques,” IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops, Istanbul, pp. 307-311, September 2010.

[61] R. Wang, J. S. and H. Hass, “A novel time-domain sleep mode design for energy-efficient LTE,” International Symposium on Communications, Control and Signal Processing, Limassol, pp. 1-4, March 2010.

[62] Z. Zhaohui, H. Saigui and H. Jiandong, “Capacity improvement with base station antenna arrays in cellular CDMA,” Mobile Technology for Human Race., IEEE 46th Vehicular Technology Conference, Vol. 2, Atlanta, GA, pp. 1303-1306, 1996.

[63] Z. Pi, “Optimal transmitter beamforming with per-antenna power constraints,” International Conference on Communication, Ottawa, ON, pp. 3779-3784, June 2012.

[64] F. Rashid-Farrokhi, “Joint optimal power control and beamforming in wireless networks using antenna arrays,” IEEE Transactions on Communication, Vol. 46, Issue 10, p.p 1313-1324, October 1998.

[65] K. I. Pedersen, “Directional power-based admission control for WCDMA systems using beamforming antenna array systems,” IEEE Transactions on Vehicular Technology, Vol. 51, Issue 6, pp. 1294-1303, November 2002.

[66] F. Tosa, “Comparisons of beamforming techniques for 4G wireless communications systems,” International Conference on Communication, Bucharest, pp. 271-174, June 2010.

[67] T. C. Quyen and T. A. Vu, “The application of a multibeam antenna for 4G,” The 2012 International Conference on advanced Technologies for Communications, Hanoi, pp. 227-230, October 2012.

[68] T. Baumgartner and E. Bonek, “On the optimum number of beams for fixed beam smart antennas in UMTS FDD,” IEEE Transactions on Wireless Communications, Vol. 5, No. 3, pp. 560-567, March 2006.

[69] M. Kitahara, Y. Ogawa and T. Ohgane, "A base station adaptive antenna for downlink transmission in a DS-CDMA system," IEEE 51st Vehicular Technology Conference Proceedings, Tokyo, Vol. 2, pp. 710-715, 15-18 May 2000.

[70] Z. Niu, Y. Wu, J. Gong and Z. Yang, "Cell zooming for cost-efficient green cellular networks," IEEE Communication Magazine, Vol. 48, Issue 11, pp. 74-79, November 2010.

[71] X. Weng, D. Cao and Z. Niu, "Energy-efficient cellular network planning under insufficient cell zooming," IEEE 73rd Vehicular Technology Conference, Yogohama, pp. 1-5, May 2011.

[72] B. Badic, T. O'Farrell, P. Loskot and J. HE, "Energy efficient radio access architectures for green radio: Large versus small cell size deployment," IEEE 70th Vehicular Technology Conference Fall, Anchorage, AK, pp. 1-5, September 2009.

[73] K. Lee, J. Lee, G. Park and J. K. Choi, "QoS and power consumption analysis of cooperative multicast scheme with cell zooming," Asia-Pacific Conference on Communications, Jeju Island, pp. 238-242, October 2012.

[74] L. Saker, S. E. Elayoubi, L. Rong and T. Chahed, "Capacity and energy efficiency of picocell deployment in LTE-A networks," IEEE Vehicular Technology Conference, Yogohama, pp. 1-5, May 2011.

[75] L. Saker, S.E. Elayoubi, T. Chahed and A. Gati, "Energy efficiency and capacity of heterogeneous network deployment in LTE-Advanced," 18th European Wireless Conference, Poznan, Poland, pp. 1-7, 2012.

[76] J. Christoffersson, "Energy efficiency by cell reconfiguration; MIMO to non-MIMO and 3-cell sites to Omni," IEEE 73rd Vehicular Technology Conference, Yokahama, pp. 1-5, May 2011.

[77] C. U.Saraydar and A. Yener, "Adaptive cell sectorization for CDMA syatems," IEEE Journal on Selected Areas in Communications, Vol. 19, Issue 6, pp. 1041-1051, June 20 01.

[78] A. M. Elmurtada, Y. N. Awad and M. G. Elnourani, “Adaptive smart antenna in 3G networks and beyond,” IEEE Student Conference on Research and Develpoment, Pulau, Pinang, pp. 148-153, December 2012.

[79] P. Gkonis, G. Tsoulos and D. I. Kaklamani, “Performance evolution of a beam-centric adaptive admission control for WCDMA cellular network with smart antennas” Mobile and Wireless Communication Summit, Budapest, pp. 1-5, July 2007.

[80] J. Zhang, J. Liu, Q. Zhang, W. Zhu, Bo Li and Y.-Q. Zhang, “An efficient algorithm for adaptive cell sectoring in CDMA systems,” IEEE International Conference on Communication, Vol. 2, pp. 1238-1242, May 2003.

[81] M. Mahmoudi, E. S. Sous and H. Alavi, “Adaptive sector size control in a CDMA system using butler matrix,” IEEE 49th Vehicular Technology Conference, Houston, TX, Vol. 2, pp. 1355-1359, July 1999.

[82] R. Giuliano, F. Mazzenga and F. Vatalaro, “Adaptive cell sectorization for UMTS third generation CDMA systems,” IEEE 53rd Vehicular Technology Conference, Rhodes, Vol. 1, pp. 219-223, 6-9 May 2001.

[83] T. Nguyen, P. Dassanayake and M. Faulkner, “Capacity of CDMA cellular systems with adaptive sectorisation and non-uniform traffic,” IEEE 54th Vehicular Technology Conference, Atlantic City, NJ, Vol. 2, pp. 1163-1167, 7-11 October 2001.

[84] Y. Qi, M. A. Imran and R. Tafazolli, “Energy-aware adaptive sectorisation in LTE syatems,” IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications, Toronto, ON, pp. 2402-2406, 11-14 September 2011.

[85] J. M. Kelif and M. Coupechoux, “Cell breathing, sectorization and densification in cellular networks,” International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks, Seoul, pp. 1-7, 23-27 June 2009.

[86] K. Samdanis, D. Kutscher and M. Brunner, “Dynamic energy-aware network re-configuration for cellular urban infrastructures,” IEEE Globecom 2010 Workshop on Green Communications, Miami, FL, pp. 1448-1452, 6-10 December 2010.

[87] S. H. Lee, Y. Choi, S. Park and S. H. Rhee, “An energy efficient power control mechanism for base stations in mobile communication systems,” International Conference on Information Networking, Barcelona, pp. 378-383, 26-28 January 2011.

[88] M. F. Hossain, K. S. Munasinghe and A. Jamalipour “Energy-aware dynamic sectorization of base stations in multi-cell OFDMA networks,” IEEE Wireless Communications Letters, Vol. 2, No. 6, pp. 587-590, December 2013.

[89]. M. F. Hossain, K. S. Munasinghe and A. Jamalipour, “Toward self-organizing sectorization of LTE eNBs for energy efficient network operation under QoS constraints,” IEEE Wireless Communication and Networking Conference, Shanghai, pp. 1279-1284, 2013.

[90] G. Li, S. Jin, F. Zheng, X. Gao and X. Wang “Dynamic base station sleeping scheme for potential super density networks,” International Conference on Wireless Communication & Signal Processing, Hangzhou, pp. 1-5, 24-26 October 2013.

[91] F. Athley, M. N. Johansson and A. Nilsson, “Increase sectorization: Horizontal or vertical?,” 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), Las Vegas, NV, pp. 1-5, 2-5 September 2013.

[92] L. G. Hevizi and I. Godor, “Power saving in mobile networks by dynamic base station secterization,” 2011 IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications , Toronto, ON, pp. 2415-2417, 11-14 September 2011.

[93] C. Han, T. Harrold, S. Armour, I. Krikidis, S. Videv, P. M. Grant, H. Haas, J. S. Thompson, I. Ku, C. X. Wang, T. A. Le, M. R. Nakhai, J. Zhang and L. Hanzo, “Green Radio: Radio techniques to enable energy-efficient wireless networks,” IEEE Communication Magazine, Vol. 49, No. 6, pp. 46-54, June 2011.

[94] V. Baiamonate and C. F. Chiasserini, “Saving energy during channel contention in 802.11 WLANs,” Mobile Network Applications, Vol. 11, No. 2, pp. 287-296, April 2006.

[95] S. Sayed, Y. Yang, H. Guo and H. Ho, “Analysis of energy efficiency of a busy tone based cooperative MAC protocol for multi-rate WLANs,” IEEE Wireless Communication and Networking Conference, Sydney, Australia, pp. 1-6, April 2010.

[96] X. Perez-Costa and D. Camps-Mur, “IEEE 802.11e Qos and power saving feature overview and analysis of combined performance,” IEEE Wireless Communications, Vol. 17, No. 4, pp. 88-96, August 2010.

[97] E. H. Ong, K. Mahata and J. Y. Khan, “Energy efficient architecture for green handsets in next generation IP-based wireless networks,” IEEE International Conference Communications, Kyoto, Japan, pp. 1-6, June 2011.

[98] R Muller, C. F. Ball, K. Ivanov, J. Lienhart and P. Hric, “Performance comparison between open loop and close loop uplink power control in UTRAN LTE networks,” International Conference on Wireless Communications and Mobile Computing Conference, pp. 1410-1416, New York, USA, June 2009.

[99] A. Simonsonsson and A. Furuskar, “Uplink power control in LTE-Overview and performance,” IEEE 68th Vehicular Technology Conference, Calgary, BC, pp. 1-5, September 2008.

[100] E. Tejaswi and B. Suresh, “Survey of power control schemes for LTE uplink,” International Journal of Computer Science and Information Technologies, Vol. 4, Issue 2, pp. 369-373, 2013.

[101] M. Boussif, C. Rosa and R. Mullner, “Load adaptive power control in LTE uplink,” European Wireless Conference, Lucca, Italy, pp. 288-293, April 2010.

[102] C. U. Castellanaos, D. L. Villa, C. Rosa and K. I. Pedersen, “Performance of uplink fractional power control in UTRAN LTE,” IEEE Vehicular Technology Conference, Singapore, pp. 2517-2521, May 2008.

[103] S. Essassi, M. Siala and S. Cherif, “Dynamic fractional power control for LTE uplink,” IEEE International Symposium on Personal Indoor and Mobile Radio Communications, Toronto, ON, Canada, pp. 1606-1610, September 2011.

[104] M. Lauridsen, A. R. Jensen and P. Mogensen, “Reducing LTE uplink transmission energy by allocating resources,” IEEE Vehicular Technology Conference, San Francisco, CA, pp. 1-5, September 2011.

[105] R Muller, C. F. Ball, K. Ivanov, J. Lienhart and P. Hric, “Contrasting open-loop and closed-loop power control performance in UTRAN LTE uplink by UE trace analysis,” IEEE International Conference on Communication, Dresden, pp. 1-6, June 2009.

[106] S. Purnachand, K. R. Prasad, K. S. Roy and A. Suresh, “Performance analysis of open loop and closed loop power control schemes fir LTE uplink,” International Journal of Computer Science and Information Technologies, Vol. 3, Issue 2, pp. 3683-3688, 2012.

[107] B. Muhammad and A. Muhammad, “Performance evaluation of uplink closed loop power control for LTE system,” IEEE Vehicular Technology Conference Fall, Anchorage, AK, USA, pp 1-5, 2009.

[108] M. Coupechoux and Jean-Marc Kelif, “How to set the fractional power control compensation factor in LTE?,” IEEE Sarnoff Symposium, Princeton, NJ, pp. 1-5, May 2011.

[109] J. Edson V. Bautista M. Malmirchegini, R. Yenamandra and K. R. Chaudhuri, “UE-based adaptive uplink power control to enhance cell capacity of LTE systems,” IEEE 81st Vehicular Technology Conference, Glasgow, pp. 11-14May 2015.

[110] L. Ding, J. He and Z. Liu, “A novel open loop power control method in LTE uplink,” International Conference on Wireless Communication, Networking and Mobile Computing, Shanghai, China, pp. 1-4, September 2012.

[111] S. Berger, B. Almeroth, V. Suryaprakash, P. Zanier, I. Viering and G. Fettweis, “Dynamic range-aware uplink transmit power control in LTE networks: establish an

operational range for LTE's open-loop transmit power control parameters (α, P_o)," IEEE Wireless Communications Letters, Vol. 3, No. 5, pp. 521-524, October 2014.

[112] A. Mesodiakaki, F. Adelantado, L. Alonso and C. Verikoukis, "Energy-efficient user association in cognitive heterogeneous networks," IEEE Communication Magazine, Vol. 52, Issue 7, pp. 22-29, July 2014.

[113] M. Naeem, U.Pareek and D. C. Lee, "Interference-aware joint user selection and quantized power control schemes for uplink cognitive multiple-input multiple-output system," IET Communications , Vol. 5, Issue 16, pp. 2266-2274, November 2011.

[114] L. Chen and G. Wei, "Distributed power control for uplink virtual multiple-input multiple-output cellular system," IET Communications, Vol. 6, Issue 12, pp. 1812-1820, August 2012.

[115] N. Cota, A. Serrador, A. R. Beire and A. Rodrigues, "On the use of Okumara-Hata model on railway communications," International Symposium on Wireless Multimedia Communications, pp. 1-5, 24-27 June 2013.

[116] A. R. Beire, N. Cota, H. Pita and A. Rodrigues, "Automatic tuning of Okumara-Hata model on railway communications," International Symposium on Wireless Multimedia Communications, Sydney, NSW, Australia, pp. 562-567, 7-10 September 2014.

[117] M. A. Alamoud and W. Schutz, "Okumara-Hata model tuning for TETRA mobile radio nerworks in Saudi Arabia," International Conference on Advances in Computational Tools for Engineering Applications, Beirut, Lebanon, pp. 47-51, 12-15 December 2012.

[118] M. Farhoud, Amr El-Keyi and A. Sultan, "Empirical correction of the Okumura-Hata model for the 900 MHz band in Egypt," 2013 3rd International Conference on Communication and Information Technology (ICCIT-2013): Wireless Communication and Signal Processing, Beirut, pp. 386-389, 19-21 June 2013.

[119] N. Elfadhil, M.A. Salam, A. Al-Lawait, O. Al-Qasmi, M. Al-Gheithi and Z. Nadir, "Modification of an open area Okumura-Hata propagation model suitable for Oman," IEEE Region 10 Conference, Melbourne, Qld, Australia, pp. 1-4, 21-24 November 2005.

[120] L. Akhoondzadeh-Asl and N. Noori, "Modification and tuning of the universal Okumura-Hata model for radio wave propagation predictions," Asia-Pacific Microwave Conference 2007, Bangkok, Thailand, pp. 1-4, 11-14 December 2007.

[121] A. Medeisis and A. Kajackas, "On the use of the universal Okumura-Hata propagation prediction model in rural areas," IEEE 51st Vehicular Technology Conference Proceedings, Tokyo, pp. 1815-1818, 15-18 May 2000.

[122] W. Bhupuok amd K. Dejhan, "A new method for prediction 3G path loss propagation in suburban of Thailand," International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Phetchaburi, Thailand, pp. 1815-1818, 16-18 May 2012.

[123] A. Vinaye and M. Ramraj, "Path loss analysis for 3G mobile networks for urban and rural regions of Mauritius," International Conference on Wireless and Mobile Communications, Valencia, Spain, pp. 164-169, 20-25 September 2010.

[124] Y. Singh, "Comparison of Okumura, Hata and COST-231 models on the basis of path loss and signal strength," International Journal of Computer Applications, Vol. 59, No. 11, pp. 74-79, 2011.

[125] R. V. Akhpashev and A. V. Andreev, "COST-231 Hata adaptation model for urban conditions in LTE networks," International Conference on Micro/Nanotechnologies and Electron Devices, Erlagol, Russia, pp. 64-66, 2016.

[126] T. S. Rappaport, "Wireless Communication: Principles and Practice," 2nd ed, New Jersey, Prentice Hall, 2002.

[127] S. R. Saunders and A. Aragn-Zarala, "Antenna and Propagation for Wireless Communication Systems," 2nd ed, John Wiley & Sons, 2007.

[128] Y. Okumura et al. "Field strength and its variability in VHF and UHF land mobile radio service," 16 Rev. of The Electronic Communication Lab, pp. 825-828, 1968.

[129] F. Ikegami, "Mobile radio communication in Japan," IEEE Transactions on Communication , Vol. 20, Issue 4, pp. 738-746, August 1972.

[130] N. Yoshikawa and T. Nomura, "On the design of small zone land mobile radio system in UHF band," IEEE Transactions on Vehicular Technology, Vol. 25, Issue 3, pp. 57-67, August 1976.

[131] M. Hata, "Empirical Formula for propagation loss in land mobile radio services," IEEE Transactions on Vehicular Technology, Vol. 29, No. 3, pp. 317-325, August 1980.

[132] E. Damosso, L. M. Correia and European Commission, "COST Action 231: Digital mobile radio towards future generation systems: Final report," European Commission, EUR 18957, 1999.

[133] N. Shabbir, M. T. Sadiq, H. Kashif and R. Ullah, "Comparison of radio propagation models for long term evolution (LTE) network ," International Journal of Next-Generation Networks, Vol. 3, No. 3, pp. 27-41, September 2011.

[134] D. Feng, C. Jiang, G. Lim, L. J. Cimini, G. Feng and G. Y. Li, "A survey of energy-efficient wireless communications," IEEE Communications Surveys & Tutorials, Vol. 15, Issue 1, pp. 167-178, February 2012.

[135] Y. S. Soh, T. Q. S. Quek, M. Kountouris and H. Shin, "Energy efficient heterogeneous cellular networks," IEEE Journal on Selected Areas in Communications, Vol. 31, Issue 5, pp. 840-850, May 2013.

[136] G. Y. Li, Z. Xu, C. Xiong, C. Yang, S. Zhang, Y. Chen and S. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," IEEE Wireless Communications, Vol. 18, Issue 6, pp. 28-35, December 2011.

[137] IMS Research, "Handset Power Requirements Dramatically Outpacing Capacity," 2009.

[138] 3GPP, Multiplexing and Channel Coding, TS 36.212 V 8.8.0. 2010, accessed 30 July 2017.

[139] 3GPP, UE radio transmission and reception, TS 36.101 V 8.20.0. 2013, accessed 30 July 2017.

[140] B. Kim, C. Kawak and J. Lee, "A dual-mode power amplifier with on-chip switch bias control circuits for LTE handsets," IEEE Transactions on Circuits and Systems II, Vol. 58, Issue 12, pp. 857-861, December 2011.

[141] H. Holma and A. Toskala, "WCDMA for UMTS-HSPA Evolution and LTE," 5th ed, John Wiley & Sons, 2010.

[142] Y. Li, J. Lopez. P.-H. Wu, W. Hu, R. Wu and D. Y. C. Lie, "A SiGe envelope-tracking power amplifier with an integrated CMOS envelop modulator for mobile WiMAX/3GPP LTE transmitters," IEEE Transactions on Microwave Theory and Techniques, Vol. 59, Issue 10, pp. 2525-2536, October 2011.

[143] J. Borremans, G. Mandal, V. Giannini, B. Debaillie, M. Ingels, T. Sano, B. Verbruggen and J. Craninekx, "A 40 nm CMOS 0.4-6 GHz receiver resilient to out-of-brand blockers," IEEE Journal of Solid-State Circuits, Vol. 46, Issue 7, pp. 1659-1671, July 2011.

[144] C. Studer, C. Benkeser, S. Belfanti and Q. Huang, "Design and implementation of parallel turbo-decoder ASIC for 3GPP-LTE," IEEE Journal of Solid-State Circuits, Vol. 46, Issue 1, pp. 8-17, January 2011.

[145] L. L. Hanzo, T. H. Liew, B. L. Yeap, R. Y. S. Tee and S. X. Ng, "Turbo Coding, Turbo Equalization and Space-Time Coding: EXIT-Chart-Aided Near Capacity Designs for Wireless Channels," Wiley-IEEE Press, 2011.

[146] 3GPP, Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, TS 36. 211 V 9.1.0. 2010, accessed 30 July 2017.

[147] E. Dahlman, S. Parkrall, J. Skold and P. Beming, "3G Evolution HSPA and LTE for Mobile Broadband," Academic Press, 2008.

[148] 3GPP, E-UTRA User Equipment (UE) radio transmission and reception, TS 36.101 V 9.4.0. 2010, accessed 30 July 2017.

[149] http://www.telecomsource.net/showthread.php?5346-What-is-Maximum-Allowed-Uplink-Transmission-power-of-the-UE, accessed 15 October 2016.

[150] NRPB report NRPB-R321., “Exposure to radio waves near mobile phone base stations” (Public Health, England, 2000), pp.1-55, 2000.

Appendix

MATLAB CODE

% Okumura/Hata Model

```
clc;

close all;

clear all;

d = 1:0.01:10;

hue = 1.5;

hbs=10;

hbs1 = 35;

hbs2 = 50;

hbs3 = 75;

fc = 100;

% a. For Large Cities

% fc  >= 400MHz

ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;
```

% A. Typical Urban

```
Plurban  = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs))*log10(d)  -
13.82*log10(hbs)  - ahm;
```

```
Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) -
13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) -
13.82*log10(hbs2) - ahm;

Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) -
13.82*log10(hbs3) - ahm;
```

% B. Typical Suburban

```
Plsuburban  = Plurban  - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban1 = Plurban1 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban2 = Plurban2 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban3 = Plurban3 - (2*(log10(fc/28)).^2 + 5.4);
```

% C. Typical Rural

```
Plrural  = Plurban  - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural1 = Plurban1 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural2 = Plurban2 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural3 = Plurban3 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

figure(1);

plot(d,  Plurban, '.r', d, Plurban1, 'r', d, Plurban2, '--r', d, Plurban3,':r');
```

```
hold on;

plot(d,  Plsuburban, '.b',d, Plsuburban1, 'b', d, Plsuburban2, '--b', d, Plsuburban3, ':b');

hold on;

plot(d, Plrural, '.g',d, Plrural1, 'g', d, Plrural2, '--g', d, Plrural3, ':g');

hold on;


legend('large urban hbs=10', 'large urban hbs=35', 'large urban hbs=50', 'large urban
hbs=75','suburban hbs=10','suburban hbs=35', 'suburban hbs=50', 'suburban
hbs=75','rural hbs=10', 'rural hbs=35', 'rural hbs=50','rural hbs=75');


grid on;

xlabel ('UE distance from the base station in km');

ylabel ('Pathloss in dB');

title('Pathloss of different base station using Okumura-Hata model');
```

%UE Transmit Power with different BTS height (Urban)

```
Po=-90;

alpha=0.8;

%Pl=0:25:150;

M=48;

d = 0:0.01:5;

hue = 1.5;

hbs  = 10;

hbs1 = 35;

hbs2 = 50;

hbs3 = 75;

fc = 100;

% a. For Large Cities

% fc  >= 400MHz

ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;
```

% A. Typical Urban

```
Plurban  = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs))*log10(d)  -
13.82*log10(hbs)  - ahm;
```

```
Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) -
13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) -
13.82*log10(hbs2) - ahm;

Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) -
13.82*log10(hbs3) - ahm;


PSDtx=Po+(alpha*Plurban)+(10*log(M));

PSDtx1=Po+(alpha*Plurban1)+(10*log(M));

PSDtx2=Po+(alpha*Plurban2)+(10*log(M));

PSDtx3=Po+(alpha*Plurban3)+(10*log(M));

figure(1);

plot(d,  PSDtx, 'r', d, PSDtx1, '--g', d, PSDtx2, 'b', d, PSDtx3,'--m');

hold on;


legend(' Urban hbs=10m', ' Urban hbs=35m', ' Urban hbs=50m', ' Urban
hbs=75m','suburban hbs=10','suburban hbs=35', 'suburban hbs=50', 'suburban
hbs=75','rural hbs=10', 'rural hbs=35', 'rural hbs=50','rural hbs=75');


%grid on;

xlabel ('UE distance from the base station in km');

ylabel ('UE Transmit Power [dBm]');

title('UE Transmit Power with Different BTS height (Urban)')
```

%UE Transmit Power with different BTS height (Suburban)

```
Po=-90;

alpha=0.8;

%Pl=0:25:150;

M=48;

d = 0:0.01:5;

hue = 1.5;

hbs  = 10;

hbs1 = 35;

hbs2 = 50;

hbs3 = 75;

fc = 100;

% a. For Large Cities

% fc  >= 400MHz


ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;
```

% A. Typical Urban

```
Plurban  = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs))*log10(d)  -
13.82*log10(hbs)  - ahm;
```

```
Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) -
13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) -
13.82*log10(hbs2) - ahm;

Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) -
13.82*log10(hbs3) - ahm;


% B. Typical Suburban


Plsuburban  = Plurban  - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban1 = Plurban1 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban2 = Plurban2 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban3 = Plurban3 - (2*(log10(fc/28)).^2 + 5.4);


PSDtx=Po+(alpha*Plsuburban)+(10*log(M));

PSDtx1=Po+(alpha*Plsuburban1)+(10*log(M));

PSDtx2=Po+(alpha*Plsuburban2)+(10*log(M));

PSDtx3=Po+(alpha*Plsuburban3)+(10*log(M));

figure(1);

plot(d,  PSDtx, 'r', d, PSDtx1, '--g', d, PSDtx2, 'b', d, PSDtx3,'--m');

hold on;
```

```
legend(' Suburban hbs=10m', ' Suburban hbs=35m', ' Suburban hbs=50m', ' Suburban
hbs=75m','suburban hbs=10','suburban hbs=35', 'suburban hbs=50', 'suburban
hbs=75','rural hbs=10', 'rural hbs=35', 'rural hbs=50','rural hbs=75');

%grid on;
xlabel ('UE distance from the base station in km');
ylabel ('UE Transmit Power [dBm]');
title('UE Transmit Power with Different BTS height (Suburban)')
```

%UE Transmit Power with different BTS height (Rural)

```
Po=-90;
alpha=0.8;
%Pl=0:25:150;
M=48;
d = 0:0.01:5;
hue = 1.5;
hbs  = 10;
hbs1 = 35;
hbs2 = 50;
hbs3 = 75;
fc = 100;
```

% a. For Large Cities

% fc >= 400MHz

ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;

% A. Typical Urban

Plurban = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs))*log10(d) - 13.82*log10(hbs) - ahm;

Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) - 13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) - 13.82*log10(hbs2) - ahm;

Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) - 13.82*log10(hbs3) - ahm;

% C. Typical Rural

Plrural = Plurban - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural1 = Plurban1 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural2 = Plurban2 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural3 = Plurban3 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

PSDtx=Po+(alpha*Plrural)+(10*log(M));

PSDtx1=Po+(alpha*Plrural1)+(10*log(M));

```
PSDtx2=Po+(alpha*Plrural2)+(10*log(M));

PSDtx3=Po+(alpha*Plrural3)+(10*log(M));

figure(1);

plot(d,  PSDtx, 'r', d, PSDtx1, '--g', d, PSDtx2, 'b', d, PSDtx3,'--m');

hold on;


legend(' Rural hbs=10m', ' Rural hbs=35m', ' Rural hbs=50m', ' Rural hbs=75m','suburban
hbs=10','suburban hbs=35', 'suburban hbs=50', 'suburban hbs=75','rural hbs=10', 'rural
hbs=35', 'rural hbs=50','rural hbs=75');


%grid on;

xlabel ('UE distance from the base station in km');

ylabel ('UE Transmit Power [dBm]');

title('UE Transmit Power with Different BTS height (Rural)')
```

% PSDtx VS Distance (Varies Alpha)

Po=-54.5;

alpha=0.4;

%Pl=0:25:150;

M=48;

d = 0:0.01:10;

hue = 1.5;

hbs1 = 35;

hbs2 = 50;

hbs3 = 75;

fc = 100;

% a. For Large Cities

% fc >= 400MHz

ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;

% A. Typical Urban

Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) - 13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) - 13.82*log10(hbs2) - ahm;

```
Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) -
13.82*log10(hbs3) - ahm;
```

% B. Typical Suburban

```
Plsuburban1 = Plurban1 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban2 = Plurban2 - (2*(log10(fc/28)).^2 + 5.4);

Plsuburban3 = Plurban3 - (2*(log10(fc/28)).^2 + 5.4);
```

% C. Typical Rural

```
Plrural1 = Plurban1 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural2 = Plurban2 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

Plrural3 = Plurban3 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);


PL = (40*log10(d)+13.47-(14*log10(hbs3))-(14*log10(hue))+(6*log10(fc/5)));

PSDtx = Po+(alpha*Plsuburban3)+(10*log10(M));

plot (d, PSDtx, 'g');

hold on;

xlabel ('UE Transmit Power [dBm]');

ylabel ('CDF');

title ('UE VS CDF with Different Pathloss');
```

% PSDtx VS Distance (Varies M)

```
Po=-100;

alpha=1;

%Pl=0:25:150;

M=48;

d = 0:0.01:10;

hue = 1.5;

hbs1 = 35;

hbs2 = 50;

hbs3 = 75;

fc = 100;

% a. For Large Cities

% fc  >= 400MHz

ahm = 3.2*(log10(11.75*hue)).^2 - 4.97;
```

% A. Typical Urban

```
Plurban1 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs1))*log10(d) -
13.82*log10(hbs1) - ahm;

Plurban2 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs2))*log10(d) -
13.82*log10(hbs2) - ahm;
```

```
Plurban3 = 69.55 + 26.16*log10(fc) + (44.9 - 6.55*log10(hbs3))*log10(d) -
13.82*log10(hbs3) - ahm;

% B. Typical Suburban

Plsuburban1 = Plurban1 - (2*(log10(fc/28)).^2 + 5.4);
Plsuburban2 = Plurban2 - (2*(log10(fc/28)).^2 + 5.4);
Plsuburban3 = Plurban3 - (2*(log10(fc/28)).^2 + 5.4);

% C. Typical Rural

Plrural1 = Plurban1 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);
Plrural2 = Plurban2 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);
Plrural3 = Plurban3 - (4.78*(log10(fc)).^2 + 18.33*log10(fc) - 40.94);

PL = (40*log10(d)+13.47-(14*log10(hbs3))-(14*log10(hue))+(6*log10(fc/5)));

PSDtx = Po+(alpha*Plurban3)+(10*log10(M));
plot (d, PSDtx, '--b');
hold on;
xlabel ('UE Distance From Base Station [km]');
ylabel ('UE transmit power[dBm]');
```

```
%grid on;

title ('OLPC transmit(dBm) of different Po value vs distance, alpha=1');
```