



3D FEMTOCELL PATH LOSS MODEL IN WIRELESS
NETWORKS

BY

ALHARETH M T ZYOD

A thesis submitted in fulfilment of the requirement for the
degree of Doctor of Philosophy (Engineering)

Kulliyyah of Engineering
International Islamic University Malaysia

NOVEMBER 2017

ABSTRACT

Femtocells are home access points installed by end consumers inside their houses which are an important and a promising technology in future wireless networks. It was proposed as a solution to the indoor propagation problems and to increase the indoor bandwidth. However, many challenges need to be addressed before deployment of femtocells. One of the most important challenges are assessing and mitigating the interference. In order to calculate the Signal to Interference plus Noise Ratio (SINR), an accurate path loss model is required. Most of the studies in the open literature considered a two dimensional scenarios where the femtocell has specific location and uniformly distributed in the network. On the contrary, this research will consider more practical scenarios where the femtocell is randomly distributed in a three Dimensional (3-D) environment to accommodate interference from cells spaced horizontally on a terrestrial access or stacked vertically as in the case for office or residential towers. The vertical interference is still not considered in the open literature yet. The most important parameter that should be considered once calculating the interference is the path loss. Since femtocell is installed in an indoor environment, this thesis addresses only the indoor propagation channel. Most of the available propagation models are for long range communication networks like macro and micro cellular networks. Models for femtocell networks, where the effects of walls and floors are considered, appeared to be necessary. In this research six different models of indoor propagation were studied and compared with measured data. Comprehensive measurements were conducted in a four storey building using most popular frequencies for Long-Term Evolution (LTE) networks of 1.8 and 2.6 GHz. Three different scenarios with different numbers of penetrated walls and floors were considered. The results were analyzed statistically using linear and non-linear regression methods. Further, a three dimensional path loss model based on two distance concept is proposed for indoor femtocells. In this model, the path loss intercept is made equal to the free space losses. Two path loss exponents were proposed. The first one is the vertical exponent that equals 7.62, and was inferred based on the vertical propagation measurements. The second path loss exponent is the horizontal one (variable) and it is found to be a function of transmitter and receiver heights. This model is found to be suitable for applications in LTE wireless networks and maybe applied in both LTE and LTE-Advanced (LTE-A) system level simulators. In addition, path loss has been evaluated in terms of various antenna aspects such as polarization and directivity. Finally a three dimensional system level simulator is developed and integrated into the famous Vienna LTE simulator in order to help the researcher in LTE femtocell field to analyze and investigate more real scenarios of femtocell deployment. The developed simulator allows the researcher to locate a multi-storey building in the region of interest, choose the number of floors, determine the ceiling height, and allocate the position of the femtocell inside the house. The proposed three dimensional indoor propagation model is implemented in the simulator and is used to assess and model interference. Different parameters such as Signal to Interference plus Noise Ratio (SINR), and throughput, were studied especially for vertically stacked femtocells. Results indicate the validity of the proposed 3-D model and confirm that it is a more realistic tool for assessment and model of femtocell interference.

خلاصة البحث

تعتبر محطة الإتصالات المنزلية المسماة (Femtocell) من التقنيات المهمة والواعدة في مجال الإتصالات اللاسلكية. حيث تم إقترانها لحل مشكلة ضعف إشارة الإتصال داخل المنزل. مع ذلك، هناك العديد من التحديات التي يجب التغلب عليها قبل تطبيق هذه التقنية. ومن أهم هذه التحديات هي مشكلة التداخل الحاصل في الإشارة. لحساب هذا التداخل بشكل دقيق فإن الأمر يتطلب وجود نموذج دقيق لحساب الخسائر الناتجة عن إنتقال الإشارة من المرسل للمستقبل. غالبية الدراسات السابقة بسطت الموضوع بإعتماد نموذج ثنائي الأبعاد بين المرسل والمستقبل. على العكس من ذلك، تهدف هذه الدراسة لدراسة أمثلة أكثر واقعية بإعتماد محيط ثلاثي الأبعاد بين المرسل والمستقبل وبفرض توزيع عشوائي لمحطة (Femtocell) كما هو الواقع في البنايات السكنية. لم يتم التطرق للتداخل العمودي سابقا. كون التطبيق لمحطة (Femtocell) سيكون داخل البنايات فإنه سيتم التطرق للنماذج الخاصة بالأماكن الداخلية فقط. غالبية النماذج السابقة تم إقترانها لمسافات طويلة بين المرسل والمستقبل ولكن هذا الوضع مختلف لمحطة (Femtocell) كون المسافة قصيرة بين المرسل والمستقبل وقد يتخللها بعض الجدران الداخلية والأسقف. في هذا البحث تم دراسة 6 نماذج سابقة لتوقع الخسائر بين المرسل والمستقبل ومقارنتها مع بيانات واقعية تم قياسها في 3 مباني مكونة من 4 طوابق وبتقسيمات داخلية مختلفة. تمت عملية القياس على الترددات الأكثر إستخداما في شبكات الجيل الرابع (LTE) وهي 2.6 و 1.8 غيغاهيرتز. تم تحليل البيانات بإستخدام طرق الإحصاء الخطية وغير الخطية. وبناء عليه تم إقتران نموذج جديد لحساب الخسائر بين المرسل والمستقبل. النموذج المقترح يعتمد على المسافة غير المباشرة بين المرسل والمستقبل (المسافة العمودية والمسافة الأفقية). وبناء عليه تم إقتران معاملي ميل أحدهما عمودي ومقداره 7.62 والآخر أفقي ويعتمد على إرتفاع المرسل والمستقبل. بالإضافة لذلك تم دراسة تأثير تغيير قطبية الهوائي ومدى توجيهه على الخسائر المنتوقعة للإشارة. وأخيرا، تم تطوير برنامج محاكاة أكثر واقعية بحيث يمكن للباحث دراسة أمثلة ثلاثية الأبعاد كما الحياة الواقعية. بحيث يمكن إضافة مبنى مكون من أكثر من طابق وإضافة محطة (Femtocell) في كل طابق والتحكم بإرتفاع السقف ومكان المحطة ودراسة مدى التداخل بين هذه المحطات بعضها ببعض والمحطة الرئيسية وتأثير ذلك على المستخدمين. بعد إضافة النموذج المقترح الى البرنامج المطور يمكن للباحث دراسة أكثر من معامل خاص بالشبكات مثل نسبة التداخل (SINR) والفعالية ونسبة التغطية. النتائج أظهرت مدى فعالية البرنامج المقترح لأمثلة أكثر واقعية خاصة بمحطة (Femtocell).

APPROVAL PAGE

The thesis of Alhareth M T Zyoud has been approved by the following:

Mohamed Hadi Habaebi
Supervisor

Md. Rafiqul Islam
Co-Supervisor

Mohamed Umar Siddiqi
Internal Examiner

Shahrul Kamal B. Abd Rahim
External Examiner

Aduwati Binti Sali
External Examiner

Md. Yousuf Ali
Chairman

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Alhareth M T Zyoud

Signature

Date

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR
USE OF UNPUBLISHED RESEARCH**

**3D FEMTOCELL PATH LOSS MODEL IN WIRELESS
NETWORKS**

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

Copyright © 2017 Alhareth M T Zyoud and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Alhareth M T Zyoud

.....
Signature

.....
Date

ACKNOWLEDGEMENTS

Praise and thanks are due to Allah, the lord and the Creator. His bounties on me are countless. This work would not complete without His guidance and support. I pray to Allah that He accepts from me this humble work and account it in my good deeds.

The advice and directions of Assoc. Prof. Dr. Mohamed Hadi Habaebi, my advisor, can never be forgotten. He pushed me to reach my limits in a very genteel and polite way. His continuous encouragement, invaluable comments, fruitful suggestions and consistent guidance are highly appreciated. I have learned a lot from working with him. I owe my thanks to him for all that. I would like to express my deep and grateful thanks to my co-supervisor Prof. Dr. Md. Rafiqul Islam for his excellent help, timely suggestion, guidance and active support. Special thanks are also extended to Assoc. Prof. Dr Jalel Chebil for his invaluable help in pursuing my PhD.

My sincere thanks go to every person who cooperated with me to finish this study, especially Dr Samer Zain, Mohd Shukur Ahmad, Abdul Rahmat Abdul Latiff, Mohd Norazizi Bin Hamzah, Ali Lwas, Mohammed Al shibly, and Ahmed Badawi. May Allah reward them all.

Finally special thanks are due to parents, wife, daughter, brothers and sisters who consistently encouraged me to follow higher studies.

TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Approval Page	iv
Declaration	v
Copyright Page	vi
Acknowledgements	vii
List of Tables	x
List of Figures	xi
List of Abbreviation	xvii
List of Symbols	xix
CHAPTER ONE: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Philosophy	3
1.4 Research Objectives	4
1.5 Research Scope	5
1.6 Research Methodology	5
1.7 Thesis Outline	9
CHAPTER TWO: LITERATURE REVIEW	11
2.1 Introduction	11
2.2 Indoor Propagation Models	12
2.2.1 WINNER II D112 V1.2 Model	13
2.2.2 ITU-R M.2135-1/ 3GPP TR 36.914 Model	14
2.2.3 COST 231 Models	15
2.2.4 ITU-R P1238-7 Model	16
2.2.5 The Multi Wall Multi Floor Model (MWMF)	17
2.2.6 IEEE 802.11n Model	18
2.2.7 Esposti Model	18
2.3 Three Dimensional Indoor Propagation Models	20
2.4 Antenna Parameters	23
2.5 Link And System Level Simulators	25
2.5.1 Link Level Simulators	26
2.5.2 L2S Models	27
2.5.3 System Level Simulators	27
2.6 Interference Mitigation Schemes	29
2.6.1 Centralized Schemes	33
2.6.1.1 Clustering or Grouping	33
2.6.1.2 Dynamic Sub-channel Allocation	35
2.6.1.3 Self Organization	35
2.6.2 Distributed Schemes	36
2.6.2.1 Aware Schemes	36
2.6.2.2 Non-Aware Schemes	38
2.7 Chapter Summary	44

CHAPTER THREE: METHODOLOGY	45
3.1 Introduction.....	45
3.2 Data Collection and Data Analyses	45
3.3 Mathematical Modelling.....	57
3.4 Simulation Approach.....	64
3.5 Chapter Summary	71
CHAPTER FOUR: 3-D PATH LOSS AND INTERFERENCE MODELLING	72
4.1 Introduction.....	72
4.2 Two Dimensional Path Loss Model	73
4.2.1 Path Loss	73
4.2.2 Model Validation	79
4.3 Three Dimensional Path Loss Model	80
4.3.1 Comparison of the Measured Data to That of Previous Models	80
4.3.2 Proposed 3-D Model	84
4.3.3 Validation of the 3-D Model.....	94
4.3.4 Shadow Fading.....	97
4.4 Antenna Parameters	99
4.4.1 Antenna Polarization.....	99
4.4.2 Antenna directivity.....	103
4.5 Chapter Summary	109
CHAPTER FIVE: 3-D SYSTEM LEVEL SIMULATOR	111
5.1 Introduction.....	111
5.2 Verification of the Developed SLS.....	113
5.3 Investigation of SINR.....	117
5.4 Investigation of UE Throughput.....	125
5.5 Chapter Summary	127
CHAPTER SIX: CONCLUSION AND FUTURE WORKS	129
6.1 Conclusion	129
6.2 Contributions	132
6.3 Future Works and Recommendations.....	133
REFERENCES	135
LIST OF PUBLICATIONS	146
APPENDICES	147
Appendix A.....	147
Appendix B.....	152
Appendix C.....	156
Appendix D.....	157
Appendix E.....	158

LIST OF TABLES

	<u>Page No.</u>
Table 2.1 Parameters of previous 2-D models	19
Table 2.2 Parameters of previous 3-D models	21
Table 2.3 Review of system level simulators	29
Table 3.1 Measurement scenarios	54
Table 3.2 Simulation parameters that are employed in the execution time comparison process.	68
Table 4.1 RMSE for different indoor scenarios	79
Table 4.2 Path Penetration Loss for Different Obstruction Levels	83
Table 4.3 Parameters of modelling approaches	85
Table 4.4 Indoor path loss parameters at 2.6 GHz for different scenarios	94
Table 4.5 Indoor path loss parameters at 1.8 GHz for laboratory	94
Table 4.6 RMSE for proposed and previous models	95
Table 4.7 RMSE for proposed and previous models	99
Table 4.8 Additional path loss due to polarization.	103
Table 5.1 Simulation parameter settings (3GPP, 2009; 2010; 2012; 2016).	112
Table 5.2 Debugging parameters for distance close the microcell	114
Table 5.3 Debugging parameters for distance in the middle of ROI the microcell	115
Table 5.4 Debugging parameters for distance in the edge of ROI the microcell	116

LIST OF FIGURES

	<u>Page No.</u>
Figure 1.1 Femtocell network architecture (Small cell forum, 2008).	1
Figure 1.2 Flow chart of the research.	8
Figure 2.1 Indoor scenarios layout for WINNER II models (Winner II, 2008).	13
Figure 2.2 Indoor environment (one floor) for ITU-R M.2135-1/ 3GPP TR 36.914 model (ITU-R, 2009).	14
Figure 2.3 Wireless system simulation process (Hanzaz & Schotten, 2013).	26
Figure 2.4 Building configuration (a) dual stripe blocks and (b) 5 X 5 apartment grid (Ubisse & Ventura, 2011).	28
Figure 2.5 Interference management scheme using FFR (Lee T. et al., 2010a).	38
Figure 2.6 Proposed frequency band/time slots allocation with FFR for macrocells (Kim and Lee, 2008).	39
Figure 2.7 Proposed sub-channel allocation (Oh C.-Y. et al, 2010).	40
Figure 2.8 SFR 3/7 scheme (Kosta et al., 2011).	40
Figure 3.1 Agilent signal generator	46
Figure 3.2 Advantest spectrum analysers	47
Figure 3.3 Keysight spectrum analysers	47
Figure 3.4 L-com directional antenna	48
Figure 3.5 L-com Omni-directional antenna	48
Figure 3.6 Birds Technology omni-directional antenna	48
Figure 3.7 Test of the transmitted signal	49
Figure 3.8 Test of the received signal	50
Figure 3.9 Layout of considered indoor scenarios at laboratory a) top view; b) side view	51
Figure 3.10 Layout of considered indoor scenarios at class room top view	52

Figure 3.11 Layout of considered indoor scenarios at corridor top view	52
Figure 3.12 Example of received signal strength in different scenarios	55
Figure 3.13 Measured and averaged path loss at 2.6 GHz at scenario 11.	56
Figure 3.14 Measured and averaged path loss at 2.6 GHz at scenario 23.	56
Figure 3.15 Measured and averaged path loss at 2.6 GHz at scenario 27.	57
Figure 3.16 MATLAB curve fitting tool	62
Figure 3.17 Imported data from work space	62
Figure 3.18 MATLAB curve fitting general models	63
Figure 3.19 Fitting options	63
Figure 3.20 Example of data fitting	64
Figure 3.21 Example of fitted coefficient and fit results	64
Figure 3.22 LTE Link-to-System model (Ikuno, 2013).	66
Figure 3.23 Inputs of LTE SLS.	67
Figure 3.24 Simulation time as a function of number of floors for 1 microcell with 5 users per sector and 2 users per femtocell.	68
Figure 3.25 Simulation time as a function of number of microcells with 5 users per microcell sector and 2 users per femtocell.	69
Figure 3.26 Simulation time as a function of number of users per microcell for 1 microcell and 2 users per femtocell.	69
Figure 3.27 Simulation time as a function of number of users per femtocell for 1 microcell with 5 users per sector.	70
Figure 4.1 Estimated path loss as a function of distance at 2.6 GHz.	73
Figure 4.2 Measured and models at 1.8 GHz at scenario 12.	75
Figure 4.3 Measured and models at 2.6 GHz at scenario 10.	75
Figure 4.4 Measured and models at 2.6 GHz at scenario 11.	75
Figure 4.5 Measured and models at 2.6 GHz at scenario 12.	76
Figure 4.6 Measured and models at 2.6 GHz at scenario 23 LOS.	76
Figure 4.7 Measured and models at 2.6 GHz at scenario 23 NLOS.	76

Figure 4.8 Measured and models at 2.6 GHz at scenario 27.	77
Figure 4.9 Averaged actual and fitted path loss at 2.6 GHz at scenario 23 NLOS.	77
Figure 4.10 Path loss for different paths with omni-directional Tx and omni-directional Rx.	78
Figure 4.11 Comparison of measured data and previous path loss models at scenario 5.	81
Figure 4.12 Comparison of measured data and previous path loss models at scenario 6.	81
Figure 4.13 Comparison of measured data and previous path loss models at scenario 14.	82
Figure 4.14 Comparison of measured data and previous path loss models at scenario 15.	82
Figure 4.15 Measured data at multi-floors as a function of direct distance at classroom.	86
Figure 4.16 Measured data at multi-floors as a function of direct distance at laboratory.	87
Figure 4.17 Vertical path loss at classroom (Scenario 20 and Scenario 21) at 2.6 GHz.	88
Figure 4.18 Vertical path loss at corridor (Scenario 25 and Scenario 26) at 2.6 GHz.	89
Figure 4.19 Vertical path loss at laboratory (Scenario 3 and Scenario 4) at 1.8 GHz.	89
Figure 4.20 Vertical path loss at laboratory (Scenario 7 and Scenario 8) at 2.6 GHz.	89
Figure 4.21 Vertical path loss for different indoor depth at 2.6 GHz.	90
Figure 4.22 Vertical path loss for different indoor depth at 2.6 GHz.	90
Figure 4.23 Vertical path loss for different indoor depth at 1.8 GHz.	91
Figure 4.24 Vertical path loss for different indoor depth at 1.8 GHz.	91
Figure 4.25 Measured data at multi-floors as a function of horizontal distance (d_2) at classroom.	92
Figure 4.26 Measured data at multi-floors as a function of horizontal distance at laboratory.	92

Figure 4.27 Comparison of measured data and proposed model at scenario 5.	95
Figure 4.28 Comparison of measured data and proposed model at scenario 6.	96
Figure 4.29 Comparison of measured data and proposed model at scenario 14.	96
Figure 4.30 Comparison of measured data and proposed model at scenario 15.	96
Figure 4.31 Shadow fading at same floor scenarios.	97
Figure 4.32 Shadow fading at one floor scenarios.	98
Figure 4.33 Shadow fading at two floors scenarios.	98
Figure 4.34 Shadow fading at vertical scenarios.	98
Figure 4.35 Path loss as a function of distance for different antenna polarizations for classroom at Scenario 23.	99
Figure 4.35 Path loss as a function of distance for different antenna polarizations for corridor at Scenario 27.	100
Figure 4.36 Path loss as a function of distance for different antenna polarizations for laboratory at Scenario 12.	100
Figure 4.38 Path loss as a function of distance for different antenna polarizations for classroom at Scenario 22.	101
Figure 4.39 Path loss as a function of distance for different antenna polarizations for classroom at Scenario 24.	101
Figure 4.40 Path loss as a function of distance for different antenna polarizations for corridor at Scenario 28.	102
Figure 4.41 Path loss as a function of distance for different antenna polarizations at Scenario 25.	102
Figure 4.42 Path loss as a function of distance for different antenna polarizations at Scenario 26.	102
Figure 4.43 Example of antenna gain pattern.	103
Figure 4.44 Path loss as a function of distance for different antenna directivity at Scenario 12.	104
Figure 4.45 Path loss as a function of distance for different antenna directivity at Scenario 23 NLOS.	104

Figure 4.46	Path loss for different paths with directional Tx and omnidirectional Rx.	105
Figure 4.47	Path loss as a function of distance for different antenna directivity at Scenario 10.	106
Figure 4.48	Path loss as a function of distance for different antenna directivity at Scenario 11.	106
Figure 4.49	Path loss as a function of distance for different antenna directivity at Scenario 22.	107
Figure 4.50	Path loss as a function of distance for different antenna directivity at Scenario 24.	107
Figure 4.51	Path loss as a function of distance for different antenna directivity at Scenario 28.	107
Figure 4.52	Path loss as a function of distance for different antenna directivity at Scenario 6.	108
Figure 4.53	Path loss as a function of distance for different antenna directivity at Scenario 20.	108
Figure 4.54	Path loss as a function of distance for different antenna directivity at Scenario 26.	108
Figure 5.1	Simulated ROI for 2-D simulators	114
Figure 5.2	Simulated ROI for 3-D simulators	115
Figure 5.3	Path loss difference with distance for two UEs at the third and ground floors.	117
Figure 5.4	Layout of simulated ROI.	118
Figure 5.5	Maximum SINR map for all cells at ROI.	119
Figure 5.6	SINR map of vertically stacked femtocell over the ROI at four different floors using dual slope model.	120
Figure 5.7	SINR map of femtocell deployed at ground floor on other floors using dual slope model.	120
Figure 5.8	SINR map of vertically stacked femtocell over the ROI at four different floors using dual slope model plus floor losses factor.	121
Figure 5.9	SINR map of femtocell deployed at ground floor on other floors using dual slope model plus floor losses factor.	122
Figure 5.10	SINR map of vertically stacked femtocell over the ROI at four different floors using proposed 3-D path loss model.	123

Figure 5.11 SINR map of femtocell deployed at ground floor on other floors using proposed 3-D path loss model.	123
Figure 5.12 SINR map of femtocell deployed at second floor on other floors using proposed 3-D path loss model.	124
Figure 5.13 Layout of simulated ROI for different femtocell deployment scenarios.	125
Figure 5.14 Cumulative distribution function of average throughput using dual slope model.	126
Figure 5.15 Cumulative distribution function of average throughput using dual slope model plus floor losses factor.	127
Figure 5.16 Cumulative distribution function of average throughput using 3-D path loss model.	127

LIST OF ABBREVIATION

2-D	Two-dimensional
3-D	Three-dimensional
3GPP	3rd Generation Partnership Project
AI	Available Interval
CINR	Carrier to Interference plus Noise Ratio
CSG	Closed Subscriber Group
dB	Decibel
DL	Downlink
EESM	Exponential Effective SINR Mapping
FFR	Fractional Frequency Reuse
GSM	Global System for Mobile Communications
HSS	Home Subscriber Server
HSG	Hybrid Subscriber Group
ITU-R	International Telecommunication Union – Radio communication Sector
L2S	Link to System model
LA	Link Adaptation
LCS	Location Services
LDO	Low Duty Operation
LTE	Long Term Evolution
LTE-Advanced	Long Term Evolution (LTE)-Advanced
MIMO	Multiple Input Multiple Output

MIESM	Mutual Information Effective SINR Mapping
NS-3	Network Simulator-3
OFDMA	Orthogonal Frequency Division Multiple Access
OSG	Open Subscriber Group
PRB	Physical Resource Block
QoS	Quality of Service
RBs	Resource Blocks
RMSE	Root Mean Square Error
RR	Round Robin
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio SNR
SISO	Single Input Single Output
SFR	Soft Frequency Reuse
TTI	Transmission Time Interval
UEs	User Equipments
UMTS	Universal Mobile Telecommunication System
UAI	Unavailable Interval
WCDMA	Wideband Code Division Multiple Access
WINNER	Wireless World Initiative New Radio
WiMAX	Worldwide Interoperability for Microwave Access

LIST OF SYMBOLS

D	diameter
d	distance
f	frequency
F_L	Floor losses factor
L_{FSL}	Free space path loss
L_o	The path loss at the reference distance
n_f	Number of floor
n_w	Number of walls
PL	Path Loss
α	Path loss exponent
λ	The wave length
β	Frequency dependent Factor

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The rapid development of smart phones and tablet PCs has transformed cellular networks from being essentially voice networks to becoming mostly data networks. This has led to unpredictable growth in global mobile and internet data traffic rate. In consequence, it is expected that monthly global mobile and tablet data traffic will exceed 30.6 Exabyte in 2020 (Cisco, 2016). Moreover, the attenuation of cellular signal inside buildings reduces the signal strength and causes the signal not to be available in some regions, since the macrocell signals do not penetrate walls. Thus, to overcome the rapid increase in the traffic data and to solve the indoor coverage problem, small cells called femtocells are introduced.

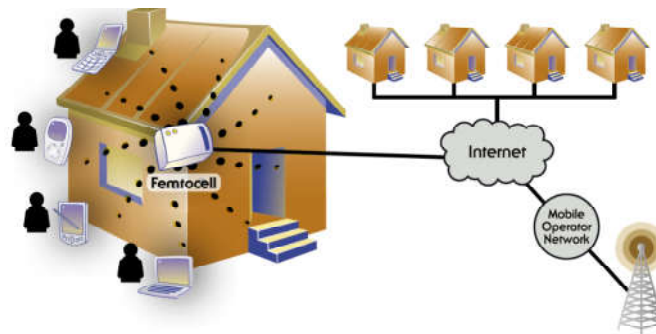


Figure 1.1 Femtocell network architecture (Small cell forum, 2008).

Femtocell is a small range (10-30 m), low-power access point (10-100 mW) that can be installed by end users to connect them to a network via the internet as shown in Figure 1.1 (Airvana, 2007; Small cell forum, 2008). Millions of femtocells are already deployed in all over the world. Since January 2012, eight of the top 10

mobile operator groups have provided femtocell services (Informa Telecoms & Media, 2011; Small cell forum, 2012). Femtocell shipment is expected to increase from 4 million femtocells in 2016 to nearly 10 million femtocells by 2020 (Small cell forum, 2016).

Femtocell has been introduced as a solution to the indoor coverage problems, since it increases the network's coverage and capacity, and reduces both cost and power. Reducing the transmission distance improves the link capacity, and saves the mobile battery. Moreover, the deployment of femtocells in an existing macrocell scenario reduces the indoor traffic, thus the network capacity and reliability will improve. However, there are many challenges that face the success of deployment of femtocell. One of the most important challenges is the interference assessment, modelling and mitigation. In order to achieve that, realistic propagation models that capture the Three Dimensional (3-D) stacking of femtocells so mitigation techniques can be applied, is of paramount importance. There are two types of interference in femtocell networks; the first one is interference between femtocell and macrocell which called cross-layer interference; and the other one is the interference between femtocell and other femtocells that are deployed in the coverage of the main macrocell, this type of interference is called co-layer interference. Both type of interference should be considered when designing femtocell networks.

Next section presents the statement of problem that is going to be addressed and solved in this research.

1.2 PROBLEM STATEMENT

Several challenging issues must be addressed and resolved before femtocell technology becomes a reality. One of the most important challenges is assessing and

mitigating the interference. Therefore, interference management is necessary and a practical interference mitigation method is a must. As stated in the open literature review, most of the proposed schemes assumed specific locations and uniform distributions for the femtocells in the network. On the contrary, in practical scenarios, the femtocells are randomly distributed in a dense 3-D environment. Such distribution is required in order to study interference effect not only from cells spaced horizontally on a terrestrial access, but also stacked vertically as in the case for office or residential towers. Few research has considered the vertical interference. Therefore, developing a 3-D System Level Simulator (SLS) is required.

In addition, most of the available propagation models in the literature are for long range wireless networks. Hence, indoor propagation channel needs to be investigated in short range environment. According to Saunders (1999) and recent studies (Valcarce & Zhang, 2010; Zhao et al, 2013; Degli-Esposti et al, 2013), the available indoor path loss models may not be suitable for femtocell networks and require further improvements in order to predict the indoor propagation more accurately.

Furthermore, the antenna directivity and polarization effect on the path loss and interference level need to be studied, especially, for 3-D environment. None of the previous studies investigated these two parameters on users stacked vertically at different floors of the transmitter.

1.3 RESEARCH PHILOSOPHY

Femtocells are promising technology to increase the capacity, efficiency and the coverage of the cellular networks (Chandrasekhar et al., 2008; Zhang & De la Roche, 2010). Due to their low cost, they can be deployed as consumer equipment, reducing

the capital load and operating expenses of the host network. However, in order to implement femtocell in real advantage for network operator and consumer, several challenging issues must be addressed first and resolved before this technology becomes a reality. Path loss and Interference management are considered key challenging issues for this promising technology to become real. Since most of the available indoor path loss models are developed based on two dimensional (2-D) measurements for long range networks, those do not reflect the vertical femtocell environment. Therefore, the philosophical approach followed in this thesis, to address the issues of path loss and management of interference in 4G femtocells, is based on a 3-D concept. Empirical model based on comprehensive measurements in a practical multi-storey building with different scenarios can reflect the femtocell accurately. Empirical models can be further enhanced by integrating antenna directivity and polarization effects on interference. Not only a 3-D path loss model is proposed, but also a 3-D SLS is developed to handle the 3-D deployment scenarios.

1.4 RESEARCH OBJECTIVES

The main objectives of this research are:

- 1- To conduct indoor received signal strength measurements campaign for 2-D and 3-D Environments.
- 2- To propose a 3-D path loss model for indoor femtocell networks.
- 3- To develop a 3-D Long-Term Evolution (LTE) SLS.
- 4- To evaluate, verify and compare the performance of the proposed model and the developed SLS using the measurement campaign.

1.5 RESEARCH SCOPE

The scope of this research is to model the interference for Orthogonal Frequency Division Multiple Access (OFDMA) indoor femtocells, which use LTE. Moreover, OFDMA works as a multi-access technique and exploits channel variations in frequency domain and time domain to avoid interference (Lopez-Perez et al, 2009). The access mode that will be considered is the Closed Subscriber Group (CSG), where the worst scenario occurred. A four storey building with all possible indoor scenarios is considered in the measurement. A maximum of 20 dBm transmit power is used during measurements. Two types of antenna directional and omnidirectional are used during measurements. Three different polarization, namely Vertical-Vertical (VV Transmitter (Tx) is vertical and Receiver (Rx) is vertical), Horizontal-Horizontal (HH), and Horizontal-Vertical (HV) are used. The frequencies considered in this research are 1.8 and 2.6 GHz. Far field distance is $d > 2D^2/\lambda$ is considered only, where D is the maximum antenna dimension and λ is the wavelength (Nikitin et al., 2007). Therefore, it is assumed throughout this study that the signal is propagating through far field region. The simulator is developed based on MATLAB platform and then integrated into the famous Vienna simulator.

1.6 RESEARCH METHODOLOGY

The research methodology is based on a combination of three different approaches. The first approach is experimental, where real measurements were conducted to evaluate the available indoor path loss models. The second approach is mathematical, where regression methods were applied to fit the measured data and proposed a new empirical model for 3-D indoor environment. The last approach is to develop a 3-D