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3D FEMTOCELL PATH LOSS MODEL IN WIRELESS NETWORKS

BY

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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 اللاّسلكية. حيث تم إقتراحها 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 فان 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 فانه سيتم التطرق للنماذج الخاصة بالأماكن الداخلية فقط. غالبية النماذج السابقة تم إقتراحها 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 إقتراح نموذج جديد لحساب الخسائر بين المرسل والمستقبل. النموذج المقترح يعتمد على المسافة غير المباشرة بين المرسل والمستقبل(المسافة العمودية والمسافة الأفقية). وبناء عليه تم إقتراح 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 بالمتوقعة 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 والرئيسية 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

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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.

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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.

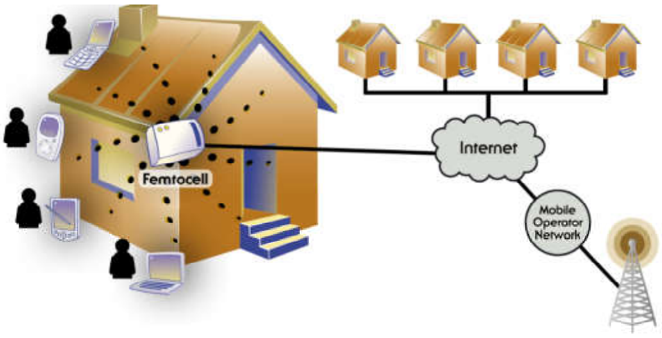

Figure 1.1 Femtocell network architecture (Small cell forum, 2008).

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 recieved 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 interfernce 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 occured. 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 polariztion, namly Vertical-Vertical (VV Transmitter (Tx) is vertical and Receiver (Rx) is vertical), Horizontal-Horisontal (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 considereed 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