ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A SPATIAL ESTIMATION-BASED HANDOVER MANAGEMENT FOR CHALLENGING FEMTOCELL DEPLOYMENTS

M.Sc. THESIS

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ZORLU FEMTOCELL KONUŞLANMALARI İÇİN UZAYSAL SİNYAL KAYBI KESTİRİMİ TABANLI AKTARIM YONETİMİ

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Tuğrul Murat MUTLU, a M.Sc. student of ITU Graduate School of Science Engineering and Technology 504091539 successfully defended the thesis entitled **"A SPATIAL ESTIMATION-BASED HANDOVER MANAGEMENT FOR CHALLENGING FEMTOCELL DEPLOYMENTS"**, which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my spouse,

FOREWORD

I would like to thank my thesis supervisor Asst. Prof. Dr. Berk CANBERK for his support during my study.

I should admit that this work would not find chance to come true without my dear wife. She is the only one that stands me during this long way. I owe her a great debt of gratitude.

May 2014 | Tuğrul Murat MUTLU (Computer Engineer)

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ABBREVIATIONS

CAPEX	**:**	Capital Expenditure
CSG	**:**	Closed Subscriber Group
fBS	**:**	Femto Base Station
mBS	**:**	Macro Base Station
MS	**:**	Mobile Station
OSG	**:**	Open Subscriber Group
RSS	**:**	Received Signal Strength
UMTS	**:**	Universal Mobile Telecommunications System
WLAN	**:**	Wireless Local Area Network

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SUMMARY

In next generation cellular systems, femtocell technology has been emerged as one of the leading deployment strategies aiming for a better indoor coverage and “5-bar" signal strength. Especially, in indoor environments, performance of femtocell-based networks is higher than the conventional macrocell-based networks in terms of throughput and service quality. In these types of networks, generally femto base stations which have low transmit power are deployed at indoor environments within the coverage region of macro base stations which have higher transmit power than fBS for covering a wide geographic area. Although widely studied in the literature handover management in these types of networks remains as a technical challenge in need of effective solutions.

In this thesis, introducing a new handover algorithm and a handover management mechanism for femtocell-based networks are aimed. Since generally femtocells are located in indoor environments which consist of several walls and other physical obstacles, the conventional received signal strength based handover algorithms might be inadequate. Therefore in this study, path loss measurements are used in order to make handover decision. However, path loss measurements might also fluctuate in small distances which result unnecessary handover and so called ping-pong handovers. To overcome this issue, the path loss measurements of future locations which are the locations that the mobile station will most likely reach in the future, are also estimated and considered for handover decision. To estimate these path loss values, the spatial analysis using ordinary kriging methods is used.

To reduce the unnecessary handover number and ping-pong handover rate, a new handover management mechanism is proposed. According to this mechanism, first the path loss measurements are collected from the connected mobile stations. Secondly, a set of future locations which are the locations that mobile station will most likely reach are defined. Then from the path loss collections, future locations’ path loss values are estimated by using ordinary kriging methods. Finally, considering the future locations and their path loss values, proposed algorithm decides whether to handover or stay connected to the associated base station.

There are two parameters which are analysed in this paper. These are the total number of handovers and the rate of ping-pong handovers. In order to increase the performance of femtocell-based networks, both of these parameters should be minimized. Simulation results show that there is a chance of decreasing the unnecessary handover numbers and the ping-pong handover rate by using the proposed study. Since the algorithm has the ability to make handover decision according to future locations, the gain in terms of ping-pong handover rate is larger than the gain in terms of the total handover numbers.

ZORLU FEMTOCELL KONUŞLANMALARI İÇİN UZAYSAL SİNYAL KAYBI KESTİRİMİ TABANLI AKTARIM YONETİMİ

ÖZET

Yeni nesil hücresel haberleşme sistemlerinde, femtocell baz istasyonları sinyal kalitesini arttırmak ve toplam transfer edilen veri miktarını çoğaltmak için önemli çözümlerden biri olarak ortaya çıkmıştır. Özellikle kapalı alanlarda femtocell baz istasyonları, geleneksel yöntem olan makrocell baz istasyonlarına göre önemli ölçüde performansı arttırmaktadır. Bu sebeple, operatorlar daha iyi hizmet sağlayabilmek için femtocell destekli hücresel ağları tercih etmektedir.

Femtocell destekli ağlarda, genellikle femtocell kapalı alanlara yerleştirilir ve kapalı alan içerisinde ve yakınında kalan kullanıcılara hizmet verir. Fakat bu alan dışındaki kullanıcılara düşük transmisyon gücünden dolayı hizmet veremezler. Bu kullanıcılara femtocell kapsama alanlarını içerisine alacak şekilde yerleştirilen makrocell hizmet verecektir. Makrocell kullanıcısı femtocelle yaklaştıkça femtocellden daha kaliteli sinyal almaya başlayacak ve dolayısıyla genel sistem performansının artması için aktarım (handover) yapacak ve femtocelle kayıtlanacaktır. Aynı durum femtocell kullanıcısının femtocell kapsama alanından çıkmaya başladıgı zamanda da oluşacak ve kullanıcı makrocelle aktarım yapacaktır. Eski makrocell tabanlı ağlara göre, femtocell tabanlı ağlarda baz istasyonu sayısının çok olmasından ötürü aktarım sayısının çok olacağı bir gerçektir. Bu sebeple femtocell tabanlı ağlarda mobil kullanıcının doğru zamanda, doğru sekilde aktarım yapmasını sağlayacak algoritma, ağın genel performansı için çok önemlidir.

Bu araştırma, zorlu ve kapalı alan topolojileri için yeni bir aktarım algoritması ve aktarım yönetim mekanizması tanımlamaktadır. Zorlu alan topoloji, etrafında belirli bir kurala göre dizilim göstermeyen duvarlardan oluşan bir kapalı alanı ifade etmekdedir. Çevreleyen duvarlar sebebiyle, sinyal kalitesi kısa mesafelerde çok hızlı değişim gösterebilir. Dolayısıyla bu topolojilerde doğru aktarım yapma kararı vermek, klasik makrocell topolojilere kıyasla daha sık olacaktır. Fakat daha sık aktarım yapmak her aktarımın belirli bir sinyalleşme yükü getirdiğini varsayarsak genel sistem performansının düşmesine sebep olacaktır. Bu sebeple, bu araştırmada toplam aktarım sayısı ve ping-pong aktarım oranının değişiminin, geliştirilen mekanizma ile nasıl değiştiği incelenmektedir. Ping-pong aktarımdan kasıt, bir mobil kullanıcının aktarım yaptıktan kısa bir süre sonra tekrar aktarım yapmasıdır.

Femtocell kapalı alanlarda limitli kullanıcı için tasarlanmıştır. Makrocell ise daha geniş coğrafi alanları kapsamak için kullanılır. Bu sebeple makrocellin transmiyonu gücü femtocellin transmisyon gücünden bir kaç kat daha fazla olabilir. Bu durum, femtocellin makrocell kapsama alanının içerisinde olduğu var sayılırsa, femtocelle kayıtlanma anlamında probleme sebep olmaktadır. Bir mobil kullanıcı femtocelle çok yakın olmasına rağmen makrocellden aldığı sinyalin daha güçlü olmasından ötürü femtocelle kayıtlanamayacaktır. Bu durumu çözmek için araştırmalarda belirli

yöntemler kullanılmaktadır. Bunlardan biride aktarım ve hücre seçme algoritmalarında sinyal gücünün yerine, sinyal kaybının kullanılmasıdır. Sinyal kaybı transmisyon gücünden çok uzaklığı ifade ettiği için, femtocellin kapsama alanı arttırılmış olacaktır. Literatürde sinyal kaybı hücre seçme ve aktarım algoritmalarında kullanılmaktadır. Bu çalışmada da sinyal kaybı parametresi aktarım algoritmasında kullanılmaktadır.

Sinyal kaybı değerleri, etrafında farklı kalınlıklarda duvarlardan bir topolojide kısa mesafelerde bile çok değişkenlik gösterebilecektir. Bu durum bir mobil istasyonun sürekli aktarım yapmasına sebep olacaktır. Bu çalışmada, mobil istasyonun kısa süre sonra bulunacağı alanların sinyal kaybı değerleri tahmin edilebilindiği takdirde gereksiz aktarım sayısının düşürülebileceği düşünülmüştür. Bu fikir ile mobil istasyonun her hareketinde belirli bir hedef lokasyon kümesi belirlenmektedir ve bu hedef lokasyon kümesinin sinyal kayıp değerleride olasılıksal olarak göz önünde bulundurularak yeni bir sinyal kaybı değeri oluşturulmakta ve aktarım kararı artık bu değere göre alınmaktadır.

Sinyal kaybı değerlerinin ölçümleri mobil kullanıcılardan gelmektedir. Fakat her lokasyonda kullanıcı olamayacağından ötürü güncel sinyal kaybı ölçüm bilgilerinin topolojinin her noktası için bilinmesi mümkün olmayacaktır. Dolayısıyla mobil kullanıcı için tanımladığımız hedef lokasyonlar kümesinin sinyal kaybı değerleri bilinmiyor olabilir. Bu çalışmada bilinmeyen bu değerlerin kestirimi için Ordinary Kriging yöntemleri kullanılmaktadır. Ordinary Kriging jeoistatistikte özellikle kömür rezervlerinin yoğunluğunu uzaysal olarak kestirebilmek için kullanılan bir yöntemdir. Belirli lokasyonlarda kömür oranı için ölçüm yapılır ve bu ölçümlere dayanarak Kriging yöntemleri ile bilinmeyen diğer alanların kömür rezerv miktarları kestirilir. Bu çalışmada da benzer fikirle, bilinen sinyal kaybı değerlerinden bilinmeyen sinyal kaybı değerleri kestirilmeye çalışılmıştır.

Gereksiz aktarım sayısını azaltmak ve ping-pong aktarım oranını düşürmek için bu çalışmada bir mekanizma geliştirilmiştir. Bu mekanizma ilk olarak sinyal kaybı değerlerini mobil kullanıcılardan periyodik olarak toplamaktadır. Toplanan değerler topolojinin büyüklüğüne göre bir vektörde saklanmaktadır. İkinci olarak, her mobil istasyon için ayrı ayrı hedef lokasyon kümesi oluşturulmaktadır. Hedef lokasyon kümesi mobil kullanıcının her hareketinde tekrar oluşturulmaktadır. Sonraki adımda, hedef lokasyon kümesinde sinyal kaybı değeri bilinmeyen lokasyonların her biri için mobil istasyonlardan toplanan sinyal kaybı ölçümlerini kullanarak Ordinary Kriging yöntemleri ile sinyal kaybı kestirimi yapılmaktadır. Mekanizmanın son adımında kestirim yapılan sinyal kaybı değerlerini kullanarak bir aktarım kararı alınmaktadır. Geleneksel yöntemde bu karar mobil kullanıcının sadece o anki yerinin sinyal kaybı değerine göre alınmaktadır. Sinyal kaybı değeri belirli bir eşik değerinden yüksek yada düşük olmasına göre aktarım kararı alınmaktadır. Bu çalışmada ise yeni bir sinyal kaybı parametresi tanımlanmıştır. Bu yeni parametre mobil istasyonun sadece o anki lokasyonun sinyal kaybı değil, aynı zamanda hedef lokasyonların sinyal kaybı değerlerine göre hesaplanmaktadır. Bu çalışmada artık aktarım kararı mevcut sinyal kaybına göre değil, yeni hesap edilen sinyal kaybı değerine göre yapılmaktadır.

Tasarlanan algoritma ve mekanizmanın performansını anlamak için farklı topolojilerde simulasyonlar yapılmıştır. Bu topolojiler ilk olarak $50mx50m$'lik bir haritaya bölünmüştür ve bu haritada kapalı bir alanı oluşturmak için belirli bölgelere farklı kalınlıklarda duvarlar yerleştirilmiştir. Haritadaki her lokasyonun sinyal kaybı değerinin belirlenmesi için similasyonlarda ampirik bir sinyal kaybı modeli kullanılmıştır. Bu model uzaklığa göre sinyal kaybını belirlemektedir. Fakat duvarlardan ötürü Euclidean uzaklık sinyal kaybını tam olarak yansıtmamaktadır. Bu sebeple duvar kalınlıklarını göz önünde bulunduran bir uzaklık formulu kullanılmıştır. Bu formul basitçe iki nokta arasında duvar var ise aralarındaki uzaklığı arttırmaktadır. Hesaplanan sinyal kaybı değerlerinin bir kısmı olasılıksal olarak bilinen nokta olarak kabul edilmiştir. Diğer noktalar ise sinyal kaybı bilinmeyen noktalar olarak kabul edilmiştir.

Bu çalışmada iki performans kriteri göz önünde bulundurulmuştur. Bunlar toplam aktarım sayısı ve ping-pong aktarım oranıdır. Performansı daha iyi bir sistemde bu kriterlerin düşük olması beklenir. Aslında amaçlanan gereksiz aktarım sayısının düşürülmesidir. Gereksiz aktarım sayısının düşmesi toplam aktarım sayısının da düşmesine sebep olacağı için, toplam aktarım kriteri doğru bir parametredir. Performans kriterleri çeşitli topolojilerde incelenmiş ve önerilen sistemin daha yüksek performansa sahip olduğu gözlemlenmiştir. Toplam aktarım sayısının topolojiye bağımlı olarak belirli oranda düştüğü saptanmıştır. Aynı şekilde ping-pong aktarım oranının da azaldığı görülmüştür. Bunun yanında her iki parametrenin grafiklerinin çok benzer özelliklere sahip olduğu anlaşılmıştır. Bunun sebebinin sistemin hedef lokasyonları düşünerek verdiği aktarım kararının ping-pong aktarımları yakalaması ve sonuc olarak toplam aktarım sayısının azalması olduğu anlaşılmıştır.

1. INTRODUCTION

The recent mobile technology applications increase the use of data services tremendously. This issue leads the operators and researchers to find alternative solutions to mobile cellular services. In order to meet the demands on mobile cellular wireless systems, the development of femtocell-based networks is an effective way. Especially in indoor environments, performance of femtocell-based networks is higher than the conventional macrocell-based networks in terms of throughput and service quality. In these types of networks, generally femto base stations (fBS) which have low transmit power are deployed at indoor environments within the coverage region of macro base stations (mBS) which have higher transmit power than fBS for covering a wide geographic area. Several fBS might be deployed at mBS coverage region. In these types of deployments, the goals of fBS are to provide high throughput to the mobile stations (MS) which are connected to it and to decrease the distance between these mobile stations and corresponding the base station.

One of the main advantages of fBS is auto-configuration but that advantage comes with an issue. Because the fBS coverage areas are not planned by operators, the mobility management of mobile stations in these unplanned networks becomes an important challenge. Not only the auto-configuration property of fBS makes it difficult to manage the mobility of users, but also since fBSs are generally located in challenging indoor environments which consist of several walls and other physical obstacles, unnecessary handovers caused by unpredictable path losses are triggered in many situations leading a degradation of services, reduction in throughput and increases in the blocking probability and packet loss. More specifically, in the area of mobility management, guaranteeing a seamless and fast handover is a major goal from fBS to mBS, or vice versa.

Handover procedures are an important issue of cellular network design, since the users are generally mobile in these networks. When a MS moves to a region where the strength of signal it receives from its associated base station is lower than that of another base station, a handover procedure is triggered. Simply expressed, when a MS moves closer to a new base station than its currently associated base station, it switches its association to the new base station and this switching process is called a handover.

Handover in femtocell-based network is different from the conventional handover in macrocell networks in several aspects. First, the transmit power from the mBS can be up to two order of magnitudes higher than that from the fBS. Relying on the received signal strength (RSS), the MS might still favor the mBS for association, diminishing the advantage of deploying fBSs. Second, the maximum number of MS that can connect to the fBS is generally smaller than mBS. As a result, although a nearby MS has a strong signal strength to the fBS, connecting to the fBS may not be possible. In order to reduce the probability of connecting to mBS and increasing the chance to connect to the fBS, path loss-based cell selection removes the issue of huge difference in fBS and mBS transmit powers [1].

Our goal in this thesis is to design a handover management scheme, which depends on the path loss measurements at MS in femtocell-based networks in order to reduce the unnecessary handover caused by the challenging indoor environment. Since path loss measurements are important guidances for mobility management in femtocell-based networks, it is important to get accurate path loss values. In the literature there are several empirical path loss models [2] [3] in order to estimate path loss. In this thesis, instead of using empirical path loss models, the Kriging interpolator using semivariogram analysis is adopted for spatial estimation of path loss.

1.1 Purpose of Thesis

The main objective of this study is to introduce a new approach to reduce unnecessary handovers in femtocell-based networks in challenging indoor environments. These challenging environments may consist of several walls and other physical obstacles. This unpredictable topological changes result significant changes for path loss of mobile stations in small distances. As a result unnecessary handover may occur in these networks. Proposed scheme aims to overcome this issue by introducing a handover management mechanism. A new handover algorithm which is based on the spatially estimated path loss values of neighbour locations will be introduced.

1.2 Literature Review

There are many studies carried out for the design of handover algorithms on femtocell-based networks based on different concepts. The main objective in these works is to find the optimal base station to camp on with respect to the connection requirements, while minimizing the number of handovers.

The most commonly used algorithms are generally based on the comparison of RSS's (Received Signal Strength) with hysteresis and threshold. The threshold defines the minimum level of the RSS from a base station and the hysteresis adds an extra margin to the RSS. There have been several studies for handover algorithms based on RSS with hysteresis to reduce unnecessary handovers. In order to determine the hysteresis value, in [4], the author combines the RSSs from both mBS and the associated fBS. In [5], the author proposes a handover process using a queuing model and a new cell selection method to achieve load balancing among mBS and fBS. The author in [6] proposes a new handover procedure for UMTS networks using hybrid access type fBSs. In [7] the author analyzes both mobility and signal strength in handover procedure in order to reduce unnecessary handovers. In addition to these handover algorithms using RSS, there are different parameters based on distance, bit error rate and achievable bandwidth for handover decisions.

In femtocell-based networks, mobility prediction methods are also used to make fast and seamless handover. The author in [8] creates a mobility database depending on the acts of mobile users. Then according to the historical information, the number of unnecessary handovers is minimized. On the other hand, the author of [9] claims that these mobility prediction techniques may be somewhat complex and may require more than a simple change of the system. Therefore they propose a mobility management technique with simple handover prediction.

Since fBS and mBS have different functionality, they have also different transmit signal powers. The transmit signal power from the mBS can be up to two order of magnitudes higher than that from the fBS. As a result, although MS is too close to the fBS, if the

MS compares the downlink RSS of both mBS and fBS, it might still favor mBS for association. As a result, the performance of femtocell-based networks will not be too much as expected. To increase the chance of selection the fBS and solving the problem of strong mBS transmit power, the cell selection algorithm may depend on path loss measurements [10]. It means that instead of using RSS, path loss measurements of MS for fBS and mBS is used in order to decide for association. The drawback of this approach is that the MS will receive strong interference from the mBS in the downlink, resulting in throughput degradation.

Relying on the fact that path loss is a good measurement for handover processes in femtocell-based networks because of the reasons we have already explained, in this thesis, we try to find a way to exploit path loss measurements. In [11] the author proposed a method in order to design a wireless local area network (WLAN) to provide 100% coverage with signal strength above a minimum threshold value over all its target area. Different from the conventional method which is site survey techniques or signal propagation models, the author adopted an ordinary kriging-based empirical approach to estimate the path loss in WLANs. The main objective of this study is to create a path loss map of a WLAN from several test points measurements. In addition, the author also considers path loss due to obstacles and other factors in indoor environments. Since WLANs are generally used in indoor environments, the fluctuations in the path loss due to surrounding concrete walls and other topological infrastructures are significant. To take obstacles into account, in this study a new distance measure is proposed based on an empirical path loss model.

1.3 Organization of The Thesis

The structure of the thesis is as follows: In chapter 2, the general aspects and technical challenges of femtocell-based networks are given and handover process is explained. In chapter 3, spatial analysis using ordinary kriging and the corresponding models are introduced. In chapter 4, methodology of the proposed approach is described. Experimental set-up and measurement results are detailed in chapter 5. Finally, chapter 6 is the analysis of the study and the conclusion.

2. FEMTOCELL-BASED NETWORKS

The main purpose of cellular wireless system is shifting from voice service support to data centric support, since today's popular social networks' (Facebook, Tweeter, Youtube, etc.) packet traffics dominate the entire system. To meet such demands, operators and researchers are trying to find new solutions which leads to create new wireless standards like LTE and WIMAX. Although new software and hardware are integrated according to these newly defined standards, still it might not be enough for future data centric applications. For example, according to [12], the author claims that, the data traffic caused by mobile users is bigger than the entire global internet traffic in 2000. In addition, a future expectation is given in [13] that, 1 billion mobile users are expected to send data traffic in 2015. It is obvious that, the operators which have already at a point of failure in several data services, will not probably meet these demands with the traditional solutions which are just increasing the spectrum or deploying more macro base stations.

In order to meet the demands on high wireless data rate, several types of low power base stations which are microcells, picocells, relays are deployed within the macro base station coverage region. Since they have low transmit powers, the coverage region of these small base station will also be small. As a result, these types of small base stations are generally preferred for indoor and crowded regions. However, installation and maintenance of these indoor stations generate some additional costs to the operators. Femtocells are also small, low-power base stations. However, different from the other small base stations, they are generally end-consumer deployed and connected to the network by using customers owned wired backhaul connection. With this property, they may seem as WiFi access points, but instead they use the same spectrum with the macrocell. From the user's perspective, femtocells are indistinguishable from a macrocell, since both femtocell and macrocell are originating from the same specifications. According to [14], 49 million femtocells are expected to be deployed by 2014. It is expected that, 114 million mobile users will access mobile through femtocells during that year.

2.1 General Aspects of Femtocell

2.1.1 Basic definition of femtocell

Since the purpose of the femtocell is to serve indoor environments, it is designed for short ranges. Generally a femtocell may serve users at 10-100 meters distance away from its transmitter. Different from WiFi access points, it is functioning in operator owned licensed spectrum like macrocell. In addition, femtocell may carry the wireless user traffic using IP network based backhaul connections like xDSL. These backhaul connections are also used not only for carrying user traffic data, but also for signaling between macrocell and femtocell. To guarantee a seamless and a fast handover, this wired backhaul connection is crucial. A typical femtocell network architecture is shown in Fig. 2.1.

In femtocell-based networks, low-power fBS would be deployed at indoor within the coverage of mBS that typically uses large transmit power for covering a wide geographic area. This combined architecture consists of a mBS and several fBSs that aims to provide better performance in terms of throughput and coverage for indoor mobile users. By the help of deployed fBS, the indoor mobile users will be much more close to the base station. These will increase the spectrum efficiency. As a result the capacity of the base stations will be increased.

2.1.2 Benefits of femtocell

The femtocell offers some significant advantages for next generation wireless networks. These are coverage and capacity, macrocell reliability, cost, subscriber turnover, plug and play property, and access methods.

The main reason to developed femtocells is to bring a solution to indoor coverage issues and try to have "5-bar" signal at indoor environments, particularly households, offices, shopping malls, etc.. Therefore fBS’s transmit power is low and as a result the

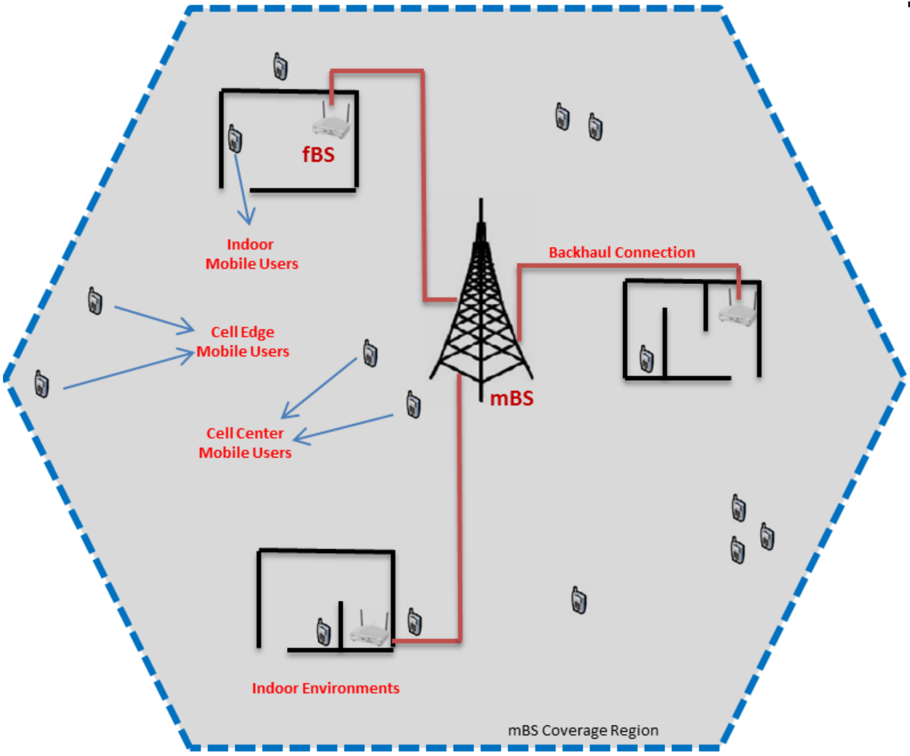

Figure 2.1: Femtocell network architecture.

coverage area is very small compared to mBS. Fig. 2.2 in [15] provides a comparison of base stations and depicts the femtocell coverage range as less than 50 meters radius.

Indoor users are always a problem for operators. Since there are some walls and obstacles in indoor environments, the signal quality will be quite less than outdoor environments. As a result, in order to give the same services to both indoor and outdoor users, the macrocell will assign more resources to indoor users. It is obvious that, not only the indoor users are affecting from these situations, but also the outdoor users are affecting. For these kinds of issues, the use of femtocells helps to reduce the load on the macrocells. This is because femtocells absorb some of the indoor traffic and give better services. This makes macrocell a more reliable service point.

In terms of cost reduction, femtocells are designed to reduce the CAPEX for the operators. Not only the electricity and the backhaul connections are reduced but also it offers the operators additional benefit of offloading macro network spectrum that helps to avoid the cost of deploying extra macrocells.

Most of the customers are complaining about signal quality when they enter a closed space which could be a house, a mall or an office. This situation may affect the

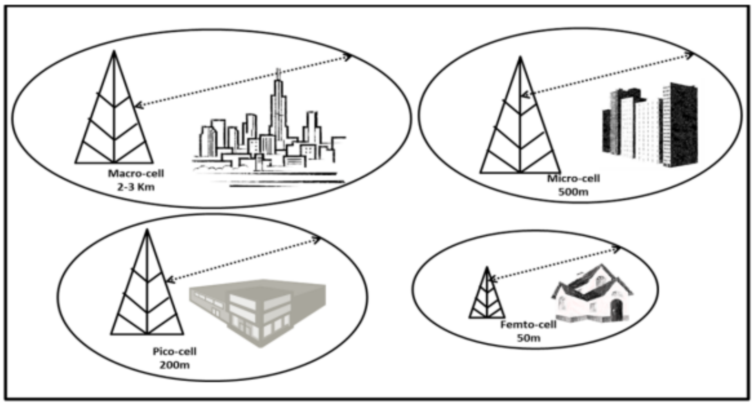

Figure 2.2: Base station ranges [15].

opinion of the customers badly about the associated operator. As a result customers are changing their operators more often. Therefore, the use of femtocell will help in creating a better customer's perspective in this regards.

Femtocells are installed by customers or private enterprises in an ad hoc manner without any cell planning. Although these unplanned networks come with some issues, it is a great advantage from operator's service and maintenance point of view. It is expected that the number of femtocell is much greater than macrocells. As a result, manual network planning and maintenance is simply not scalable in a cost-effective manner. Therefore, femtocells must support essentially plug and play operation.

Femtocells being a network used for private, enterprise or service providers purpose needs to operate on different accessing modes so as to provide the service for targeted user. This will let customers to control their own network which makes them to feel safe and comfortable in data communication environment. There are three different accessing modes can be used.

- Open Access Mode
- Closed Access Mode
- Hybrid Access Mode

In Open Access Mode any mobile user trying to access the femtocell service is allowed to do so without any discrimination or extra charge similar to the macrocell. These types of users are also called Open Subscriber Group (OSG). With this type of

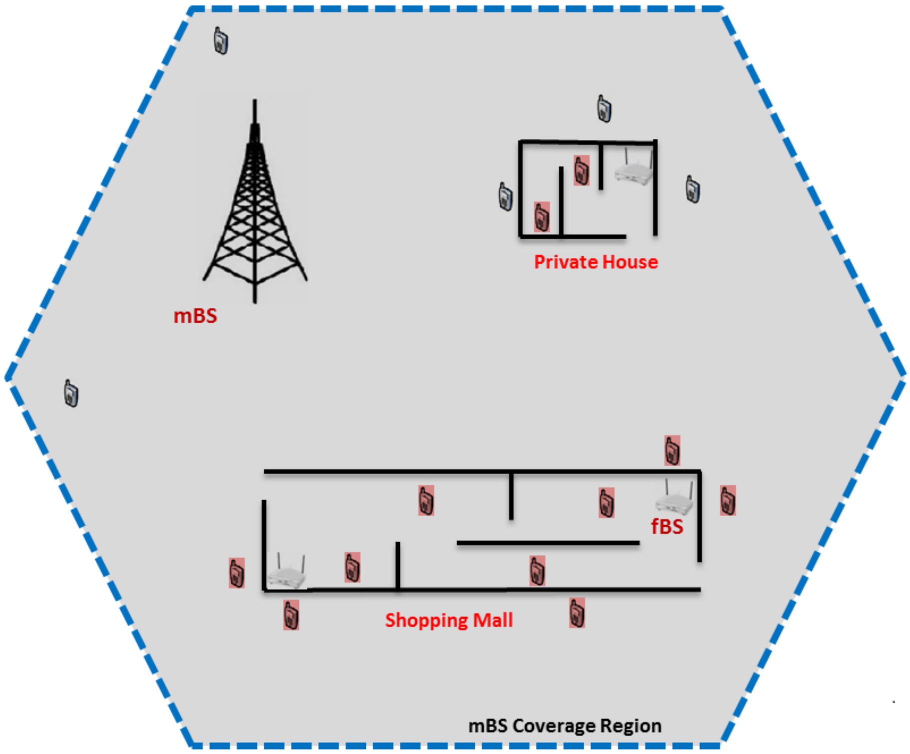

Figure 2.3: Femtocell access modes.

femtocell access, the cross-layer interferences among base stations are reduced. On the other hand, because the number of cell is increasing, the number of handover for a mobile user is also increase. Since most home users prefer the closed access, open access femtocells are deployed by service providers to enhance their coverage area and capacity.

In Closed Access Mode, a predefined group of users which is also called Closed Subscriber Group (CSG), are allowed to connect the femtocell network and use network services. An unregistered user could not be able to access the network even if it gets the strongest signal among the base stations. Since the CSG list is specified by the customer, the capacity of the femtocell network is only utilized by these registered subscribers. A disadvantage of these types of access mode is the high cross-layer interference that occurs between the macrocell and the femtocell. To overcome this issue, a closed access mode must need to cancel such type of interferences. Generally, customers deploy such type of femtocell for individual usage.

Hybrid Access Mode tries to combine the advantages of both closed and open access methods. To increase the overall system capacity, a limited number of unsubscribed users are let to access network's services together with the existing subscribed users. There should be a mechanism running on the femtocell that needs to be implemented in order to prioritize the subscribed users over the unsubscribed guest users. Besides, if the system resources are enough, any user without regarding if it is subscribed or unsubscribed, may connect to the network; otherwise the users in the CSG list have the right to connect.

2.2 Technical Challenges of Femtocell-Base Networks

Although, there have been lots of advantages in the use of femtocells, there have been also so much challenges that needs to be handled for the deployment of femtocells. Most of these challenges are generally based on unplanned and user-installation deployment nature of the femtocells. Another important issue comes with the frequency usage of femtocells and macrocells. Since femtocells and macrocells use the same frequency band, interference and mobility problems occur. In this section, we will focus on the technical challenges comes with the femtocell deployments.

2.2.1 Interference coordination

Different from Wi-Fi, femtocells use the licensed spectrum in order give services to the users which are developed for these kinds of networks. From the service provider's point of view, sharing the same spectrum for both macrocell and femtocell is more useful then allocating separate channels inside the spectrum for femtocell internal usage. Furthermore, femtocells could be installed by customers in a plug and play manner. They can be deployed anywhere inside the macrocell coverage area without any planning. Because of these reasons, the interference management scheme in femtocell-based networks is very different from conventional macrocell-based networks. Three types of interferences exist in femtocell-based networks which are depicted in Fig. 2.4 in [13]. These interference types are :

- Macrocell to Femtocell;
- Femtocell to Femtocell
- Femtocell to Macrocell

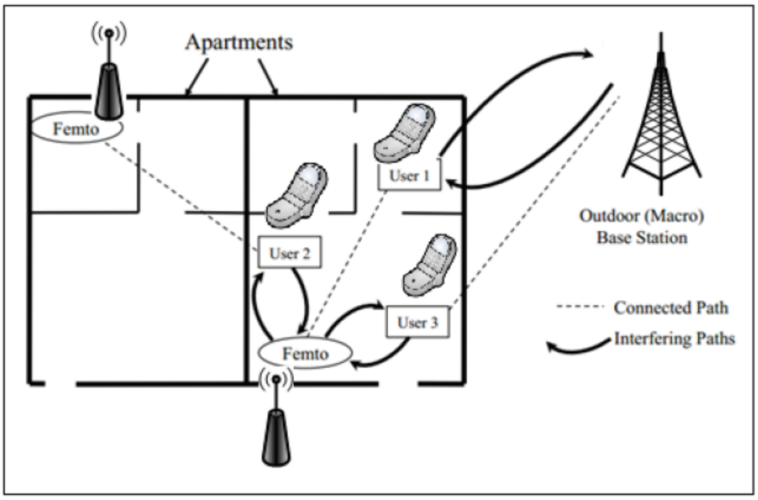

Figure 2.4: Cross tier interference illustration [13].

2.2.2 Mobility management

In femtocell-based networks, mobility management which is one of the major functions of next generation networks that allows mobile stations to work, becomes an important challenge. More specifically, in the area of mobility management, guaranteeing a seamless and fast handover is a major goal. Since femtocells have limited coverage, even users with low profile may frequently move out of coverage area of fBSs for a short interval. As a result, it is expected that the number of handover will be much more than conventional cellular systems. In addition, a typical handover problem is the increase in unnecessary handover number which is caused by the plug and play property of femtocells. As we mention before, femtocell are deployed by customers and consequently they may be deployed in unsuitable locations. This property of femtocell may cause to make unnecessary handover for mobile users which are just passing by the coverage area of femtocell.

The femtocells must protect itself against unnecessary handovers and may apply an threshold to minimize it. There should also be a mechanism to detect frequent handovers or the ping-pong handovers. Ping-pong handovers are determined according to a predefined threshold. If the connection duration of a MS after a handover is less than the threshold and a handover occurs, then this handover is called a ping-pong handover. In order to solve this problem, the mobile users need to be forced to remain connected to its base station for a certain time interval even if the signals of the other base stations are stronger.

Since the mobility in femtocell-based networks is an important challenge, the standards bodies also put emphasis on this subject. For instance the specification of 3GPP [16] describes the mobility management in femtocell or so-called Home NodeB.

In addition to these femtocell mobility issues, perhaps the most difficult aspect of femtocell networks is its backhaul connectivity. Because femtocells are not directly connected into the wireless network and mobility management is coordinated by signaling procedures between base stations, the high delay to the network may result significant problems. Femtocell software block should also take this situation into account while making handover decision.

2.2.3 Cell selection

Cell selection for a MS in a two-tier cellular network is a challenging problem. It is different from the conventional cell selection of a single-tier network in several aspects. The simplest way for cell selection is to connect to the base station which has the strongest signal that the MS receives. In fact this method lets the operators to maximize the signal strength of each MS. However simulations show that this approach does not increase the overall throughput, since the number of users camping on the fBS will be less.

In order to cover huge areas, generally mBS uses high transmit powers. Since the coverage area is increased, the mBS has the chance to serve the users at cell edge. However, the signal qualities of these cell edge users are going to be bad. This is one reason of using femtocells. In addition, femtocells are not only deployed to cell edges, but also deployed close locations to macrocell where the transmit power of macrocell is high. As a result, since the signal strength of macrocell is stronger, and then the users may camp on the macrocell, even if they are very close to femtocell. To overcome this issue and reduce the chance of selecting macrocell, path loss based selection [1] might be adopted. Furthermore, with using the method so called "range expansion", again the chance of selecting the femtocell might be increased. However, if the user selects femtocell for association, it will receive strong interference from the macrocell. These are depicted in Fig. 2.5 [17].

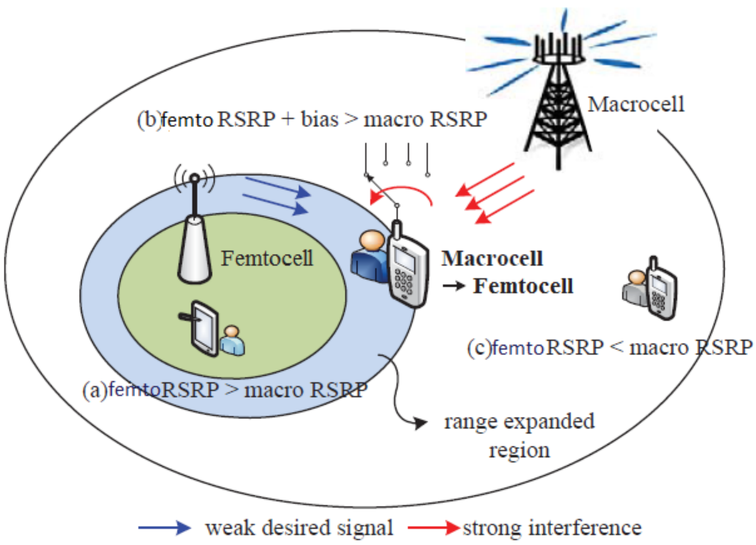

Figure 2.5: Cell selection with biasing [17].

2.3 Handover in Femtocell-Base Networks

If a mobile user moves towards to the cell edge of its associated base station, obviously the channel quality of it will decrease. On the other hand, the operator should handle this issue in order to make it transparent to the mobile user which may send or receiving data with a fix connection rate. This operation is done in several ways which generally cause to give more radio resources to such mobile users. Therefore from the base station point of view, these types of mobile users are heavy burdens that the base station should get rid of them as soon as possible. Since the stability of the connection is essential in wireless networks, the only option of the base station is making handover decisions to the appropriate neighbour base station for these mobile users. Although handover process is essential to increase the overall throughput of the base station, in some situations it could make it worse since there is a signaling overhead in handover process.

Especially in femtocell-based networks, because of its overlaid structure, handover is more complex and challenging procedure compared to conventional macrocell-based networks and different in several aspects. First of all, it is obvious that, because macrocells are designed to cover huge areas, their transmit power can be up to two order of magnitudes higher than that from fBS. Therefore, handover decisions could be inadequate since, RSS is the most important parameter for handover. Second, since femtocells are designed for indoor purposes, the signal quality measurements might

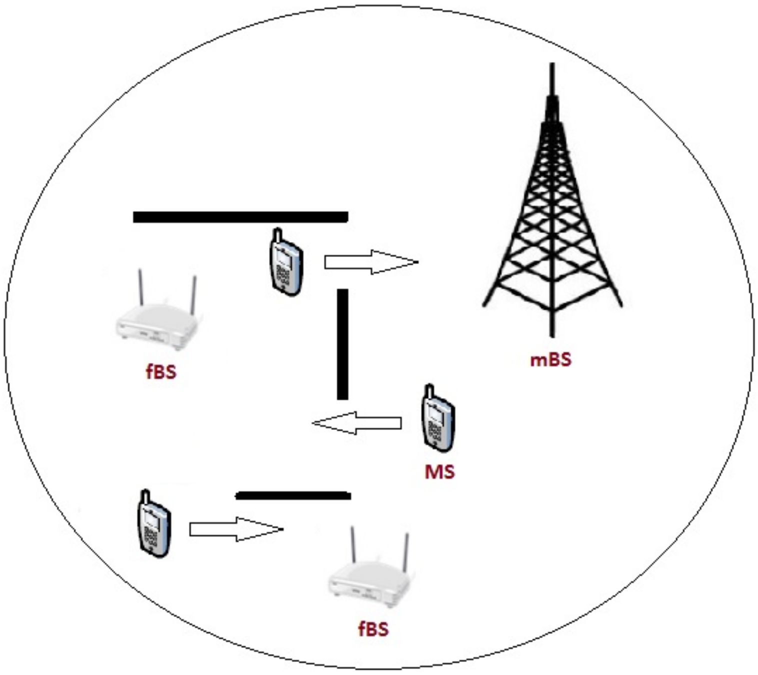

Figure 2.6: Handover in femtocell-based networks.

fluctuate very fast which causes to make wrong handover decisions. Furthermore, the backhaul line of femtocell base station is not capable of maintaining quality of service for real time voice communications, so handover decision algorithms should consider femtocell backhaul quality in order to increase user satisfaction level.

There are three types of handover in femtocell-based networks which are depicted in Fig. 2.6. These are macrocell to femtocell, femtocell to macrocell and femtocell to femtocell. In this thesis we are interesting in designing an efficient handover mechanism for macrocell to femtocell and femtocell to macrocell.

3. SPATIAL ANALYSIS

Geostatistics is a branch of statistics using statistics analysing methods for geographic purposes. Actually, it is developed to predict the distributions of an ore grades in a mine. In geostatistics the term ‘spatial’ means that, each data have geographical reference. There are some techniques and models are defined in geostatistics to understand the relation between the data and its location. The collection of these techniques and models are called ‘spatial analysis’. In ‘spatial analysis’, it is assumed that there is a connection between the data and its corresponding location. From this idea, some interpolation methods are proposed, in order to find the value of interest of a location. The most common method is called Kriging.

Kriging was developed by Georges Matheron and Daniel Krige in order to predict the rate of ore grades for unknown locations. Currently, Kriging is frequently used to interpolate the ore grades in mining fields. In order to predict the ore grades, first some samples are taken in different places in a mining field. The locations of these samples should be well-planned in order to have a successful interpolation, since unknown locations are going to be estimated from these sampled locations. The accuracy of the Kriging interpolation depends on several factors. These are:

- The number of data locations and integrity of the measurements
- Coordinates of data locations and their distributions on the topology
- Distance between unobserved locations and data locations

It is obvious that the validity of the interpolation is directly related with the number of data locations. This means that, with more known values, the extraction of unknown values by using Kriging interpolation is much more valid. However, the increase in the number of data locations may not be enough solely for accurate interpolation. Their spatial distribution on the topology is also crucial. Because of the fact in geostatistics, "everything is related with each other, but close things are more related", the distances between these data locations and the unobserved locations are also very important for Kriging interpolation.

There are several type of Kriging methods in the literature. The popular methods are Simple Kriging, Universal Kriging and Ordinary Kriging. In this thesis, because our aim is to define a handover mechanism in challenging indoor environments, the details of Kriging interpolation methods are not mentioned. The most popular method which is also used in this thesis is explained in the following section.

3.1 Ordinary Kriging

In Ordinary Kriging, the most commonly used type of Kriging, the aim is to find the associated value of an unknown location from the sampled locations. This value of interest might vary according to the case that the Kriging is used. In geostatistics, it might be the rate of an ore mine in a specific location. On the other hand, in computer science this value might be the signal strength of a room in indoor environments.

In order to explain Ordinary Kriging, let's assume that each point i in a topology, is related with a value p_i. This means that we know the associated value of the point i. Let u represent a point in the same topology, that we do not know the value of it which is defined as p_u. In addition, let $S(u) = \{1, ..., N_u\}$ be the set of points in the neighborhood of point u such that value p_i is known for each point $i \ \varepsilon \ S(u)$. By the help of Ordinary Kriging the unknown value p_u could be estimated using the set of points in $S(u)$. An example of Kriging approach is shown in Fig. 3.1. In Ordinary Kriging, unknown value p_u at a point u is estimated as a weighted-linear combination of the known values $S(u)$ as follows:

$$p_u = \sum_{i \varepsilon S(u)} w_i p_i \qquad \textbf{(3.1)}$$

where $\sum_{i \varepsilon S(u)} w_i = 1$. These formulas show that, in Kriging, the value of an location is related with its neighbour locations proportional with its Kriging coefficients and the sum of these coefficients is equal to 1.

The problem here is to find the optimal coefficients for the neighbour locations in the topology. For this purpose, in Kriging variogram analysis is used.

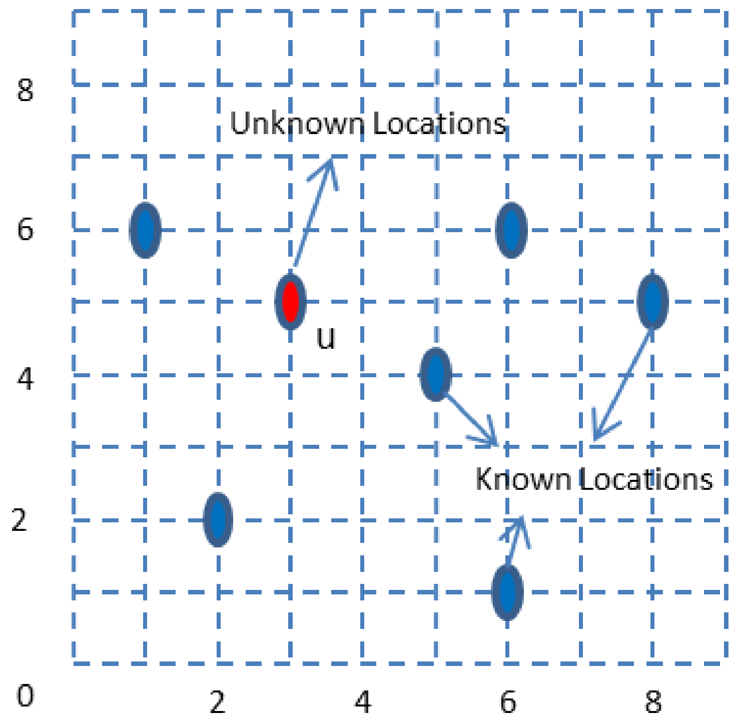

Figure 3.1: Ordinary Kriging.

In spatial analysis, the dependency of two locations is expressed by the function of variogram which is the variance of the difference between the values of these locations. The variogram function is:

$$2\gamma(x,y) = var(Z(x) - Z(y)) \quad \textbf{(3.2)}$$

which is also equal to:

$$2\gamma(x,y) = E(|(Z(x) - m(x)) - (Z(y) - m(y))|^2) \quad \textbf{(3.3)}$$

If we assume that the mean of the location in a topology is same, which is the idea behind the Ordinary Kriging, then the equation becomes:

$$2\gamma(x,y) = E(|Z(x) - Z(y)|^2) \quad \textbf{(3.4)}$$

Here the term $\gamma(x,y)$ is called semivariogram, which represents the correlation of two points in a topology. With using the related semivariogram values of the set of locations $S(u)$ and the unknown location p_u, the coefficients are calculated as follows:

$$\begin{pmatrix} w_1 \\ . \\ . \\ w_{N_u} \\ \lambda \end{pmatrix} = \begin{pmatrix} \gamma_{1,1} & \cdot & \gamma_{1,N_u} & 1 \\ . & . & . & . \\ . & . & . & . \\ \gamma_{N_u,1} & \cdot & \gamma_{N_u,N_u} & 1 \\ 1 & . & 1 & 0 \end{pmatrix}^{-1} \begin{pmatrix} \gamma_{1,u} \\ . \\ . \\ \gamma_{N,u} \\ 1 \end{pmatrix} \tag{3.5}$$

where $\gamma_{i,j}$ is a semivariogram between points i and j and λ is the Lagrange multiplier to minimize the Kriging error.

In equation (3.5), since the value of interests for the set of locations $S(u)$ are assumed to be known, then it is simple to calculate the first matrix of the right side of the equation. On the other hand, because the value of interest for the point u is unknown, then some assumptions have to be made in order to make the semivariogram analysis for the second matrix of the right side. Therefore prior to determining the weights, a suitable semivariogram model has to be chosen in Ordinary Kriging. The success rate of Ordinary Kriging is highly related with the choice of semivariogram model.

The simplest way to finding a semivariogram model is to use the values of interest in the set of locations $S(u)$. For this purpose, the related semivariograms of $S(u)$ are calculated according to (3.4) which are also used to calculate the first matrix of the equation (3.5). Then depending on the distances, several semivariogram groups are created and plotted in a x-y coordinate system. This is depicted in Fig. 3.2 [18]. Finally from this graph a suitable semivariogram model could be obtained. The empirical semivariogram models are explained in the next section.

Another important property of Ordinary Kriging is, every estimation has its own standard deviation. After calculating the coefficients and λ, the variance of estimation could be calculated as follows:

$$\sigma^2 = \sum_{i \varepsilon S(u)} w_i \gamma_{i,u} + \lambda \tag{3.6}$$

3.2 Semivariogram Models

Because there are different kinds of data sets in the world, lots of semivariogram models exist in the literature. These models are representing the behaviour of the values of interest in specific environments. In order to increase the accuracy of the

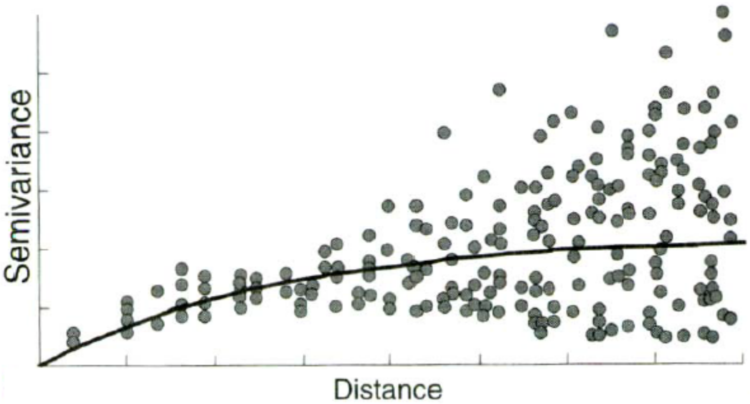

Figure 3.2: Determining semivariogram model [18].

interpolation, the selection of semivariogram model is very important. Some of these models are commonly used, such as spherical, exponential and gaussian [19]. These are calculated as follows:

- Spherical semivariogram model :

$$\gamma = \begin{cases} 0 & h = 0 \\ c_0 + (c - c_0)(\frac{3}{2}\frac{h}{a} - \frac{1}{2}(\frac{h}{a})^3) & h > 0 \end{cases} \quad \textbf{(3.7)}$$

- Exponential semivariogram model :

$$\gamma = \begin{cases} 0 & h = 0 \\ c_0 + (c - c_0)(1 - \exp(-\frac{h}{a}) & h > 0 \end{cases} \quad \textbf{(3.8)}$$

- Gaussian semivariogram model :

$$\gamma = \begin{cases} 0 & h = 0 \\ c_0 + (c - c_0)(1 - \exp(-\frac{h^2}{a^2}) & h > 0 \end{cases} \quad \textbf{(3.9)}$$

In this thesis, we also need to adopt a semivariogram model to make an efficient handover decision. Since the power of the signal is diminishing very fast at the very first meter and then changing slowly, the exponential semivariogram model is chosen in this thesis.

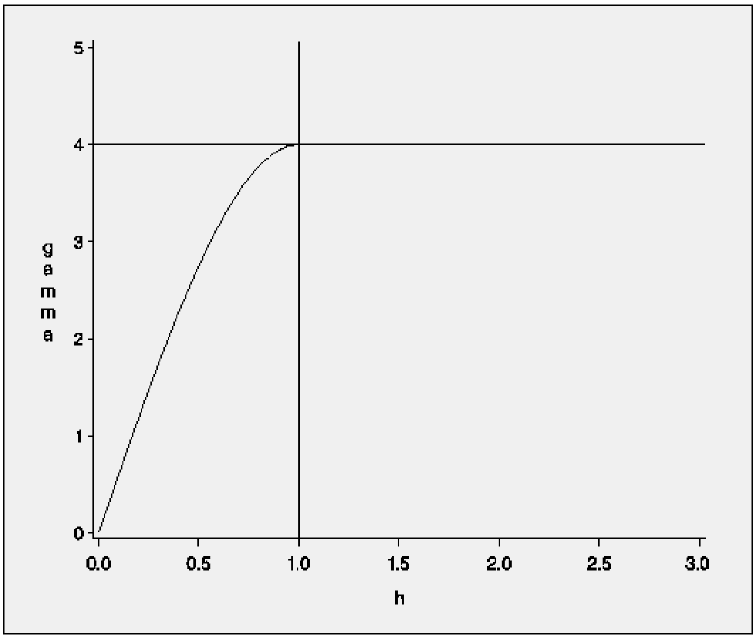

Figure 3.3: Spherical semivariogram model [19].

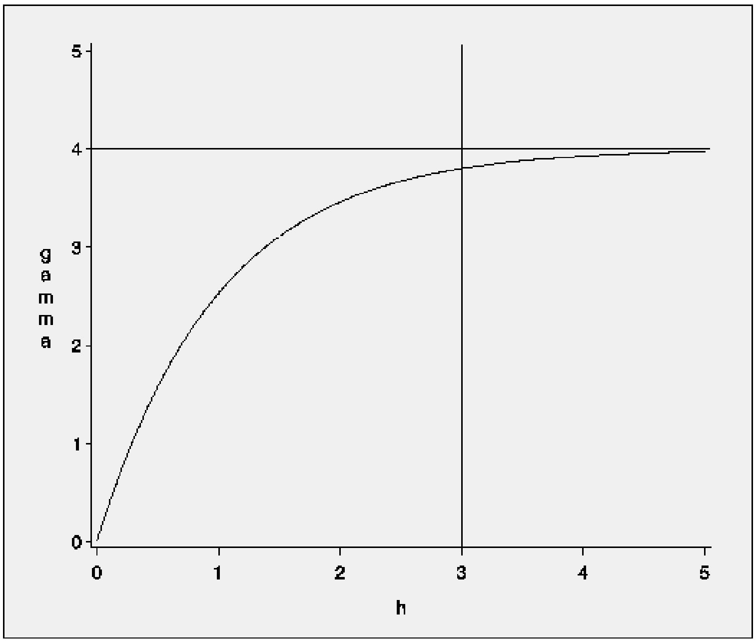

Figure 3.4: Exponential semivariogram model [19].

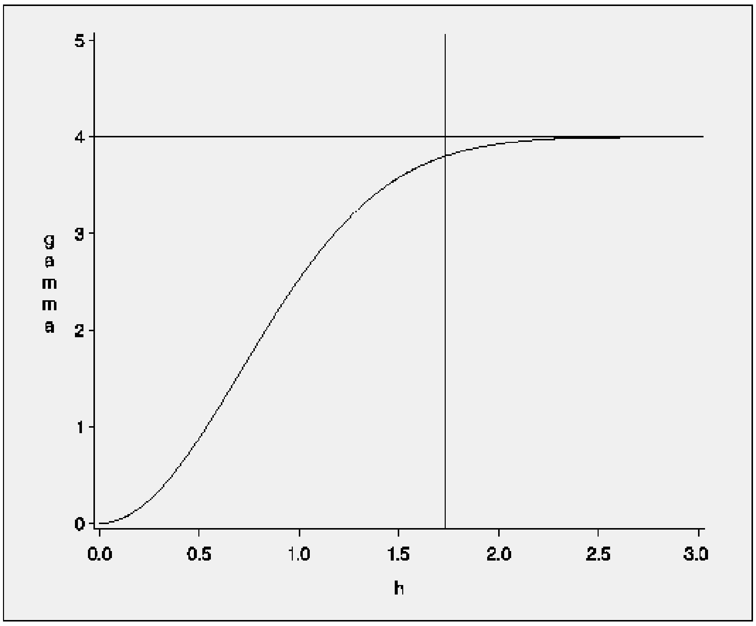

Figure 3.5: Gaussian semivariogram model [19].

4. PROPOSED HANDOVER METHOD

Since femtocells are generally deployed at indoor hot spots densely, in this thesis a femtocell-based network which consists of a fBS which is located in a challenging indoor environment and a mBS with several MS moving in the coverage region is considered. The network topology will be explained in Section 4.2.1.

In these networks, it is assumed that the MS walks with a constant speed until the movement duration equals to a predefined threshold. The mobility model of the MS used in this thesis is explained in Section 4.2.2.

In this thesis, prediction-based handover method is proposed to compare with conventional handover scheme. This method is devised for minimizing unnecessary handovers and number of ping-pong handovers between fBS and mBS, by estimating the path loss of future locations which are the locations that the MS will most likely reach in the future. For this purpose, the Kriging interpolator using semivariogram analysis is adopted for spatial estimation of path loss.

4.1 Challenging Issues

Seamless and fast handover is a big challenge in femtocell-based networks. Especially in challenging indoor environments which consist of several walls and other physical obstacles, unnecessary handovers caused by unpredictable path losses are triggered in many situations leading a degradation of services, reduction in throughput and increases in the blocking probability and packet loss. In order to manage the misleading handover decisions caused by these challenging topological infrastructures, a spatial estimation can be implemented into the handover algorithm.

An example situation in femtocell-based networks is depicted in Fig. 4.1. In the figure $F(u)$ represents the set of points locating on the same direction of MS's movement path. According to the scenario, in the very first step of the movement, MS is out of fBS's coverage area. In its next steps, for a small period, MS enters the coverage area

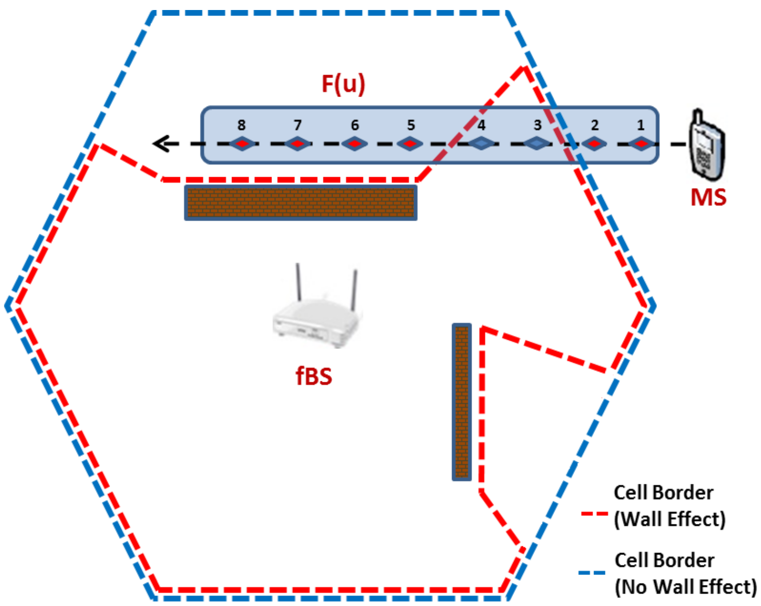

Figure 4.1: A Simple challenging scenario in femtocell-based networks.

of fBS, but then it passes behind the wall where it is out of fBS's coverage area again. Since the main idea of the conventional handover algorithm is to compare the measured path loss p_u at location u with a predefined threshold Q_{HO} to decide whether to start handover procedure or not, this situation may lead to increase unnecessary handover number and ping-pong handover rate.

However, if somehow, the path loss measurements of points locating in movement direction of MS are known, for this example these points are 3 and 4, then there could be a chance to prevent unnecessary handovers. Depending on this idea to solve such problems depicted in Fig. 4.1, we are interested in designing an efficient handover algorithm to be used in the femtocell-based networks for indoor mobile users.

4.2 System Setup

In these section, the network layout used in this thesis and the mobility model of the MS are explained. In final chapter of this section a previously proposed [11] distance measure which is used in order to estimate the path loss of a location is explained.

4.2.1 Network model

As shown in Fig. 4.2, we consider a femtocell-based network environment that consists of a mBS and a fBS with several MS moves from fBS's coverage area to mBS's

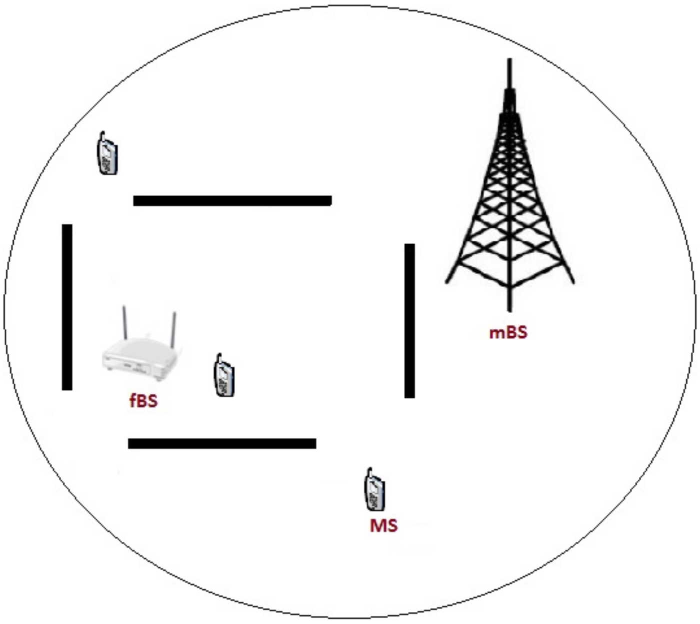

Figure 4.2: A femtocell-based network.

coverage area and vice versa. The coverage area of mBS which is a regular circular network layout and it covers entire network include both indoor and outdoor users.

The fBS is located in a challenging indoor environment surrounded with several types of concrete walls within the coverage region of the macrocell. These walls have different kinds of thickness coefficients. It is expected that, the walls with bigger thickness coefficients should cause bigger path loss.

4.2.2 Mobility model

It is obvious that, handover is an issue for mobile users. Generally MSs moving from one coverage region to the other coverage region make handover to increase its signal quality. In order to simulate handover in femtocell-based networks, a simple mobility model is adopted which is based on random waypoint mobility model. An example mobility scenario is depicted in Fig. 4.3.

In random waypoint model, each direction has its own probability. The mobile user will go to that direction depending on this probability and its previous direction. In addition in this study, in order to have more accurate results, the MS is forced to move around the critical regions. Here critical regions are the locations in the topology that a MS has a high probability to make handover decision. These locations could be at the edge of the fBS coverage region or near the concrete walls.

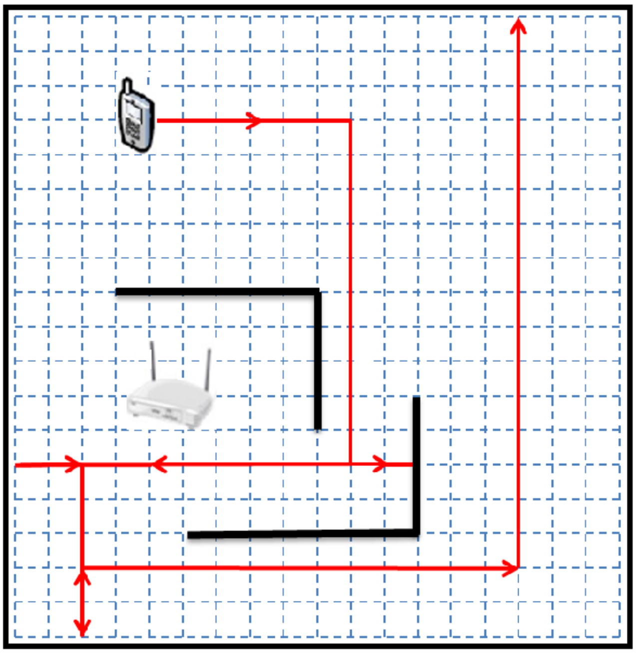

Figure 4.3: Mobility of MS.

4.2.3 Distance measure

In Ordinary Kriging, the correlation between two locations depend on the distance between them. Although the Euclidean distance is a good measure in outdoor environments, it may not be proper for indoor environments. For example path loss values of two different locations may be very different because of the concrete wall between them. As it is expected the concrete wall will decrease the signal strength according to its thickness coefficient. To take the effect of walls a recent study [11] proposes a distance measure which will be adopted in this thesis, based on the equation given as follows:

$$h_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} + 10^E \qquad \textbf{(4.1)}$$

where (x_i, y_i) denote the xy-coordinates of a point i, and $E = (10c)^{-1} \sum_{r \varepsilon W_{i,j}} L_r$ where, $W_{i,j}$ is the set of walls and obstacles between locations i and j, c represents the path loss exponent of the environment and L_r represents the wall thickness coefficient. With using this equation, the distance between two locations i and j is increased according to the walls around them in terms of the Euclidean distance.

4.3 Handover Management Mechanism

There are several reasons why unnecessary handover numbers might be greater in femtocell-based networks than the conventional macrocell-based networks. These reasons could be:

- Small coverage region of fBS
- Challenging indoor network topology
- Strong mBS radio signal

To overcome these issues and minimize unnecessary handovers and ping-pong handover rate, we propose a handover management mechanism in this study. This mechanism is depicted in Fig. 4.4. The mechanism has four basic operations, two inputs and one output as it can be seen in Fig. 4.4, which are received path loss collection, determining future locations, spatial estimation and finally handover estimation.

This mechanism should work on both mBS and fBS with a small difference. In fBS, the Received Path Loss Collections shown in Fig. 4.4, are the reports that are measured by MSs which camp on fBS. On the other hand, in the mBS, the Received Path Loss Collections are not the path losses reported to the mBS, but these are the same path loss measurements which are reported to fBS. It means that for both mBS and fBS only path losses related with fBS are considered for handover decision. This is because, in the proposed scheme, only fBS to mBS and mBS to fBS handover is studied with the assumption that MS will always move in the coverage region of mBS. According to considered topology all fBSs are within the coverage region of the mBS. Therefore handover can occur only if the path loss related with fBS is less or greater than a predefined threshold Q_{HO} which is related with fBS receiver sensitivity.

4.3.1 Received path loss collections

In this study, we are trying to estimate the path losses of neighbourhood locations of a MS. These neighbourhood locations are the locations that MS will most likely reach in the future. In order to estimate the associated path loss values, the mechanism uses

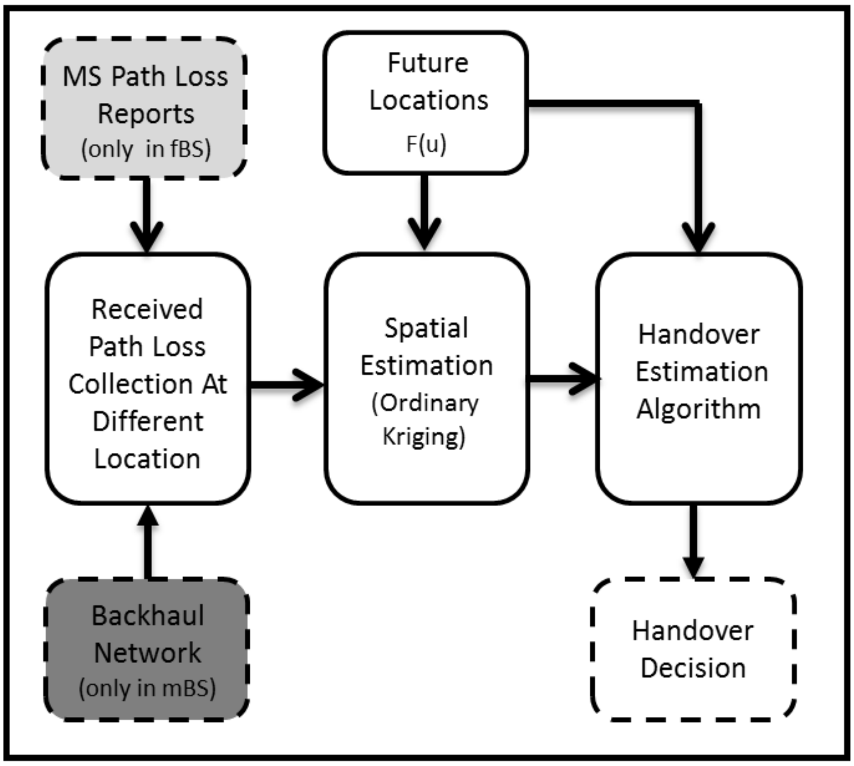

Figure 4.4: Proposed handover management mechanism.

the path loss values of known locations. These locations are assumed to be known due to a newly received path loss measurement report from a MS which is connected to the base station. It is assumed that these path loss measurement reports are sent by MS periodically to the base station. These received path loss measurements are stored in a $N_{MS}xN_L$ vector in the base station. After each measurement report, the corresponding field is updated with the new path loss measurement.

In these thesis, only fBS to mBS and mBS to fBS handovers are analysed. Since fBSs are located in the coverage region of mBS, then the signal quality of mBS is irrelevant for handover process. This is because, the reason to connect or disconnect to the fBS could be only related with the fBS signal quality. If the signal quality of fBS is bad, then the only base station to connect for this MS will be mBS. To sum up, there is no need to store path loss measurements related with mBS. However, this situation raises a problem that, mBS will also need fBS related path loss measurements to make handover decision. To overcome this problem, in our study, it is assumed that these fBS related path loss collections are shared to mBS using backhaul network connections.

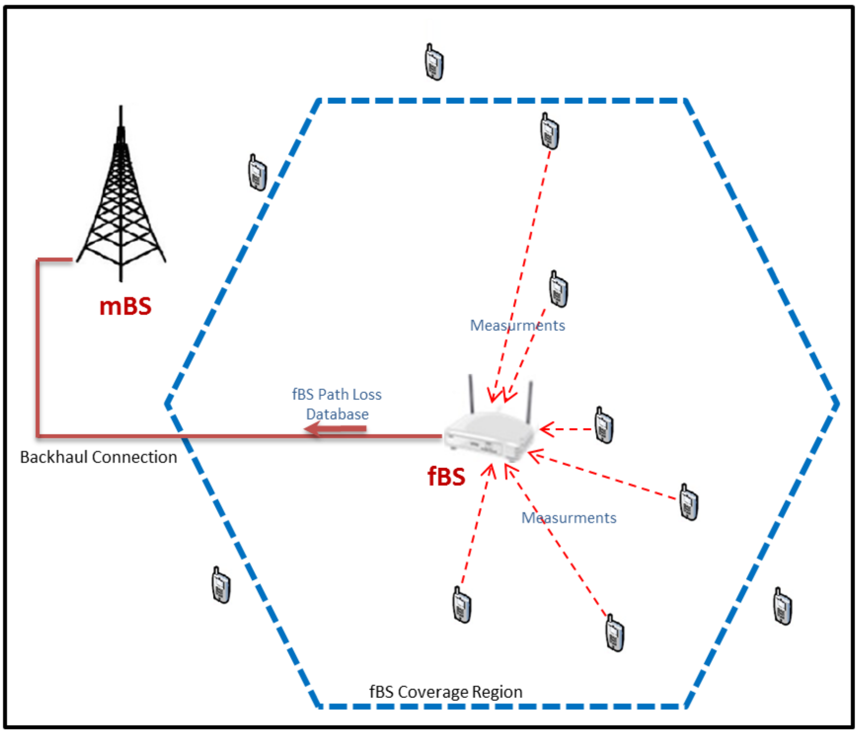

Figure 4.5: Received path loss collections.

These situation is depicted in Fig. 4.5. Then, these collections are given as inputs to the Spatial Estimation block as shown in Fig. 4.4.

4.3.2 Determining future locations

The proposed handover mechanism tries to minimize the unnecessary handover by basicly finding an answer to question, "what might be the path loss of the MS and which base station should MS connect shortly after current time?". To answer this question, in this thesis a set of future locations $F(u)$ is defined which is depicted in Fig. 4.6. The set of future locations $F(u)$ are the neighbourhood coordinates of a MS which the MS will most likely reach in the future. In each step of movement of MS, a new $F(u)$ is generated. As it can be seen from the Fig. 4.6, in this study, it is assumed that while determining the elements of $F(u)$, only the locations which are in the same direction with the MS's current direction are considered. Since the probability of changing the direction of the movement is small in our mobility model, the other potential future locations can be ignored. Then the set of future locations $F(u)$ is given as inputs to the Spatial Estimation block as shown in Fig. 4.4.

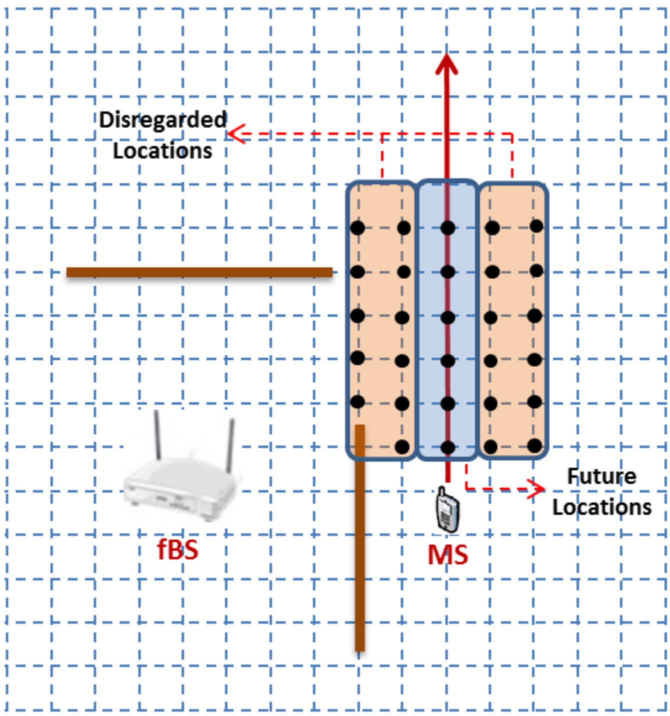

Figure 4.6: The set of future locations.

4.3.3 Spatial estimation with Ordinary Kriging

After collecting path loss measurements from the connected MSs and determining the set of future locations $F(u)$, then Spatial Estimation is done. The Spatial Estimation uses an Ordinary Kriging interpolation to estimate the path loss p_i for all locations i where $i \, \varepsilon \, F(u)$. Since the considered topology is an indoor environment, p_i could vary in small distances because of the concrete walls. We take into account path loss due to walls by using the distance equation in (4.1).

4.3.3.1 Semivariogram analysis

As we mention in chapter 3, semivariogram represents the correlation of two location. Since in this thesis, we are interesting in to find the path loss values, the semivariogram analysis of path loss values of locations in the topology has to be done. In order to do that, a proper semivariogram model has to be determined according to path loss values in the topology and their corresponding locations.

In section 3.2, a simple way to find the properties of semivariogram model is defined. Since we are using exponential semivariogram model in this thesis, the task here is to find fitting range, nugget and sill values for the path loss data set.

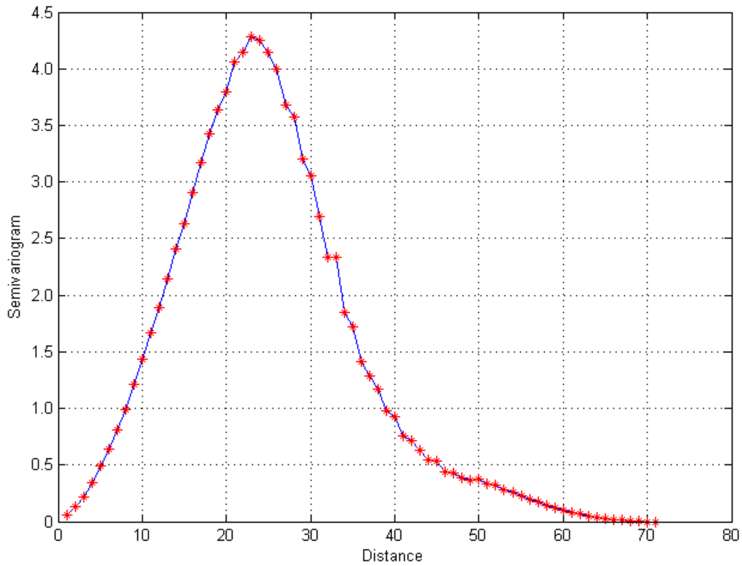

Figure 4.7: Semivariogram analysis.

In Fig. 4.7 the semivariogram graph of the whole locations without any restriction is shown. There is a peak semivariogram at the distance $25m$. Then the semivariogram is falling with the increase in the distance. This is because, in this scenario the fBS is located at the centre of the $50x50m^2$ grid topology. Therefore path loss measurements become equal when the distance is beyond $25m$. Since we have no restriction in this semivariogram analysis, we calculate all semivariogram values $\gamma(h_{i,j})$ for locations i and j. Then the average of these semivariogram values is calculated among the locations which have same distance value $h_{i,j}$. As a result, this average semivariogram $\gamma(h_{i,j})$ which stands for not the correlation between two specific locations, but the correlation between pair of locations which have the same distance measure $h_{i,j}$ between them. This situation is depicted in Fig. 4.8. There are four locations A,B and C,D are shown in the topology. They have the same distance measure between them. As a result the associated $\gamma(h_{i,j})$ will be same for these locations. However this may result inaccurate estimation of path loss values. It is obvious that, because the path loss is changing faster at several meter from the base station, the correlation of A and B must be less than the correlation of C and D, since C and D is locating far away from the base station.

In semivariogram analysis, anisotropy is a term describing the existence of directional differences in spatial dependence. It means that, by using anisotropy, the correlation of locations may be somehow related with the direction of the line between the locations

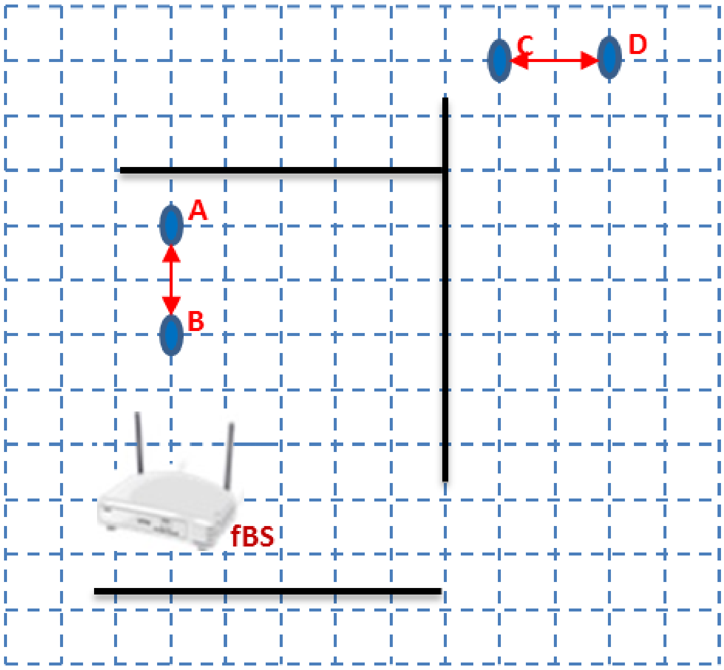

Figure 4.8: The correlation of two pair of locations.

Table 4.1: Exponential semivariogram model parameters.

Parameter	Value
Range	$21m$
Sill	4.55
Nugget	0.94

pair. An example of direction for semivariogram analysis using anisotropy is depicted in Fig. 4.9 and the result is shown in Fig. 4.10. From the result, it is easy to understand that, the model is behaving like an exponential function. Therefore in this thesis, exponential semivariogram function is adopted like it is suggested in the study [11]. As a result, after doing several simulations, in this thesis the values in Table 4.1 are used for exponential semivariogram model which are also explained in chapter 3.

Note that, in this thesis simulated path loss measurements are used in order to test proposed approach. Our selected parameters in Table 4.1 are suitable according to the simulated measurements. On the other hand, these parameters of the semivariogram model should be fitted based on empirical data sets in the real-world.

4.3.3.2 Path loss estimation

After finding the proper semivariogram model and its related parameters, the next task is to find the associated path loss p_i for all locations i where $i \varepsilon F(u)$. Here u is the

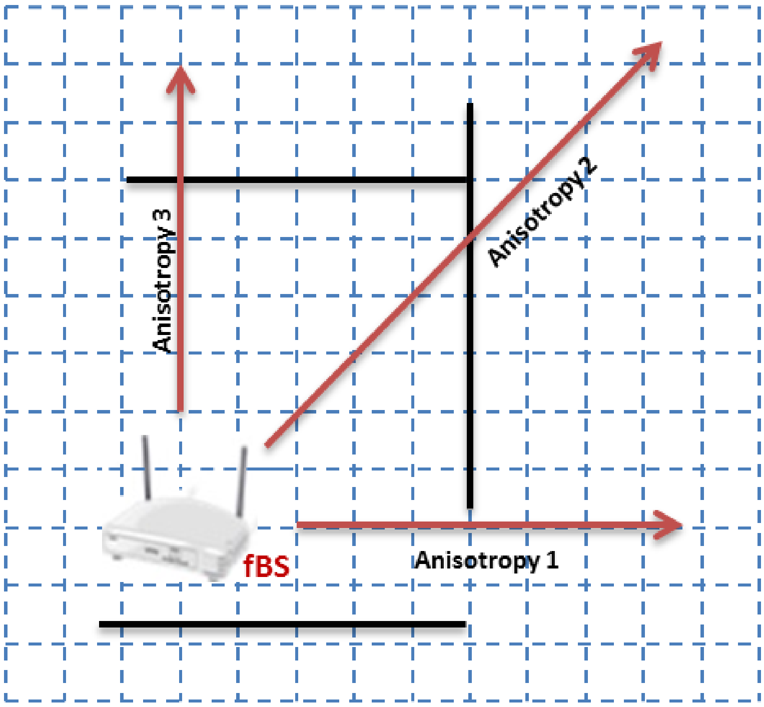

Figure 4.9: The movement path of Semivariogram analysis with anisotropy.

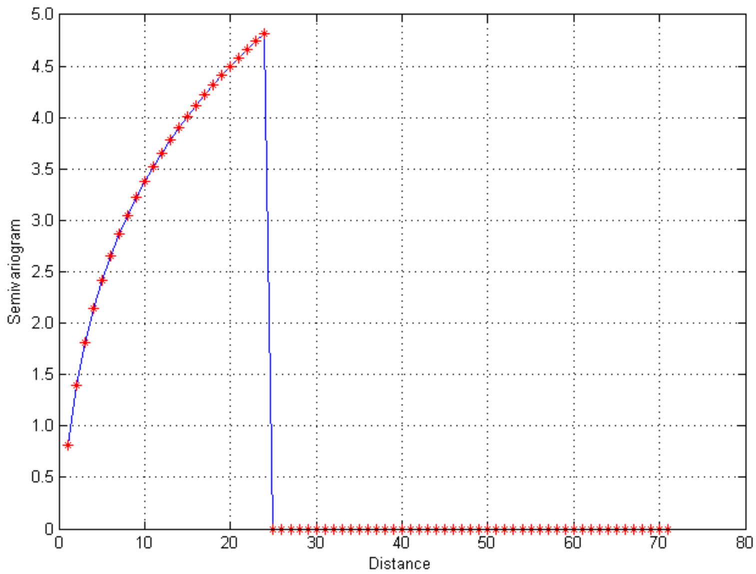

Figure 4.10: Semivariogram analysis with anisotropy.

current location of the MS. Ordinary Kriging interpolation is used to estimate the path loss p_i for each location i.

To estimate p_i, there are several steps need to be done. These steps are:

- The first step is to define a set of known locations $S(i)$ which are neighbourhood of the location i. In this study, while building $S(i)$ only the locations which have smaller distance than range parameter are considered for accurate interpolation. Since range parameter is the distance where the correlation between two points becomes constant, then it will be necessary to limit the maximum range of neighbour locations.
- Secondly, we need to create the semivariogram matrix with using the equation (3.4). In order to create the semivariogram matrix, the semivariograms are calculated according to the exponential semivariogram model (3.3) using the parameters in Table 4.1.
- In the next step, by using the semivariogram matrix and the equation (3.5), the kriging coefficients are calculated.
- Finally, after calculating the kriging coefficients, the path loss p_i can be calculated with using the equation (3.6).

4.3.4 Handover decision

The last step of the handover management mechanism which makes the decision according to the other steps is the handover prediction. These decisions are based on not only the path loss value of current location of MS, but also the set of future locations F_u which are the locations that MS will most likely reach in the future.

According to the conventional handover algorithm, the decision is based on only the current location. The main idea of the conventional handover algorithm is to compare the measured path loss p_i at location i with a predefined threshold Q_{HO} to decide whether to start handover procedure or not. However, as it is explained before, this situation may increase the unnecessary handovers and the ping-pong handover rate.

To overcome this issue, in this study, a new handover path loss parameter $\tilde{P}_{(u,F(u))}$ is defined as a function of $F(u)$. Different from the conventional approach, instead of comparing only the path loss of current location, $\tilde{P}_{(u,F(u))}$, which also represents the future locations' path losses, is compared with a predefined threshold Q_{HO}. $\tilde{P}_{(u,F(u))}$ is defined as follows:

$$\tilde{P}_{(u,F(u))} = \frac{p_u + \sum_{i \varepsilon F(u)} p_i w_i}{1 + \sum_{i \varepsilon F(u)} w_i} \quad \textbf{(4.2)}$$

where w_i is the coefficient for the path loss of point i and defined as follows:

$$w_i = W^{d_i} \quad \textbf{(4.3)}$$

where W is the coefficient which is a parameter for this thesis to study the effect of W on the estimation error. d_i stands for the distance between current point and point i. In this thesis, the effect of d_i is also studied.

5. PERFORMANCE EVALUATION

Once the theoretical concepts of femtocell-based networks, Ordinary Kriging and the proposed handover mechanism have been explained, the next step is to obtain results in order to understand how proposed approach could be useful for handover scenarios. We perform several experiments with the objective of evaluating the performance of proposed handover management mechanism and the handover algorithm with spatial estimation of path loss using Ordinary Kriging approach. In the experiments, proposed algorithm is compared with conventional approach. The main idea of the conventional handover algorithm is to compare the measured path loss p_u at location u with a predefined threshold Q_{HO} to decide whether to start handover procedure or not. This predefined threshold and The relevant simulation parameters common to all the experiments are shown in Table 5.1.

5.1 Simulation Models

In order to understand how the proposed study could be useful for mobility management, we create indoor environments which consist of several walls. In the simulations, these walls might have different thickness coefficients. If a wall has a higher thickness coefficient, then it will absorb more signal strength. In addition, to sample the path loss values of known locations, an empirical path loss model is used. This model will also be explained in this section.

5.1.1 Considered topologies

A simple scenario which is used in the simulations is depicted in Fig. 5.1. In this topology there are four concrete walls with different thickness coefficients. By deploying these walls, we try to simulate a simple indoor environment. In addition, there is only one fBS and one mBS deployed in the topology. However, the indoor environments might not be just consisting of four walls. To demonstrate this fact, in Fig. 5.2, a complex scenario is depicted.

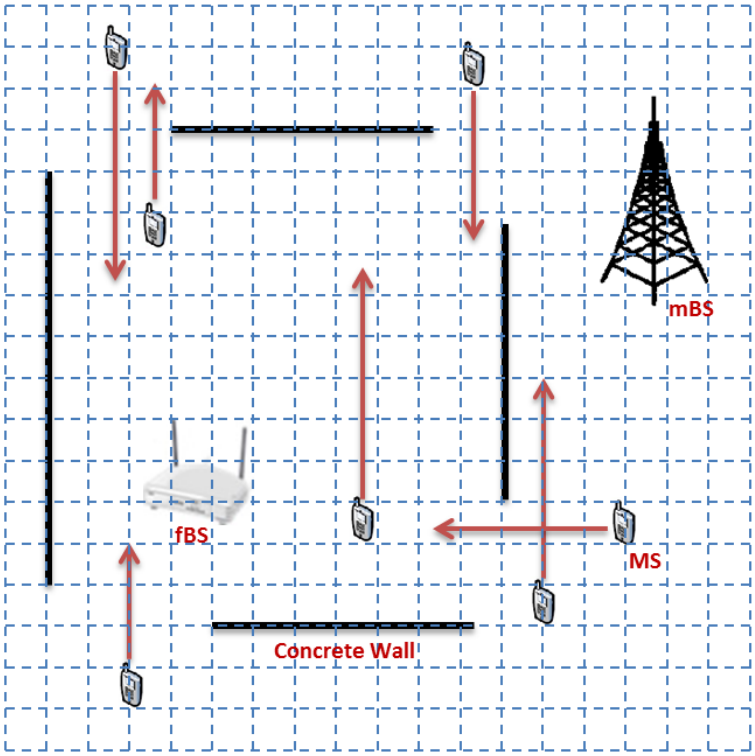

Figure 5.1: An example of simple simulation scenario.

To simulate the proposed approach, these topologies are built over an area of 50x50 m^2 with several types of walls. Since the fBSs are generally used for the ranges less than 50 m, the simulation area is suitable.

5.1.2 Path loss interpolation

Since we do not have the real path loss measurements, we need an empirical path loss model to find the corresponding path loss for each location. For each location in the grid, path loss value is calculated according to the general empirical path loss model which is also adopted in a similar work [11]. The path loss model is defined as follows:

$$P(d) = P_0 + 10c\log_{10}(d) \quad \textbf{(5.1)}$$

where P_0 is the initial path loss of a location and measured at one meter (m) distance away from the transmitter, c is the path loss exponent that determines how the environment affects path loss and d is the distance in meter from the transmitter. By using this path loss model and the distance measure in equation 4.1, path losses of entire locations in the grid are calculated. Let us called these real path loss values, P_R.

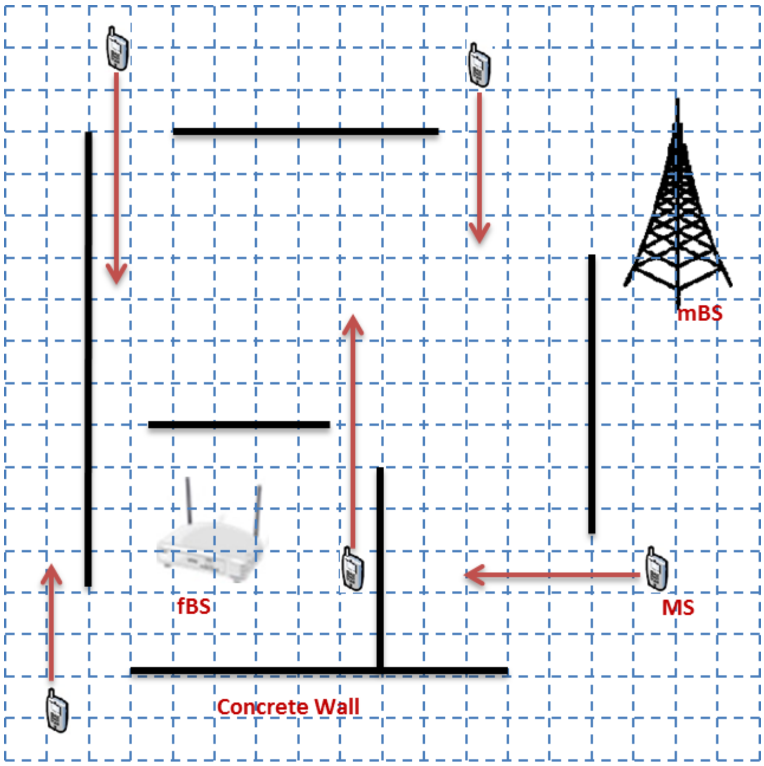

Figure 5.2: An example of complex simulation scenario.

After calculating the path loss of the entire locations in 50x50 grid, some of these locations assumed to be known locations with a probability p and the remaining locations assumed to be unknown locations. By the help of Ordinary Kriging, the path loss of these unknown locations will be interpolated from the path loss of known locations. Let us called these known and interpolated path loss values, P_I.

To understand the accuracy of Kriging interpolation, path loss map of P_R is shown in Fig. 5.3 and path loss map of P_I is shown in Fig. 5.4. The fBS network is located within the coverage region of the mBS. Therefore only the path loss distribution map of fBS is displayed.

To corroborate the kriging interpolation, the path loss map of Fig. 5.2 is also depicted. The corresponding path loss graphs are shown in Fig. 5.5 and in Fig. 5.6

5.2 Simulation Results

There are two parameters which are analysed in this thesis. These are the total number of handovers and the rate of ping-pong handovers. Ping-pong handovers are determined according to a predefined threshold Q_{PP}. If the connection duration of a

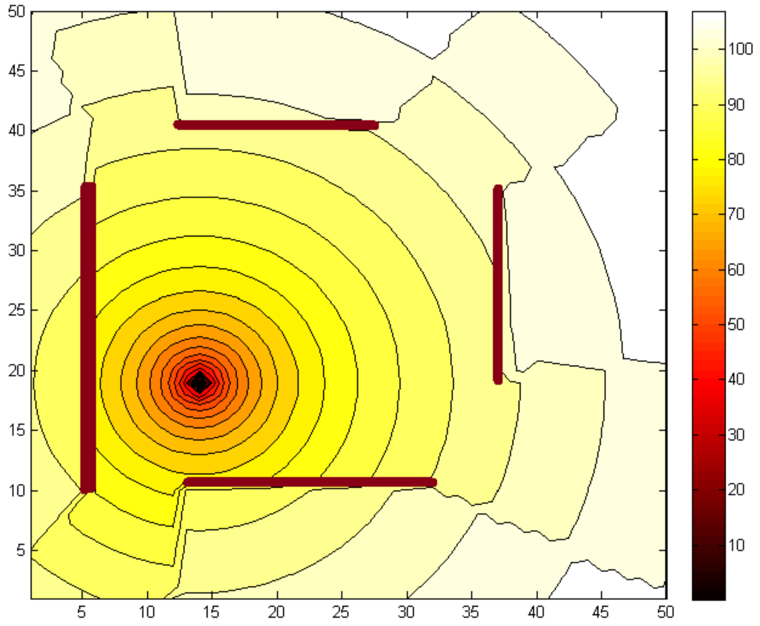

Figure 5.3: Path loss map of P_R.

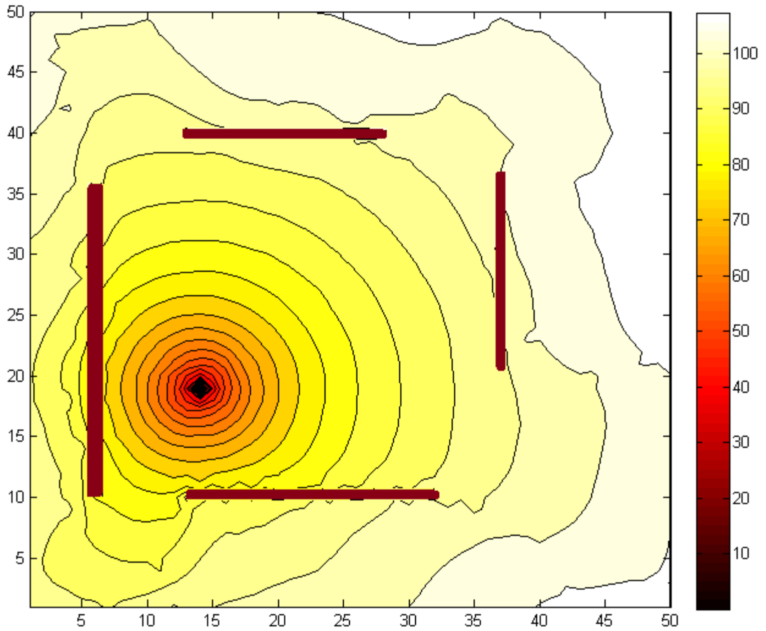

Figure 5.4: Path loss map of P_I.

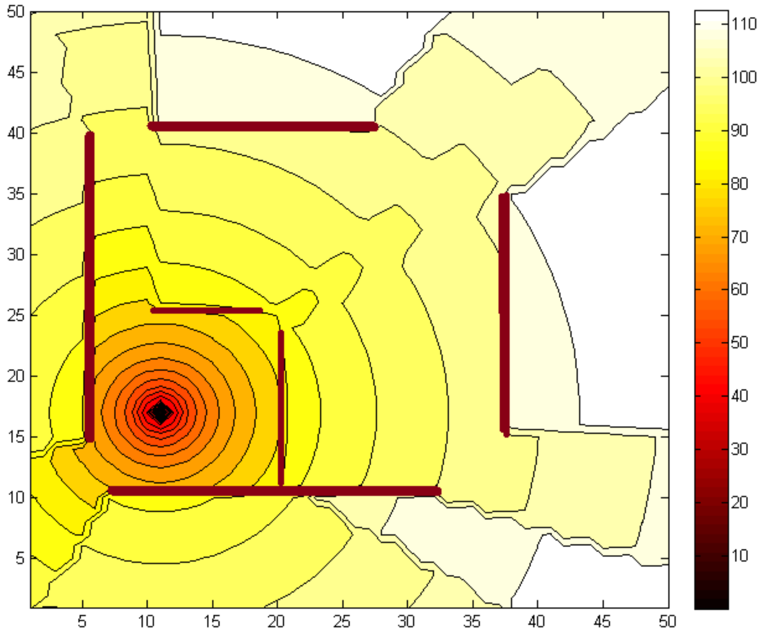

Figure 5.5: Path loss map of $P_R(ComplexScenario)$.

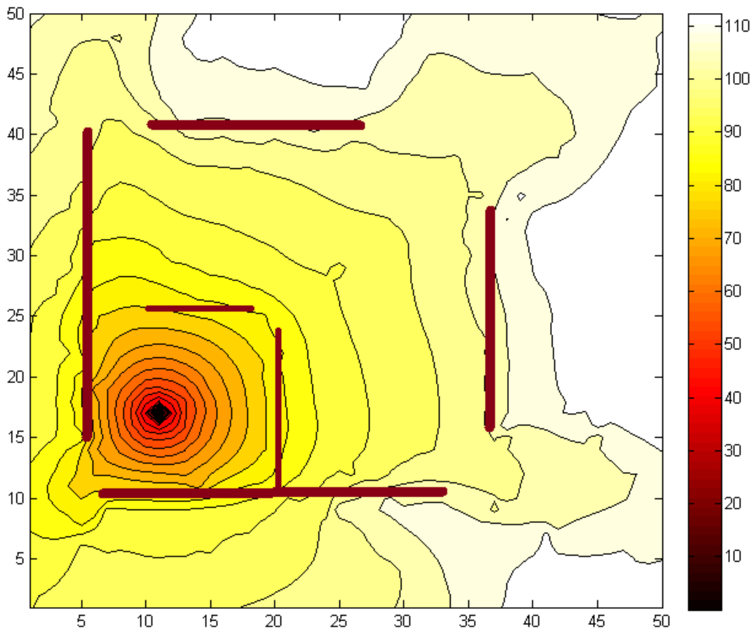

Figure 5.6: Path loss map of $P_I(ComplexScenario)$.

MS after a handover is less than Q_{PP} and a handover occurs, then this handover is called a ping-pong handover. In order to increase the performance of femtocell-based networks, both of these parameters should be minimized. The parameters common to all simulations are shown in Table 5.1

5.2.1 The number of handovers

Since the aim of this study is to decrease the number of unnecessary handover, the total number of handovers should also diminish. The simulation result for the topology shown in Fig. 5.1 is depicted in Fig. 5.7. In this figure x label represents the distance parameter which is used to define the set of future locations F_u. The red line represents the conventional handover scheme. Since it does not consider future locations, the number of handovers do not change with the distance. In addition, blue line represents the proposed algorithm. According to the figure, the number of handovers is decreasing with the distance. Since the probability of reaching a far location is less than reaching a close location, the proposed study shows an exponential behavior.

In this simulation, we let MS to move 1 million times on the simulation topology, according to the mobility model depicted in section 4.2.2. In Fig. 5.7, it is shown that the MS has made $2.35x10^4$ handover decision with conventional handover approach. On the other hand, according to the proposed study, with assuming $d = 10$, the number of handovers diminishes to $2.1x10^4$.

In this thesis, we also interested in studying the effect of coefficient W. W represents the consideration level of future locations. Higher W means, handover decision is more related with future locations. The simulation results with different coefficients are depicted in Fig. 5.8. According to the results, the performance of the proposed approach is higher if we pick a higher coefficient value. In addition, even if we pick the smallest coefficient value, it is 0.3 in this simulation, the performance of the algorithm is still higher than conventional approach. As it is expected, when coefficient W gets smaller, the distance value that the number of handovers becomes constant gets smaller. The exact numerical results are depicted in Table 5.2.

Actually the performance of the first simulation is only valid for the topology in Fig. 5.1. To obtain a more general result which is independent from a specific topology,

Table 5.1: Simulation parameters.

Parameter	Value
Range	$21m$
Sill	4.55
Nugget	0.94
Simulation movement count	$1x10^6$
Path loss exponent (c)	4.2
Probability of known point (p)	0.15
Ping-pong handover threshold (QPP)	$4steps$
mBS maximum transmit power	$42dB$
fBS maximum transmit power	$30dB$
mBS rx sensitivity	$-120dB$
fBS rx sensitivity	$-65dB$
fBS handover threshold (Q_{HO})	$80-95dB$
The number of backhaul packet group (N_m)	5

we built several kinds of topologies randomly. This topologies have different number of walls and thickness coefficients in different locations. The performance of this simulation is depicted in Fig. 5.9. As for the number of handovers, it is shown that the proposed technique is about 7% better than conventional handover method.

5.2.2 Ping-pong handover rate

The second aim of this study is to decrease the ping-pong handover rate. The simulation result for the topology shown in Fig. 5.1 is depicted in Fig. 5.10. It is obvious that the behavior of the graph is similar to the one shown in Fig. 5.7. Actually it is an expected situation. If the number of ping-pong handovers is decreasing, the number of total handover will also decrease. In addition, the ping-pong handover rate is also constant for conventional approach. On the other hand, it is decreasing for proposed approach.

Although the graphs have same behaviors, the proposed study shows better performance in terms of ping-pong handover rate. It is because, the proposed study is capable of handling the situations depicted in Fig. 4.1. According to the Fig. 5.10, 0.24 of the handovers are ping-pong handover for conventional handover algorithm. On the other hand, according to the proposed study, with assuming $d = 10$, 0.17 of the handovers are ping-pong handover.

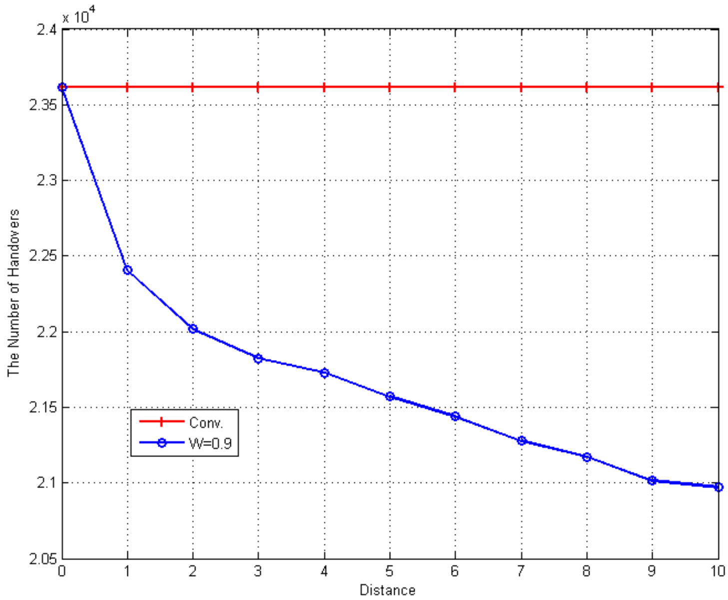

Figure 5.7: The number of handovers with different distance parameter.

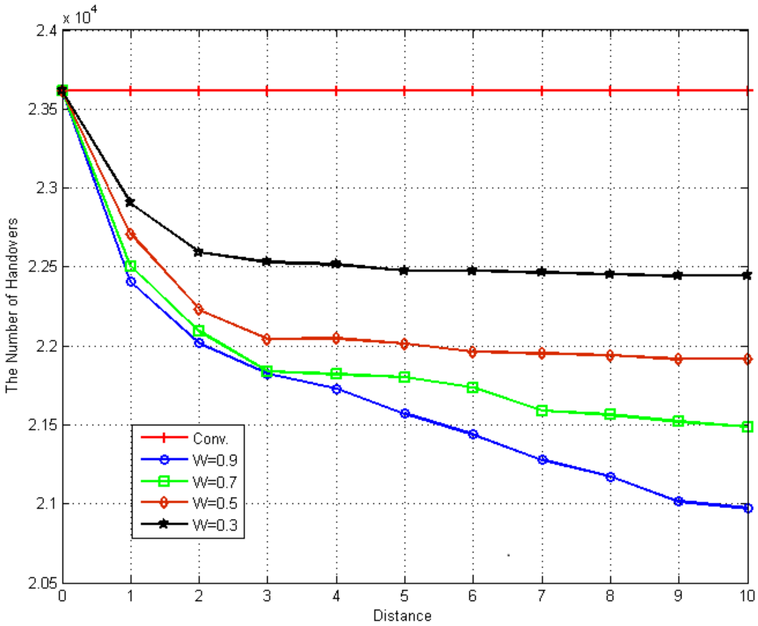

Figure 5.8: The number of handovers with different coefficients W.

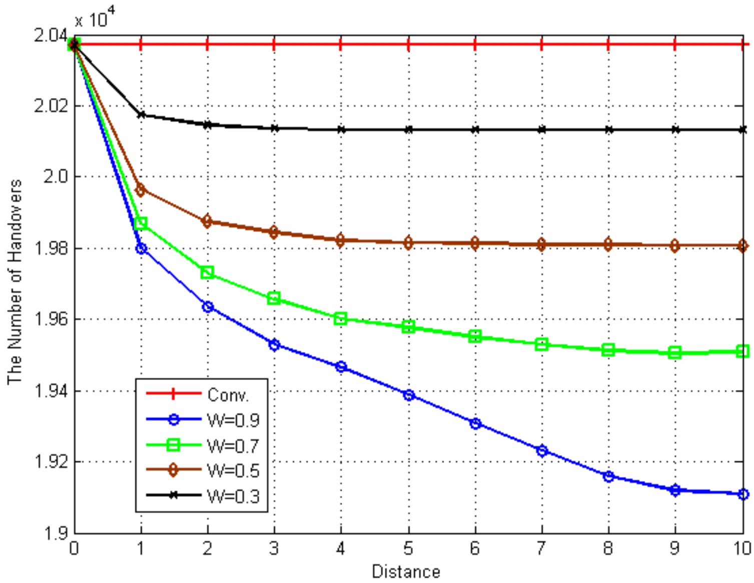

Figure 5.9: The number of handovers - general performance.

Table 5.2: The number of handover numerical results.

Distance (in meters)	Coefficient			
	$W = 0.9$	$W = 0.7$	$W = 0.5$	$W = 0.3$
0	3614	3614	3614	3614
1	2405	2506	2708	2902
2	2016	2091	2229	2594
3	1824	1840	2043	2528
4	1728	1819	2048	2515
5	1572	1801	2013	2475
6	1438	1737	1964	2477
7	1279	1590	1951	2465
8	1173	1564	1941	2454
9	1013	1521	1915	2442
10	0970	1487	1915	2442
11	0864	1427	1915	2442
12	0787	1395	1915	2442
13	0726	1395	1915	2442
14	0664	1382	1915	2442
15	0544	1374	1915	2442
16	0475	1353	1915	2442

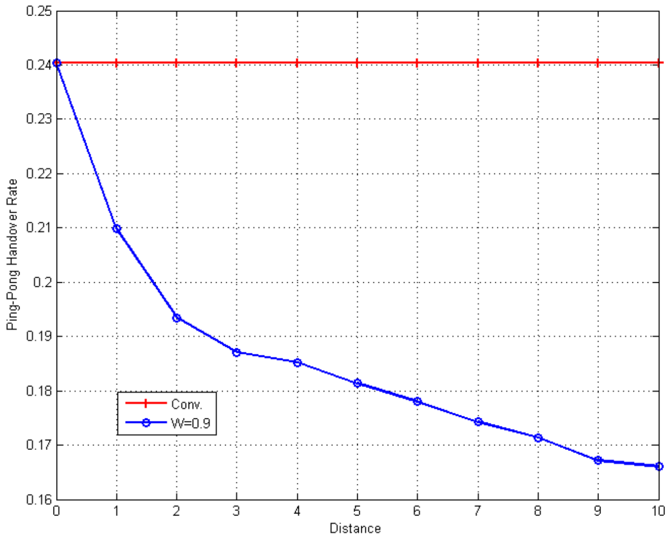

Figure 5.10: The ping-pong handover rate with different distance parameter.

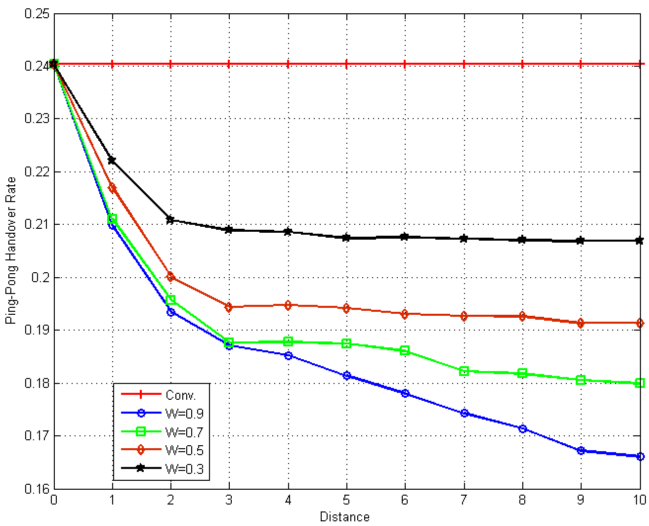

Figure 5.11: The ping-pong handover rate with different coefficients W.

Furthermore, the performance of the proposed study for ping-pong handover rate is also analysed for different W. The related simulation results are depicted in Fig. 5.11. As it is expected, the results show similar behavior like the results for the number of handover parameter. The exact numerical results are depicted in Table 5.3. However this simulation is only valid for the topology depicted in Fig. 5.1. Just like the number of handovers parameter, to obtain a more general result, the ping-pong handover rate parameter is analysed on randomly generated topologies. The performance of this simulation is depicted in Fig. 5.12. The proposed technique was about 17% better than conventional handover technique.

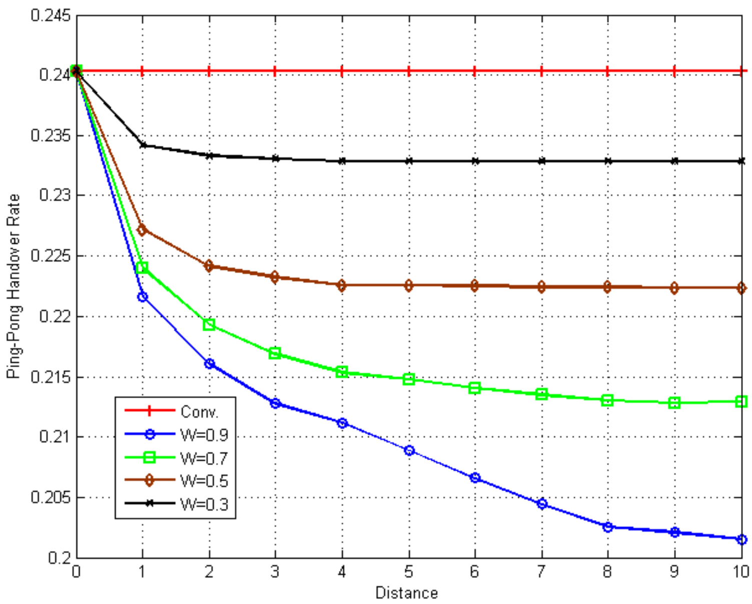

Figure 5.12: The ping-pong handover rate - general performance.

Table 5.3: Ping-pong handover rate numerical results.

Distance	Coefficient			
(in meters)	$W = 0.9$	$W = 0.7$	$W = 0.5$	$W = 0.3$
0	0.2403	0.2403	0.2403	0.2403
1	0.2098	0.2110	0.2170	0.2220
2	0.1934	0.1957	0.2000	0.2108
3	0.1871	0.1877	0.1944	0.2089
4	0.1853	0.1878	0.1947	0.2086
5	0.1814	0.1874	0.1942	0.2074
6	0.1780	0.1861	0.1931	0.2075
7	0.1743	0.1822	0.1927	0.2073
8	0.1714	0.1817	0.1926	0.2070
9	0.1672	0.1806	0.1913	0.2068
10	0.1661	0.1799	0.1913	0.2068
11	0.1651	0.1784	0.1913	0.2068
12	0.1644	0.1777	0.1913	0.2068
13	0.1629	0.1777	0.1913	0.2068
14	0.1622	0.1772	0.1913	0.2068
15	0.1610	0.1770	0.1913	0.2068
16	0.1597	0.1769	0.1913	0.2068

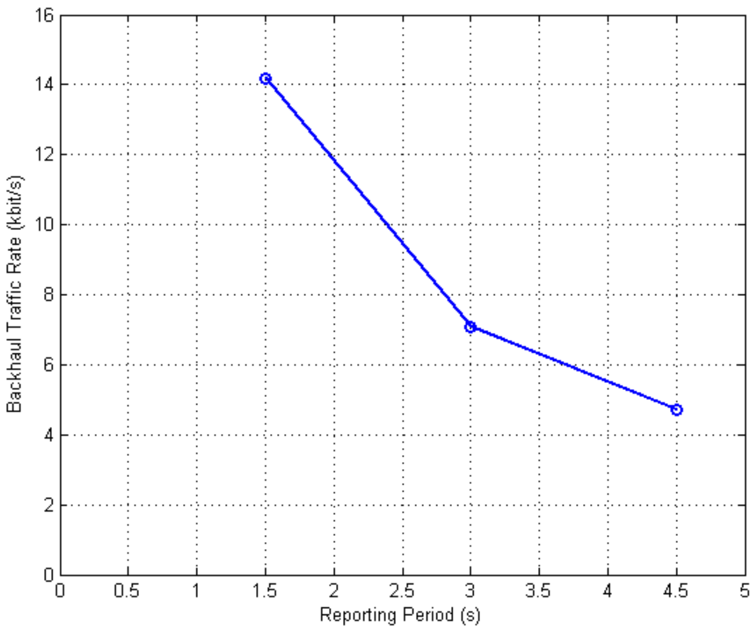

Figure 5.13: The signaling traffic rate due to proposed study.

5.2.3 The backhaul traffic rate

Although, the proposed study offers a significant gain in femtocell-based networks in terms of the number of handover and the ping-pong handover rate, it also generates a newly defined signaling traffic in backhaul network. In this thesis, the overhead due to the backhaul signaling traffic is also analysed.

In Fig. 5.13 the overhead of the proposed study in terms of signaling traffic is depicted. X label represents the period of the signaling messages. In period T, path loss measurements for entire locations are transmitted to mBS. Y label represents the signaling overhead in terms of $kbit/s$. As it is expected, the overhead is increasing if a higher signaling period is used.

In order to measure the traffic rate, a simple IP packet is considered. To increase the performance of the handover management mechanism, path loss measurements are separated into N_m groups. Then each group is transmitted at each T/N_m intervals.

In order to understand the effect of T on the performance of the proposed study and determine a proper period, several simulations are performed. The results of these simulations are depicted in Fig. 5.14 and Fig. 5.15. In these simulations the performance of the proposed study with different period is analysed. The simulation results show that, the duration of the signaling messages does not affect

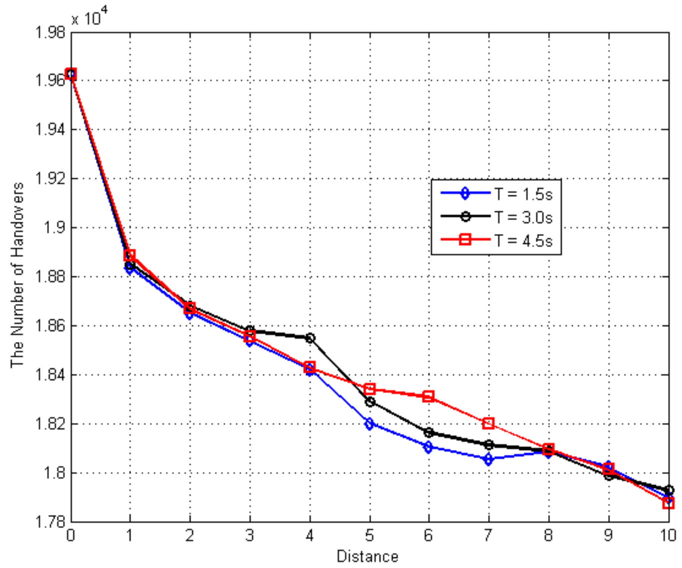

Figure 5.14: The number of handover with different period.

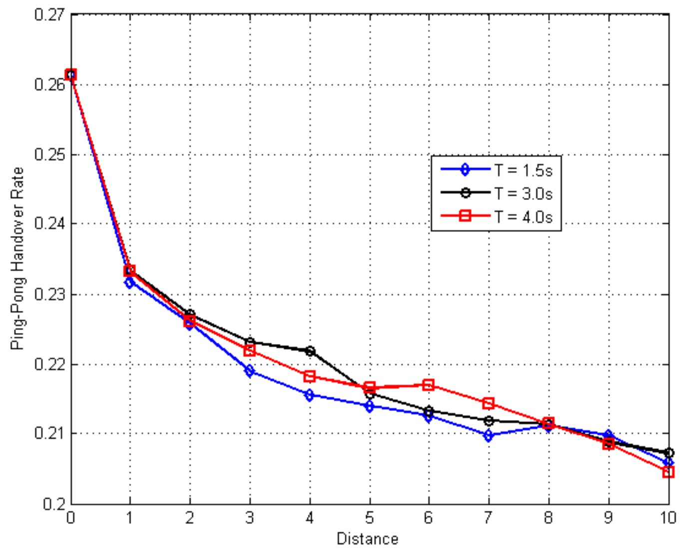

Figure 5.15: The ping-pong handover rate with different period.

the performance of the mechanism in terms of both parameters. This is because; the Ordinary kriging techniques are able to interpolate the path loss measurements even if the number of known locations are less.

6. CONCLUSIONS AND RECOMMENDATIONS

In this thesis, we propose a new path loss-based handover algorithm that is suitable for femtocell-based networks. A challenging indoor environment consisting of several walls is considered in this thesis where estimating the path loss is more challenging than for outdoors, since the variability in the environment is much greater in short distances.

Unlike the other algorithms that are based on RSS measurements for handover decision, path loss measurements are used in this thesis. More specifically, the proposed handover algorithm depends on not only the path loss measurements at mobile stations, but also the spatially estimated path loss of future locations which are the locations that the mobile station will most likely reach in the future. To estimate the path losses of these future locations, Kriging interpolation methods are used in this study.

The proposed scheme is designed to make handover decision in order to minimize the unnecessary handovers and the number of ping-pong handovers due to challenging environments. To achieve this goal, a handover management mechanism is proposed. At first, this mechanism collects related path loss measurements from mobile stations. Secondly, it decides the future locations. After that, path loss values of future locations are estimated from the collected measurements. Finaly, a handover decision is made according to these future locations.

Several simulations are performed with the objective of evaluating the performance of proposed handover management mechanism. There are two parameters which are analysed in this thesis. These are the total number of handovers and the rate of ping-pong handovers. Ping-pong handovers are determined according to a predefined threshold. If the connection duration of a mobile station after a handover is less than this threshold and a handover occurs, then this handover is called a ping-pong handover. Numerical results demonstrate that the proposed handover scheme is superior to conventional handover scheme from the viewpoints of both the number of unnecessary handovers and the ping-pong handover rate.

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

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